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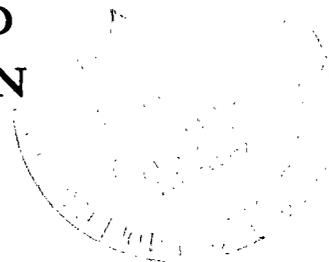## APPLICATION OF REMOTELY SENSED MULTISPECTRAL DATA TO AUTOMATED ANALYSIS OF MARSHLAND VEGETATION

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16. Abstract

The techniques used for the automated classification of marshland vegetation and for the color-coded display of remotely acquired data to facilitate the control of mosquito breeding are presented. A multispectral scanner system and its mode of operation are described, and the computer processing techniques are discussed. The procedures for the selection of calibration sites are explained. Three methods for displaying color-coded classification data are presented.

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SUMMARY

A freshwater-to-brackish marsh near Slidell, Louisiana, was studied to demonstrate the use of remotely sensed data from an airborne multispectral scanner and computer processing techniques for identifying and classifying vegetational cover to determine areas that are potential breeding sites for the salt marsh mosquito, Aedes sollicitans. Supporting ground investigations were performed to locate areas of uniform plant species or plant communities for use as calibration sites, or "training fields," in the computer analysis. The spectral signatures of these training fields provide the basis for computer decisions on the classification of vegetational complexes in the total study area. Later ground studies indicate a high degree of accuracy in the overall classification. The computer programs used for processing the data were developed at the Purdue University Laboratory for Application of Remote Sensing and modified for this study. In the CLASSIFY program, the digital table look-up method was found to be the fastest and the most economical.

INTRODUCTION

Personnel of the NASA Lyndon B. Johnson Space Center Earth Resources Laboratory (ERL) at the NASA National Space Technology Laboratory (formerly the Mississippi Test Facility) are conducting a series of investigations to develop remote-sensing techniques that apply to the study of wetlands. For one of these investigations, the results of which are presented in this report, a 24-channel multispectral scanner that can acquire time-coherent spectra covering a dynamic range of 0.3 to 13 micrometers was used. Limited ground-truth data were obtained for comparison with remotely sensed data and for aiding in the selection of training fields.

Several computer programs are required for adequate processing of the remotely sensed data. The output of the computer analysis can be generated as a computer character printout or can be presented as a color display through the use of

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an additional program and a photographic process. The color-coded display was found to be the most satisfactory for this particular analysis. The colors chosen for the output display are at the option of the user; the colors chosen for display in this study were those that would clearly show significant differences between the selected vegetational categories.

By using the computer-determined vegetational classes, known relationships between plant species associations and the egg-laying habitats of the salt marsh mosquito were employed to outline the probable areas where mosquito control would be most effective. For this purpose, vegetational types were analyzed for indications of positive or negative mosquito-breeding terrain. This technique and the selection of the habitat sites are discussed in detail.

A note of special appreciation must be accorded to Dr. R. H. Griffin of the ERL and to Dr. Walter Eppler of the Lockheed Electronics Company (LEC) for their efforts in preparing some of the statistical data and in preparing the computer-derived color classification. The author is also grateful for counsel from Samuel Riché of the St. Tammany Parish (Louisiana) Mosquito Abatement District No. 2.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unites (SI). The SI units are written first, and the original units are written parenthetically thereafter.

THE MARSH USED AS A STUDY AREA

Coastal marshes are an important ecological system in the Gulf Coast area. As pointed out by Penfound and Hathaway (ref. 1), "Louisiana has the doubtful honor of having nearly twelve times as much salt marsh as New Jersey and almost half the total salt marsh of the Atlantic and Gulf Coasts." Viosca (ref. 2) notes that, of the total area of Louisiana, nearly one-third (40 500 square kilometers (10 000 000 acres)) consists of swamps, marshes, or open water. Viosca also observes that, in southeastern Louisiana, there are approximately 7100 square kilometers (1 750 000 acres) of freshwater marsh and approximately 10 100 square kilometers (2 500 000 acres) of sea or salt marsh. These marshes serve an important ecological function as part of the primary food supply for much of the marine life in the Gulf of Mexico. In addition, these marshes are the prime breeding habitats for the salt marsh mosquito.

The study area, known as Fritchie Marsh, is located just west of the western termination of Avery Estates Road, which, at its eastern terminus, intersects U.S. Highway 190. The location of the study area is shown in figure 1. Figures 2 and 3 are aerial photographs (using color negative film) taken over the marsh in late summer of 1971. The total area studied is approximately 15 square kilometers (6 square statute miles), including a 2.5-square-kilometer (1 square statute mile) area that was studied intensively for training samples. The study area also lies just north of the Oak Island transect, which was examined extensively by Penfound and Hathaway in their definitive study on plant communities in southeastern Louisiana marshes (ref. 1).

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The study area is part of an older portion of the Mississippi Delta (an extensive alluvial plain having little relief that gradually slopes toward the Gulf of Mexico) and is very near sea level over most of its extent. In some regions, elongated-to-circular areas that are several feet higher than the surrounding marsh are found. These elevated areas are believed to be either former barrier beaches or outlying fragments of the Gulf Coast. When one of these elevations is covered with live oak (Quercus virginiana), it is termed a "cheniere."

It is apparent that minor changes in elevation cause major changes in the nature of the plant communities that are present. Penfound and Hathaway (ref. 1) observe: "It should be emphasized also that the transition from one community to another is conditioned by a change in elevation of as little as three inches since four communities may occur on a slope having a fall of less than one foot."[1] This transition is shown clearly in figure 4, which is representative of most communities in the study area. In the foreground, a portion of some deep water is covered with the white waterlily (Nymphaea odorata). In shallow water immediately behind this, foursquare grass (Eleocharis quadrangulata) is found; and, in the intertidal area, the wiregrass/blackrush or spikerush (Spartina patens/Juncus roemerianus) association is seen. On slightly higher elevations, normally above the intertidal zone, southern waxmyrtle (Myrica cerifera) and eastern baccharis (Baccharis halimifolia) are found; on still higher ground, stands of slash pine (Pinus eliotti) and loblolly pine (Pinus taeda) or live oak (Quercus virginiana) are seen. This abrupt change in elevation is atypical of the marsh as a whole but does allow the differing communities to be seen in a single photograph. As concluded by Penfound and Hathaway (ref. 1), pine is probably subclimax because if this area were protected from fire for a long time, live oak would be climax.

In other regions of this marsh, there are extensive areas of sawgrass (Cladium jamaicense) and some cattail (Typha species). The sawgrass is found west of a small lagoon near the northern border of the study area. Within the lagoon (seen in the foreground of fig. 4), one finds primarily bladderwort (Utricularia vulgaris) and the previously mentioned white waterlily. As evidenced by the vegetational types present, this portion of the marsh is fresh to only slightly brackish. Measurements of salinity, hydrogen ion concentration (pH), and sulfite for two samples collected just west of Avery Estates Road on September 7 and 9, 1971, are presented in the following table.

Measurement	Sample 1006	Sample 1007
pH	5.7	5.7
Salinity, $^o/_{oo}$	.99	1.00
Sulfite, mg/liter . . .	1.88	2.19

[1]Underscore is Penfound's and Hathaway's.

The south side of the study area is more saline, as evidenced by the lack of cattails and white waterlilies in the lagoons. In fact, at Oak Cheniere, Penfound and Hathaway (ref. 1) calculated that the salinity of the lagoon (located just east of Louisiana Route 433 at Salt Bayou) averaged 0.2 percent but reached 0.7 percent during the dry weather of midsummer. They also noted that the soil water at this location was much more brackish. Their studies on this area were begun in January 1932; since then, channelization and dredging alterations have probably caused the salinity levels to rise even further.

The presence or absence of certain species associations has been shown to depend in part on the mean water depth present in the marsh. Also, the salinity of the marsh exerts yet another controlling influence on these associations. Therefore, it is evident that inferences can be made about the nature of the environment from the vegetation present. If the ecological niches occupied by other life forms can be determined, it may well be that vegetation can be used as a tool for identifying these other ecological associations. Because the salt marsh mosquito breeds primarily in the intertidal zone, which is occupied by the Spartina patens/Juncus roemerianus association,[2] these areas can be examined in detail to learn whether differentiation from other plant communities can be accomplished by using remote-sensing techniques.

MULTISPECTRAL SCANNER

This section and the two succeeding sections, in which the training field selection and the data processing techniques, respectively, are described, may be combined to provide a description of the overall approach to identifying and classifying surface vegetation in a marsh area by using remote-sensing and automated computer techniques. The multispectral scanner system (MSS) used for this study is an airborne imaging spectrometer. In operation, scanning is accomplished by means of a rotating mirror that, combined with the other optical components, has an angle of acceptance of 2 milliradians (0.1146°). The mirror rotates so that the sweep of the spectrometer field of view is perpendicular to the flightpath. The total sweep or scan angle is 80°, consisting of a scan line beginning at 40° to one side of vertical and extending to 40° on the other side. As the mirror rotates, the MSS acquires time-coherent spectra, covering the dynamic range from 0.3 to 13 micrometers, from each element. Each scan line consists of 700 elements. The projection on the ground of the 2-milliradian angle of acceptance determines the element size, which obviously is a function of altitude. From an altitude of 1220 meters (4000 feet), an area 2.4 meters (8 feet) in diameter is examined at any one instant; whereas from an altitude of 6100 meters (20 000 feet), an element would be 12 meters (40 feet) in diameter. For each element in each scan line, the reflected or emitted radiation between 0.3 and 13 micrometers is divided into 24 channels, and the signal developed by each channel is recorded on an AR 1600 magnetic tape recorder. Figure 5 is an illustration of the sensor capabilities that are available in the MSS as compared with the range of human vision and with some other more common receptors of data. The channels

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[2]Samuel Riché (St. Tammany Parish (La.) Mosquito Abatement District No. 2), personal communication, Oct. 1971.

that are available are listed in table I. For each channel, without switching to another range, there are 256 arbitrary units of intensity that can be recorded. If the radiation intensity is low, yielding a maximum reading of only 10 units, the recording range may be turned to a more sensitive range so that the maximum is close to 256. The total calibrated operating dynamic range for each channel is approximately 1×10^5.

For each channel, a detector, preamplifiers, a bias video processor, an integrate-and-hold unit, an analog-to-digital converter, and a data buffer are provided. The 24 channels of data, digitized in 8-bit words, are recorded on 12 channels of the 14-channel tape recorder. The 13th track of the tape recorder is used to control voltages and to record aircraft altitude and location and all housekeeping information. The 14th track contains timing code signals.

At the completion of each scan line, the rotating mirror examines a series of calibration sources, which are listed in table II. In this manner, the scanner looks sequentially at all calibration sources and at the scene. Because calibration occurs after each line scan, difficulties caused by slow electronic drift are obviated.

