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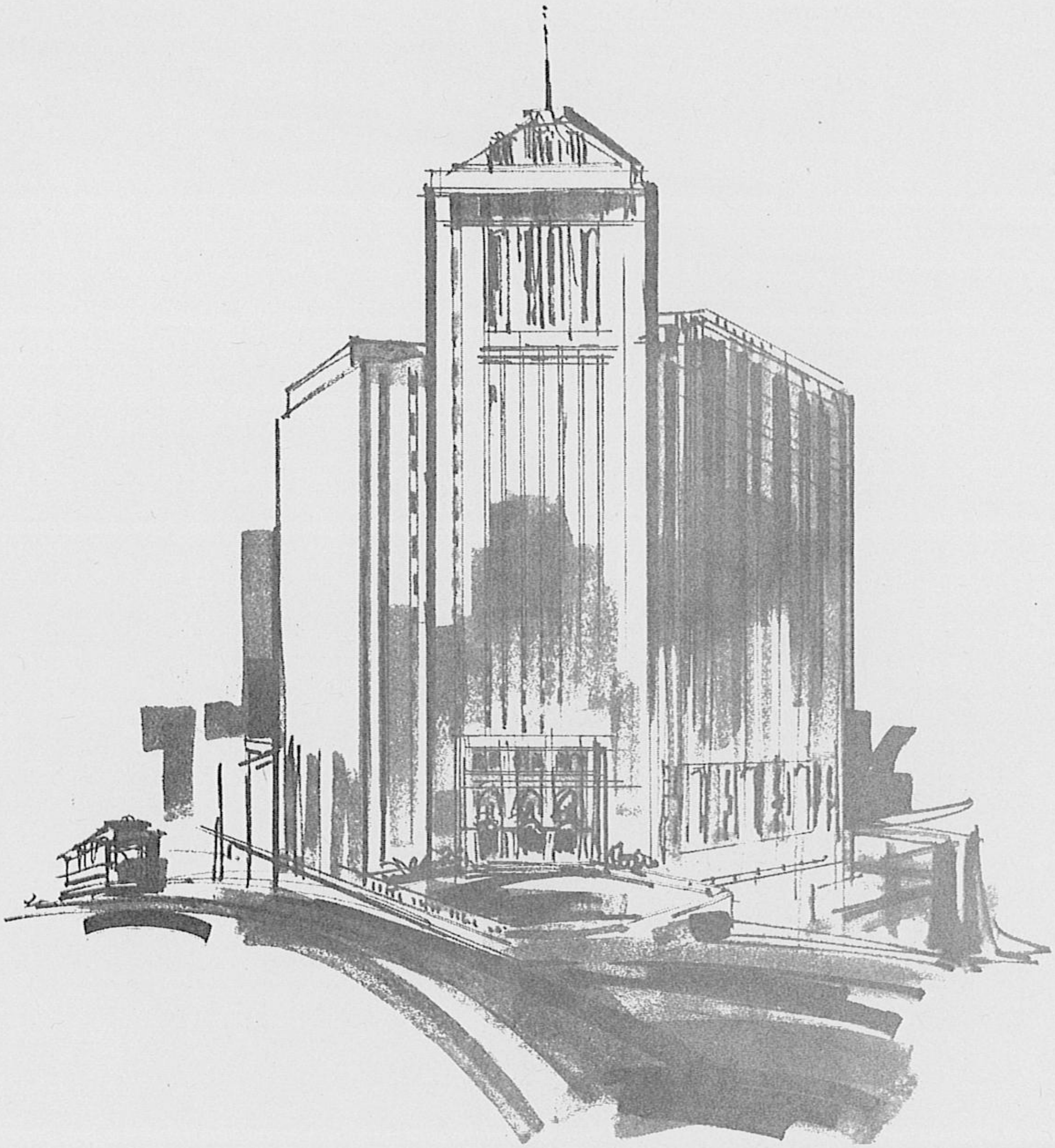

