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Evaluation of Satellite Remote Sensing and Automatic Data Techniques for Characterization of Wetlands and Coastal Marshlands

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Abstract

The evaluation was conducted in a humid swamp and marsh area of southern Louisiana. Earth Resources Technology Satellite (ERTS) digital multispectral scanner data is compared with similar data gathered by intermediate altitude aircraft. Automatic data processing is applied to several data sets to produce simulated color infrared images, analysis of single bands, thematic maps, and surface classifications. These products were used to determine the effectiveness of satellites to monitor accretion of land, locate aquatic plants, determine water characteristics, and identify marsh and forest species. The results show that to some extent all of these can be done with satellite data. It is most effective for monitoring accretion and least effective in locating aquatic plants.

The data sets used in this study show that the ERTS data is superior in mapping quality and accuracy to the aircraft data. However, for some applications requiring high resolution or maximum use of intermittent clear weather conditions, data gathering by aircraft is preferable. Data processing costs for equivalent areas are about three times greater for aircraft data than ERTS data. This is primarily because of the larger volume of data generated by the high resolution aircraft system.

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PREFACE

This evaluation has been conducted in the Atchafalaya River Basin of south central Louisiana. The basin is a humid area of heavily forested swamps and coastal marshes with a large volume of flow mostly from a diversion of the lower Mississippi River.

The study has two purposes which are of general concern to all remote sensing research efforts. These are, first, the determination of the usefulness of data which is obtained from various remote sensors and their associated platforms, and second, the development of automated techniques to process the large volumes of data generated by the sensors.

This study is to evaluate or demonstrate the effectiveness of remote sensing to accomplish five specific objectives. These are as follows:

(1) Evaluate techniques for monitoring accretion and erosion.

(2) Demonstrate a technique for determining salt water intrusion by classification of pertinent plant communities.

(3) Demonstrate a technique for location and classification of aquatic plants.

(4) Evaluate techniques for determination of water characteristics such as turbidity, source, and inlet-outlet conditions.

(5) Evaluate techniques for differentiating swamps, marsh and dry land area by means of forest and plant species identification.

These objectives were pursued by evaluating products obtained by automated processing of computer compatible tapes of ERTS-1 data and an aircraft underflight. The principal products developed were simulated color infrared images, simple computer analysis of one or two bands of multispectral scanner (MSS) data and classification of surface materials using spectral pattern recognition techniques.

The conclusions are that the ERTS data sets studied are superior to aircraft data for large area applications. ERTS gives uniform maps reasonably accurate in scale with a somewhat higher degree of classification accuracy. Aircraft remote sensing data is advantageous when high resolution is essential to accomplish the objective and when maximum use must be made of intermittent clear weather conditions.

Data processing costs for equivalent areas is about three times greater for aircraft data than ERTS data. This is primarily due to the larger volume of data generated by the high resolution aircraft system. Experience to date indicates that the data processing costs can be greatly reduced for both ERTS and aircraft data.

Remote sensing from satellites is effective to some degree in achieving the specific investigation objectives. It is most effective for monitoring accretion and erosion and least effective in locating aquatic plants.

Recommendations are as follows:

1. Great consideration should be given to cloud cover statistics and satellite overflight frequency before integrating satellite data into an environmental monitoring system. This is especially true of such monitoring systems that require precise time of overflight. Examples are determining the effects of a vegetation eradication program, calculation of the percent of harvest, the limits of flood inundation, etc.
2. Simple processing procedures of ERTS MSS digital data should be

used where possible to satisfy specific information needs because of the savings in cost. This would include single band intensity analysis or two band decision rules using a standard computer printout.

3. Vegetational analysis should be done by use of all available bands with pattern recognition techniques. A priori probabilities of occurrence should be used if known or be determined from a preliminary analysis using equal probabilities. This will result in an increased accuracy of classification.

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I. INTRODUCTION

Recently national interest in wetlands and coastal marshlands has greatly increased. These areas were originally avoided by settlers because they are unsuitable for agriculture or habitation. However, biologically they now appear among the most productive areas of the world. They are also among the last remaining wilderness areas of the southern United Sates. A large area of swamps and marsh exists in southern Louisiana as a result of the deposition of Mississippi River sediment on the continental shelf. In this report a distinction is made between swamp and marsh. Both are covered with water a good part of the year, but swamps are forested and marshes are treeless. The Atchafalaya River basin is one of the largest swamp areas in the country. This basin, with its adjacent marshlands, was selected for this ERTS investigation because of the encroachment of modern civilization into a wilderness area. Remote sensing would also provide an ideal means of environmental measurement because access and movement in the area is difficult on the ground.

A. Description of the Study Area

The Atchafalaya River Basin study area is located approximately 60 miles west of New Orleans in south central Louisiana and is outlined in Figure 1 (plus an extension to the marsh areas to the southeast, not shown). The basin lies in the low area between the existing Mississippi River, Bayou LaFourche and Bayou Terrebonne on the east and Bayou Teche on the west. The Atchafalaya River is used as a distributary of the Mississippi River, and is an integral part of the U. S. Army Corps

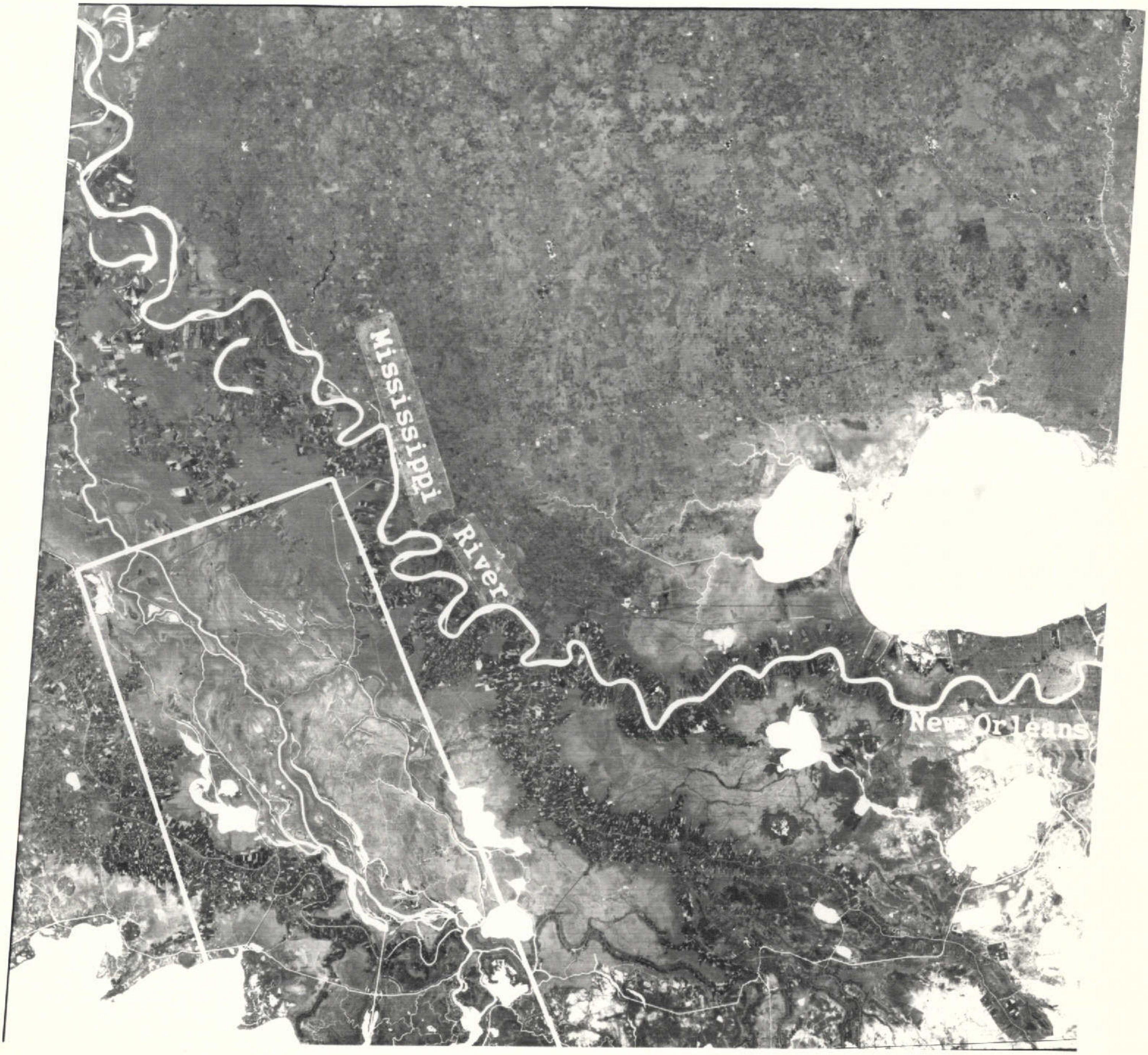


Figure 1 Page 2

ERTS frame 1070-16073 showing the location of the Atchafalaya Basin study area.

of Engineers' flood protection plan for the city of New Orleans and its environs. The entire basin is defined on the east and west sides by constructed levees down to Morgan City. The Atchafalaya River floodway is designed to pass one-half, 42,500 cubic meters per second (1,500,000 cubic feet per second), of the project design flood of the Mississippi River through a diversion on control structure located about 130 miles northwest of New Orleans.

A barge navigation channel is maintained throughout the length of the river. In addition, the Gulf Coast Intracoastal Waterway crosses the basin in the southern portion, branching at the Lower Atchafalaya outlet, one route going east to New Orleans, the other proceeding up the interior side of the east levee. This route pierces the levee at Bayou Sorrel Lock and goes to the Baton Rouge area.

The topography of the basin is extremely flat and low. Consequently there are large amounts of swamp and marsh. Much of the area is subject to overflow from the river. Only in the northern portions of the basin is there sufficient high ground to support roads. The study area, which consists of the lower half of the basin, is devoid of roads except in the Morgan City - Franklin area. Due to the channelization of the river to provide navigation, the river is relatively straight and does not exhibit the sinuosity that would be expected in such terrain. One result of the channelization has been the lack of sediment deposits in the straight reach of the river. The sediment has been deposited instead in the quiet waters of Grand Lake and Six Mile Lake just north of

Morgan City. This has resulted in the rapid filling of these lakes. An average of three square miles of new land is formed per year.

The lower portion of the basin is served by a network of artificial channels, canals, and natural bayous. The flow regime of this part of the basin is difficult to determine. There are numerous small flow diversion structures located in the basin to order the flow regime and to provide water to channels either on the inside or the outside of the basin depending on the need.

The drainage of the lakes through the outlets is affected by tides and wind. The tidal range in the shallow Atchafalaya Bay where the outlets discharge the water is about two feet. In addition, because of the shallowness of the bay (about five feet), the depth of water is affected by onshore and offshore winds. Thus the slope of the water level of the outlets, and hence the flow through them, is erratic. The volume of flow is so large, however, that the waters of the bay near the outlets are usually fresh.

The vegetation of the basin is very dense. The principal trees in swamp areas are cypress and tupelo with some willow and cottonwood mixed in with varying proportions. The newly accreted areas created by sediment deposition are usually covered with Willow. Along the better drained natural levees of the water courses a typical mixed bottomland hardwood forest prevails.

The understory of the forest varies depending on the type of overstory. Where standing in water the cypress-tupelo forests have no understory. The newly accreted land forested by willows most commonly has an understory of swamp privet. The mixed forests along the levees and cypress-tupelo forests that are now standing in dry sediment filled areas have a variety of understory plants. Rattan, smilax, blackberry, wax myrtle, and butterweed are common. In the fall blue mist replaces the butterweed.

Below the Intracoastal Waterway marshlands prevail and the vegetation is primarily marsh grasses with some large areas of wax myrtle and other scrubby brush vegetation.

Figures 2 through 6 show some typical scenes from the study area. Figure 2 shows some cypress trees in their normal environment. These trees along with water tupelo, are the only species in this area that can survive in a swamp environment. They are not highly competitive with other species in a dry land condition. So while they may live in areas where the swamp has been filled with sediment, if they are removed they will not regenerate.

Figure 3 shows four successive growth stages of willow trees. New land masses formed by accretion are usually vegetated by willow. The reason is that willow thrives on exposed soil in full sunlight and dominates other species. These trees provide the best indication of newly accreted areas. However, the appearance of the trees changes greatly with age, as Figure 3 well shows.

Willow will not succeed itself in pure form because seedlings cannot become established in the shade of older trees. Therefore, within about thirty years another set of species will take over, the exact outcome depending on the nature of the change in environmental factors. If

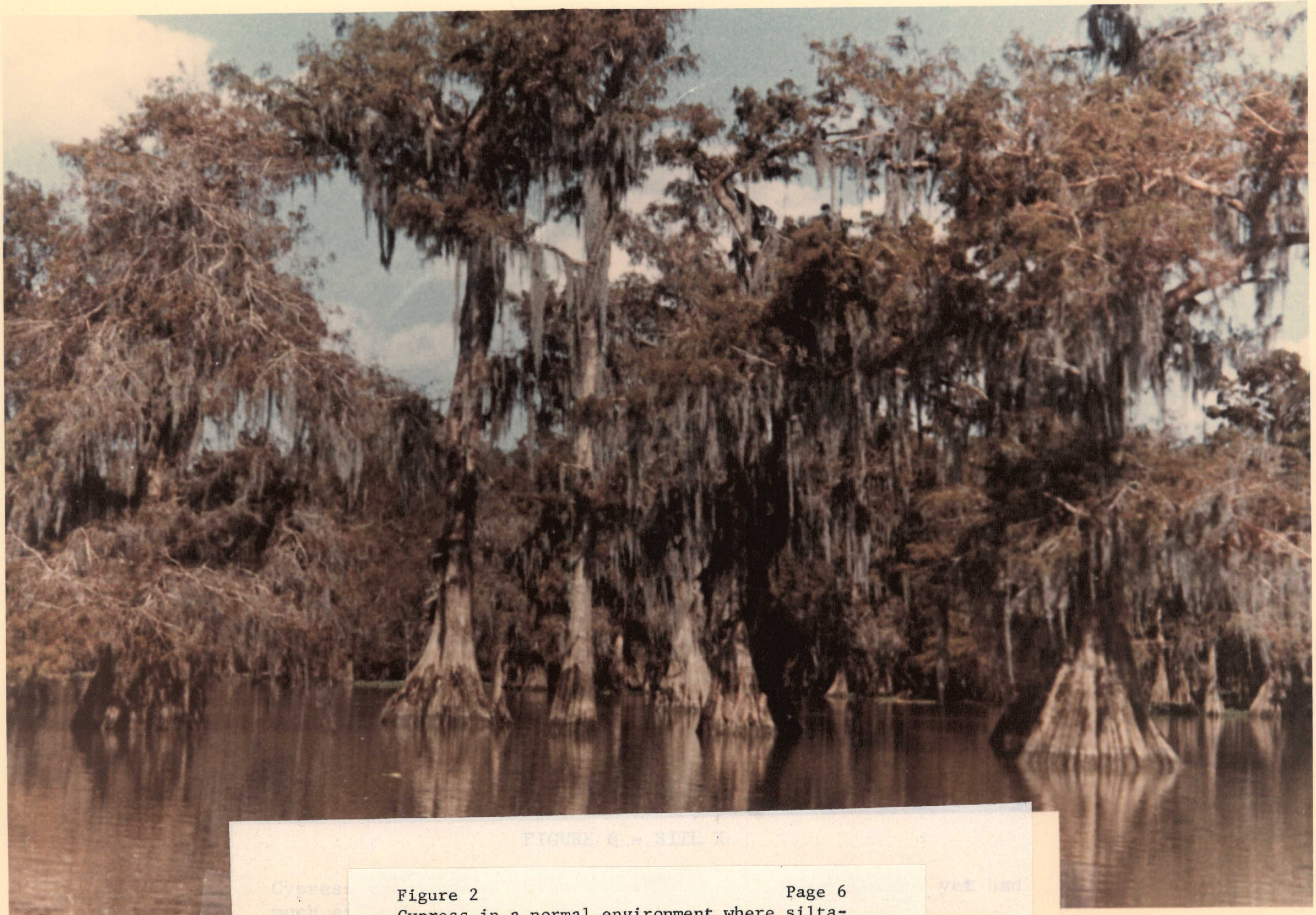


Figure 2 Page 6
Cypress in a normal environment where siltation has not yet caused major change.

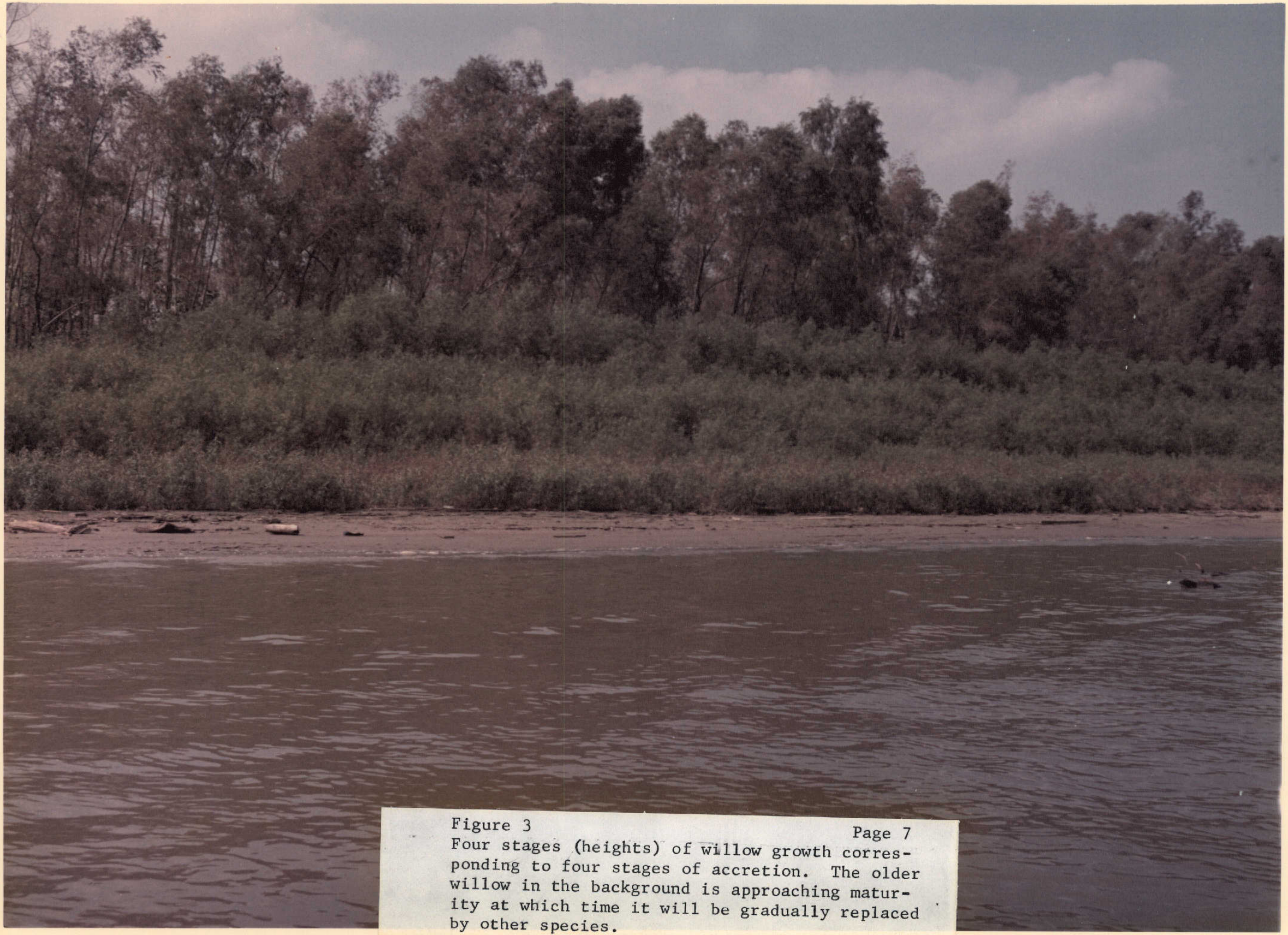


Figure 3 Page 7
Four stages (heights) of willow growth corresponding to four stages of accretion. The older willow in the background is approaching maturity at which time it will be gradually replaced by other species.

Figure 4 Page 8
Yellow flowering butterweed indicating a drier condition caused by a build up of the land mass.

Figure 5

Typical marsh area in the southern part of the study area. Note the numerous small lakes and islands and the scattering of scrubby, woody plants.

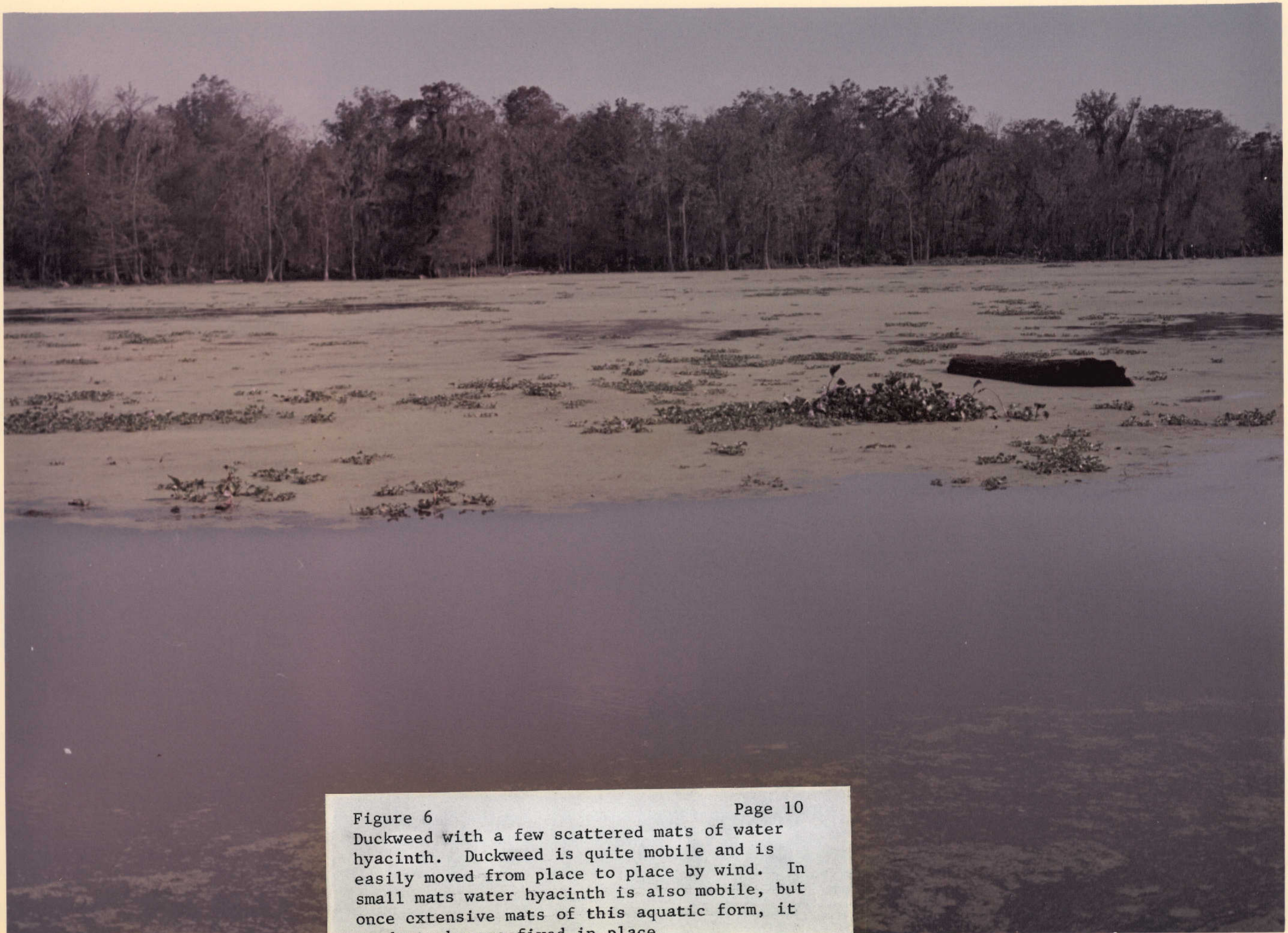


Figure 6 Page 10

Duckweed with a few scattered mats of water hyacinth. Duckweed is quite mobile and is easily moved from place to place by wind. In small mats water hyacinth is also mobile, but once cxtensive mats of this aquatic form, it tends to become fixed in place.

accretion proceeds to the point that the land area is built-up so that it is seldom flooded, as indicated by butterweed shown in Figure 4, a set of species that survive in the shade, do not require an exposed seed bed, and do not have high moisture reuirements will replace the willow. This gives rise to a typical southern bottomland hardwood forest including such species as elm, sugarberry, and oaks.

