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MONITORING OF A PHOSPHATE MINING AREA IN CENTRAL FLORIDA USING LANDSAT SATELLITE DATA

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MONITORING OF A PHOSPHATE MINING AREA IN CENTRAL
FLORIDA USING LANDSAT SATELLITE DATA

by

Michael Inglis¹ and Thomas K. Budge²

ABSTRACT

This document contains an investigation into the applicability of Landsat MSS satellite data and simulated thematic mapper data to the phosphate mining area of central Florida. An evaluation is made of these sensors as mine monitoring tools. The report describes the computer software and hardware used in the digital analysis of the scanner data, the theory of unsupervised classification, the methodology of image processing, and documents the classification of selected mining and wetland areas. Conclusions are discussed and recommendations are made for future investigations.

INTRODUCTION

Florida is the leading producer of phosphate rock in the world, supplying about 80% of domestic requirements and 30% of the world's requirements. Present production in Florida is about 40 million tons annually and increasing at 3% per year. Phosphate mining disturbed over 6,000 acres in 1980 with an expected increase as the industry continues to expand.

Since the discovery of phosphate in the Bone Valley District of central Florida near Fort Meade in 1881, disturbed land surfaces have become a characteristic of phosphate mining in

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Florida. As mining practices have changed so has the resulting terrain. Initially, the widening of rivers resulting from river channel hydraulic dredging was the only physical change, but by 1920 a move to land surface mining and the use of draglines took place. Overburden piled in windrows and mined out pits were typical of mined land. Today these pits are normally steep sided and water-filled and the windrows are, in most cases, heavily vegetated. With the advent of the flotation process the recovery of phosphate increased, but resulted in the accumulation of fine sand tailings and very fine grained silts and clays. In order to store the suspended clays and silts for dewatering they are pumped back into mined out pits enclosed by dikes. Overburden and tailings materials are used in the construction of these dikes.

Two land surfaces associated with past mining are present today. The random rows or piles of overburden and open pits, a result of mining prior to the use of flotation; and, since that time the appearance of tailings and settling ponds. In many cases, 1.5 times the volume mined is left in settling ponds as fluid clays and silts. In 1977 an estimate of 127,578 acres of mined lands was made by the state of Florida Department of Natural Resources; 100,000 acres have been mined since 1956, and 58,704 acres were inventoried as settling ponds¹.

Prior to 1947, there was no concerted reclamation effort. In 1947 an agreement between the Lakeland Chamber of Commerce and

¹Phosphate Land Reclamation Study Commission Report to Reubin Askew, Governor of Florida, on Phosphate Mining and Reclamation, 1977, pp. 1-8.

the phosphate industry was struck which initiated reclamation. In 1960, after numerous efforts towards reclaiming the land by several members of the phosphate industry, eight companies established a Land Use and Reclamation Committee through the Florida Phosphate Council to coordinate and promote reclamation. As a result of these efforts, a reclamation program known as "land and lakes" resulted which demonstrated the economic feasibility of reclaiming through proper planning.

In 1972 the Florida state legislature imposed a severance tax on solid minerals from the soils and waters of Florida. As a result of this legislation, mining companies were encouraged to reclaim the lands they disturbed. In 1975 the Florida legislature revised previous legislation to include, among others, mandatory reclamation and authorized the Department of Natural Resources to establish time schedules for completion of reclamation and restoration programs.

To implement an inventory program for the phosphate mining industry it is necessary to develop a cost effective system by which acreage figures and land condition (or change) can be determined accurately. An inventory of mining and reclamation performed in 1977 utilized high altitude color infrared photography for orientation and interpretation. The use of aerial coverage was quite successful but would be expensive should it be required annually. Due to the low cost per unit area for data acquisition relative to aerial photography, Landsat satellite data came under consideration. Should Landsat be effectively applied, many other characteristics of the data could

be applied to large area inventories. These include rapid area measurement, geometric correction, flexible map scale output, and frequent data availability.

In an effort to apply Landsat technology, the Technology Application Center (TAC) contracted with the U. S. Bureau of Mines to examine the effectiveness of the satellite data in performing cover type classifications in the phosphate mining area of central Florida. A methodology was developed to analyze the data from one Landsat scene (34,225 sq. km) to identify mining and mine reclamation activities. These activities include clearing prior to mining, mining, sand tailings disposal, settling pond sites, and reclaimed areas.

Just after receipt of the contract, a modification was made to include a simulated flight of thematic mapper (TM) data over the proposed test area. Although originally the MSS of Landsat was to be the single data source for this study, the contract overlapped the launch of Landsat 4. Landsat 4 was to contain a MSS system as have all previous Landsat satellites, but also a thematic mapper (TM) with its greatly improved spatial resolution (30 meters by 30 meters) and 7 channels of spectral data rather than the 4 provided by MSS. Anticipating this future technology, simulated thematic mapper and color infrared aerial photography was required. The area selected for study is shown in Figure 1. The quality of data received was excellent and led to the use of TM as the principal data source for accurate cover type type classifications. The color infrared photography was important in field verification and classification.

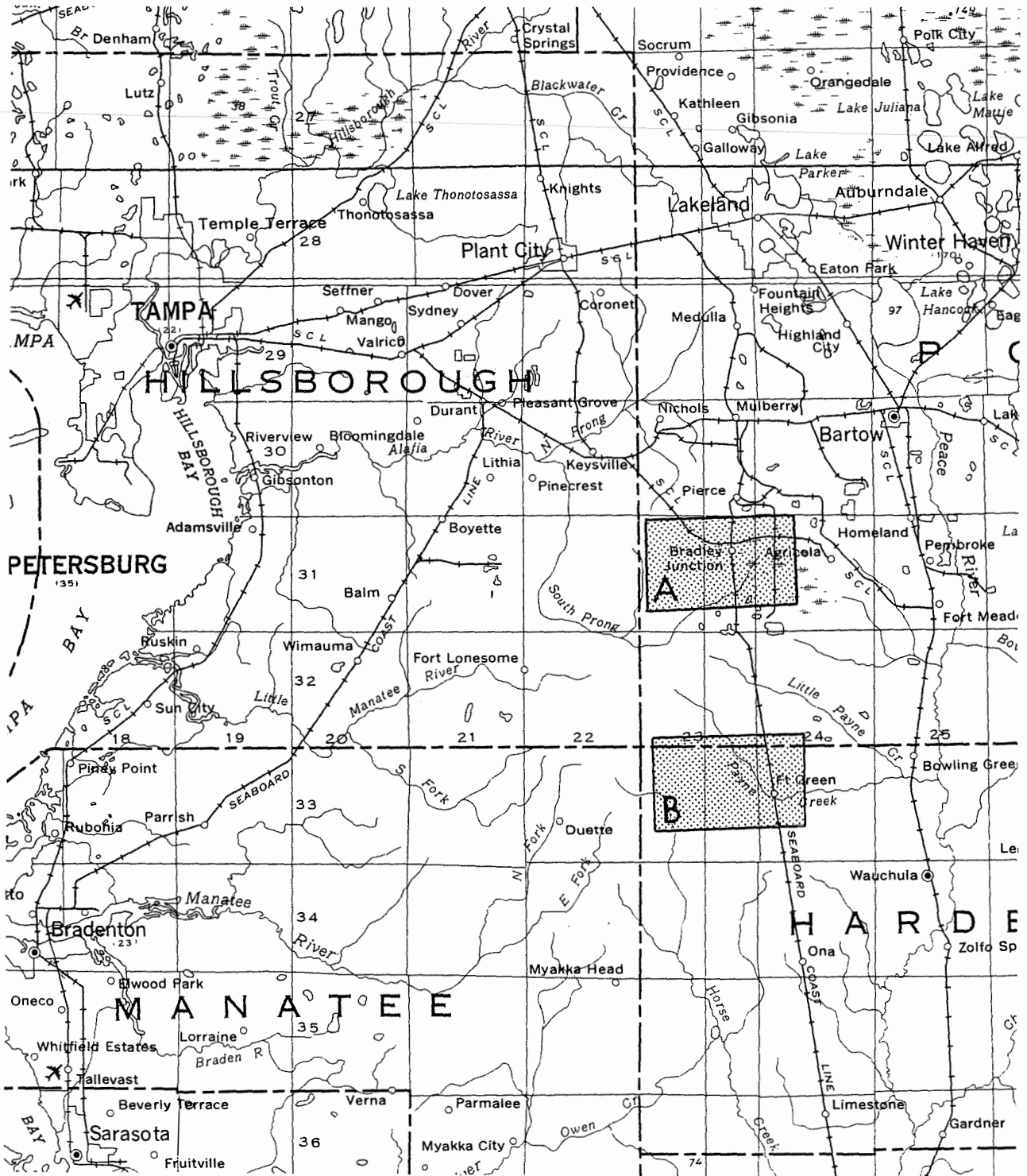


Figure 1. Phosphate Mining Region of Central Florida.
 A. Mine study site.
 B. Wetland study site.

From the simulated TM flight two study sites within the mining region were selected as representative of mining, post mining, and the premining wetland conditions. Each site is approximately 7.7 kilometers by 12.5 kilometers in area. The restricted area of study was proposed to allow for the necessary field evaluation and verification, a time consuming task which could not have been performed economically over the entire phosphate mining region. The actively mined site contains all features characteristic of phosphate mining such as beneficiation plants with associated acid ponds, settling ponds, tailing piles, active pits including windrows of overburden and reclaimed areas. Limited amounts of prereclamation law and "pre flotation" unreclaimed land are present. Various stages of age or use can be identified within settling ponds. Several of the ponds are no longer active and are developing a dense vegetation cover.

Much of the unmined study site has a mining potential given the proper economic environment. It is also viewed as a "typical" example of the environment in the area. The site contains a wide range of land uses and land cover types including improved and unimproved pasture, orange groves of various ages, wetlands, palmetto shrub lands, and native woodlands. There is a wide variation of vegetation density between cover classes. Pasture may extend from 100 percent grass, to grass with a few trees, to grass codominant with trees, and scattered palmetto. This is also the case with wetlands. These will vary in water regime from permanently flooded, to semipermanently flooded, to intermittently (seasonally) flooded. Vegetation consequently

varies from emergent wetland plants such as cattails, to forested wetlands.

Both of the study sites were classified and evaluated by computer enhancement and classification of the MSS and TM data. After classifying data from the sites and identifying the computer generated spectral clusters, or groups, through photo interpretation and field work, seven cover type groups resulted. These groups were: water, grass, shrubs, agriculture, timber, wetland, and barren. Although each of these labeled groups was composed of several spectral classes, only the final 7 groups were considered in the final inventory. A detailed analysis of the image processing methodology applied (with emphasis on thematic mapper) and results obtained is contained within this report. Photo interpretation and field work were conducted on each of the sites. The U. S. Fish and Wildlife Service collaborated in labeling the computer generated spectral clusters according to a wetland inventory and classification system developed by that agency. Additional support was provided by the Florida Bureau of Geology and the Florida Institute of Phosphate Research. Technical and logistic support was provided by the U. S. Bureau of Mines.

PLATFORMS AND SENSORS

Since this project has analyzed data from several different remote sensing platforms and sensors, it is appropriate that they be discussed individually.

Landsats 1, 2, and 3

Each image from Landsats 1, 2, and 3 is taken from an altitude of 920 kilometers and shows a ground area of 185 x 185 kilometers. The main sensor on these satellites is the multispectral scanner or MSS. Spectral data are recorded in four wavelengths: visible green, visible red, and two reflective infrared channels. The polar orbits of the satellites permit each 185 x 185 kilometer image to be reimaged every 18 days, cloud cover permitting. This allows for the reexamination of ground features for change detection every 18 days, every month, multiple times each year, or from year to year.

Landsat data are recorded radiometrically rather than photographically. Spectral radiation reflected from the ground is measured in the four wavelengths and stored in a digital format. The area on the ground covered by one data point, or pixel, is 57 x 79 meters, or approximately 1.1 acre.*

When the satellites transmit data for each scene back to the ground, they are recorded on magnetic tape. They can then be analyzed by two basic methods. A photograph can be generated from the tape which can then be analyzed using standard photo interpretation techniques. The data tape can also be analyzed on a computer image processing system and displayed on a color television screen. The computer can then be instructed to group or classify the pixels on the basis of statistical characteristics of their spectral data.

*The size of individual pixels varies slightly between the satellites due to design changes in sampling rate.

Landsat 4 and the Thematic Mapper

Landsat 4 is the newest generation of earth resources satellites. It was launched in the fall of 1982 and should be operational in 1983.

Landsat 4 has an orbital altitude of 704 kilometers and will maintain a 16 day cycle of repetitive coverage. The two onboard sensors provide ground coverage of about 185 x 170 kilometers per scene.

The MSS on Landsat 4 senses data in the same four bands as the present MSS on Landsat 3, and has the same resolution (57 x 79 meters). The thematic mapper operates over 7 bands and has a resolution of 30 meters. Band 6, the thermal wavelength, has a resolution of 120 meters. The TM is a high resolution, multispectral sensor designed to significantly increase the capabilities of the Landsat spacecraft in differentiating between various types of agricultural crops and expanding capabilities for mineral exploration.

Simulated Thematic Mapper

When it became apparent that TM data from Landsat 4 would not be available until sometime in 1983, NASA's Earth Resources Laboratory at the National Space Technology Laboratories was assigned the responsibility of providing airborne simulated TM data to users until Landsat 4 data were obtained.

The airborne TM simulator is a conventional MSS four channel scanner that has been redesigned for seven channels and increased resolution. It is flown on a Lear 23/24 jet aircraft along with a Zeiss RMK15/23 aerial mapping camera that operates

at the same time as the scanner. To obtain 30 meter resolution equivalent to that obtained from the satellite, the aircraft is flown at an altitude of 12 km. This puts the aircraft above 80% of the earth's atmosphere. The major differences between the imagery expected from the satellite and that obtained by the aircraft is that the thermal channel on the satellite is numbered as band 6 and has a 120 meter resolution. On the aircraft the thermal channel is numbered as band 7 and has a resolution of 30 meters. Table 1 shows the spectral responses of both sensors.

Table 1. TM Satellite and Aircraft Spectral Responses

	Satellite TM Specifications	Band	Aircraft TMS Response
1	0.45 μm - 0.52 μm	1	0.46 μm - 0.52 μm (Blue-Green)
2	0.52 μm - 0.60 μm	2	0.53 μm - 0.60 μm (Green-Yellow)
3	0.63 μm - 0.69 μm	3	0.63 μm - 0.69 μm (Orange-Red)
4	0.76 μm - 0.90 μm	4	0.77 μm - 0.90 μm (Ref. IR)
5	1.55 μm - 1.75 μm	5	1.53 μm - 1.73 μm (Ref. IR)
6	10.4 μm - 12.5 μm	6	2.06 μm - 2.33 μm (Ref. IR)
7	2.08 μm - 2.35 μm	7	10.3 μm - 12.3 μm (TIR)

Design and Operation of a Multispectral Scanner

The operation of a multispectral scanner is illustrated in Figure 2a. An oscillating mirror moves the field of view of the scanner along a scan line perpendicular to the direction of flight. The forward motion of the aircraft advances the viewed strip between scans, causing an image data set to be recorded.

