Remote Sensing of Agriculture, Earth Resources, and Man's Environment

Introduction

Man's Environment and Remote Sensing

To map natural and man-planned vegetation, to detect pollution and environmental problems, to uncover needed hidden mineral resources, to predict accurately crop yields and hence our food supply, to rapidly assess the damage of a disaster—these tasks are important to our nation's growth and survival. A new technology—remote sensing—is being developed to perform them.

The cover illustration, a computer-derived classification of Lake Texoma, Oklahoma was made with data received from the Earth Resources Technology Satellite (ERTS-1). Each color represents a different class of surface cover or land use. Such remotely sensed information can be valuable in the management of developed lands. In underdeveloped lands remote sensing may be the only technology which can provide this type of management information at reasonable cost.

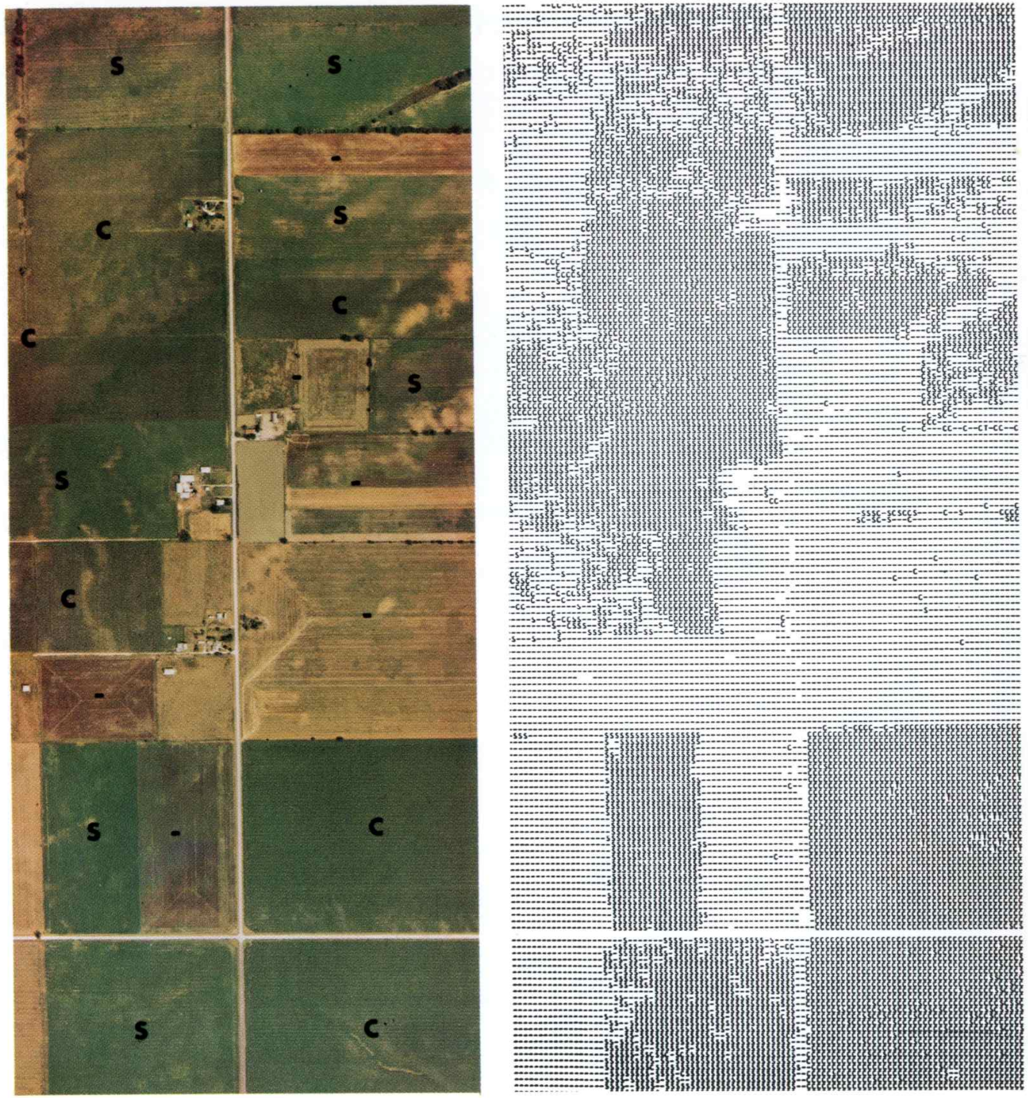


Figure 1

Color aerial photograph and a computer-produced vegetative map of the same area. The computer map contains the following symbols: C = corn, S = soybeans and — = pasture and stubble.

Figure 1 illustrates how remote sensing technology uses the computer to map crops. Such a computer map may be displayed on a television screen or with a computer printer.

This can be done for many types of resources. Identified in Figure 2 are various subcategories of water, and a suspected effluent is marked by the arrow. The symbols below the arrow have changed, indicating a physical change in the river.

If such maps can be inexpensively produced on a regular basis, the comparisons of results from week-to-week or month-to-month may highlight important changes. This would be a significant new capability in the management of earth resources and our environment.

This booklet is intended to illustrate the promise of the new technology—computer-aided multispectral remote sensing—for earth resources inventory and management.

