Remote Sensing--A Tool for Resource Management[1/]

by Roger M. Hoffer[2/]

Abstract

Accurate interpretation of imagery from remote sensing systems requires an understanding of the instrument systems, the spectral characteristics of the earth resource materials present, and of the several energy-matter interactions involved. This paper discusses some of the advantages and disadvantages of photographic and multispectral scanner systems, along with a brief mention of the potentials for use of radar data. Emphasis is placed upon the spectral characteristics of vegetation, soil, and water, and the need for this knowledge in the interpretation of remote sensor imagery. Characteristics and use of color infrared film, showing several examples of possible applications to resource management are given. The need for automatic data processing is discussed, and examples of automatic analysis of multispectral data in several discipline areas are shown to illustrate the potentials for these techniques. Thus, some phases of remote sensing are operational today for the resource manager; but other aspects offering great potential are still to be proven.

Introduction

In order to manage our nations available resources intelligently and in the best interests of society, it is essential that detailed, timely information concerning these resources be available. Information about the location, condition, and extent of the various resources is needed--and at several levels of detail. For example, agencies such as the U. S. Forest Service require generalized information for the entire country concerning the timber, range, water, and soil resources, whereas the supervisor of an individual forest requires much more detailed information over a much smaller area. One means of obtaining some of the generalized as well as the detailed information required for proper management of our resources is by remote sensing.

1/ Paper presented at the Third International Symposium of Hydrology Professors, July 19-30, 1971, Purdue University.

2/ Associate Professor, Department of Forestry and Conservation, and Leader, Biogeophysical Research Programs, Laboratory for Applications of Remote Sensing, Purdue University.

Remote sensing is a developing technology involving the acquisition of information about a portion of the earth's surface by using sensing devices operated from a remote location. A more complete definition could describe remote sensing as the discipline involved with the gathering of data about the earth's surface or near surface environment, through the use of a variety of sensor systems that are usually borne by aircraft or spacecraft, and the processing of these data into information useful for the understanding and managing of man's environment.

Sensor Systems

There are many types of sensor systems that can be utilized in remote sensing. Photographic systems are the most common and are capable of being utilized with many combinations of films and filters. There are several advantages found in photographic systems, including the minimal maintenance requirements and ease of operation, relatively low cost for obtaining data, a well-known and easily understood data format, good spatial resolution in the resultant data, and a capability for photogrammetric and stereoscopic measurements. However, as seen in Figure 1, photographic films are sensitive only to energy from a limited portion of the electromagnetic spectrum, including the visible and near infrared wavelengths. It is known that valuable information concerning the thermal characteristics (temperature and emissivity) and the reflectance characteristics of the vegetation, soil, and water cover types on the earth's surface can be obtained in the longer wavelengths (or lower frequencies). To obtain data in these wavelengths, optical-mechanical scanners are utilized.

The method of operation of a multispectral optical-mechanical scanner is illustrated in Figures 2 and 3. The energy reflected or emitted from a small area[1] of the earth's surface at a given instant in time is reflected from the scanning mirror, through a system of optics which cause the energy to be dispersed spectrally onto an array of detectors. The detectors, carefully selected for their sensitivity to energy in the various portions of the spectrum, measure the energy in the different wavelength bands. The output signal from the detectors is amplified and recorded on magnetic tape. The energy from a single ground resolution element can thus be measured in several wavelength bands. As the aircraft or spacecraft flies over an area, the ground surface is scanned in successive strips by the rapidly rotating mirror. The rotating motion of this mirror allows the energy along a scan line (which is perpendicular to the direction of flight) to be measured, while the forward movement of the aircraft or spacecraft brings successive strips of terrain into view. Thus, a continuous area of the earth's surface can be sensed, using several wavelength bands which can encompass the entire optical portion of the electromagnetic spectrum.

---

[1] The instantaneous field of view of the scanner is a function of the scanner configuration and altitude of the aircraft or spacecraft.

Scanners such as that illustrated are mechanically and optically complex but as remote sensing devices do have many advantages over photographic systems. The major advantage is that they allow data to be obtained over a much greater range of frequencies than is possible with photographic systems. This is illustrated in Figure 4, which shows a forest fire as viewed on an ordinary panchromatic photograph and as sensed by a scanner operating in the 8-14 μm or thermal infrared wavelengths. Energy in the visible wavelengths is scattered by smoke particles, so the photograph shows only the smoke pall above the fire; the longer wavelengths in the 8-14 μm region (thermal infrared) are not scattered by the smoke and can therefore be sensed by a scanner operating in this wavelength region. This capability of thermal infrared scanners (i.e. scanners operating only in the thermal infrared region) to penetrate smoke is proving of great operational value to the U. S. Forest Service in their fire fighting program (17). Scanners operating in the thermal portion of the spectrum are also able to collect data at night as well as during the day, a fact which further increases their value for forest fire detection and suppression.

Data from optical-mechanical scanners does not have as good spatial resolution as can be obtained from photographs (i.e. small objects cannot be resolved as well on scanner data). However the spectral resolution is much better for scanner data (i.e. energy from much narrower wavelength bands can be measured). Of particular importance are the facts that scanner data can be accurately calibrated and is in a format suitable for quantitative, computerized data handling. These facts make feasible the obtaining of remote sensing data over large portions of the earth's surface, and then supplementing manual interpretation of the data with automatic data handling and analysis techniques.

Side-Looking Airborne Radar (SLAR) systems have been intensively studied in recent years and offer much potential (5, 33). The major advantage for SLAR is its capability to penetrate cloud cover, thereby allowing all-weather data collection. These radar systems can also be used either day or night. Geologists have been particularly interested in SLAR data and have obtained much useful information through use of these systems. However, since relatively high resolution SLAR imagery is not yet easily obtained (as compared to photographic data), and since less potential has been demonstrated for automatic analysis of SLAR data (as compared to multispectral scanner data), and for purposes of limiting the scope of this paper, radar data will not be discussed further. However, SLAR should be recognized as one of the major instrument systems used in remote sensing and one having some distinct advantages (as well as some disadvantages) not found in other remote sensing systems. Its potential is great.

The Need for Automatic Data Analysis Techniques

It is well recognized that high-flying aircraft or satellites can collect enormous quantities of data covering vast geographic areas in relatively short periods of time. For example, the Earth Resources Technology Satellite (ERTS) will have the capability of collecting data over every square mile of the earth's surface every 18 days! Each individual 9" x 9" image from ERTS will cover an area of 10,000 square miles. Even high-altitude aircraft can collect vast quantities of data in short periods of time. Figure 5 is a single frame of photography obtained by NASA's RB-57 from 60,000 feet altitude. The number of individual fields of agricultural cover is rather impressive.

It would seem that the collection of remote sensor data is not as large a problem as is the reduction of this data into useful information. If you were asked to determine the total acreage of corn or of forest land shown only on the photo in Figure 5, your task would be a big one--first to identify the areas containing the cover type of interest and then to determine the acreage of each area and to summarize the acreages. The effort required to convert this single piece of data to various items of useful information would indicate that either a sampling system or some type of automatic data analysis technique, or a combination of the two, could be of great benefit. Since multispectral scanner data can be easily handled by computer techniques, is capable of calibration, and allows for analysis in a relatively wide range of wavelengths, this type of data offers great potential for automatic data analysis. In fact, automatic data analysis is a requirement for handling more than small quantities of multispectral scanner data, because data is collected over the same area simultaneously in many wavelength bands, as indicated by Figure 6. It would be impractical and perhaps impossible for a person to interpret the subtle differences in response from one wavelength band to another for a large number of spectral bands. However, a person is required to formulate and direct the automatic analysis in order to achieve desired results, and this requires a thorough knowledge of the spectral characteristics of the cover types of interest. This point also emphasizes that automatic analysis techniques applied to remote sensing data must involve man-machine interaction.

Spectral Characteristics of Basic Cover Types

Data collected by multispectral scanner represents the spectral characteristics of the various cover types over which the aircraft or spacecraft has flown. It is known that various cover types reflect and emit different amounts of energy in a single spectral band and that a single object reflects and emits different amounts of energy in the various wavelength bands. The proper interpretation of multispectral scanner imagery or other remote sensor imagery--such as color infrared film--requires a knowledge of the spectral characteristics of the various vegetation, soil, water, and man-made features over which the aircraft or spacecraft has flown.

Figure 7 is an example of the spectral characteristics of typical green vegetation and air dry soil. The green vegetation curve clearly shows the changes in reflectance due to the chlorophyll absorption bands at approximately 0.45 and 0.65 μm, the typical high reflectance in the 0.75-1.3 μm region, and the distinct and dominant water absorption bands at approximately 1.45 and 1.95 μm. Minor water absorption bands are also evident at about 0.96 and 1.2 μm. In this portion of the spectrum the energy incident (I) upon an object that is not reflected (R) by the object must be either absorbed (A) or transmitted (T) through the object, or, for any particular wavelength (λ), $I_\lambda = R_\lambda + A_\lambda + T_\lambda$. For turgid, green vegetation, most of the energy in the visible wavelengths (below about 0.72 μm) is absorbed by the chlorophyll, with less absorption and higher reflectance in the green wavelengths (about 0.55 μm) between the two chlorophyll absorption bands. Very little energy in the visible wavelengths is transmitted through a leaf, but in the reflective infrared wavelengths from about 0.75 to 1.3 μm, only very small amounts of energy are absorbed, and nearly all energy not reflected is transmitted through the leaf. In the wavelengths from 1.3 to 2.6 μm, much of the energy not absorbed by the water in the leaf is reflected, leaving much smaller amounts to be transmitted (16).