The forward speed of the aircraft is adjusted to the altitude and the speed of rotation of the mirror in such manner that the next scan line begins when the aircraft has advanced a distance equal to the dimension of the resolution element. For an MSS mission flown at an altitude of 1220 meters (4000 feet), the aircraft will advance 2.4 meters (8 feet). In this manner, the terrain is continuously examined, scan line by scan line, in a sweep that is 700 elements wide.

The 24-channel scanner yields a reflectance/emittance spectrum for each 2.4-meter (8 foot) element. The fact that spectra differ for differing materials is the basis for classification when using this scheme. These spectra are quantified to allow classification of an unknown element by comparison with the known spectra of a particular element. These known elements and their measured spectral characteristics form, collectively, the concept of training fields.

After the data have been recorded, the tapes are screened at a data analysis system (DAS) ground station (fig. 6). The DAS provides a capability for data screening, for certain types of data processing, and for data recording. By use of the DAS, flight data tapes can be reformatted into computer-compatible tapes for later processing. In addition, training fields that will be analyzed in detail can be identified and located in the multispectral scanner data. Three of the 24 channels of recorded data may be recalled and displayed in color at commercial-television scan rates. Each of the three selected channels is assigned arbitrarily to the red, green, or blue gun in the television monitor. The televised image enables the observer to recognize geographic areas for location of known ground truth (training fields). The operator controls a cursor that is used to outline the boundaries of the training fields and to record their locations for use in further processing (fig. 7). All elements within the outlined area are subsequently processed to determine the signature of the material that constitutes the training field. The details of these calculations and their relationship to the overall classification scheme are described in the following section.

TRAINING FIELD SELECTION

Training fields are selected to provide the computer with an example of the type of material to be classified. The type of training fields (or calibration sites) will vary, depending on the ultimate need in classification, and may be various soil types, water of differing temperature or turbidity (or both), geological formations, plant communities, and so forth. For this study, plant communities and representative samples of water were chosen.

The size of an area examined at any given instant depends on the angle of acceptance of the sensor and the altitude of the sensor with respect to the terrain being examined. In this study, the element was 2.4 meters (8 feet) in size. However, the area chosen for a training field must be much larger than this, for reasons that will become clear later in this section. For this study, areas smaller than 30 by 30 meters (100 by 100 feet) were not considered for training fields.

In addition to the size, the homogeneity of the training field must be considered. For the marsh, which contains several species associations, training fields should be chosen that accurately represent each association but are uniform in composition. This means that each training field should contain only a very minimum number of species not belonging to the association depicted by the training field in question. For example, when selecting a sample of loblolly pine on a cheniere, it is better to choose a training field in which the forest has complete crown closure rather than one having more widely spaced trees. In the latter case, if a 2.4-meter (8 foot) element is used, some elements in the training field would examine tree crowns and others might examine the understory between trees. This situation would lead to a training field that had a mixed classification, which is very undesirable. It is possible to differentiate between pine and understory if two training fields are provided separately. If the association is one of several species that are integrated effectively by the 2.4-meter (8 foot) element, however, training fields can be chosen on the basis of plant communities, as in the case of the Spartina patens/Juncus roemerianus association. This procedure can also be employed for a plant or a plant community that requires consideration of some other aspect of the environment as part of the overall signature of the training field. This situation is found with Typha species whenever the individual Typha plants and the open water between the plants are detected by the MSS as an integrated signal. Only in these situations can discontinuities be permitted, because only then can the integrated signal be examined and tested as a single classification. In all other situations, the training field should be homogeneous for the material examined.

With the preceding criteria in mind, field studies were undertaken in the Fritchie Marsh to select training fields that would be representative of the major vegetational types present. All training fields used for this study are listed in table III.

For each training field, plants were collected and detailed observations were made to ascertain the accuracy of the MSS-acquired data and to determine the relative percentages of the dominant species present if the chosen field represented a distinct community (species association). The collected plants were mounted for herbarium preservation to build a data base for the field studies accomplished during the course of this research.

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PROCESSING THE MSS DATA

To process the MSS data so as to yield a color-coded classification map as a final product, a number of computer programs are required. These programs (initially developed by the Purdue University Laboratory for Application of Remote Sensing (LARS) and later modified by Dr. Walter Eppler of LEC) are described briefly in the following paragraphs.

The PICTOUT Program

The PICTOUT program allows for the graphic display of the MSS-acquired data for any one of the 24 channels by producing alphanumeric, pictorial printouts. For each channel, there are 256 possible levels. Each level must be assigned to one of 16 possible symbols in some fashion. An example of a PICTOUT display is shown in figure 8. A PICTOUT display can also be used to locate training fields that are too small to be located accurately by use of the cursor described previously. This location is possible because the PICTOUT program also displays the scan-line and element numbers and, thereby, allows the user to locate the four corners of a training field.

The STAT Program

The STAT program is used to compute and display statistics from the data obtained from the training fields. For any one training field, each element is examined for each channel, and a calculation is performed whereby the mean reflectance/emittance values for that particular channel and a calculation of the standard deviation are given. Also included in the calculations are histograms and a covariance matrix by class and channel and a composite spectral signature for each class. An example of the mean calculations and the covariance matrix is shown in figure 9. Figure 10 is a histogram of the two channels of recorded information for the Spartina patens/Juncus roemerianus training fields. The abscissa is relative radiance (increasing toward the left), whereas the ordinate gives the number of resolution elements having that particular radiance in the training field. The histogram is quite useful for determining the homogeneity of training fields. If the histogram has the appearance shown in figure 10, the training field likely is homogeneous. Conversely, a bimodal histogram is a good indication of a training field that is heterogeneous. Such a training field should be eliminated from those that will finally be employed in the classification effort.

Figures 11(a) and 11(b) are examples of spectral plots. Figure 11(a) is the spectral plot of the Spartina patens/Juncus roemerianus association, and figure 11(b) is the spectral plot of the training field for water. When the two plots are compared, a significant difference between the signatures of these two training fields is obvious immediately. On the basis of that difference, the classes that are considered can be distinguished.

The SELECT Program

To minimize computer calculation time, the SELECT program is used to calculate the minimum number of channels necessary for a classification and, in so doing, to determine the relative importance of the individual channels. This calculation is accomplished by first computing the degree of separability of each training field and then determining the optimum set of channels for classification purposes. The algorithms used in the SELECT program are detailed by Marill and Green (ref. 3). An example of the SELECT program is shown in figure 12, in which the white waterlily is compared with a number of different classifications. The first choice is the one that gives the best separation between all classes considered; then, choices are arranged in descending order to choice 50.

The CLASSIFY Program

Once the signatures have been developed by the minimum number of channels established and selected, the individual elements of the total set of data may be classified. In the CLASSIFY program, elements of MSS-acquired data are analyzed to determine the probability of an element being identified with or contained within one of the known classifications (previously established by the signatures developed for the training fields).

Briefly stated, calculations are performed on the statistical data from each training field to partition a specific region of multispace to contain only a selected classification. The spatial dimensionality needed is determined by the number of channels required to separate all classes. These calculations are performed in the SELECT program described previously. If only two channels are needed, calculations are needed only to partition two-dimensional space; with three channels, calculations are necessary to partition three-dimensional space; and so forth.

For a further illustration of the technique, assume that three channels are sufficient for a classification, and, for the moment, examine received radiation from the same three channels of two differing plant communities, the Spartina patens/ Juncus roemerianus association and Eleocharis quadrangulata. Assume that this information was received on channels 1, 2, and 3, respectively, and arbitrarily assign these channels to the x, y, and z axes of a coordinate system (fig. 13). In figure 13, the space surrounding the points for each of the two classifications represents areas that will be classified as that material if three coordinate values fall within that region. The scalar that exists between the two points for both classifications is a value that indicates the degree of separability of these two classifications. The larger this value is, the less chance there would be of having a miscalculation with respect to these two classifications. Materials for classifications having coordinate values that do not fall within two partitioned areas, as shown in figure 13, would be unclassified. In examining the received radiation from the Spartina patens/Juncus roemerianus association, the use of mean values from all elements in this training field as the x, y, and z coordinates will give a precisely located point in three-dimensional space. If, in examining the histograms, upper and lower values are placed on either side of the mean values for each channel, a volume of space is enclosed that also encloses the point. If the allowed deviation above and below the mean on all channels is the same, a spherical region of space will have been partitioned. If the allowed deviations are not equal, an ellipsoidal region of space is enclosed.

Even if more than three channels are used, the principle would still be the same. Working in N dimensional space, where N represents the number of channels used, the space partitioning would be hyperspherics or hyperellipsoids of revolution and, again, would depend on the positive and negative deviations allowed from the mean values of all channels used.

Imagine that the boundary of these defined spaces is the boundary for a particular classification. If the information received from an unclassified element places it within one of the partitioned regions of space, that element is assigned the classification type with which it is grouped. If, however, the spectral information from an element falls outside the partitioned areas for the classifications, that element is designated as unclassified. In this manner, each element in each scan line from an MSS mission is examined and classified. Because training fields form the primary standard for classification, obviously they must be chosen with exactitude. Two different methods were used in this classification.

The LARS system.- For one classification printout, the LARS system was employed. The same four best channels as determined in the SELECT program for all classifications were used. In the LARS system, Gaussian statistics are employed and the calculations to partition space are performed at classification time for each element as it is examined.

The digital table look-up method.- For the second classification printout, the digital table look-up (DTL) method was employed. Again, four channels were used, but the four channels used were not always necessarily the same. In space partitioning, the four channels used for a given calculation were those that had proved to be the best for separating that classification from all other classifications. The DTL method differs additionally from the LARS system in that space-partitioning calculations are not performed for each element at classification time but are done earlier. In this manner, the desired answer (plant community) is prestored in the fast random-access core memory. Each set of measurements from an element is interpreted as that address in core memory from which the answer can be retrieved. This approach means that DTL computer classification processing time is less than that of the LARS system by more than an order of magnitude and that the data can be processed by computers having less sophistication, complexity, and cost. This approach is well documented in reference 4.

VEGETATION CLASSIFICATION

The plant communities were classified by using the techniques described in the preceding section. The display used to give the most immediate readout was a character display in which particular alphabetic characters represented particular classification types. Each element was given an alphabetic letter if classified as one of the training fields or was left blank if unclassified. An example of a character printout is shown in figure 14. The first color-coded product was generated by using an SC 4020 plotter to produce sets of three color masks. These color masks

were superimposed on a I^{2}S Mini Adicol viewer, using red, blue, and green light, respectively, to illuminate each mask. This display was photographed on Ektacolor negative film and printed. Later, a procedure was developed at the ERL to produce a color-coded display by using an ancillary program in conjunction with the SC 4020 plotter. The result was a 35-millimeter color negative, which then could be enlarged and printed.