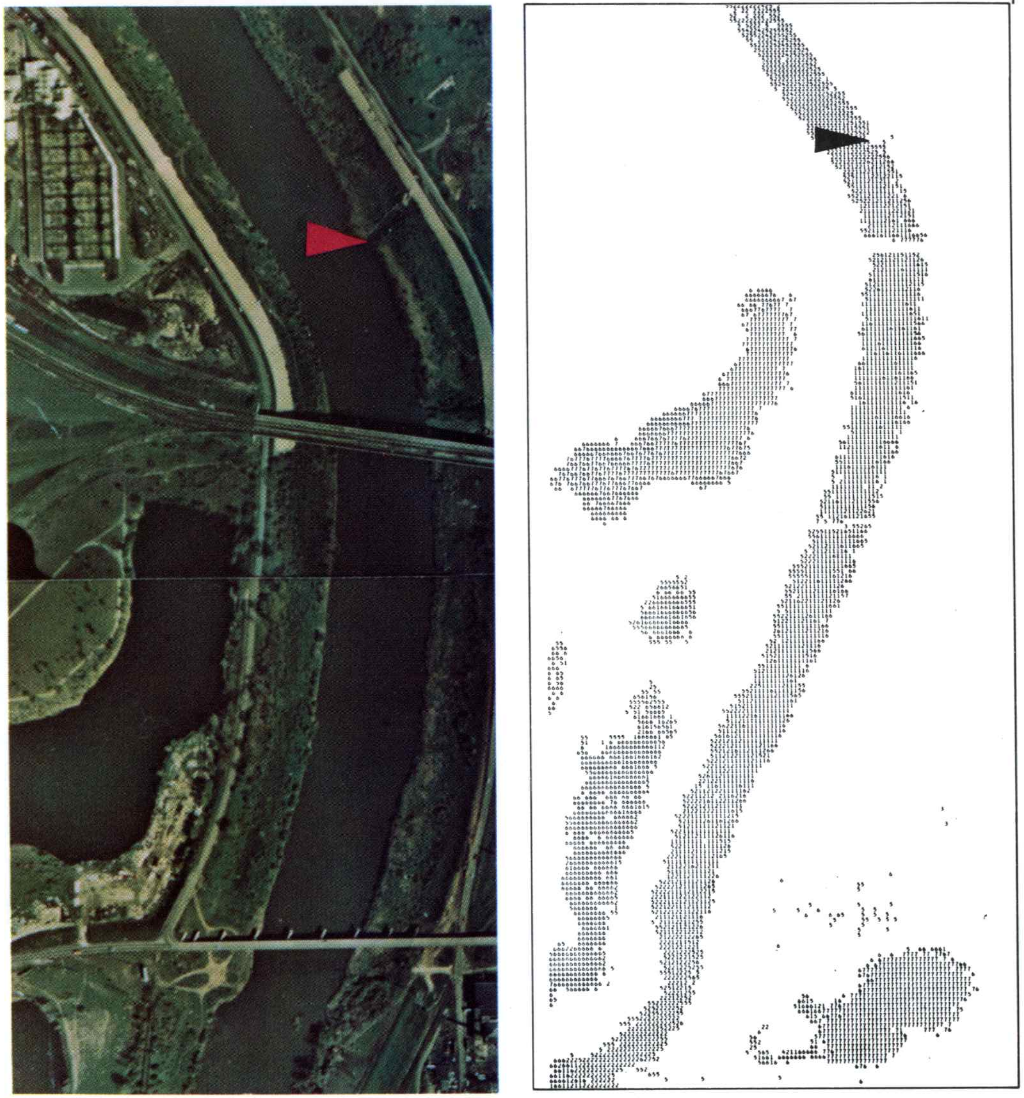


Figure 2
Computer printout (right) showing subcategories of water detected by remote sensing techniques in the White River near Indianapolis. The color aerial photograph (left) is of the same area.

Remote Sensing . . . New Technology

"Remote sensing" means measuring an object from a distance, whether by photography or by one of the newer non-photographic techniques. Cameras, microwave instruments, spectroradiometers, multispectral scanners, and the human eye are all examples of remote sensors.

Remote sensing largely concerns the measurement of electromagnetic energy which is reflected, scattered or emitted by objects receiving, and then returning, energy from the sun. Different objects return different kinds and amounts of energy. In remote sensing, detecting these differences enables identification of the ground object from the air or from space.

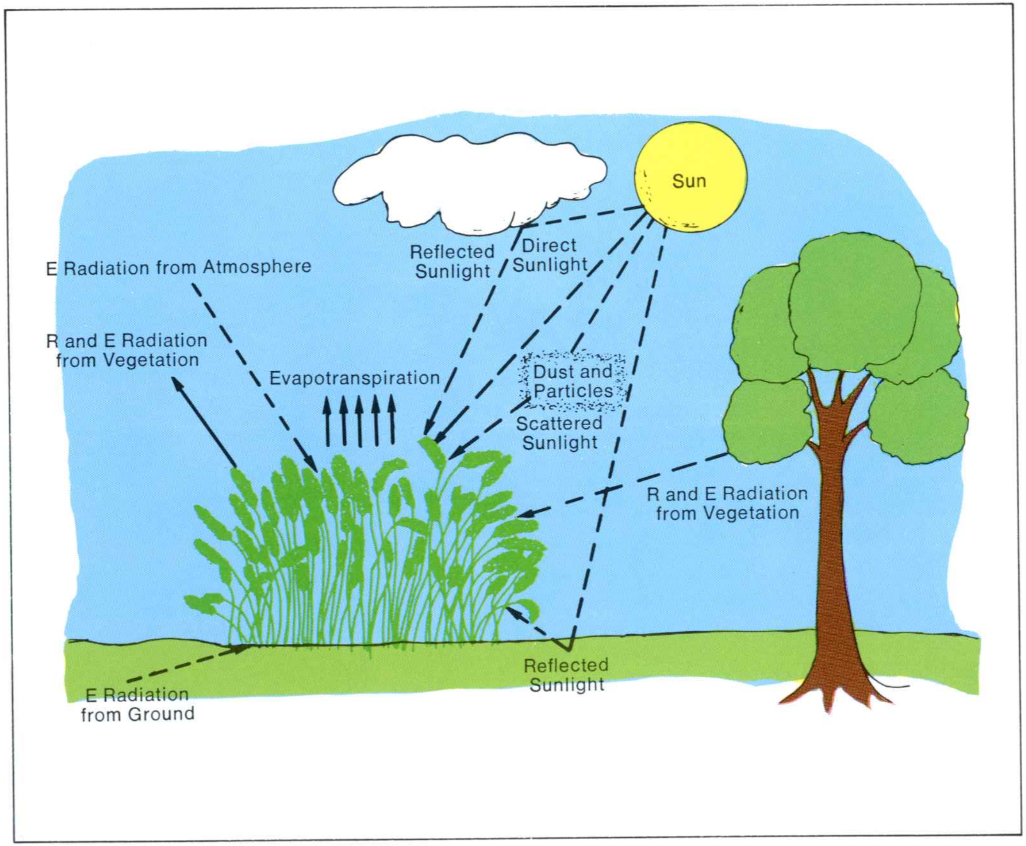
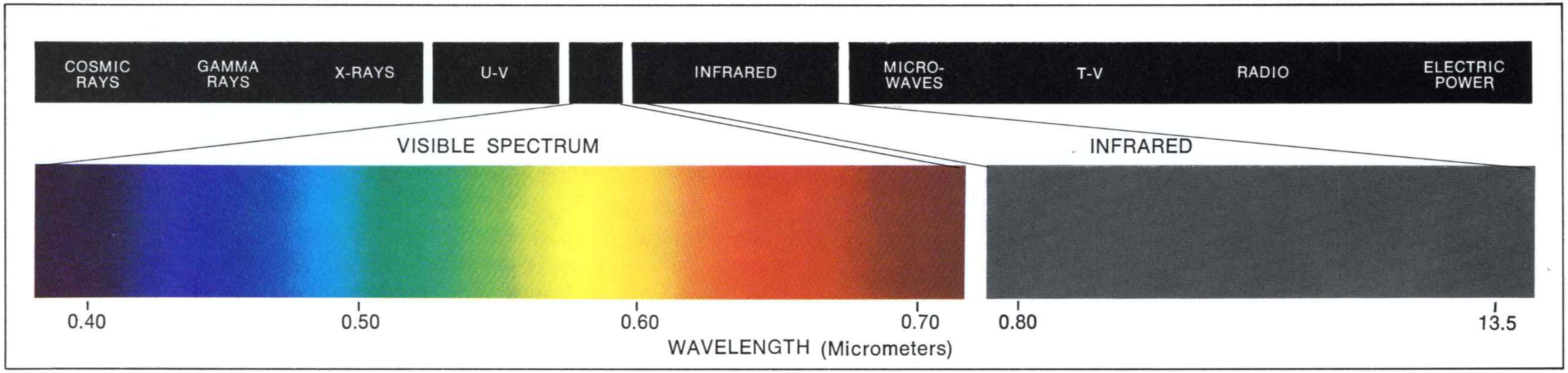


Figure 3

Energy flow in the environment is an essential part of the biological processes of nature. Remote sensing techniques make use of this phenomenon by measuring the reflected (R) and emitted (E) energy from objects on the ground.

