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REMOTE SENSING PROVIDES A NEW LOOK AT THE EARTH AND ITS RESOURCES[1]

Marion F. Baumgardner[2]

INTRODUCTION

In 1948 the British astrophysicist Fred Hoyle wrote:

"Once a photograph of the Earth, taken from the outside, is available--once the sheer isolation of the Earth becomes plain-- a new idea as powerful as any in history will be let loose".

In 1977 Robert Frosch, administrator of the U. S. National Aeronautics and Space Administration (NASA), observed:

"This is the first generation of people that has actually seen the Earth. What men saw before were only little bits and pieces of the Earth. Man would take these little bits and pieces and hang them together in maps in an attempt to construct a picture of the Earth as it would be seen from space. A few decades ago he invented

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[2] Professor of Agronomy

the camera and later placed it on airplanes. He could then get bigger pictures, and less piecing together was necessary. But this is the first generation that has seen data flow in the opposite direction--data that began with a broad synoptic view from which one then has to extract the details. In a sense, we have turned the whole enterprise around. Instead of starting with the details and trying to construct the big picture, we now have the capability to go the other way--to look at the big picture and then learn how to extract the details which explain it" (Frosch, 1977).

Modern engineering technology has given our generation the first opportunity to view the Earth as a whole. Dramatic advances in remote sensing technology make it possible not only to survey Earth surface features with a high degree of detail and accuracy but also to monitor changes occurring on the Earth surface.

NEW TECHNOLOGY FOR OBSERVING THE EARTH

Advances in three areas of technology during the past twenty-five years have made possible the development of repetitive Earth observation systems. These areas of new technology involve a sensor system, computers, and communications.

1. Sensor systems. During recent years a broad array of instruments have been developed for observing and measuring specific components or features of our environment. These possibilities range from a

look at the interior of the atom to a synoptic, repetitive color view of the entire surface of the Earth; from a sub-microscopic examination of plant cells under moisture or disease stress to a view of thousands of hectares of wheat suffering from drought. The wide array of new instruments and analytical techniques allows us to observe the same environment at different scales and levels of detail.

2. Computers. Another new capability is provided by the electronic computer without which many of the new data acquisition instruments could not function. The computer provides data storage, retrieval and analytical capabilities unthinkable even a decade ago. The age of the electronic, digital, stored program computer began in the early 1950s (Davis, 1977). A profound admiration of and interest in computers by people is to be expected. Computers are properly cited as the first as well as the most important invention ever that significantly extends human intellectual capabilities. Davis (1977) suggests that until the age of computers, inventions had primarily extended human muscular powers as well as certain sensory powers. Now within the past 25 to 30 years there has descended upon us an electronic array of big computers, super computers,"intelligent" terminals, industrial robots, minicomputers, microcomputers, computers-on-a-chip and tele-operators. This technology provides the opportunity for a conceptual framework for resource information systems inconceivable a generation ago.

3. Communications. A third development of significance to resource information systems is in the area of communications. Present capabilities of communications satellites permit the high quality, instantaneous transmission of verbal messages, images and mass quantities of data from any location to any other location on the surface of the Earth. A remarkable outgrowth of this new communications technology has been the organization and operation since 1964 of INTELSAT, an international organization consisting of membership of more than one hundred signatory nations. INTELSAT's prime objective is the provision, on a commercial basis, of the space segment required for international public telecommunications service of high quality and reliability, to be available on a non-discriminatory basis to all areas of the world (INTELSAT, 1978).

AN INFORMATION SYSTEM FOR EARTH RESOURCES

Information is a valuable commodity. One of the often overlooked features of the development and management of resources--agricultural, forestry, mineral--is the supporting information system. As the demands increase for greater and more efficient production of food or more efficient utilization of dwindling resources, the role of information becomes more critical. It becomes more important that accurate, useful, inexpensive and timely information be available to the decision-makers and policy-makers. Accurate and timely information must be available to policy-makers so that rational decisions may be made in the allocation of limited resources for development. The efficiency of a nation's agriculture may be related to the quality and quantity of information available to decision-makers and policy-makers.

The lack of accurate and timely information about natural resources--soils, land capability, land degradation, areas and conditions of crops, quantity and quality of water resources, quantity and conditions of forests and rangelands, rates of change in land use--places great limitations on resource managers and policy-makers in making rational decisions.

It is now technically possible to design and implement an Earth resources information system supported by Earth orbiting satellite sensors. Data from such a system could be used to derive a current inventory of land, crop, forest, rangeland and surface water resources. Further, regular sequential scanning of these resources could provide a quantitative assessment of seasonal and yearly changes which occur in the landscape.

CURRENT EARTH OBSERVATION SATELLITE SYSTEMS

The decade of the 1970's introduced the world to the concept of observing the Earth from space. During this decade much has been learned about collecting data from space, extracting useful information from space-derived data, and interpreting and using such information.

1. Data acquisition. Modern remote sensing techniques are based upon the fact that information is conveyed from the Earth to the sensor in force fields and electromagnetic fields emanating from the scene and and in particular through the spectral, spatial and temporal variations of such fields (Figure 1). In order to derive information about the scene, one must be able to measure these field variations and relate them to scene characteristics or Earth surface features of interest.

Although remote sensing techniques are being used effectively near ground level in the field and at low and high altitudes with aerial sensors, the primary objective of this paper is to describe the characteristics and use of data derived from current Earth observation satellites.

In July 1972 the National Aeronautics and Space Administration (NASA) launched the first Earth observation satellite with instruments designed to observe the land areas of the globe. Known as Landsat 1, this satellite was placed in a near polar sun-synchronous orbit at an altitude of approximately 920 km. Landsat 1 was equipped with an array of three return beam vidicon (RBV) cameras and a four-band multispectral scanner (MSS). The orbital design was such that Landsat 1 had the capability of scanning the entire surface of the Earth every eighteen days.

Landsat 2 with specifications identical to those of Landsat 1 was launched in January 1975. Landsat 3 was placed into orbit in March 1978. In addition to the four MSS bands of Landsats 1 and 2, the scanner of Landsat 3 had a thermal infrared band. Improved spatial resolution was built into the one-band RBV of Landsat 3. Specifications of the sensors of Landsats 1,2, and 3 are summarized in Table 1.

After five years of successful transmission of Earth resources data, Landsat 1 was retired from service in January 1978. Deterioration in performance of Landsat 2 in late 1979 led to a shutdown of its data aquisition system after almost four years of service.

Landsat D, which will become Landsat 4 after a successful launch, is scheduled to be placed in polar orbit during the fourth quarter of 1981. The two on-board sensors (MSS and thematic mapper, TM) will provide ground coverage of approxiamtely 31,450 square kilometers per scene. The MSS will obtain data in the same four reflective bands as those of previous Landsats and have the same instantaneous field of view (80 m). The TM, a line-scanning device also, will operate over seven bands of the visible and infrared range of the electromagnetic spectrum and have an instantaneous field of view (IFOV) of 30 meters for all reflective bands (Table 2).

