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SUMMARY

Various image products and computer-classified images are presented to illustrate the application of satellite (Landsat) and aircraft multispectral scanner data to distinguish land cover related to surface-mining activities for a specific surface-mine test site in eastern Kentucky. Changes in the strip-mine area were monitored over a 5-year period by using image interpretation techniques and computer analysis. Comparisons are made of original and computer-enhanced single-band imagery, band-ratio imagery, and computer-classified, color-coded imagery. The mining and reclamation changes that are detectable from satellite data for a 5-year period are presented.

Band 5 imagery was useful for detecting changes in the disrupted area of the mine. Band-ratio imagery (bands 5/6) provided greater contrast than single-band data for separating the data into land-cover features and could be used to provide a qualitative level I classification of the mine area. However, if an accurate estimate of the barren and revegetated areas was required, it was necessary to use the four Landsat data bands and to rely on computer analyses based on either supervised or unsupervised statistical analysis techniques. Unsupervised analyses can be used for high-contrast conditions, but supervised techniques are recommended for greater accuracy if aerial photography or ground-survey data are available to guide the analysis.

The land-cover classification obtained from a computer analysis of 11-channel, aircraft multispectral data obtained at an altitude of 3000 meters is also included. The spatial resolution of 7.5 meters corresponding to this aircraft altitude is useful for providing a very detailed description of the area; however, more time, effort, and funds are required for the analysis of aircraft data than for satellite data.

INTRODUCTION

The environmental problems related to surface-mining operations are well recognized (refs. 1 to 4). In general, surface-mining operations require the removal of the existing natural vegetation, the topsoil, and a significant amount of subsoil to expose the underlying coal seam. After the coal has been removed, the stripped area must be regraded, revegetated, and restored to a useful state as required by state and federal regulations.

During active stripping operations, the land is laid bare. The resulting effect is a major change in the watershed drainage with a corresponding increase in erosion and sediment transport, potentially high levels of acid mine drainage, and an overall degradation of the entire surrounding area. There are no mining methods available to prevent damage to the environment during stripping operations. However, modern mining techniques, with effective erosion control practices and conscientious reclamation efforts by the mine operators, can minimize the deleterious effects of surface mining on the surrounding area, and eventually the mined area can be restored for useful purposes.

The detection and monitoring of the large land areas that are disturbed during mining operations is an application that is well suited to data obtained from satellite remote-sensing platforms. Such an application has been studied in various Appalachian and Western states (refs. 5 to 9) with encouraging results primarily for the detection of mines that have at least 100 acres of disturbed area. However, routine use of satellite data by state agencies for monitoring mining operations has not occurred. The reasons are not clear but appear to be related to the need for higher-spatial-resolution data and more detailed site-specific information. This information must be compatible with the 24 000-scale-factor United States Geological Survey topographic maps that are commonly used for "permit" purposes or for direct comparison with high-resolution aerial photographs, which are occasionally available. The reluctance of state agencies to incorporate satellite remotely sensed data into surveillance programs also appears to be related to the need to identify various surface-mine features that are influenced by such factors as the local topographic and geological characteristics, the surrounding environment, and the mining equipment and mining techniques being used. Presently, on-site inspections provide the necessary data. If an application using satellite data is to be developed, it will be necessary to develop analysis techniques that can complement and minimize the required on-site inspections.

To provide detailed, site-specific information for a surface mine from satellite data is not a simple or inexpensive task. The analyses that must be used can require intensive interpretation of special imagery or the detailed computer analysis of multispectral scanner data for land-cover features that are unique to a mining site. Such analyses may also require extensive computer hardware and software systems as well as ancillary data, from many different sources, that can be incorporated into the computer analysis. The techniques available for the analysis of multispectral digital data are currently in an evolving stage of development. The accuracy and thoroughness of an analysis are presently related directly to the skill and experience of the analyst and the inherent versatility and capability of the computer system being used. To a potential user of satellite data the computer analysis is an abstract and intuitive operation, and the resulting image products may be of limited value because of the user's unfamiliarity with the analysis procedures and his subsequent reluctance to accept the computer results.

This report presents and compares a variety of image products and computer procedures that have been used to study an active surface mine in eastern Kentucky with about 400 acres of disturbed area. The intent of the study is to provide a variety of data products that potential users may study and evaluate to explore the applicability of satellite data to specific strip-mining needs. Not all the techniques, computer analyses, or final image products that are available are included in this study. However, the variety of image products and analyses that are included is typical of current system capabilities and can serve as an introduction for the practical user.