The first method for color coding in which the Adicol viewer was used employed the LARS system and four channels that were invariant for all classifications. The color-coded output of this method is illustrated in figure 15. For this presentation, the available colors were restricted to white, black, and the three primary colors and their complements. Black represented unclassified samples. For example, because there were no road or bare-earth classifications, roads appeared black. White was chosen to represent two classifications that were so different in habitat that little likelihood of confusion would exist. These classifications were sawgrass, found only in very wet areas of freshwater marsh, and unidentified grasses, represented primarily by lawns and pasture grasses on higher elevations.

The second color display (fig. 16) was used for the DTL classification. For this display, 27 different colors were available; thus, there was no necessity for using the same color twice.

The results of initial field checks performed by using both the LARS and the DTL presentations indicate that the DTL method is more accurate. In particular, when the cattail classification is examined, those areas classified as cattail in the LARS display (fig. 15) are unclassified when the DTL system is used (fig. 16). Also, the latter display is more accurate because the unclassified areas represent two differing plant communities, Distichilis spicata and Eleocharis microcarpa, for which there were no training fields. It is obvious, then, that these areas should be unclassified. Studies are currently in progress to determine the percentage accuracies of both classifications by using statistical sampling methods coupled with field studies.

INTERRELATIONSHIPS BETWEEN VEGETATION AND OTHER ECOLOGICAL FACTORS

Earlier in this report, a correlation was shown for both salinity and mean water depth with the plant communities that would be present in a marsh having these conditions. During the life cycle of the salt marsh mosquito (Aedes sollicitans), the female lays eggs only on soil or leaf litter interstices between plants where there is a periodic removal of water by tidal action. The eggs will not hatch until they are immersed in freshwater. The female of this species of mosquito cannot lay her eggs on land that is primarily covered with water. Conversely, if the eggs are laid in an area where there is no periodic flooding, they will not hatch. Thus, the range for egg laying is restricted to the intertidal area of the marsh that is intermittently flooded with freshwater.[3] By observing the marsh vegetation, it is found

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[3]Samuel Riché, personal communication, Oct. 1971.

that the spikerush/wiregrass association is characteristic of this area.[3] By contrast, stands of cattail, white waterlily, pine and other shrubs, sawgrass, four-square grass, and Eleocharis microcarpa are found in areas where the favorable egg-laying habitat does not exist.

By use of the preceding information, the computer is programed to combine or lump the characters that represent each type of vegetation found in the area that is intermittently flooded with freshwater and to present the total as one character that represents positive mosquite-breeding areas. Likewise, the computer is programed to add the characters representing other vegetation and to present them as one character representing negative mosquito-breeding areas. The computer output can then be presented (by use of a photographic process to produce the final product) as a color-coded display reflecting positive mosquito-breeding areas in red and negative mosquito-breeding areas in green. Figure 17 is an example of this product. Note that both water and vegetation-covered water are displayed in blue for identifying landmarks; unclassified elements are displayed in white for the same reason. The value of such a display becomes obvious when it is realized that its use may well restrict areas of stern measures for mosquito control to much smaller portions of the map. Savings to be gained are twofold: less expenditure and the confinement of toxic sprays to more restricted areas.

CONCLUDING REMARKS

A procedure has been described and demonstrated for classification of plant communities in a marsh area. The procedure involves the use of an airborne multi-spectral scanner, automatic pattern-recognition techniques, and limited ground measurements for calibration purposes. The procedure has been applied to the location of probable mosquito-breeding areas based on known relationships between these areas and certain plant communities. The procedure, which allows identification and classification of vegetation cover on a large scale, appears to offer significant potential for studying a variety of aspects of the ecology and ecological changes. For computer classification processing, the digital table look-up method proved to be faster, more economical, and more accurate than other documented pattern recognition software.

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National Aeronautics and Space Administration
Houston, Texas, June 13, 1975
160-75-85-03-72

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Zaitzeff, E. M.; Korb, C. L.; and Wilson, C. L.: MSDS: An Experimental 24-Channel Multispectral Scanner System. IEEE Transactions on Geoscience Electronics, vol. GE-9, July 1971, pp. 114-120.

TABLE I.- MULTISPECTRAL SCANNER CHANNEL ALLOCATION

Array number	Channel number	Bandwidth, μm	Detector	Absolute calibration source
0	1	0.34 to 0.4	Photomultiplier	uv/V/IR[a]
	2	.4 to .44		
	3	.46 to .5		
1	4	0.53 to 0.57	Silicon	uv/V/IR
	5	.57 to .63		
	6	.64 to .68		
	7	.71 to .75		
	8	.76 to .80		
	9	.82 to .87		
	10	.97 to 1.05		
2	11	1.18 to 1.30	Germanium	uv/V/IR
	12	1.52 to 1.73		
3	13	2.1 to 2.36	Indium antimonide	uv/V/IR
	14	3.54 to 4.0		Black bodies
	15	4.5 to 4.75		Black bodies
4	16	6.0 to 7.0	Mercury-doped germanium	Black bodies
	17	8.3 to 8.8		
	18	8.8 to 9.3		
	19	9.3 to 9.8		
	20	10.1 to 11.0		
	21	11.0 to 12.0		
	22	12.0 to 13.0		
2	23	1.12 to 1.16	Germanium	uv/V/IR
1	24	1.05 to 1.09	Silicon	uv/V/IR

[a]uv/V/IR = ultraviolet/visible/near infrared.

TABLE II.- CALIBRATION SOURCES

Wavelength region, μm	Source	Accuracy	Comments
0.35 to 2.5	Tungsten-quartz iodide	±2 percent	Traceable to National Bureau of Standards
.3 to 13	Two thermoelectrically heated and cooled black bodies	.25 K (.25° C)	Feedback-controlled black bodies designed by EG&G, Inc.
.35 to 1.5	Sky irradiance	--	Accuracy depends on signal-to-noise ratio, which depends on integration time

TABLE III.- TRAINING FIELDS SELECTED FROM FLIGHT LINE 5-1 FOR FRITCHIE MARSH INVESTIGATION

Training field number	Initial scan line	Last scan line	Initial element	Last element	Classification
5-1	10464	10472	601	613	Mixed Gramineae other than species separated below
5-2	10482	10490	638	650	Mixed Gramineae other than species separated below
5-3	10520	10528	569	581	Mixed Gramineae other than species separated below
5-4	10532	10540	629	641	Mixed Gramineae other than species separated below
5-5	10600	10616	557	585	Pine
5-7	10694	10710	437	467	Pine
5-9	10955	10971	279	301	Pine
5-10	11001	11013	279	301	Pine
5-11	11145	11161	298	320	Pine
5-14	11435	11447	269	287	Spartina patens/Juncus roemerianus
5-15	11465	11477	235	260	Eleocharis quadrangulata
5-19	11525	11537	461	472	Nymphaea odorata
5-20	11555	11567	445	457	Typa Sp.
5-23	11625	11637	470	482	Nymphaea odorata
5-25	11669	11681	209	221	Water
5-26	11679	11687	224	234	Water
5-28A	11793	11817	436	476	Cladium jamaicense
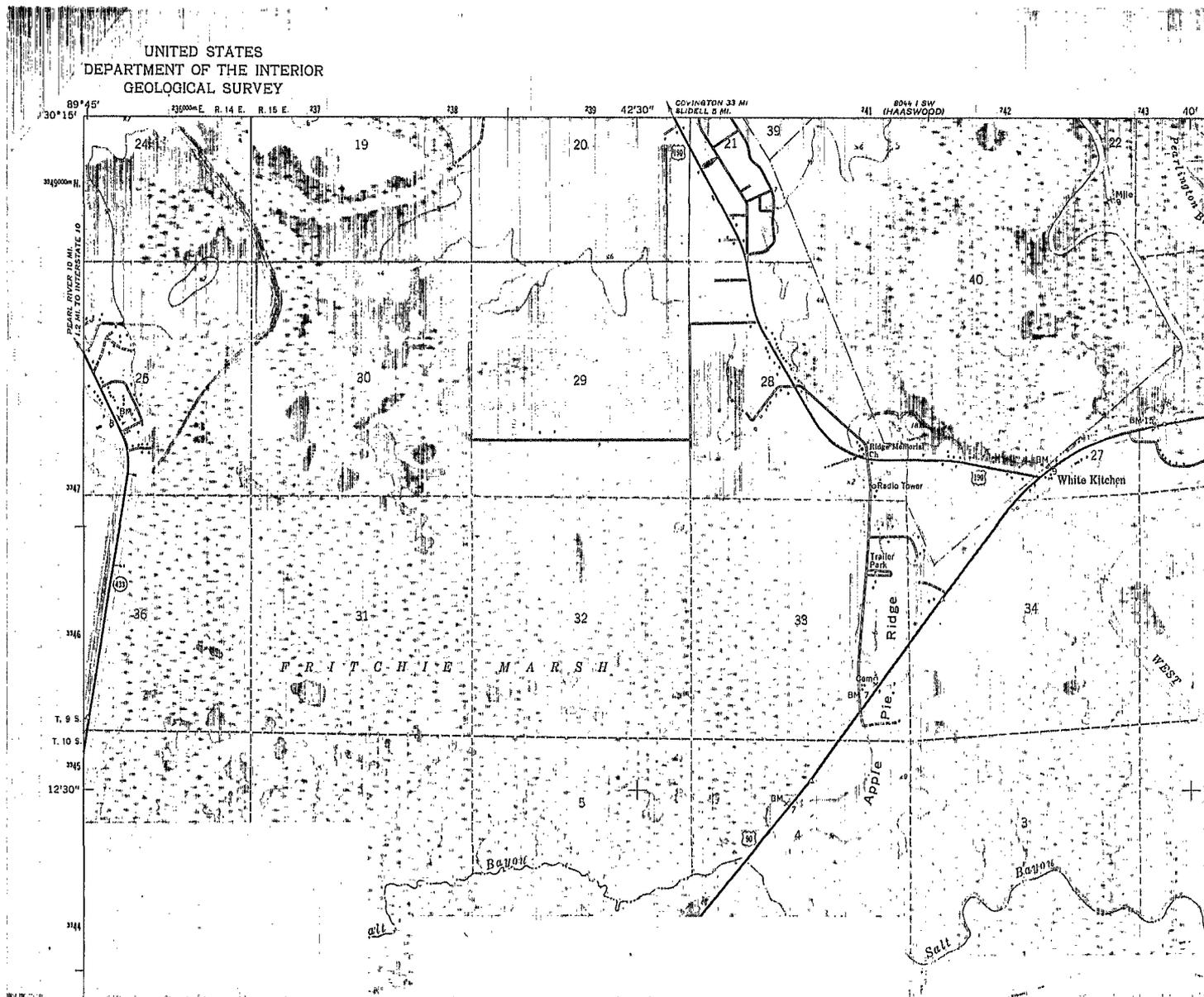
Figure 1.- Location map of Fritchie Marsh Study area.
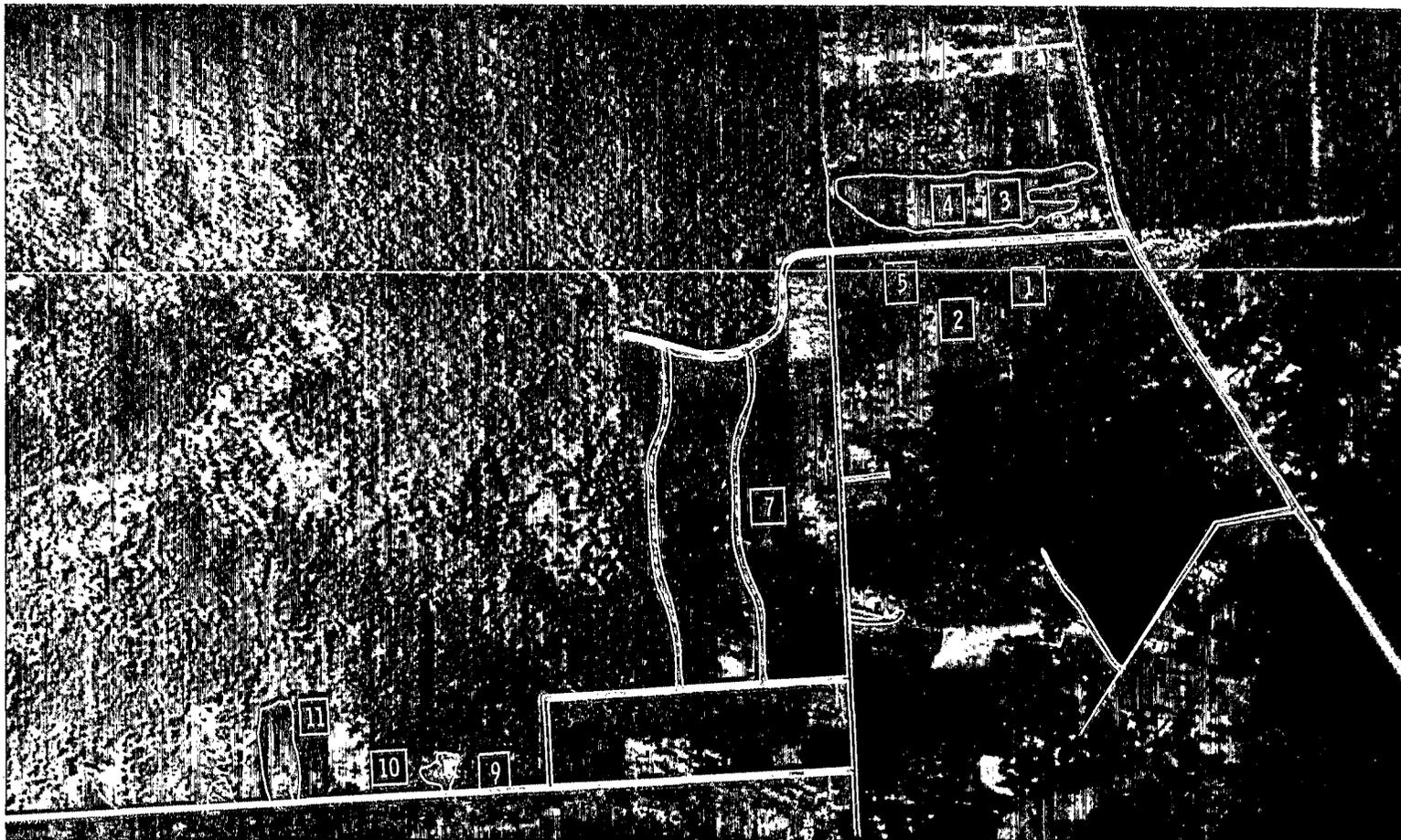
Figure 2.- Aerial photograph of study area showing locations of training fields 1 to
5, 7, and 9 to 11.