A comparison between the orbital and scanning characteristics of Landsat D and the first three Landsats is presented in Table 3.

When Landsats 1, 2 and 3 are beyond the reception range of a receiving station all sensor data must be recorded on-board the satellite and transmitted later when the space vehicle moves within the range of a station. Data volume constraints of the recording tape and technical problems with the on-board recording systems have seriously limited the capability of the Earth observation satellites to obtain data regularly over land areas outside the reception range of ground stations. The common reception radius of ground receiving stations is 2,780 km.

Data from Landsat sensors are transmitted to receiving stations in digital form. Receiving stations in operation as of October 1979 include the following:

United States of America (3 stations)

- Greenbelt, Maryland
- Goldstone, California
- Fairbanks, Alaska

Canada (2 Stations)
  - Prince Albert, Saskatchewan
  - Shoe Cove, Newfoundland

Brazil - Cuiaba
Italy - Fucino
Japan - Tokyo
Sweden - Kiruna

Receiving stations are under construction in Argentina, Australia and India.

The data products available from receiving stations include single-band black and white images, color composite (multi-band) images, and digital data on computer compatible tape (CCT). These images can be analyzed and interpreted by visual methods, or the digital data can be analyzed by computer-implemented pattern recognition techniques.

2. Data analysis. Traditionally the ability of the observer to acquire data has exceeded by far his or her ability to analyze and interpret data. The computer revolution of the past twenty-five years has provided a major advance in the human capability to cope with the masses of data which are accumulated. Computers, or hardware, together with computer languages and analytical programs, or software, which have evolved during the past two decades, place at our disposal for the first time a capability to store, retrieve, overlay, analyze and interpret vast quantities of data.

Computer technology is essential for handling and analyzing the masses of data acquired by the sensors of Landsats 1, 2, and 3, each of which was designed to transmit more than one million quantitative reflectance measurements per second. In the analysis of Landsat data computers may be used to produce high quality images for visual analysis by the human interpreter (Figure 6) or to analyze the data by pattern recognition techniques for producing a classification of landscape features of a specific area (Figure 7). Results of such analyses may be presented as a map, as spectral curves, and/or in tabular format indicating quantitatively the area classified as wheat, maize, poorly drianed soil, sand, coniferous forest or other landscape features of interest.

In this paper emphasis will be given to the application of pattern recognition techniques by digital analysis of multispectral data. The principle of computer-implemented pattern recognition techniques may be illustrated by examination of the spectral properties of different features in the landscape. Typical spectral curves have been plotted for green vegetation, bare soil and water (Figure 2). The horizontal axis represents wavelength in the visible (0.38 to 0.72 μm) and reflective infrared (0.72 to 2.50 μm) portions of the electromagnetic spectrum. The vertical axis represents the intensity of reflected energy as measured by a spectroradiometer. An examination of these curves reveals that there are certain wavelengths that are much better than others in separating green vegetation, soil and water.

The same data used for plotting these spectral curves may be plotted in another fashion. For example, the reflectance values for each landscape feature (vegetation, soil, water) at three different wavelengths, represented by λ_1, λ_2, λ_3, may be plotted in three dimensional space (Figure 3).

In the analysis of multispectral data by pattern recognition techniques, one of two general approaches is usually followed.

One approach is termed "clustering" or "non-supervised" classification. With this approach an algorithm is used which directs the computer to examine the spectral data for the area of interest and to assign each picture element (pixel) to a cluster of pixels having similar spectral characteristics. The number of cluster classes to be spectrally separated is generally set arbitrarily by the analyst and may or may not be determined by the analyst's prior knowledge of the area being analyzed.

The other general approach is termed "supervised" classification. In this case the analyst provides the computer with a spectral definition of the classes to be spectrally separated. This spectral definition is provided in the form of a set of training samples of known identity from specific addresses within the multispectral data. The quality of the supervised classification results is dependent upon the spectral separability of the desired classes with existing spectral data and upon the quality or representativeness of the training set selected by the analyst.

The identification and delineation of green vegetation, bare soil and water by spectral analysis is quite simple and can be accomplished with a high level of accuracy with little or no knowledge of the ground scene by the analyst. However, the classification problem by spectral analysis becomes much more difficult when the objective is to classify the ground scene into many different subcategories of green vegetation, soil and water. Subcategories of interest might include many crop species, differences in plant vigor and biomass production, soils with varying contents of organic matter or different internal drainage characteristics, and water containing varying amounts of suspended matter. Complexity of classification at this level requires special interpretive skills by the analyst. Such skills can best be obtained through broad experience in spectral analysis and intimate knowledge of the area being classified.

Although human experience is limited to three-dimensional perception, the computer has no such constraints; it can operate in n-dimensional space. Thus, with appropriate algorithms the computer can examine the quantitative reflectance values for each of the four wavelength bands of the Landsat scanners and classify or assign each data point or picture element(pixel) to a specific spectral category. Many different algorithms have been developed for the computer-implemented analysis of multispectral data.

The remainder of this paper will be a presentation of applications of the digital analysis of remotely sensed data.

USES OF LANDSAT DATA

Since the launch of Landsat 1 in July 1972, scientists in many nations have used satellite data to inventory and monitor land, mineral, vegetation and water resources. Case studies discussed in this paper will be limited to applications related to agricultural production.

1. Soil survey. During the 1970s, scientists in increasing numbers have been exploring methods of using satellite-derived images for delineating meaningful soil boundaries and characterizing soil conditions. One of the important uses of Landsat images is as a base from which preliminary soil legends can be described and general soil differences can be mapped. A single satellite image has a particular advantage over aerial photography because it provides a synoptic view of a contiguous area covering 34,000 km^2. This synoptic view is valuable to the soil surveyor in correlating soils mapped in adjacent counties or political units by different surveyors at different times.

Visual interpretation of black and white and color composite images produced from Landsat data were used by Westin and Frazee (1976) to produce general soil maps at scales of 1:250,000 or smaller with map units of 260 hectares or larger. Weismiller et al (1979) visually interpreted black and white and color composite Landsat images to determine soil parent material boundaries in Jasper County, Indiana (Figure 4). Confirming these boundaries by field observations, they then digitized these boundaries and overlaid them onto the digital data of the four Landsat MSS reflectance bands which had been adjusted to a scale of 1:15,840. Spectral maps delineating soil differences were then produced at this scale for the entire county (1453 km^2) with map units as small as one hectare. These maps delineating more than fifty different spectral classes in six different parent material areas are being used by soil surveyors to supplement conventional black and white aerial photographs in the preparation of a detailed soil survey of Jasper County (Figure 5). Soil surveyors have observed that satellite-derived spectral maps can make a significant contribution in improving the accuracy of the final soil map and in decreasing the time required to produce a detailed soil survey.