Figure 5 pictures a marsh area in the extreme southern portion of the basin. These grasses thrive in a continuously innundated area, often with some salt content in the water. In slightly higher areas small scrubby bushes and trees can establish themselves.

Throughout the basin there are numerous small lakes, sloughs, and canals. Much of these water surfaces is covered with either duckweed or water hyacinths. Figure 6 shows a typical lake partially covered by these plants. The flowering water hyacinth was originally imported into this country as an ornamental plant. They can multiply to such an extent that they often form a thick mat that impedes small boat navigation.

Commercial activity in the study area is principally oil production. There are literally hundreds of oil and gas wells in the area; however, no new drilling is in progress. A very small amount of timber is cut. This has been one of the principal products of the area in the past. The second growth of timber will reach commercial maturity about 1980. A little commercial fishing is done in the basin. In addition, the study area includes a crawfish farm as well as an ample supply of wild crawfish. This unique and delicious delicacy not only provides income, but combined with seafood provides a substantial part of the diet of the inhabitants of the area. The study area also encompasses the cities of Morgan City, Patterson, and Franklin and the surrounding agricultural land. This land is located on the natural levees of the ancient Bayou Teche outlet of the Mississippi River. It is devoted almost exclusively to the production of sugarcane. There is a considerable marine industry in the area. Various crafts are required for the oil field operations in the basin and offshore in the Gulf of Mexico. Shrimping in the nearby Gulf of Mexico is also an important industry. Little emphasis is placed on the identification of the urban and agricultural areas because that is not an objective of this study. They are included in the classification of the surface features because they do occur in the blocked out study area. Except for a few isolated cabins, the study area both above and below Morgan City is uninhabited. A more detailed account of the geologic development, hydrology, history, and vegetation of the basin is given by Cartmill _et al._, (1973).

The climate of the region is generally warm and humid. Freezing temperatures occur nearly every year, but frosts come late, usually in December, and the last killing frost usually occurs in late February. Vegetation does proceed through an annual cycle with loss of leaves or frost killback every year. Cloudiness is more common in the winter than at other times. The summer climate is typical of humid tropical climates with a cumulus cloud buildup beginning in the morning, frequently resulting in afternoon thunderstorms and showers.

B. History of the Project

Although considerable oil production activity takes place in the basin, the area remains a large wilderness area. Its use as a floodway ensures that the region will remain essentially uninhabited. There exist many environmental problems and many groups with special interest in the basin -- local inhabitants who use it for recreation and commercial fishing; the oil industry; the lumber industry; and the Corps of Engineers. One of the most obvious and pressing problems is the accretion of new land and the filling of swamp and lake areas by the deposition of sediment from the Mississippi River diversion upstream. With increased public concern in the late 1960's, interest in the environmental aspects of the basin became a powerful political force.

On May 26, 1971, the Governor of Louisiana formed the Commission of the Atchafalaya Basin. This group responded quickly and began a serious study on the methods of providing a master plan for the optimum use of the basin.

In October, 1971, the Chairman of the Joint Legislative Committee on Environmental Quality enlisted the aid of many state agencies having trained scientists on their staffs to participate in a wetlands environmental study. He also requested help from Federal agencies including the National Aeronautics and Space Administration. In response to this request the Earth Resources Laboratory, located at NASA's National Space Technology Laboratories in Bay St. Louis, Mississippi, proposed to conduct remote sensing research investigations in the basin. Within the scope of the general objective of gathering sufficient environmental data to develop a rational master plan, the Laboratory defined a set of detailed objectives to be accomplished by using remote sensing methods as follows:

(1) Evaluate techniques for monitoring accretion/erosion.

(2) Demonstrate techniques for determining salt water intrusion by classification of pertinent plant communities.

(3) Demonstrate techniques for location and classification of aquatic plants.

(4) Evaluate techniques for determination of water characteristics, e.g., turbidity, source, inlet-outlet conditions.

(5) Evaluate techniques for differentiating swamps from dry land areas by means of forest species identification.

All of these objectives require a reasonably accurate classification of the surface materials as a prerequisite. Most of the effort of this study was spent on obtaining these classifications.

The initial study was to use aerial photography and intermediate altitude (6,100 meters, 20,000 feet) aircraft multispectral scanner data to achieve the objectives. The lower portion of the basin below Highway I-10 was selected as the study area. It was in this area that the environmental problems appeared most acute. Work began at once gathering ground truth and surface measurements. The first aircraft photographic and multispectral scanner data was gathered on October 28 and 29, 1971.

At the same time an ERTS-1 proposal was submitted to the Goddard Space Flight Center. The specific objectives were the same ones as listed above. However, there were two other more general objectives. These were as follows:

(1) Determine the usefulness of various sensors and their associated platforms to characterize wetlands, i.e., aircraft at intermediate altitudes and ERTS at satellite altitude.

(2) Develop automated techniques to process the large volumes of data gathered by the sensors with the multispectral scanner computer compatible tapes.

These objectives were to be accomplished by noting the time of ERTS passes over the study area and scheduling aircraft data underflights under some of them and processing the data through similar series of programs and comparing the results. This proposal was approved on May 30, 1972, and preliminary work began in the following July.

In addition, a Skylab proposal for the same area was submitted to the Johnson Space Center and this proposal was approved on September 13, 1972. Work on this study is now underway.

A list of data gathered in pursuit of these investigations is listed in Appendix A along with a list of Earth Resources Laboratory reports that have been completed to date.

Study of the Atchafalaya River basin by other state and federal agencies is continuing. By means of a $5,700,000 bond issue the State of Louisiana has established an Atchafalaya Basin Division of the

Department of Public Works to establish a wildlife refuge and recreational site in the basin and to build a Visitor Information Center. The New Orleans District of the U. S. Army Corps of Engineers is being funded in accordance with a resolution of the Committee on Public Works of the U. S. Senate to develop "a comprehensive plan for the management and preservation of the water and related land resources of the Atchafalaya River Basin, Louisiana, which would include provisions for reduction of siltation, improvement of water quality and possible improvements of the area for commercial and sport fishing." The Corps is enlisting the aid of the Atchafalaya Basin Division to define the needs and goals, the Environmental Protection Agency to derive alternative plans and the Bureau of Sports Fisheries and Wildlife of the Department of Interior to assist in the preparation of an environmental impact statement. These agencies have in turn enlisted the aid of several groups in the Louisiana University system as well as other state and federal agencies. Many of these groups have contributed to this ERTS remote sensing study.

C. Approach to Achieve the Objectives

Considering the setting of this investigation, the basic approach to accomplish the objectives was to integrate ERTS satellite data into the ongoing investigation. A large number of ground truth sites had been visited and the preliminary data on soils, water quality, vegetation, etc. had been gathered, Cartmill et al.(1971). By the time of the first work on the ERTS project, a photo interpretation of the study area had been completed by Joyce (1972). Also, computer programs had been written and checked out to process aircraft multispectral scanner data.

However, the inclusion of ERTS data in the study required some additional planning and work. The ground truth sites which were used for training samples in the pattern recognition programs were reexamined for suitability of use with ERTS data. Training samples and pattern recognition programs will be discussed later, but in essence, the samples are required to be representative of the populations of materials which are being sampled. This required that a reasonably large sample be chosen (say 30 observations). Since the previously selected sample sites were established for a scanning instrument with higher resolution, the sites had to be examined to see if they could be enlarged to include approximately 30 ERTS resolution elements -- 400 by 480 meters.

Also required was a decision on how to format the ERTS data. It was decided that the ERTS computer compatible tapes would be reformated into the already existing format used for the aircraft multispectral scanner data. In addition, special programs had to be written to perform ERTS data verification, rectification of the display products, and programs to tally the results over geographical areas on an element by element basis.

The objective of determining the usefulness of various sensors to characterize wetlands required the scheduling of aircraft photographic and multispectral scanner underflights of ERTS passes. The study area has two basic hydrologic regimes--a low water condition in the late summer and early fall and high water in the winter and spring. Although two underflights were scheduled only one was flown--the high water condition. For purposes of comparison the scanner data collected from aircraft and

ERTS were taken at approximately the same time and processed in the same manner.

D. Operational Difficulties

In applying new technology to any existing problem, difficulties can be expected. So it was with ERTS. Cloud cover was the most persistant problem. Cloud cover statistics for 10:00 a.m. local time (ERTS pass time) prepared by Brown (1970) are given below.

Month	J	F	M	A	M	J	J	A	S	O	N	D
Probability of cloud-free pass	.16	.21	.20	.18	.14	.13	.12	.20	.29	.33	.29	.22

These statistics applied to the frequency of ERTS observations yields an expected value of 4.17 cloud-free ERTS passes per year. In order to use the pattern recognition programs to identify the surface materials and then make a tally of the results, cloud-free passes are required. Another weather related problem arose with the large flood of the spring of 1973. The Atchafalaya floodway was activated. While this presented a great opportunity to observe the floodway under unusual conditions, it did innundate large areas of basin and rendered them unobservable.

A second major problem was equipment difficulties. The aircraft multispectral scanner is a newly designed experimental instrument. Maintenance problems caused cancellation of one of the scheduled aircraft underflights. The ERTS satellite also experienced equipment problems. The data sets (computer compatible tapes) taken prior to April 1973 contained errors described by Thomas (1973) as striping. This problem resulted in some misidentification of materials where it occurred in the data sets. And finally the ground receiving stations for ERTS data were often unable to receive data south of latitude 29°30'N in the study area.

The foregoing difficulties did not negate the study. Often ways were found to circumvent them or exploit the data available in such a manner as to proceed with attaining the objectives.

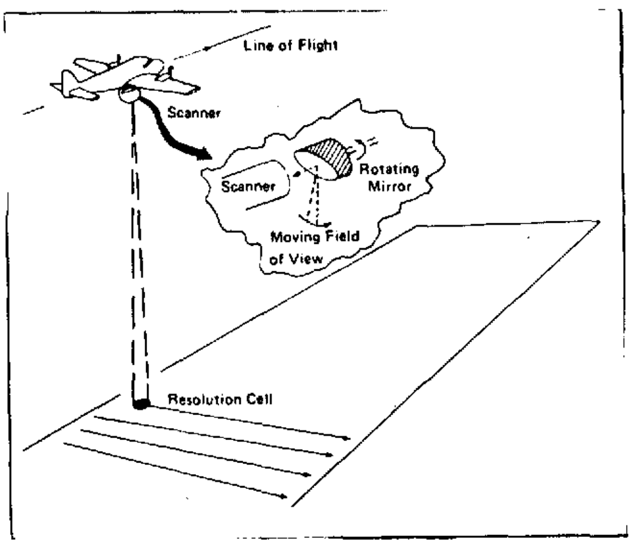
II. EQUIPMENT AND TECHNIQUES EMPLOYED IN THE STUDY

A. Sensor Systems and Platforms

In this study primary emphasis was on the analysis of data collected by multispectral scanners carried on board an aircraft flown at 6,100 meters (20,000 feet) altitude and the ERTS spacecraft at an altitude of 917 km. (494 nautical miles). A brief description of these platforms and instruments and the principle on which they work is presented below.

The aircraft used was the NASA Earth Resources C-130B. This is a large four-engined turboprop airplane. The instrument is the Bendix 24-channel multispectral scanner (MSS). This instrument can detect and record energy over a broad range of wavelengths (.34 to 13 micrometers). The MSS records the quantity of energy received in 24 different narrow bands, using a separate detector for each channel (wavelength band). The absolute quantity of energy received in each band can be determined by comparison with calibration sources internal to the instrument. The aircraft is also equipped with aerial cameras which can simultaneously take vertical photography.

The data is gathered by the use of the scanning principle. This principle is quite different than the standard photographic process which simultaneously views a wide area. The radiated energy is collected by a rotating mirror which causes the field-of-view to scan from 40^{0} to the left to 40^{0} to the right of the line of flight as shown in the figure below. Each scan line contains 700 resolution cells or elements. The field-of-view of the scanner at any one time is very narrow - a circle with a diameter of only 2/1000th of the altitude (12.2 meter, 40 foot resolution cells for this flight). The speed of rotation of the



mirror is adjusted for the speed and altitude of the aircraft so that the resolution elements of each scan line just touch those of the preceding scan line as shown in the figure. The quantity of energy collected by each of the 24 detectors is digitally quantified on a scale of 0 to 255 for each resolution element and recorded on magnetic tape. Papers by Korb (1969)and Zeitzeff et al. (1971) contain more details of this instrument.

The ERTS satellite was launched on July 23, 1972. It is the first satellite to be dedicated to earth resources observations. The observatory operates in a circular near polar orbit at an altitude of 917 kilometers (494 nautical miles). The orbit is designed to observe the same locality on earth at approximately 10:00 a.m. local time every 18 days. The satellite has a slight east to west inclination as it orbits from the northern polar regions to the south.

This satellite is equipped with a multispectral scanner. This instrument differs somewhat from the one described above. The principal difference is that the ERTS scanner has only 4 channels or bands covering the wavelengths from .5 to 1.1 micrometers instead of the 24 channels in the aircraft scanner which include a wider range of wavelengths. The ERTS scanner also has a coarser scale of digital data. The scale is 0 to 63 (0 to 127 in special cases on some bands). Another major difference is that the ERTS scanner has much finer angular resolution than the aircraft scanner. This is accomplished by having 6 detectors for each band, thus breaking up the instantaneous field-of-view into 6 equal parts. The result is that even though the altitude is 150 times greater than aircraft altitude, the size of each resolution cell is 79 meters, compared with 12 meters for the aircraft at 6,100 meters. The scanner over-samples in its across track scan, taking a sample every 59 meters. Details of operation of the satellite and the scanner are contained in the NASA Earth Resources Technology Satellite Data Users Handbook (Goddard Space Flight Center 1971).

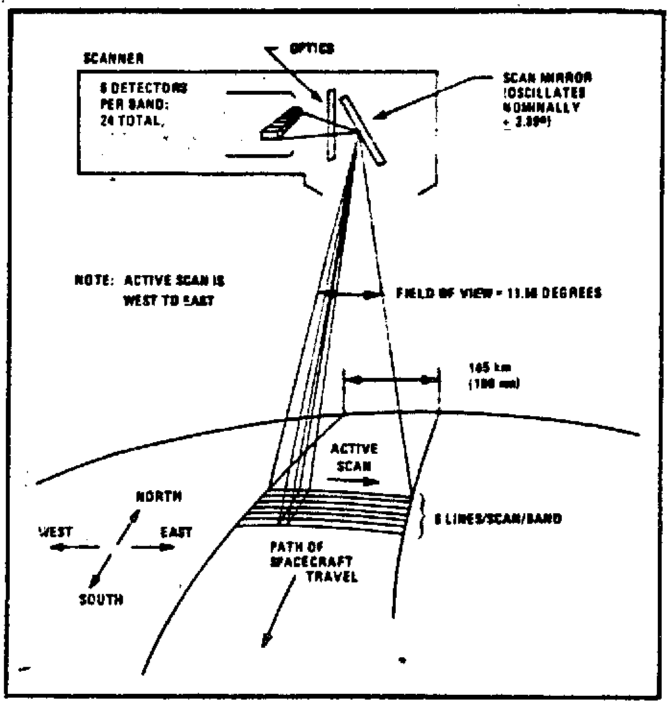


Illustration of the ERTS Scanner Coverage

B. Ground Data Processing Equipment

The ERTS MSS data is telemetered to ground receiving stations daily. This data is forwarded to the NASA Data Processing Facility at the Goddard Space Flight Center, Greenbelt, Maryland. This facility produces a standardized computer compatible magnetic tape and images in black and white of the data in each band and a color composite image by superposition of three of the black and white images. The images are standardized into frames which cover 100 by 100 nautical miles at a scale of 1:1,000,000. Four computer compatible tapes are generated for each frame. The aircraft MSS data is digitized and placed on a special magnetic tape at the time it is taken. The raw data is returned to the ground for transcription on standard computer compatible tapes either at the Johnson Space Center or the Earth Resources Laboratory.

The magnetic tapes from both the aircraft and ERTS are processed by the Earth Resources Data Analysis System located at the Earth Resources Laboratory facilities at NASA's National Space Technology Laboratories. Some processing requires the use of a large general purpose computer. The laboratory uses the NASA Univac 1108 computer located at nearby Slidell, Louisiana. Figure 7 shows the Data Analysis System (DAS). The parts of this system which were used for this study are as follows:

(1) A 14-channel broadband instrumentation tape reproducer/recorder used to read the aircraft MSS data.

(2) A high-speed, general purpose digital mini computer

(3) A high-speed line printer.

(4) Two 150ips digital tape recorders/reproducers used to read the ERTS MSS magnetic tapes received from the Goddard Space Flight Center.

(5) A high resolution three color TV display used to provide fast presentations of sensor data for evaluation by the system operator. A light pen cursor

Figure 7
Earth Resources Data Analysis System.

system is provided for rapid delineation of data areas of interest.

(6) A high resolution, 24 cm. (9-1/2 inch) wide strip film camera system capable of recording on film data presentations in color or black and white.

(7) A versatile Interactive Operator Control Console (IOCC) providing complete operator-processor communication and control.

The two features of this system which are unusual are the color TV display and the film recorder. Any three bands or linear combination of bands of the MSS data can be displayed simultaneously on the screen. Each band is assigned either a red, blue, or green color. The intensity of the color is proportional to the digital number recorded on the magnetic tape. When the three primary colors are superimposed a multicolored picture containing all colors is produced. The system is provided with a memory unit so that the image stays on the screen without movement. Approximately 450 elements of 500 scan lines can be displayed on the screen. The system is implemented with an over-riding cursor which is used to mark the corner coordinates of any convex four sided figure. These coordinates can be stored on magnetic tape for later reference.

The television screen has performed well and proven to be a very useful aid in the analysis of the data. It serves as an elementary data verification system. Garbled or missing data can be detected immediately. It also serves as a quick look check of the output products of the data processing effort. It has reduced the time to identify the scan line and element coordinates of areas of special interest manyfold over a system that relies on computer printout.

The film recorder is the device which makes a final record of the output products of this study. Like the television it can color code any digital data in one of three colors. The digital data determines the intensity of the beam on a black and white cathode ray tube. A red, blue, or green color slide is mechanically inserted between the cathode ray tube and the film. Before the film is advanced, another digitally recorded band controls the cathode ray tube and a different color slide is inserted. After all three bands have been superimposed on the same line of film, the film is advanced one scan line and the process is repeated. Either positive or negative film can be exposed permitting a record of either a film transparency or paper prints. The data processing equipment used by the Earth Resources Laboratory is described well by Whitley (1973).

C. Programs Developed and Processing Procedures

The attainment of the specific objectives requires a classification of the surface of the basin. Consequently, the majority of the effort on the study was directed toward this end. The theory of classifcation of different materials by use of multispectral data was pioneered by the Environmental Research Institute of Michigan (ERIM). Further theorectical work and development of computer programs for processing multispectral data was done by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University. The Earth Resources Laboratory uses a modified version of the LARS program. These classification programs are called spectral pattern recognition programs.

In addition to the pattern recognition programs several auxiliary programs were developed to edit and screen data, perform special analyses, and produce output products. Prior to the processing of any data from the ERTS computer compatible tapes or aircraft tapes, they are placed in a standard format and screened on the DAS for a quality evaluation. Each channel of MSS data is displayed on the television screen and checked for data dropouts or irregularities. Because of the striping problem on the ERTS tapes mentioned earlier a special program was written to detect a change in the intensity of any scan line. This program averages the value of all elements of each scan line and compares this value to the average of its two neighboring scan lines. Any significant difference can be detected readily. The striping problem has been greatly reduced on all tapes manufactured after April 1973. Programs were also developed to print the digital data from both aircraft and ERTS tapes and to print the value of the calibration data.

Special analyses are sometimes desired. These include such things as the tally of acreages of the different classifications in a given geographical area, the signal strength analysis of just one band or channel of MSS data, or the mapping of only one class of material (or theme) by use of a simple decision rule.

The final digital output of these programs and the pattern recognition programs are recorded on the film recorder. Useful but somewhat distorted maps can be produced with a small program directed to the computer which controls the film recorder. In order to produce rectified maps to a more precise scale, the film recorder must be directed to produce the image with slanted sides as shown in Figure 1. The program which does this requires the input of such data as satellite altitude, velocity to height ratio, scanning rate, sample rate, and the center element of the scan line. All of the analyzed data products can be recorded in a manner similar to that described above.

The pattern recognition programs are considerably more complex. An excellent description of the basic theory of pattern recognition is given by Duda (1970). As applied to multispectral scanners, the term pattern recognition is somewhat misleading. The images which are produced from the scanner data are not analyzed to identify geometric patterns, such as straight lines for streets and canals or rectangular fields for agriculture, etc. The pattern of signal strengths measured by each band of the sensor is analyzed. The ERTS MSS has four bands of data and the aircraft MSS has twenty-four. Specific kinds of material give specific strengths of signals in each of the bands. The essence of this type of pattern recognition is to match the pattern (strength of signals in each band) with some standard pattern of a known material.

These standard patterns for different materials can be obtained by either of two methods. The first, and as yet undeveloped, is to consider basic physical concepts of reflectance and emittance characteristics of materials, atmospheric effects upon the reflected and emitted energy, and the energy losses of the sensor. This approach has great merit in its generality, but has proven difficult to apply in practice.

The second approach, which is usually taken, is to define samples of known homogeneous composition and statistically analyze the scanner data received from these samples. In other words, the computer is "trained" to identify the different materials in the samples. Then, based on the knowledge gained from the training samples, the computer can proceed to classify the remainder of the data elements. Obviously this method lacks generality. The statistics derived from a training sample may be altered by changes in such factors as sun angle, ground temperature, atmospheric conditions, and so forth. Hence, a set of training samples may provide a valid set of data for only a given time and place. Also this method requires a training sample or set of samples for each classification desired. This naturally requires ground truth effort to identify good training sample sites.

After the best sites of each class of material have been located by ground teams or observers in low flying aircraft, the locations are marked on mylar overlays of ERTS or aerial imagery taken simultaneously with the MSS data. The MSS data is then displayed on the television screen of the Data Analysis Station, and the corners of each training are then marked by use of the light pen cursor. The DAS computer calculates the scan line and element coordinates of the corners automatically and records them on magnetic tape and the printer. These recorded coordinates are then applied to the reformated raw data tapes and the readings from the training fields of the ERTS bands or desired aircraft channels along with the calibration data are transcribed to another magnetic tape.

In a separate computer operation the data from the training fields are statistically analyzed and the standard training field patterns or signatures are determined.

The next processing stage consists of preparing tables of training field signatures. The tables are four dimensional. All of the ERTS bands are used to construct them. If more than four bands are available, as in the case of the aircraft scanner, a selection is made of the best four bands for each class of material to achieve maximum separability of the classes. In this study, however, the choice of aircraft scanner bands was dictated by the requirement that they match the ERTS bands as nearly as possible. If known, the a priori probability of occurrence of each class is entered into the computer and the classification of the whole data set begins. Each data element is then compared with each training field signature in the table until a statistical match is found or until the table has been exhausted. If a match is found the data element is classified as being in the same class as that of the training field. Otherwise the data element is not classified. In any event, the results of this process are recorded on magnetic tape; thus each data element is classified into one of the classes or it is not classified. See Appendix B for further details.