Figure 2b illustrates the components of a typical scanner. In the MSS, the incoming energy is separated in several spectral wavelengths that are sensed independently. A dichroic grating is used to separate the reflected wavelengths from the emitted wavelengths in the incoming radiation. The reflected wavelength component is directed from the grating through a prism that splits the energy into a continuum of ultraviolet, visible, and reflected infrared wavelengths. At the same time, the grating

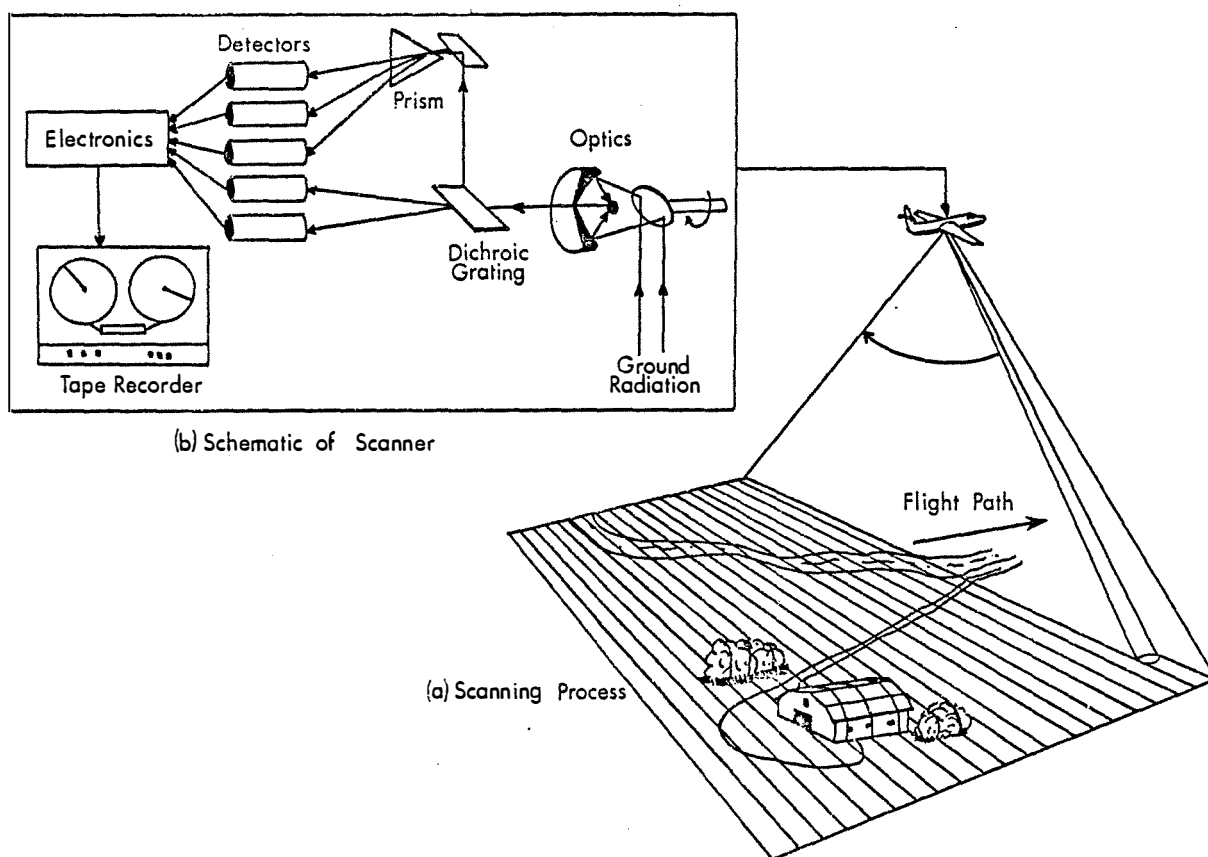


Figure 2. Multispectral Scanner Operation

disperses the emitted component of the incoming signal into its constituent wavelengths. By placing an array of detectors at the proper geometric positions behind the grating and the prism,

the incoming beam is essentially separated into multiple narrow channels, each of which is measured independently.

As shown in Figure 2, the signals generated by each of the detectors of an MSS are amplified by the system electronics and recorded by a multi-channel magnetic tape recorder. If the MSS data analysis procedure is to be visually oriented, the scanner output is normally recorded on an analog recorder and converted to images after the flight using a ground-based film recorder. If the analysis procedure is to be digitally oriented, it is preferable to electronically convert the analog scanner output signal to a digital format prior to recording in flight. The digitization process ensures that data collected in several spectral bands are precisely synchronized. These data are initially recorded on high density digital tape on board the aircraft. On the ground, the tape is converted to computer tape (CCT) for subsequent processing².

IMAGE PROCESSING SYSTEM

In 1979 TAC acquired a computer system for the analysis of digital remote sensing data. Called TDIPS (TAC Digital Image Processing System), the system possesses a wide range of capabilities designed to analyze digital data from aerial and satellite scanners and maps. The components of the system are:

PDP 11/34A Processor by Digital Equipment Company, 256K bytes memory

ELAS Image Processing Software

²Lillesand, Thomas M., and Kiefer, Ralph W. Remote Sensing and Image Interpretation, 1979, pp. 443-445.

Two RL01 and two RL02 Disk Drives containing a total of 31.2 megabytes

TMell-EA Magnetic Tape Drive, 45 IPS and 800 BPI

Grinnell 256 X 512 3-color image display

Two VT100AA terminals

One ADM 3 terminal

Printronic Matrix Line Printer

36" x 48" digitizer tablet by Summagraphics

Anderson-Jacobsen Modem, 300/1200 Baud

The Earth Resources Laboratory Applications Software (ELAS) is a geobased information system designed for analyzing and processing digital image data. ELAS was developed mainly to process remotely sensed scanner data, especially the multispectral data acquired by the various NASA Landsat satellites. In addition to Landsat multispectral data, the ELAS system will support the processing of other data such as aircraft-acquired scanner data, digitized topographic data, and numerous other ancillary data, such as soil types and rainfall information, that can be stored in digitized form. As an integrated image processing and data base maintenance system, ELAS offers the user of remotely sensed data a wide range of easy-to-use capabilities in the area of land cover analysis.

THE UNSUPERVISED CLASSIFIER

Using NASA's ELAS software, TAC's computer image processing system employs a maximum likelihood unsupervised classification algorithm to classify land cover types. Unsupervised classifications involve algorithms that examine a large number of

unknown pixels and divide them into classes based on natural groupings present in the image values. The basic premise is that values within a single cover type should be close together in the measurement space, whereas data from different classes should be comparatively well separated.

The classes that result from unsupervised classification are spectral classes. Because they are based on natural groupings of the image values, the identity of the spectral classes will not be initially known. The analyst must compare classified data to some form of reference data (such as air photos or maps) to determine the identity and informational value of the spectral classes.

The unsupervised method can be illustrated with a two channel data set. Natural groupings in the data can be visually identified by plotting a scatter diagram. For example, in Figure 3 pixel values acquired over an agricultural area have been plotted. Three groupings are apparent in the scatter diagram. After comparing the classified image data to ground reference data, we might find that one cluster corresponds to wheat, one to barley, and one to soybeans (indicated by W, B, and S in Figure 3).

For image data of more than two channels, it is difficult to plot image values to visually identify natural spectral groupings. Fortunately, statistical techniques are available that can be used to automatically group an n-dimensional set of observations into their natural spectral classes. Such a procedure is termed cluster analysis. The result of applying a

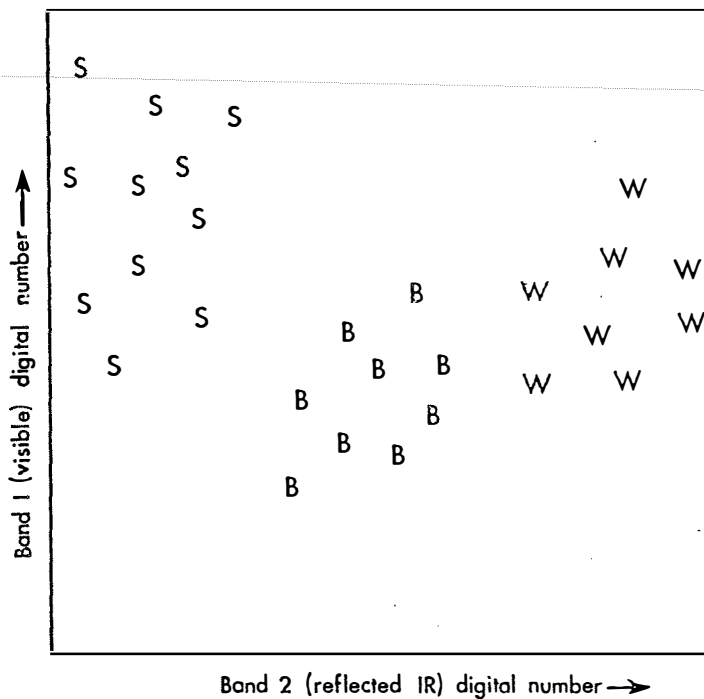


Figure 3. Two Channel Plot Example.

cluster analysis is simply the identification of spectrally distinct classes in the image data. After the data are clustered, the analyst must use reference data, such as maps and images, to associate the spectral classes with the cover types of interest.

Table 2 illustrates several possible outcomes of associating spectral classes with information classes for data from a typical Landsat scene. The ideal outcome would be Result #1, in which each spectral class is found to be associated uniquely with a feature type of interest to the user. This outcome will occur only when the features in the scene have highly distinctive spectral characteristics.

Table 2. Possible Classification Results

Result #1

Spectral Class	Identity of Spectral Class	Desired Class Result
1	Water	Water
2	Agriculture	Agriculture
3	Timber	Timber
4	Urban	Urban

Result #2

Spectral Class	Identity of Spectral Class	Desired Class Result
1	Turbid Water	Water
2	Clear Water	
3	Wheat	Wheat
4	Barley	Barley
5	Spruce	Timber
6	Fir	
7	Urban	Urban

Result #3

Spectral Class	Identity of Spectral Class	Desired Class Result
1	Turbid Water	Water
2	Clear Water	
3	Wheat	Agriculture
4	Barley	
5	Range Grass	Range Grass
6	Urban	Urban

A more likely result is presented in Result #2. Here, more than one spectral class is attributable to several information categories desired by the user. These "sub-classes" may be of little informational utility (turbid versus clear water) or they may provide useful distinctions such as spruce versus fir if the project objective is to categorize timber types. In either case, the spectral classes may be aggregated after classification into the smaller set of categories desired by the user.

Result #3 represents a more troublesome result in which the analyst finds that several classes relate to more than one information category. For example, spectral class #5 was found to correspond to agriculture in some locations and range grass in others. This means that these information categories are spectrally similar and cannot be differentiated in a given data set.

METHODOLOGY

Raw Data Examination

The first step in computer processing of remotely sensed data is to identify where on the raw data tape the study area is located. This is done by analyzing a hard copy photo of the scanner image or, if a photo is not available, by analyzing large portions of the raw data until the study area is located. Once identified, the raw data for the area are stored on disk as a subscene. The individual channels of data are then displayed on a CRT monitor to check their quality. A number of corrections can be applied to the data to eliminate scanner noise or striping. These corrections are always done before the data are

classified. A false color composite can also be made by simultaneously displaying three channels of data, each through a different color gun in the CRT. By using different combinations of channels and colors, it is possible to highlight or emphasize certain ground features.

Training Data Collection

In order to classify the raw data it is necessary for the computer to search the file for spectrally homogeneous blocks of data with which to train itself. There are several parameters which can be adjusted so that the search program will arrive at a roughly predetermined number of classes. For this project it was felt that approximately 30 classes would be a large enough number to adequately classify the land use/land cover categories, at the same time being small enough to handle efficiently.

The search program begins by examining 3 x 3 blocks of pixels looking for spectrally homogeneous blocks. As these blocks are found, a series of statistics is compiled on them such as their mean, standard deviation, and coefficients of variation. The program is designed to compile statistics on a maximum of 60 classes. If the program finds statistics for 60 classes before reaching the end of the file, it looks back through the data and merges the two classes that are most statistically similar, thus freeing space to add one more class. The search process then continues in this manner until the entire file has been searched and 60 classes have been statistically identified.

When the entire raw data file has been searched and statistics on 60 classes obtained, the computer operator applies

a clustering algorithm to the training data. This algorithm clusters together those class statistics that are the most similar. By adjusting several parameters and rerunning the algorithm several times, the operator can modify the clustering until the desired number of classes results. As stated previously, the objective for this project was approximately 30 classes.

The final step in the training data collection process was the generation of a two channel plot. The two channel plot allows the operator to plot the means of all classes in the statistics file for any two Landsat channels. Figure 4 shows a two channel plot made from an ELAS statistics file of Landsat MSS data. Each letter and number on the plot represents the spectral means of one of the classes. The double column on the left is used to correlate the number of the class with its plot symbol. It is immediately evident that the classes on this plot are clustered into four distinct groups. Circles and labels have been provided to identify each group. The whole purpose of the plot is to provide the operator with a preliminary name for each class depending on where the class is located on the plot. For example, bare soil usually occupies the diagonal at the upper right because soil is usually bright on all channels and water is usually at the lower left because it tends to be dark on most channels. Urban and vegetation classes are usually found in the lower center of the plot. It should be pointed out that most plots do not produce as clean a cluster pattern as that found in Figure 4.

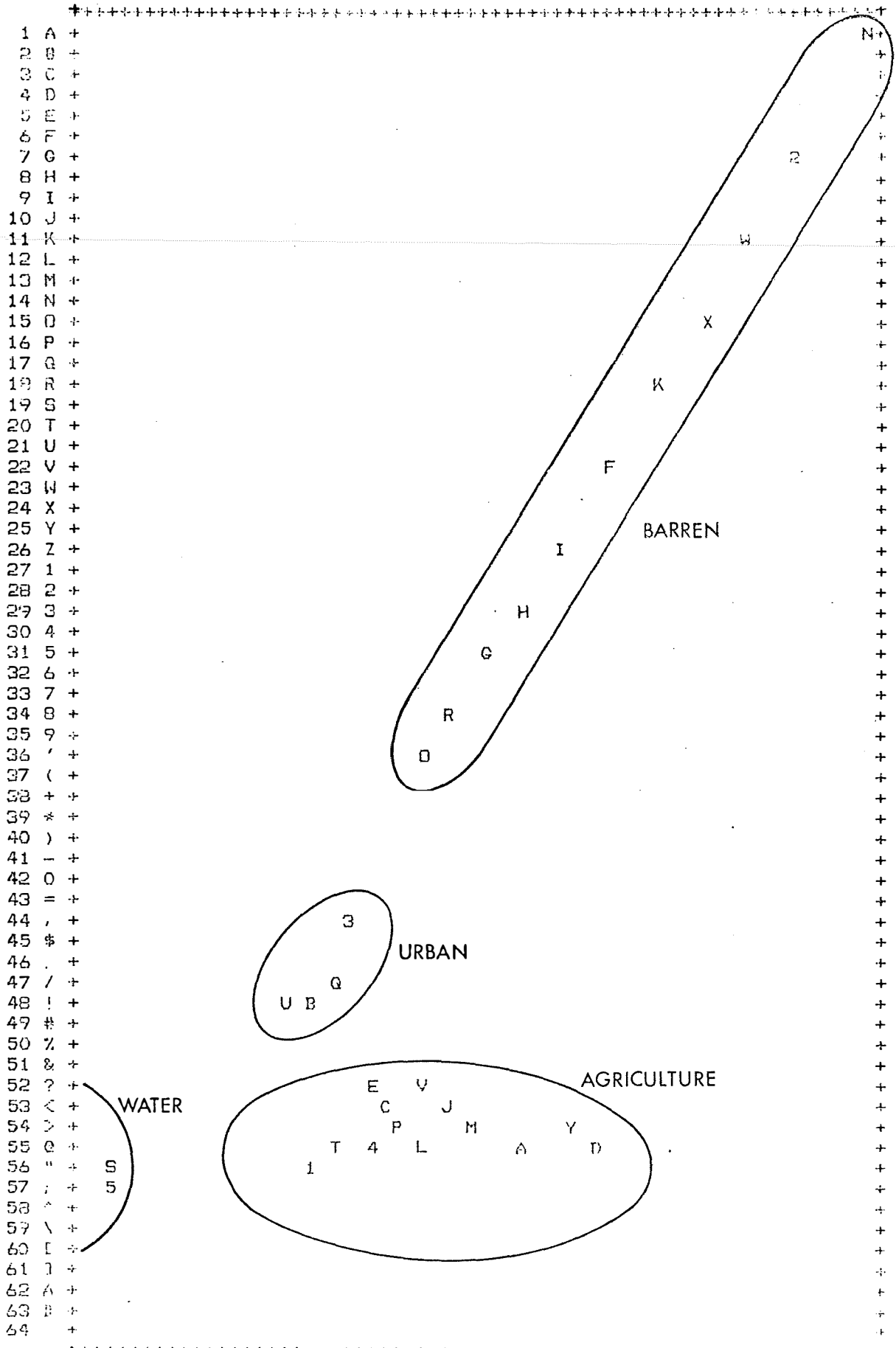


Figure 4. Landsat MSS Two Channel Plot.