Reprinted from the

PROCEEDINGS OF THE

THIRD ANNUAL
AMERICAN WATER RESOURCES CONFERENCE

Sponsored by the

American Water Resources Association

HOTEL MARK HOPKINS
San Francisco, California
November 8-10, 1967

APPLICABILITY OF REMOTE SENSING AND SYSTEMS ANALYSIS TECHNIQUES TO RIVER BASIN PLANNING*

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Since man first began to hunt for food, he has been worrying about "information-gathering." Where do the fruit trees grow? Where is the best place to hunt game for food? Through the thousands of years of man's quest for better systems of obtaining information or collecting data, he has made a number of startling breakthroughs; some of these include the microscope, the telephone, the radio, the spectrometer, television and the space probe.

Today information systems make use of components ranging all the way from written questionnaires to the Trans-Atlantic cable to multispectral scanners orbiting the earth or the sun. Some devices collect information only by having direct contact with the subject, but others can obtain information at a distance by measuring information transmitted from the subject. These latter devices are sometimes known as remote sensors. Regardless of nomenclature, the output of such information collecting devices is no more or no less than information.

J. A. Eikelman has stated that "information science can provide decision makers faced with complex resource problems a rigorous approach to assessing complex, multidimensional resource systems, leading to a much clearer insight into what the overall performance objectives and major constraints should be if the maximum benefit is to be derived from the resource system" [1].

"Information science includes concepts and technologies embodied in control theory, decision analysis, management analysis, operations research, econometrics, and statistics, and offers the combined analytical methodology and techniques for carrying out advanced systems analysis within a rigorous mathematical framework" [2].

The vast amount of information needed for the planning, development, and management of earth resources is almost staggering. The preoccupation of the majority of humanity is that of satisfying man's hunger. Today the impending crises of bulging human populations, water shortages, and limitations of arable land present a new problem unique in man's history. Man is challenged to devise new techniques for the development and management of the earth's resources.

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*Journal Paper No. 3224, Purdue Agr. Exp. Sta. This research was supported by the Nat'l. Aero. and Space Adm. and the U.S. Dept. of Agr.

According to the President's Science Advisory Committee,

> The scarcest and most needed resource in the developing countries is the scientific, technical, and managerial skill needed for systematic orderly decision-making and implementation [3].

An attempt will be made in this paper to show how remote sensing, automatic data processing and systems analysis techniques can be put to use in river basin planning.