The digital format of Landsat MSS data permits rapid and easy merging and/or recombination of spectral classes to produce a wide array of smaller scale base maps for soil surveys at different levels of generalization.

2. Land degradation. There is increasing evidence that Landsat data can be useful for mapping and monitoring land degradation caused by wind erosion, water erosion, salinization and flooding. A striking example of denudation and sand dune encroachment caused by wind action can be seen in an area along the Wadi Abu Habl in Western

Sudan (Figure 6). The same data from which this synoptic view of the area at a scale of 1:250,000 was produced, was also used to examine in detail at a scale of 1:25,000 the characteristics of the cultivated areas of one of the sand dunes (Figure 7). The three spectral classes of the cultivated sands seemed to correlate well with the areas of millet, peanuts and fallow.

Severe erosion caused by rainfall has been detected and separated spectrally in the humid temperate regions of nothern and central Indiana (Figure 8). In these cultivated soils the exposure of subsoil resulting from severe erosion gives reflectance values measured by the satellite sensors which are considerably different from those of the less eroded surrounding soils (Figure 9).

3. Crop inventory. One of the most obvious agricultural applications of remote sensing technology is the identification and area measurement of cultivated crops (NASA, 1978). Equally important, but somewhat more complex is the use of this technology to improve crop yield predictions. An increasing research effort is being expanded to use remotely sensed data to provide essential inputs into crop yield prediction equations.

For many years government agencies in some countries have used aerial photography to identify crop species and measure the areas planted to specific crops. This is a rather expensive and time-consuming method to conduct crop inventories which may change from year to year.

The need to have more accurate and timely information about global grain supplies and food crop conditions has intensified during the past two decades. The Earth Observation Satellite program has opened new possibilities for inventorying the major food crops of the world and for monitoring crop conditions periodically through the growing season.

An example of the use of digital analysis of Landsat data to identify and measure the area of wheat is illustrated in Figure 10. In this example spectral analysis was used to identify three features in the landscape of Greeley County, Kansas. These features were fields of winter wheat, fields prepared for seeding summer crops and rangelands generally associated with the rough terrain along natural drainageways. In this county with a total land area of 202,803 hectares, the U.S. Department of Agriculture area estimate for winter wheat in 1973 was 73,000 hectares ± 5%. This estimate was derived from a standardized field sampling scheme which examines no more than two percent of the land area of the county. The 1973 wheat estimate for the county derived from data obtained by a Landsat 1 pass on 19 June 1973 was 77,000 hectares. In this instance with Landsat data every hectare of the county was examined and analyzed spectrally.

Early results such as these led to the planning and implementation of the Large Area Crop Inventory Experiment (LACIE), a cooperative research program involving the U.S. Department of Agriculture (USDA), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA).

LACIE research was conducted during the period 1974 to 1978. Its primary objective was to improve the area, yield and production estimates of wheat in the winter and spring wheat area of the Central Great Plains of the United States. Results confirmed that remote sensing can make a significant contribution in identifying crops and making area estimates over large regions. Evidence was observed that remote sensing can be used effectively to monitor gross changes in crop conditions over large areas.

Although the LACIE program was terminated in 1978, new research programs are being continued and planned for the 1980s. These programs will expand crop inventory research to include other major food crops. Much emphasis will be given to the improvement of crop yield predictions.

THE FUTURE OF EARTH OBSERVATION PROGRAMS

Throughout the 1970s the Landsat program was officially experimental. In November 1979 the President of the United States issued a directive assigning the responsibility for civil operational land remote sensing activities to the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. This provides the long awaited assurance to the international community that the civil satellite-based Earth resources observation program of the United States will shift from an experimental to an operational status. This has several important implications for those in the global community who wish to utilize this technology in the development and management of resources. First, it may be interpreted as an expression of the intent of the United States to continue the Earth observation satellite program and make satellite data available to anyone who wishes to purchase it on a non-discriminatory basis. Second, it suggests that research and development will continue to support and improve current and future data acquisition and analysis systems. Third, an operational Earth Observation Satellite system which can readily make high quality data available to anyone will greatly accelerate the need for trained personnel to use the technology. Over the next decade the shortage of persons specialized in the applications of remote sensing technology may be the single most serious constraint in its acceptance and use by many nations.

If famine is to be averted and global agricultural resources are to be managed efficiently in the decades ahead, a great improvement must be made in the acquisition, analysis and delivery of accurate, essential, useful and timely information to decision-makers and policy-makers involved in food production. Although remote sensing is only one of many tools for acquiring and analyzing data, it promises to become an increasingly important one in the future.

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Table 3 Orbital and Scanning Characteristics of Landsats 1, 2, 3 and D

Characteristics	Landsats 1, 2, 3	Landsat D
Altitude	920 km	705 km
Frequency of repetitive coverage	18 days	16 days
Width on ground of scan path	185 km	185 km
Dimension of each Earth scene scanned	185 x 185 km	185 x 170 km

Table 4 Description of lacustrine soils within eight spectral classes derived from Landsat data obtained over Jasper County, Indiana (Figure 5)

Class	Description
1	Excessively to well drained soils with significant inclusions of moderately well drained soils.
2	Excessively to well drained soils with significant inclusions of moderately well drained soils. Minor inclusions of somewhat poorly drained and very poorly drained soils occur.
3	Excessively to well drained soils with a nearly equal amount of moderately well drained soils. Minor inclusions of somewhat poorly drained and very poorly drained soils occur.
4	Very poorly drained soils with significant inclusions of excessively to well drained, moderately drained, and somewhat poorly drained soils.
5	Very poorly drained soils with significant inclusions of somewhat poorly drained soils. Minor inclusions of excessively to well drained and moderately well drained soils occur.
6	Very poorly drained soils with significant inclusions of excessively to well drained and moderately well drained soils.
7	Very poorly drained soils. Minor inclusions of excessively to well drained, moderately well drained and somewhat poorly drained soils occur.
8 (Vegetation)	Predominately moderately well drained soils with significant inclusions of excessively to well drained and very poorly drained soils.