These differences affect the spectrum far beyond the small portion perceived by the eye. This portion, from 0.4 to 0.7 micrometers, is referred to as the visible portion. The wavelengths shown in the figure quantify the colors of the rainbow—violet, indigo, blue, green, yellow, orange and red—and infrared, most of which is not visible. No single instrument is capable of sensing and measuring energy at all wavelengths of the electromagnetic spectrum. To extend this range, however, multiple detectors have been unified behind a single set of optics to form multispectral scanners (see next page); they cover the largest portion of the spectrum of energy of any remote sensor used in the air or in space.

Figure 4
The electromagnetic spectrum including the small portion which is visible.



Remote Sensing . . . Equipment and Techniques

Data Collection

The machine-produced maps shown in this brochure are derived largely from data measured with a multispectral scanner (Figure 5). Such an instrument may be mounted in either an aircraft or a spacecraft. Scanner data have been taken during the flights of both Skylab and ERTS, as well as several airborne scanners.

A scanner picks up the reflected and emitted energy of a scene in a line-by-line fashion. The optics of the system refract this beam of energy, separating it into components according to wavelength. The response in each wavelength band may then be stored on magnetic tape. Simultaneous recording of the signal from each wavelength band synchronizes the data for all channels. This is important later when the data are analyzed to establish the unique spectral

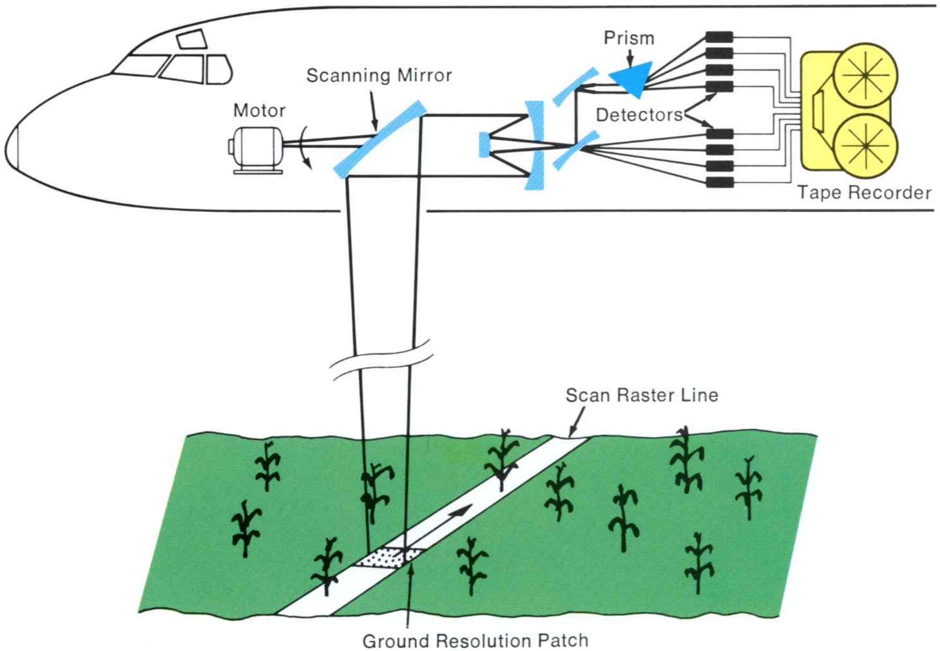


Figure 5

When data are collected by an airplane, this type of an optical-mechanical scanner is often utilized to collect research information.

characteristics of different kinds of objects in the ground scene.

The strength of this system lies in its quantitative nature. Computer programs operate on numerical values from different wavelength channels which have been ascribed to the energy levels coming from a given spot on the ground. Through the computer-aided examination of these values, areas on the ground showing similar responses can be related.

Multispectral scanner data has high spectral resolution, the capability to sense and record responses in narrow wavelength bands. This high spectral resolution coupled with a quantitative analysis method provides a reliable basis for identifying the ground cover of natural and cultivated tracts.

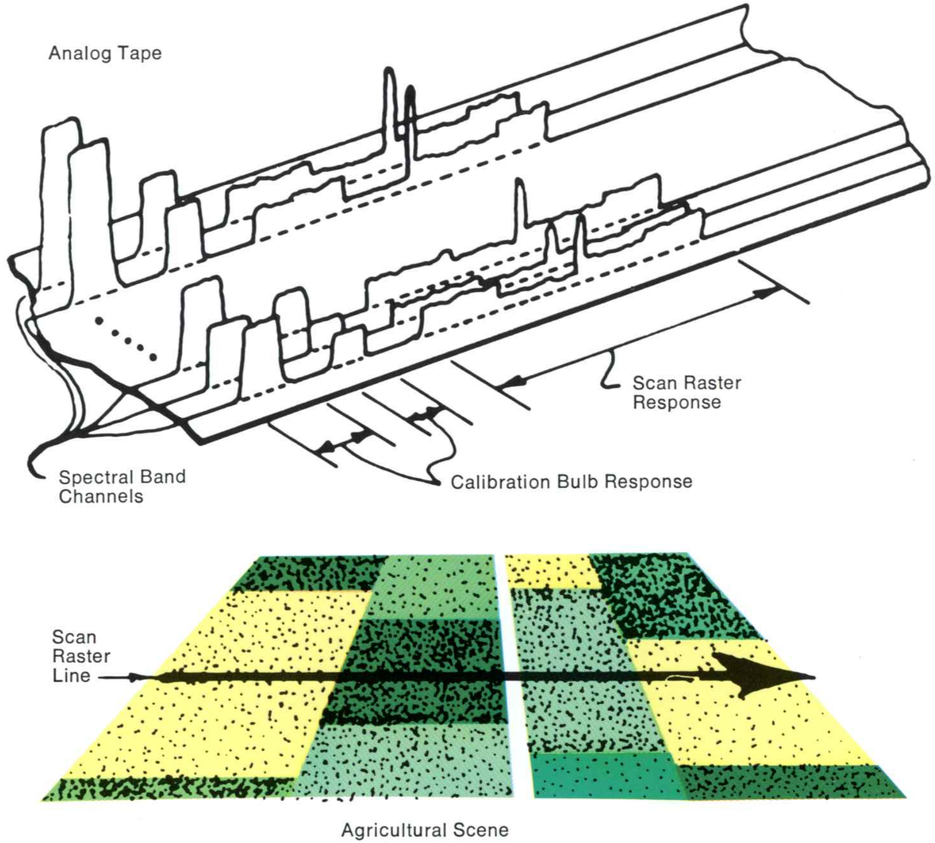


Figure 6

While the airplane's scanner is collecting data, the responses of energy are recorded on a multi-channel tape to be brought to the analysis facilities for analysis.