Figure 3.- Aerial photograph of study area showing locations of training fields 6,14, 15, 17 to 20, 23, 25, 26, and 28.

Figure 4.- An example of marshland plant succession.
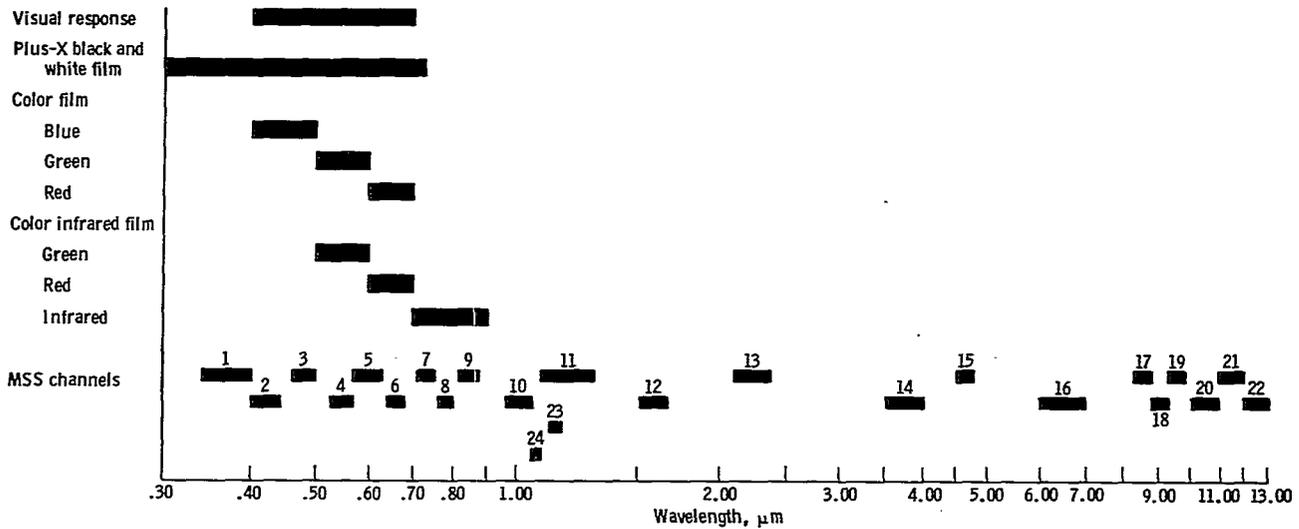
Figure 5.- Sensor spectral characteristics.
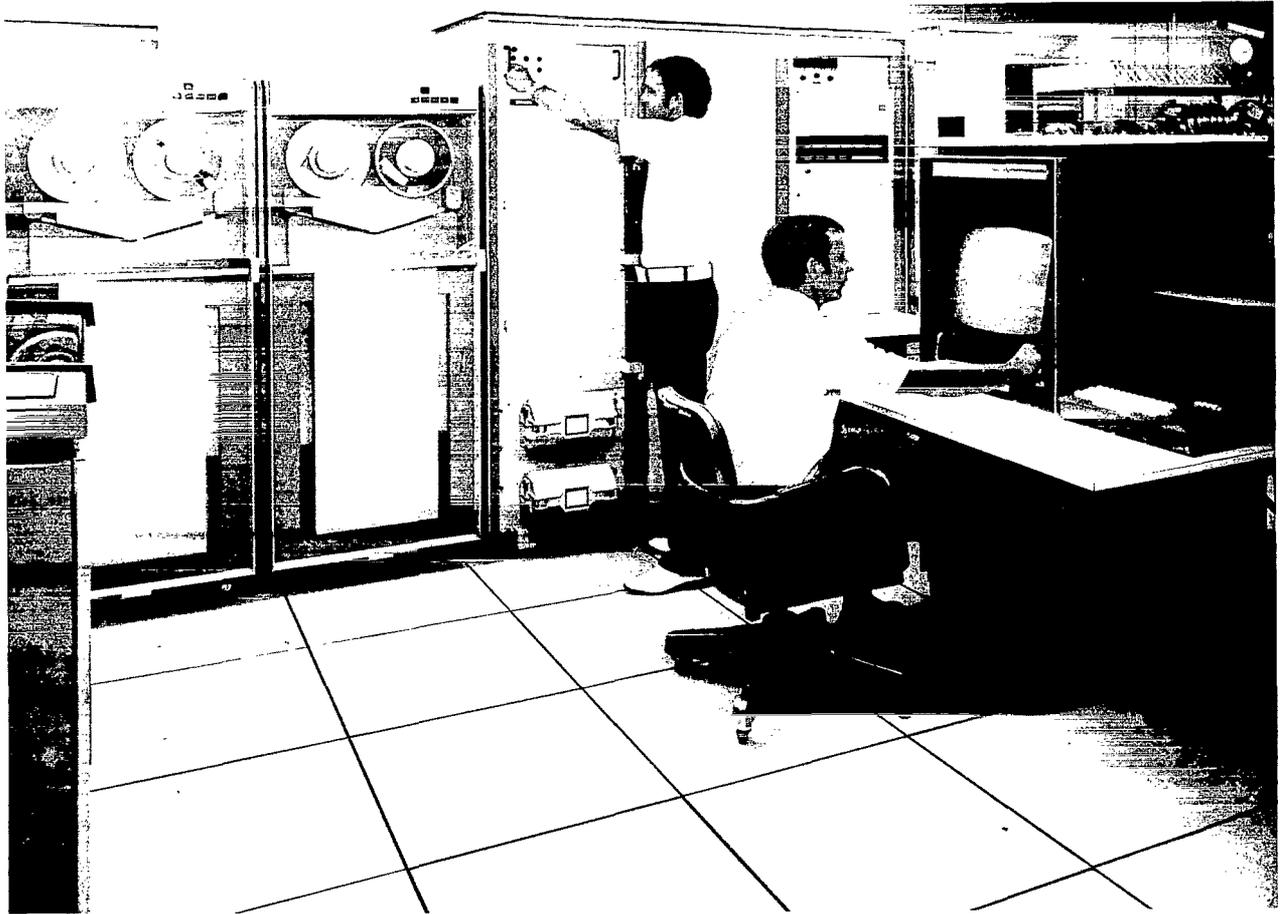
Figure 6.- Data analysis system ground station.
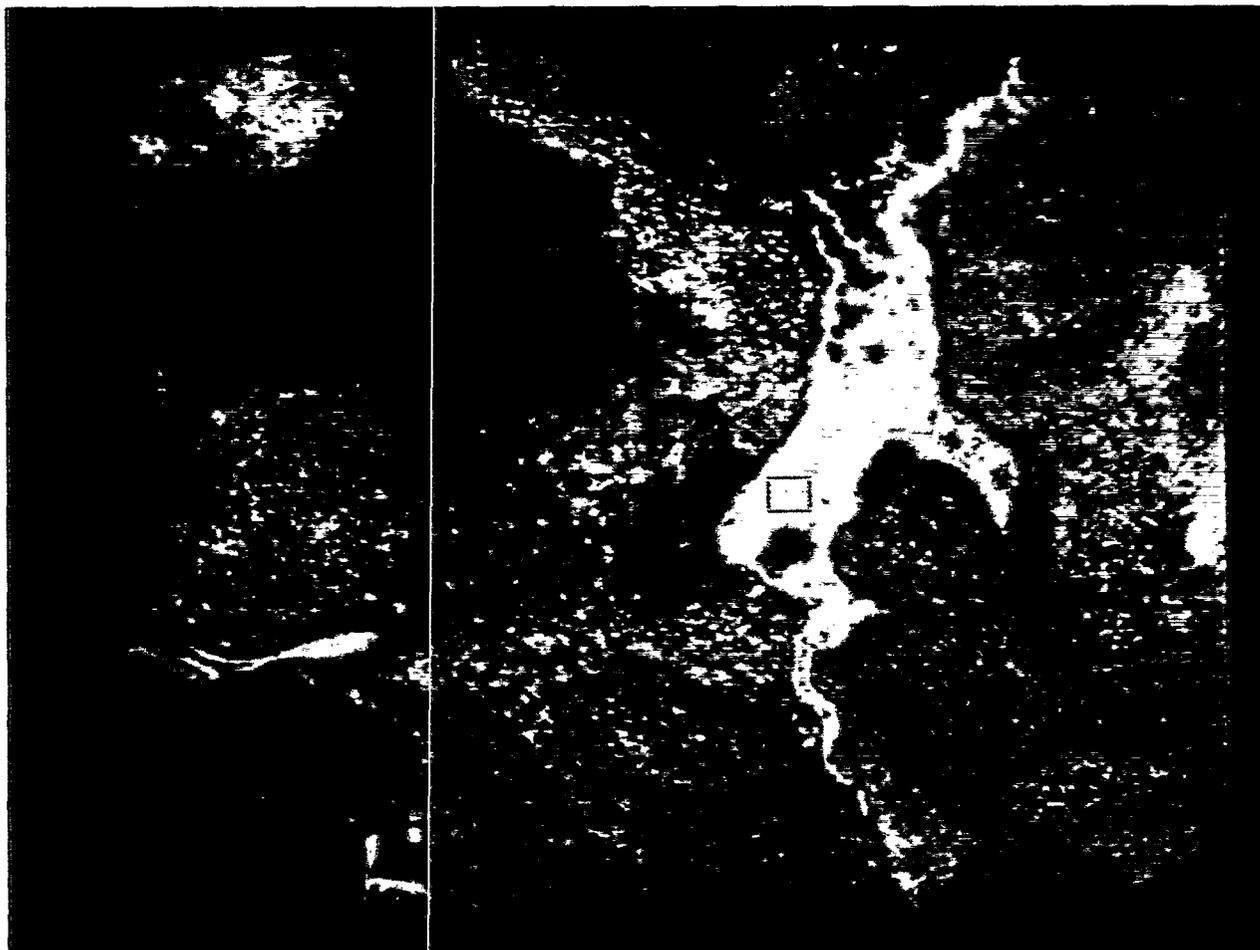
Figure 7.– Color display produced by using three channels of MSS-acquired data. The cursor, which encloses an area chosen as a training field, is shown within the lake, which is covered with aquatic vegetation (yellow area).