The soil curve is much easier to interpret, since all incident energy that is not reflected must be absorbed. Comparing the relative reflectances of the vegetation and the soil shown in Figure 7, one sees that the soil reflects more than the vegetation in both the visible wavelengths and in the region dominated by water absorption (1.3-2.6 μm), but that in the 0.72-1.3 μm region (where vegetation has such high reflectance), the soil reflects less than the vegetation.

Referring back to Figure 6--and remembering that in order to see maximum contrast in each wavelength band, such imagery depicts relative differences in reflectance--one quickly observes that the relative differences in reflectance shown in Figure 7 are also found in the multispectral imagery of Figure 6. The vegetation reflects relatively more than the soil in the 0.72-0.92 μm and 1.0-1.4 μm wavelength bands, therefore having a higher response or lighter tone on the imagery, whereas the soil has a higher response (relatively higher reflectance) than the vegetation in the remaining wavelength bands. This helps to explain why the 1.5-1.8 and 2.0-2.6 μm bands in scanner imagery have an appearance similar to the visible wavelength bands. However, since even a thin (1 cm) layer of water will absorb energy in all of the reflective infrared wavelength bands shown in Figure 6 (14), it is not surprising that the river appears black (indicating relatively little reflectance) on the imagery in all bands above 0.72 μm. This situation allows better contrast to be seen between the vegetation, soil, and water in the 1.5-1.8 μm and 2.0-2.6 μm bands than is evident in any of the visible wavelength bands. We thus have some insight concerning the reason the 1.5-1.8 μm and 2.0-2.6 μm wavelength bands are so frequently shown to be among the most valuable in the automatic data analysis. These examples of spectral reflectance data and multispectral scanner data offer a good illustration of the manner in which the study of the spectral characteristics of various materials can help in the interpretation of multispectral scanner data.

The data shown in Figure 7 are rather typical, but as any natural scientist knows, there are many variables in nature, and it is the variation in spectral characteristics which is of particular interest in remote sensing. Soil patterns are seen on remote sensing imagery because of variations in spectral response from one area to another, largely caused by differences in texture, soil moisture, and organic matter (see Figure 8) (7, 25, 27). As vegetation matures, pigmentation changes can cause striking differences in spectral response, and as the moisture content in the leaves decreases, reflectance in the reflective infrared wavelengths (particularly those above 0.7 μm) will increase, as seen in Figure 9 (19,226).

Considerations for Interpretating Remote Sensor Imagery

These data illustrate that the study of remote sensing imagery must involve consideration of the

- spectral,
- spatial, and
- temporal

characteristics of the materials of interest, as well as the surrounding (or background) cover types. The uniformity or heterogeneity in spectral response of an area (spatial characteristics) defines the texture of imagery from that area (i.e. forest cover--coarse texture, vs. oats--smooth texture). The shape (spatial characteristics) of agricultural fields can indicate topographic relief characteristics of an area (refer to Figure 5). Sometimes the spectral characteristics of a material are not sufficient to identify it, and one must rely on temporal changes in the spectral characteristics for identification. For example, it may be difficult to differentiate spectrally between wheat and pasture grass in early June, but in late June in Indiana the wheat matures and can be rather easily distinguished from the pasture and other green vegetation on the basis of spectral response. Thus, study of temporal changes in spectral characteristics of the cover types of interest is essential.

Laboratory and field studies form an integral part of a well-rounded remote sensing research program, enabling one to study spectral characteristics and the temporal changes in these characteristics for materials of interest. One might envision a situation such as shown in Figure 10, in which carefully controlled, detailed studies over limited areas can be conducted from ground-based platforms in the field, and on the basis of this knowledge, one can better interpret data collected from aircraft and spacecraft altitudes. Another reason for conducting field studies is an economic one. When frequent measurements are required over limited areas, (e.g. studying spectral changes in moist soil as it dries or in diseased vegetation), a ground-based platform can be utilized much more effectively and at much lower cost than an aircraft for collection of the data. As one collects data from higher altitudes, much larger areas can be covered. However, as altitude increases, one must contend with differences in atmospheric scattering and attenuation. Atmospheric effects on remote sensor data require a great deal of additional study.

Advantages and Use of Color Infrared Film

As previously mentioned, photographic techniques offer several advantages for remote sensing and have been the main tool in many research and operational programs. It has only been since the early 1960's, when more exotic sensor systems (such as thermal infrared and multispectral scanners, side-looking airborne radar and passive microwave radiometers) were first used by a variety of scientists interested in earth resource surveys, that the term "remote sensing" came into common use to define a discipline which involved use of not only the more exotic sensors, but also photographic systems. In recent years, considerable work has been done with multi-band camera systems, employing a variety of films and filters (1, 31, 34, 35). These systems offer considerable promise, particularly for studying the relative reflectance of various cover types from aircraft altitudes. Of even greater significance, however, has been the large amount of research and interest in the use of color infrared film.

Color infrared film, officially designated as "Kodak Aerochrome Infrared Film, Type 2443", is a film similar to regular color positive films. The main difference is that where the three emulsion layers of regular color film are sensitive to energy in the blue, green, and red portions of the spectrum (all in the visible wavelengths), the three emulsion layers of properly filtered color infrared film are sensitive to the green, red, and reflective infrared wavelengths. Thus, regular color film has a total sensitivity range of about 0.4-0.7 μm, whereas properly filtered color infrared film is sensitive to a wavelength range of about 0.5-0.9 μm (15, 31). It is very important to note that color infrared film is not sensitive to the thermal infrared wavelengths. Therefore, this film cannot be used to detect or monitor thermal phenomena such as the heated discharge onto rivers from hydroelectric plants. It is equally important to note that color infrared film is sensitive to most of the visible portion of the spectrum in addition to the 0.7-0.9 μm reflective infrared wavelengths. This implies that spectral variations either in the visible or in the reflective infrared wavelengths, or a combination of both, will cause tonal differences on color infrared film. This makes color infrared film somewhat difficult to interpret unless you know something about the spectral characteristics of the materials of interest, either in the visible or in the infrared wavelengths. For example, turgid, green vegetation appears red to magenta on color infrared film and soil appears in tones ranging from black to green, dark blue, or even light blue or white, depending on the spectral characteristics of the soil and the exposure and development of the film. Water will appear black on color infrared film, if it looks blue or black to our eyes. However if the water body is very shallow and over a sandy bottom area, or if it has a high sediment load or is otherwise polluted and is a rather ugly brown color as we look at it, color infrared film will portray the same water body in very pretty tones of blue. Figures 11, 12, and 13 compare the appearance of various cover types on color infrared film with that on color film.

In order to interpret color infrared film properly, one must either know the spectral characteristics of the materials of interest or know the visual appearance of an object (from which the spectral characteristics of the visible wavelengths can be inferred for naturally occurring materials). Only then can one properly interpret the color infrared film and infer the infrared reflectance characteristics. Thus, just because different objects appear different on color infrared film, it does not necessarily follow that a difference in infrared reflectance is present. The difference in tone observed on color infrared film could be caused solely by differences in reflectance in the visible wavelengths, with no difference in infrared reflectance present. Frequently, however, differences in tone on color infrared film are caused by a combination of spectral differences in both the visible and infrared wavelengths.

It has been observed that when plants are affected by some stress condition, such as that caused by disease or insect damage, changes take place in the spectral reflectance of the foliage. Sometimes these changes start with variations in reflectance in the near infrared wavelengths, even before noticeable or significant changes occur in the visible wavelengths. This has led to considerable interest among plant scientists in the use of color infrared film for early detection of various plant stresses. Diseased vegetation tends to cause deep red to black or brown tones on the color infrared film, as opposed to the red to magenta tones of healthy vegetation. Colwell (11), Manzer and Cooper (28), and others (1, 6, 9, 29) have shown many interesting examples of the use of color infrared film to detect various insect and disease stresses. In work conducted in 1970 at LARS, different levels of infection of southern corn leaf blight could be detected using color infrared film (Figures 14 and 15). Investigations are now being conducted into ways to use this film type for applications in more and more problems involving insect, disease, and other stress conditions. It offers great promise.

One additional major advantage of color infrared film is its ability to enhance subtle differences in reflectance that are barely discernable in the visible wavelengths alone. Frequently, spectral differences due to variations in vegetative species or to a stress condition will exist but will be so subtle that they are difficult to see on regular color film and might even be missed by the photo interpreter. However, since color infrared film is sensitive to both the visible and reflective infrared wavelengths, spectral differences that may be very small in the visible wavelengths are often pronounced in the near infrared wavelengths and thus show clearly on the color infrared film. There seem to be relatively few cases of spectral effects in vegetation, soils, or water that can be seen on color infrared film but cannot be seen at all on properly exposed color film. However, there are many cases where spectral differences are so subtle that the situation or material of interest would be missed if the photo interpreter were relying only on regular color film. For example, deciduous and coniferous trees are not easy to distinguish on regular color film, but with the use of color infrared film the task can be done more easily, accurately, and faster (see Figure 16).

Studying the amount of vegetative cover on an area is also much easier using color infrared film because of the manner in which this film shows vegetation in easy-to-see tones of red and pink, as shown in Figure 17, a strip-mined area in southern Indiana. Also, because atmospheric scattering of light is more pronounced in the shorter wavelengths (as defined by the Raleigh Scattering Equation[2]), and because color infrared film is sensitive to longer wavelengths than regular color film and is not sensitive at all to the strongly scattered blue wavelengths (assuming proper filtration), color infrared film has a very distinct advantage for penetrating haze and smog, as shown in Figure 18.