TEST SITE

The test site that was selected is a coal strip mine located in eastern Kentucky that has been in operation since 1972. A color, infrared (IR) photograph that was obtained in June 1976 is presented in figure 1. A 1-kilometer grid is placed on the photograph for reference. The mine is in rugged, mountainous terrain that is almost totally covered with native hardwood trees. The mine is a relatively large, hilltop mining operation that, in 1976, consisted of approximately 450 acres of active barren area, 200 acres of regraded and recently revegetated areas, and 600 acres of older revegetated strip-mined land. To comply with Kentucky strip-mine laws, the mining activity is considerably diversified, and varying surface features related to active operations, regrading, and revegetation occur within the test site.

The test site was selected in cooperation with the Kentucky Department of Natural Resources and Environmental Protection (KY/DNR&EP). The KY/DNR&EP participated in the study in order to explore the potential application of satellite data for monitoring surface-mining activities. The mountainous topography and the many active mines in the eastern Kentucky coal field impose a difficult problem for the Division of Reclamation if frequent and repetitive inspections are to be made to insure that all mines comply with existing strip-mine laws. The application of satellite data, even within the spatial resolution limitations of the existing Landsat satellite sensors, can aid the current surface-mine inspection program.

DATA BASE

The data base that was used for the analysis of the mine area consisted of the following:

(1) Satellite (Landsat), four-band, multispectral scanner data obtained on four dates: April 14, 1978; August 19, 1976; July 29, 1975; and July 12, 1973

(2) Aircraft (NASA C-47, 11-band, mulispectral scanner data obtained at an altitude of 3000 meters on October 22, 1976.

(3) RC-10 color, IR, aerial photography obtained on June 6, 1976

(4) Kentucky DNR&EP ground-survey taken during August 1976

The Landsat multispectral scanner system (ref. 10) is a line-scanning instrument that collects scene data in four spectral wavelength bands. The spatial resolution of each picture element (pixel) is 57 meters by 79 meters (approximately a 1.1-acre pixel). Satellite data are recorded on an 18-day repetitive cycle and are available as either a single-channel, black-and-white photographic image; a multiband, false-color composite image; or a four-band, magnetic-tape digital format suitable for computer analysis. The four scenes that were used for this study were the result of reviewing a 5-year period of satellite data to select a consecutive set of suitable data with which to illustrate the capability of various image products and computer analysis techniques.

The aircraft multispectral scanner system is an 11-band, line-scanning instrument manufactured by the Bendix Corp. of Ann Arbor, Michigan, and was mounted on board the NASA Lewis Research Center C-47 aircraft. The multispectral scanner is described in reference 11. The spatial resolution of the scanner picture element at nadir is 0.0025 times the aircraft altitude, or 7.5 meters at an aircraft altitude of 3000 meters.

DATA ANALYSIS

A variety of image products, data presentations, and computer analyses can be generated from multispectral scanner data. The list is extensive, and both analyses and image products are constantly being improved. At this time there are no generally accepted procedures that can be universally recommended to cover all mine operations and that also consider such important factors as cost, timeliness, and available equipment. This study is limited to the following image products and analyses:

(1) Image products

- (a) Single-band, black-and-white (B&W), 1 000 000-scale-factor, original Landsat imagery with photographic magnification
- (b) Single-band, B&W imagery from satellite and aircraft computer-compatible tapes (CCT)
- (c) Single-band, B&W imagery obtained from the ratio of two bands of satellite data
- (d) Three-band, false-color imagery of satellite and aircraft multispectral data

(2) Computer analyses

- (a) Purdue University, Laboratory for Application of Remote Sensing (LARSYS) III/UNIVAC 1110, unsupervised and supervised, multiband statistical classification of satellite data (ref. 12)

(b) Bendix Corp. multispectral data analysis system (MDAS) supervised, multispectral, statistical classification of aircraft data (ref. 13)

The single-band and band-ratio B&W imagery are generated on an interactive minicomputer system by using a Varian dot printer or a Dicomed film recorder. The Varian dot printer is a 200-dot-per-inch recorder and is usually used to provide imagery with four gray levels of separation. The Dicomed film recorder is a 1200-dot-per-inch recorder and can provide imagery with up to 10 gray levels of separation.

The three-band, false-color superposition images were generated on the Bendix MDAS film recorder system or by photographing directly the video display, which assigns a single data band to each of the red, blue, and green "guns" of the cathode-ray-tube (CRT) video display monitor. The varying gray levels of each channel (or band) were superimposed to generate a false-color image that can be considered a three-band, color-composite image on the scene.