RUN NUMBER ... 26600061   DATE .... September 9, 1971

FLIGHT LINE .. 10   TIME .... 1521 hours

TAPE NUMBER .. ****   ALTITUDE ..... 1097 meters (3600 feet)

CHANNEL NUMBER 8   SPECTRAL RANGE 0.76 TO 0.080 micrometers

THE CHARACTER SET USED FOR DISPLAY IS

FROM   0 TO   33 DISPLAYED AS
FROM   34 TO   34 DISPLAYED AS –
FROM   35 TO   35 DISPLAYED AS =
FROM   36 TO   37 DISPLAYED AS /
FROM   38 TO   49 DISPLAYED AS I
FROM   50 TO   59 DISPLAYED AS *
FROM   60 TO   64 DISPLAYED AS X
FROM   65 TO   69 DISPLAYED AS 0
FROM   70 TO   195 DISPLAYED AS 8
FROM 196 TO   229 DISPLAYED AS M
FROM 230 TO   233 DISPLAYED AS W
FROM 234 TO   237 DISPLAYED AS W
FROM 238 TO   241 DISPLAYED AS W
FROM 242 TO   245 DISPLAYED AS W
FROM 246 TO   249 DISPLAYED AS W
FROM 250 TO   255 DISPLAYED AS W
ILLEGAL DATA VALUES DISPLAYED AS $

Figure 8.– An example of a PICTOUT display.

FLIGHT 10-5-1, LINES 11250-11950, ELEMENTS 241 TO 460

SPARTINA PATENS/JUNCUS ROEMERIANUS

RUN NO. 26600061, FIELD 5-22
NO. OF SAMPLES = 169; FROM LINES 11595 TO 11607 (EVERY 1 LINE), SAMPLES 96 TO 108 (EVERY 1 SAMPLE)

THE COVARIANCE AND MEAN FOR TRAINING FIELD 5-22

	0.46 TO 0.50	0.57 TO 0.63	0.71 TO 0.75	0.76 TO 0.80	0.82 TO 0.87	0.97 TO 1.05	1.18 TO 1.30	2.10 TO 2.36	8.30 TO 8.80	9.30 TO 9.80	10.10 TO 11.00	1.05 TO 1.09
MEAN	41.46	45.79	45.57	66.17	57.41	54.56	63.11	13.71	86.92	98.20	226.77	81.26
STANDARD DEVIATION	1.85	2.28	2.46	4.84	4.49	4.08	5.07	2.96	5.73	5.93	5.95	8.15

COVARIANCE MATRIX

0.46 TO 0.50	0.57 TO 0.63	0.71 TO 0.75	0.76 TO 0.80	0.82 TO 0.87	0.97 TO 1.05	1.18 TO 1.30	2.10 TO 2.36	8.30 TO 8.80	9.30 TO 9.80	10.10 TO 11.00	1.05 TO 1.09
3.40											
.43	5.19										
.46	.76	6.06									
-.36	.26	10.12	23.44								
.99	1.30	9.44	18.46	20.17							
.74	.03	8.22	17.11	16.06	16.64						
1.26	-.72	8.93	17.99	17.10	18.88	25.73					
.36	-.04	1.42	2.56	1.53	3.54	6.65	8.80				
1.42	-.32	1.71	2.47	.13	3.06	7.43	5.92	32.85			
.13	-1.27	1.06	2.26	-1.16	5.12	11.55	6.43	14.03	35.05		
2.71	-.17	1.91	1.65	4.76	6.52	10.24	4.06	7.59	11.53	35.36	
.61	1.48	14.21	27.81	28.00	27.11	27.75	2.89	1.68	2.49	10.20	66.65

Figure 9.- Mean calculations and covariance matrix of the STAT program for train-
ing field 5-22.

HISTOGRAM FOR SPARTINA PATENS/JUNCUS ROEMERIANUS

CHANNEL 9   .82 -   .87 microns

    EACH * REPRESENTS 4 POINT(S)

```
60 1
56 1
52 1
48 1                                                          2
44 1                                                          *
40 1                                                         1*
36 1                                                         **
32 1                                                         **
28 1                                                         **
24 1                                                        3***
20 1                                                        ****
16 1                                                       3****
12 1                                                      *****2
 8 1                                                     1******
 4 1                                                   11********3
   +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
    255       230       204       179       153       128       102       77        51        26        0
```
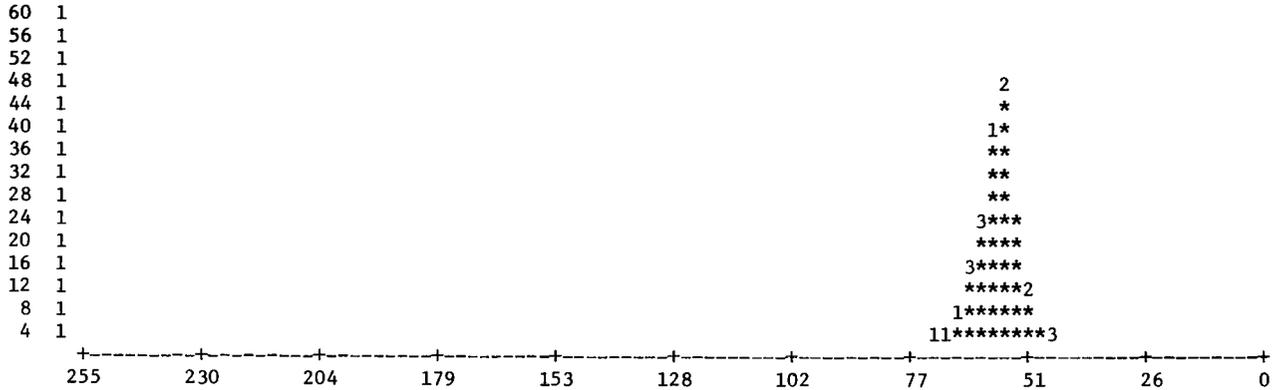
CHANNEL 10   .97 - 1.05 microns

    EACH * REPRESENTS 5 POINT(S)

```
75 1
70 1
65 1                                                          2
60 1                                                          *
55 1                                                          *
50 1                                                          *
45 1                                                          *
40 1                                                          *
35 1                                                          *
30 1                                                         4*
25 1                                                        **41
20 1                                                        ****
15 1                                                        ****1
10 1                                                       3*****3
 5 1                                                       3*******3
   +---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
    255       230       204       179       153       128       102       77        51        26        0
```
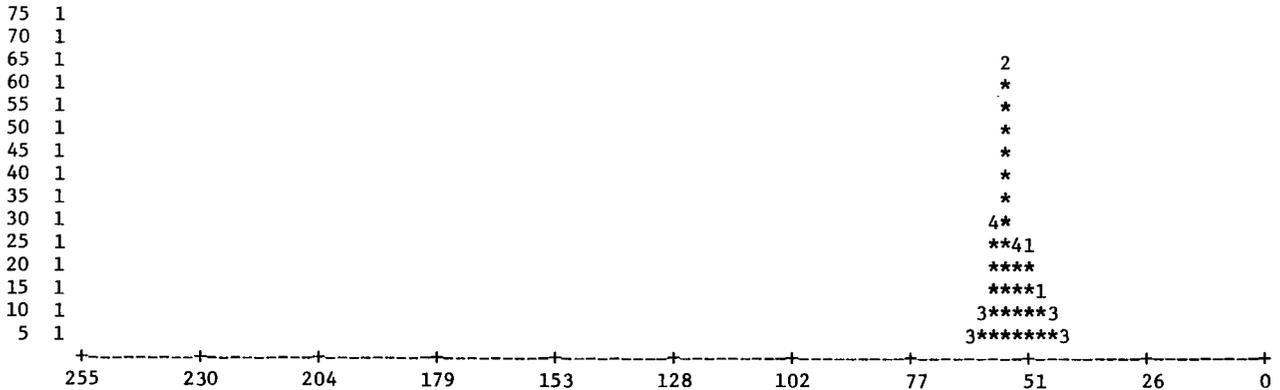
Figure 10.- A STAT program histogram of two channels (5 and 6) of recorded data
for Spartina patens/ Juncus roemerianus training fields. The abscissa is relative
radiance (increasing toward the left); the ordinate values are the number of reso-
lution elements having a particular radiance in the training field.