---

[2] Amount of energy scattered, $S = \frac{1}{\text{Wavelength}^4}$ or $S = \frac{1}{\lambda^4}$

Potentials for Automatic Data Analysis Techniques

As previously pointed out, there are many situations existing today in which resource managers and policy-making groups need information about our resources that is current and, in many instances, pertaining to vast geographic areas. To help answer these types of needs, the Laboratory for Applications of Remote Sensing (LARS) at Purdue University was established by NASA and the U.S.D.A. in 1966 with the objective of developing techniques for automatic analysis of remote sensor data. LARS has demonstrated the feasibility of automatic data processing of multispectral scanner data (26, 27, 28). For example, automatic mapping of basic cover types for relatively large geographic areas (70 square miles) has been accomplished using training samples of only a few acres (20, 21). Figure 19 shows some of these results.

In essence, this analysis technique involves the location of selected areas in the data where the identification and condition of the ground cover is known. These areas are then designated to the computer, using an X-Y coordinate system. Statistical parameters of the multispectral scanner data are determined for these "training sample" areas. Then, a suitable pattern recognition algorithm is used to classify each resolution element viewed by the airborne scanner into one of the categories for which the computer was trained. The results can be displayed in map format showing the various cover types or in a table, perhaps showing acreage of the various cover types over which the aircraft flew. By designating additional areas in the data where ground cover is known, one can also obtain a table giving a quantitative evaluation of the accuracy of the automatic classification results.

Considerable emphasis has been placed on the identification and mapping of crop species using such automated analysis techniques. Results to date indicate great potential for this approach (2, 26, 27, 31). Figures 20 and 21 show a computer-produced map and table of results for a crop species identification analysis, using data collected from 5000 feet over Tippecanoe County, Indiana.

There is also great interest and considerable potential in the automatic mapping of soil conditions and perhaps soil types. The ability to determine quantitatively both the soil type boundaries and the areas having similar surface soil characteristics would be of great advantage to soil mappers, even if the exact soil type could not be determined by remote sensing. Figure 22 shows some of the results of automatic soil mapping research. It has been found that a high degree of correlation exists between the spectral characteristics of soil and its organic matter content (7). It is also known that soil moisture differences cause significant changes in spectral response. This is easily seen in the satellite photograph shown in Figure 23. Much additional study is required to determine the full potential for accurate analysis of soil characteristics using remote sensing techniques.

LARS automatic analysis techniques have also been tested over limited areas in forest cover-type mapping and in the automatic identification of beetle-infested conifers (8). These results (Figures 24 and 25) also indicate promise.

One of the most exciting potential applications of remote sensing is in water quality mapping and monitoring. Research to date has shown that in some cases water pollutants will cause spectral changes in the water that can be accurately mapped using multispectral scanner data and pattern recognition techniques (Figure 26). Experience has also shown that the temperature of water bodies can be mapped to within 0.5° C of the true surface temperature from altitudes of several thousand feet (4). An example of this work is shown in Figure 27. This capability of remote sensing could be applied on an operational basis to monitoring thermal discharge from hydroelectric plants and to studying the effects of thermal pollution on various aspects of stream ecology.

These same pattern recognition techniques have been applied to satellite and high altitude aircraft photography. Figure 28 shows the results of applying the analysis techniques developed by LARS to a frame of digitized Apollo 9 color infrared photography. The classification of the data was directed toward geologic mapping. The results have indicated good correlation between the map derived through automatic analysis and the existing geologic maps of the area (3). Figure 29 shows the results of an automatic classification of a portion of the same frame, with the emphasis this time on agricultural cover identification. Barley, sugar beets, alfalfa, bare soil, salt flats, and water were the cover types classified, and the results on 174 test fields showed an overall accuracy of about 70% correct identification (2, 3). These results indicate that such techniques have promise for application to satellite data.

Summary and Conclusions

It is apparent that automatic data processing techniques are required if we are to take full advantage of our ability to collect data at frequent intervals over vast geographic areas. Further developments in the handling of spatial and temporal data, in addition to spectral data, will bring significant improvements in automatic data analysis. It also seems clear that both satellites and aircraft will continue to be used in the collection of remote sensing data, and that ground observations will continue to be a necessity and an integral requirement for accurate data analysis. Although major improvements in automatic data analysis techniques will be achieved, man's contributions will always be required in the analysis of remote sensor data. A good understanding of the energy-matter interrelationships and the spectral reflectance and emittance characteristics of the various cover types of interest is necessary. This will allow man to be effective in maintaining a close man-machine interaction in automated data analysis techniques. There will also continue to be a major requirement for accurate and detailed manual photo interpretation in many application areas.

When one considers the current situation of our natural resources, along with the predictions of continued population growth, one cannot help but be concerned about the manner in which we will be utilizing our resources during the next few decades and beyond. One of the major factors which will influence many decisions on use of these resources is the amount and detail of information available about the various land and water areas.

Remote sensing has already proved to be a very useful tool in several areas of application in the management of our natural resources, and the potential applications seem almost unlimited. It is the goal of our research in remote sensing to develop a technology that will help us to obtain the best possible information concerning the location, extent, and condition of our resource base, and to make this information available in a timely manner to the people involved in the management of our resources.

Acknowledgements

All multispectral scanner data were collected by the Institute of Science and Technology, Unifersity of Michigan.

The author acknowledges his collegues at LARS who were involved in the development of the analysis techniques described and who analyzed the data shown in several of the examples.

The research reported upon in this paper was conducted under NASA Grant NGL 15-005-112.

References

1. American Society of Photogrammetry. 1968. Manual of Color Aerial Photography. George Bantan Co., Menasha, Wisconsin. 550 pp.

2. Anuta, P. E. 1970. "Multispectral Classification of Crops in the Imperial Valley, California from Digitized Apollo 9 Photography." LARS Information Note 070770, Laboratory for Applications of Remote Sensing, Purdue University. 11 pp.

3. Anuta, P. E., S. J. Kristof, D. W. Levandowski, R. B. MacDonald, and T. L. Phillips. 1971. "Crop, Soil, and Geological Mapping from Digitized Multispectral Satellite Photography." Proceedings of the 7th International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor. (In Press.)

4. Atwell, B. H., R. B. MacDonald, and L. A. Bartolucci. 1971. "Thermal Mapping of Streams from Airborne Radiometric Scanning." Water Resources Bulletin 7(2); 228-242.

5. Barr, D. J. and R. D. Miles. 1970. "SLAR Imagery and Site Selection." Photogrammetric Engineering. 36(11): 1155-1170.

6. Bauer, M. E., P. H. Swain, R. P. Mroczynski, P. E. Anuta, and R. B. MacDonald. 1971. "Detection of Southern Corn Leaf Blight by Remote Sensing Techniques." Proceedings of the 7th International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan. (In Press.)

7. Baumgardner, M. F., S. Kristof, C. J. Johannsen, and A. Zachary. 1970. "Effects of Organic Matter on Multispectral Properties of Soils." Proceedings of the Indiana Academy of Science. 79: 413-422.

8. Bell, J. C., Jr. 1971. "Infrared Surveillance of the Forest." Forest Farmer. 30(2): 8-9.

9. Ciesla, W. M., J. C. Bell, and J. C. Curlin. 1967. "Color Photos and the Southern Pine Beetle." Photogrammetric Engineering. 33(8): 883-888.

10. Clark, Walter. 1946. Photography by Infrared. John Wiley and Sons, Inc., New York.

11. Colwell, Robert N. 1956. "Determining the Prevalence of Certain Cereal Crop Diseases by Means of Aerial Photography." Hilgardia 26(5): 223-286.

12. Colwell, Robert N., (Chairman). William Brewer, Glenn Landis, Philip Langley, John Morgan, Jack Rinker, J. M. Robinson, and A. L. Sorem. 1963. "Basic Matter and Energy Relationships Involved in Remote Reconnaissance." Photogrammetric Engineering XXIX: 761-799.

13. Colwell, R. N. 1968. "Remote Sensing of Natural Resources." Scientific American. 218(1): 59-69.

14. Forsythe, W. E. and F. L. Christison. 1930. "The Absorption of Radiation from Different Sources by Water and Body Tissue." Journal of the Optical Society of America. 20: 693-700.

15. Fritz, N. L. 1967. "Optimum Methods for Using Infrared-Sensitive Color Films." Photogrammetric Engineering. 30(10): 1128-1138.

16. Gates, D. M., H. J. Keegan, J. C. Schleter, and V. R. Weidner. 1965. "Spectral Properties of Plants." Applied Optics 1(4): 11-20.

17. Hirsch, S. N., R. L. Bjornsen, F. H. Madden, and R. A. Wilson. 1968. "Project Fire Scan Fire Mapping Final Report." U. S. Forest Service Research Paper INT-49. Intermountain Forest and Range Experiment Station, Missoula, Montana. 49 pp.

18. Hoffer, R. M. 1967. "Interpretation of Remote Multi-spectral Imagery of Agricultural Crops." Laboratory for Agricultural Remote Sensing, Vol. No. 1. Research Bulletin 831, Agricultural Experiment Station. Purdue University. 36 pp.

19. Hoffer, R. M. and C. J. Johannsen. 1969. "Ecological Potentials in Spectral Signature Analysis." In Remote Sensing in Ecology, P. Johnson, ed. University of Georgia Press, Athens, Georgia. pp. 1-16.

20. Hoffer, R. M., and F. E. Goodrick. 1970. "Geographic Considerations in Automatic Cover Type Identification." Proceedings of the Indiana Academy of Science. (In Press.)

21. Hoffer, R. M., and F. E. Goodrick. 1971. "Variables in Automatic Classification Over Extended Remote Sensing Test Sites." Proceedings of the 7th International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan. (In Press.)

22. Holmes, R. A., and R. B. MacDonald. 1969. "The Physical Basis of System Design for Remote Sensing in Agriculture." Proceedings of the IEEE 57(4): 629-639.

23. Hope, John R. 1966. "Path of Heavy Rainfall Photographed from Space." Bulletin of the American Meteorological Society. 47(5): 374-373.