A list of the data processing steps is shown in Table I below:

TABLE I DATA PROCESSING STEPS

STEP NO.	PROGRAM NAME
1. Verify, decommute, reformat and film record raw data.	Various
2. Select training fields and generate edit tape.	Training sample select, digital tape copy
3. Compute statistics, separability and best channels.	STAT, CHOICE
4. Build tables, classify and compute classification accuracy.	RTABLE, RCLASS, DISPLAY
5. Screen, rectify and film record classified data.	TCOLOR
Miscellaneous analyses	Various

The ability of the multispectral scanner to detect and quantify energy in different wavelengths makes it a very powerful tool for remote sensing work. This instrument together with associated data processing techniques can be used to identify different materials on the surface when viewed from above. Taking a simple two dimensional case for example, green grass can be distinguished from blue water by noting the relative strengths of the signals received in Channel 2 (blue) and Channel 4 (green) of the aircraft scanner. The recorded strengths may be shown as follows:

	Channel 2	Channel 4
Grass	32	128
Water	97	16

The grass appears green because it reflects the green light (.53 to .57 micrometers) of the sunlight, whereas the water absorbs this light and does not appear green.

While the basic concept of classifying objects on the surface is quite simple, complications arise when attempting to process a great deal of data and to distinguish between a large number of different materials.

For example, the detectors record the <u>average</u> signal received from each scan element. Again using the grass and water example, if the instantaneous field-of-view is large and includes an area that is half water and half grass, then the values recorded in Channels 2 and 4 would be the average of the numbers shown. On comparing these averaged numbers with data taken while viewing a stand of pure grass and a surface of pure water, one could not determine if the mixed area was water, grass or something entirely different.

This averaging of the signal from a given cell size causes misclassifications along borders of different adjacent materials. Small streams less than one resolution cell in width (12 meters for the aircraft scanner, 79 meters for ERTS) are often classed as some material other than water. Areas containing scattered trees are often misclassified. Naturally the smaller the size of resolution cell, the less significant the problem becomes. However, aside from the difficulties of constructing a scanner which can detect energy from small areas of the ground, the volume of data increases enormously with small resolution elements. An ERTS classification of the study area is comprised of approximately 750,000 resolution elements. The aircraft classification of the same area is comprised of about 28,000,000 elements.

D. Ground Truth and Sensor Data Used

Because of the extensive ground truth effort that was staged for previous remote sensing studies of the basin, little was required for this ERTS study. The ground truth data collected for the previous studies was published by Cartmill *et al*. (1972) and Mix *et al*. (1972). A small ground truth expedition was mounted in mid January 1973 in conjunction with the aircraft underflight of ERTS and a low level aerial reconnaissance was made on October 2, 1973, to survey the effects of the large flood of the spring of that year. Low altitude aerial photography of all the training sample sites was taken in May of 1974.

During the period of the study very little man-made change occurred in the basin. As previously noted the area is nearly uninhabited and oil industry activities are limited to production from existing wells and drilling of a few new wells.

After careful consideration the best ground truth sites were selected for training samples for the pattern recognition programs. The location of these samples are shown in Figures 8 and 9. Also shown are the flight lines of the aircraft underflight of the wintertime ERTS pass. Appendix C gives a description of these sites and photographs of them taken at an altitude of 230 meters.

The data sets used in this study are listed in Table II below:

Table II Data Sets Used in the Study

Platform	Local Time	Date	Sensors	Solar Alt.	Products*
ERTS-1	10:03	Oct. 1, 1972	MSS - all bands	47°	1,2,3,4
Aircraft - 6100m.	12:45-1400	Jan.15, 1973	RC-8 camera Bendix 24 channel MSS - chans. 4,5, 7,10	30°-39°	4
ERTS-1	10:04	Feb. 4, 1973	MSS - all bands	34°	1,4
ERTS-1	10:04	May 5, 1973	MSS bands 1,2,4	60°	1,3
ERTS-1	10:03	Aug.21, 1973	MSS - all bands	56°	1,3,4
ERTS-1	10:02	Nov. 1, 1973	MSS - all bands	40°	1,4

*Products:
1. Simulated color infrared image.
2. Signal strength analysis of a single band
3. Thematic mapping (water)
4. Surface classification maps. (7 - 12 classes)

ATCHAFALAYA BASIN

ATCHAFALAYA BASIN, LOUISIANA

Uncontrolled Mosaic
Photography Dated April 1972
Flown by U.S. Air Force
Prepared by EROS Experiments and Evaluation Office
Mississippi Test Facility

N

SCALE
STATUTE MILES

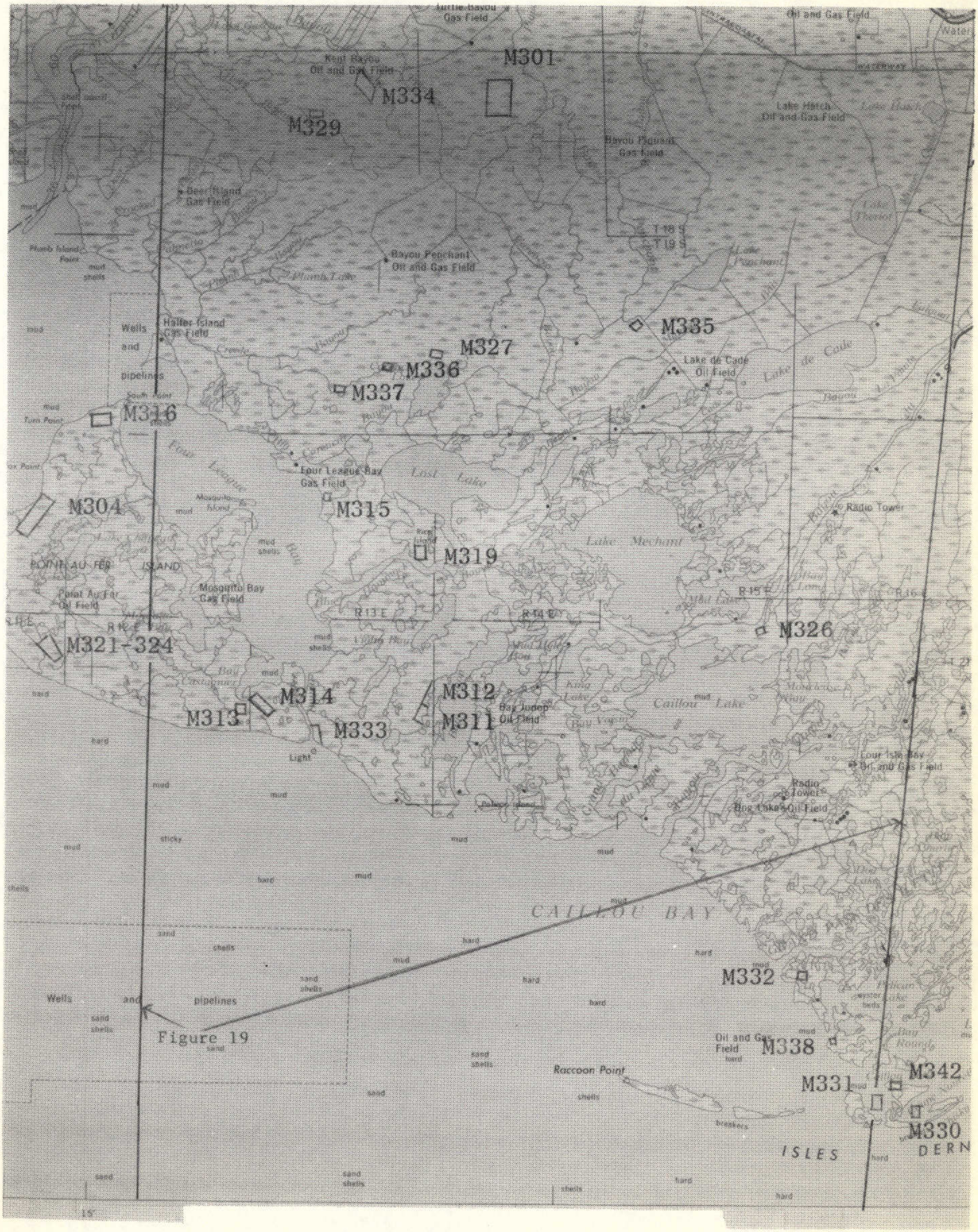


Figure 9
Location of marsh training sample sites.

III. RESULTS OF THE DATA PROCESSING AND EVALUATION

A. Images from Digital Data

One of the great advantages of a digital processing of ERTS data with a system employing a film recorder is that color images of any set of ERTS data can be made to many scales. Even without refined corrections to the data useful images can be manufactured. Any of three bands are selected and a specific color is assigned to each band on the television screen. The intensity of each color is varied by the operator until the desired color balance is achieved. The data is then switched to the film recorder for making a permanent record. The film recorder prints a square block for each element. The elements, if placed on film in a consecutive manner, will produce an image which is elongated in the across track direction because of the oversampling of the ERTS scanner in the across track direction. In order to obtain an enlarged image it is necessary to repeat the elements several times. If each element of each scan line is repeated three times and each scan line is repeated four times the effect of the oversampling can be nearly compensated. The film recorder can place 2400 squares across a nine inch wide film (8½ inches of actual exposure). Each ERTS computer compatible tape contains 810 data elements. Thus all but 10 data elements of a tape can be recorded on one pass through the recording system. This results in an image at a scale of approximately 1:218,000. Figure 10 shows such an image. The original image has been slightly reduced photographically to a scale of 1:250,000. A portion of this same data is shown in Figure 11. This figure was produced by repeating each element nine times and each scan

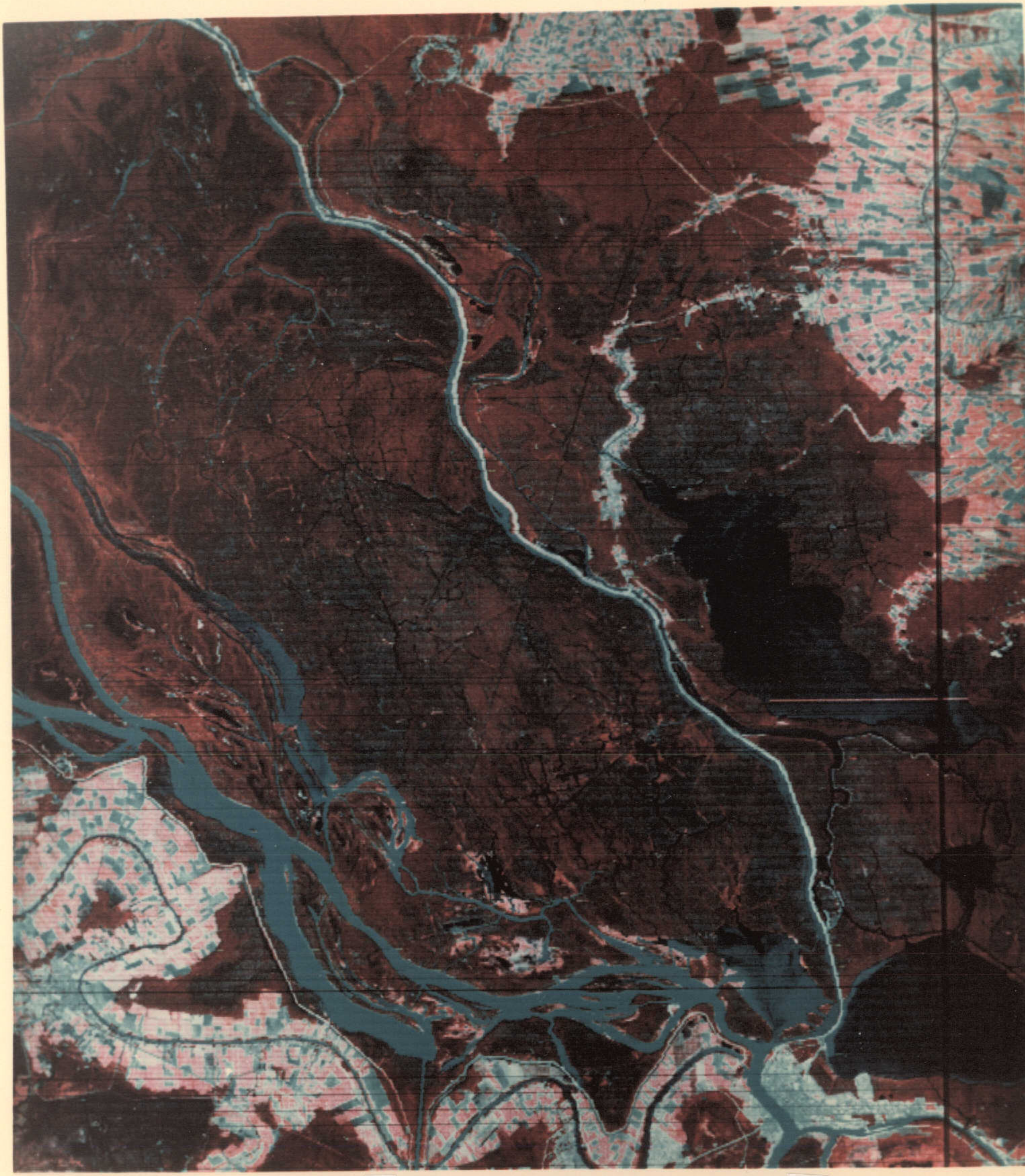


Figure 10 Page 37
Computer expansion of ERTS frame 1070-16073, October 1, 1972, showing the lower Atchafalaya River basin in simulated Color IR. Scale approximately 1:250,000.

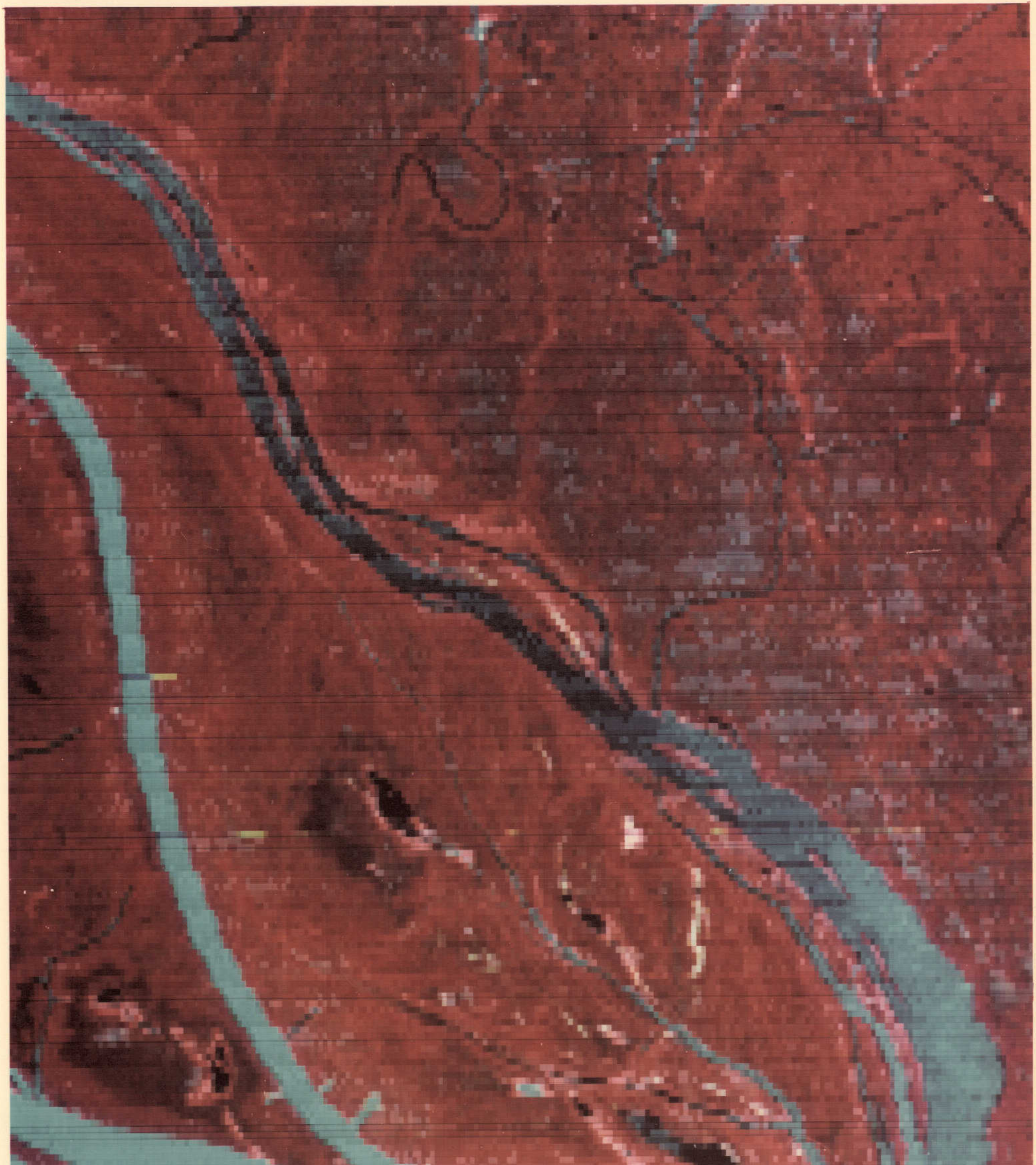


Figure 11

Computer expansion of ERTS frame 1070-16073, October 1, 1972, scale approximately 1:62,500.

line thirteen times. This enlargement produces a blocky image because each element is clearly distinguishable. However, the detail that is observable is superior to that which can be seen by photographically enlarging an ERTS image. There is some distortion in these figures, principally because of the rotation of the earth under the satellite. This may largely be corrected by simple programming of the computer which controls the film recorder.

Some experimentation was done making even larger enlargements of ERTS data (1:24,000). For some purposes this scale may be very useful. The image quality is good enough to permit planimetering of areas, for example.

Another advantage of the film recording system is that the color levels of each band used to manufacture the image can be adjusted to emphasize any desired feature. The image can be viewed on the television screen prior to filming. Products can thus be made to order without extensive runs of photographing.

B. Signal Strength Analysis of Single Bands

The simplest quantitative analysis of ERTS digital data is a signal strength analysis of a single band. With the use of the Data Analysis System colored maps of any desired scale can be produced in a manner similar to that described above. The procedure used at present is to take a few samples of data from specific areas representing desired classes of material. One band of ERTS data is then processed through a general purpose computer which assigns a number for a given range of scanner counts. The assigned number is then converted into a color for display on the television screen or for use by the film recorder.

The principal advantage is its simplicity; another is that all data elements are assigned a color. There are no unidentified elements. This means that if one band can accurately identify an item of interest, then a tally of the percentage of an area may be made and the item can be mapped at very low cost.

Figure 12 shows an example of this technique applied to Band 3 (.7 - .8 micrometers) of ERTS data. Note the effect of the sixth line striping at the bottom of the figure. In this case the colors were as follows:

Band 3 Digital Counts	Color
0-15	Dark Blue
16-25	Yellow
26-30	Green
31-35	Orange
36-40	White
41-45	Black
46-50	Light Blue
51-64	Magenta

Certainly rivers, streams and standing water (yellow) can be easily distinguished from lakes (dark blue) and vegetation (all other colors). Comparison with Figure 10 shows clearly that the definition of agricultural fields is very poor. In general, the ability of this technique to identify vegetation is unsatisfactory.

C. Thematic Mapping

For many uses only one class of surface cover may be desired to be mapped. This technique is called thematic mapping. This can be done by

Figure 12

Single band intensity analysis and expansion of ERTS frame 1070-16073, October 1, 1972, Band 3 showing the lower Atchafalaya River Basin.

classifying many of the surface covers of the area by pattern recognition techniques and distinctively coloring the desired theme (surface cover). All the other materials can be colored a neutral color to emphasize the theme of interest. However, this requires a complete classification of the data. The Earth Observations Division at Johnson Space Center (1973) has developed a relatively simple technique for mapping visible surface water. A modification of their procedure was used to produce Figure 13. This figure shows all water visible to the satellite. At the time the data was collected the river stage was relatively low and it shows a near maximum amount of land. The technique was also applied to ERTS data gathered at the time of near maximum water level during the spring flood of 1973. A 1:62,500 water map of the flood of the entire basin was also prepared. The technique used involved the use of only two bands and was run on the DAS computer. The two dimensional decision curve which was used is shown below.

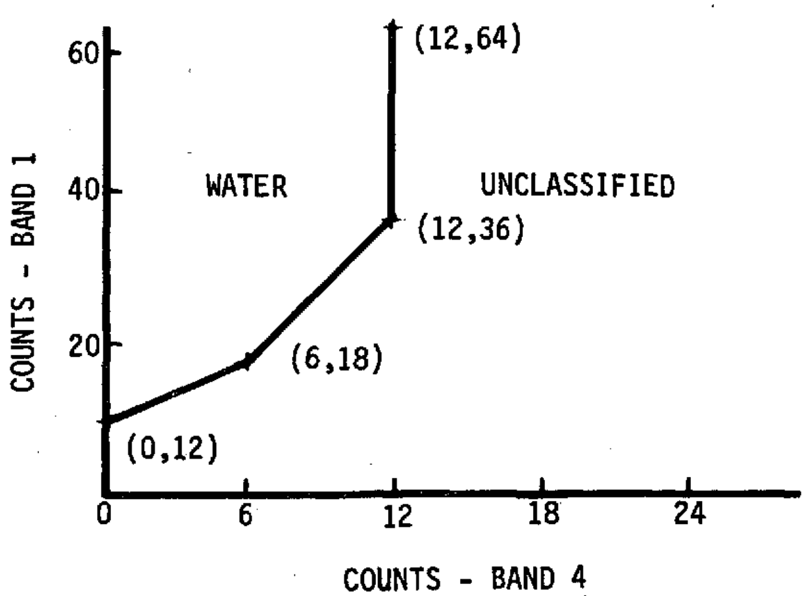


Figure 13 Page 43
Thematic mapping (water) using bands 1 and 4 of MSS data from ERTS frame 1070-16073, October 1, 1972.

The program has adjustable input values so that the decision curve can be altered to reflect the results of sample data. Water mapping has many uses in the study area, such as determining the vegetated areas of marshlands, the extent of flooding, and the erosion of accretion of land. Unfortunately it does not have the capability of detecting water under a thick vegetative canopy.

D. Classification by Pattern Recognition Techniques

Figures 14 through 17 show the products of the pattern recognition programs. Figure 14 is a classification of the basin from ERTS data taken on February 4, 1973 using all four bands. Figure 15 is a mosaic of processed aircraft MSS data from five flight lines taken on January 15, 1973, using four channels. Both figures show the same general features although there are noticeable differences in detail. Figure 16 is a large scale version of the ERTS classification, Figure 14. Figure 17 is a contact print of the aircraft classification, Figure 15, at a slightly different scale than Figure 16. The location of these two detail figures is shown on Figure 8.