Image Classification

When the training data process has been completed, the raw data file can be classified using a maximum likelihood unsupervised classifier. An unsupervised classification simply means that the computer has compiled its own training statistics without help from the operator. The term "maximum likelihood" means that the computer compares the spectral values of each pixel in the raw data file to each of the statistically-defined classes in the statistics file. The computer then calculates the probability that a pixel belongs to each class in the statistics file and assigns the pixel to the class to which it is statistically closest. This calculation is performed for every pixel in the raw data file. When the classification is completed, it can be displayed on the television screen and analyzed. A color table is then loaded onto the classification. This color table is created by the computer whereby each class is assigned a color based on the class location on the two channel plot. The operator can then highlight each class in a distinctive color to view its precise distribution and location.

Analysis of Landsat MSS Data

The Landsat data to be analyzed over the phosphate mining area was ID #22561-15153 taken on January 26, 1982. A false color composite of a subscene in which the mining area study site is located is shown in Figure 5. The entire phosphate mining district was searched and classified in the manner previously described and two classifications resulted, one with 29 classes and one with 40 classes. The two channel plot for the 29 class



Figure 5. Landsat False Color Composite of Phosphate Mining Area.

classification is shown in Figure 6. While the plot shows several distinct clusters that could be assigned to one of the predetermined group names discussed in the introduction, the actual classification was unsatisfactory. There was enough spectral overlap among classes to force certain classes into an obviously wrong cluster. However, to place those classes in another cluster produced a likewise undesirable result. The same was true for the 40 class classification. This problem probably occurred because of Landsat's large 1.1 acre resolution cell and the highly complex pattern of land cover.

Analysis of Simulated Thematic Mapper Data

Although the entire phosphate mining area was imaged with the airborne thematic mapper on September 28, 1982, it was decided to select two subscenes of the data for detailed analysis and field

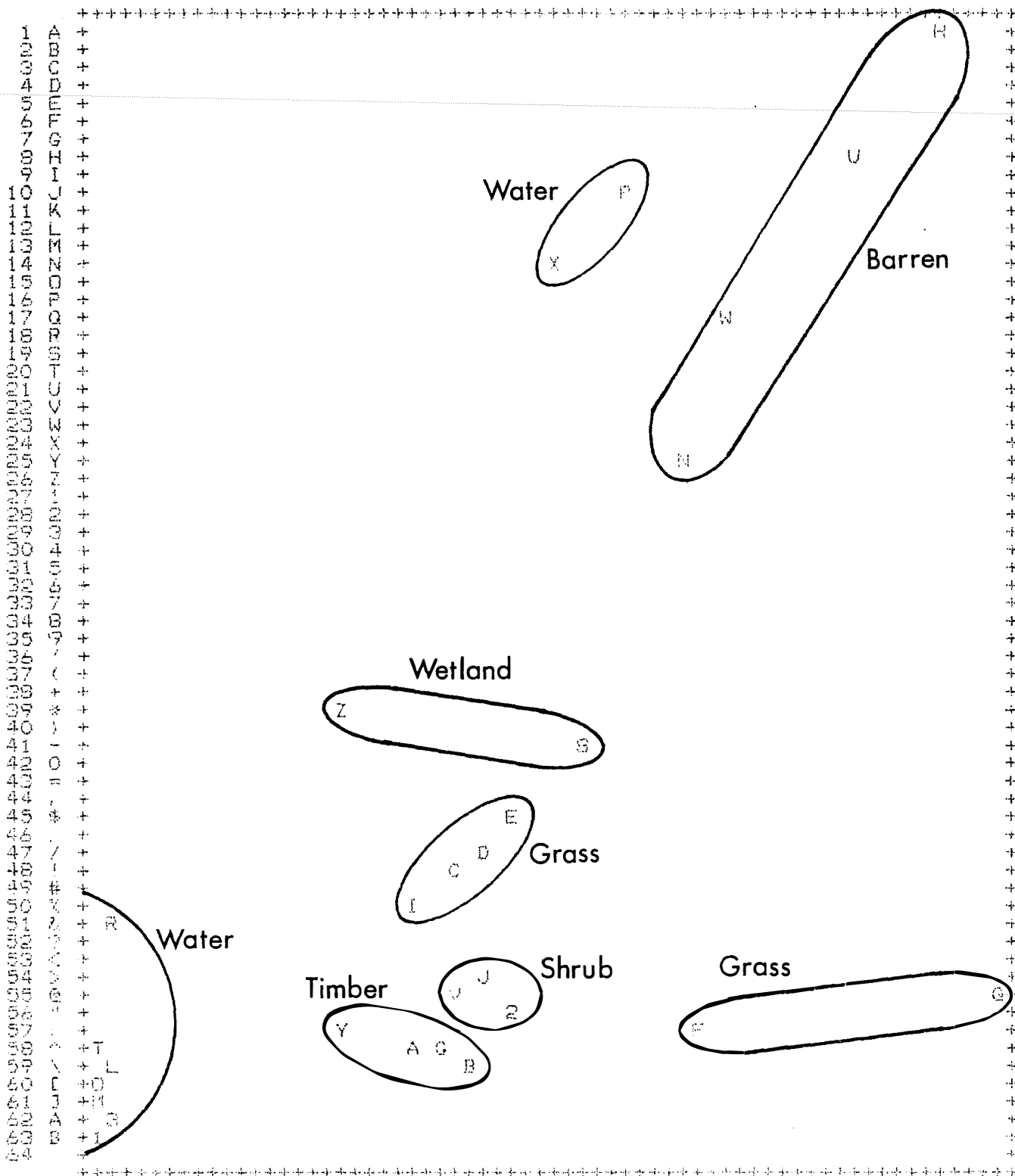


Figure 6. Two Channel Plot of Landsat Classification.

verification. Each subscene was the equivalent of one screen full of data (256 lines x 418 pixels). One subscene was centered on Bradley Junction and was predominantly an active and historic mining area (Figure 1). The second subscene was located just south of state road 62 near Ft. Green Springs and consisted of wetland and pasture. This second area has been earmarked for future mining expansion. Figure 7a, b, and c shows an aerial photo of the mining subscene, a TM false color composite taken at the same time, and the TM classification, respectively. Figure 8a, b, and c shows the same information over the wetland subscene. The quality and detail of the TM data are immediately evident.

On analyzing the seven raw channels it was found that channel 4, one of the three reflective infrared wavelengths, had a number of bad scanlines. It was decided to drop this channel from the list of useable channels unless it was needed at a later date. Channel 1, the blue-green wavelength, was slightly noisy, probably due to atmospheric water vapor; the noise was not severe enough to cause the data to be rejected, however. Thermal channel 7 was used in several classifications even though its resolution was four times better than that expected from the satellite. Because of this it is difficult to comment on how applicable the satellite's coarser thermal data will be to phosphate mine studies.

It was difficult to predict which combinations of raw channels would provide the best classification, so several different combinations were tried. The following channel

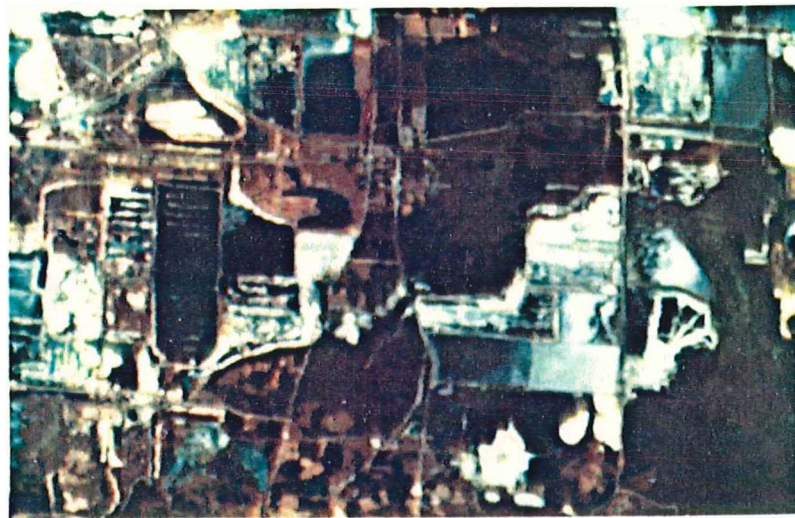


Figure 7. Mining Area Subscene

- a. Aerial photo of subscene
- b. TM false color composite of subscene
- c. TM classification of subscene.

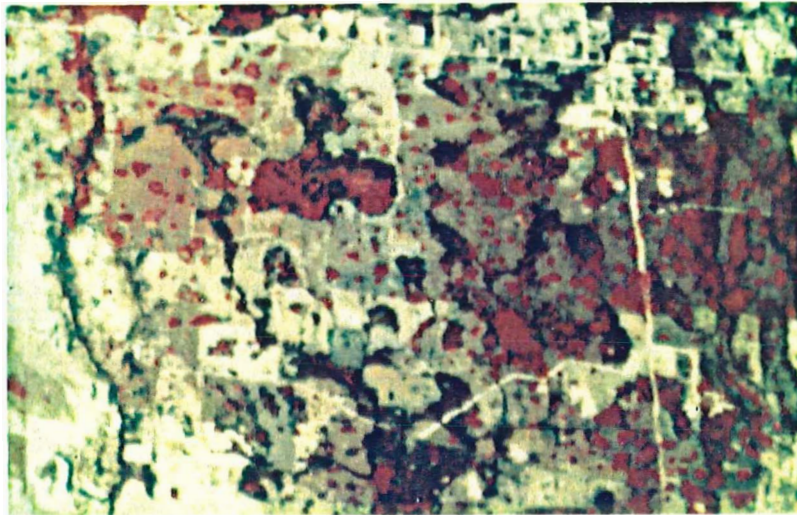
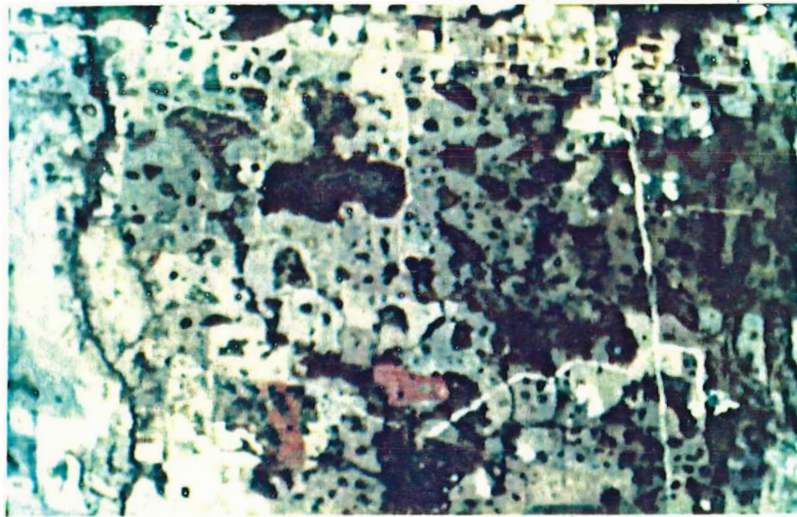


Figure 8. Wetland Area Subscene

- a. Aerial photo of subscene
- b. TM false color composite of subscene
- c. TM classification of subscene

combinations were tried for both areas:

- 1) 2, 3, 5, 7
- 2) 2, 3, 5, 6
- 3) 2, 5, 7
- 4) 1, 3, 6

Of these, the 2, 3, 5, 6 combination was by far the best for both areas, and much better than the Landsat classification; combinations 2, 3, 5, 7 and 2, 5, 7 worked to a lesser degree. The 1, 3, 6 combination provided a very detailed water breakdown in the mine subscene, but did very poorly on vegetation. Since the wetland subscene apparently had very little standing water of any size at that time of year, the 1, 3, 6 combination for that area was totally inadequate. From these observations the classifications from channels 2, 3, 5, 6 were examined in detail.

Analysis of 2, 3, 5, 6 Classifications

Figures 9 and 10 show the two channel plots for the 2, 3, 5, 6 classifications for the mine and wetland subscenes, respectively. Note that the clusters on the plots seem to be more complex and interfingered than the Landsat MSS plot in Figure 6. What the differences between these plots indicate is that the coarse resolution and fewer available wavelengths on Landsat are not able to discriminate between those cover types that are spectrally similar but very different from the standpoint of land use/land cover. Dissimilar classes are often grouped together by Landsat MSS and, hence, the cleaner appearance of the MSS plot. On the other hand, the TM classifications are much more accurate and their plots are more detailed and interfingered. The conclusion

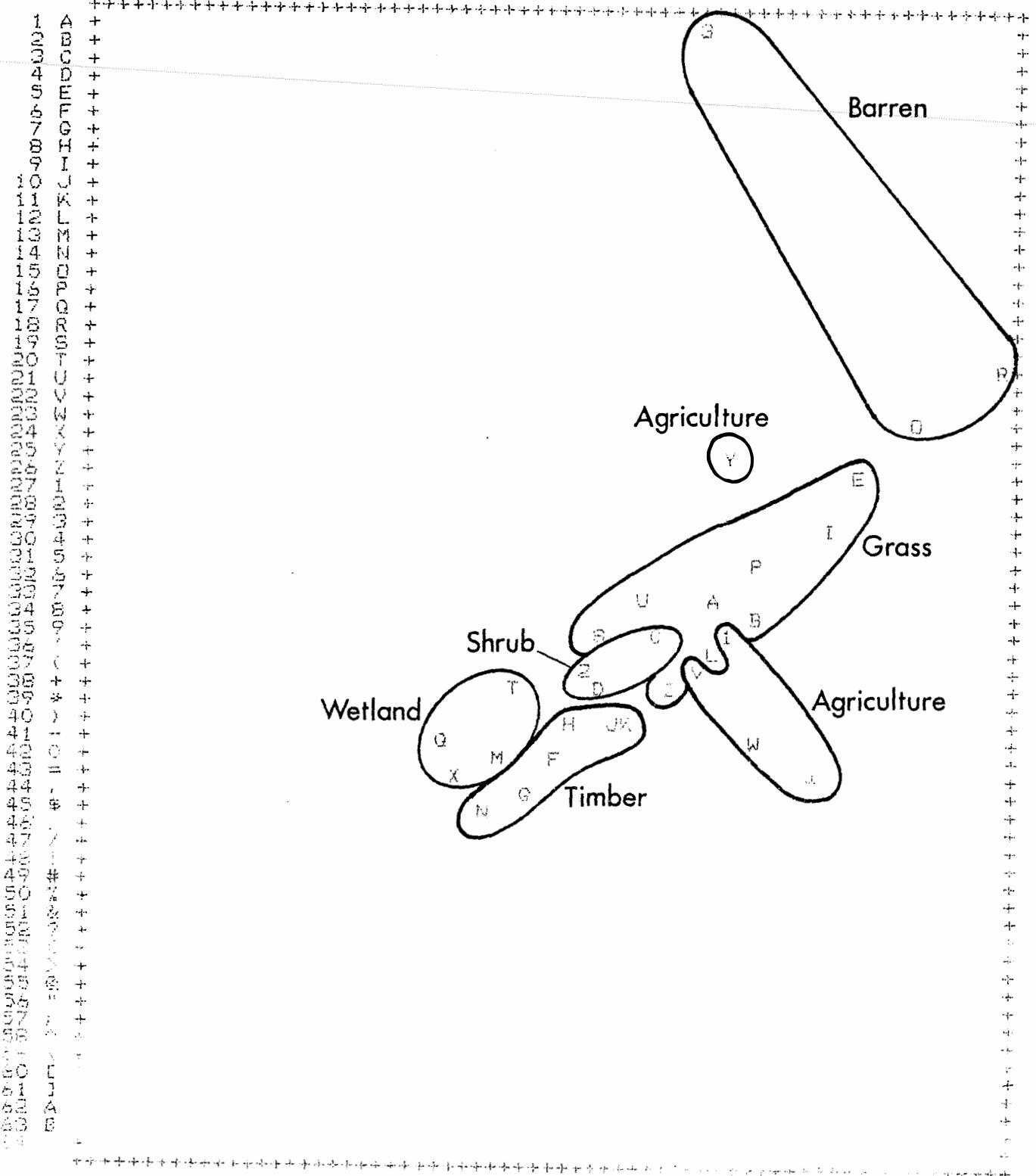


Figure 10. Two Channel Plot of Wetland Classification

from these comparisons is that the increased resolution and finer spectral range of the thematic mapper allow it to classify ground cover types which would normally be incorrectly sensed by the Landsat MSS.