24. Knipling, E. B. 1967. "Physical and Physiological Basis for Differences in Reflectance of Healthy and Diseased Plants." Proceedings of the First Workshop on Infrared Color Photography in the Plant Sciences. Florida Dept. of Agriculture, Winter Haven, Florida. 24 pp.

25. Kristof, S. J., and A. L. Zachary. 1971. "Mapping Soil Types from Multispectral Scanner Data." Proceedings of the 7th International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan. (In Press.)

26. Laboratory for Agricultural Remote Sensing. 1968. Remote Multispectral Sensing in Agriculture. Volume No. 3, (Annual Report). Research Bulletin No. 844, Agricultural Experiment Station, Purdue University, 176 pp.

27. Laboratory for Applications of Remote Sensing. 1970. Remote Multispectral Sensing in Agriculture. Volume No. 4, (Annual Report). Research Bulletin No. 873, Agricultural Experiment Station, Purdue University. 113 pp.

28. Landgrebe, D. 1971." "Systems Approach to the Use of Remote Sensing." LARS Information Note 041571. Laboratory for Applications of Remote Sensing. Purdue University. 40 pp.

29. Manzer, F. E. and G. R. Cooper. 1967. "Aerial Photographic Methods for Potato Disease Detection." Maine Agricultural Experiment Station Bulletin 646.

30. Murtha, P. A. 1969. "Aerial Photographic Interpretation of Forest Damage: An Annotated Bibliography." Information Report FMR-X-16, Forest Management Institute, Ottawa, Ontario. 76 pp.

31. National Academy of Sciences. 1970. <u>Remote Sensing, With Special Reference to Agriculture and Forestry</u>. 424 pp.

32. Olson, C. E., Jr. 1963. "The Energy Flow Profile in Remote Sensing." Proceedings of the Second Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, Michigan. pp. 187-197.

33. Rydstrom, H. O. 1970. "Geologic Exploration With High Resolution Radar." Goodyear Aerospace Corporation, Litchfield Park, Arizona.

34. Scherz, J. P., D. R. Graff, and W. C. Boyle. 1969. "Photographic Characteristics of Water Pollution." Photogrammetric Engineering 35(1): 38-43.

35. Yost, E. F., S. Wenderoth. 1967. "Multispectral Color Aerial Photography." Photogrammetric Engineering Vol. 33(9): 1020-1033.

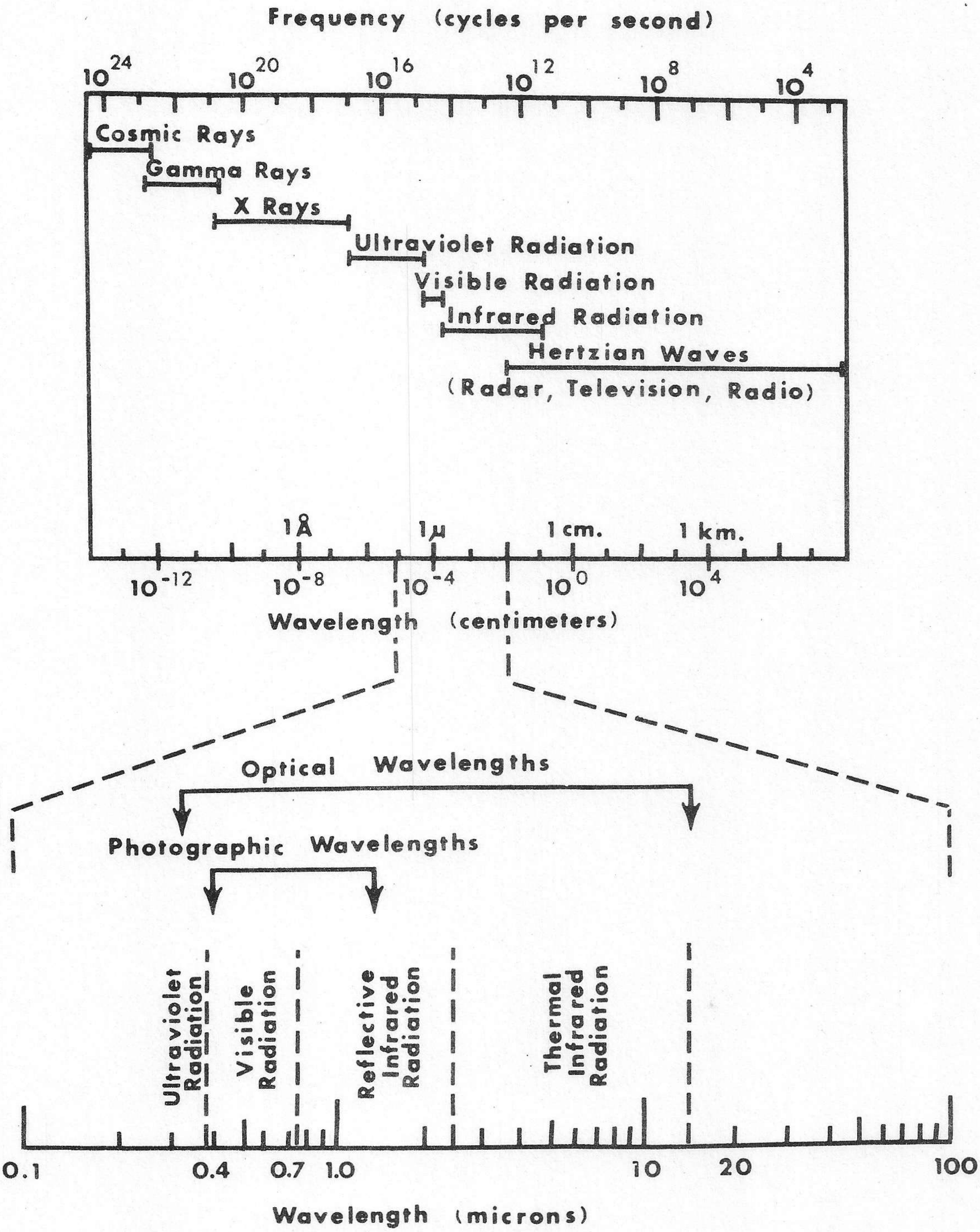


Figure 1. The Electromagnetic Spectrum. Note the relatively range of wavelengths to which our eyes are sensitive. (From Hoffer, 1)

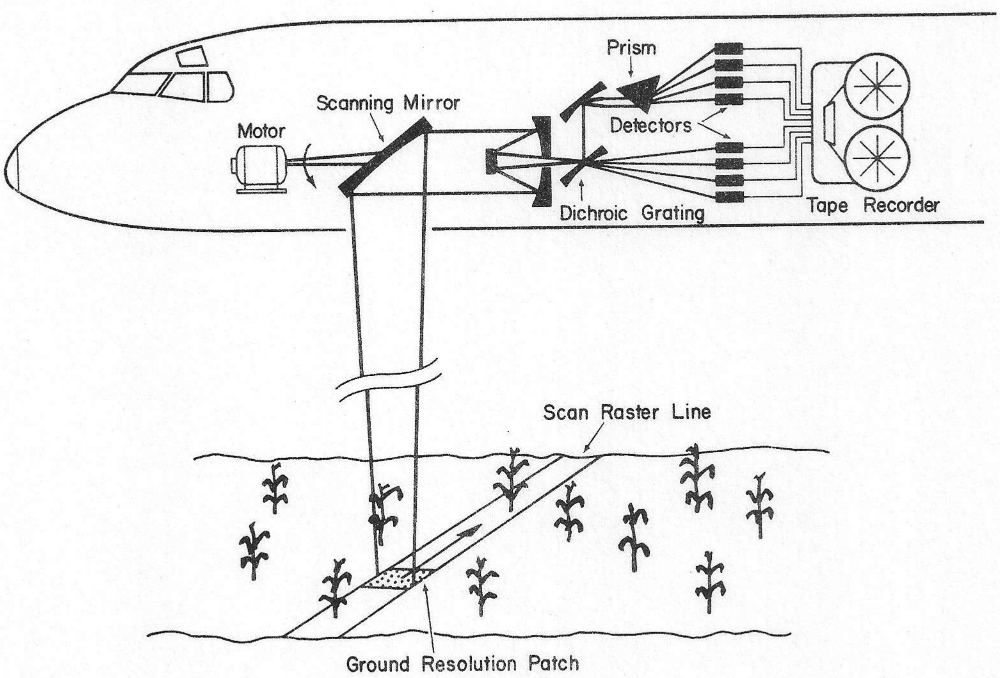


Figure 2. Schematic of a Multispectral Optical-Mechanical Scanner. (From LARS, 26)