D SPARTINA PATENS/JUNCUS ROEMERIANUS

SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS*D

```
        LEGEND    + = CLASS D
                  + 11          (+)233

    20 I------------------------------------------------------------------------------I 20
    23 I                                                                              I 23
    26 I                                                                              I 26
    29 I                                                                              I 29
    32 I                                                                              I 32
    35 I                                                                              I 35
    38 I                                                                              I 38
    41 I      +                                                                       I 41
    44 I      +      +      +                                                         I 44
    47 I             +      +                                                         I 47
    50 I                                 +                                            I 50
    53 I                          +      +                                            I 53
    56 I                          +      +                                            I 56
    59 I                          +      +      +                                     I 59
    62 I                   +      +             +                                     I 62
    65 I                   +                    +                                     I 65
    68 I                   +                    +                                     I 68
    71 I                   +                                                          I 71
    74 I                                                                   +          I 74
    77 I                                                                   +          I 77
    80 I                                              +                     +          I 80
    83 I                                              +                     +          I 83
    86 I                                              +                     +          I 86
    89 I                                              +                                I 89
    92 I                                              +      +                         I 92
    95 I                                                     +                         I 95
    98 I                                                     +                         I 98
   101 I                                                     +                         I 101
   104 I                                                     +                         I 104
   107 I                                                                              I 107
   110 I                                                                              I 110
   113 I                                                                              I 113
   116 I                                                                              I 116
   119 I                                                                              I 119
   122 I                                                                              I 122
   125 I                                                                              I 125
   128 I                                                                              I 128
   131 I                                                                              I 131
   134 I                                                                              I 134
   137 I                                                                              I 137
   140 I                                                                              I 140
   143 I                                                                              I 143
   146 I------------------------------------------------------------------------------I 146
```
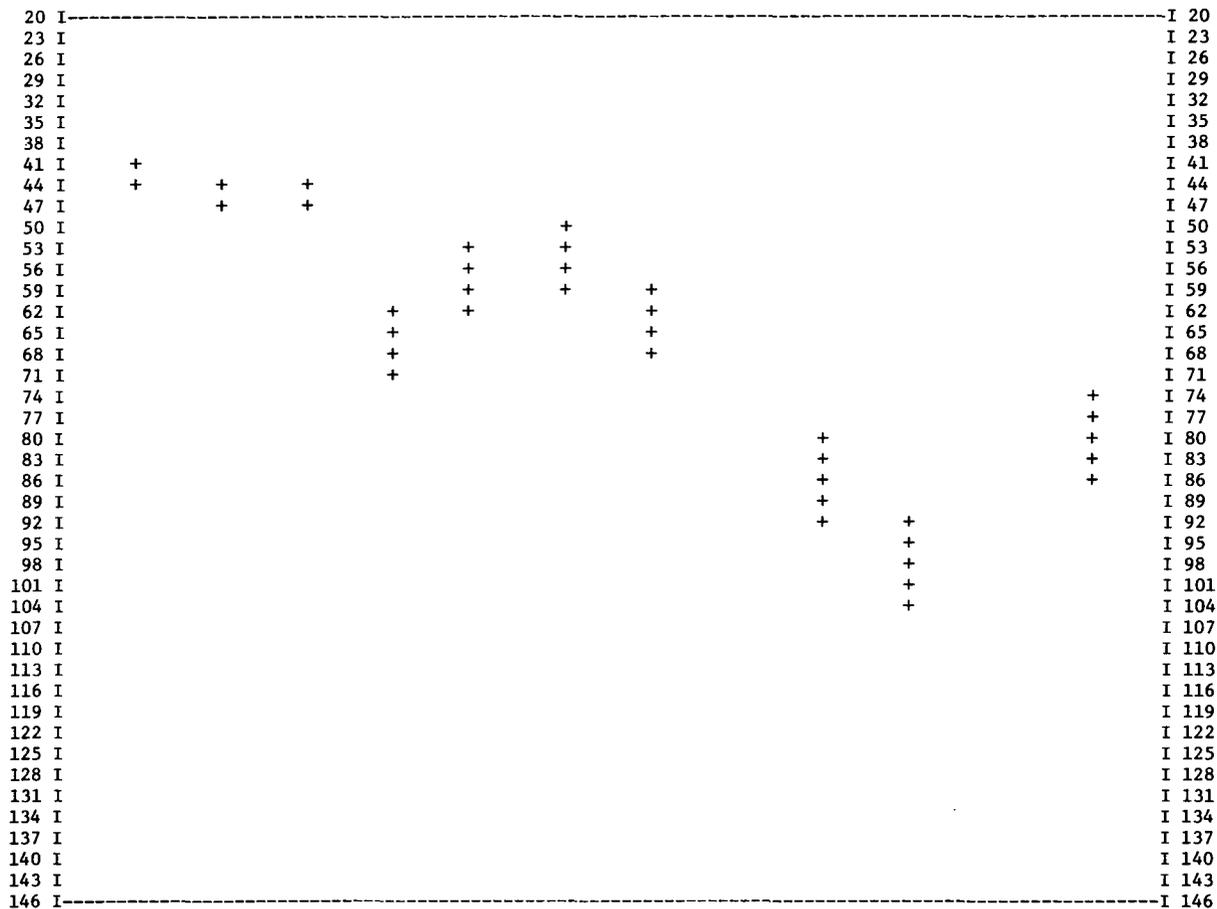
(a) Spartina patens/ Juncus roemerianus association (training class D).

Figure 11.- Spectral plots produced by the STAT program.

24

WATER

RUN NO. 26600061, FIELD 5-25
NO. OF SAMPLES = 169, FROM LINES 11669 TO 11681 (EVERY 1 LINE(S)), SAMPLES 189 TO 201 (EVERY 1 SAMPLE(S))

SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING FIELD 5-25

```
       LEGEND   + = FIELD 5-25
                (+) 2          (+)212


    20 I------------------------------------------------------------------------------------------I 20
    23 I                                                        +                                 I 23
    26 I                                           +                                              I 26
    29 I                    +             +        +       +                              +       I 29
    32 I              +     +       +     +                +                              +       I 32
    35 I        +     +             +                                                     +       I 35
    38 I        +                                                                         +       I 38
    41 I        +                                                                                 I 41
    44 I                                                                                          I 44
    47 I                                                                                          I 47
    50 I                                                                                          I 50
    53 I                                                                                          I 53
    56 I                                                                                          I 56
    59 I                                                                                          I 59
    62 I                                                                                          I 62
    65 I                                                                                          I 65
    68 I                                                       +                                  I 68
    71 I                                                       +                                  I 71
    74 I                                                       +                                  I 74
    77 I                                                             +                            I 77
    80 I                                                             +                            I 80
    83 I                                                             +                            I 83
    86 I                                                             +                            I 86
    89 I                                                                                          I 89
    92 I                                                                                          I 92
    95 I                                                                                          I 95
    98 I                                                                                          I 98
   101 I                                                                                          I 101
   104 I                                                                                          I 104
   107 I                                                                                          I 107
   110 I                                                                                          I 110
   113 I                                                                                          I 113
   116 I                                                                                          I 116
   119 I                                                                                          I 119
   122 I                                                                                          I 122
   125 I                                                                                          I 125
   128 I                                                                                          I 128
   131 I                                                                                          I 131
   134 I                                                                                          I 134
   137 I                                                                                          I 137
   140 I                                                                                          I 140
   143 I                                                                                          I 143
   146 I                                                                                          I 146
   149 I                                                                                          I 149
   152 I                                                                                          I 152
   155 I                                                                                          I 155
   158 I                                                                                          I 158
   161 I                                                                                          I 161
   164 I                                                                                          I 164
   167 I                                                                                          I 167
   170 I------------------------------------------------------------------------------------------I 170
         I     I     I     I     I     I      I     I     I     I      I      I
SPECTRAL BAND  .46   .57   .71   .76   .82   .97   1.18  2.10  8.30  9.30  10.10  1.05
 (MICRONS)     .50   .63   .75   .80   .87   1.05  1.30  2.36  8.80  9.80  11.00  1.09
```
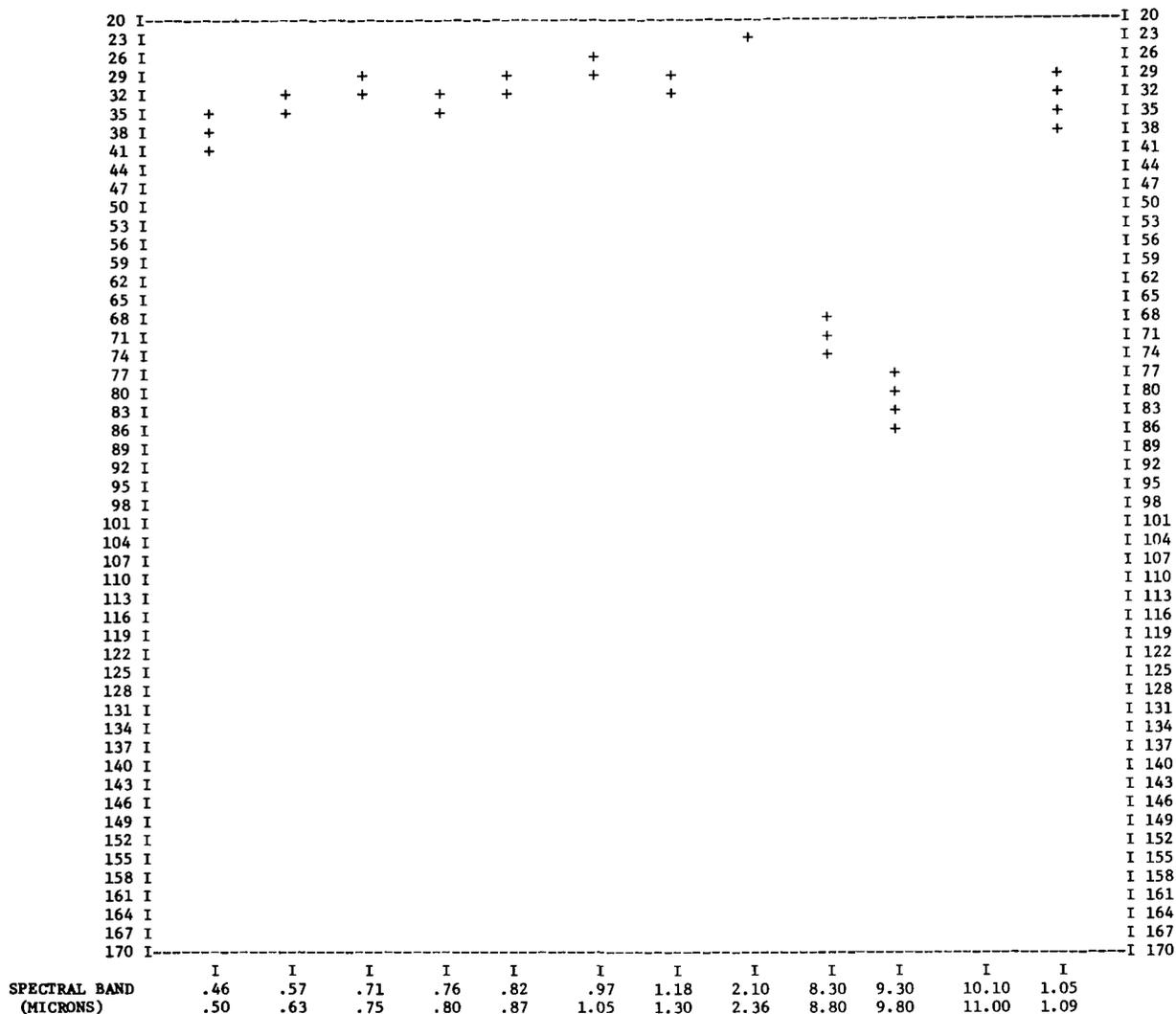
(b) Training field for water (5-25).