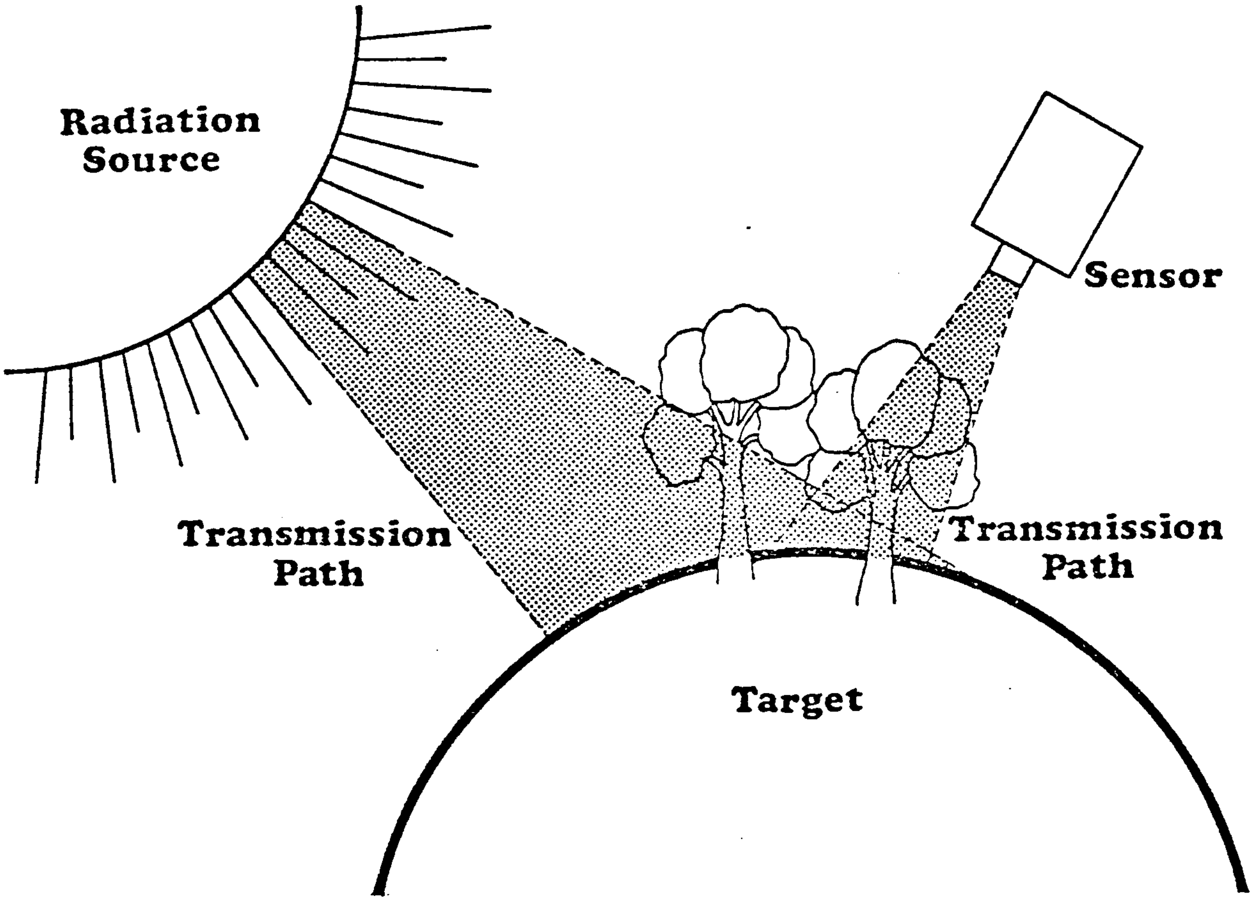


Figure 1. A data acquisition system based on solar radiation and a remote sensor to measure radiation from the scene.

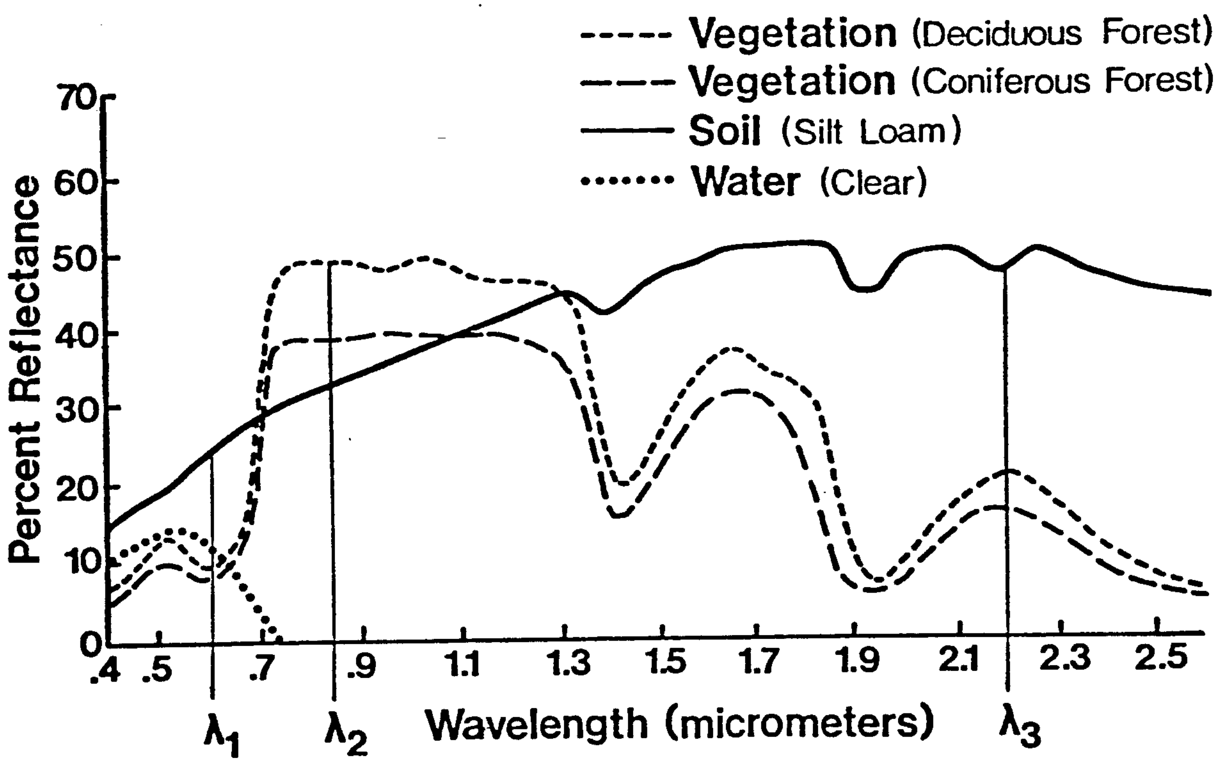


Figure 2. Reflectance curves for green vegetation, soil and water.