Data Handling and Analysis

The data taken by a multispectral scanner is "digitized" so that it can be handled by computer. That is, the output from each channel at a single instant of time is expressed as a value representing the strength of response of the signal from a given area on the ground in a given wavelength. These digitized channels may be displayed as black and white images. Often these intermediate images are quite revealing, though generally they are not used as a finished result.

Instead, the digitized values from all channels are used by the computer to construct a response profile for each spot on the ground. With the aid of computer programs using pattern recognition techniques the response profile is then compared to previously derived profiles of "training" classes which have been defined for the purposes of a particular application.

The response profiles of the training classes are generated with the aid of the computer by an analyst familiar with the desired classes. The analyst uses a digital display of a known area to interact with the computer as shown in Figure 7. This procedure for chosing the classes is some-

Figure 7

Special display systems such as this allow the operator to direct the computer's handling of image data. The light pen in the researcher's hand can be used to mark the screen, recording the address of a point or field of interest.

times called "training the computer." Briefly, a known part of the image is identified as being, say, corn. The computer uses this data to construct a statistical response profile for corn. This process is followed for all classes of interest. The resulting statistics can then be used to classify any area of interest into the trained classes.

The bookkeeping agility of a computer as shown in Figure 8 permits an earth resource manager to sort the results and express them in tabular form or in various image formats. For example, every point having a response profile similar to the corn class can be identified with a "C" on an alphanumeric printout, or in a contrasting color if projected on a television-type screen.

This analysis process, called computer-aided classification, is one of the key aspects of remote sensing technology. The accuracy of results compiled using these techniques compares well to results of surveys now compiled by conventional means. The potential of rapid survey offered by this new technique has great significance for many applications requiring timely information.

Figure 8
The LARS/Purdue computational facility, an IBM 360/Model 67 time-share computer with terminals for analysis of data on this system located in several other offices and laboratories across the country.

New Instruments to Answer Questions

Building, improving and evaluating complex energy-measuring and calibration instruments is an important part of remote sensing.

For field studies and collecting "ground truth" or ground observation data, special equipment and instruments are used (Figure 9). The measurements taken in the visible, reflective infrared, and thermal infrared regions of the spectrum provide a means to interpret and understand the data collected by scanners in airplanes and satellites. For example, during the summer of 1973, a multispectral scanner and a spectrometer pointed by an astronaut aboard Skylab measured the radiation from an Indiana test site. Measurements were made by surface-based instruments at the site, by a multispectral scanner at 5000 feet, and by cameras at 50,000 feet, all in addition to Skylab. A day earlier the ERTS-1 satellite passed over the same test site and recorded data under the same good weather conditions. These data, when analyzed, help to determine the effects of atmospheric conditions on classification accuracy and calibration of aerospace sensors.

Figure 9
The LARS/Purdue mobile lab, field radiometer and aerial tower.

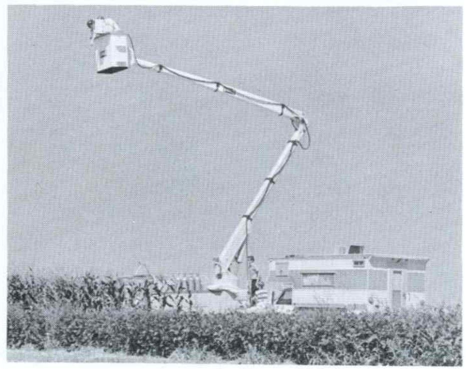
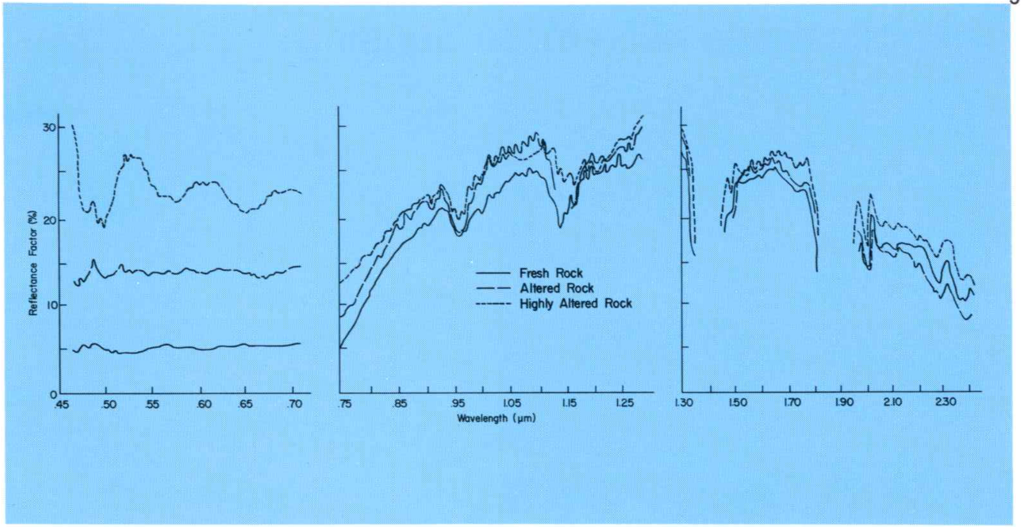


Figure 10

Effect of hydrothermal alteration on the spectral response of rocks.



Specialized computer programs can quickly convert the field data to useful tables and graphs. For example, the graphs shown in Figures 10 and 11 are based on data taken with a field spectroradiometer (shown mounted in the bucket of the aerial tower). Information such as this provides insight into the spectral variations which may be attributed to such factors as moisture stress, nutritional stress, and the percentage of ground cover.