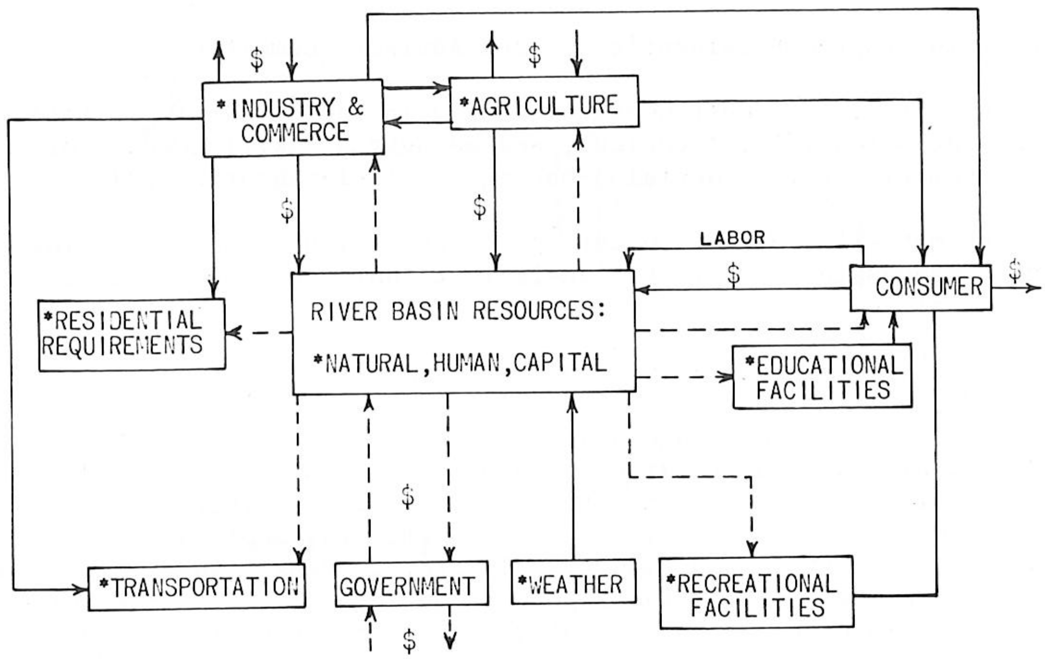
Analysis of River Basin Systems

The broad concept of systems design as applied to water resource projects involves the simultaneous consideration of the influence which planning decisions concerning individual subsystems of the overall river basin have on decisions concerning other parts of the system. The application of this technique requires three fundamental and related steps: identification of the broad objectives of the planning function in terms of meaningful design objectives; devising plans to accomplish these objectives; and evaluation of the consequences of various plans and the selection of the "best" one. Information presented in this paper is applicable primarily to the third step, i.e., the development of methodology for evaluating the consequences of alternative comprehensive river basin plans.

One of the most promising techniques for objectively evaluating the response of a complex system such as a river basin to a proposed plan of action is through mathematical simulation. A simplified flow diagram of a general river basin is shown in Figure 1. In order to simulate the behavior of this system, mathematical models are required to describe the manner in which the basin resources are transformed within one subsystem and made available to others. The details of a particular watershed plan control the amount of the limited basin resources which are allocated to each subunit. These relatively controllable allocations are indicated with broken lines in Figure 1. The integration of the component mathematical models of each subsystem with the operational rules specified by the proposed river basin plan may be accomplished by suitable computer programming techniques. The result is a comprehensive simulation of the behavior of the complete system which may be evaluated to determine how well it satisfied the broad planning objectives. Various basin plans are then evaluated in a systematic manner to determine the one(s) which produce the most desirable results.

The application of a comprehensive simulation as outlined above to a large river basin is not yet entirely feasible. Suitable mathematical models are not available for many of the subsystems outlined in the flow diagram; however, a great deal of research effort is currently being directed toward this goal. As evidenced by the work of the Harvard Water Program [4], projects less complex than the simulation of an entire river basin system have been accomplished. The rate of development of better component models and the rapid advances in computer technology are opening opportunities for much more ambitious studies.

An important characteristic of all the methods being proposed to simulate the behavior of a river basin is their requirement for vast quantities of timely data to quantify and characterize the particular basin being studied.



*Areas with remote sensing applications

Figure 1. Schematic flow diagram of river basin system.

In addition, these data, because of their bulk, need to be in a format available for direct automatic processing. Although much of the data required by these models is available from diverse sources in a highly developed country such as the U.S., it is often not current and is seldom in a format suitable for direct computer processing.

The lack of suitable basic data has been a major handicap to the development of large scale river basin models. Fortunately, new remote sensing techniques being developed to acquire automatically many types of physical data concerning the earth's natural resources from aircraft and satellites offer exciting possibilities for providing economically feasible solutions to these problems. Included among these relatively new techniques are multispectral scanners, radar, and laser altimeters. The applications of multispectral scanners will be discussed in detail below. Radar has the advantage of not being bound by weather conditions which might restrict the use of multispectral scanning. Laser altimeters offer the possibility of being able to automatically obtain topographic maps over vast areas and present this data in a format suitable for direct computer input.