E. Evaluation of the Results

The output products presented in this section, Figures 10 through 17, have some things in common. Because of the color coding, they vividly present the information content that they possess. However, they also have some common deficiencies. One is that even with correction for the earth's rotation they do not possess extreme accuracy in scale. Part of this difficulty is inherent in the film recording apparatus and in the mechanics of film processing and printing. Part of the difficulty is that the Earth Resources Laboratory has not yet perfected a technique

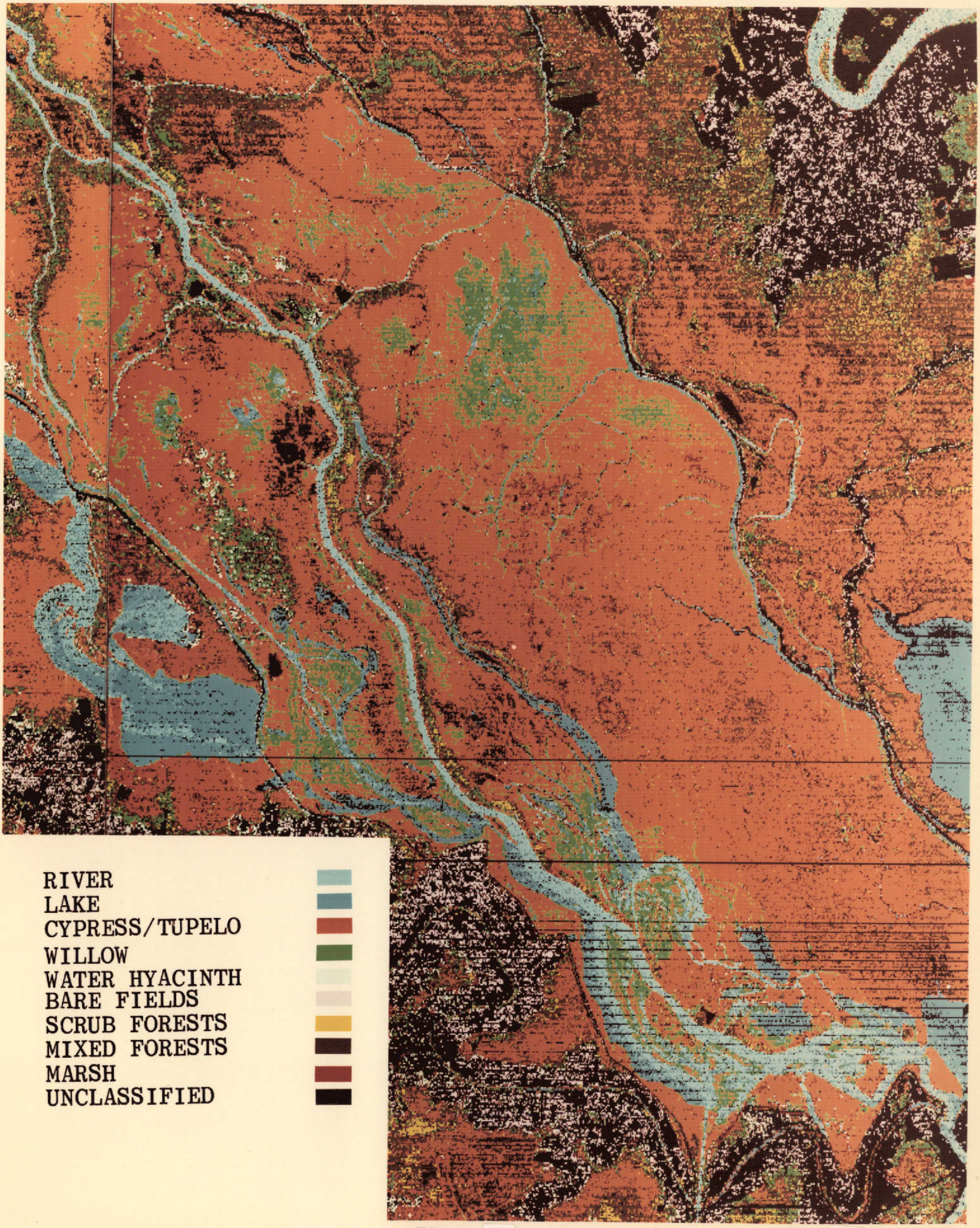


Figure 14

Computer derived classification map from ERTS-1 MSS data from frame no. 1196-16082 February 4, 1973.

Figure 15 Page 46

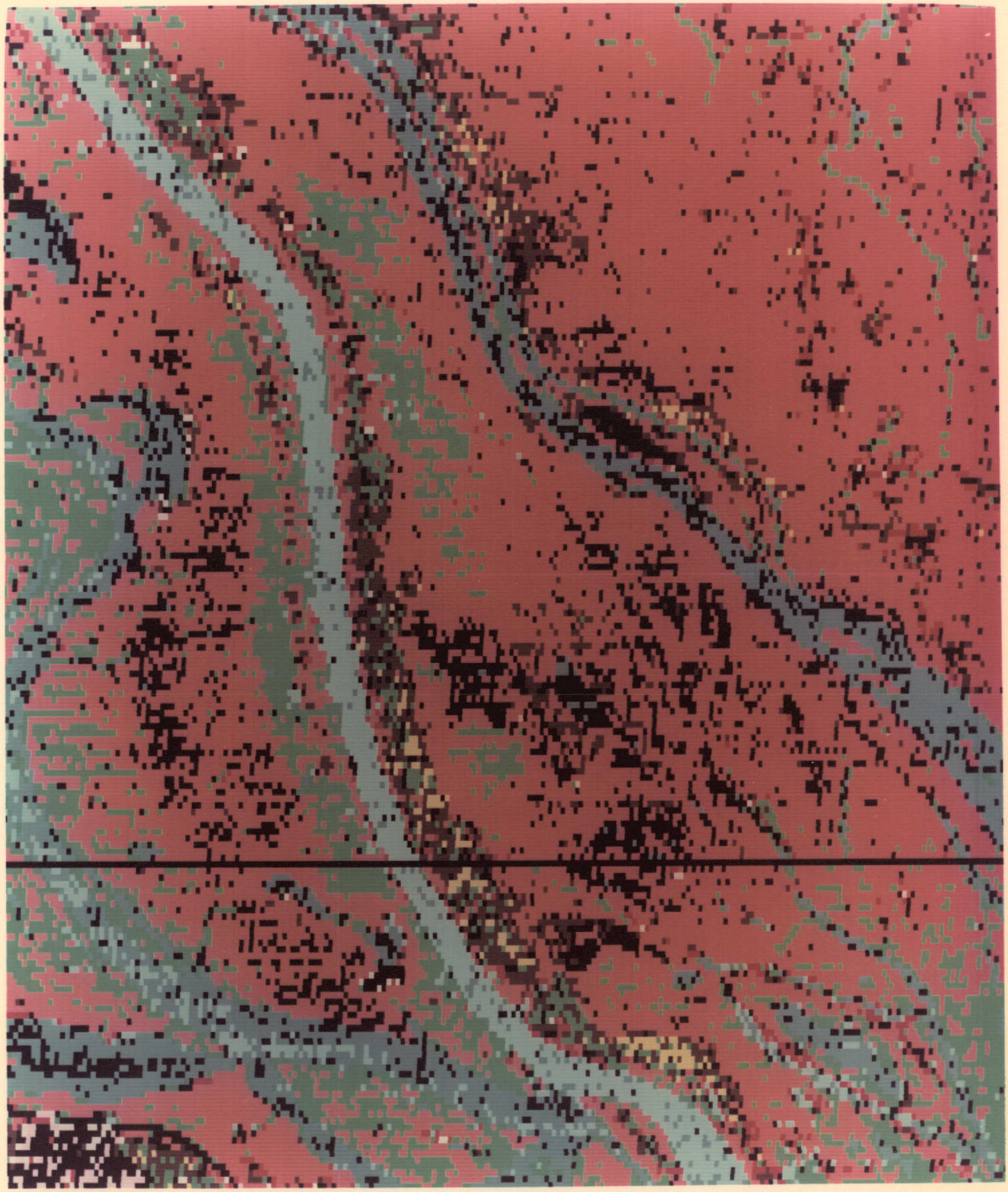


Figure 16
Large scale computer derived classification map from ERTS-1 MSS data from frame no. 1196-16082, February 4, 1973.

Figure 17
Computer derived classification map of aircraft multispectral scanner data taken on January 15, 1973.

for properly rectifying the data. For many purposes National Map Accuracy Standards are not required. Certainly the computer expanded simulated color IR maps, Figures 10 and 11, could be planimetered to give a good estimate of the area under cultivation, for example. Likewise the other products could be tallied by the computer to yield areas of each identifiable material.

A second technical problem is that the colors depicted are not always exactly the same. The color scheme is identical for Figures 14 through 17, although it is obvious the coloration of the final products is not the same. This is again due to two causes: one is a manual adjustment of the film recording mechanism and the other is differences due to film processing and printing.

More important than these technical problems is the matter of the accuracy of the information content. An unbiased check on the accuracy of the pattern recognition techniques has not been made. The principal reason was that almost all of the most uniform areas of forest species were used as training samples, leaving almost no good sites to use as test fields. Qualitative checks with a carefully prepared classification derived by photo interpretation and a comparison of the ERTS with the aircraft classification show good agreement in the general distribution of vegetation. A quantitative computation was made for the two classifications of the training sample sites used in each of them. The details of the scoreboard are presented in Tables B-I and B-II. The overall accuracy of the classifications was 77.5% correct for ERTS and 72.8% for the aircraft classification. When the categories of these classifications were grouped into the broader categories of water, forest, aquatics, bare fields, and marsh, the classification accuracy of the training samples rose to 91.3% for ERTS and 84.8% for the aircraft classification. These figures probably represent the upper limit of the classification accuracy for this complex area. The training samples are the most homogeneous areas of each class that can be found in the area. The four dimensional decision spaces used by the classify program were built from the statistics of these samples. Consequently, areas of poorer examples of these classes would not be expected to score as high a correctly classified percentage. Finally a semi-quantitative check of accuracy of the aircraft classification was made based on ground truth data published by Mix et al. (1972). Some 67 sites were compared with the unreduced original of Figure 15. Based on a subjective scoring system of one point for 100% correct classification, 3/4 point for a majority of the actual vegetations described, 1/2 point for about 50% correct identification, 1/4 point for just one of several of the listed species identified, and 0 for no correct answers; a score of 70.1% was achieved. The sources of the errors in both classifications have not been examined in detail, but undoubtedly some of the following are contributing factors: (1) a probabilistic classification scheme will inherently produce misclassifications (see discussion in Appendix B); (2) natural vegetation is highly mixed as to species, strict homogeneity is seldom found even in the training fields thus a training field which does not classify 100% pure may be correctly classified; and (3) the averaging of energy received from all points in the resolution element will sometimes produce a confusing signal as discussed in the preceeding section.

Figures 16 and 17 show the difference in detail that exists between the two sensor systems at their respective altitudes. Figure 16 is particularly jarring when compared to the image shown on Figure 11. When the smooth tones of the image are replaced by an artificial classification color for each material the individual elements show up vividly. The higher resolution of the aircraft system produces a very much more pleasing appearance at that scale as well as greater detail. Figures 14 and 15, however, illustrate some of the advantages of the ERTS system. The satellite system is a very stable platform traveling at uniform velocity and scans a much wider swath than the aircraft system. The aircraft MSS has provisions for gyro stabilization, but it was not operating during the flight. As a result Figure 15 has a somewhat shaky appearance. Also, the speed of rotation of the mirror of the MSS must be adjusted depending on altitude and speed over the ground. If the setting is not exactly correct for each flight line, the scanner will not have the same horizontal distance between scan lines. As a result two different flight lines of the same length will have a different number of scan lines. This will make it impossible to smoothly mosaic the filmed output from adjacent flight lines. This was obviously the case in the data set which made up Figure 15. The mismatch makes the calculation of areas a much more difficult process since each flight line must be handled separately.

ERTS imagery has been hailed as giving man a new and synoptic view of nature. With the aid of the human brain it undoubtedly appears to be the case. However, when the data is computer processed and the data is classified element by element the extreme complexity of nature is revealed. The detailed analysis of the Atchafalaya Basin presents the problem of synopsizing the analyzed data. Comparison of Figures 14 and 15 with hand drawn maps based on aerial photography show that the basin is far more complex in its makeup than the human mind can conveniently assimilate. The computer may rapidly tally the areas of each class in the region, but still the problem remains in depicting the gross features of the basin so that the principal natural forces operating may be discovered. The difficulty is not in acquiring detailed knowledge from poor resolution data, but rather in synthesizing understandable relationships (building ecological and hydrological models, for example) from a vast amount of data.

It is in this effort that the computerized data can be of most help. The various classes can be combined in a various number of ways at very little expense. Special maps required for each study can be created without laborious hand drawing. Likewise, the data is in a form which can rapidly be utilized by a computerized model of a physical process.

IV. RESULTS OF WORK ON SPECIFIC OBJECTIVES

A. Accretion Monitoring

The monitoring of accretion throughout the basin is a promising application of remote sensing to a practical problem. All of the sensors employed (aerial photography, aircraft and ERTS multispectral scanners) have been able to discriminate between sediment-laden river water and clear lake water. Areas where the river water flows into and mixes with clear water are areas where the accretion process is most active. These areas are easily determined by use of remote sensing.

Since late 1971 several areas of high accretion have been monitored by remote sensing data. At times of low water, the percentage of land in the delineated areas has been computed from different remote sensing data. This percentage is a function of water level, so measurements made at different water levels cannot be directly compared. Table II shows the results of these measurements in one of the selected areas.

Table III. Percentage of Land in Accretion Study Area

Date	River Stage(ft)*	% Land	Data Used
10/30/70	2.92	71	Color aerial photography from 60,000 ft.
10/29/71	2.14	76 72	Color IR aerial photography Classification of aircraft MSS data both from 17,600 ft.
10/1/72	2.64	79	Intensity analysis of ERTS Band 3 - Figure 12

*U. S. Army Corps of Engineers gage at Verdunville, LA (nearest gage).

Unfortunately the water levels in the fall of 1973 after the large spring flood never receded to the levels shown above and no calculations were made for that year. The actual calculations from the ERTS data was made from a computer printout alphabetically coded to match the classes shown on Figure 12. The 1970 data and the 1972 ERTS data with water levels only 8.5 cm. apart indicate that accretion is occurring in the area. The total area under surveillance was about 1400 hectares (3460 acres). The eight percent increase in the land area represents an accretion of 112 hectares (277 acres).

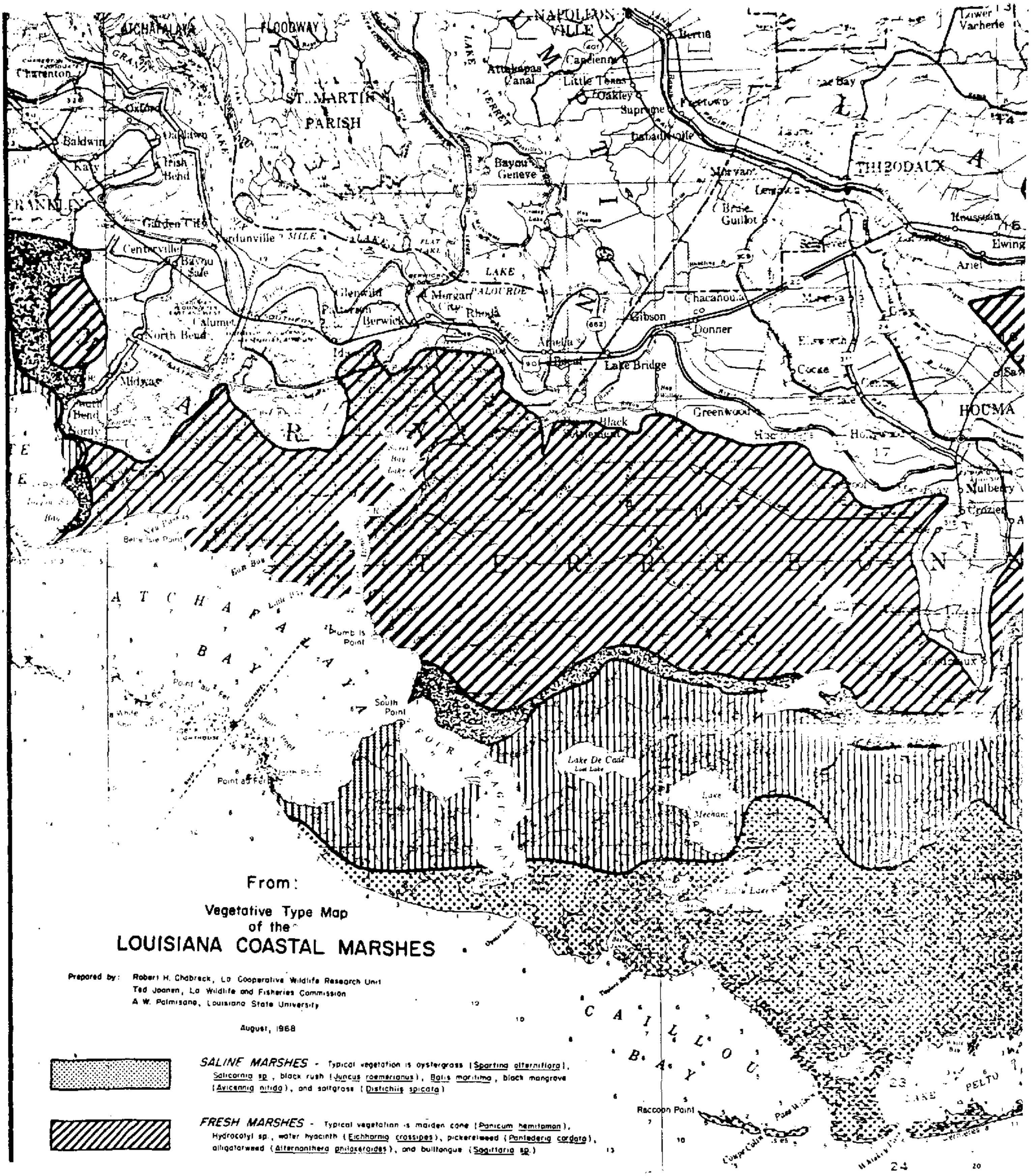
B. Marsh Salinity Definition by Use of Vegetative Analysis

The marsh areas of the study area are typical of much of the Louisiana coasts. They are important biologically and provide "nursery" areas to the young shrimp. Shrimping is a major Louisiana industry. The marshes also support many other important fauna. The marshes are essentially uninhabited and are a barrier to transportation of petroleum from the offshore wells. Many pipeline canals have been dredged through them. These canals alter the natural drainage system and provide a channel for salty Gulf of Mexico water to enter. This recent dredging work has sparked controversy and interest in the marshlands.

The first detailed study of the Louisiana marshes was made by Pendfound and Hathaway (1938). They classified the marsh areas as fresh, nearly fresh (intermediate), in which the average salinity of the soil water does not exceed 5^{o}/oo, brackish (5^{o}/oo to 20^{o}/oo) and saline (20^{o}/oo to 50^{o}/oo). Each of these salinity classes supported a distinctive group of plant species. The reasons for the soil water salinities are very complex and are not uniquely determined by the salinity of the surface water.

The recent interest in coastal wetlands ecology has provided impetus for more comprehensive studies. A comprehensive vegetation and soil study of the entire Louisiana coastal region was made in August 1968. This study resulted in a publication by Charbuck (1972) and a map of the salinity vegetative zones, a portion of which is shown in Figure 18. The map is based on 39 equally spaced north-south transects with vegetation estimates made at 0.25 mile intervals along each transect line from a hovering helicopter and taking soil, water, and ground measurements of vegetation every two miles. The result of this comprehensive study showed that the vegetative types were not as neatly classed into salinity groups as indicated by the earlier work. Some species showed a rather broad tolerance for salt. However, the map was basically a vegetation map based on the categories and associated plant communities as defined by Penfound and Hathaway.

In attempting to classify marsh areas by remote sensing, training samples were located in each of the zones of the map. Ground truth in the form of a helicopter reconnaissance with some landings was conducted. The location of these sites is shown on Figure 9 and site descriptions and photographs are shown in Appendix C. The first cloud-free ERTS data of the marsh area was not taken until November 1, 1973. A four band computer classification of this data is shown on Figure 19. Training samples were selected in the usual way. After the training sample statistics were reviewed, the statistics were grouped two ways -- one with the salinity classes presented in Figure 18, the other so that groups had maximum statistical separation (divergence). The additional classes,



From:

Vegetative Type Map of the LOUISIANA COASTAL MARSHES

Prepared by: Robert H. Chabreck, La. Cooperative Wildlife Research Unit
Ted Joanen, La. Wildlife and Fisheries Commission
A. W. Palmisano, Louisiana State University

August, 1968

SALINE MARSHES - Typical vegetation is oystergrass (Spartina alterniflora), Salicornia sp., black rush (Juncus roemerianus), Batis maritima, black mangrove (Avicennia nitida), and saltgrass (Distichlis spicata)

FRESH MARSHES - Typical vegetation is maiden cane (Panicum hemitomon), Hydrocotyl sp., water hyacinth (Eichhornia crassipes), pickerelweed (Pontederia cordata), alligatorweed (Alternanthera philoxeroides), and bulltongue (Sagittaria sp.)

BRACKISH MARSHES - Marshes of moderate salinity with typical vegetation consisting of wiregrass (Spartina patens), three-cornered grass (Scirpus olneyi), coco (Scirpus robustus), and widgeongrass (Ruppia maritima)

INTERMEDIATE MARSHES - Marshes of low salinity with typical vegetation consisting of wiregrass, deer pea (Vigna repens), bulltongue, wild millet (Echinochloa walteri), bullwhip (Scirpus californicus) and sawgrass (Cladium jamaicense)

NON-MARSH AREAS

Figure 18

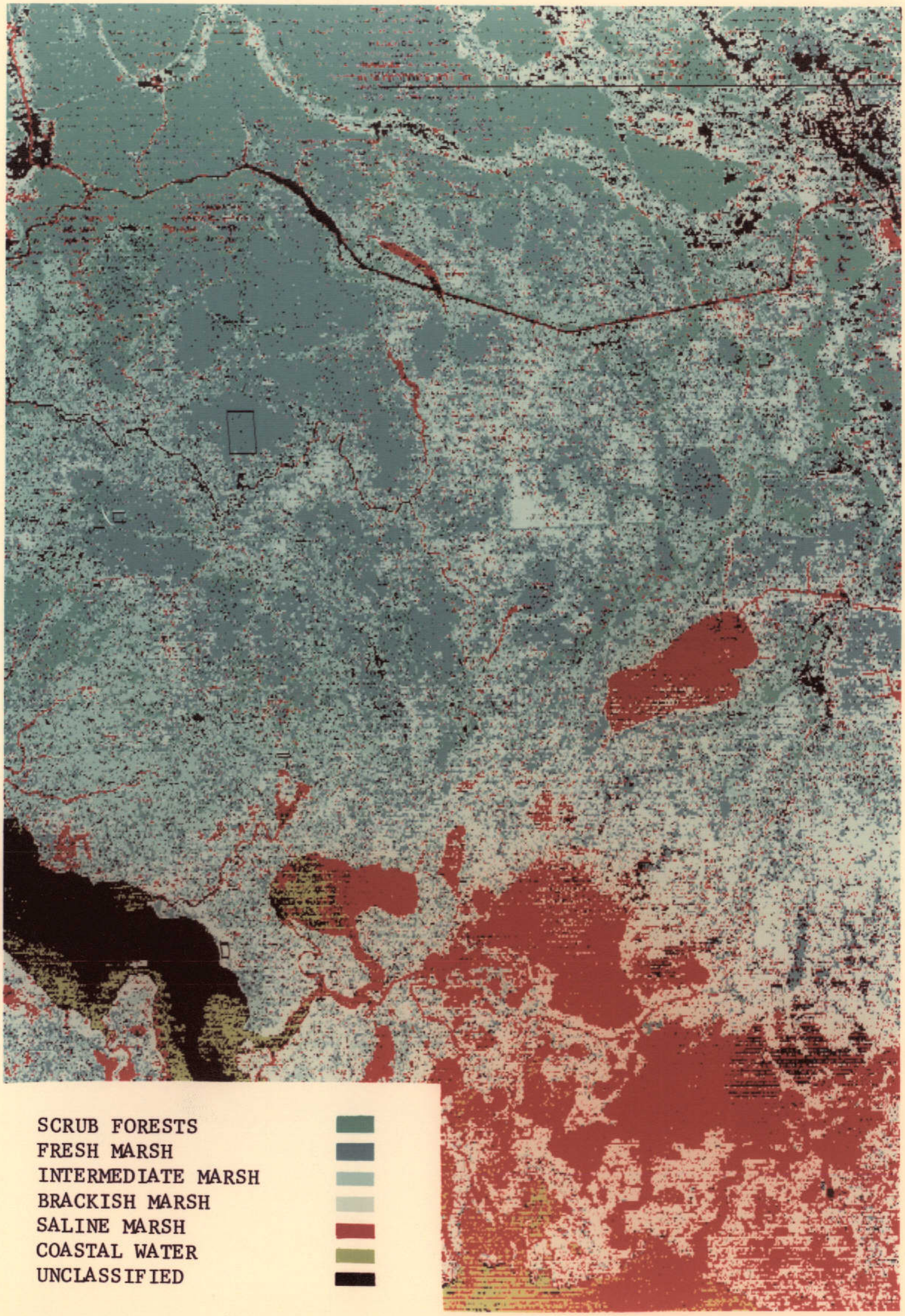


Figure 19

Computer derived Marsh classification map from ERTS-1 MSS data from frame no. 1466-16060, November 1, 1973.

scrub forest (green) and coastal water (yellow green), were added to the classes of the map. The general agreement with the map is fair except for the saline marsh which is nearly absent from the computerized classification. Water areas falsely appear as saline marsh (red). The classification accuracy of the map is low - only 57.6 percent of the training sample areas classified correctly. The classification accuracy of the training samples of the maximum divergence grouping was 64.6 percent.