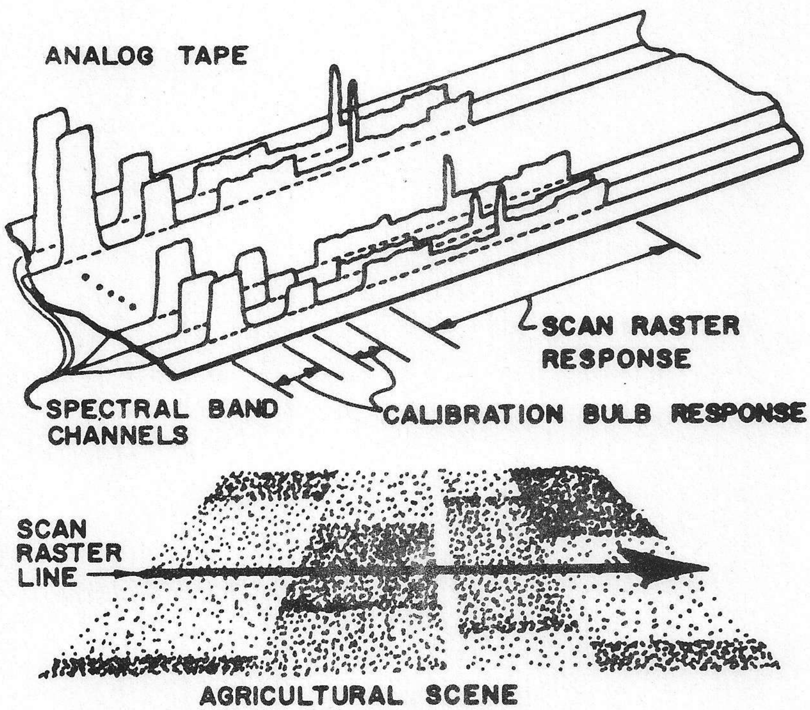
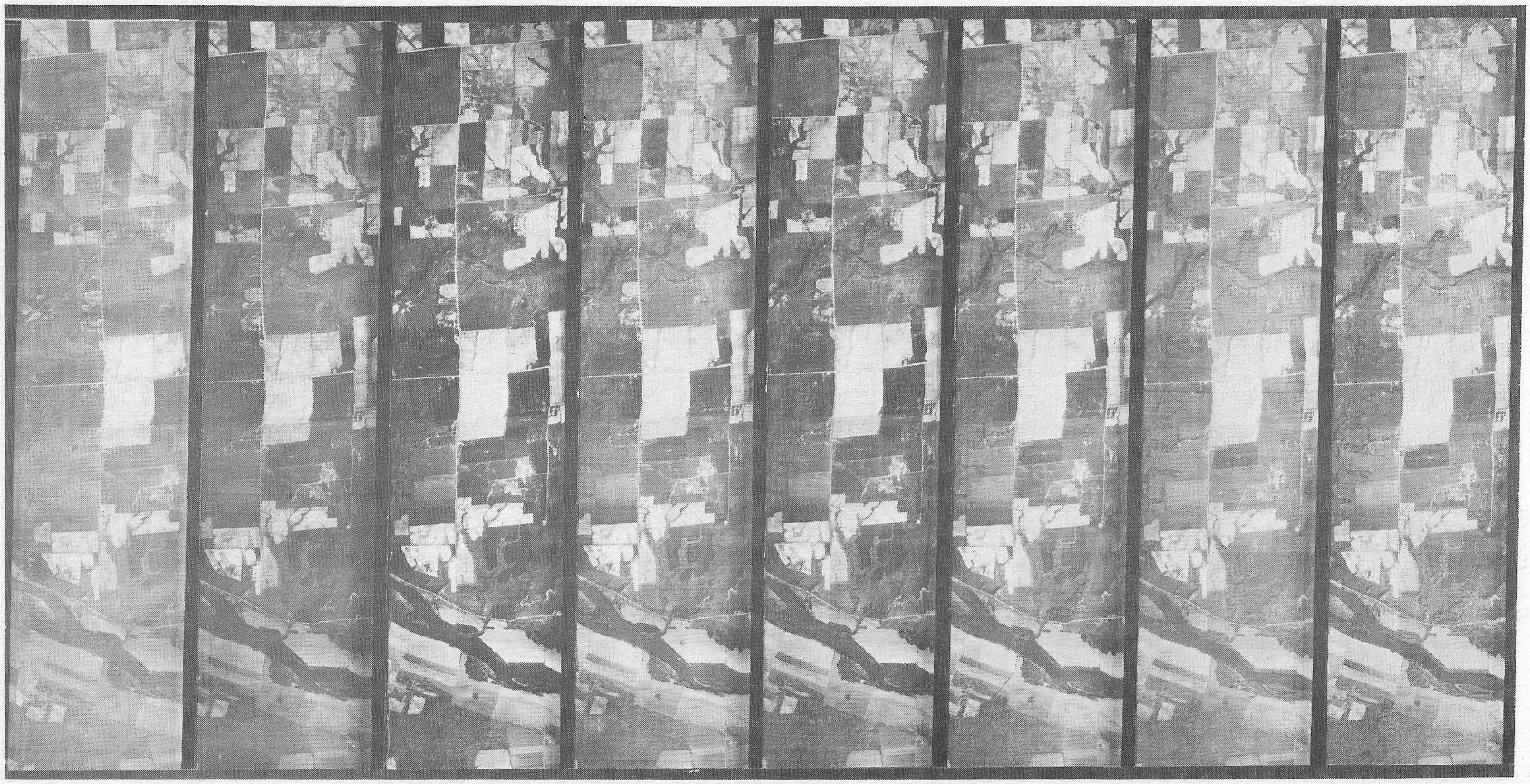


Figure 3. Data Collection Format, Using a Multispectral Scanner and Multiple-Track Tape Recorder. (From Holmes, 22)

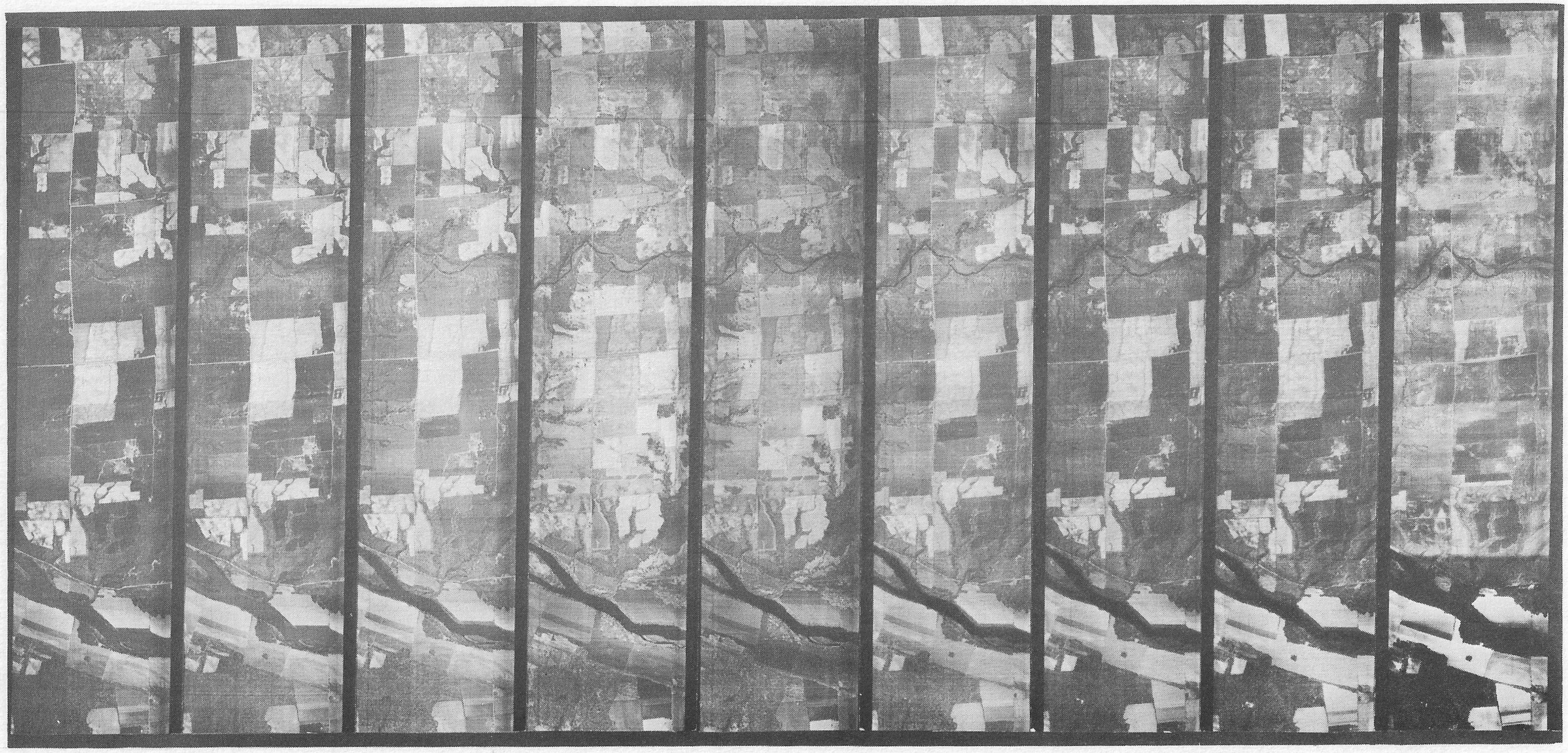


.32-.38 .40-.44 .44-.46 .46-.48 .48-.50 .50-.52 .52-.55 .55-.58

MULTISPECTRAL SCANNER IMAGERY

IN 17 WAVELENGTH BANDS, INCLUDING:

·Ultraviolet (.32-.38) ·Visible (.40-.72) ·Reflective Infrared (.72-4.1) ·Thermal Infrared (8-14)