Figures 11 and 12 show the six major class groups formed from the mine subscene classification. Each group is shown in bright red. Each group corresponds to one of the labeled groups on the two channel plot in Figure 9.

For the sake of field verifying the classifications, all classes for each subscene were printed at a scale of 1:50,000 and a transparent base map was overlain to provide a means to accurately locate each class on the ground. Figures 13 through 18 show the six clustered groups for the mine subscene and Figures 19 through 23 show the five individual classes that constitute the barren cluster. Scale is approximately 1:70,000. Figures 24 through 29 show the six clustered groups for the wetland subscene, and Figures 30 through 33 show the four individual classes that constitute the wetland cluster. In nearly all cases the thematic mapper classes were well defined and easy to name.

Ratioing

Ratioing of raw channels is a method of image enhancement whereby the spectral values of one raw channel are divided by the values of a second raw channel to create a new channel of data which may reveal ground characteristics not visible on the original data. Figure 34 shows a false color composite of the wetland subscene created by using the channel ratios 2/5, 3/5,

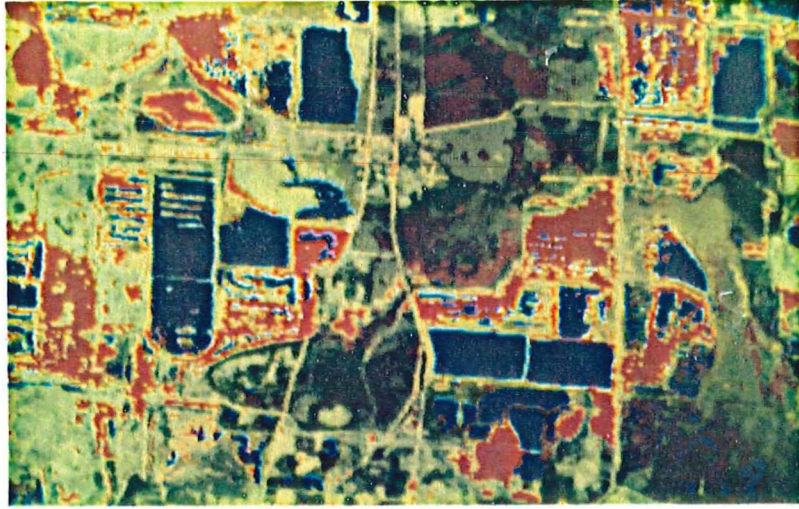


Figure 11. Barren, Water, and Timber Classes of Mining Subscene

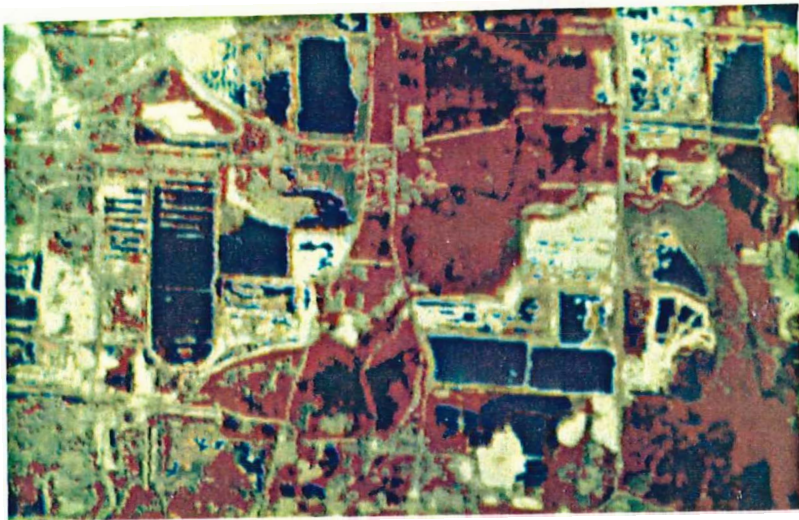
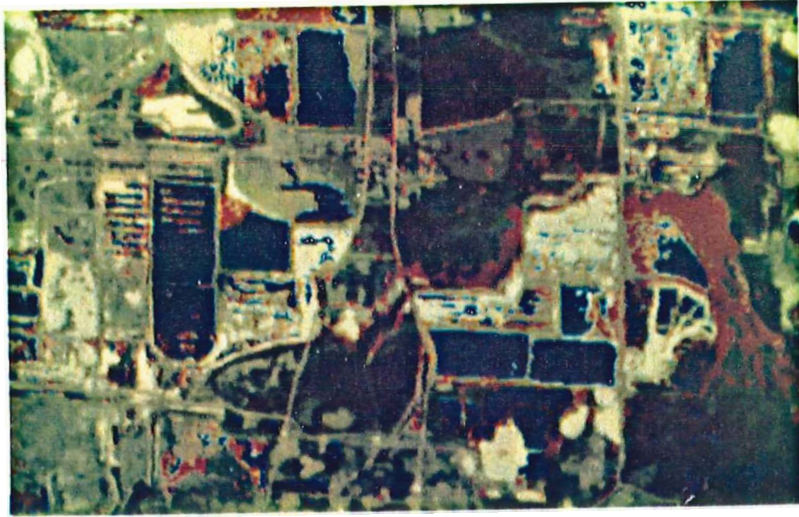


Figure 12. Wetland, Shrub, and Grass Class Groups of Mining Subscene.