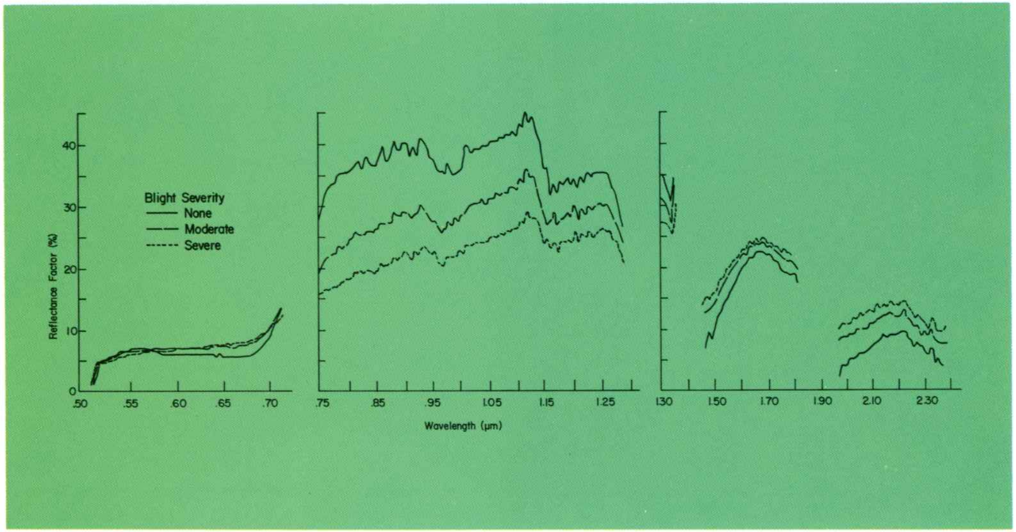


Figure 11

Effect of southern corn leaf blight on the spectral reflectance of corn.

Applications of Remote Sensing

Crops

Crop identification has long been recognized as one of the potential applications of remote sensing. In fact, accurate identification of crop species is a prerequisite to deriving crop production estimates. The value of this information is substantial to today's world with its rapidly increasing demand for food.

Many of the illustrations shown here, including that on the cover, are derived from ERTS-1 data. This satellite, which passes over every point on the earth's surface every 18 days, has been a tremendously effective source of rapid survey information since its launch in mid-1972.

The map shown in Figure 12 represents a significant accomplishment—the accurate identification of crops from satellite data. The wide-area, sequential coverage from ERTS-1, combined with the capabilities of computer processing, offers a new opportunity to improve the accuracy and timeliness of crop production estimates. Quantitative evaluation of computer-processed ERTS data shows that major crop species—corn and soybeans—were accurately identified. Comparisons of acreage estimates from ERTS data and ground surveys agree well.

The classification of satellite data over a 2000-square-mile area not only covered more than 100 times the area previously covered by aircraft data, but training sets could be extended over far larger areas than was ever possible with aircraft data.

The results demonstrate the feasibility of this technology for obtaining crop production information. Current investigations are verifying the applicability of computer-aided analysis of ERTS data to identifying crops and making acreage estimates over a wide range of environments with differing soils, weather, and cultural practices. In the future remote sensing technology may be used to obtain information on the condition and predicted yield of crops as well as their acreages.

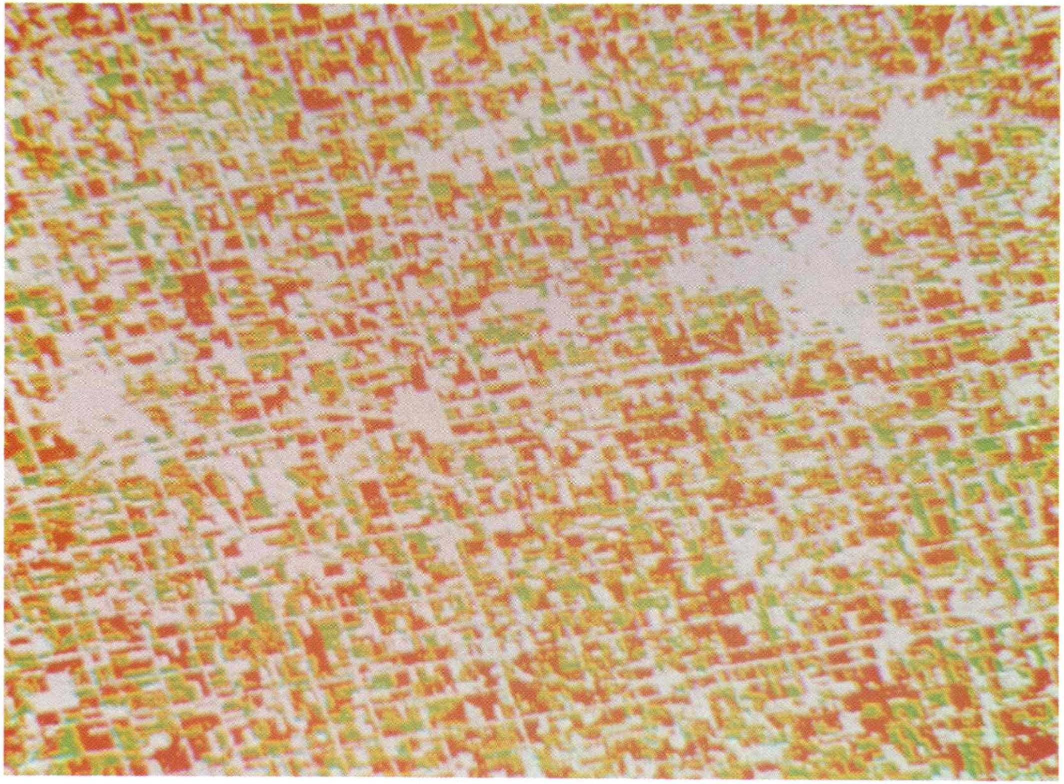


Figure 12
Computer classification of ERTS data identifying corn (red) and soybeans (green).