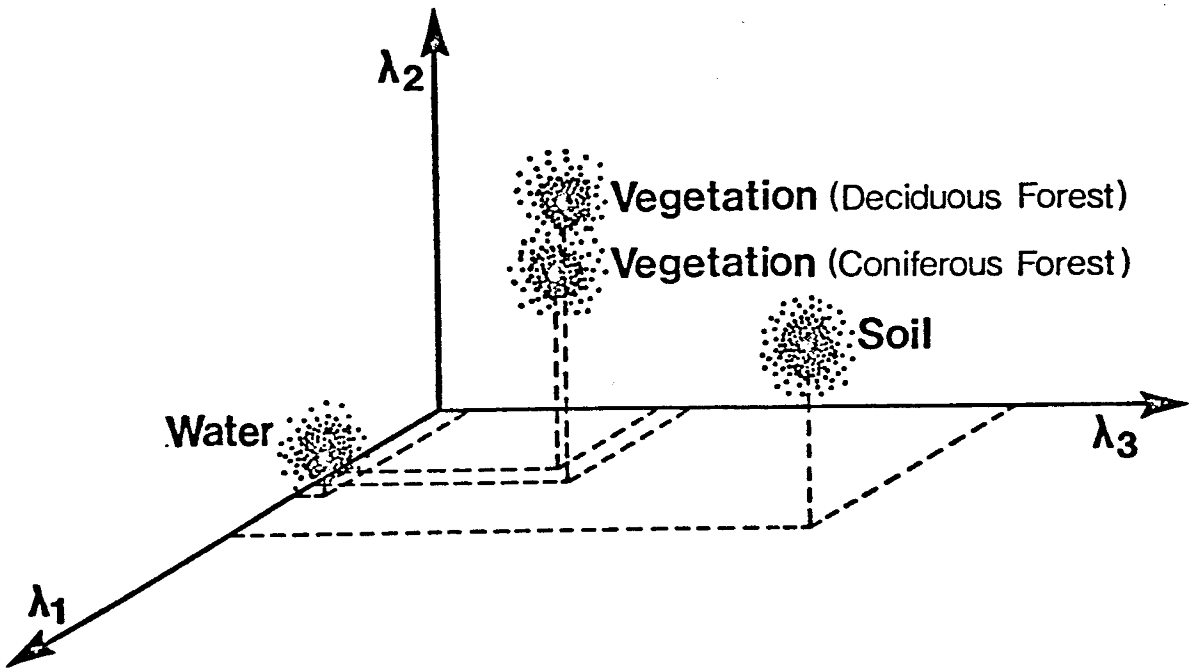


Figure 3. Locating green vegetation, soil and water in three dimensional space defined by specific wavelengths, λ_1, λ_2, and λ_3.

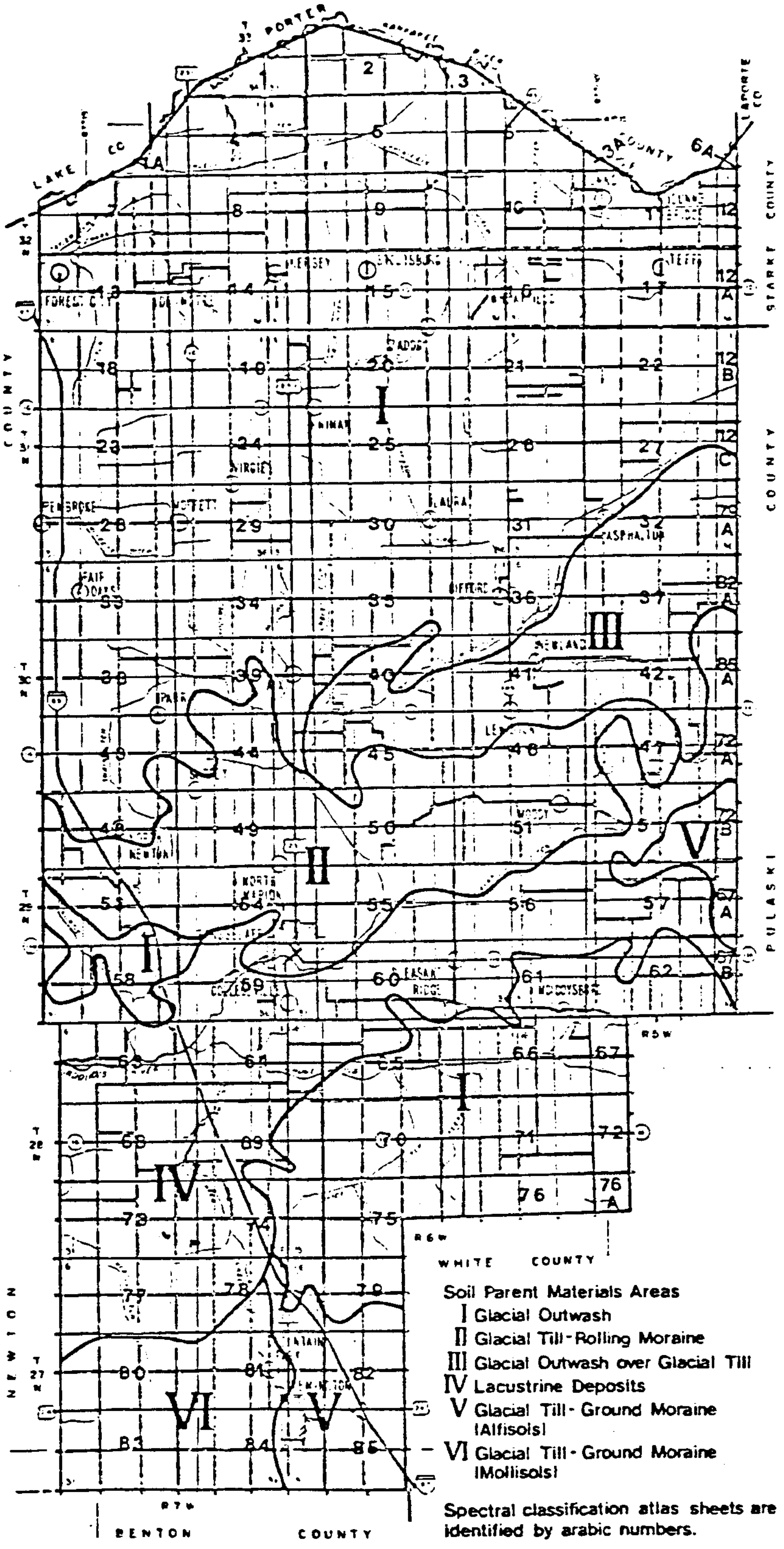


Figure 4. Parent material map of Jasper County, Indiana produced from visual interpretation of Landsat images. Original scale 1:125,000.