.58-.62
.62-.66
.66-.72
.72-.80
.80-1.0
1.5-1.8
2.0-2.6
3.0-4.1
8-14

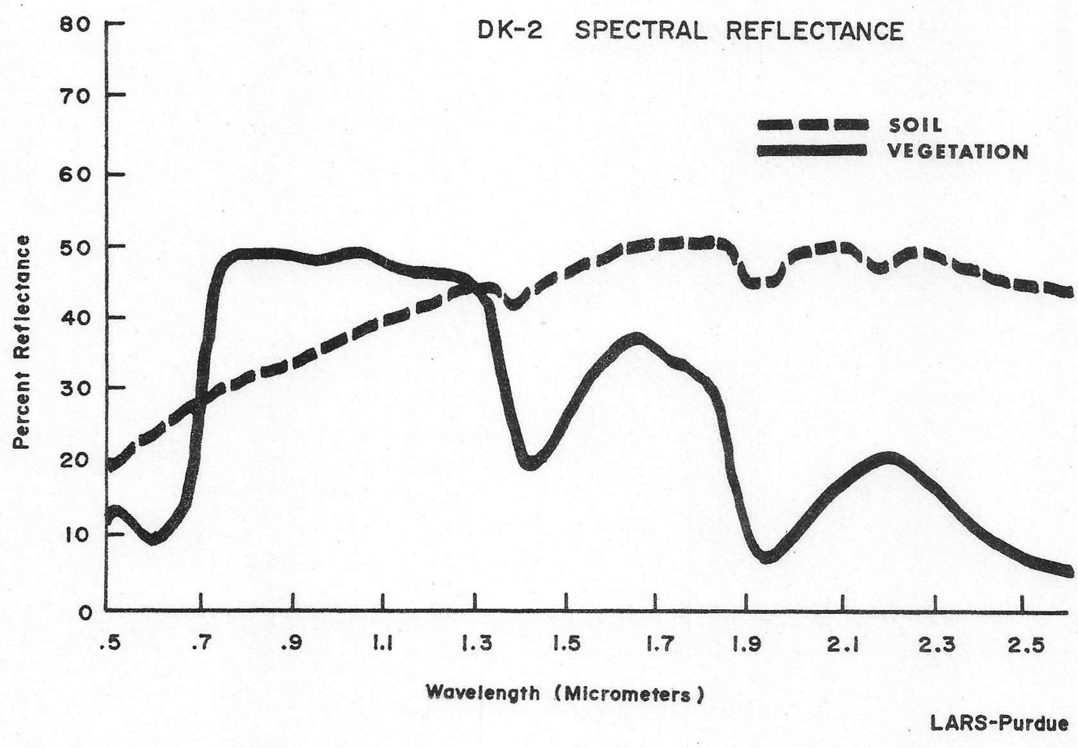


Figure 7. Spectral Reflectance Curves for Green, Turgid Vegetation and Air Dry Soils. These curves represent averages of 240 curves of vegetation and 154 curves of air dry soils.

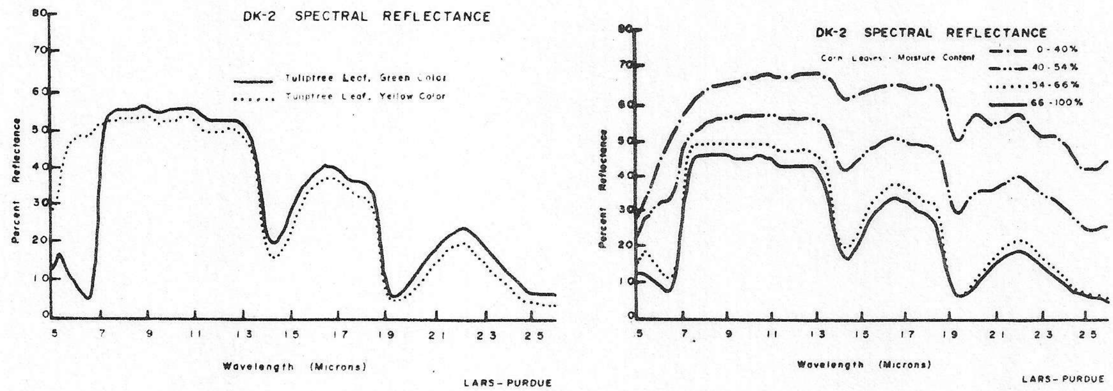


Figure 9. Spectral Variation in Vegetation Due to Differences in Senescence Which Causes Differences in Pigmentation and Moisture Content. (From Hoffer, 19)

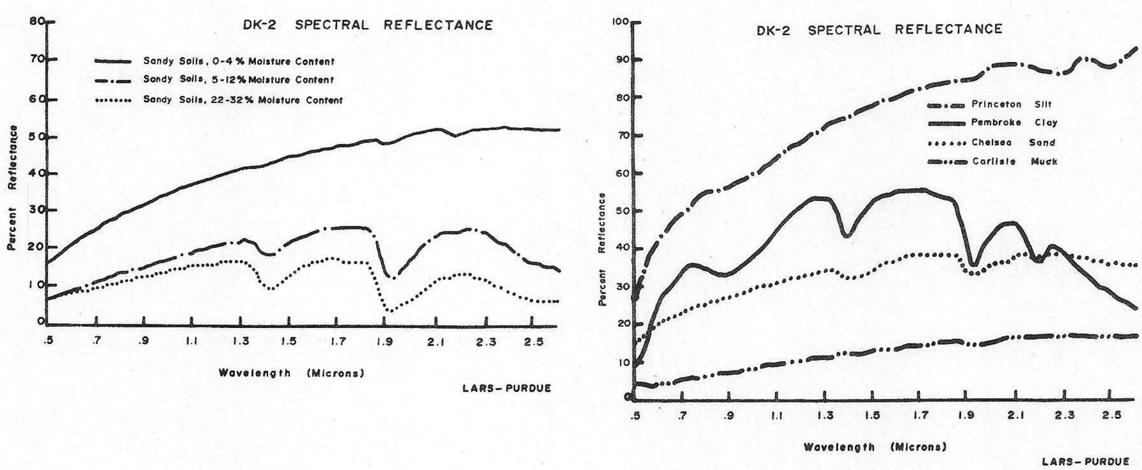


Figure 8. Spectral Variation in Soil, Due to Differences in Moisture Content and Texture. (From Hoffer, 19)

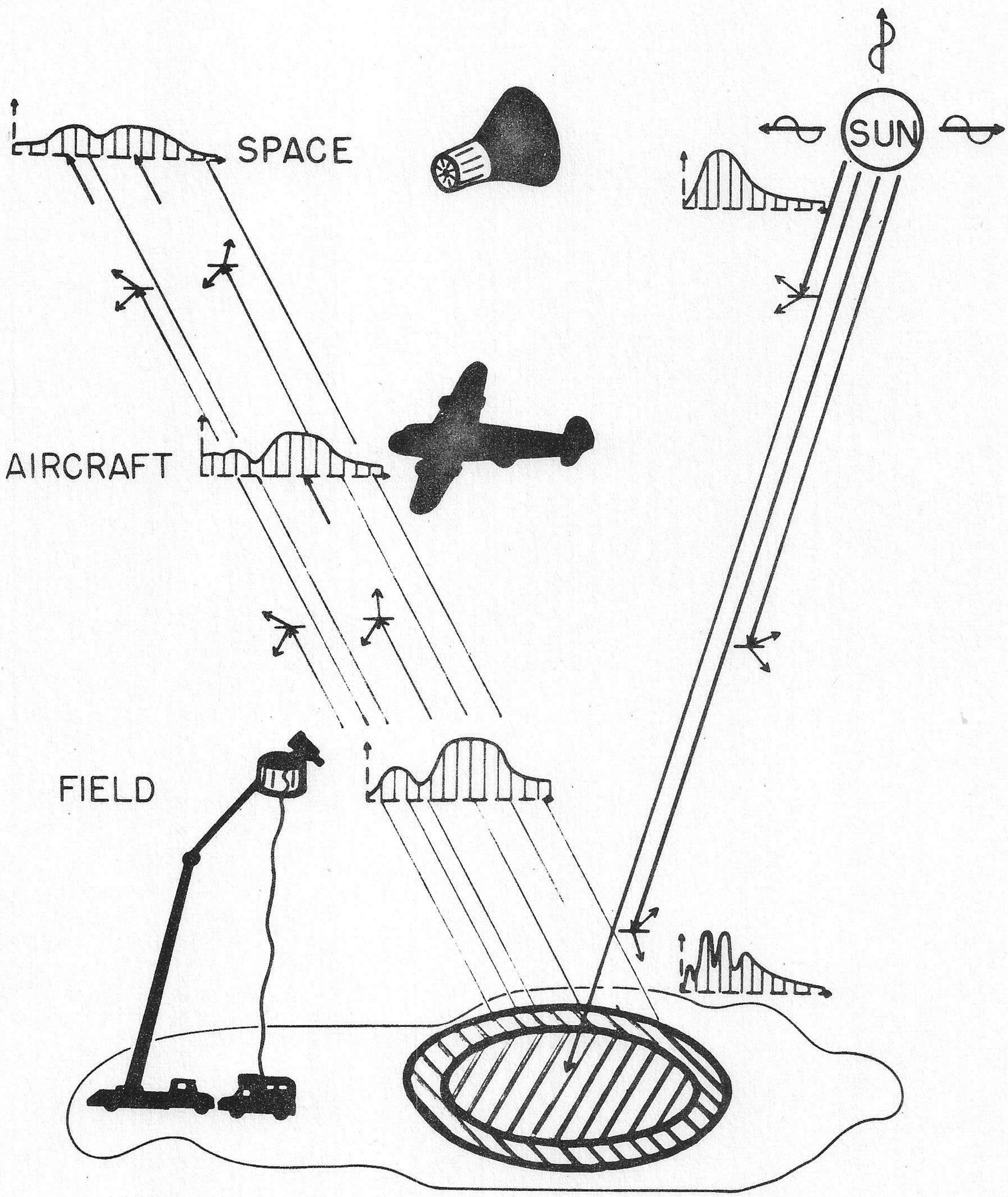


Figure 10. Schematic of an Energy-Flow-Profile Concept in Remote Sensing Research. The importance of detailed field and laboratory studies on the spectral characteristics of the materials of interest is emphasized. (From Landgrebe, 25 and Olson, 32)