The color-coded, multiband, computer-classified results were obtained from the LARSYS III computer analysis system, and the color images from the Dicomed film recorder. The color-coded images of the Bendix MDAS system were photographed directly from the video display of the MDAS system. Both the LARSYS III and MDAS systems use a maximum-likelihood statistical classification procedure, and both systems are highly regarded and widely used for data analysis.

RESULTS AND DISCUSSION

The test site, as it appears in original Landsat band 5 imagery, is shown in figure 2(a). The capability of photographic magnification to improve the detection and interpretation capability can be determined from figures 2(b) to (d). The original image is the August 19, 1976, scene; and the image scale factor of 1 000 000 is a standard product (180-mm format) that can be purchased from the EROS Data Center in Sioux Falls, South Dakota. The band 5 images are shown in negative print format in order to highlight the barren areas, which appear as dark gray tones. The barren areas stand out clearly against the native hardwood forests, which are the light gray tones in the negative image. The revegetated or drainage areas are the medium gray tones. The test site is easily detected and recognized on the image. There are many surface-mining operations in the area, and the extent of the surface-mining activity is clearly established. The ×20 magnification (50 000 scale factor) of figure 2(d) is a useful scale at which to visually estimate the extent of the area disrupted by mining activity.

Band 5 imagery in negative print format is the most useful band for delineating the extent of surface-mining operations because of the high scene contrast during the summer months between the barren mine areas and the native hardwood forests of eastern

Kentucky. There are slight variations in gray level within the barren mine area, which can be correlated to some extent with reclamation activity.

The general-purpose images of figure 2 are useful for many routine monitoring and surveillance purposes such as detecting the gross changes in disrupted area. The imagery, however, has obvious limitations for providing site-specific information. The usefulness of band 5 imagery for detecting and monitoring progressive mining changes over a 3-year period is evident in figure 3. Figure 3 shows three different scenes of the test-site area taken between July 12, 1973, and August 19, 1976, at a scale factor of 100 000. A 1-kilometer grid overlay, which is consistent with the grid overlay in figure 1, is included for convenient reference. The mine changes that occurred over the 3-year period are readily detected and could be transferred to maps in order to document mine changes if the need existed.

Computer-Generated, Single-Band Imagery

One method of improving the single-band imagery so that it yields additional information is to analyze the satellite digital data from computer-compatible tapes (CCT). The digital tape format is also a standard EROS data product; however, an appropriate computer system must be available. In addition, special-purpose display and/or film recording equipment is required for analysis and documentation. Single-band data can be computer manipulated to enhance the gray level range and improve the image contrast in order to isolate specific features or to magnify the image to any desirable scale. Contrast-enhanced, computer-generated imagery for the August 1976 scene is shown in figure 4 in negative print format. The figure 4 images were made on a Dicomed film recorder with a 10-gray-level density range that was carefully selected to enhance the land cover of the mine area. The Dicomed film recorder generates the image point by point at 1200 points per inch and uses a 6×8 dot matrix to represent each satellite pixel. The figure 4 image, which has been photographically enlarged to a scale factor of 100 000, shows the pixel quality of the data as the rectangular array representing pixels becomes noticeable.

Comparing figure 4 with figure 2(d) shows the improved contrast that can be obtained for barren areas by using computer magnification and gray level enhancement from the CCT data format. The medium gray tones can be related to various stages of vegetation.

The enhanced contrast between barren and vegetated areas is also evident in the figure 4 imagery. The band 4 image is the only other image that is comparable in quality to the band 5 image. The mine outline is barely detectable in the band 7 image, and the mine cannot even be detected in the band 6 image. Band 7 imagery has been used for surface-mine studies; however, caution must be exercised in generating the enhanced image and in interpreting the scene. Band 6 imagery has limited application for surface-mine studies.

The improved capability of computer-processed, single-band imagery to monitor mine changes is shown in figure 5. The contrast has been improved for all of the images as compared with the original imagery in figure 3. With experience, photointerpretation techniques can even be used to provide some site-specific information. The original gray level range for single-band data is limited, however; and only a modest overall improvement can be expected.