Remote Multispectral Scanning and Data Processing

A system which seems to hold great promise for river basin planning and earth resources development consists of spectral data collection with a multi-channel optical-mechanical scanner mounted in air- or spacecraft. Figure 2 shows such a scanner as it might be mounted in an aircraft. Landgrebe and Phillips [5] describe the operation of this scanner as follows:

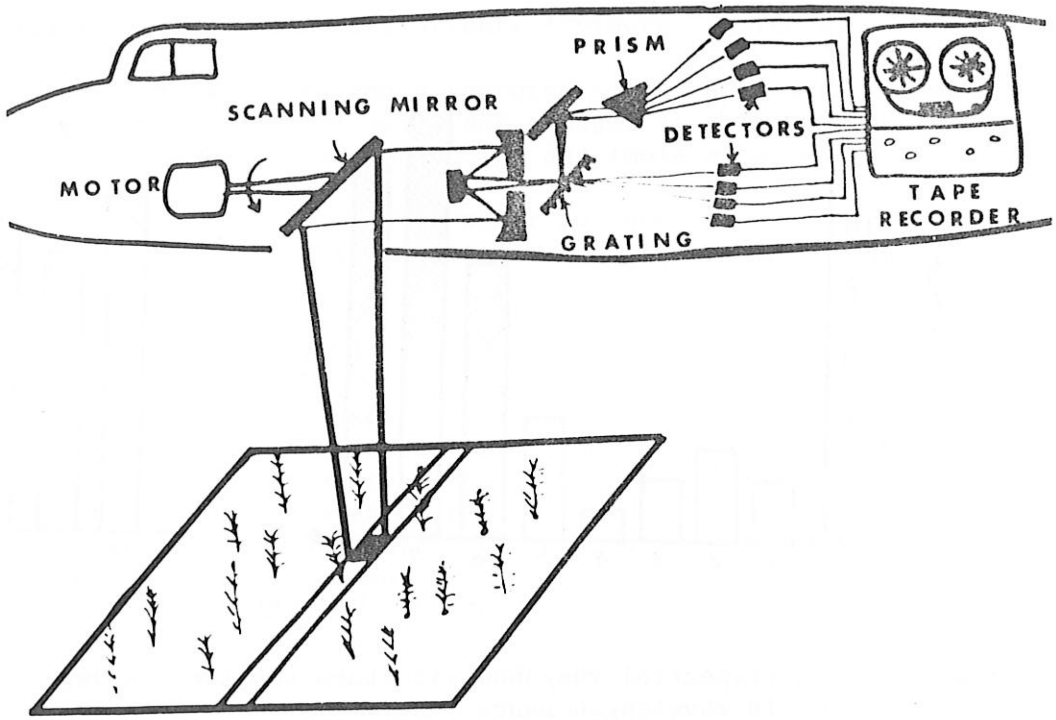


Figure 2. A multi-channel optical-mechanical scanner.

> The energy radiated by a specific ground resolution element at a given instant of time passes through the scanner optics and is divided according to its spectral wavelength and directed to an appropriate detector. The output of all such detectors are simultaneously recorded on a multiband instrumentation recorder. The transverse motion provided by the rotating mirror and the forward motion of the aircraft cause a continuous raster to be formed for each spectral band of the scanner output. An important feature of a system such as this is that by simultaneously sampling the output of all bands, one obtains a vector which contains all spectral information available about a given resolution element on the ground.

With such sensor systems one can integrate the energy received from a relatively small portion of the earth's surface over a small given wavelength band. The size of the area covered is dependent upon the optical characteristics of the system being used and the altitude from which one is obtaining such data. By sensing the reflected or emitted energy from a given area in each of many discrete wavelength bands, a "multispectral response pattern," similar to that shown in Figure 3 was derived by Hoffer, et al. [6]. This pattern represents a combination of signals received from a given surface target feature on a given date. It is hoped that by studying many such patterns for each resource characterization of interest, one may establish a unique, consistent, and predictable pattern, capable of quantitative expression and of known statistical reliability. Such a pattern would be a "multispectral response signature."