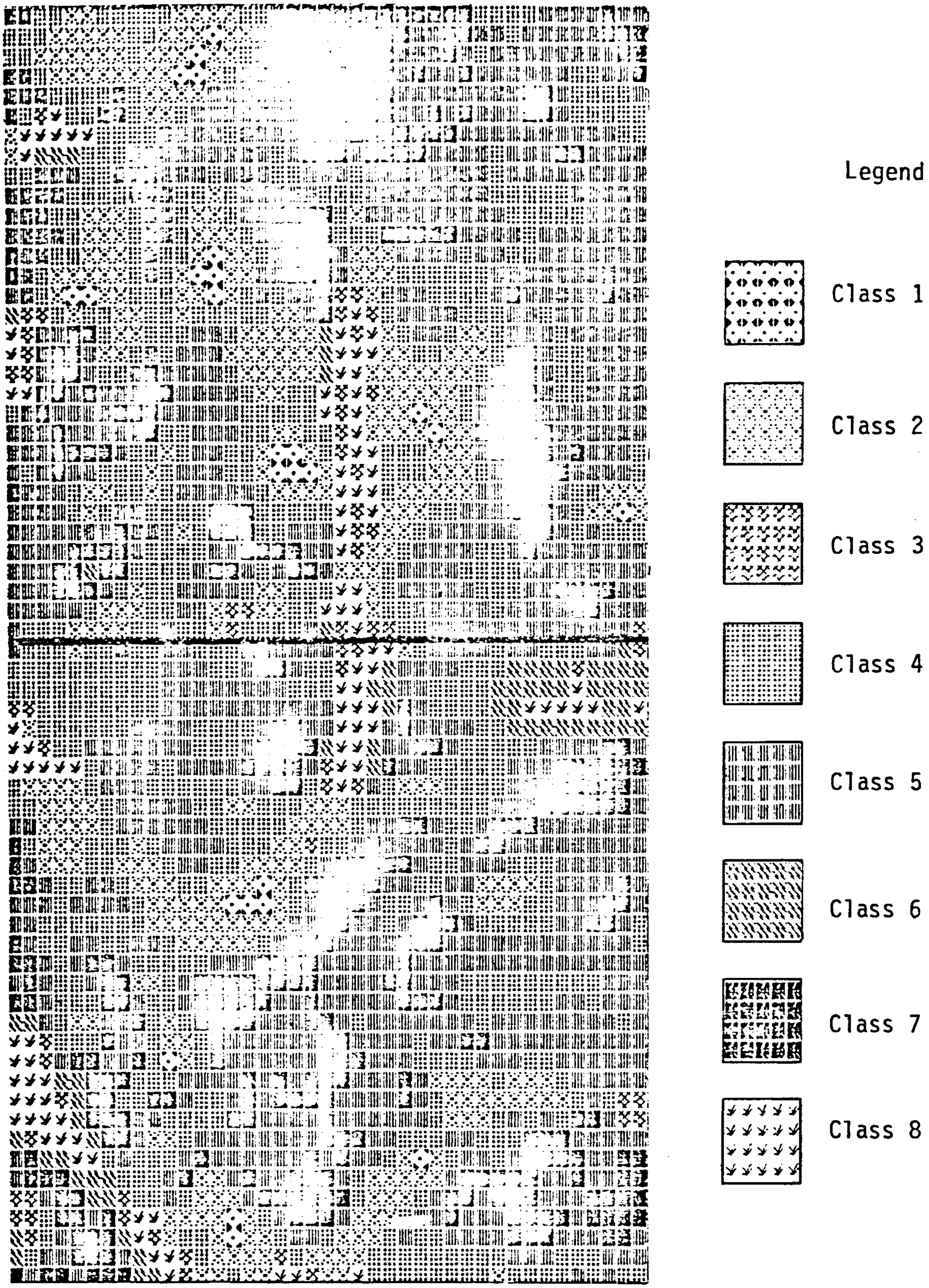
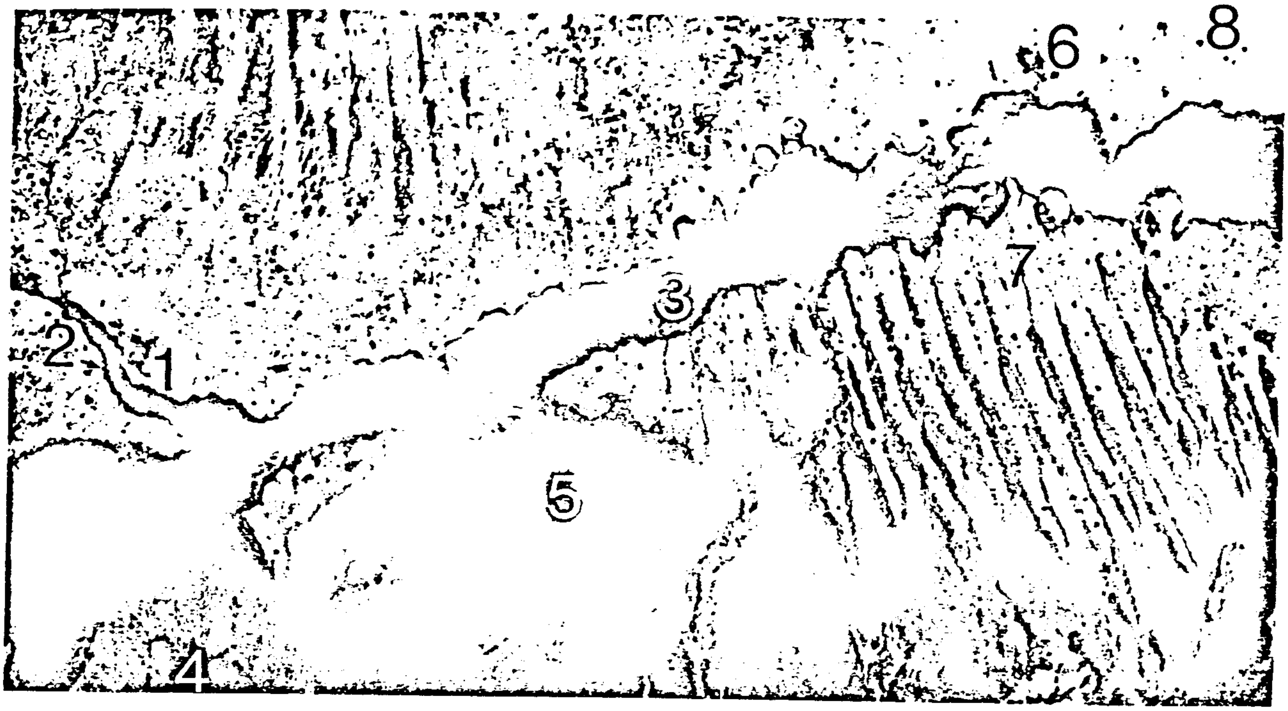


Figure 5. Spectral map derived from Landsat data delineating soil characteristics of a lacustrine area in Jasper County, Indiana. Scale 1:15,840. See Table 4 for class descriptions.