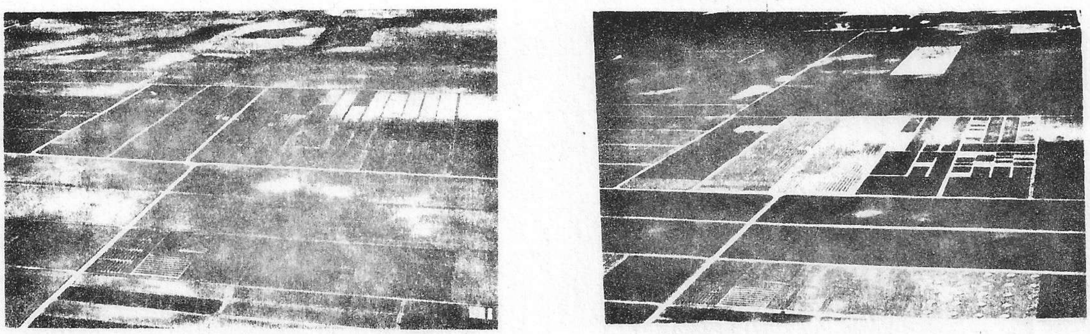


Figure 11. Color and Color Infrared Photos. This photo pair illustrates the differences in appearance of vegetation and soil on the two films. (Photos by J. Halsema, LARS)

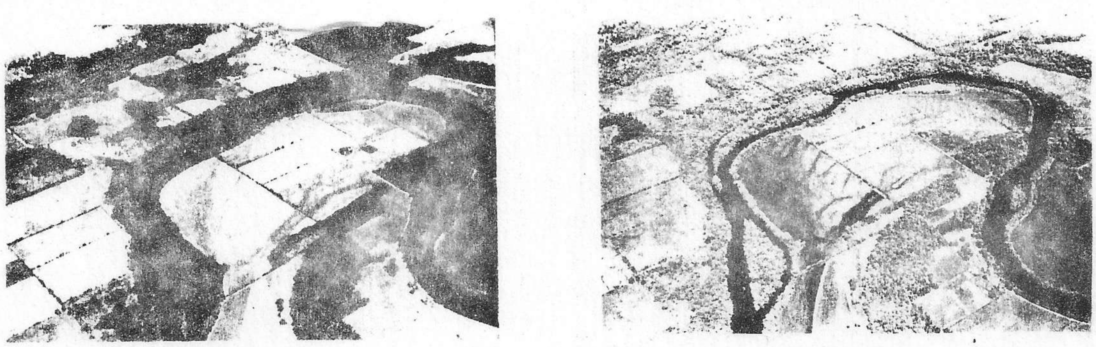


Figure 12. Color and Color Infrared Photos of the Wabash River and Surrounding Area. (Photos by J. Halsema, LARS)

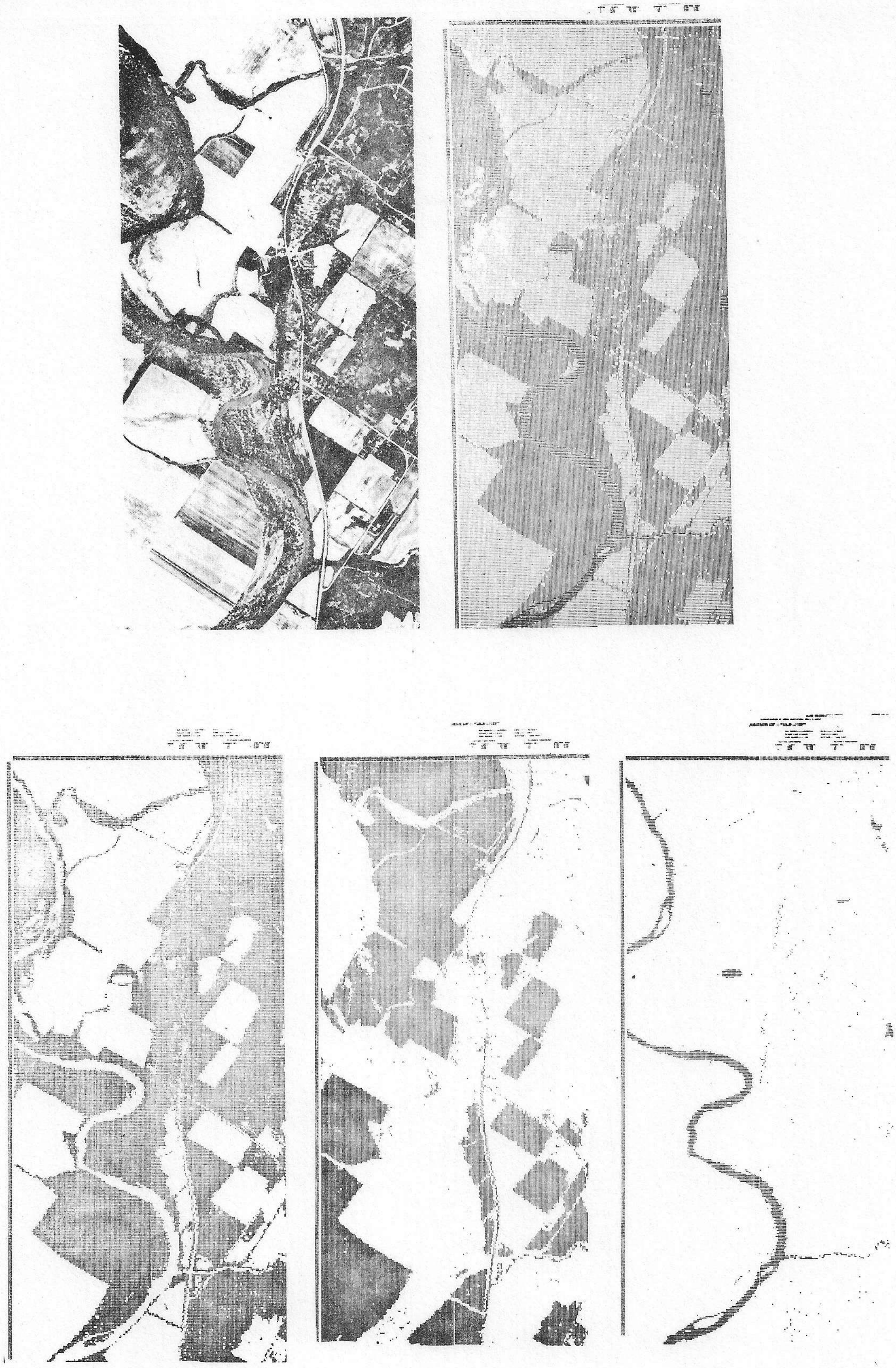


Figure 19. Basic Cover Type Mapping Using Automatic Data Analysis Techniques. Top left: aerial photo mosaic, obtained 10 days before scanner data was obtained. Top right: classification into 3 cover types (light tone is soil, medium tone is vegetation, and dark tone is water). Lower left: printout of green vegetation only. Center: printout of bare soil. Lower right: printout of water only.

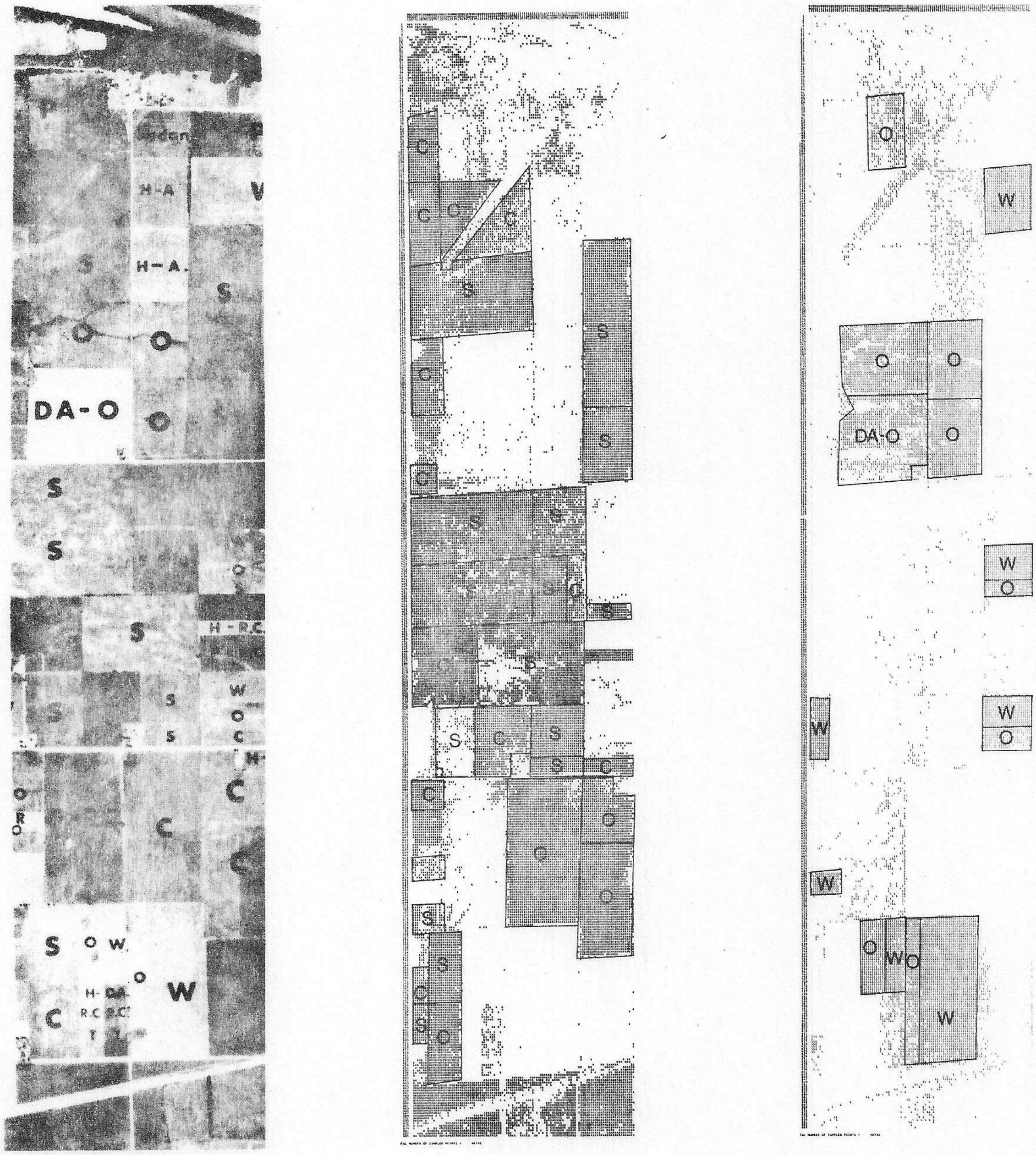


Figure 20. Automatic Crop Species Identification. This figure, shows two cover type groupings--row crops (corn and soybeans) and small grains (wheat and oats). In this classification, 24 spectral classes and 12 wavelength bands were used by the computer. The complete classification results are shown in tabular format in Figure 21.