This was the first attempt by the laboratory to classify an extensive marsh area from ERTS data. These results indicate that more work is needed. Several problems can be identified. One was the data set itself which was below standard quality for at least two bands. Another was that November 1 is probably too late in the year for good discrimination between species. And finally obtaining good vegetation training samples that do not include some water is very difficult especially near the coast; see Figure 5. One method of excluding water in the sample would be to use the thematic mapping program to identify all open water and then select the vegetative samples from the remainder of the data.

C. Determination of Water Characteristics

The one water characteristic that can be detected well by ERTS and aircraft data is turbidity. This can be done by use of imagery, Figure 10; single band analysis, Figure 12; or pattern recognition techniques, Figures 14 and 15. This capability can be used to trace flow patterns and inferences can be made from these patterns, such as areas of probable accretion, estimates of salinity, river water intrusion into marshes and coastal bayous, etc.

The fact that turbidity can be readily detected implies that it could be measured quantitatively. Also Cartmill et al. (1971) has reported a relationship between turbidity and total suspended solids. This work has not been pursued for several reasons. One is the expense of gathering surface samples at many locations concurrently with an ERTS pass especially in view of the uncertainty of obtaining cloud-free conditions. Another reason is the lack of demand for such data and its questionable utility considering that it would represent conditions at or near the surface only. However, it may have value as an input to an ecological energy model to assist in a calculation of radiation inputs at different depths.

There are many practical considerations which limit the use of ERTS data for direct hydrological applications. Salomonsom (1974) rates river monitoring low on a feasibility index and low for anticipated benefits. There appears to be no way to measure flow rates by remote sensing. This would be expected since flow rate is a function of three dimensions and time and ERTS data is two dimensional at one instant of time. The inability of ERTS data to detect dissolved chemicals or provide a measure of conductivity of water limits its use as a water quality measurement tool. Thus the most significant river measurements of flow, sediment transport, and chemical composition appear to be beyond the capability of the satellite. One feasible application would be providing data to construct a sedimentation model of Atchafalaya Bay. This area is now filling in and in the process is creating a strong environmental impact in the region. ERTS data delineating the extent of the sediment plume at high and low outflow rates could provide some necessary inputs for the construction of the model. The satellite could also monitor the emergence of the new land.

D. Identification of Aquatic Plants

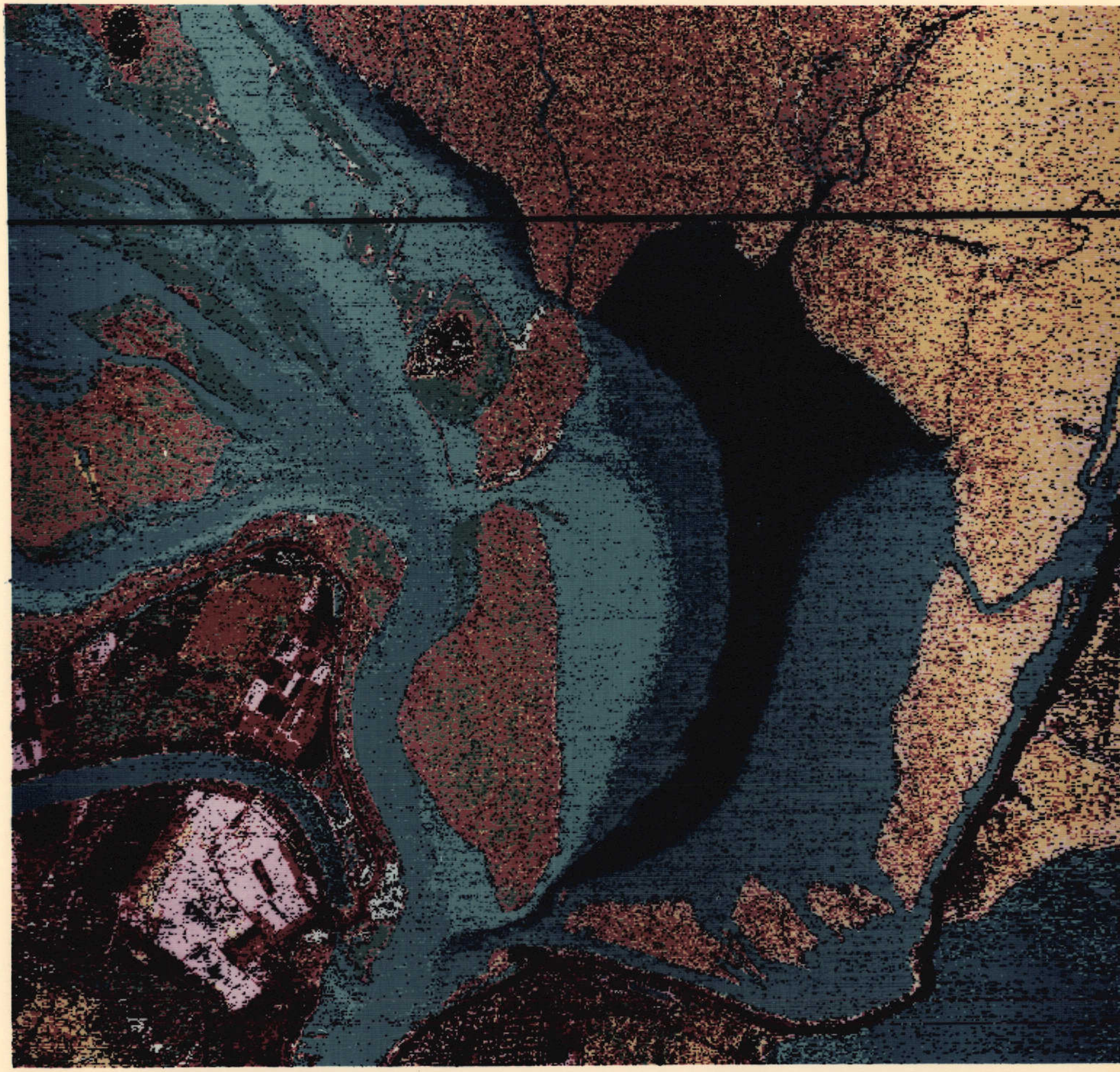
Figure 20 shows an aerial photograph taken of the lake area north of Morgan City, Louisiana, on January 15, 1973 from an altitude of 20,000 feet. The aquatic plants (water hyacinths) are the beige patches occurring in some of the smaller waterways and ponds. They are easily detected. Figure 21 is the classification of the aircraft MSS data taken coincident with the photograph shown in Figure 20. Many aquatics have not been detected by the MSS system which has poorer resolution than photography. Figure 22 shows the four band classification of ERTS data taken on February 4, 1973. Very few of the plants are identified. Since there is no valid reason for expecting disappearance of these plants in the three week interval, it is assumed that they cannot be identified very well by ERTS. There exists a strong relationship between detection of aquatic plants and the resolution of the sensor system. These plants collect in the smallest of waterways and in sheltered areas where they are blown by the wind. They seldom occur in patches the size of one ERTS resolution element. As a result the detection of these plants is best accomplished by the sensor system that possesses the highest resolution.

E. Forest Species Identification and Inventory

More effort was expended on this specific objective than all of the rest combined. Other studies have shown that bottomland hardwoods can be distinguished from conifers with a high degree of accuracy. Since there are no conifers within the study area, the identification of various hardwood

Figure 20

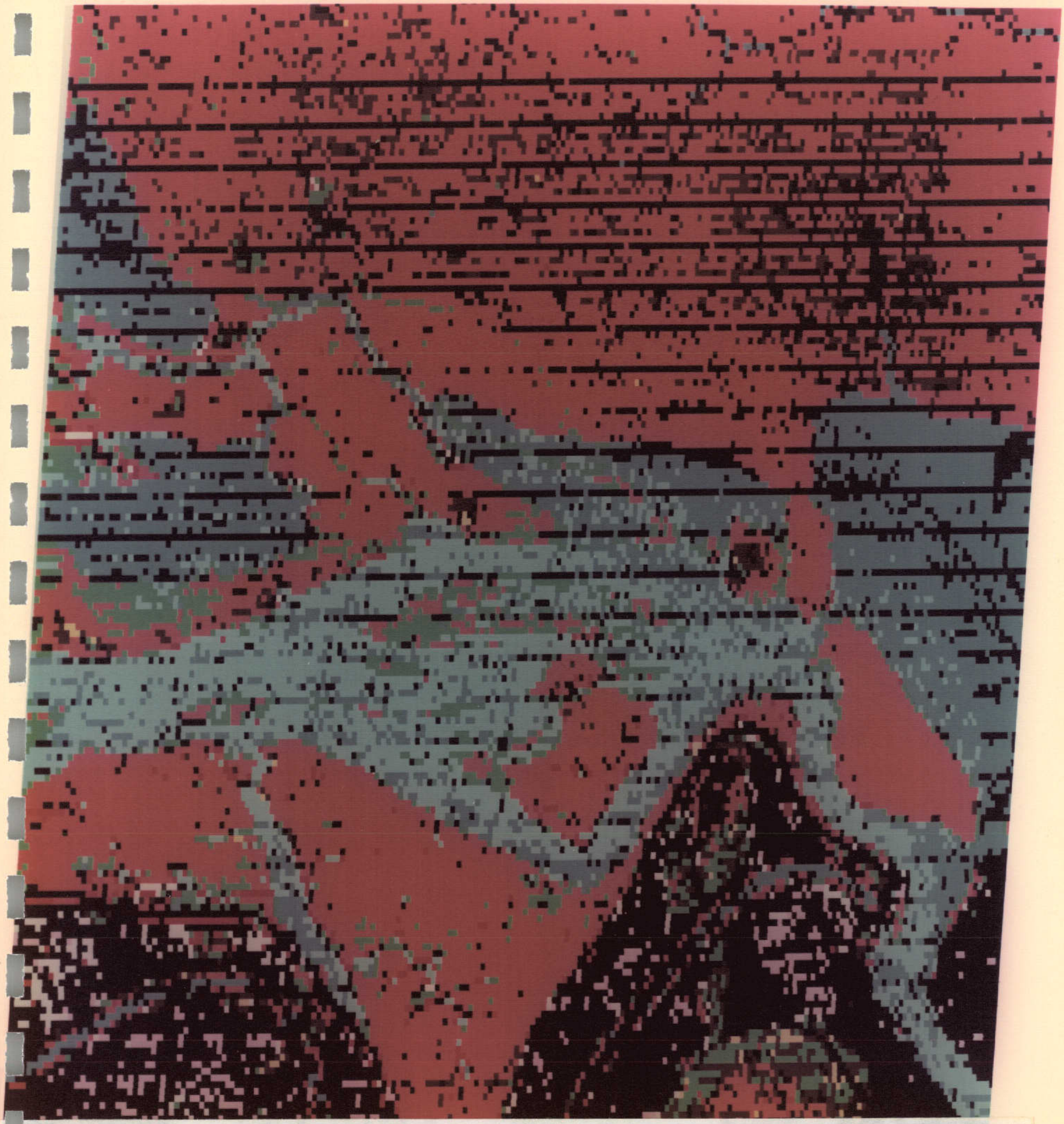
RC-8 Color IR photograph of the lake area north of Morgan City, Louisiana.



RIVER	MIXED FOREST
DEEP LAKE	WILLOW
SHALLOW LAKE	HYACINTH
CYPRESS	BARE FIELD
TUPELO	MARSH
	UNCLASSIFIED

Figure 21

Computer derived classification map of aircraft multispectral scanner data taken coincident with the preceding photograph.



LEGEND

RIVER	-	LIGHT BLUE	BARE FIELDS	-	PINK
LAKE	-	DARK BLUE	SCRUB FOREST	-	YELLOW
CYPRESS/TUPELO	-	RED-ORANGE	MIXED FOREST	-	BROWN
WILLOW	-	GREEN	MARSH	-	RED
WATER HYACINTH	-	WHITE	UNCLASSIFIED	-	BLACK

Figure 22
Computer derived classification map of ERTS multispectral scanner data showing the same area as the preceding figure.

species was the objective. The principal forest species are a cypress-water tupelo swamp forest, willows, a mixed bottomland forest and some scrubby, brush type vegetation near the marsh areas. The cypress-tupelo forest is second growth timber located in the old swamp areas of the basin. The willows up to 60 years old occupy recently accreted land; the mixed forest is located along the natural levees of the secondary channels. Thus forest species can define the location of higher well drained land, recently accreted land and swamp. The application of pattern recognition programs to the MSS data of the winter ERTS pass and aircraft underflight has been described in the preceding section. The results were moderately successful. One interesting problem that was never solved was the poor statistical separation between the multispectral signatures of cypress trees and tupelo trees. These trees are easily distinguishable to the eye, but repeatedly gave nearly the same signatures from the multispectral data.

The same problem was encountered with the aircraft scanner data. The aircraft classification also frequently confused these two species. This was most apparent in the overlap areas between two adjacent flight lines. Figure 23 shows a portion of the aircraft classification of the data from the flight line adjacent to the flight line shown on Figure 21. Notice that the vegetative cover of the island indicated by the arrow is classified as cypress in Figure 23 and as tupelo in Figure 21. The color coding is the same in both figures. The reason is that the MSS spectral signatures of the two species are nearly identical despite the fact that the photograph shown in Figure 20 shows a marked contrast. In Figure 21 the

Figure 23

Computer derived classification map of aircraft multispectral scanner data illustrating the effects of different illumination.

scanner was viewing the sunlit side of the trees and in Figure 23 it was viewing the shady side. This difference in illumination was sufficient to change the classification between the two flight lines. This problem has been discussed in detail in a report by Cartmill and Boudreau (1973). This difficulty has not been encountered in the small angle ERTS data.

Forest classifications using four band ERTS data were made during three different times of the year: October 1, February 4, and August 21. For the August 21 pass the classification was performed twice; once with the a priori probabilities proportioned according to the estimated percentage of each type of forest occurring in each ERTS tape and once with the probabilities set equal. Basically the same set of training fields were used for all four classifications. The results of the a priori classification are shown on Figure 24. The training field accuracy score cards for three of the four classifications are shown in Table III. As indicated in the table there was a significant improvement in the classification accuracy when the a priori probabilities are used. It is gratifying that the results were consistent with the theory. These results would indicate that a two stage classification procedure would lead to significant improvement in classification accuracies. This procedure would be that if the probabilities were unknown in an area, first classify the area with equal probabilities of occurrence, then use the results of this classification to establish a priori probabilities for each class. If the probability of occurrence is known a priori, this information should be used as it will significantly affect the results.

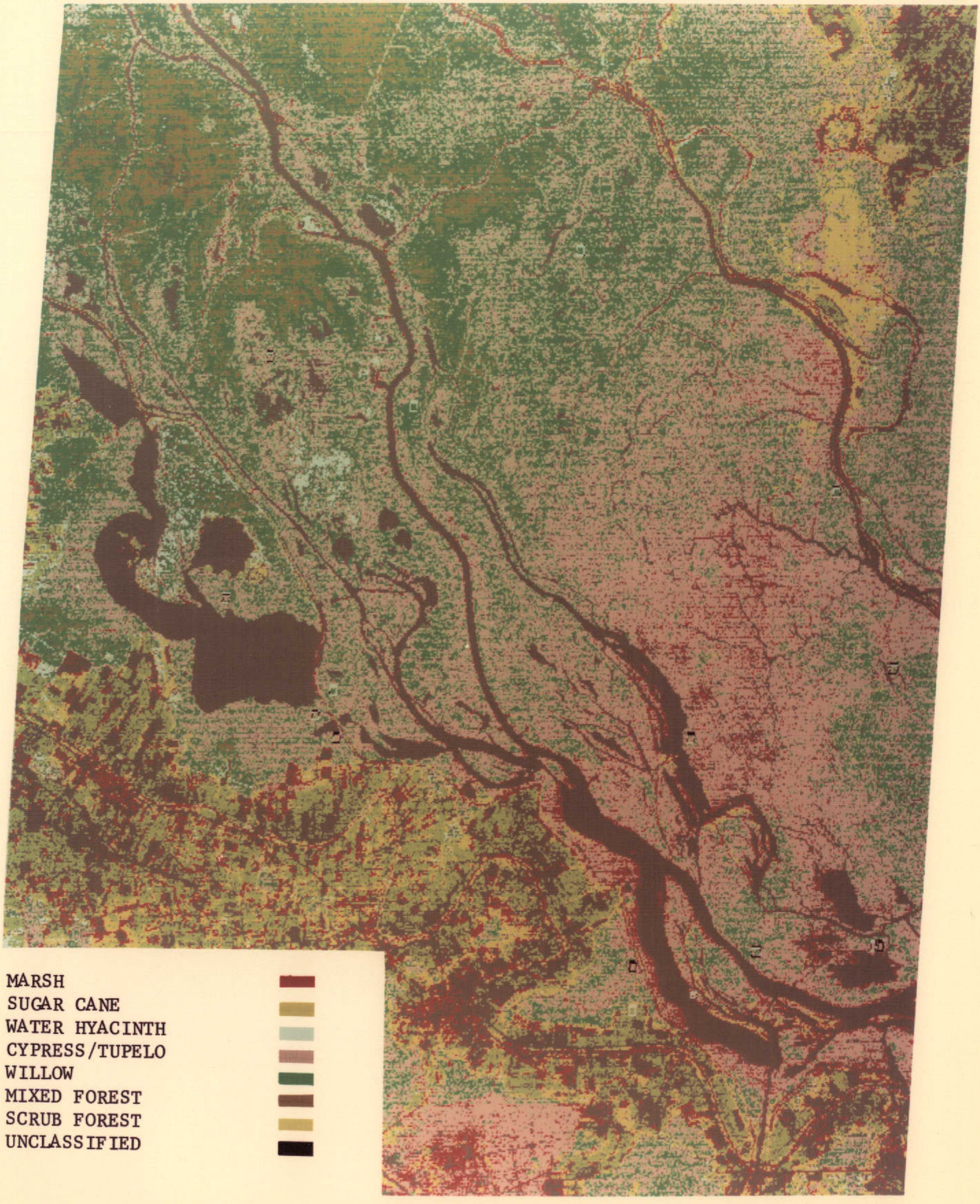


Figure 24
Computer derived forest species classification using unequal a priori probabilities from ERTS frame no. 1394-16071, August 21, 1973.

TABLE IV. CLASSIFICATION SCORECARD
OF ERTS TRAINING SAMPLES

Forest class	Percentage Correct Classification Data 2/4/73	8/21/73 equal probabilities	8/21/73 *a priori* probabilities
Cypress-Tupelo	94.3	71.3	79.2
Willow	74.4	75.4	76.9
Mixed forest	77.6	75.0	96.9
Scrub forest	100.	90.0	88.9
Weighted average	87.7	76.0	81.5

The weighted average in Table III would indicate that wintertime would be the best time of year to make forest classifications. However, this average was heavily weighted in favor of the scrub forest which was 100 percent correctly classified in February pass. Based on individual species identification accuracies and inspection of the complete classifications, there did not appear to be an obvious best time of year to perform the classifications. Some of the results and subjective analysis would tend to favor the late fall and winter as giving the greatest differentiation among forest groups. No data was available for the early spring when the new leaves were appearing. This time of year could present serious complications, as it did in the winter classification, since most training sites would contain water. Also the leafing of each species would be a function of location because the cold Mississippi River water inhibits the spring leafing. Consequently those trees adjacent to the main channels or in areas of overflow would be retarded in their development compared to trees of the same species located in protected areas.

V. ESTIMATED COSTS

No estimate of the total costs involved in conducting these studies can be made by the Earth Resources Laboratory at this time. Nor can comparative costs be made between the digital-computer analysis vs. conventional photo interpretation methods be made because very little effort was expended on photo interpretation and no manhour or cost data was compiled.

Table IV below shows the manhours, working days, and cost estimates in 1974 dollars of the individual processing steps to obtain the products described in Section III of this report. The costs are based on processing approximately one-half of an ERTS frame (two ERTS data tapes) and 50,000 scan lines of aircraft MSS data. Although the study area included only about 1/6 of a complete ERTS frame the irregular shape and location in regard to the data arrangement on the magnetic tapes required processing of about 1/2 of an ERTS frame. The costs also include photographic costs to produce one contact size nine-inch format positive transparency of the output product.

In the cost figures presented in Table IV many items which enter into the total costs of production are not included. This is because they are either unknown or the research and development costs are impossible to separate from normal production figures. Listed below are the costs which are <u>not</u> included.

1. Government costs of the satellite, airplane sensor systems, ground receiving stations, etc.
2. Amortization and maintenance costs of the Data Analysis System.

TABLE V. PRODUCTION COSTS OF AUTOMATIC DATA PROCESSING

	Aircraft MSS-50,000 Scan Lines			ERTS MSS-1/2 Frame		
ITEM	Man hours	Working days	$ [1]	Man hours	Working days	$
1. Raw data tapes and photo products (U. S. Dept. of Interior, Sioux Falls, S. D.).	-	-	225[2]	-	-	160
2. Verify, decommutate, reformat, film record raw data.	450	15	4050	45	7	405
3. Select training samples, generate edit tape.	84	7	756	84	7	756
4. Compute statistics, separability, and best channels.	210	12	1890	210	12	1890
5. Build tables, classify, compute classification accuracy.	300	20	2700	30	4	270
6. Screen, rectify, film record classified data.	125	12	1125	30	3	270
7. Miscellaneous analysis (thematic mapping, acreage tally, etc.).	40	5	360	40	5	360
8. Central computer processing at $350 per hr. CPU time required for items 4 and 5.	-	-	3500	-	-	300
9. Film and photo processing each product items 2 and 6.	Contract	2	80	Contract	2	25,small scale 80,large scale
TOTAL	1209	73	-	439	40	-

1. Dollar figures for items showing manhours are computed at a rate of $9.00 per hour.
2. Estimated. At present these tapes are not available from the Dept. of Interior.

3. Salary and administrative costs of the principal investigator.
4. Overhead costs of maintenance technicians, programmers, and other employees employed in the production of products.
5. Costs of rent, taxes or taxes foregone, maintenance of buildings, offices, etc.
6. Cost of ground truth.
7. Reports and data preparation (mosaicing, layout, etc.)

Table V shows the production costs of the various data products described in Section III.

These costs should not be extrapolated to areas of different size. Economies of scale are introduced when larger areas are being classified, particularly for ERTS data. For example, a whole ERTS frame (13,000 square miles) could be processed for very little more than is shown in Tables IV and V. Likewise, rapid advancement is being made in reducing the time and costs of computer processing multispectral scanner data. See Jones (1974). The costs shown are based on the procedures, equipment and programs available at the time and do not reflect the economies of the new processing techniques.

TABLE VI. PRODUCTION COSTS OF DATA PRODUCTS

ITEM	Example * Figure No.	Cost Items from Table IV	Total Cost - $
1. ERTS Simulated Color IR Map Scale 1:250,000	10	1,2,9	995
2. ERTS Simulated Color IR Map Scale 1:62,500	11	1,2,9	1050
3. ERTS Signal Strength Analysis of One Band, Scale 1:250,000	13	1,2,7,9	1335
4. ERTS Thematic Map, Scale 1:250,000	12	1,2,7,9	1335
5. ERTS classify, Scale 1:250,000	14	All	4436
6. ERTS classify, Scale 1:62,500	16	All	4491
7. Aircraft classify, Scale 1:54,000	17	All	14686

*Costs are for products which cover the whole basin study area. The figures show only a portion of this area.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The conclusions to be reached concerning the usefulness of various sensors and their associated platforms to characterize wetlands are as follows:

1. Satellite MSS data is superior to aircraft scanner data in the coverage of extensive areas (2500 square kilometers or greater). The surface viewed is exposed to more uniform illumination; the data is taken in a more uniform spacial pattern. As a result the ERTS four band classification maps are more accurate both in degree of proper classification and in geometric accuracy.