Key to prominant features in landscape:

1. Er Rahad (town)
2. Er Rahad Reservoir
3. Floodplain of Wadi Abu Habl
4. Jebel Ed Dair (granite hill)
5. Upland Clay Plain
6. Umm Ruwaba (town)
7. Sand Dunes
8. Villages

Figure 6. Single-band Landsat image showing denuded areas and dune encroachment along Wadi Abu Habl in Western Sudan. Original scale 1:250,000.

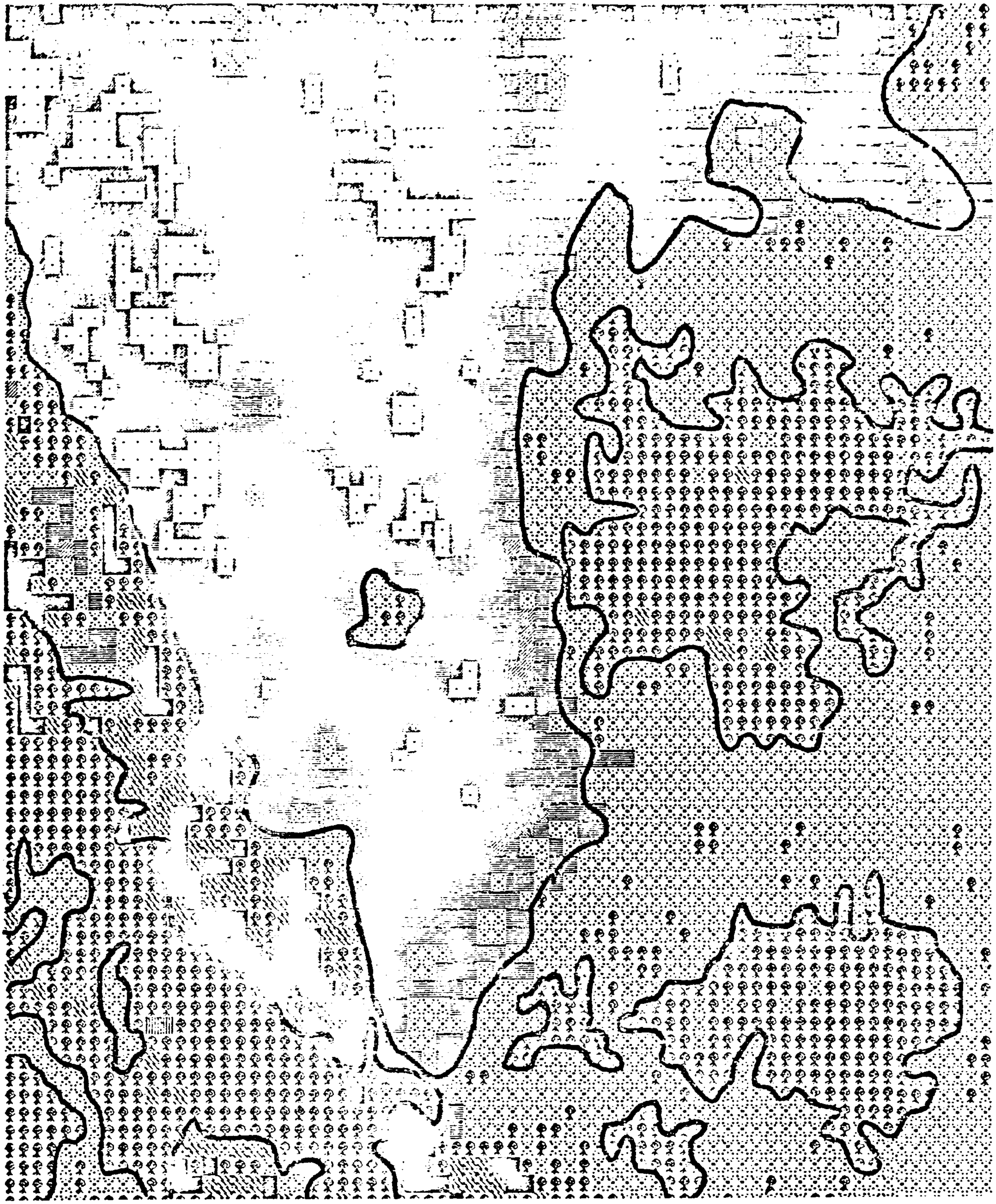


Figure 7. Spectral classification of sand dune area south of Wadi Abu Habl in Western Sudan. Scale: 1:25,000.