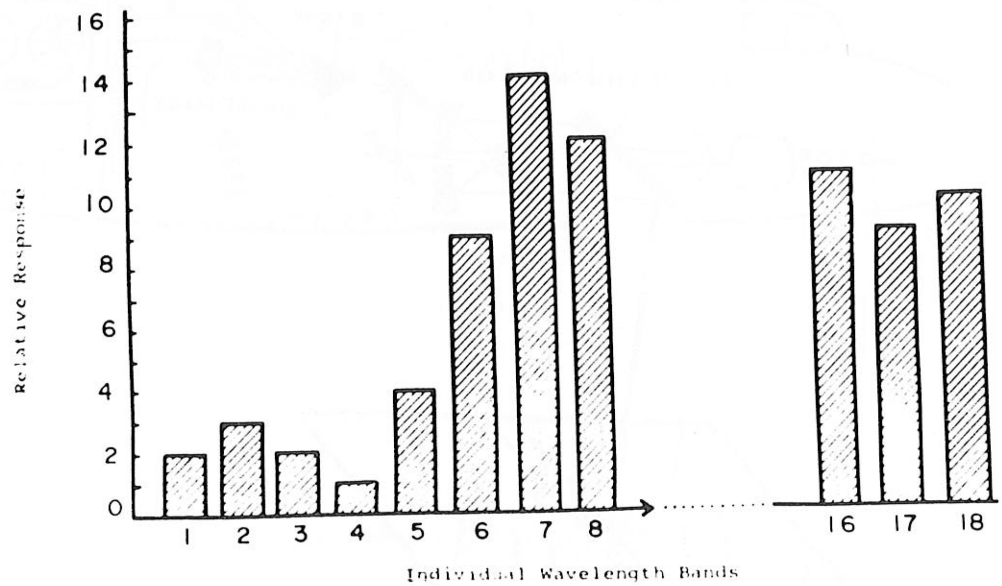


Figure 3. Multispectral response signature obtained through use of 18 wavelength bands.

Two primary advantages of this system over photographic sensors is that data in this form can be analyzed (1) very rapidly and (2) in large quantities with the aid of computers. Another major advantage is the capability of sensing energy in wavelengths outside the spectral regions in which photographic emulsions are sensitive and thus secure information not otherwise available.

Data Processing. The key to developing a capability for identification of unknown situations using these techniques lies in a rapid method of handling and processing large amounts of quantitative data. Methods currently being studied involve the application of pattern recognition techniques to identify each multispectral response signature.

To apply these techniques to such situations, the radiance is measured in each wavelength band and a measurement vector obtained. On the basis of this vector, a pattern recognition categorizer is programmed to determine the differences among the various materials. The categorizer is "trained," using known target materials. Then measurement vectors for unknown target materials or test samples are examined and classified on the basis of the training vectors. Thus the categorization phase of spectral pattern recognition techniques involves decisions as to which category of target materials the unknown data fits. It should be noted that the spectral measurement vector can include a large number of measured response values, each corresponding to a different wavelength band of spectral data. As the number of wavelength bands or categories of target materials are increased, the complexity of the categorizer is increased enormously.

Laboratory for Agricultural Remote Sensing

The Laboratory for Agricultural Remote Sensing (LARS) at Purdue University was established in 1965 as a result of the intense interest of the

National Aeronautics and Space Administration and the U.S. Department of Agriculture in the development of remote sensing techniques for characterizing agricultural situations. In this laboratory engineers and life scientists are cooperating to develop techniques to sense at a distance agricultural situations and to assess their important characteristics automatically. The research is directed at establishing methods to determine species identification, state of crop maturity, disease conditions, soil types, soil moisture conditions, areas under water, and many other natural resource parameters.

LARS Research Programs. To achieve current objectives, research programs have been instituted in the following interrelated areas:

°Measurements Research to develop instrumentation and procedures for collecting accurate measurements.

°Biophysical Research to relate measured radiance variations to chemical and physical properties of radiating sources.

°Data Processing Research to develop data handling and analysis (pattern recognition) techniques.

Research projects include multispectral sensing studies involving aircraft data collecting systems. Reflectance and emittance radiance data are collected within spectral bands located between 0.32 and 15 micron wavelengths. This project is exploring the feasibility of utilizing automatic techniques for surveys to supplement existing techniques in the future.