2. Aircraft MSS and photographic data has two advantages over a satellite observation system. One is higher resolution which may be essential for some purposes. The other is flexibility in scheduling the time of observation which allows effective use of clear weather conditions.

The accuracy of classification is about 90 percent (measured in the training sample areas) for generally broad, easily distinguishable classes -- water, forest, bare soil, etc., and approximately 75 percent for finer classifications for both systems. This study shows that ERTS data gives somewhat better accuracy. This is probably due to the reduction of accuracy of the aircraft data at the edges of its wide scan angle. The costs of automated data processing for equivalent areas of ERTS and aircraft scanner data is approximately in the ratio of 1 to 3. This is primarily due to the much larger volume of data generated by the high resolution aircraft system. Experience to date and initial studies indicate that the cost and time required to produce automated classifications can be greatly reduced.

Conclusions concerning the achievement of the specific objectives are as follows:

1. Accretion (and presumably erosion) can be detected and measured using ERTS data in the coastal wetlands when the scale of the change is significant relative to the size of ERTS resolution.

2. Marsh salinity definition by use of vegetative analysis appears feasible, but will require more technique development and experience to produce a sufficiently accurate classification of marsh vegetation.

3. Some limited water characteristics, principally upper layer turbidity, can be inferred from analysis of ERTS data. From this, areas of likely sediment deposition and the limits of mixing of outflow waters from large streams with the ocean can be deduced.

4. Identification of aquatic plants can be achieved with ERTS only when the aggregation of the plants is extensive. The satellite is generally not useful in monitoring the spread or contraction of the area covered by these plants. This monitoring is best accomplished by use of aerial photography.

5. Forest species identification among various hardwood species has been attained with approximately 70 - 90 percent accuracy during three different seasons. Spectral signature similarities between certain species prevent their separate classification. The use of _a priori_ information about the frequency of occurrence of different

species in pattern recognition programs can significantly increase the accuracy of the classification.

B. Recommendations

1. Great consideration should be given to cloud cover statistics and satellite overflight frequency before integrating satellite data into an environmental monitoring system. This is especially true of such monitoring systems that require precise time of overflight. Examples are determining the effects of a vegetation eradication program, calculation of the percent of harvest, the limits of flood inundation, etc.

2. Simple processing procedures of ERTS MSS digital data should be used where possible to satisfy specific information needs because of the savings in cost. This would include single band intensity analysis or two band decision rules using a standard computer printout.

3. Vegetational analysis should be done by use of all available bands with pattern recognition techniques. _A priori_ probabilities of occurrence should be used if known or be determined from a preliminary analysis using equal probabilities. This will result in an increased accuracy of classification.

Appendix A

EARTH RESOURCES LABORATORY DATA

Atchafalaya River Basin

	Data Item	Date Acquired
1.	Color film transparencies, 60,000 ft altitude	10/30/70
2.	Color infrared film transparencies, 60,000 ft altitude	10/30/70
3.	Oblique color photography, 1,000 ft altitude	10/18/71
4.	Oblique color photography, 1,000 ft altitude	10/27/71
5.	Color infrared film transparencies, 17,600 ft altitude	10/27/71
6.	I^2S multiband black and white film transparencies 17,600 ft altitude	10/27/71
7.	Temperature, dew point and liquid water content 17,600 ft altitude	10/27/71
8.	Color infrared film transparencies, 17,600 ft altitude	10/29/71
9.	I^2S multiband black and white film transparencies, 17,600 ft altitude	10/29/71
10.	Temperature, dew point, and liquid water content at 17,600 ft altitude	10/29/71
11.	Field notes and ground photography of ground teams	10/26 to 10/29/71
12.	Water samples, soil samples, and analysis	10/26 to 10/29/71
13.	Water samples and analysis	11/4 to 11/5/71
14.	Field notes of helicopter reconnaissance	3/1 to 3/3/72
15.	Color and color infrared film transparencies, 60,000 ft altitude	3/16/72
16.	Water samples and analysis	3/28/72
17.	Field notes and ground photography of ground teams	3/27 to 4/6/72
18.	Water samples and analysis	4/6/72
19.	RS-18 thermal scanner film and magnetic tapes 1500 ft altitude	4/6/72

Data Item		Date Acquired
20.	PRT-5 magnetic tapes, 1500 ft altitude	4/6/72
21.	Color infrared photography, 4000 ft and 6000 ft altitude	4/6/72
22.	RS-18 thermal scanner film and magnetic tapes, 6000 ft altitude	4/13/72
23.	PRT-5 magnetic tapes, 6000 ft altitude	4/13/72
24.	RS-18 thermal scanner film and magnetic tapes 2300 ft altitude	4/13/72
*25.	ERTS-1 multiband black and white imagery and color composite, 491 nautical miles altitude	10/1/72
*26.	ERTS-1 multiband precision imagery B&W and color 491 nautical altitude	10/1/72
*27.	ERTS-1 multispectral scanner magnetic tapes, 491 nautical miles altitude	10/1/72
*28.	Field notes of helicopter reconnaissance and plant specimens	12/12 to 12/16/72
*29.	Field notes of helicopter reconnaissance and plant specimens	1/8 to 1/10/73
*30.	Color infrared film transparencies, 20,000 ft altitude	1/15/73
*31.	Multispectral scanner data magnetic tapes, 20,000 ft altitude	1/15/73
*32.	Temperature, dew point, and liquid water content at 20,000 ft altitude	1/15/73
*33.	Reconofax IV thermal scanner film and magnetic tapes 20,000 ft altitude	1/15/73
*34.	Field notes, ground photography, water samples and analysis	1/16 to 1/17/73
*35.	ERTS-1 multiband black and white imagery and color composite, 491 nautical miles altitude	2/4/73
*36.	ERTS-1 multispectral scanner magnetic tapes, 491 nautical miles altitude	2/4/73
*37.	ERTS-1 multiband black and white imagery and color composite, 491 nautical miles altitude	5/5/73
*38.	ERTS-1 multispectral scanner magnetic tapes, 491 nautical miles altitude	5/5/73

Data Item		Date Acquired
*39.	ERTS-1 multiband black and white imagery and color composite, 491 nautical miles altitude	8/21/73
*40.	ERTS-1 multispectral scanner magnetic tapes, 491 nautical miles altitude	8/21/73
41.	Color infrared film transparencies, 20,000 ft altitude	9/19/73
42.	Multispectral scanner data magnetic tapes, 20,000 ft altitude	9/19/73
43.	Temperature, dew point, and liquid water content, 20,000 ft altitude	9/19/73
44.	Reconofax IV thermal scanner film and magnetic tapes, 20,000 ft altitude	9/19/73
45.	Skylab multiband S190A photography including color and color infrared, 234 nautical miles altitude	9/21/73
46.	Skylab S190B earth terrain camera color infrared photography, 234 nautical miles altitude	9/21/73
47.	Skylab S192 multispectral scanner magnetic tapes, 234 nautical miles altitude	9/21/73
48.	Oblique color photography 1,000 ft altitude	10/2/73
*49.	ERTS-1 multiband (bands 2 & 4) black and white imagery, 491 nautical miles altitude	11/1/73
*50.	ERTS-1 multispectral scanner magnetic tapes, 491 nautical miles altitude	11/1/73
51.	Color infrared transparencies, 20,000 ft altitude	12/3/73
52.	Multispectral scanner magnetic tapes, 20,000 ft altitude	12/3/73
53.	Temperature, dew point, and liquid water content at 20,000 ft altitude	12/3/73
54.	Reconofax IV thermal scanner film and magnetic tapes, 20,000 ft altitude	12/3/73
*55.	Vertical color photography of training sample sites, 800 ft altitude	5/13 to 5/16/74

*Data items used directly in this study.

EARTH RESOURCES LABORATORY REPORTS

Atchafalaya River Basin

Report No.	Title	Date
008	Atchafalaya River Basin Study, Part I Surface Measurements	October, 1971
009	Atchafalaya Basic Mosaic with Surface Classification Overlay for October 1970 Data	December, 1971
011	Atchafalaya River Basin Study, Part 2, Interim Report	May, 1972
013	Atchafalaya River , Mosaic October 29, 1971	May, 1972
030	Atchafalaya River Basin Study, Standard Data Package A, Flight of April 13, 1972	October, 1972
049	Atchafalaya River Basin Study, Part 3, Remote Sensing Thermal Water Study	May, 1973
050	Study of Atmospheric Effects and Illumination in Multispectral Data (A Case Study of the Atchafalaya River Basin - Flight of October 29, 1971)	May, 1973
--	Evaluation of Satellite Remote Sensing and Automatic Data Techniques for Characterization of Wetlands and Coastal Marshes -- Proceedings of the Third ERTS Symposium, Washington, D. C. December 1973. Goddard Space Flight Center, Greenbelt, Maryland	December, 1973

Appendix B

PATTERN RECOGNITION THEORY, DATA PROCESSING PROCEDURES, AND ANALYSIS OF DATA SETS

The largest percentage of the data processing effort in this study was devoted to supervised pattern recognition techniques. This appendix presents the basic theory of these techniques, the specific procedures used to implement them, and an analysis of the characteristics of the data sets which were processed.

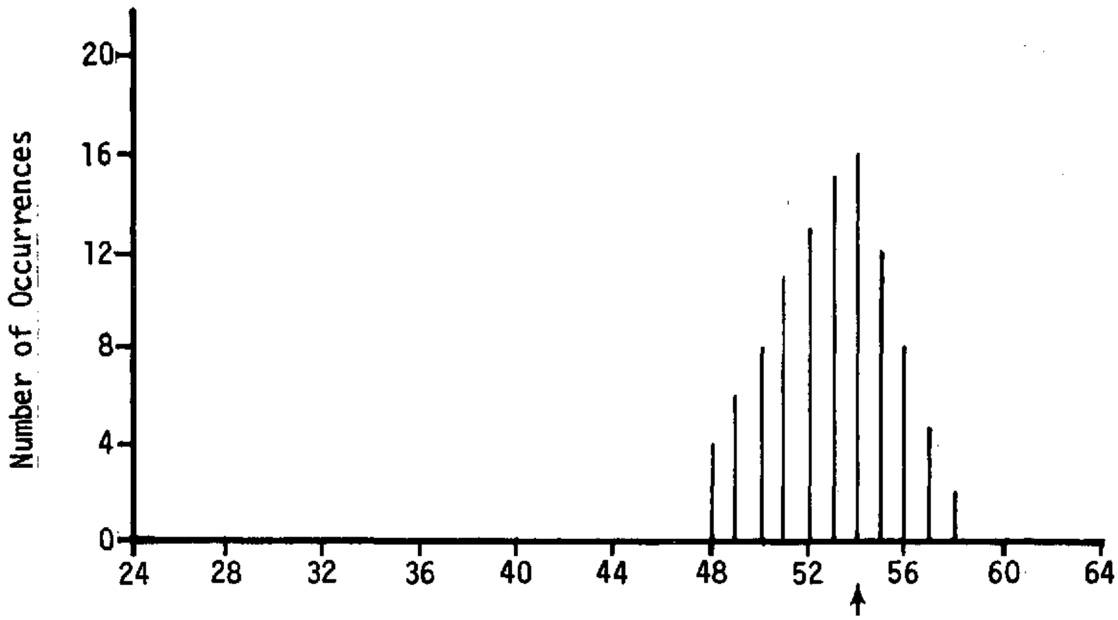
A. Pattern Recognition Theory

A very clear explanation of the elements of pattern recognition is given by Duda (1970). What follows is an exposition of pattern recognition theory as it applies to ERTS multispectral scanner data. The patterns which are to be recognized are the radiometric energies detected and recorded by the multispectral scanner. The theory is based on the presumption that different surface materials will give different measured values of reflected energy when illuminated under the same conditions. This we know to be true because surfaces have different colors created by differences in the reflection of the incident light. There are also differences in the reflection of incident near infrared energy. The ERTS scanner measures reflected energy in four band widths (.5 - .6 micrometers (green), .6 - .7 micrometers (red), .7 - .8 micrometers (near IR), and .8 - 1.1 micrometers (near IR)). The pattern of the signal strengths measured from one material can be expected to be different from the pattern measured from another surface.

The term supervised pattern recognition means that the classes of materials (and hence the patterns) to be recognized are preselected. The patterns of the materials are established by noting the measurements of homogeneous samples taken from the data set. These sample measurements are the basis for the spectral patterns to which the rest of the data are matched.

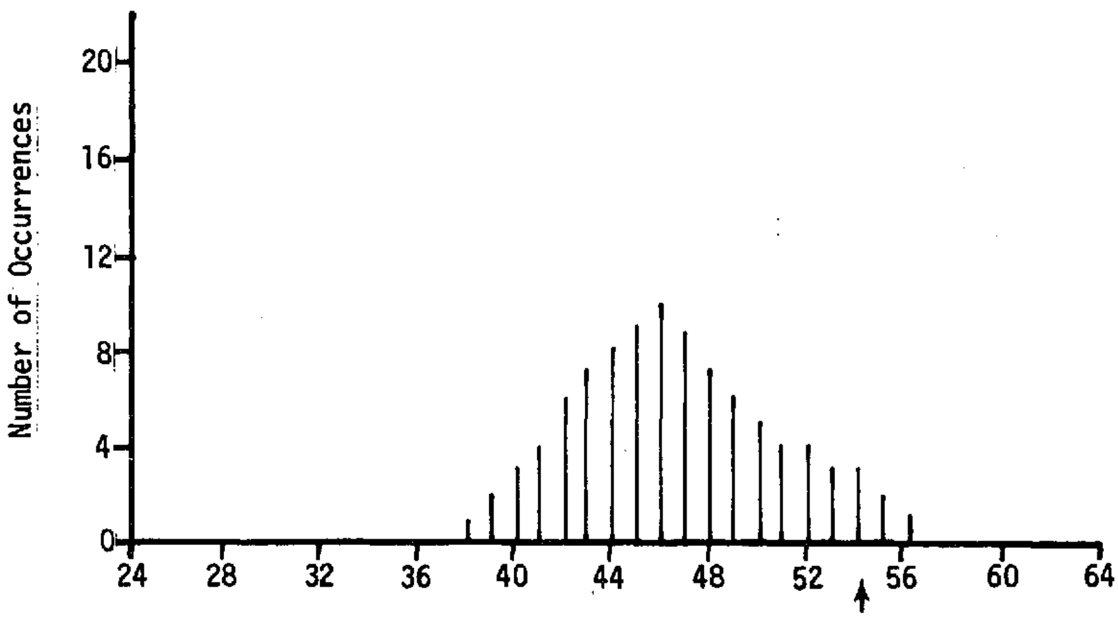
For various reasons these measurements from the same materials vary. Several of the more prominent reasons for this variation are as follows: (a) limits of accuracy of and noise within the measuring instrument, (b) slight variations in the reflectance properties of nominally the same material; water may vary in turbidity or vegetation may be different depending on soil nutrients, rainfall history, variety, maturity, density of ground cover, etc., and (c) variations in illumination or the attenuation of the reflected energy from different locations. Since the measurements are variable, a statistical problem is created. A large part of pattern recognition theory is devoted to the solution of this problem.

If only one band of the scanner data is used as the standard of patterns of materials to which the rest of the data is to be matched then for each material, the samples selected will yield a probability function, PA(x), which is the probability that the variable A (measurements from material A) takes the value x. Figure B-1 below shows the frequency distribution of 100 measurements taken from materials A and B. The probability function is obtained by dividing the frequency of each x value by the total number of samples. For example, if there are 100 sample measurements in the sample of material A and 16 of these measurements



X - Scanner Counts One Band

Material A



X - Scanner Counts One Band

Material B

Figure B-1 Frequency Distribution of Two Materials Measured by One Band were the value 54, then the probability of obtaining a measurement of 54 from material A is .16. The notation used to express this condition is P(x/A), which is read as the probability of x given A. In a similar fashion if there were 100 samples from material B and 3 of these samples were the value 54, the P(54/B) = .03. Thus from the sample data we can estimate the probability functions P(x/A) and P(x/B).

Now the problem is to classify the remaining data as either A or B by examining the measurements x. Assuming that materials A and B occur with equal abundance the probability functions define an obvious decision rule to classify the remaining data. That is for any x measurement designate the material either A or B depending on whether for that x, P(x/A) or P(x/B) is larger. This obvious rule is based on the simple logic of which classification is most likely to be correct.

Notice that it is inherent in this logic that misclassifications are evitable. In the example above all measurements of x equaling 54 will be classified as material A, even though material B occasionally gives this same measurement. Some of the elements B will be misclassified as material A.

There are other considerations which may change the decision rule listed above. If it is known beforehand, a priori, that material B occurs much more frequently than A, the decision rule should be altered to reflect this fact. For example, if it is known from planting reports that in the area from which the data has been gathered that material B, say corn, covers 9 times more area than material A, say soybeans, then the measurement of x of 54 would most likely be B rather than A. This decision rule can be formalized as follows:

$$\text{Decide A if } P(x/A)P(A) > P(x/B)P(B)\text{; otherwise decide B ,} \tag{B-1}$$

where P(A) and P(B) are the a priori probabilities of A and B respectively. This is the gut decision rule of pattern recognition theory. A similar modification can be added when the value of identification of classes differs (a loss or penalty attached to misrecognizing them). This can readily be accomplished by multiplying each side of the inequality (B-1) by an appropriate loss function.

The decision rule B-1 follows naturally from the logic presented. However, it is backwards in its description of the problem. The problem is, given an x measurement, decide which class, A or B, the element measured most likely belongs. In short given x we want a rule to tell us whether (P(A/x), the probability of A, is greater or smaller than P(B/x). It can be shown that

$$P(A/x) = \frac{P(x/A)\ P(A)}{P(x/A)\ P(A) + P(x/B)\ P(B)} \quad \text{and}$$

$$P(B/x) = \frac{P(x/B)\ P(A)}{P(x/A)\ P(A) + P(x/B)\ P(B)}$$

Thus the inequality $P(A/x) > P(B/x)$ is equivalent to B-1 because the denominators are identical and can be multiplied out.

All that is needed to apply the decision rule to a data set is to determine the conditional functions, P(x/A), P(x/B), P(x/C) ... P(x/P) (where P is the last class for each class of materials to be classified) and the associated a priori probabilities and loss functions if desired. Then for each data element measurement, x, calculate the product P(x/N) P(N), N = A, P. Classify the element as the class which yields the largest value of the calculations. The conditonal probability functions are derived from

C-2

the samples of each class taken at the beginning of the data processing. The *a priori* probabilities must be based on estimated percentages of each class in the area or in the absence of any knowledge, be set to the same value for each class.

Because each band of the scanner data is recorded in whole numbers, the probability functions are necessarily discrete functions as shown in Figure B-1. These functions are awkward to work with because there is no concise mathematical formula to define them. Generally they are approximated by the familiar Gaussian distribution which is a continuous distribution.

The power of the data to correctly classify different materials is enhanced if more than one band is used. If the probability distribution functions of materials A and B were plotted for another band in a fashion similar to that shown in Figure B-1, there again may be some overlapping but now two checks are available. For example, in the second band if the probability of obtaining a measurement of 46 were .10 for material A and .05 for material B then the probability of correct classification of the two materials is as shown below (assuming equal occurrence of A and B and the measurements in band 1 are independent of those in band 2):

	Probability A	Probability B
Band 1 alone reading of 54	.84	.16
Band 2 alone reading of 46	.67	.33
Band 1 and 2 together (54, 46)	.9143	.0857

Thus using decision rule B-1 some 16% of the elements producing a reading of 54 on band 1 are material B misclassified as A when band 1 is used above; whereas this percentage decreases to slightly more than 8 when band 1 and 2 are used in conjunction. The use of all four bands will further reduce the error of misclassification.

Materials that give very different responses in even one channel can be very easily separated from others. Figure B-2 shows a two dimensional diagram of the areas occupied on a plot of three different materials on a two band plot; misclassifications occur in the overlap areas between regions A and B, but C is unambiguously defined by band 1 alone. The distance between the centers of the regions along with some estimate of their extent provides a good estimate of how well they can be correctly identified by pattern recognition techniques. A calculation which provides an estimate of separability is called the divergence and is calculated for the n dimensional case by

$$J_{ij} = \tfrac{1}{2}\, tr\, (K_i - K_j)\, (K_j^{-1} - K_i^{-1}) + \tfrac{1}{2}\, tr\, (K_i^{-1} + K_j^{-1})\, (u_i - u_j)\, (u_i - u_j)^T \quad \text{(B-2)}$$

where:

tr = trace

T = transpose

u_i = kx1 mean vector of class i

K_i = kxk covariance matrix of class i

K_i^{-1} = inverse of the covariance matrix of class i

The first term (generally small) calculates the effect of the correlation of the measurements of each class; the second term accounts for the distance between the centers of the regions, the tightness of the clusters about the mean and the correlation.

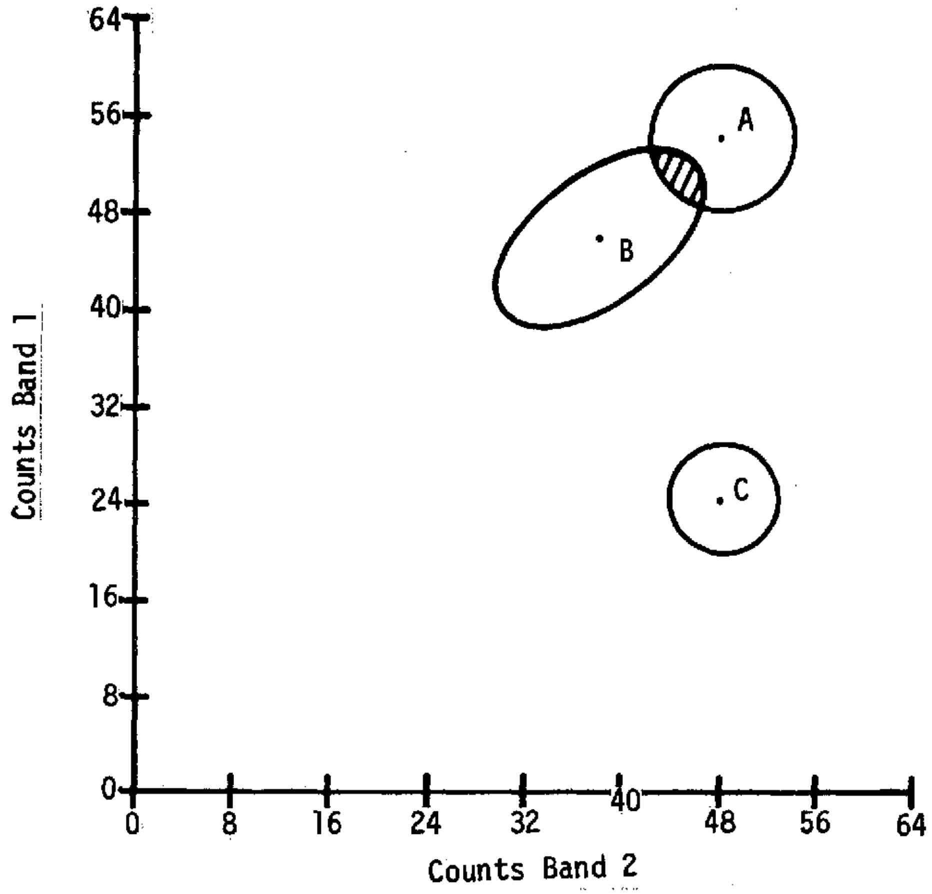


Figure B-2 Two dimensional Probability Plot of Three Materials

In the four dimensional case the decision rule B-1 can be thought of as volumes occupying the probability space. Each class volume identifies the space in which that class has the maximum likelihood of containing those particular measurements in the 4 bands. The computation of which class to place any particular data element with measurements x_1, x_2, x_3, and x_4 in the 4 bands can be done by either of two methods. One is to calculate the probability that the element is in each class and then select the class with the highest probability. The other is to predetermine the four dimensional volumes that mark the regions of highest probability of each class and store these boundaries in a computer table. The four measurements x_1, x_2, x_3, and x_4 are then compared to the table to determine in which volume they are located. In both methods limits can be set to exclude data points whose measurements indicate that their probability of being in any of the preselected classes is so low that they most likely do not fall in any class. The table look-up method requires that these limits be set. Both of these computational methods can be shown to yield identical results (Jones, 1974). The computer table look-up method is much faster and was used in this study. This program was limited to the use of four bands and twelve classes.