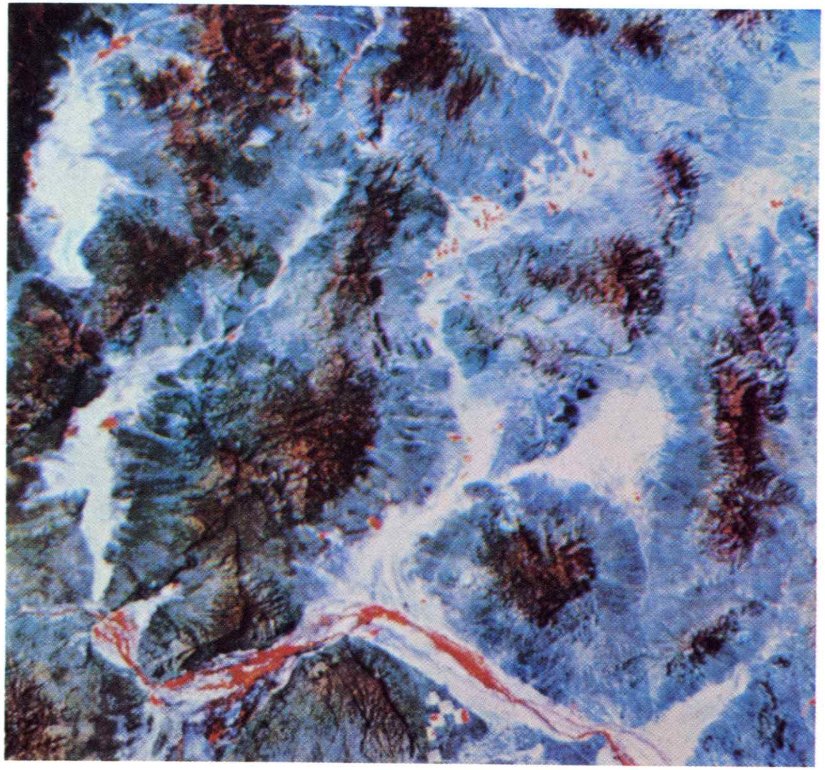
Geology

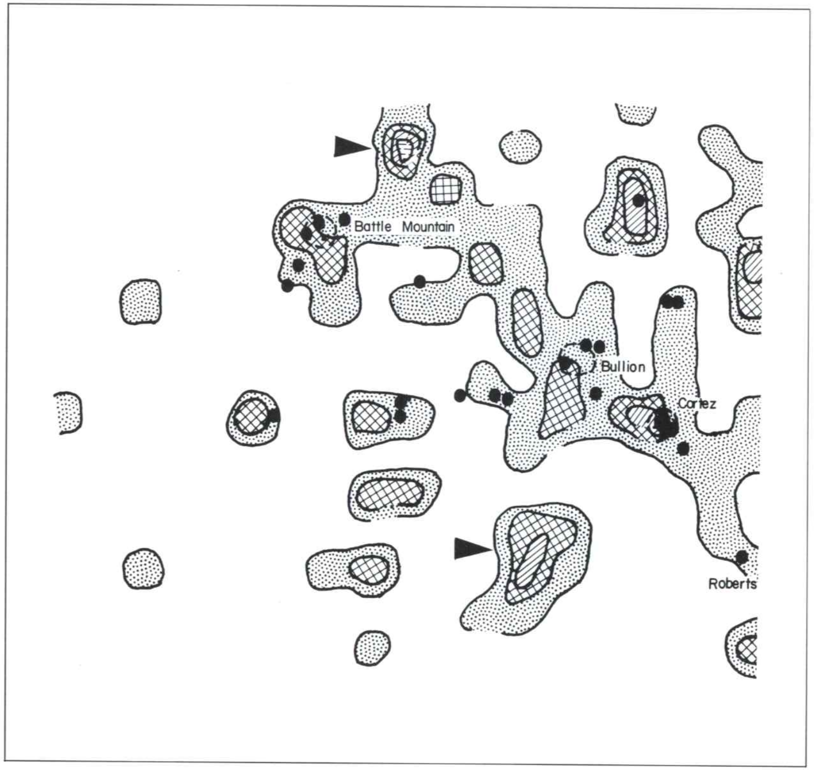
The need to discover new resources is forcing the mineral industry to inventory and renew exploration in known producing regions as well as undertake exploration of relatively unsurveyed regions of the earth. There is a need to develop reconnaissance exploration techniques which enable large areas (amounting to hundreds of thousands of square miles) to be assessed at low cost to select and reliably identify regions of highly promising ore potential. Once such regions have been identified, higher cost, detailed prospecting techniques, such as airborne and ground geophysical and geochemical techniques, can be focused in those smaller regions.

Figure 13 demonstrates the value of ERTS-1 data as a supplement to mineral reconnaissance techniques. Field studies have revealed that the major mining districts in Lander and Eureka counties, Nevada, for example, tend to be aligned in northwest-southeast belts with ore deposits occurring in places that coincide with the intersection of lineaments.

Analyses of satellite-produced color images (left) indicated that many of the ore districts related to these lineaments were not previously mapped either by aerial or field studies. These lineaments very likely indicate deep zones of structural weakness along which igneous rocks and related ore-bearing fluids have penetrated. The map (right) was prepared from an image display of ERTS-1 data. Two major areas with no known ore deposits are interpreted to be potential exploration targets (see arrows).

Figure 13
Simulated color infrared imagery from ERTS data (North Central Nevada). From study of this data, geologists have deduced that the areas indicated with arrows warrant investigation as potential mining sites.




Battle Mountain
Bullion
Cortez
Roberts

Forestry

Reliable computer-aided forest cover mapping is a goal that has been achieved from both aircraft and satellite altitudes. In addition to the separation of forest cover from all other vegetative cover types, work has been done to distinguish coniferous from deciduous forest. Figure 14 (right) is a cover type map produced by a computer from multispectral scanner data collected at an altitude of 5000 feet. The areas displayed in black are coniferous forest; the surrounding green areas are deciduous. Classification accuracy exceeds 90%. On the left is an enlargement of a small-scale (1:120,000) color infrared aerial photo taken at about the same time as the scanner data.

Results from ERTS multispectral scanner data indicate the feasibility of reliable forest cover mapping on a regional basis.

Figure 14

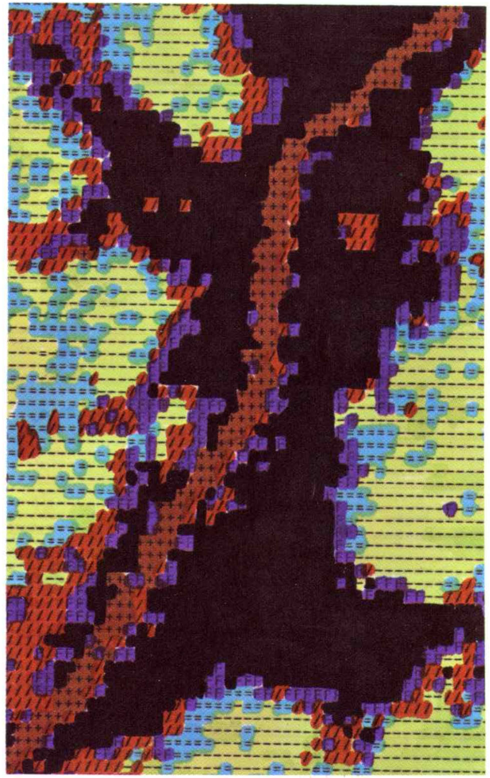
The accuracy of the computer-aided classification (right) from data taken at 5000 feet is indicated by the false color infrared (left). The coniferous areas are coded black; surrounding green areas are deciduous forest cover.

Soils

Over the years soil scientists have defined meaningful soil categories based on soil depth, texture, slope and drainage characteristics, color, and other physical and chemical characteristics. Because field mapping of soils is so time-consuming, the U.S.D.A. Soil Conservation Service and other agencies are exploring the use of airborne and spaceborne multispectral scanners and computer processing to increase the speed and accuracy of the soil survey.