Automatic Surveys. The present capabilities of the LARS research is best illustrated with an example. On June 28, 1966, the University of Michigan flew a flight line near Lafayette, Indiana, obtaining multispectral data over an area about 4 miles long and one mile wide. The far left portion of Figure 4 shows an aerial photo mosaic of this area. The various crop species or agricultural use being made of each field is indicated by the following letter symbols:

C -- Corn	R -- Rye
S -- Soybeans	T -- Timothy
RC -- Red Clover	DA -- Diverted Acres
A -- Alfalfa	P -- Pasture
W -- Wheat	BS -- Bare Soil
O -- Oats	

Twelve wavelength bands of data within the 0.4 - 1.0μ portion of the spectrum were recorded by a single aperture, optical-mechanical scanner, which allowed the reflected energy from a single small area on the ground to be recorded simultaneously in each wavelength band.

In one analysis effort with this data, a maximum likelihood technique was used in an attempt to identify the following cover types: wheat, oats, rye, corn, soybeans, red clover, alfalfa, bare soil, water, and "other," such as roads. The results of this classification are shown in Figure 4. The left side (a) shows the photo of this area, and Figure 5 shows the classification results for all cover type categories.

Figure 4. Annotated photograph and automatic printouts of specific agricultural cover types

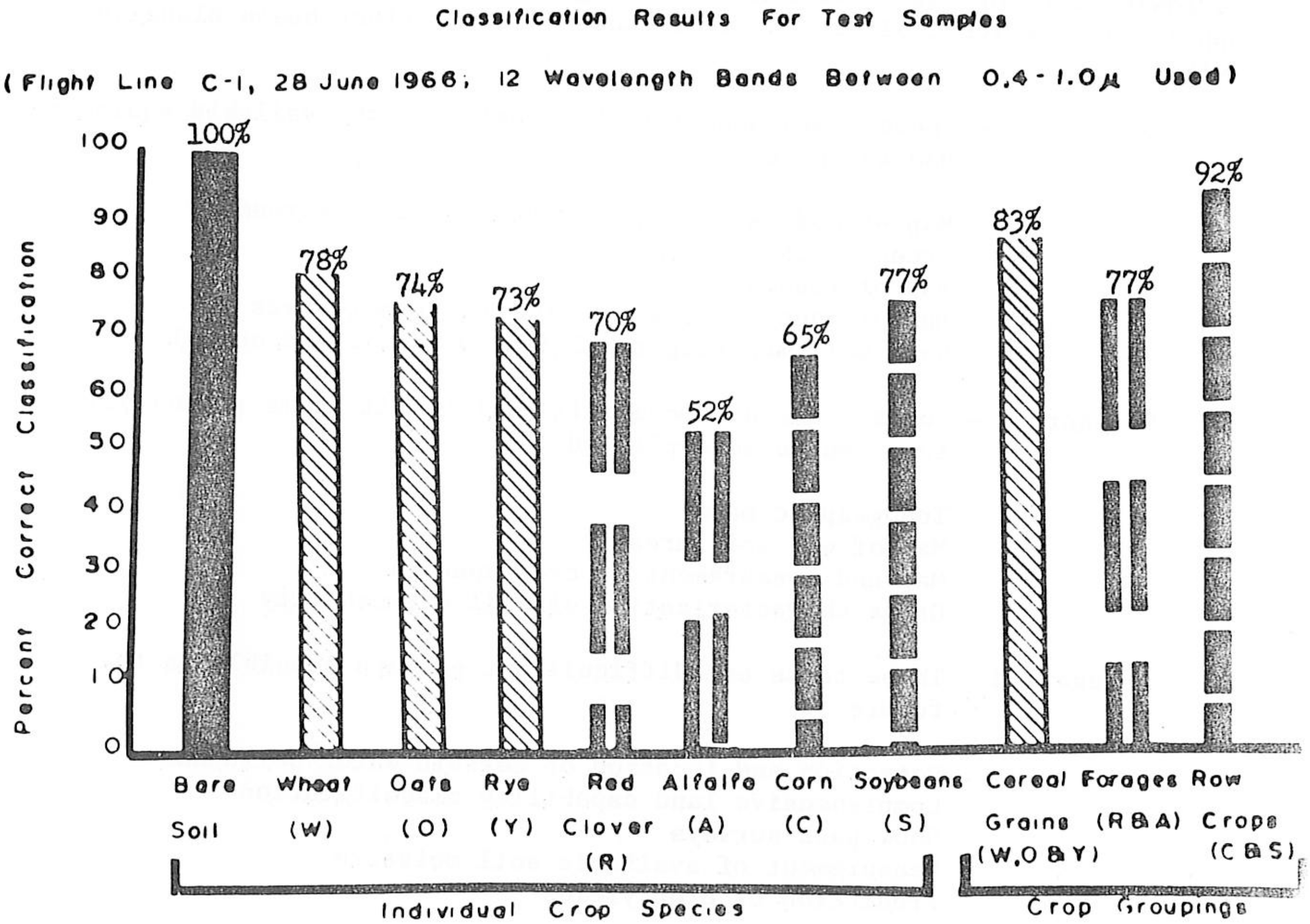


Figure 5. Comparison between test sample classification results using individual crop species and crop type groupings.

In order to accurately determine the accuracy of the classification effort, the coordinates of individual fields within the flight line were designated, and the numbers of RSU's within each field which were classified into each crop class were tabulated. Ground truth information obtained at the time of the flight revealed which fields should have been classified as wheat, corn, soybeans, and other categories. The multispectral pattern recognition results were then compared with what was known to be on the ground.

An examination of the classification results for individual fields indicated that most errors were among similar crop species, that led to an analysis of the results using crop type groupings rather than individual crop species. Figure 5 shows the comparison between test sample classification results using individual crop species and the crop type groupings. Of the 33 individual fields used in the test sample group, only 3 fields did not have better than 70% of the RSU's correctly classified on a crop type grouping basis.

Research conducted to date by the Purdue/LARS staff indicates the following categorization of remote sensing and automatic data processing applications which could be of significant value in river basin planning work:

Category A - These tasks appear to be feasible with available equipment and techniques

- Map of bodies of water (lakes, rivers, streams)
- Green vegetation map
- Map of roadways
- Measurement of relative surface temperatures
- Bare soil map (light colored, dark colored soils)

Category B - These tasks are more difficult but it seems reasonable that they can be accomplished

- Topographic maps
- Map of wet soil areas
- Map and measurement of crop species
- Gross characterization of soil permeability

Category C - These tasks are difficult but perhaps possible in the future

- Detection and location of certain water pollutants
- Comprehensive land capability classification
- Snow pack surveys
- Measurement of available soil moisture
- Prediction of crop yields

The Wabash River Basin as a Test Site

Once an operational capability of these information gathering and automatic data processing techniques have been demonstrated, some very important new tools may become available for river basin planning. As research continues in this area at Purdue University it becomes essential to establish a significant land area as a test site for developing and applying these techniques.

The Wabash River basin in which Purdue University is located offers an excellent test site for such work. Together the Wabash River and all its tributaries drain an area of 33,100 square miles which encompasses about 2/3 of Indiana, about 1/6 of Illinois, and about 319 square miles of Ohio.

Traditionally the valley has been primarily agricultural. In recent years there has been rapid industrialization and development of metropolitan areas. As a test site for developing and testing a system of mathematical modeling all the ingredients shown in the simulator of Figure 1 are present. Obviously, remote sensing cannot supply all of the varieties of data required for a large scale simulation. However, for many resource measurements requiring vast quantities of characterizing data these techniques offer possibilities of being orders of magnitude faster and less costly than conventional methods.

Summary and Conclusions

The general problem of formulating plans for the development of all the resources of a large river basin is extremely complex. The techniques of systems analysis and mathematical simulation offer a rational approach to solving these problems. Not all of the technical capability required to implement these techniques on a large scale watershed is currently available. However, research on the development of suitable component models and on the automatic data acquisition systems capable of economically providing the vast quantities of data essential to such models is rapidly making such studies feasible. It is hoped that the material presented in this paper will serve to help stimulate additional efforts in these areas.

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