Computer-Generated, Band-Ratio Imagery

Multiband analysis must be employed to exploit satellite data for the interpretation of various land-cover classes. The simplest multiband technique (or algorithm) in routine use is the ratioing of two bands of data. Reference 9 has shown that band ratio 5/6 is useful for defining the extent of surface-mining activity as well as for possibly providing a qualitative level I (ref. 14) classification of land cover. Figure 6 presents band ratio 5/6 and 7/4 images for four scenes over the 5-year period between 1973 and 1978. There is significant improvement in the overall contrast of the band-ratio image as compared with single-band imagery, as well as improved mine boundary definition. The real improvement in band-ratio imagery, however, is masked somewhat by the limited gray levels available from the photographic products.

The improved potential of the band-ratio data can be better illustrated by the histogram data shown in figure 7. The histograms were obtained from the August 1976 data and are restricted to a small area located directly at the test site. In these histograms the digital count range for each band is noted, as well as an estimated partitioning of the data into three level I classes. The overall range for the digital counts associated with each band is relatively small: for example, 30 counts for band 4; 48 counts for band 5; 40 counts for band 6; and only 28 counts for band 7. Therefore, for a 10-gray-level image, each gray level will represent a digital range of only three or four counts. The data range for band-ratio data (band ratio $\times 100$) is larger: 90 counts for band ratio 5/6 and 120 counts for band ratio 7/4. The increased count range permits not only enhanced contrast, but also improved land-cover identification because of greater separation between classes. Band-ratio imagery shows promise not only for high-contrast imagery, but also for level I classification that can be obtained inexpensively. However, the interpretation of band-ratio imagery has not been well documented nor has its utility been widely accepted. Some confusion in the distinction between classes can occur, and additional study and evaluation are required to insure accurate interpretation of band-ratio imagery.

Three-Band, Color-Composite Imagery

A multiband image product that has higher visual contrast than band-ratio imagery is the false-color imagery shown in figure 8. These images were generated by using the data from bands 4, 5, and 7 to create a color composite image. The image resembles somewhat a conventional, color, IR aerial photograph (fig. 1) in that the vegetation is red and the barren areas are gray. The many combinations of bands and photographic dyes permit a wide range of false-color renditions to be created. During the active plant-growing season, high-contrast images of surface mining in forested areas can be generated. Interpreting the imagery is difficult and is governed to a large extent by the parameters used to make the image. False-color composite imagery is not recommended for direct interpretation but can be used for identifying homogeneous color areas that may be assumed to be uniform areas of land cover.

Return-Beam-Vidicon Camera Imagery

A recent image product that has become available as a standard Landsat data product from EROS is the black-and-white image in figure 9. The image was obtained from the return-beam-vidicon (RBV) camera on the Landsat 3 satellite. An advantage of the RBV image is the improved spatial resolution of 30 meters, as compared with the 80-meter resolution of the multispectral scanner. The RBV data are obtained with a wide-spectral-band sensor, and the resulting image resembles very closely a panchromatic black-and-white aerial photograph. The improved spatial resolution is evident in figure 9; however, the lack of contrast due primarily to the April scene conditions detracts from the value of the image.

Computer Analysis of Multispectral Data

To extract the maximum information possible from satellite data requires more sophisticated computer analysis techniques that use all four data bands. The computer analysis can take many approaches; however, the maximum-likelihood statistical analysis methods of references 12 and 13 are the most common. These analyses can be conducted in either a supervised or unsupervised mode. Supervised analyses require the calibration or "training" of the computer with known training sites to identify predetermined classes of land cover obtained from a-priori knowledge of the area in the form of ground surveys or current high-resolution aerial photographs. The quantitative results obtained from supervised analyses are generally useful, but the classification accuracy depends to a large extent on the skills of the analyst, the capability and versatility of the available computer system, and the computer time allocated to the analysis.

Unsupervised (or clustering) analyses do not require a-priori knowledge of the area. The analysis is essentially "undirected" and does not require a skilled analyst. For level I classification of a reasonably uniform area that has large uniform fields, unsupervised results are generally acceptable. However, for a level I classification of a highly varied and complex area with rapidly changing surface features, clusters of pixels representing land-cover categories can be established that are a mixture of several classes ("border pixels"), will have more statistical significance than land-cover importance, and can introduce inaccuracies into the final classification.

Both supervised and unsupervised computer analyses have been made for the area. The resulting color-coded images of the classification are shown in figure 10. The supervised analysis was limited to nine different classes; the unsupervised analysis was limited to 10 clusters. However, only six colors were used for the figure 10 images.