B. Data Processing Procedures

After an initial screening and a check for data consistency, the data processing consists of selecting the best homogeneous samples of the classes desired to be classified. This is done by locating the samples on the simulated color IR images made from the CCT's as described in Section III. The sample areas which were selected from ground truth studies are marked on mylar overlays of the imagery. The general area is placed on the television screen of the DAS and the sample area is marked with an electronic cursor. The coordinates are recorded and the data, readings in all four bands and calibration readings, for the sample areas are transcribed on a separate magnetic tape. The program STAT is then executed on these data. This program computes the mean and standard deviation of each sample for each band and plots histograms similar to Figure B-1 of the frequency distribution in each band. A covariance matrix is also computed.

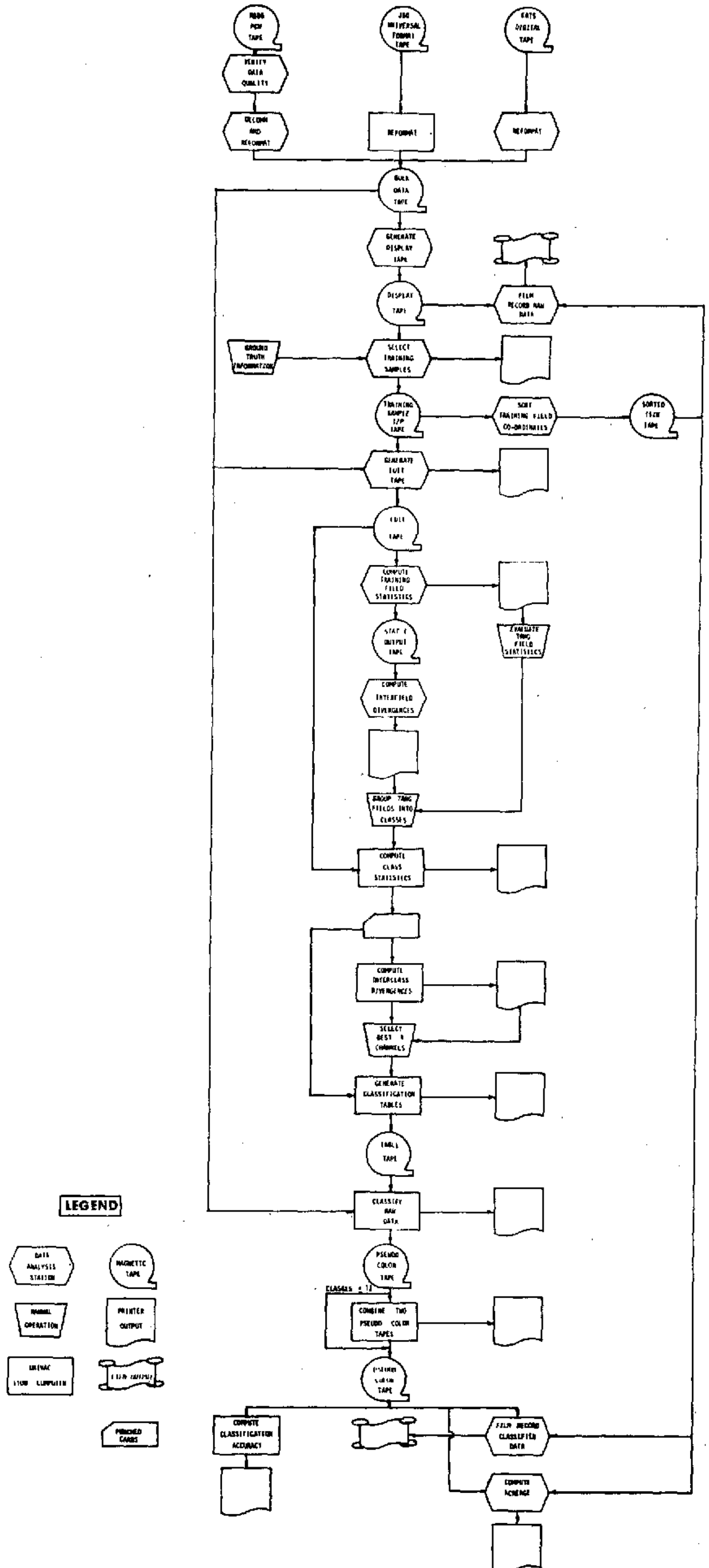
The next step in processing is to verify that the sample data is statistically adequate for describing the signature of a material. This is done by examining the histograms of the frequency distributions. Widely scattered or bimodal plots in any band are indications that the sample was not properly located or that data from that sample were nonhomogeneous or noisy.

Usually several samples are taken of each class. Often there is a wide variation of the statistics within a class. In order to identify subclasses within a class the program CHOICE is run on the sample data. This program computes the divergence and lists its value for each pair of samples. By examining these data those samples which group together (have small divergences) can be separated from other samples or subgroups of samples. Thus several subgroups of data are created. The data for each subgroup are combined and STAT and CHOICE are rerun. The divergence for each pair of the subgroups is computed. This serves as an aid in interpretation of the final classification. The expectation is high that those subgroups with the smallest divergence between them will have the most error of classification.

Finally the four dimensional decision tables are prepared and the whole data set is processed through CLASSIFY. This program operates on the whole data set and determines for each element in which four dimensional decision volume the element is located and assigns the element a subclass number. Since only 12 classes can be accommodated by this program, it must be run more than once if there are more than 12 subgroups. The two or more runs are then superimposed to give one classification output tape. (Recent improvements in this program permit up to 100 classes to be classified in one pass). Finally the subclasses are recombined in a program called DISPLAY which assigns a color to each element of subclasses; those subclasses of the same class are assigned the same color. The magnetic tape output of DISPLAY is then viewed on the television screen of the DAS and film recorded. The details of the data processing flow are shown on Figure B-3.

C. Analysis of Data Sets

Figure B-4 shows the signatures (patterns) of four different materials derived from the analysis of training samples. Also shown is the computation of the divergences of all possible pairs. It is apparent that the plot of the signatures gives a good qualitative estimate of the degree of separability of different materials. The divergence gives a quantitative estimate of this separability. Figure B-5 shows a plot of divergence x 2 versus percent misclassification of training samples as calculated by Vaughn (1974). The percentage was calculated by summing the misclassified



DETAILED PATTERN RECOGNITION DATA PROCESSING FLOW

FIGURE B-3

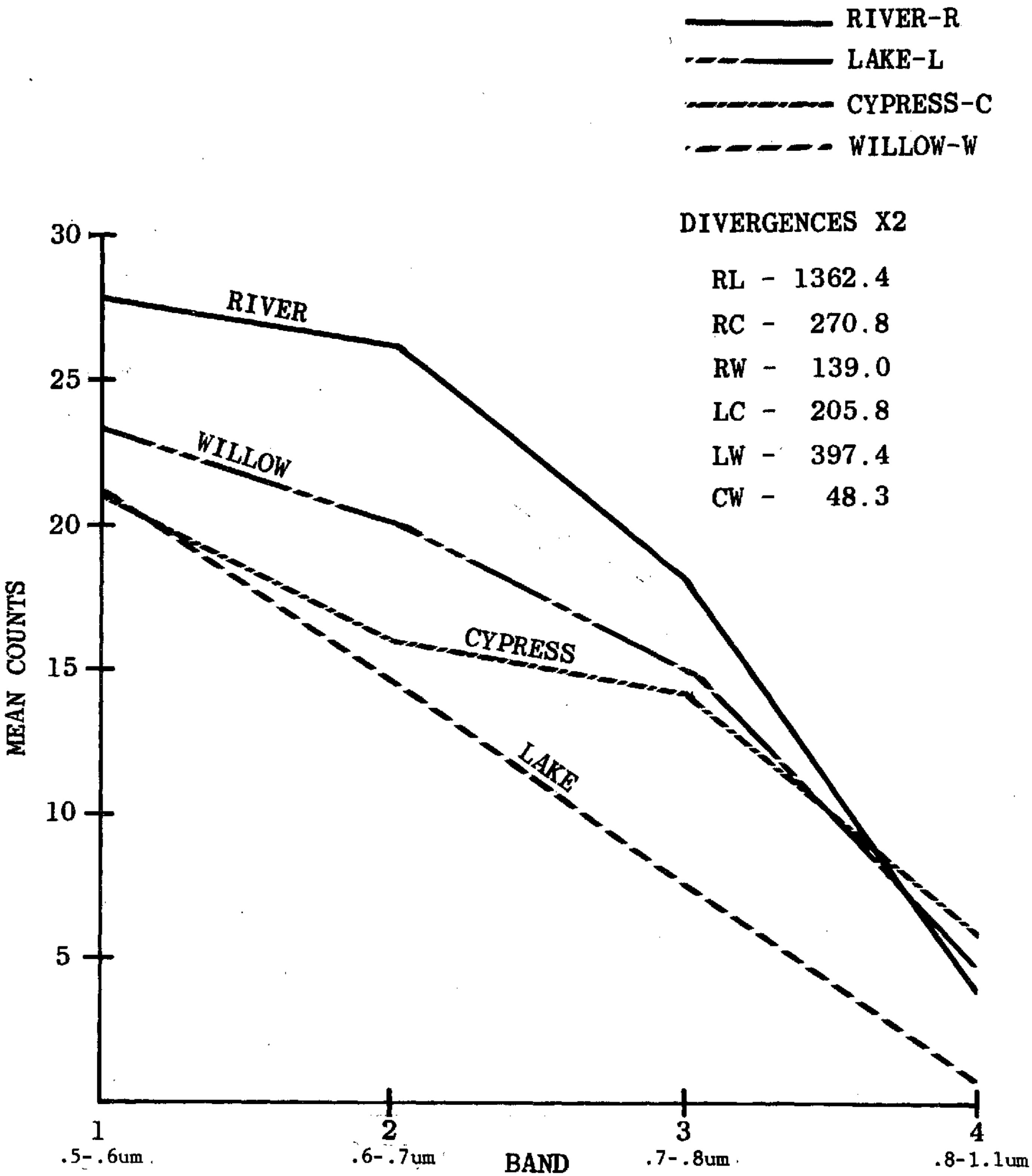


FIGURE B-4 SIGNATURES OF TRAINING SAMPLES

ERTS FRAME 1196-16082
FEBRUARY 4, 1973

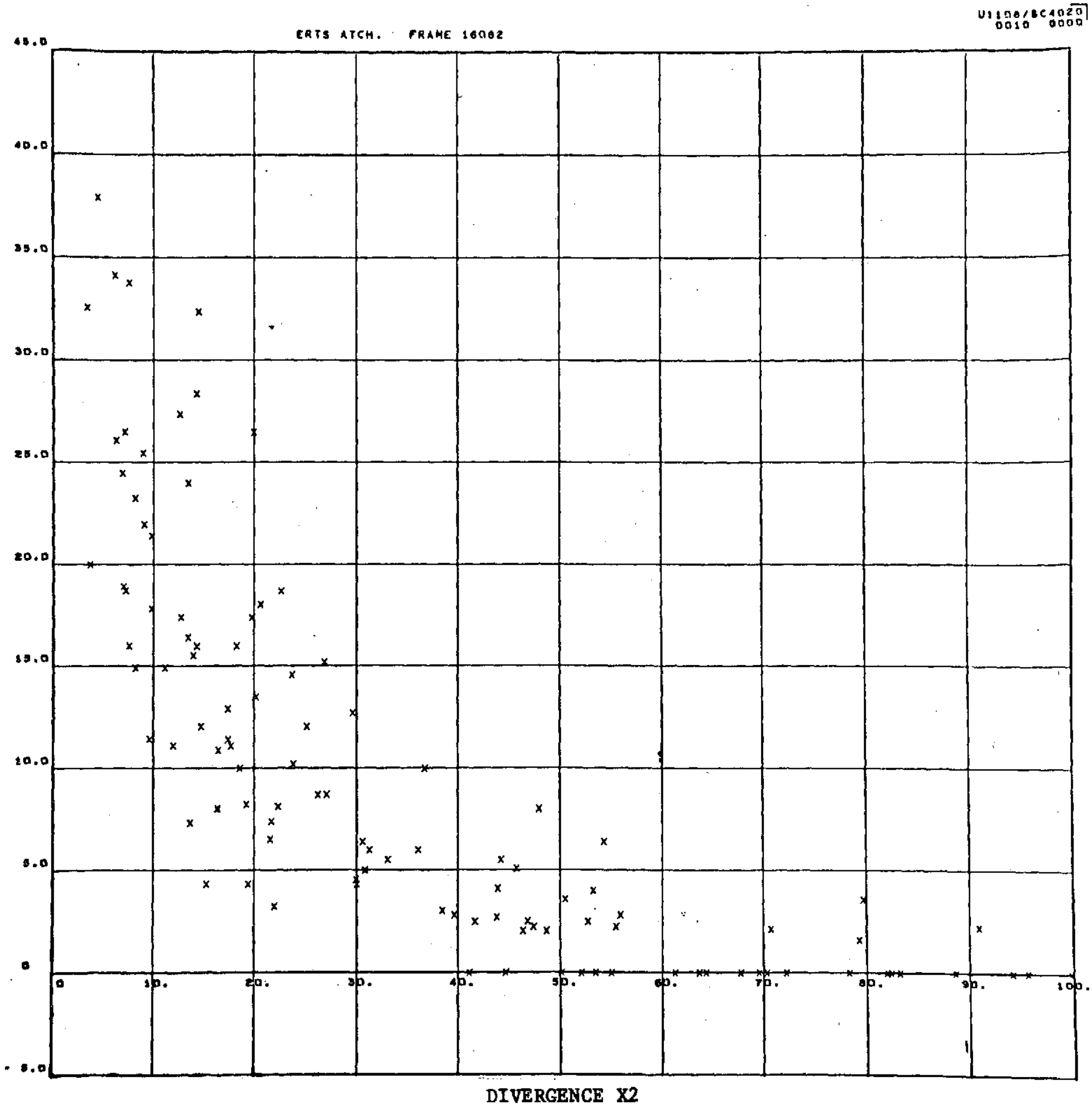


FIGURE B-5 PLOT OF PERCENT MISCLASSIFICATION VERSUS DIVERGENCE X2.

ERTS FRAME 1196-16082
FEBRUARY 4, 1973

points in each pair of samples and dividing by the total number of sample points. Although there is considerable scatter in the plotted points, a definite relationship is evident. This figure allows an investigator to have an estimate of the percentage of misclassification to be expected between pairs of subclasses. He may then make a decision as to whether to accept the results or combine the subclasses. It should be noted that Figure B-5 will not give the total percentage of any subclass which will be correctly classified. If a certain subclass has pairs with several other subclasses and each pair has low divergences then misclassification of that subclass will occur with each pair.

The percentage of correct classification for ERTS Frame 1196-16082 and the aircraft flight of January 15, 1973, is shown in Tables B-I and B-II. In both of these cases it was decided that the divergences between cypress and tupelo trees were so low that a meaningful species mapping could not be performed. These classes were combined by coloring them the same on the final DISPLAY run. These classifications percentages probably represent the upper limit of classification accuracy we can achieve using present techniques at this time of year with dormant vegetation and low sun angle. Most of the classification errors occurred between different classes of the same general materials; one species of trees being classed as a different species, for example. Combining the different classes into broader groupings will yield accuracies approaching ninety percent.

These two data sets were collected at the same time of year, used the same training samples, had the same classes, and were processed with the same procedures and programs. The data from the ERTS and aircraft under-

TABLE B-I CLASSIFICATION SCORECARD
OF THE ERTS TRAINING SAMPLES

Class	Percent Correctly Classified	Percent Misclassified	Percent Unclassified
River	69	30	1
Lake	71	24	5
Cypress-tupelo	94	0	6
Mixed forest	52	28	20
Willow	73	2	25
Scrub forest	88	12	0
Water hyacinth	96	4	0
Bare fields	100	0	0
Marsh	89	11	0

Overall percentage correctly classified - $\frac{\text{670 correct}}{\text{865 total points}} \times 100 = 77.5\%$

TABLE B-II CLASSIFICATION SCORECARD
OF THE AIRCRAFT MSS TRAINING SAMPLES

Class	Percent Correctly Classified	Percent Misclassified	Percent Unclassified
River	68	25	7
Lake	83	6	11
Cypress-Tupelo	67	16	17
Mixed Forest	72	16	12
Willow	66	26	8
Scrub Forest	--	--	--
Water Hyacinth	90	1	9
Bare Fields	83	14	3
Marsh	61	24	15

Overall percentage correctly classified - $\frac{\text{6628 correct}}{\text{9104 total}}$ X 100 = 72.8%

flight were analyzed to determine the significant causes of the misclassifications.

While the ERTS and aircraft data sets had much in common there were significant differences. The aircraft scanner has a much larger viewing angle - 80^{o} versus 11^{o} for ERTS; the data sets were not gathered on the same day or the same time of day; and the altitudes of the two platforms are radically different.

A check was to compute the coefficient of variation for each band used in the classification. This statistical measure, the standard deviation divided by the mean, gives an indication of the relative radiometric fidelity of the sensor systems. Use of this measure makes a comparison possible by eliminating the differences in scale employed by the two systems. The results are shown in Table B-III. The high value in band 4 of the ERTS data is caused primarily by the very low mean value obtained for water samples. Apparently the noise in the sensor system is nearly constant rather than being a percentage of the mean response. This probably accounts for the larger percentage of misclassification of water samples in the ERTS classification compared to the aircraft classification. The improved performance of the later ERTS data set probably reflects improvements in the calibration procedures mentioned by Thomas (1973) and the fact that no water samples were acquired.

The foregoing discussion would indicate that the aircraft scanner data should yield a more accurate classification than the ERTS data. The smaller resolution element size of the aircraft instrument allows selection of training smaller samples which are in the most homogeneous areas of each class of material. Also the aircraft data is apparently

TABLE B-III AVERAGE COEFFICIENT OF VARIATION (PERCENT)

	Band					Channel			
	1	2	3	4		4	5	7	10
	.5-.6μm	.8-.7μm	.7-.8μm	.8-1.1μm		.54-.57μm	.57-.63μm	.71-.75μm	.97-1.05
ERTS Frame 1196-16082 Feb 4, 1973 32 Samples	4.35	4.38	8.35	15.28	Aircraft Data Jan 15, 1973 32 Samples	5.33	4.27	4.51	5.97
ERTS Frame 1394-16071 Aug 21, 1973	3.11	4.14	5.03	5.72					

less noisy. However, the classification accuracy as shown by Tables B-I and B-II shows the ERTS classification is superior to the aircraft classification. The most likely explanation is that accuracy of aircraft classification decreases considerably as the scan angle increases. This is due primarily to changes in radiance detected by the scanner when viewing materials at different angles. A report by Cartmill and Boudreau (1973) treats this problem in detail.

One major difficulty is created by misclassifications in addition to the obvious production of erroneous results. This difficulty is that the misclassifications can occur in absurd locations. Willow trees placed in salt water bays, aquatic vegetation appearing in dry land farming areas, etc. From the theory presented above it is clear why this may happen. The only intelligence that is programmed into the computer is to recognize spectral patterns. The common sense available to a human interpreter is not available. A change in process in the current programs will enable the investigator to interact with the computer and change the classifications in areas of obvious error.

Appendix C

DESCRIPTIONS OF TRAINING SAMPLE SITES USED IN THE STUDY

The sites which are marked on Figures 8 and 9 were those used for training samples for the pattern recognition programs. All of these sites were not used for every classification but they were used at least once for some classification. A photograph of each site is presented following the description. The photographs are not necessarily centered in the middle of the sample site but it is believed that they show the major portion of the aircraft training sites and a significant portion of the ERTS sites. The photographs were taken from a helicopter at an altitude of approximately 240 meters (800 ft.) on May 13, 14, and 16, 1974. The photographs show a square area about 340 meters on a side (19 ERTS resolution elements). At this time of year, the sites are not necessarily representative of conditions at other times. In particular, agricultural fields are mostly bare or contain only emerging vegetation. Also the water hyacinths have not reached their maximum extent. The marsh vegetation is just beginning to protrude through the dormant growth of the vegetation of the preceding year and appears a uniform yellow green color making species identification difficult. All of the photographs have a vertical light streak through them caused by a malfunction of the camera. Flow through the basin was large at this time of year--approximately 10,600 cubic meters per second (375,000 c.f.s.). Water levels were consequently high.

Atchafalaya Basin Training Sites (Figure C-1)

R258

The mainstem of the Atchafalaya River, just after bifurcation into the Whisky Bay cut off and the Little Atchafalaya River. Most of this water has been diverted from the Mississippi River. The river is wide enough at this point to obtain a good homogeneous ERTS training sample.

MF134

A good example of the mixed bottom land hardwood forest that occupies the higher ground in the northern portion of the study area. The ground beneath the trees is dry, the crown cover is dense. Species include oak, hickory, cottonwood, sycamore, huckleberry, and elm. The site is extensive enough to provide a good ERTS sample.

B280

An agricultural field containing emerging rice seedlings. Only a small amount of rice is grown in the area. This field is typical of the rice culture.

S281

An agricultural field just outside the basin to the west. The field diked for the planting of rice.

B281

A typical sugarcane field adjacent to the basin on the west side. The sugarcane is just emerging and by late summer will form a dense cover.

CW005

Cypress trees with water standing underneath. These trees are so widely scattered that it is not possible to obtain an ERTS training sample that is not an admixture of trees, water and hyacinths.

H254

A well formed mat of water hyacinths. These areas are quite distinctive on ERTS simulated color infrared imagery. Although seldom of very large homogeneous extent a small sample can serve to establish a signature.

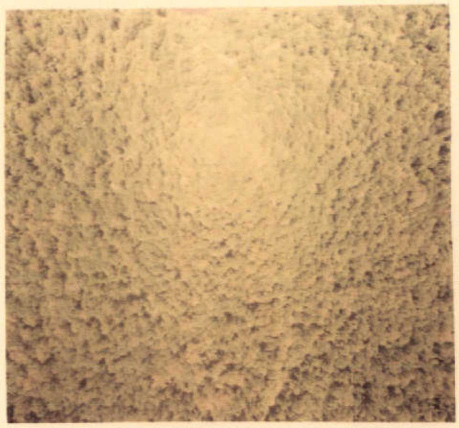
R201

The main stem of the Atchafalaya River after being joined by Bayou LaRompe, the river is wide enough to provide a homogeneous river training sample.

X252

Lake Dauterive located just outside the basin to the west. The lake has suspended sediment from local inflow, but clears up during low flow periods.

R258

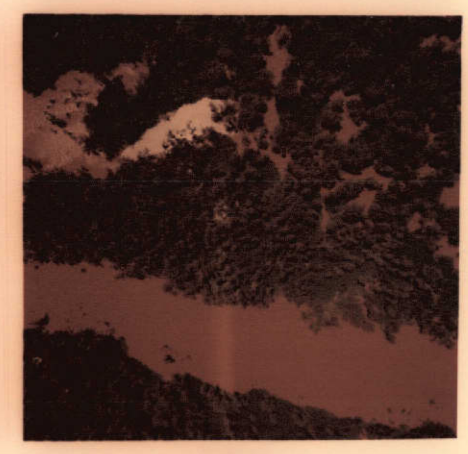


MF134

B280

S281

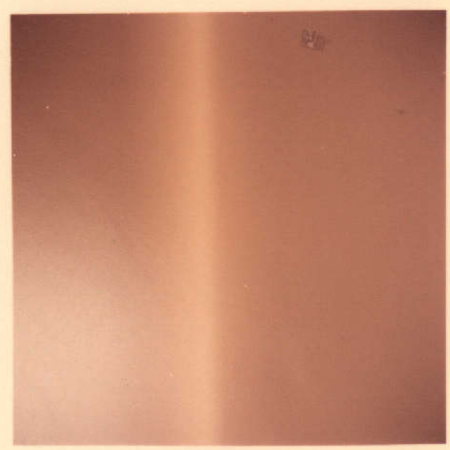
B281



CW005

H254

R201



X252

Figure C-1

Photographs of Atchafalaya Basin training sample sites.