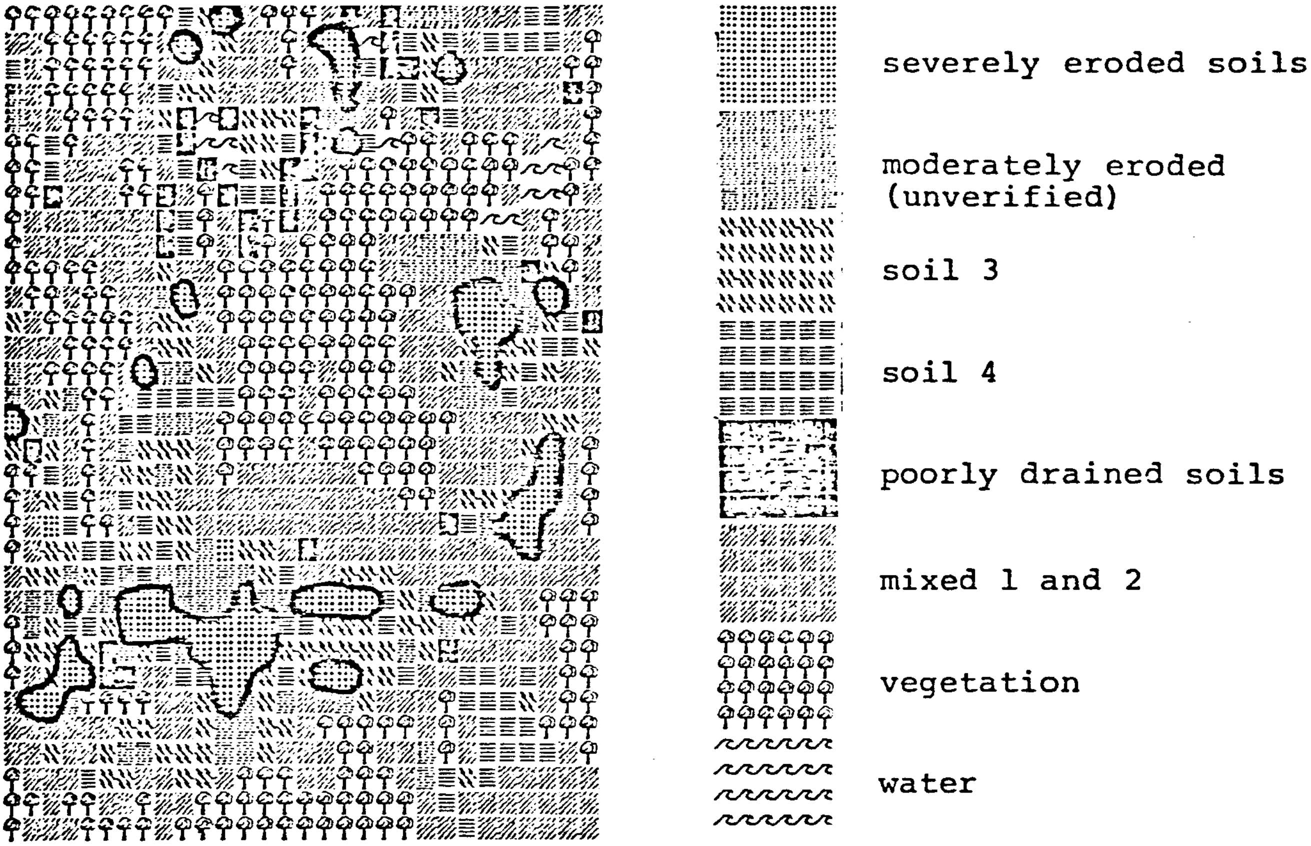


Figure 8. Spectral map units delineating severely eroded soils from other soil and vegetation classes. Scale 1:24,000.

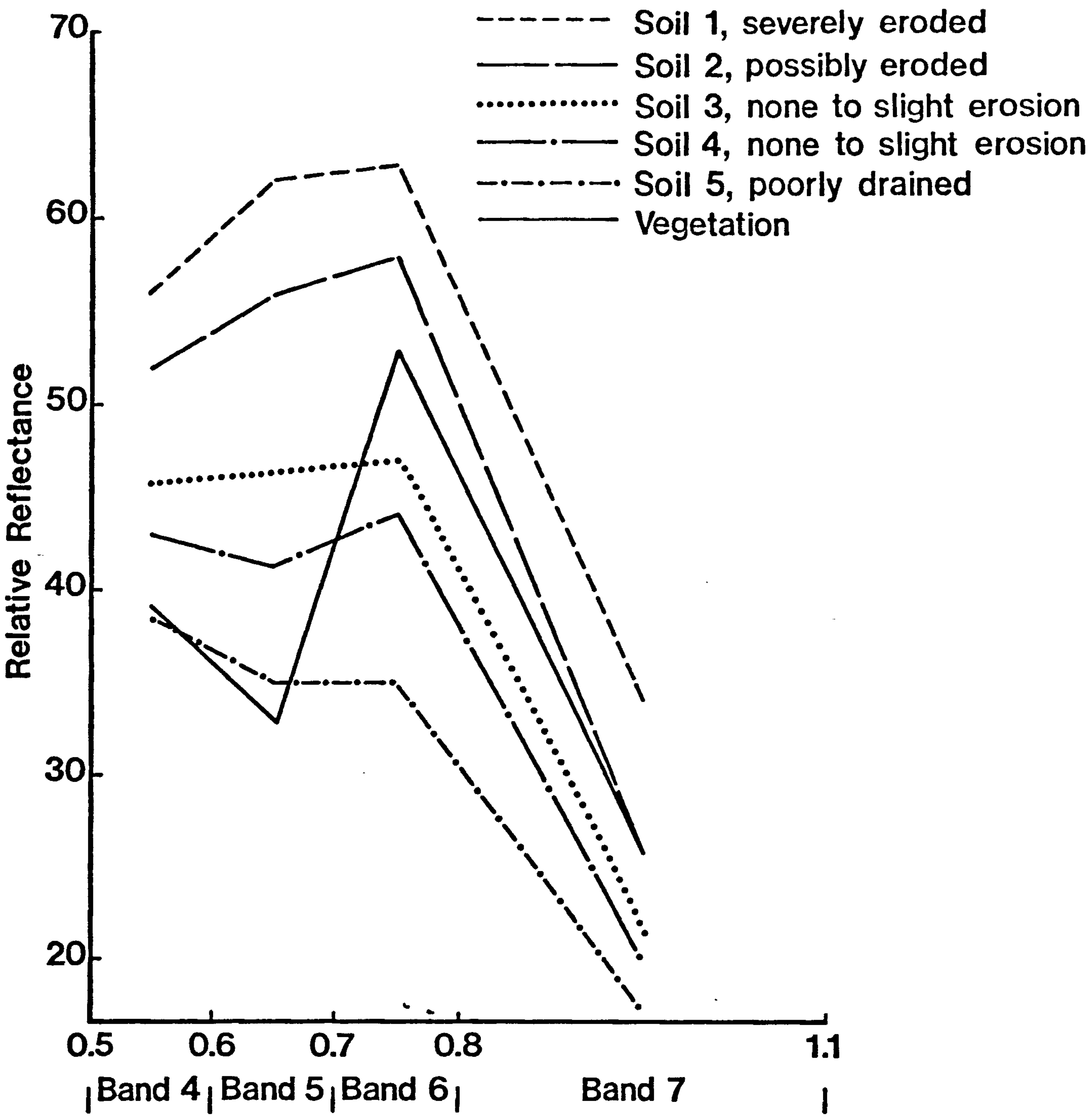


Figure 9. Spectral curves derived from Landsat multispectral data delineating severely eroded soils from other classes.

Key

White - Wheat
Black - Fallow Land
Gray - Permanent Pasture

Figure 10. Classification of Greeley County, Kansas from Landsat MSS data collected 19 June 1973.

Table 1 Specifications of Sensors on Landsats 1, 2 and 3

Landsat	Instrument	Spectral Range (μm)	Description	Spatial Resolution (m)
1, 2	RBV	0.475 - 0.575	Blue-green	80
		0.580 - 0.680	Orange-red	80
		0.690 - 0.830	Near Infrared	80
3	RBV	0.505 - 0.750		38
1, 2, 3	MSS	0.5 - 0.6	Green	80
		0.6 - 0.7	Red	80
		0.7 - 0.8	Near Infrared	80
		0.8 - 1.1	Near Infrared	80
		10.4 -12.6	Thermal Infrared	240

Table 2 Specifications of the Thematic Mapper of Landsat D

Spectral Bands (μm)	Description	Spatial Resolution, IFOV (m)
0.45 - 0.52	Visible Blue	30
0.52 - 0.60	Visible Green	30
0.63 - 0.69	Visible Red	30
0.76 - 0.90	Near Infrared	30
1.55 - 1.75	Middle Infrared	30
2.08 - 2.35	Middle Infrared	30
10.40 -12.50	Thermal Infrared	120