Soil parameters such as organic matter content (Figure 15), iron content, soil drainage patterns and color have been successfully mapped using airborne multispectral scanners. Since there is a high correlation between these parameters and those of interest when mapping soils by conventional methods, computer analysis of multispectral data is expected to play an increasingly important role in the ongoing National Soil Survey program. Multispectral data gathered at satellite altitudes have already been used effectively for generalized mapping of soils and landscape features over large areas.

Figure 15
Aerial photograph and soil organic matter content map (right) produced by computer of a soils test site in Tippecanoe Co., Indiana.



Hydrology

Emissive regions of the spectrum have been used to determine the thermal characteristics of water bodies; measurements from altitudes of several thousand feet, accurate to a fraction of a degree, can be made of the surface temperature. Such a capability for sensing thermal variations offers great promise for environmental monitoring in the future.

Figure 16 is a color-coded temperature map illustrating the pattern and extent of the waste-heat plume introduced by a fossil fuel power plant on the Wabash River. Mixing of hot and cold water takes place slowly, and their separation may be discerned for several miles downstream. Studies have shown significant changes in the fish population due to this thermal effluent.

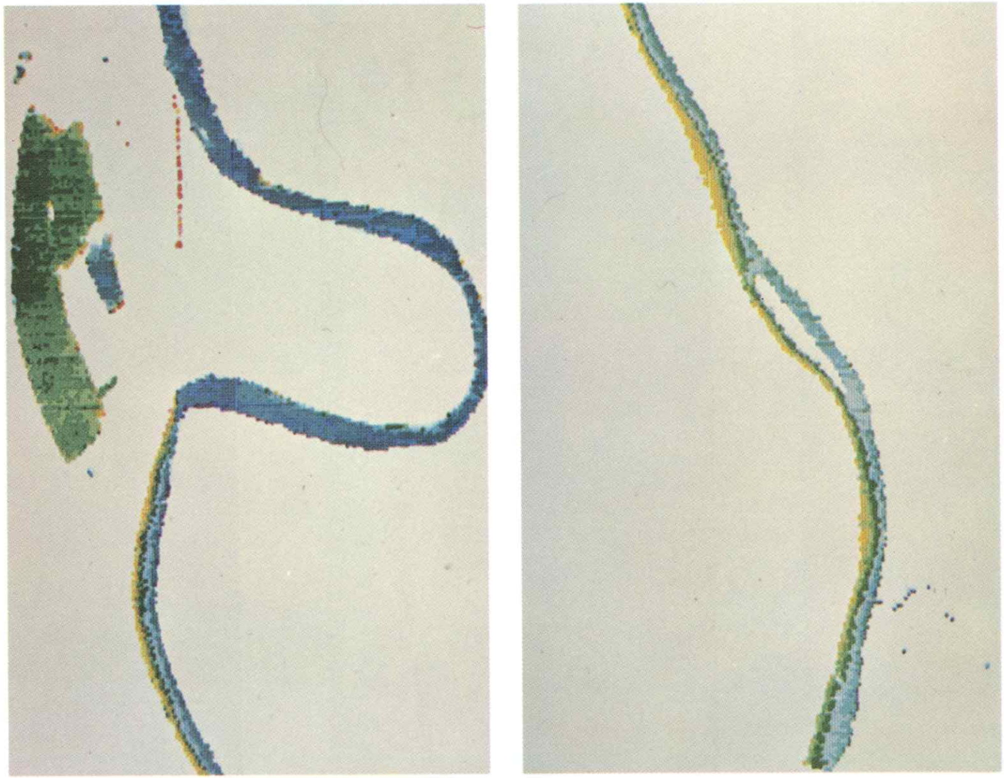


Figure 16
A "thermal map" of the Wabash River near the Cayuga power plant (left). The illustration at right is from the area immediately south.

Land Use

From multispectral data collected at low altitudes, detailed land use maps can be generated by computer-aided analysis. The data in Figure 17 were collected from 600 meters (2000 feet) over central Indianapolis. Recreational land uses are easily identified—South Grove Golf Course in the upper portion of the image, Bush Stadium in the lower right, and Belmont Park in the lower left. A residential area is seen in the upper right, while the center of the image contains an industrial area.

Such detailed inventories from low altitudes will probably not be required by planners for all areas of their jurisdiction, but orbiting satellites can provide periodic, less-detailed land use maps of entire metropolitan areas. Computer-implemented land use classifications with

Figure 17

Land use classification of area in central Indianapolis (altitude = 2000 feet). Water is blue/light blue; grass, greens/gray; roads, lavender; rooftops, red/orange/yellow; trees, purple; bare soil, light tan; shadow, black.

ERTS-1 data collected over Milwaukee (Figure 18) and Indianapolis (Figure 19) are shown in which patterns of urban growth and development are evident. In both Midwestern cities the concentric pattern of growth is present—the downtown area is surrounded by a ring of older housing, which is in turn surrounded by newer residential areas. The radial pattern of development (following major transportation routes) is also noticeable in each urban area. Urban encroachment upon rural, agricultural land has taken place in both Milwaukee and Indianapolis.

The scale of the land use analysis is an important consideration. Figure 20 is a series of color-enhanced images of ERTS data collected over the Chicago-Gary urban area. Beginning

Figure 18

Computer-aided land use classification of ERTS data collected over Milwaukee, Wisconsin. Commerce/industry is lavender; older housing, red; newer housing, orange; older, upper income areas, light tan; grassy areas, light green; wooded, dark green; water, blues; cloud, white; shadow, black.

with a full frame of ERTS data (about 10 miles on a side), the image was successively enlarged by computer methods to focus upon the East Chicago-Gary area. In the latter image, the Port of Indiana is in the left center, U.S. Steel to the southeast, and smoke plumes drift from each to the northeast. State Officials from Indiana and Illinois will benefit from a general land use analysis of the entire ERTS frame, while much information is present, too, for local or neighborhood interests.