(Figure C-2)

CW009

Scattered cypress trees with water underneath. Here the mat of water hyacinths has completely covered the water surface.

X260

Isolated arm of Grand Lake. This site is undoubtedly receiving inflow from the Atchafalaya River. During low river stages the water clears.

W010

A large and extensive stand of willows to the west of Hog Island. This is the premier willow training sample site. Sunglint indicates that there is water standing underneath the trees at this time of year.

W099

Willows growing on a spoil bank alongside the Atchafalaya River. These trees became established after the deposition of spoil during channel dredging. This site is distinctive on color infrared photography taken during the fall and winter.

MF133

A dense stand of mixed bottomland hardwoods located just outside the basin to the east. The ground beneath the trees is not flooded. This type of forest is typical of the drier areas of the basin along the natural levees of the streams in the upper portion of the study area.

W131

Stand of mature willow trees. Crown cover is not dense enough to make a good training sample. Later in the year the ground should be dry and further leafing out of the trees should make a reasonable sample.

H231

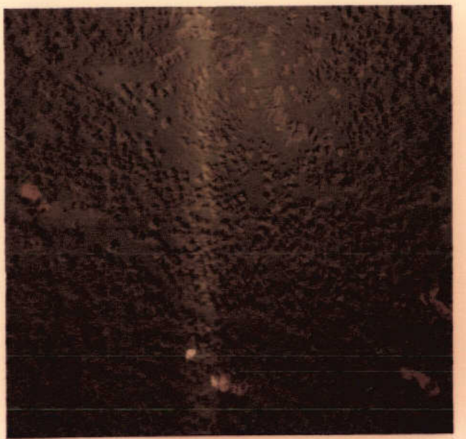
Hyacinth cover beginning to form in a portion of Buffalo Cove. Later in the year the hyacinths will probably cover the open water shown in the photograph.

C013

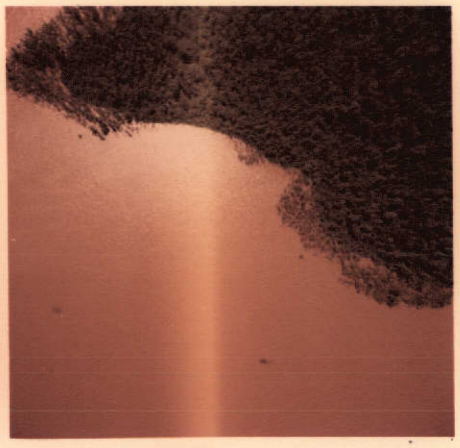
A relatively open stand of cypress in Buffalo Cove. Areas like this are usually classified as water hyacinths by the pattern recognition programs.

X299

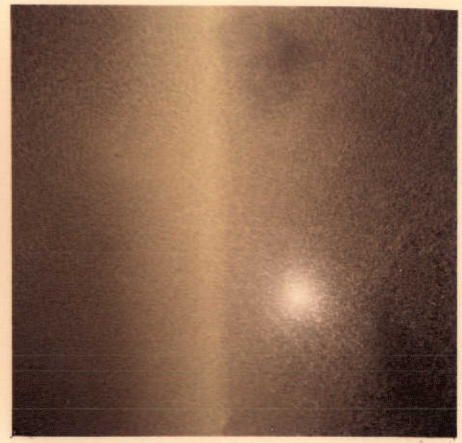
West side of Fausse Point Lake.



CW009



X260

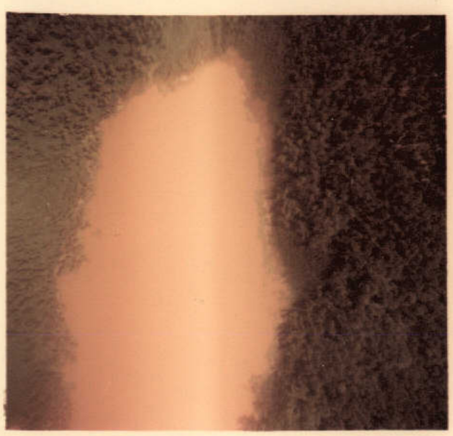


W010

W099

MF133

W131



H231

C013

X299

Figure C-2

Photographs of Atchafalaya Basin training sample sites.

(Figure C-3)

Y206

East arm of Fausse Point Lake. The uniform coloring of the water indicates a general circulation throughout the Lake.

T019

A dense stand of mixed trees. This site was intended to be a Tupelo tree training site, however, it consists of a broad mixture of different kinds of trees. This lack of homogeneity makes a poor site for a Tupelo sample. It might make a good sample for a mixed forest. More detailed ground truth would be required to determine which species were included.

CW081

Cypress trees with water standing underneath and patches of open water.

W098

Spoil bank willows. The spoil banks have created an artificial environment which has been rapidly taken over by a dense willow stand. The spoil bank line can be seen traversing the picture diagonally.

X212

Upper portion of Grand Lake. Normally this portion of the lake is clear, however, at high water there is obviously flow of sediment laden water into the lake. This site is a good ERTS training sample site.

X210

South end of Fausse Pointe Lake.

W021

A small stand of willows just inside the basin on the west side. This site is probably too small to be a good ERTS training sample.

T039

Tupelo trees outside the basin. These trees have a good dense color and are well leafed out. They have a distinctive light green color.

C037

Small stand of cypress trees outside the basin. This is a pretty well mixed site. The cypress trees are concentrated along the edge of the water. This is too small an area for an ERTS training sample.

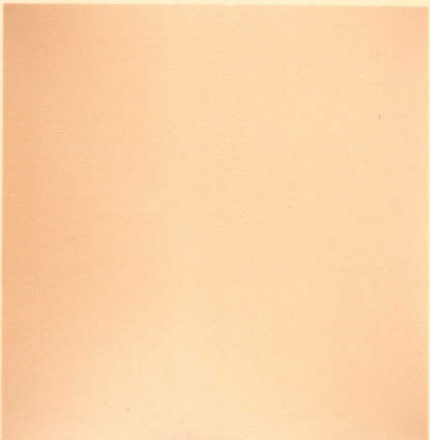
Y206

T019

CW081

W098

X212



X210

W021

T039

C037

Figure C-3

Photographs of Atchafalaya Basin training sample sites.

(Figure C-4)

C128

A small stand of cypress trees located adjacent to the navigation channel along the east levee. It is probably too small for an ERTS training sample.

R266

The navigation channel below Bayou Sorrel locks adjacent to the east levee of the floodway. Flow through this channel is sufficient to maintain suspended sediment. This site is too narrow to make a good ERTS training sample although it is sufficient for an aircraft MSS sample.

MF040

Mixed forest outside the basin to the west.

B299

A poor photograph of bare sugarcane field near Bayou Teche.

X213

Southern portion of Grand Lake. This area is often clear during low water. The suspended solids in this area of the lake depend upon the flow of water from the Atchafalaya River coming into the southern end of the lake.

W022

A stand of willows on an island in the navigation channel alongside the east levee. This site is much too small to be used effectively as an ERTS training sample.

T024

Tupelo trees. This is a good stand of Tupelo trees in the heart of the Cypress-Tupelo swamp. If care is exercised not to include the adjacent water, it will make an excellent training sample.

T043

Tupelo trees east of Grand Lake. This sample lacks good coverage and uniformity desired for a top grade sample.

C042

Cypress trees east of Grand Lake. The brown water under these trees reveals that the crown cover is only about 50 percent. At low water an understory may develop giving the appearance of complete coverage.

C128

R266

MF040

B299

X213

W022

T024

T043

C042

Figure C-4

Photographs of Atchafalaya Basin training sample sites.

(Figure C-5)

W045

A good stand of immature willows on newly accreted land.

R218

Main channel of the Atchafalaya River east of Cypress Island. About 60 percent of the flow of the river passes down this channel. It is always carrying a large sediment load. A good sample site.

T130

A portion of a large tupelo stand of tupelo trees. This site because of its extensive area will make a good ERTS training sample.

S283

Sugarcane fields adjacent to the west levee.

B290

Sugarcane fields west of the levee.

B295

Bare sugarcane fields.

B289

Bare sugarcane fields.

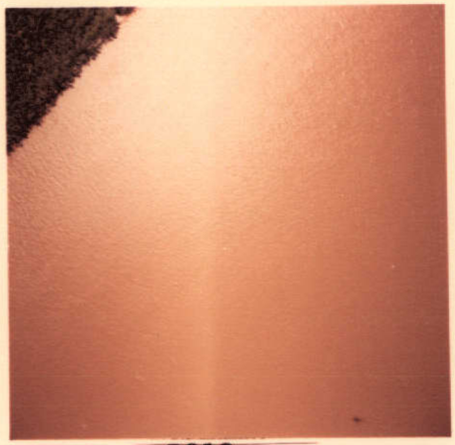
T129

A small stand of tupelo trees. Too small and mixed to be a good training sample

W116

Two different ages of willows on newly accreted land on Cypress Island. A good training sample location if care is taken to exclude water in the sample.

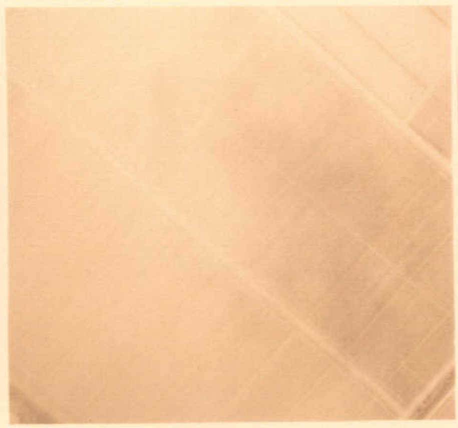
W045



R218

T130

S283

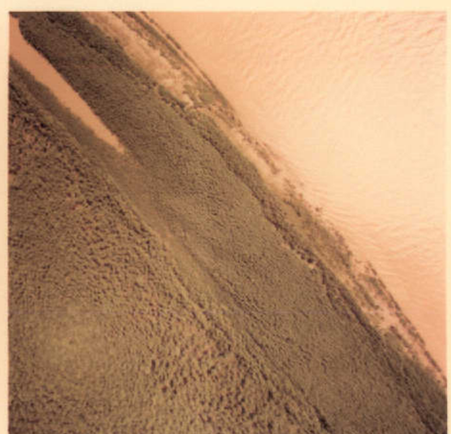


B290

B295

B289

T129



W116

Figure C-5

Photographs of Atchafalaya Basin training sample sites.

(Figure C-6)

W112

Willows in a diked area bordering the main channel. A good sample of willows in an unnatural environment.

C109

A small dense stand of cypress trees. Compared with T108 the photograph shows the striking difference in the appearance of these two species. They have been difficult to separate by pattern recognition techniques.

T108

A small dense stand of tupelo trees (white). A good but small training sample.

H275

Water hyacinths.

T103

Tupelo trees. This is one of the best training sample sites in the basin. The trees are well leafed out and very dense.

T101

A uniform stand of tupelo trees--an excellent training sample site.

X267

Lake Verret. A lake that stays clear at all times of the year--outside the basin.

C127

A small stand of cypress trees.

R268

Navigation channel along the east levee.

W112

C109

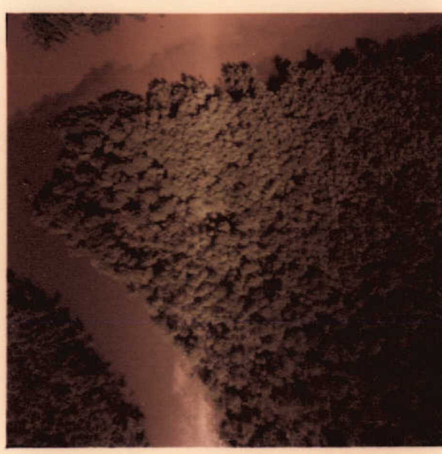
T108

H275

T103

T101

X267



C127

R268

Figure C-6

Photographs of Atchafalaya Basin training sample sites.

(Figure C-7)

C073

Cypress trees. A small dense stand. Sufficient size for an aircraft data training sample, but too small for an ERTS sample.

C071

A small dense stand of cypress trees with a few scattered tupelos.

Y229

West side of Flat Lake. This lake has inflow from the Atchafalaya River on the west and the navigation channel on the east. The lake is very shallow and filling rapidly. The flow of water entering from the swamp to the north always has a distinctive color from the river water.

R228

Atchafalaya River just north of Morgan City, La. Some of this water enters Flat Lake. Note the similarity to Y229.

X264

Isolated portion of Bayou Teche. This reach of Bayou Teche is protected by lock systems at either end. As a result the water is clear. This is a minimum size ERTS training sample.

C062

Small stand of Cypress trees.

C126

A large uniform stand of cypress. Large enough for an ERTS training sample.

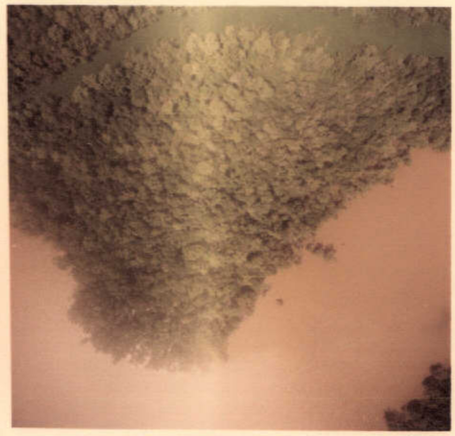
W110

Willow trees.

B285

Bare sugarcane fields.

C073



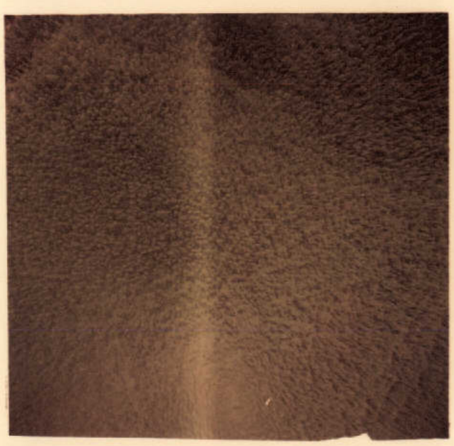
C071

Y229

R228

X264

C062



C126

W110

B285

Figure C-7

Photographs of Atchafalaya Basin training sample sites.

(Figure C-8)

S284

Bare sugarcane fields.

X265

Lake Palourde. A clear water lake north of Morgan City, La.

C076

A small stand of cypress. This is about the southern most limit of cypress trees.

Y262

Lake Avoca. A shallow lake south of Morgan City, La. It receives some sediment inflow from the Avoca Island cut off navigation channel.

Y269

Lake Avoca. The norther portion of the lake is often covered with water hyacinth. Small pieces can be seen in the photograph.

M309

An extensive area of scrub forest land. This site and M318 make excellent training samples for ERTS data.

M318

An extensive area of scrub forest land.

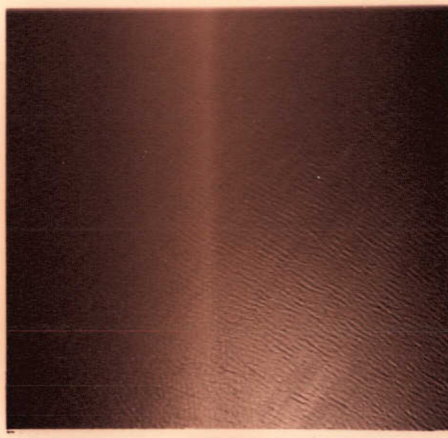
Y237

Sweetbay Lake. This is a very shallow partially filled lake.

Y257

Bay in the lower Atchafalaya River. This bay is obviously exposed to the flow of sediment laden water.

S284



X265

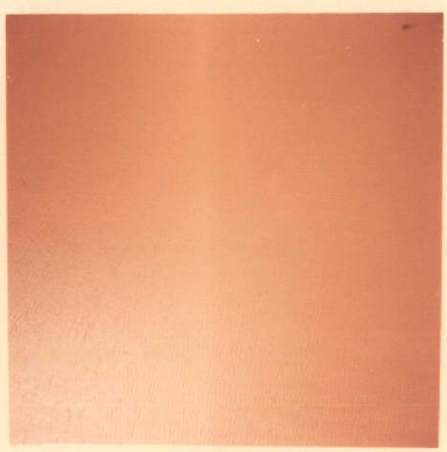
C076

Y262

Y269

M309

M318



Y237

Y257

Figure C-8

Photographs of Atchafalaya Basin training sample sites.

(Figure C-9)

M308

An extensive area of scrub woody vegetation south of the Intracoastal Waterway. Species include wax myrtle, magnolia, ilex and sabal. This area includes several water courses and a pure sample of vegetation is hard to obtain with ERTS data.

Y253

Wax Lake. This is a portion of Wax Lake which is behind the spoil bank created in dredging the channel. The spoil bank has numerous openings which allows the river water to pass into the lake. The lake is filling rapidly with sediment.

R251

Wax Lake cut off. This is an artificial channel dug to provide a second outlet for the Atchafalaya River. Approximately 40 percent of the river flow reaches the Gulf of Mexico by this outlet.

M339

Fresh water marsh. This marsh area below the Gulf Coast Intracoastal Waterway was largely flooded. The principal marsh species is Juncus.

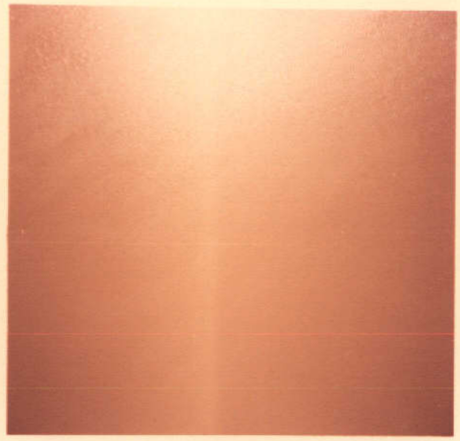
M340

A small marsh island in Wax Lake. The vegetation is about 80 percent Iris species and 20 percent small grass possibly paspalum vaginatum. Because of the large flow of fresh water from the outlet, these marshes are fresh.

R239

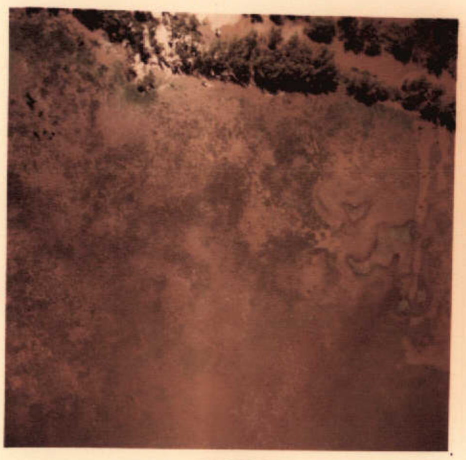
Mouth of Wax Lake Outlet in the Atchafalaya Bay.

M308



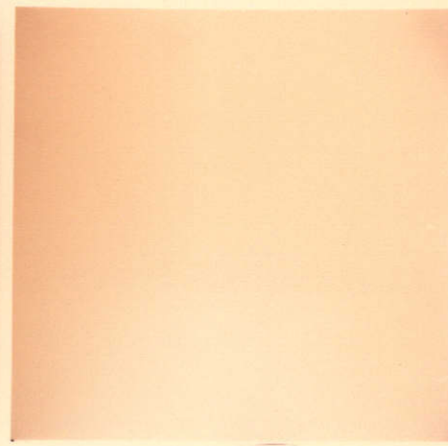
Y253

R251



M339

M340



R239

Figure C-9
Photographs of Atchafalaya Basin training sample sites.

Marsh Training Sites (Figure C-10)

Fresh Water Marsh

M334

80% Andropogon species, 10% other, 10% water.

M301

80% water. The vegetated area is 65% Eleocharis and 20% Andropogon species, 15% other.

M329

40% water. The vegetated area is 80-95% Juncus species (possibly J. Microcarpa).

Intermediate Salinity Marsh

M335

30% water. The vegetated area is 90% mixed grasses (Andropogon species plus several unidentified species) and 10% Typha. This site is not homogeneous.

M336

The vegetated area is 60% Spartina patens, 20% Typha species, 10% Myrica cerifera and Baccharis halimifolia in mixed clumps, 10% other large grasses (Erianthus and Panicum species). This site is not homogeneous.

M337

The vegetated area is 80% Spartina patens and 20% Typha species.

Brackish Marsh

M327

15% water. The vegetated area is 80-90% Spartina patens and 20-10% other grasses and leguminous shrubs.

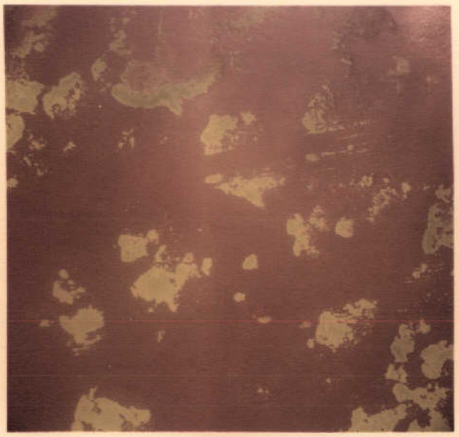
M316

Vegetated area is 60% Spartina patens, 30% Spartina cynosuroides, and 10% other.

M304

100% Spartina patens. No water.

M334



M301

M329

M335

M336

M337

M327

M316

M304

Figure C-10

Photographs of Marsh training sample sites.

(Figure C-11)

M319

100% Spartina patens. No water.

M315

15-20% water. The vegetated area is 100% Spartina patens.

M321

The vegetated area is 95% Spartina patens and 5% Distichlis spicata.

Saline Marsh

M326

Vegetated area is 70% Juncus roemerianus, 15% Spartina patens, and 15% Spartina alterniflora.

M313

5% water. The vegetated area is 85% Distichlis spicata, and 10% Spartina patens.

M314

50% Distichlis spicata and 50% Spartina patens.

M333

70% Distichlis spicata and 5% other.

M312

70% Spartina patens, 30% Distichlis spicata.

M311

60% Spartina patens, 40% Distichlis Spicata.

M319

M315

M321

M326

M313

M314

M333

M312

M311

Figure C-11

Photographs of Marsh training sample sites.

(Figure C-12)

M332

15% water. The vegetated area is 60-70% Distichlis spicata, 40-30% Spartina alterniflora.

M338

60-70% Distichlis spicata, 40-30% Spartina alterniflora, 5% Avicennia nitida.

M342

20% water. The vegetated area is 50% Avicennia nitida, 25% Distichlis spicata, 10% Spartina alterniflora and 15% other species.

<u>Off shore coastal water sites - underwater aquatic, possibly green alga, visible at low tide - noted in December 1972, and January 1973.</u>

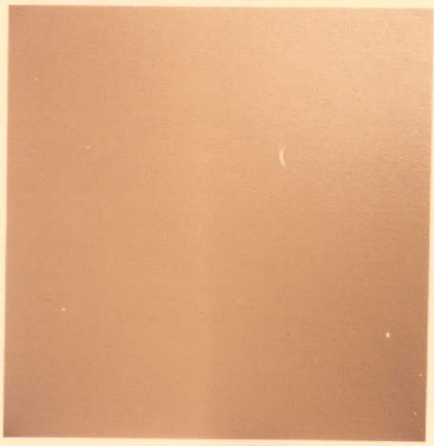
M330

M331

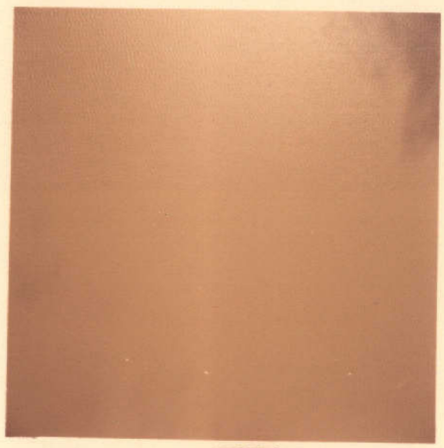
M332

M338

M342



M330



M331

Figure C-12
Photographs of Marsh training sample sites.

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