Classification Accuracy for Test Areas

Category	No. of Image Resolution Elements in Test Category	Percentage Correct Recognition	Number of Image Resolution Elements Classified Into: Row Crops	Wheat	Oats	Pasture	Hay	Bare Soil	Road	Trees	Water	No IRE's Thresholded
Row Crops	15185	92.4	14035	3	55	956	119	2	10	4	1	0
Wheat	2736	92.8	2	2540	168	0	24	0	1	1	0	0
Oats	3465	84.7	175	21	2934	184	128	0	1	21	0	1
Pasture	3595	83.7	159	1	260	3010	2	0	0	161	0	2
Hay	1291	80.7	17	2	226	0	1042	4	0	0	0	2
Soil	104	92.3	6	0	0	0	1	96	1	0	0	0
Road	85	98.8	0	0	0	0	0	1	84	0	0	0
Trees	720	86.0	8	0	18	75	0	0	0	619	0	0
Water	131	100.0	0	0	0	0	0	0	0	0	131	0
TOTALS	27312		14402	2567	3661	4225	1316	103	97	806	132	3

Overall Performance = 89.7% correct recognition

Average Performance by Category = 90.2% correct recognition

Figure 21. Table Showing Quantitative Classification Results for 66 Test Areas. These results apply to the same classification results shown in part in Figure 20.

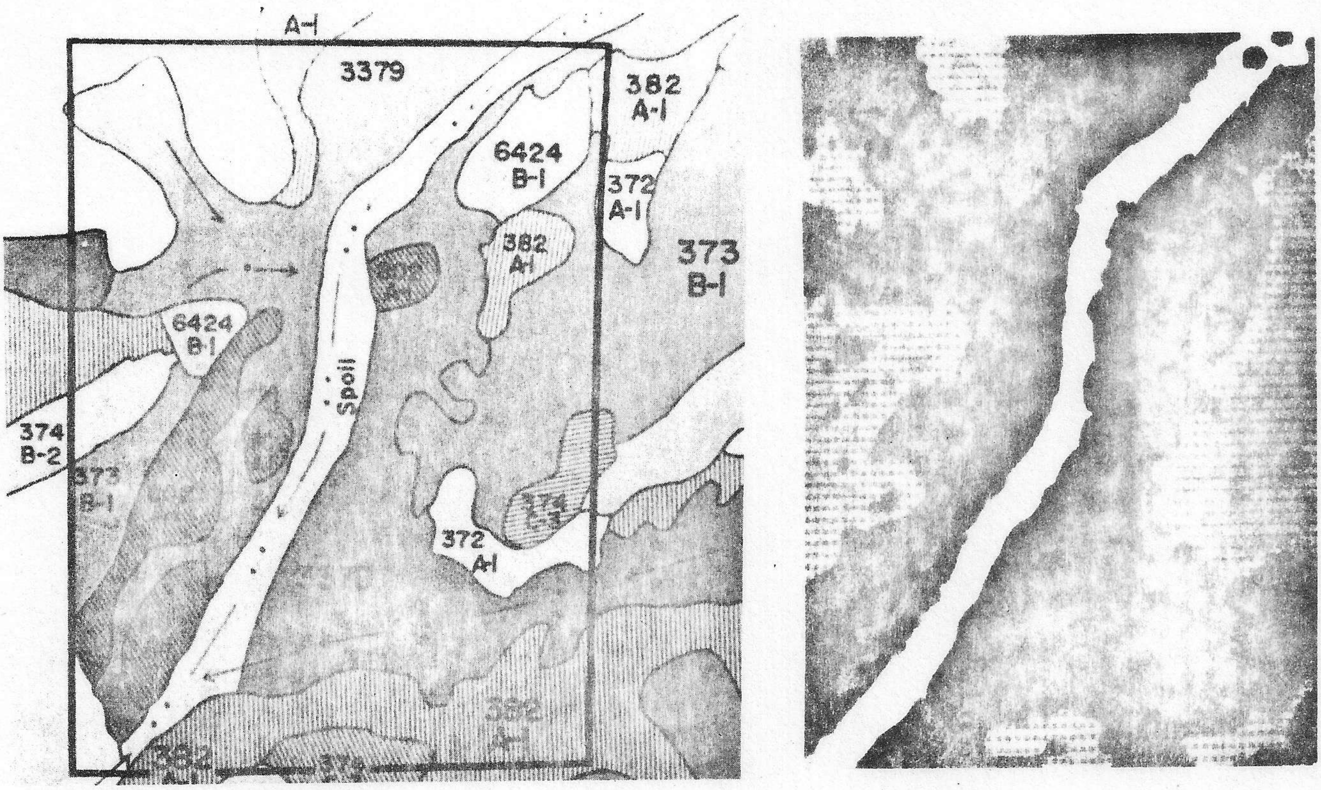


Figure 22. Conventional Soil Map and Computer Classification of 5 Soil Categories, Based Upon Organic Matter Content. (From Kristof, 25 and Baumgardner, 7)

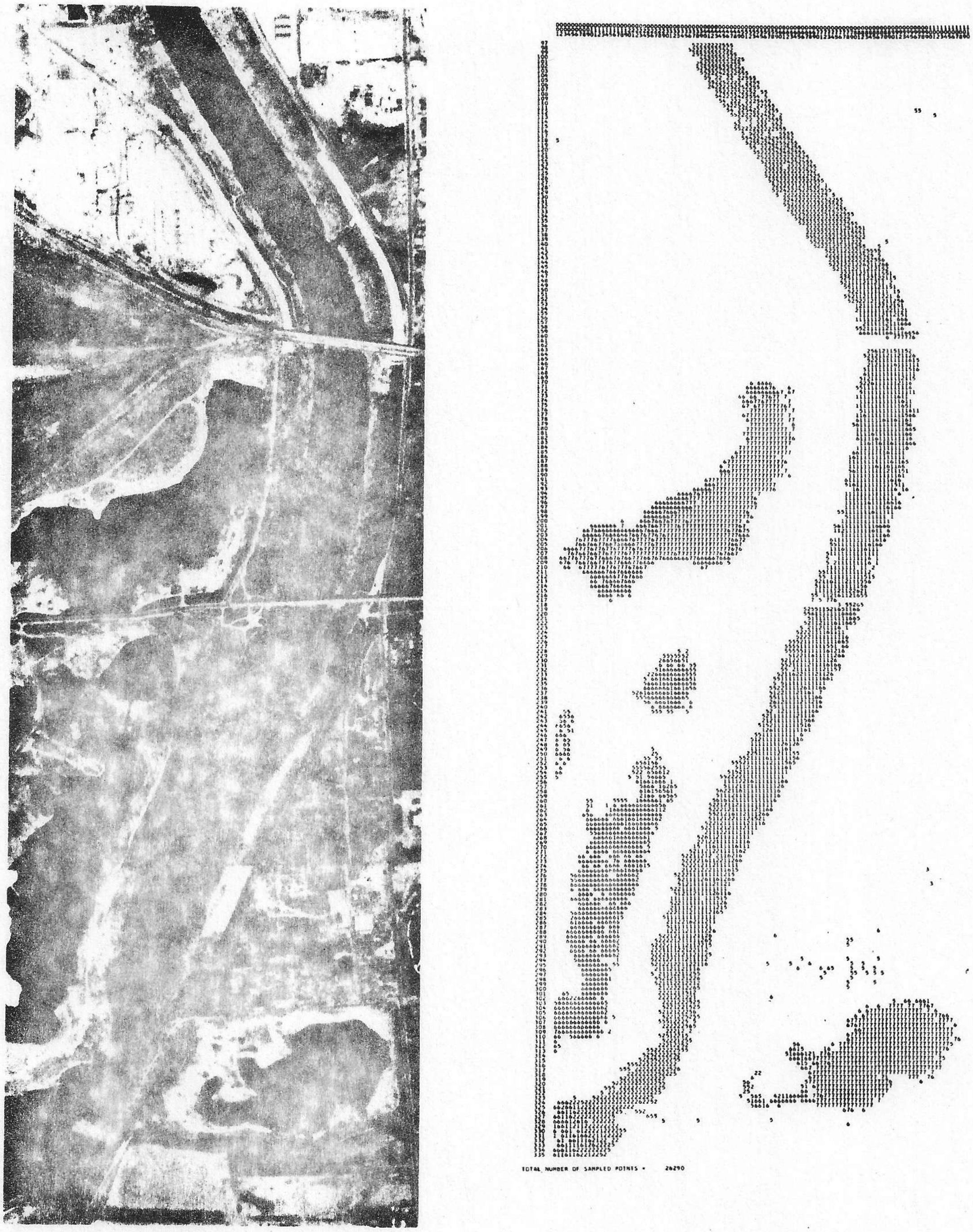


Figure 26. Computer Mapping of Water Pollutants. Spectral analysis of this data collected over the White River, Indiana, showed the location of factory effluent. This analysis utilized only reflective wavelengths.