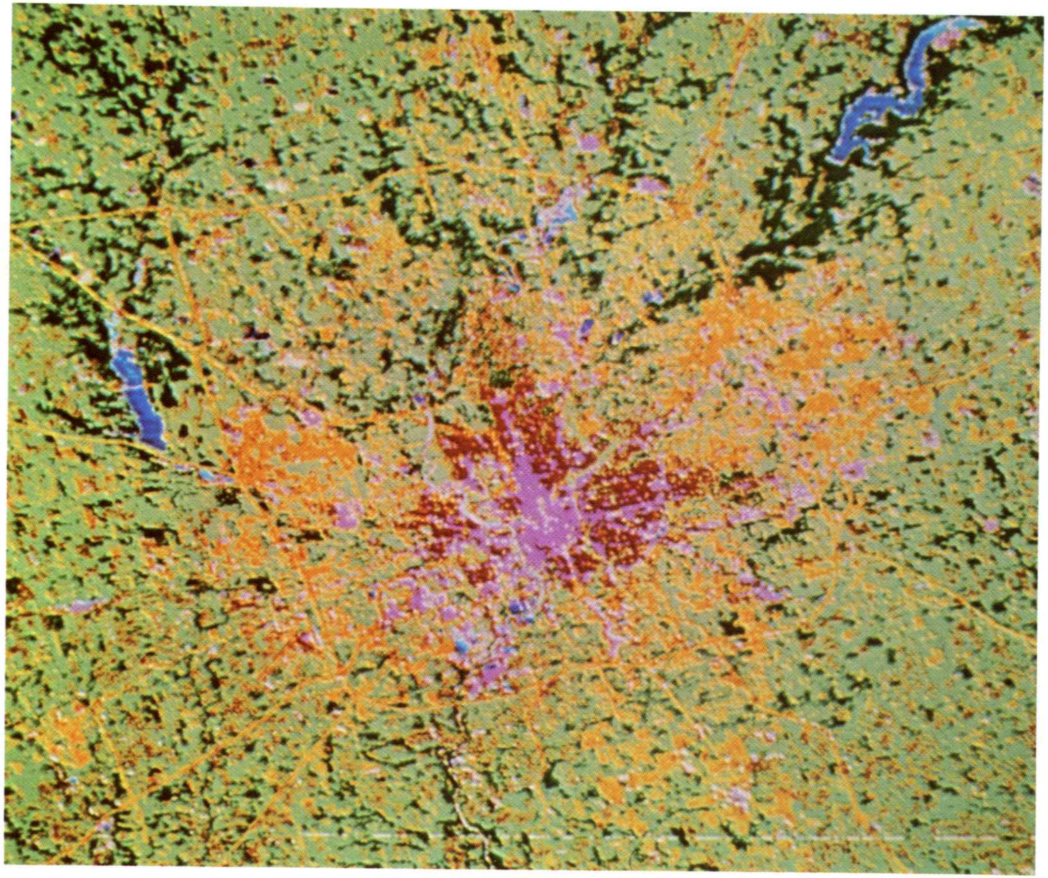
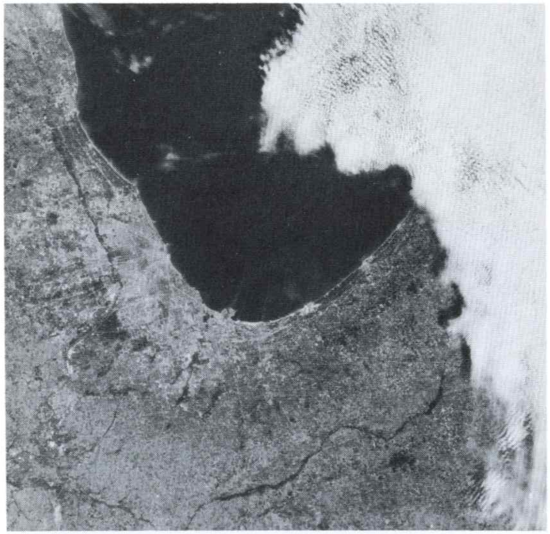
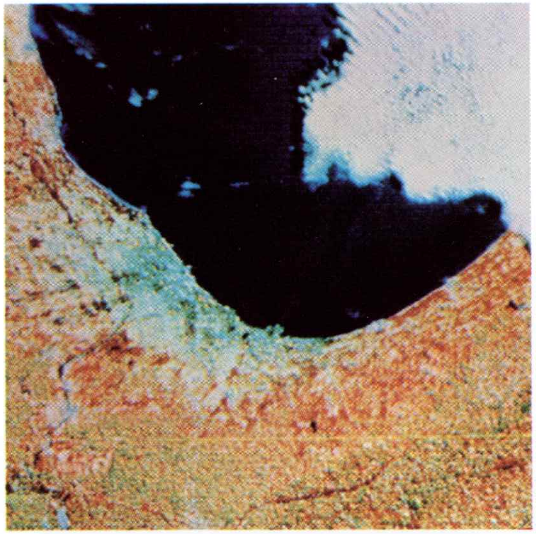
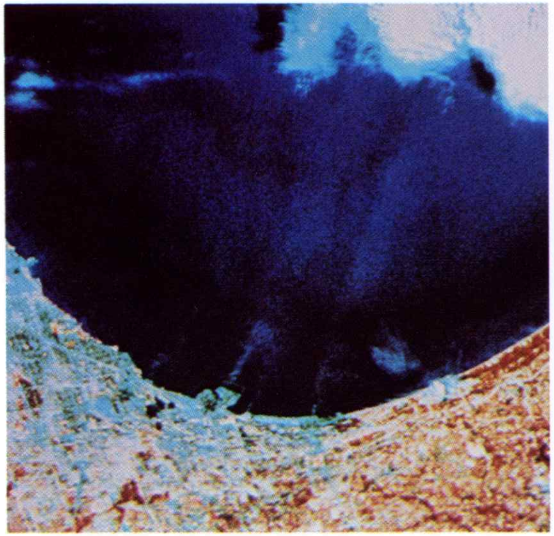


Figure 19
Computer-implemented land use classification of ERTS data collected over Indianapolis, Indiana. Commerce/industry is lavender; older housing, red; newer housing, orange; grassy areas, light green; wooded, dark green; water, blues; cloud, white; shadow, black.



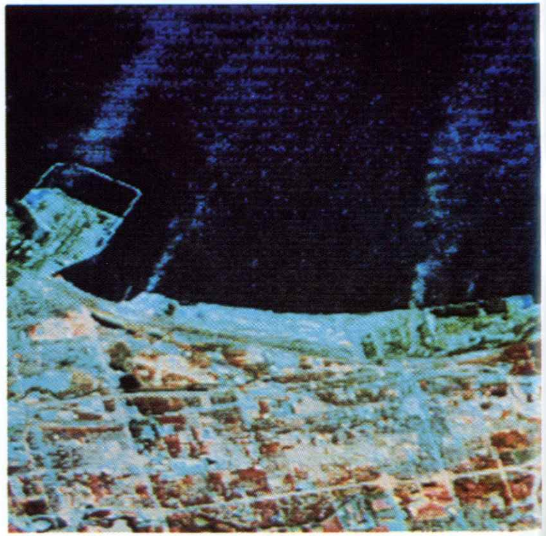


Figure 20

Color-enhanced ERTS imagery of Chicago-Hammond-Gary area. The first and second images show the entire ERTS frame. The image was successively enlarged until the fine detail in the final image of the East Chicago-Gary section.

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PRINTED IN U.S.A.