Figure 13. Mine Area Printout - Barren Group

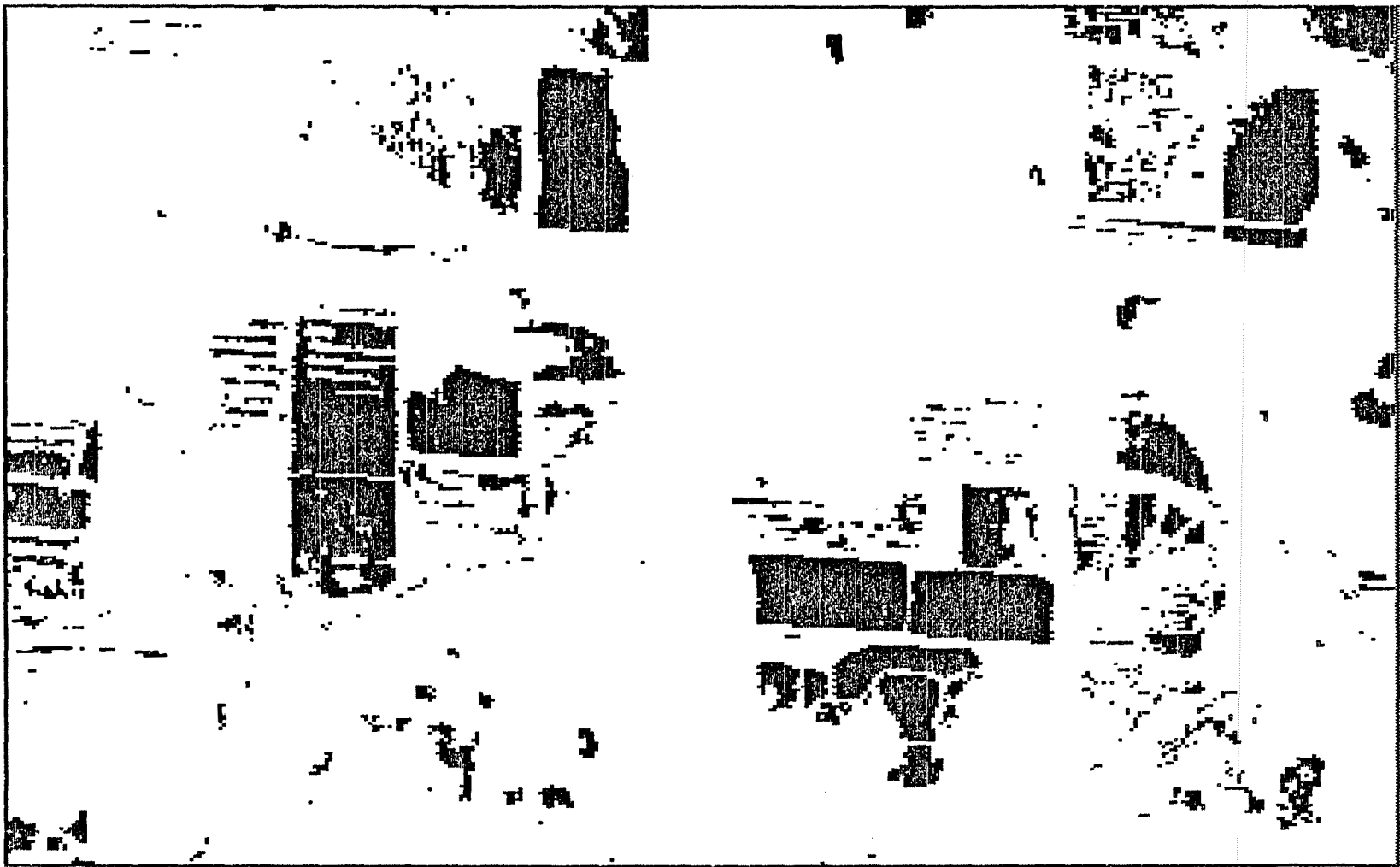


Figure 14. Mine Area Printout - Water Group

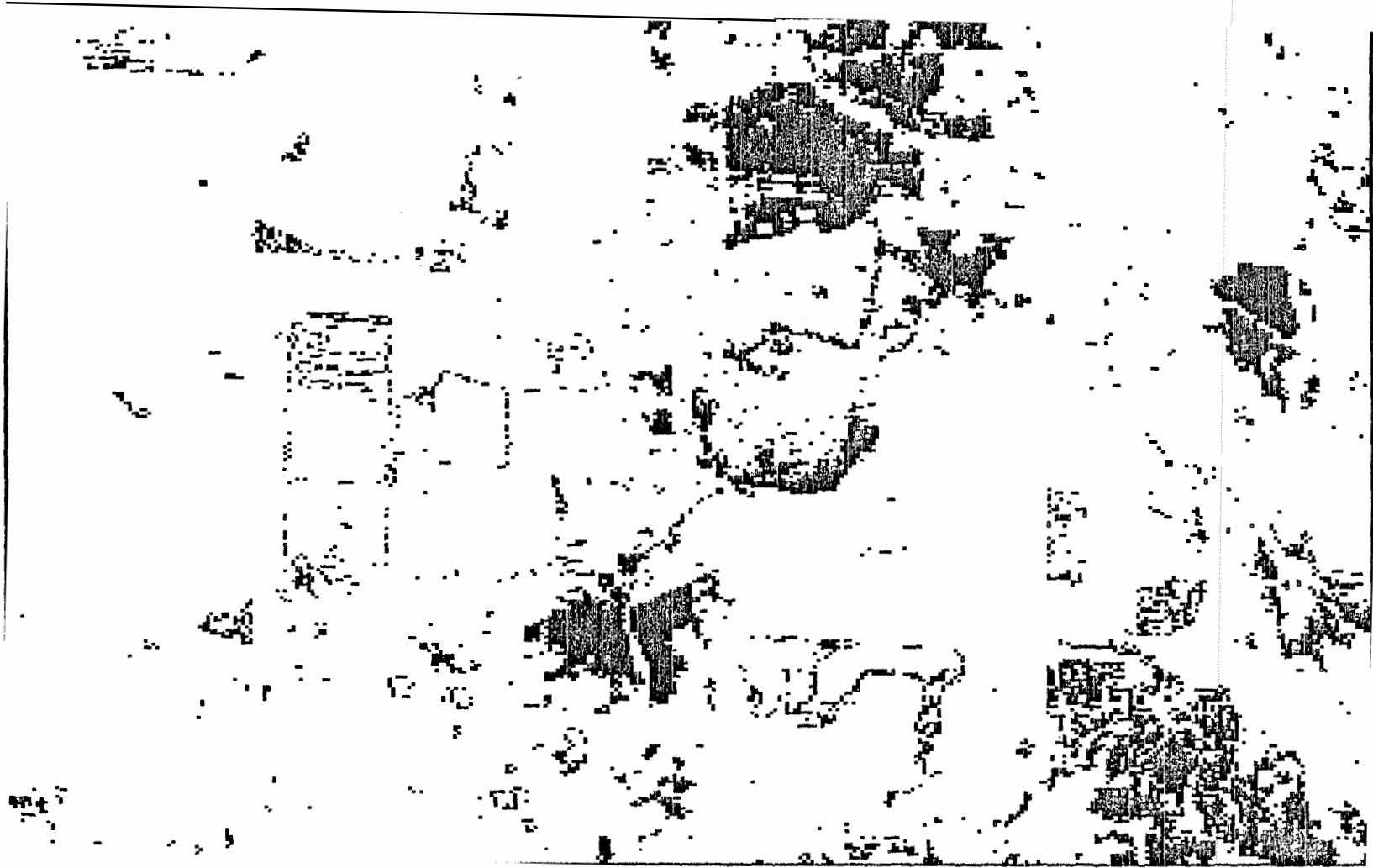


Figure 15. Mine Area Printout - Timber Group



Figure 16. Mine Area Printout - Wetland Group



Figure 17. Mine Area Printout - Shrub Group



Figure 18. Mine Area Printout - Grass Group

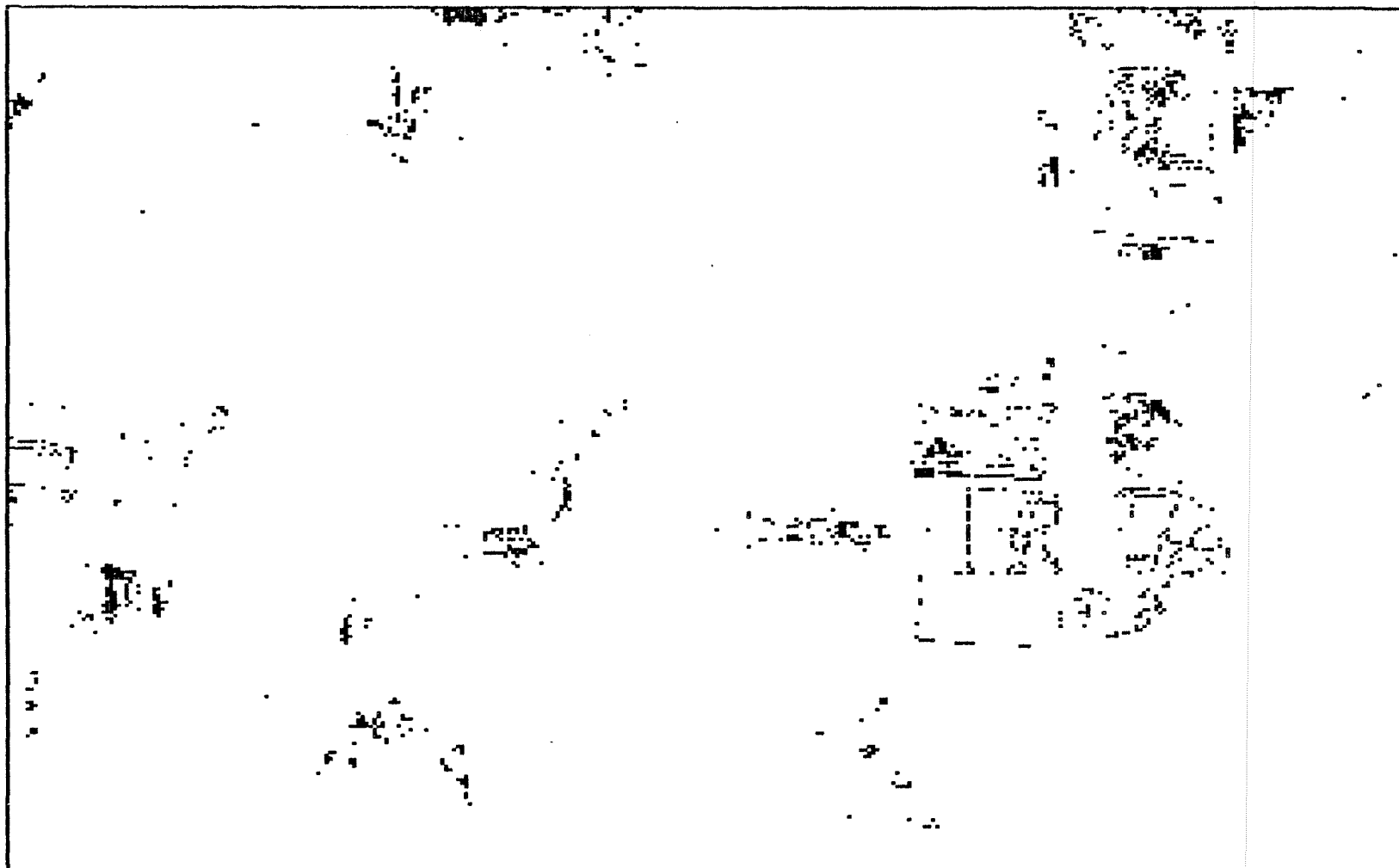


Figure 19. Mine Area Printout - Barren Class #1

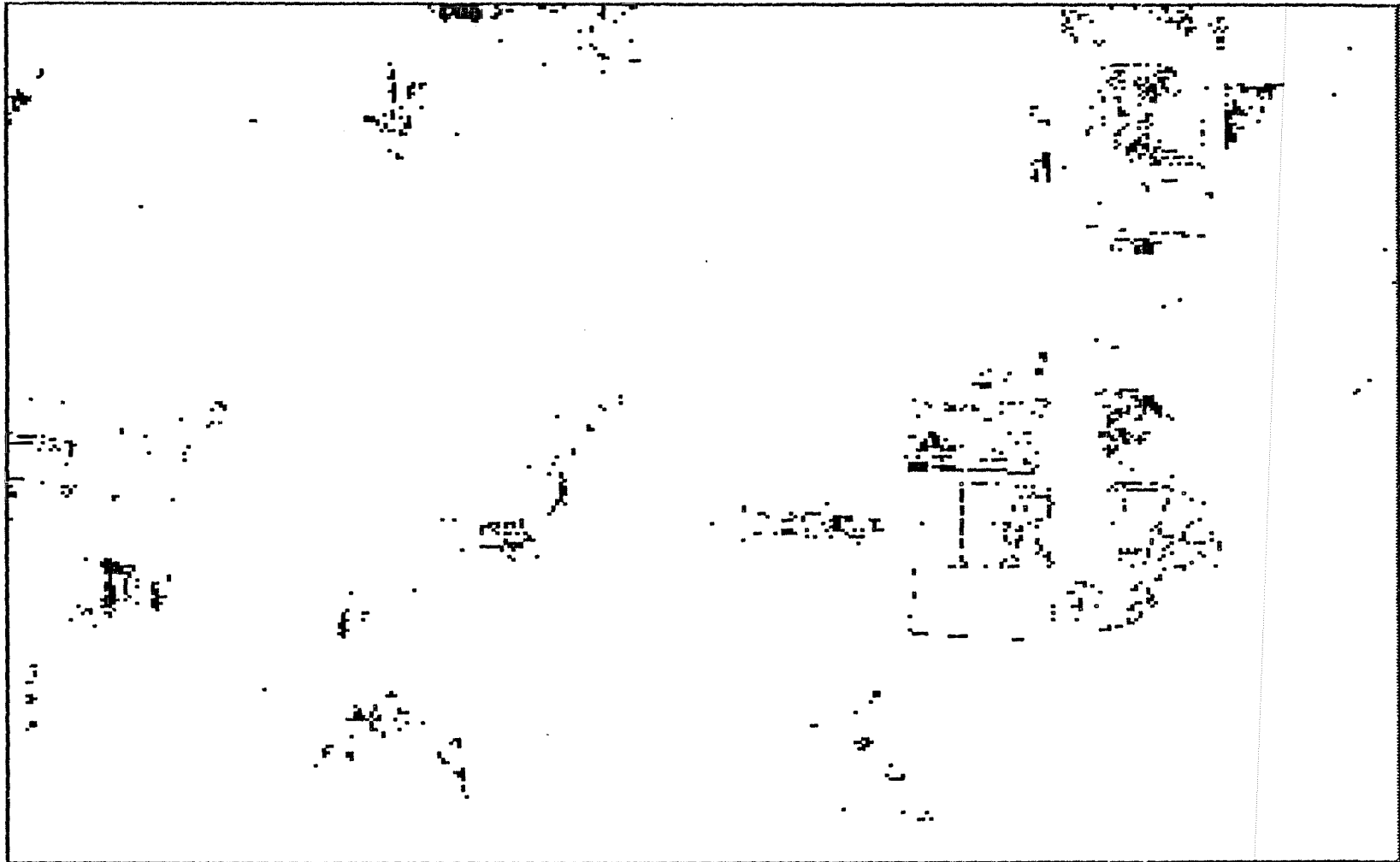


Figure 19. Mine Area Printout - Barren Class #1

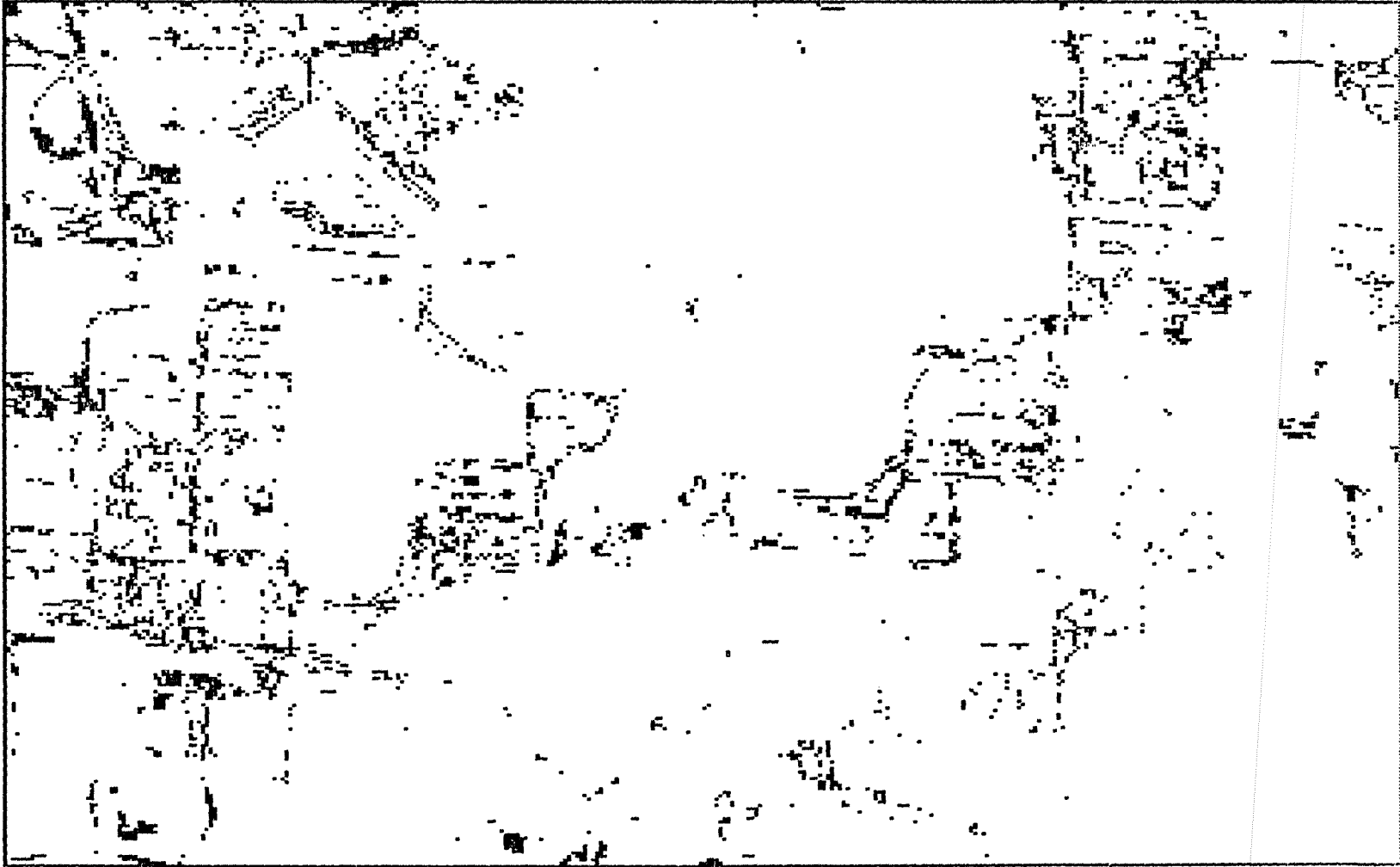
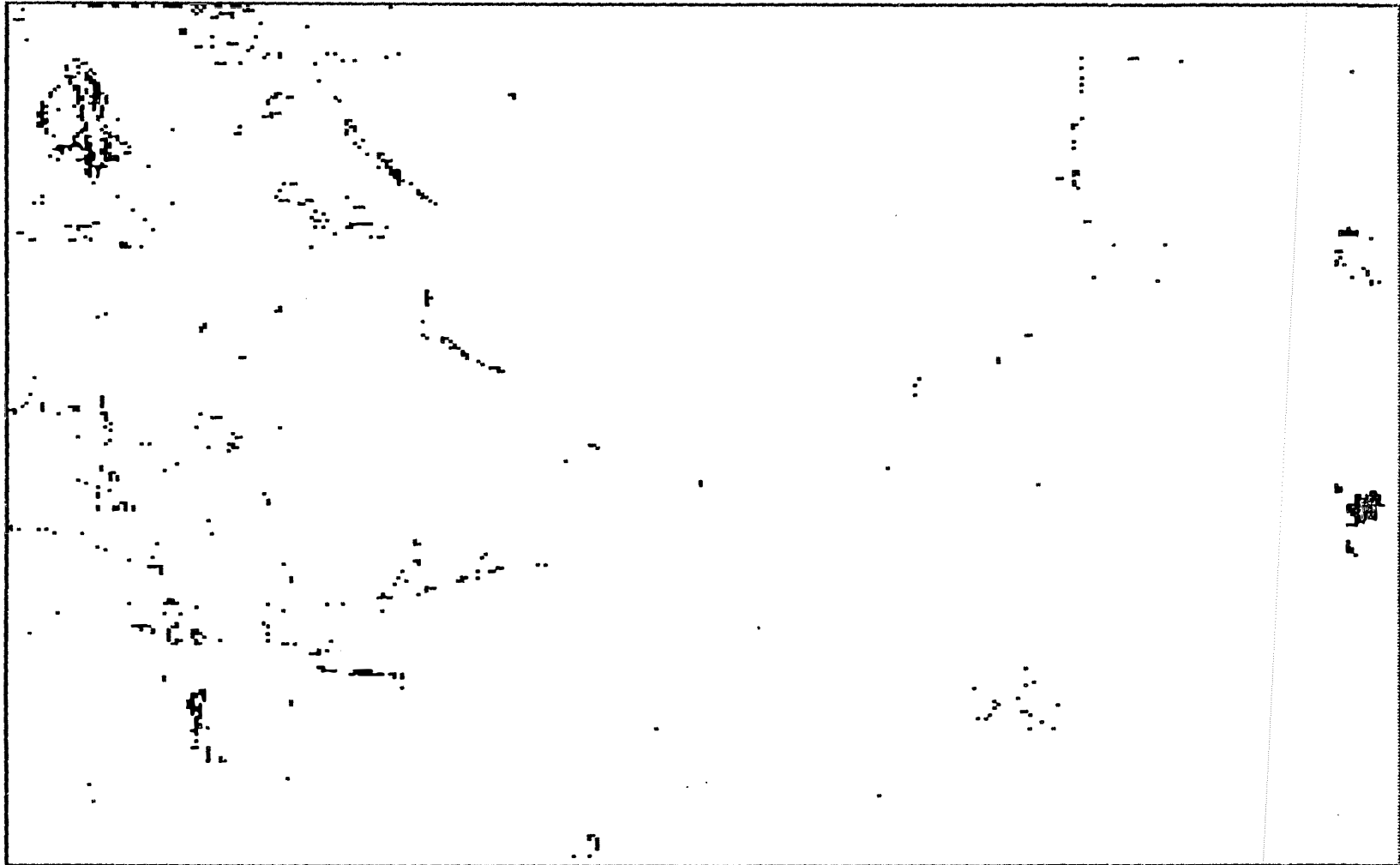