Figure 11.- Concluded.

SELECT 16 CLASSES 35 FIELDS 12 FEATURES BEST 4

CONTINUED...   M
RESTORED DATA   MINIMUM 0
RETENTION LEVEL .. 82   MAXIMUM 30000

	Channel no.				BK* (10)	BH (10)	BE (10)	BD (10)	BI (10)	BO (10)	KH (10)	KE (10)	KD (10)	KI (10)
1.	7	8	10	11	1	93	73	97	10	89	65	59	73	6
2.	7	8	9	11	1	90	77	97	9	93	63	60	74	6
3.	8	9	10	11	1	78	45	83	11	46	58	39	68	7
4.	7	8	11	24	2	95	77	100	11	93	65	58	74	6
5.	5	7	8	11	6	98	70	101	16	87	63	57	75	14
6.	3	8	10	11	1	89	46	79	15	47	66	44	67	9
7.	8	10	11	20	1	73	44	77	12	46	54	39	63	7
8.	8	10	11	19	1	72	43	78	10	43	55	37	64	7
9.	5	8	10	11	5	80	51	82	16	59	55	50	69	13
10.	7	8	11	19	1	91	71	99	10	83	64	56	75	7
11.	8	10	11	17	1	71	45	77	10	43	54	39	63	7
12.	8	10	11	13	1	72	46	82	10	45	54	38	63	7
13.	7	8	11	20	1	91	68	98	11	85	63	52	72	6
14.	3	7	8	11	2	112	68	98	14	85	79	55	74	8
15.	8	10	11	24	1	71	41	76	11	44	53	36	62	7
16.	7	8	11	13	1	91	73	100	10	84	63	55	72	7
17.	7	8	11	17	1	91	70	97	9	83	64	55	73	7
18.	7	8	9	10	1	86	55	51	8	81	59	45	41	6
19.	8	9	11	19	1	76	44	86	10	44	57	37	71	8
20.	8	9	11	24	1	79	44	85	11	46	57	37	68	6

*Differentiation of vegetation types
(e.g., type B (Nymphaea odorata) as
compared to type K (Typha latifolia)).

Figure 12.- An example of the SELECT program: a comparison of the white water-
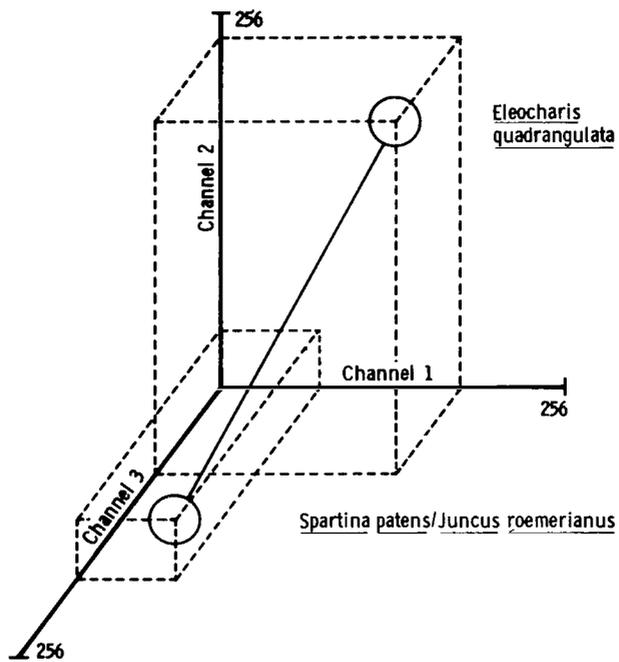lily to a number of different classifications.

Figure 13.- An example of space
partitioning in three-dimensional
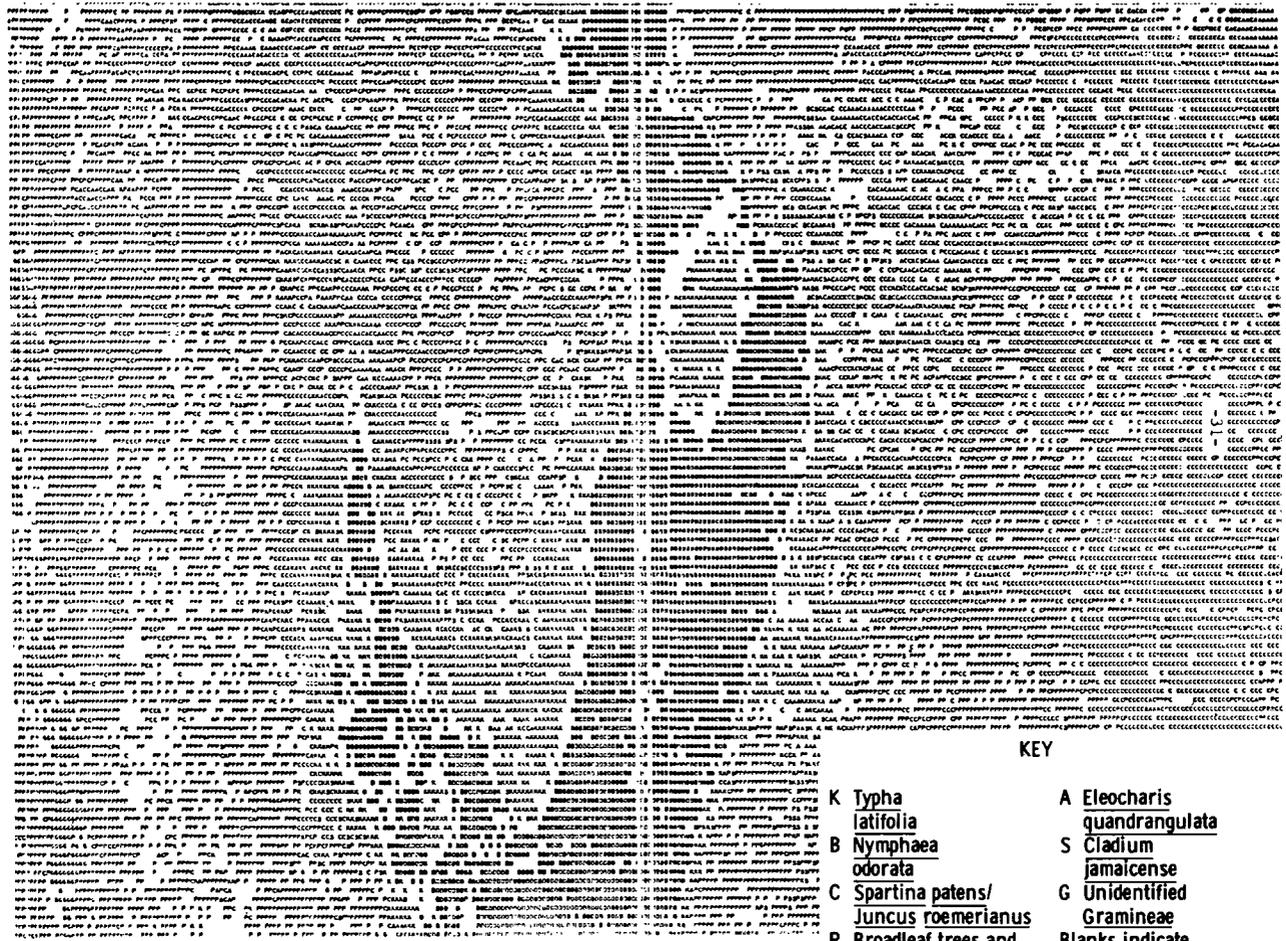space using three channels for
classification.

KEY

K Typha
  latifolia
B Nymphaea
  odorata
C Spartina patens/
  Juncus roemerianus
P Broadleaf trees and
  shrubs combined

A Eleocharis
  quandrangulata
S Cladium
  jamaicense
G Unidentified
  Gramineae
Blanks indicate
unclassified elements

Figure 14.- An example of a character printout in which each letter represents a
specific classification.