Figure 20. Mine Area Printout - Barren Class #2



41

Figure 21. Mine Area Printout - Barren Class #3

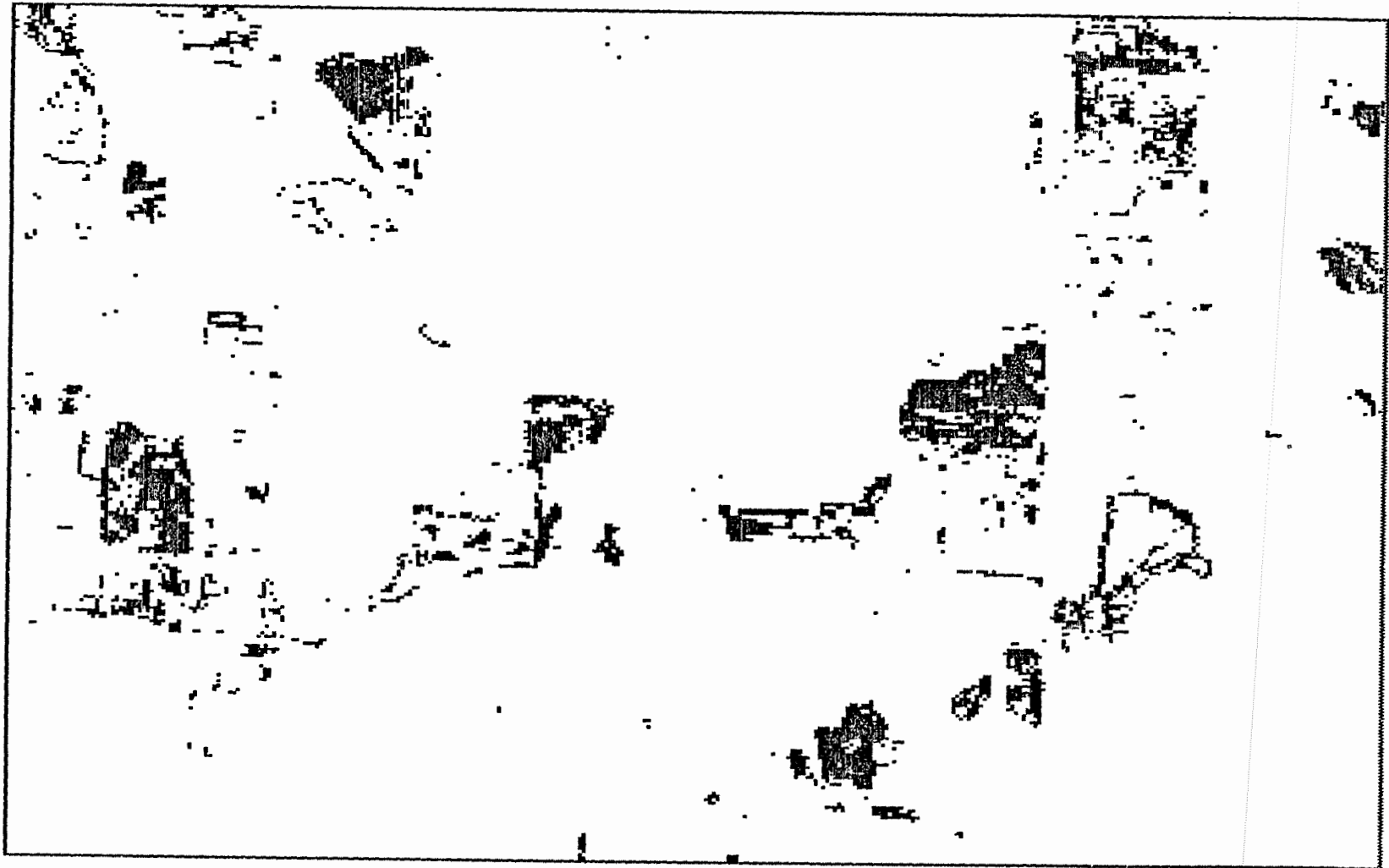


Figure 22. Mine Area Printout - Barren Class #4

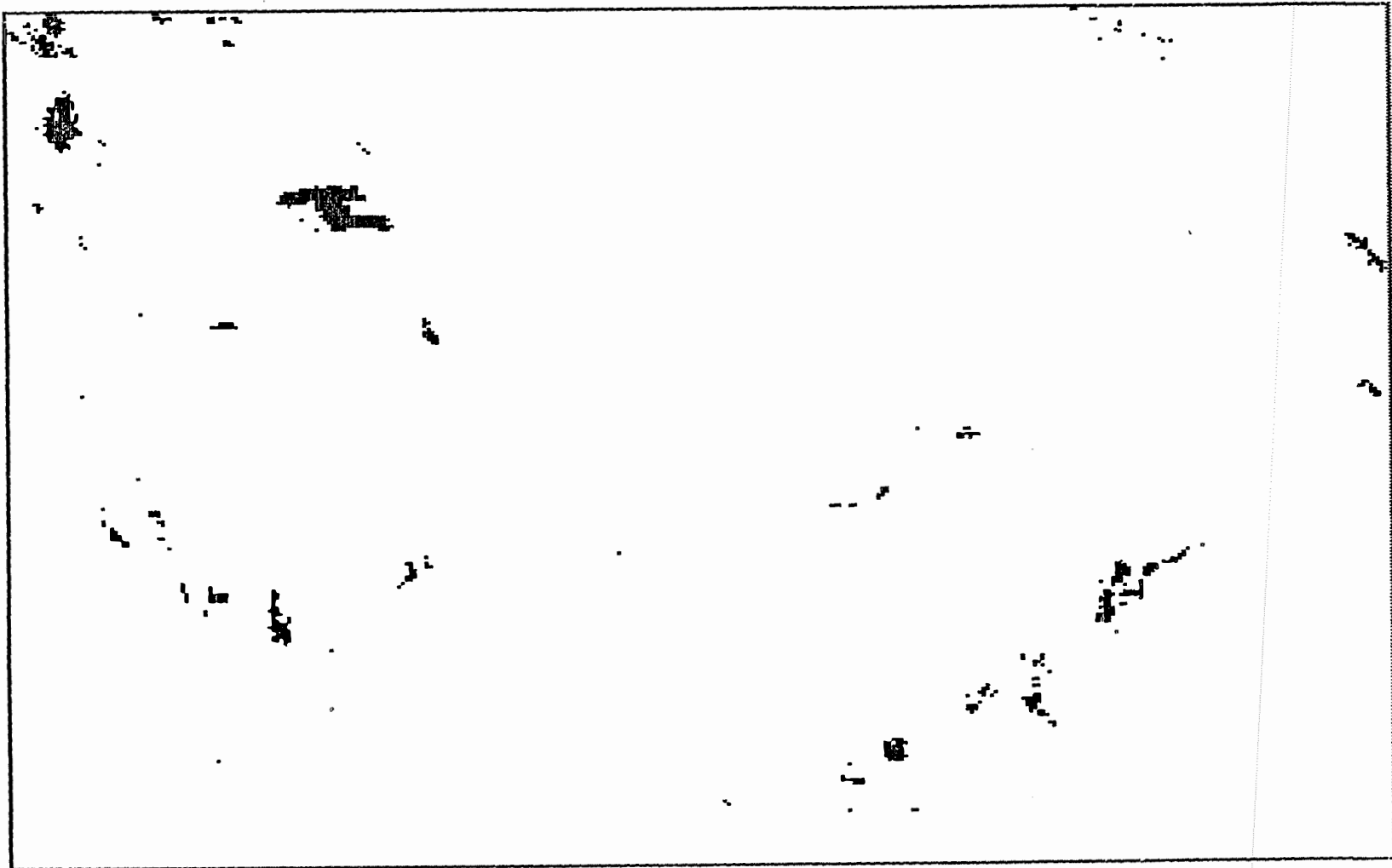


Figure 23. Mine Area Printout - Barren Class #5

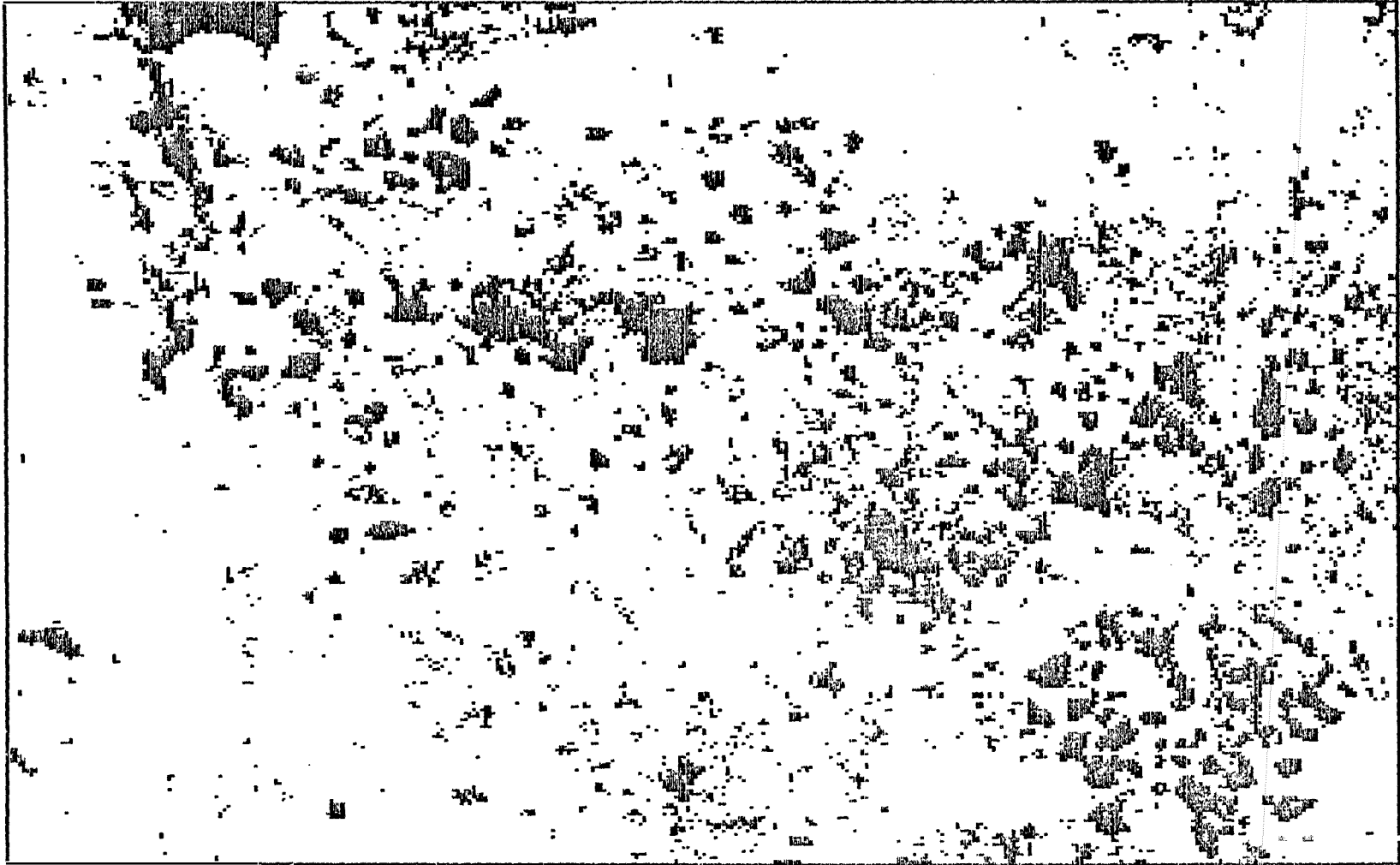


Figure 24. Wetland Area Printout - Wetland Group

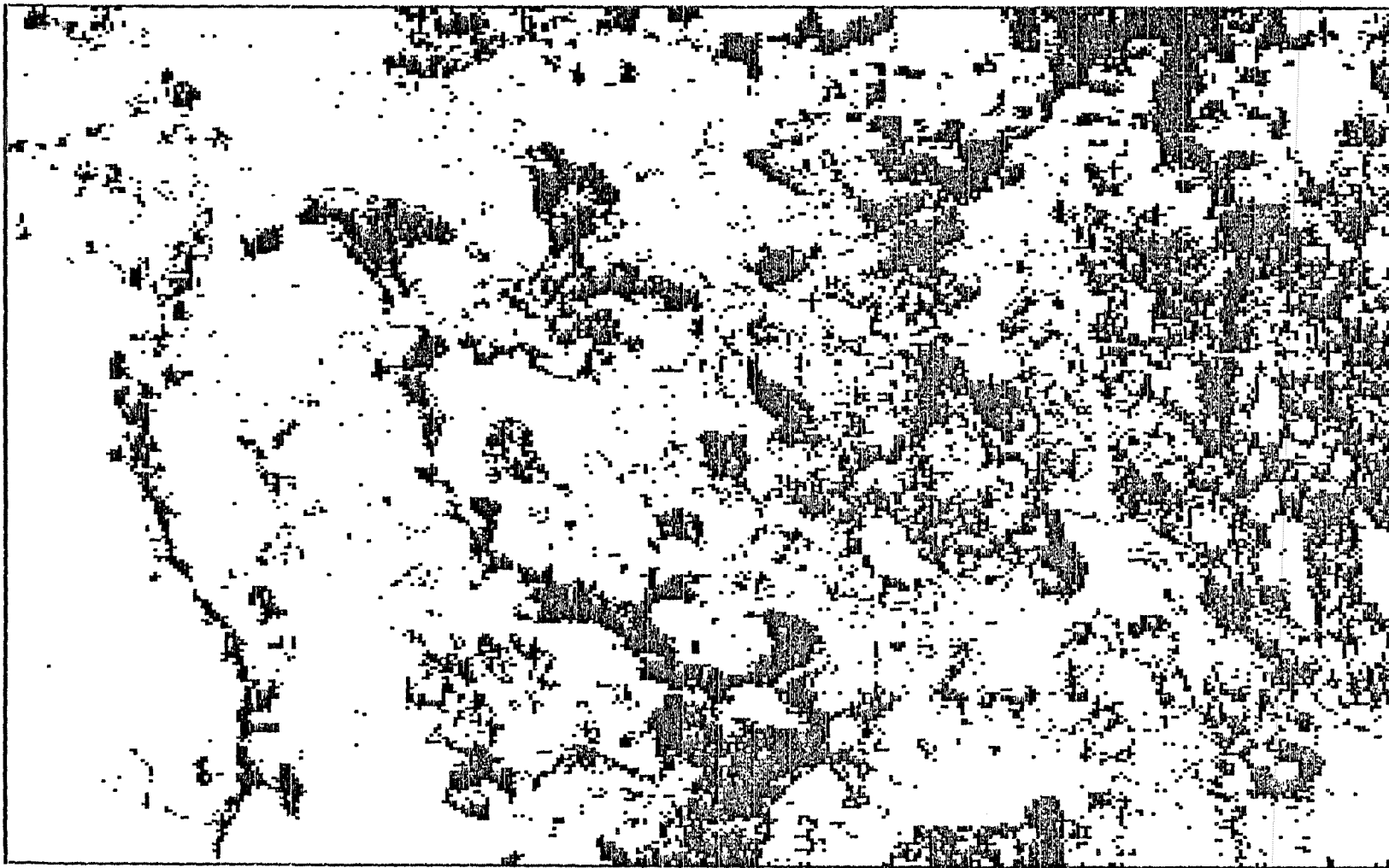


Figure 25. Wetland Area Printout - Timber Group

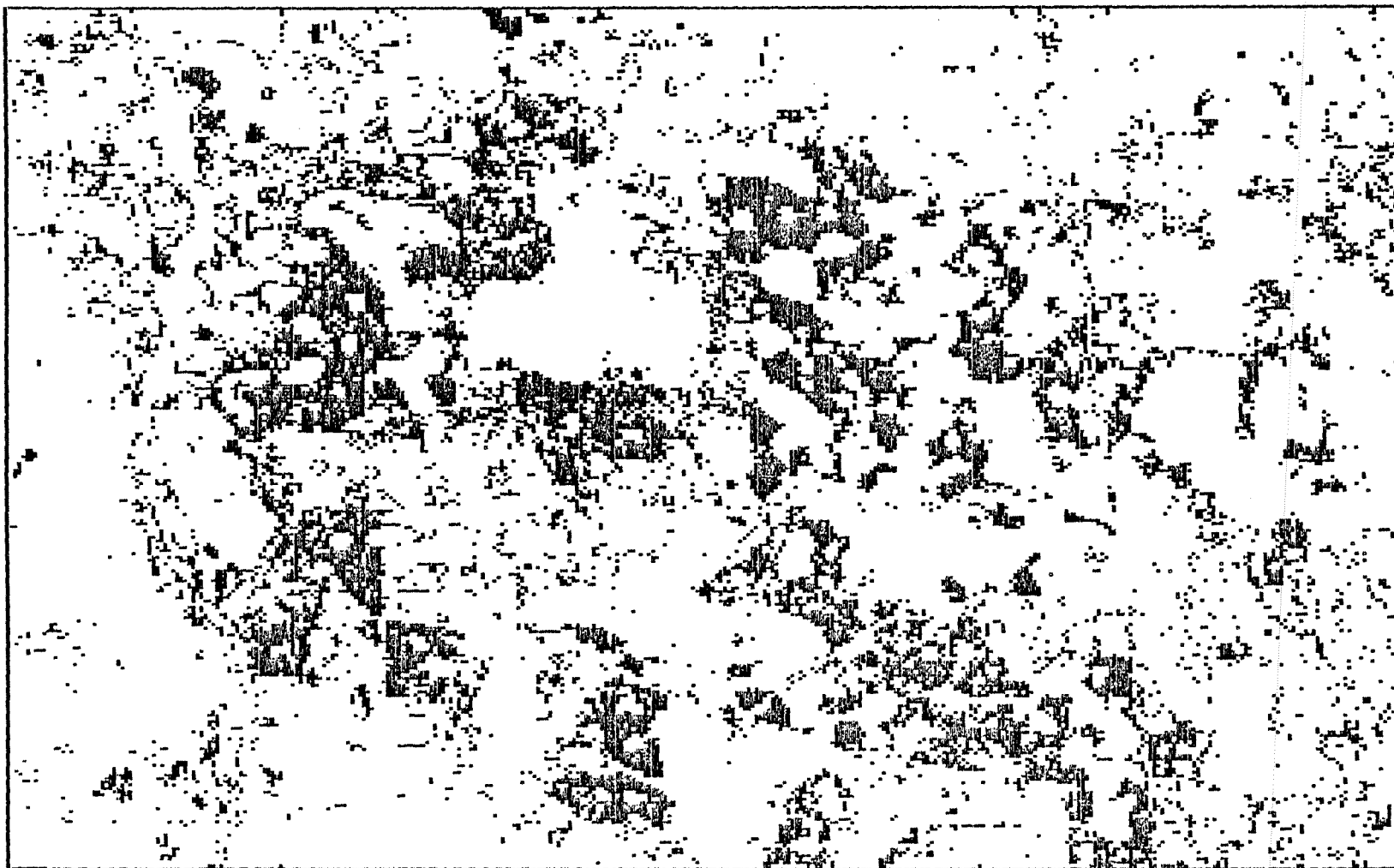


Figure 26. Wetland Area Printout - Shrub Group

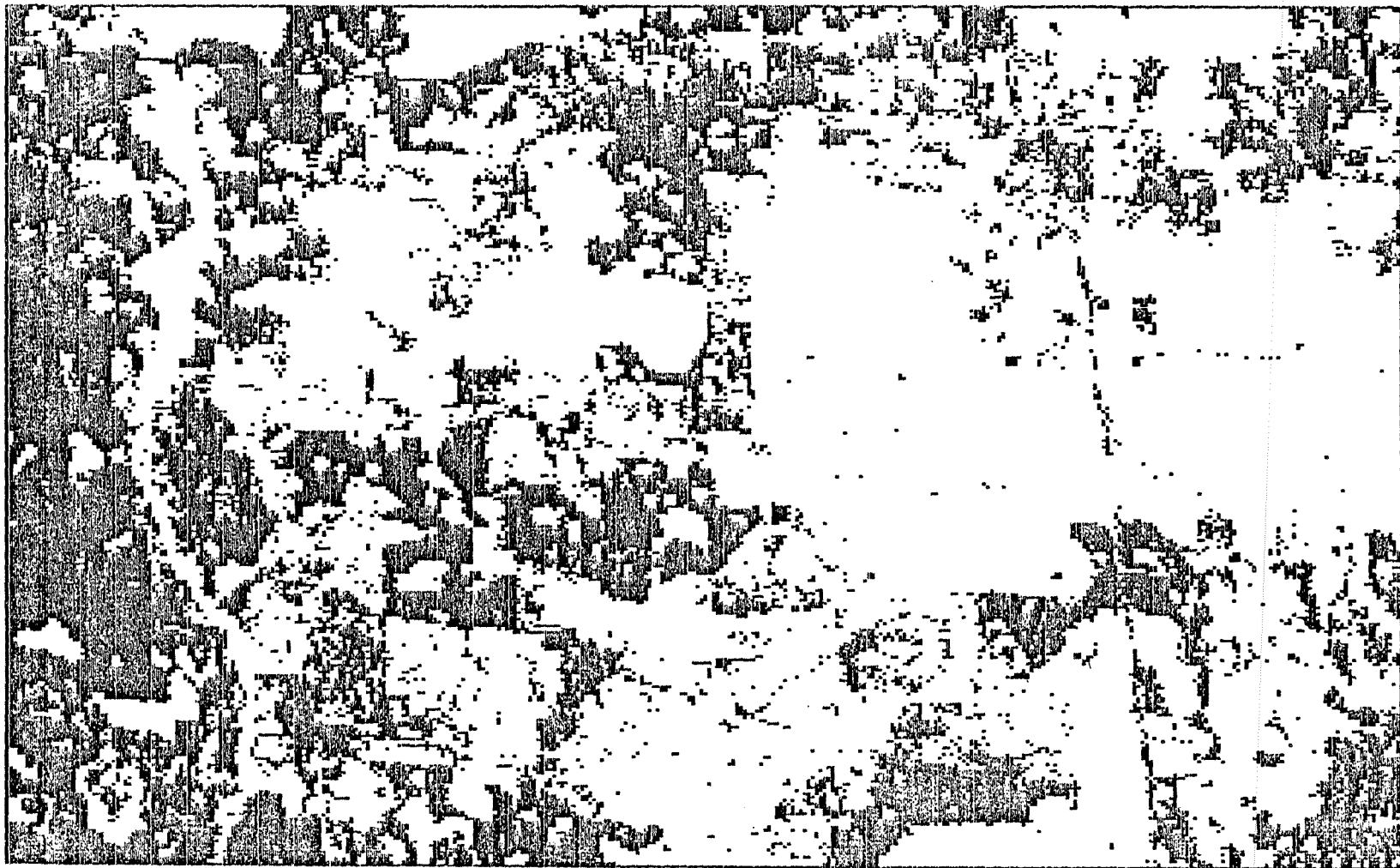


Figure 27. Wetland Area Printout - Grass Group

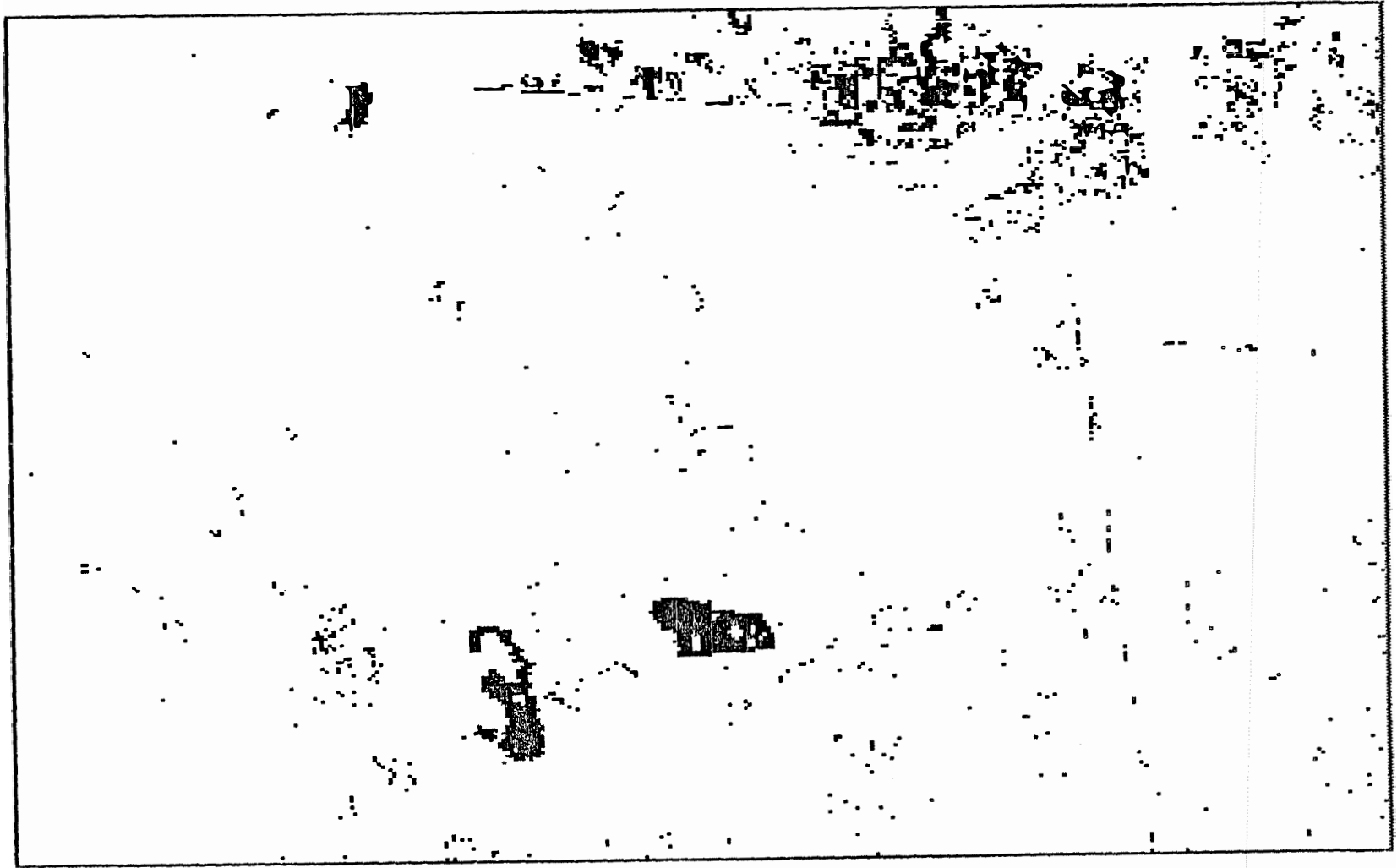


Figure 28. Wetland Area Printout - Agriculture Group

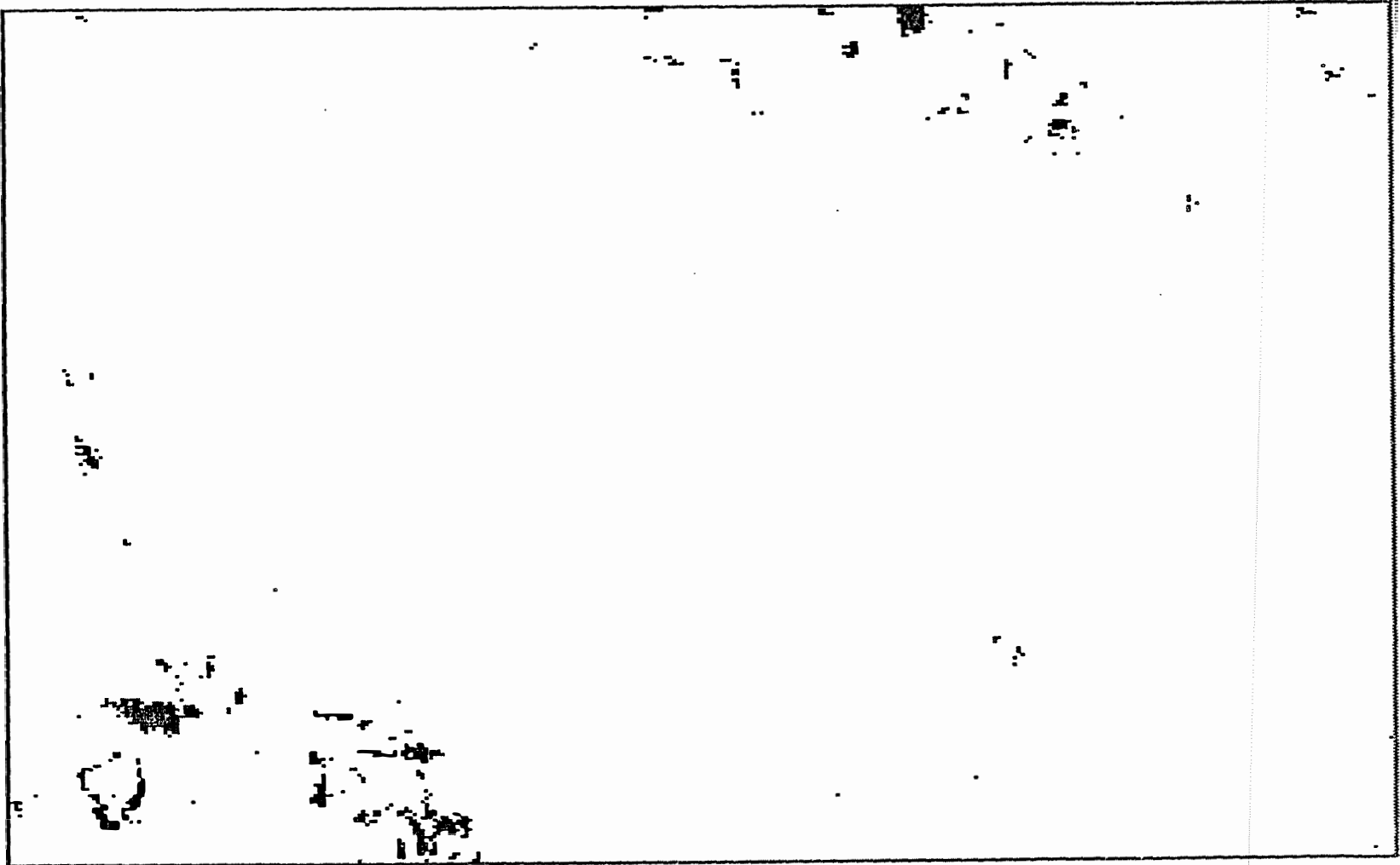


Figure 29. Wetland Area Printout - Barren Group

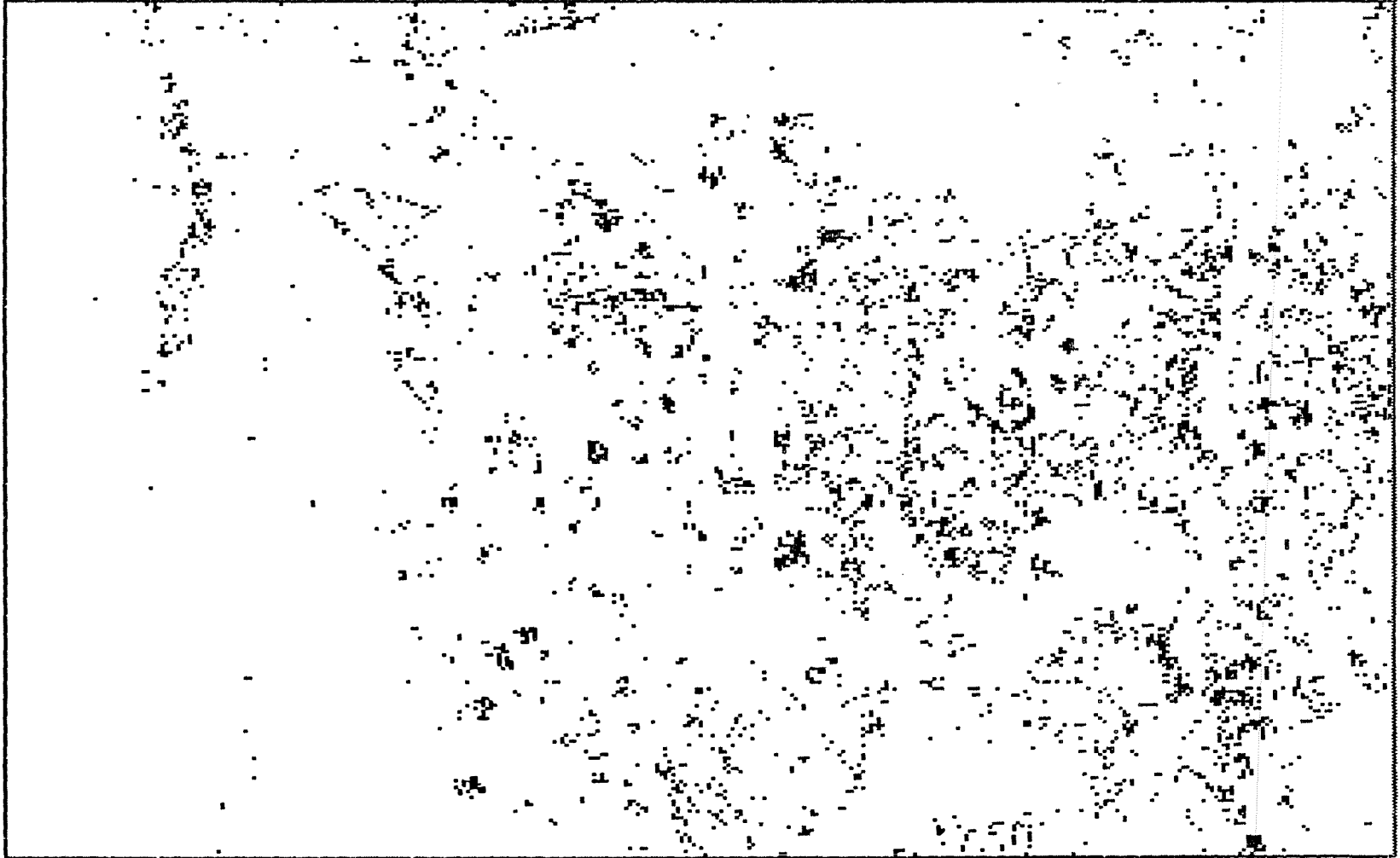


Figure 30. Wetland Area Printout - Wetland Class #1

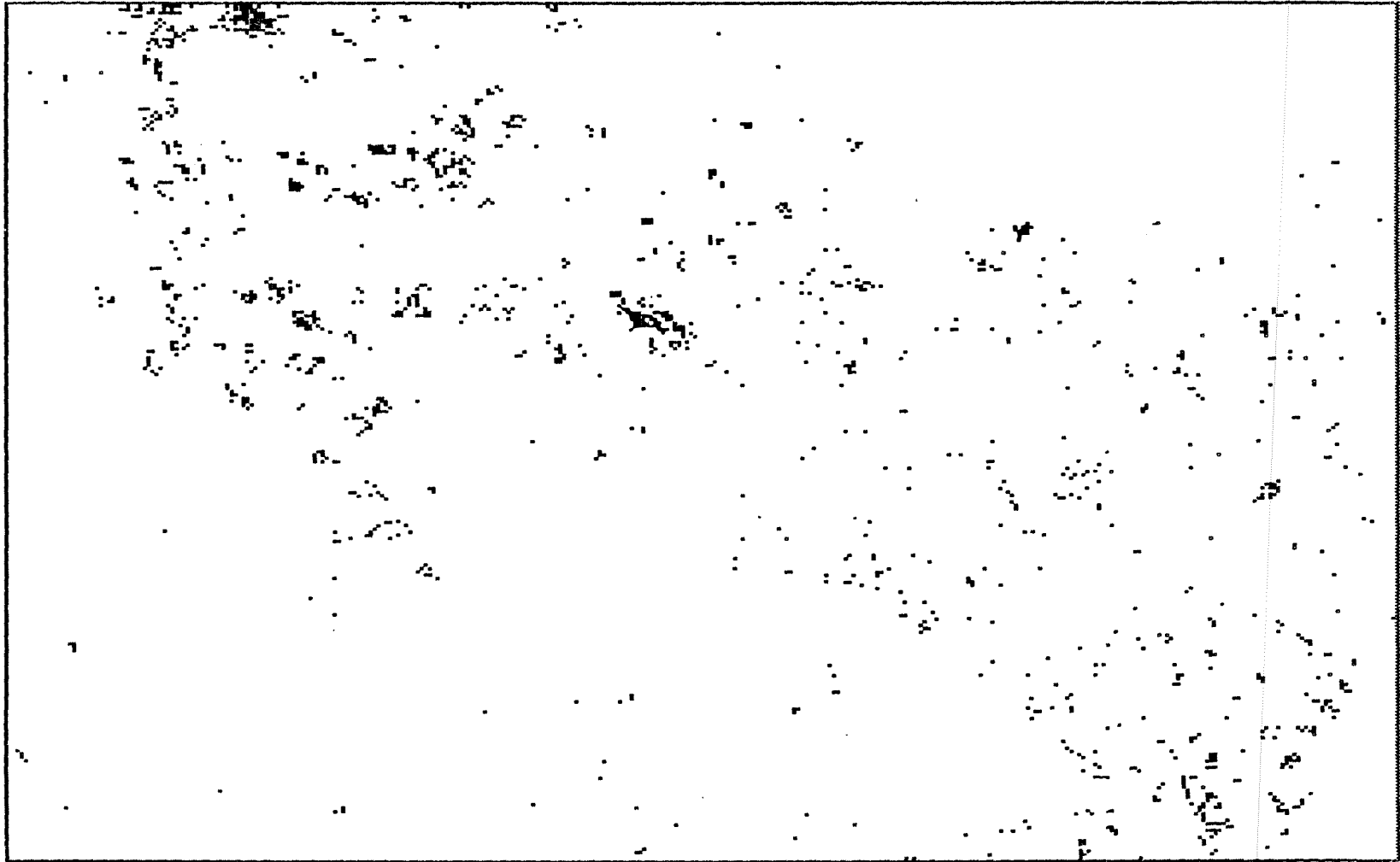


Figure 31. Wetland Area Printout - Wetland Class #2

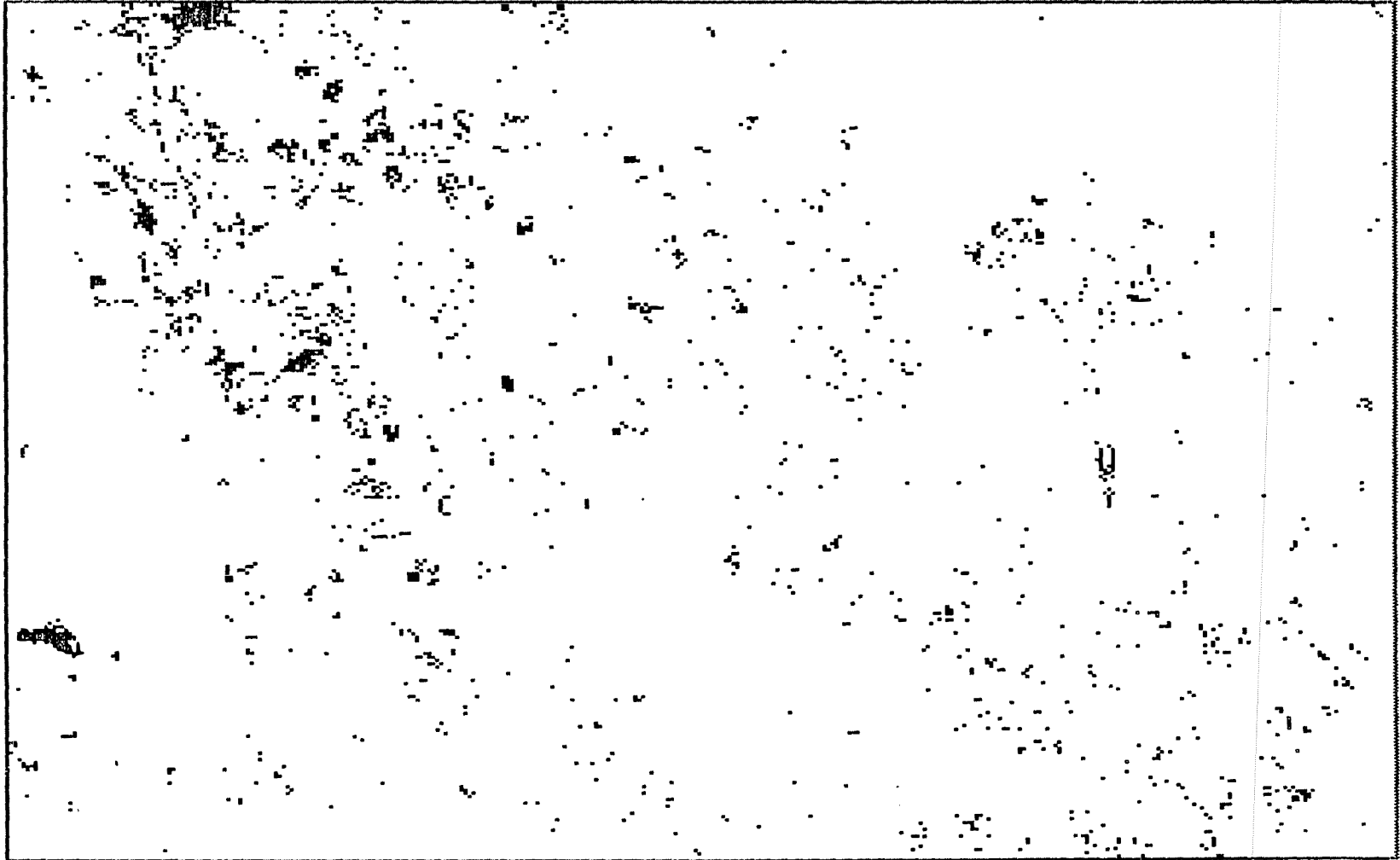


Figure 32. Wetland Area Printout - Wetland Class #3

verified TM classification was able to provide the necessary level of information needed by the Florida Department of Natural Resources, Bureau of Geology, to inventory the phosphate mining area within this study's two test sites.

A presentation of preliminary results of this study were made to industry and state government representatives at the Florida Institute of Phosphate Research in Bartow, Florida. The results were well received. Industry representatives saw the potential for site evaluation prior to development of new mines and the possibility of the measurement of large gypsum piles associated with the phosphate fertilizer manufacturing process. These applications could be spin-offs from the study after seeing the accuracy and resolution which can be provided from processed TM data.

The classification accuracy of TM data within the two study sites was most satisfying. Since aerial photography of the sites was obtained at the same time as the simulated TM data, an evaluation of each classification could be made in some detail. Seven class groups resulted from the image processing and field verification. The water group correlated to the aerial photography in all cases. There was a wide range of water clarity but no classification problems were encountered. The bare soil group was composed of active mining, sand waste piles, plant roads, stock piles, as well as clearing prior to mining and other construction. Overlap with cleared agricultural fields and young orange groves as well as thin grass covered slopes was experienced. The timber group clearly separated commercial

and 5/6. This combination clearly shows the wetland potholes as bright patterns. Ratios can be classified in the same manner as regular raw data.

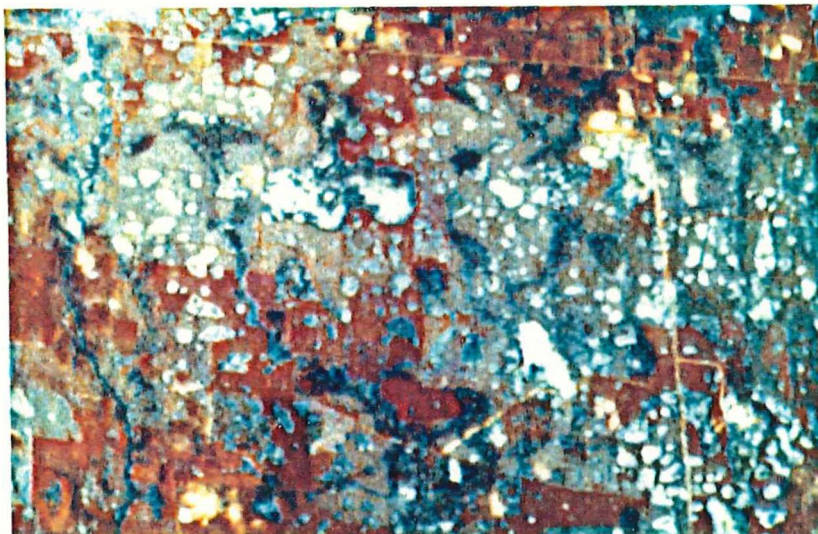


Figure 34. Ratio False Color Composite of Wetland Area