Figure 15.– An example of a color–coded output of the CLASSIFY program produced by using the LARS system.
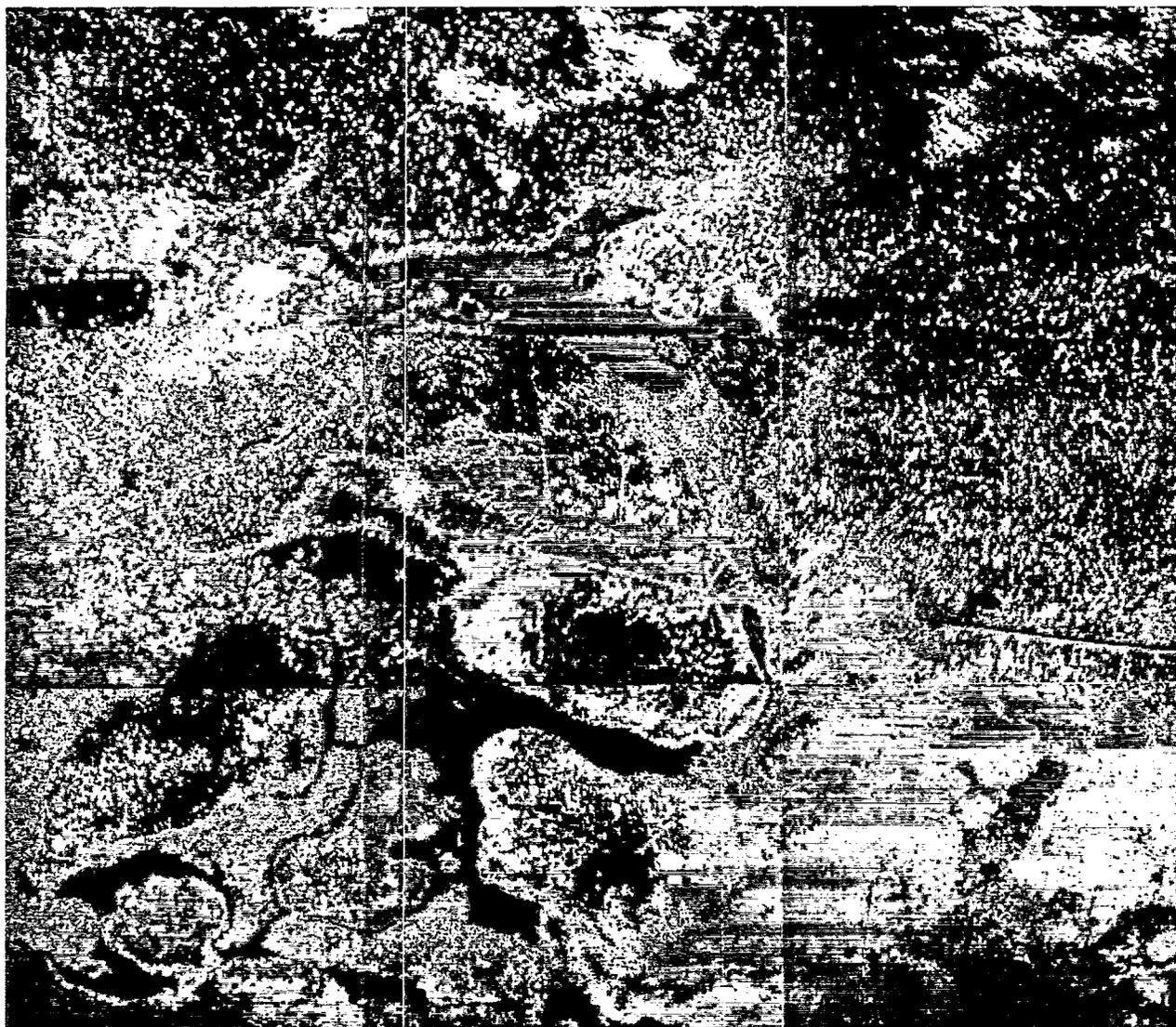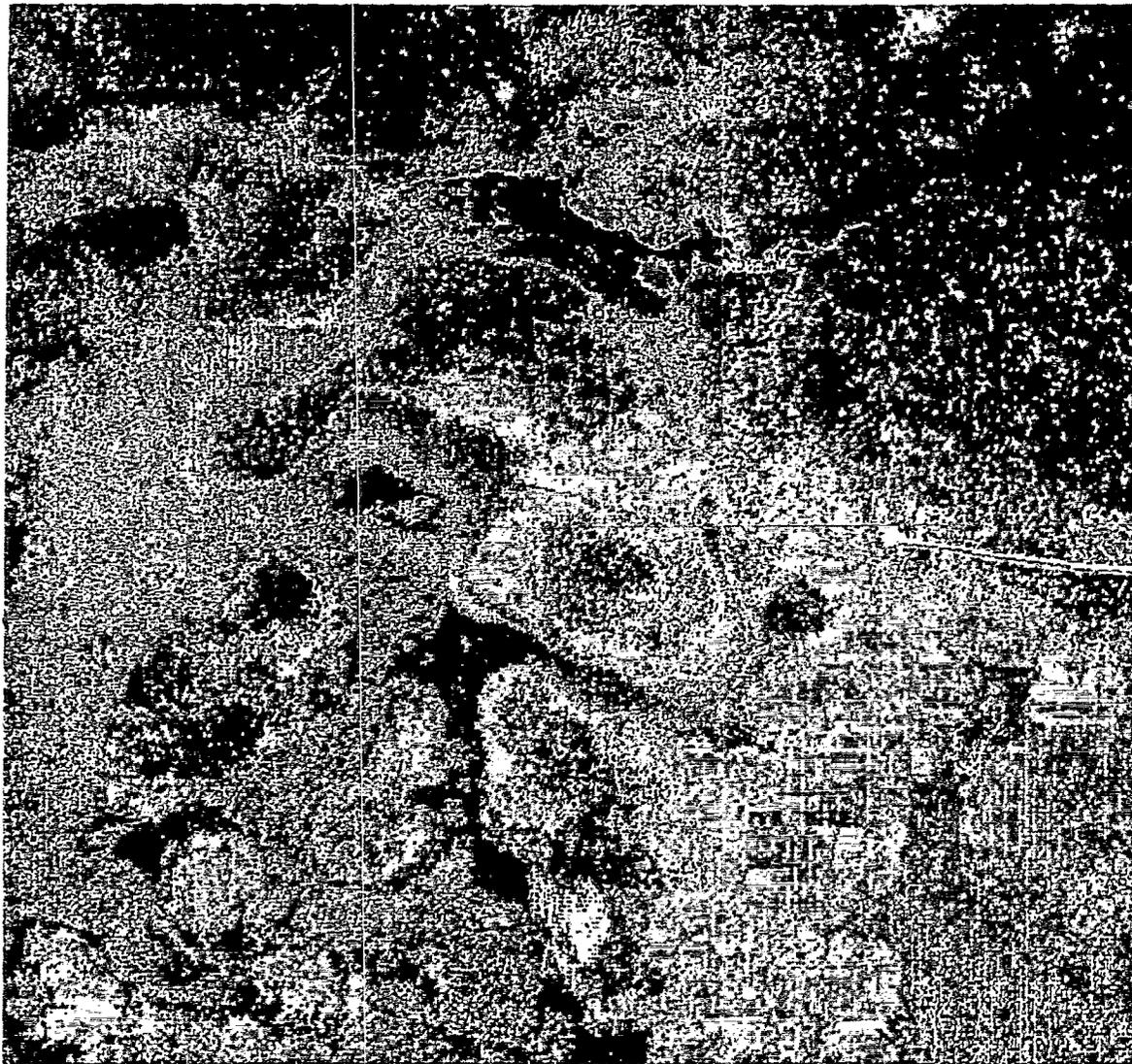
Spartina patens and Juncus roemerianus		Unidentified Gramineae	
Trees and shrubs		Cattails (Typha species)	
Sawgrass (Cladium jamaicense)		Waterlily (Nymphaea odorata)	
Open water		Eleocharis quadrangulata	
Unclassified			

Figure 16.- An example of a color-coded output produced by using DTL classification.
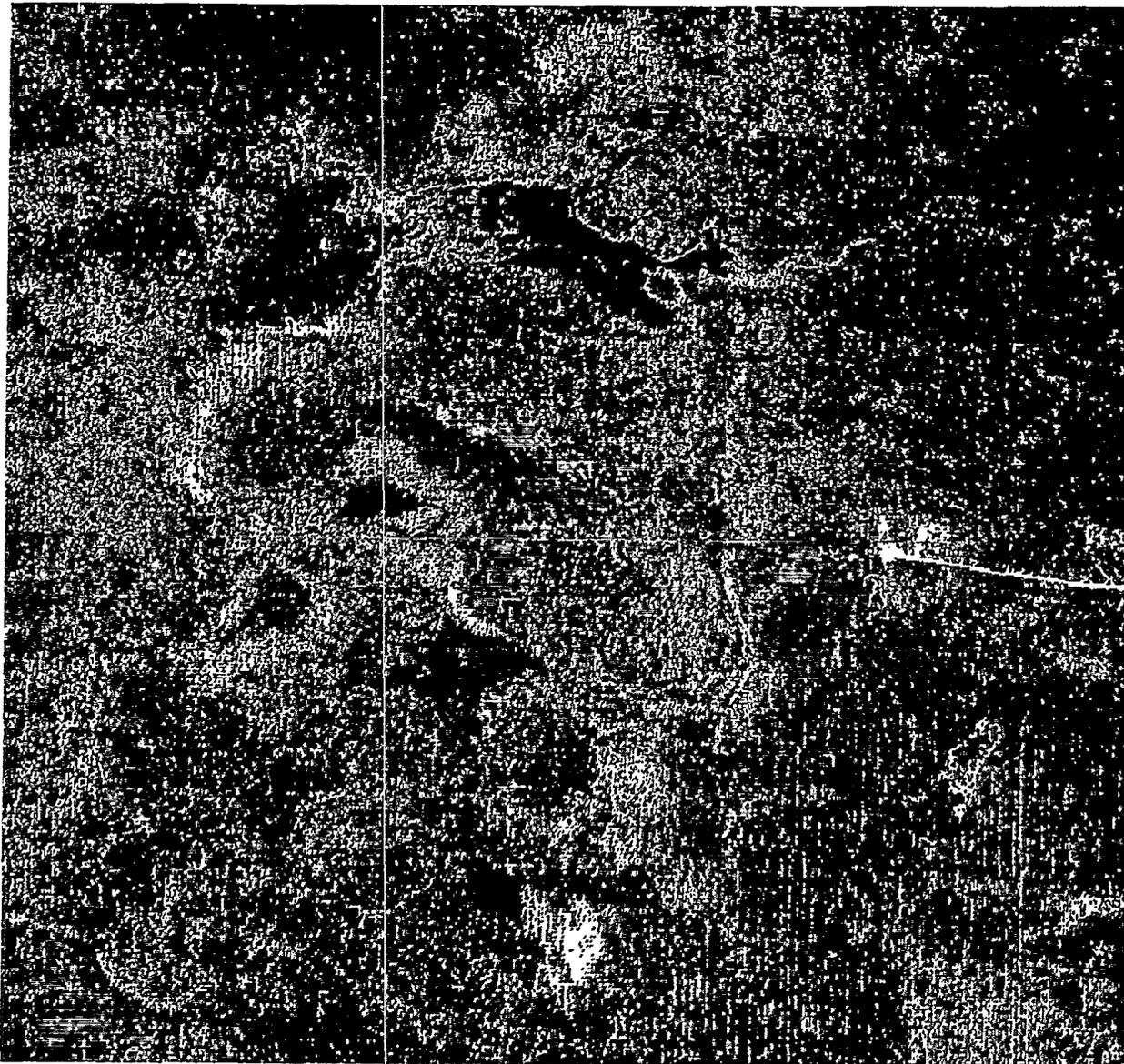
Positive mosquito-breeding areas	▇	Water		▇
Negative mosquito-breeding areas	▇	Unclassified		▤

Figure 17.- An example of a color-coded output showing positive and negative mosquito-breeding areas.

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            —NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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