CONCLUSIONS

In attempting to apply Landsat satellite data and remote sensing technology to the classification of disturbed and undisturbed land, simulated thematic mapper as well as Landsat multispectral scanner data were evaluated. In the computer classification and succeeding evaluation of these two data sets the TM was clearly more successful. The classified MSS data were not able to adequately separate and identify features within the mined and non-mined areas. The MSS classification, although useful as an indication of surface condition, was only marginal in delineating the surface relative to the TM data. The field

timber from native timber and had difficulty only in determining the proper cut-off between timber and shrubs when the density of trees was low and the understory of shrub was high. This could have been treated as a mixed timber/shrub group. The shrub group clearly defined the palmetto as well as other shrub areas and experienced some overlap with the grass class (predominantly pasture) when the grass contained a large number of shrubs (palmetto). The grass group was very accurate and delineated all improved pasture and open grass areas. An increased number of classes within the grass group was experienced when the tree or shrub cover increased beyond 20% in a grass area. At that point care was necessary to assign the spectral class to the correct group. Planted fields, although very few, were successfully classified and delineated as a separate agricultural class. The wetland group was highly varied in its components but was accurately delineated. Field verification indicated most wetland habitats were considered temporarily or seasonally flooded. Without some field support difficulty would be experienced in separating and identifying wetland units. While ratios were given only a cursory examination in this project, it appears that band ratioing holds great potential in defining wetland vegetation types in the Florida area.

The successful classification of the simulated TM data indicates successful future applications of satellite borne TM data for cover type mapping, including wetlands, as well as for mine inventory and change detection.

RECOMMENDATIONS

This study has shown that the use of Landsat MSS data for inventory and cover type mapping in the phosphate mining region of central Florida is marginal, but the use of simulated thematic mapper data was very effective. This new data system could provide the basis for large area inventories which meet the needs of cover type mapping, (including wetland mapping as defined by the U. S. Fish and Wildlife Service) and mine change overtime for input to, or in support of, a regionally based geographic resource information system. The requirements of such a system are two-fold; the first is the evaluation of TM data as a cost effective tool for mine inventory, and the second is the development of a geographic data base which utilizes information derived from satellite data, map data, and field analysis.

Thematic mapper data have been shown to be capable of satisfying the needs of the Florida Bureau of Geology in the inventory of phosphate mining within two sites. The next step in the utilization of this data resource requires a classification of the entire phosphate mining area and an evaluation of the cost effectiveness in performing this task. Once a classification has been performed, it could then be made available to the Bureau of Geology, as a base for updating.

A geographic information system for the phosphate mining area of central Florida would act as both an information source and as a repository for new data as they are acquired. The data could be retrieved in map or tabular form. Existing information already

in map form (such as phosphate reserves or hydrology) can be digitized and stored. Thematic mapper classifications can then be used to inventory and update mine progress annually and supply the necessary surface area figures useful in planning. Digitized political boundaries, as well as land ownership, transportation, etc., could then be merged and mapped or displayed to provide a current understanding of the phosphate mining environment. TM data are directly applicable in the step from data classification to information and decision making.

An interesting outgrowth of simulated thematic mapper studies by NASA's Earth Resources Laboratory has been the use of principal components analysis. This image processing technique is useful in discriminating small heterogeneous features and was successfully tested by NASA over strip mines in Kentucky. Future satellite monitoring work over the phosphate mines in Florida should investigate the applications of principal components.

BIBLIOGRAPHY

1. Cowardin, L. M.; Carter, V.; Golet, F. C.; and LaRoe, E. T. ~~Classification of Wetlands and Deepwater Habitats of the United States.~~ Fish and Wildlife Service, Office of Biological Services, Department of the Interior, 1979, 103 pp.
2. Flanagan, G. F.; and Tilton, E. L. Landsat-D Thematic Mapper Simulator. Earth Resources Laboratory, National Space Technology Laboratories, National Aeronautics and Space Administration, 1982, 8 pp.
3. Lillesand, T. M.; and Kiefer, R. W. Remote Sensing and Image Interpretation. John Wiley & Sons, New York, 1979, 612 pp.
4. National Aeronautics and Space Administration. ELAS Earth Resources Laboratory Applications Software. Earth Resources Laboratory, National Space Technology Laboratories, 1981, 463 pp.
5. Phosphate Land Reclamation Study Commission. Report to the Governor on Phosphate Mining and Reclamation. Florida, 1977, 40 pp.
6. Texas Instruments. Central Florida Phosphate Industry Areawide Impact Assessment Program. Prepared for the U. S. Environmental Improvement Agency, V. 1, 1978, 221 pp.
7. U. S. Environmental Improvement Agency. Central Florida Phosphate Industry. Final Areawide Environmental Impact Statement. Impacts of Proposed Action. 1978, 80 pp.