The color-coded images are a good representation of the area, as indicated by comparison with the color, IR aerial photograph. There are only slight differences between the two computer images. The differences are due to the differences in the analysis procedures. For a common test-site area of 2604 pixels directly in the mine area, a number count of the pixels in each category is included for comparison. The supervised analysis contains more barren area (371 pixels) than the unsupervised analysis (318 pixels), but the unsupervised analysis includes more revegetated area (334 pixels) than the supervised analysis (320 pixels). These differences are attributed primarily to the effect of "border pixels," which are included as revegetated areas by cluster 4 in the unsupervised analysis but remain unclassified or barren in the supervised analysis. (All data are classified in the unsupervised analysis.) Overall, the agreement between the two images is excellent and either classification is considered an acceptable representation of the area.

Additional insight into the classification and the analysis procedures can be obtained from table I and figure 11. Table I describes each class or cluster that was established and presents the mean radiometric values of each class for each band (i.e., the spectral signature) as well as the band ratio 5/6 and 7/4 values corresponding to the mean value of each class. Figure 11 plots band ratio 5/6 versus band ratio 7/4 for each class and groups or partitions the data into useful land-cover categories. The categorization is based on 33 training sites that were selected during the supervised analysis to establish the nine classes that were eventually used to describe the scene. Figure 11 is a useful and convenient presentation format that was used throughout the analysis procedure to insure that the training-site selection was consistent and that the description of the scene was complete.

A simpler and less expensive product than color imagery can be used to present the results of computer analyses, as shown in figure 12. These black-and-white images were generated on a Varian dot printer and present only a given theme (or class), such as the barren class or the revegetated class. Such images can be quickly evaluated to establish the extent of mining progress or can be overlayed with previous analyses for comparison.

The best estimate of accuracy that can be made for the August 1976 classification is based on the June 1976 aerial photography and ground survey. The accuracy estimates for the August 1976 scene are 90 percent for the forested and barren areas and 60 percent for the revegetated areas.

The accuracy limitations of using satellite data for surface-mine monitoring are clearly indicated in figure 12. The narrow, complex shape of the mine area, coupled with the 1.1-acre resolution of the satellite sensor makes the location and selection of uniform surface areas for training-site data a critical phase of the analysis. The revegetated areas within the mine area are generally very small, and the identification of a definable area is particularly difficult and is often limited to only a four- to six-pixel area. Training-site selection must be performed very carefully to insure proper location and identification of homogeneous areas if an accurate classification is to be obtained. If such areas can be established, the accuracy will be acceptable.

The rugged, hilly terrain of eastern Kentucky, where the test site is located, presents a high-contrast scene that is ideally suited to the detection of surface-mining operations during the summer months. However, the rugged terrain also introduces into the analysis topography problems which require that the influence of slope and direction on the radiometric values be considered for land-cover definition. For the active hilltop mining area the problem is not serious for the barren areas. However, spoilbank and end-of-hollow fill areas that are regraded and revegetated require that slope direction be considered.

Slope direction is particularly important for the undisturbed forested area. To obtain an accurate forested classification, it is necessary to include not only changes in forest type but also the effects of sun angle and sensor viewing angle.

Temporal Changes in Mine Features

The utility of computer-classified data to indicate changes in the disrupted and reclaimed areas is shown in figure 13 for the July 1973, July 1975, and April 1978 scenes. The corresponding spectral signature data are given in table II. Because ground-survey data or aerial photographs were not available for these scenes, the identification of various classes and the corresponding color coding were based on comparisons with the spectral signature data in table I and the insight developed during the August 1976 analysis. The generalized color-coding scheme shown in figure 13 was used for all scenes. The color code is identical to that of figure 10 and consists of two colors for barren areas (white and gray), two colors for revegetated areas (orange and yellow), and two shades of green for forested areas (green and dark green).

The basic color scheme was adequate for the barren and forested areas; however, some difficulty was encountered in the revegetated classes because of the complex characteristics of the class. Revegetated areas are a mixture of barren and vegetated areas, and the many levels of revegetation that occur can be represented by many different land-cover combinations, such as sparse vegetation, successful reclamation, sparse natural vegetation on spoil banks, or even "border pixels." The many possibilities that can exist for revegetation, along with the absence of complete ground-survey data or aerial photography, result in a classification that is useful for most monitoring purposes but must be accepted with reservations.

A thematic representation of only the barren areas for each of the four scenes is shown in figure 14. A composite image of the four scenes in figure 14 is presented in figure 15 to show only the new barren area that is identified each year. From such an image, it is possible to quantitatively follow the active mine progress over a long period of time.

During the 5-year period, reclamation activity was also in progress. Figure 16(a) shows the reclamation progress of the area classified as barren in the July 1973 scene. Approximately one-half of the barren area was reclaimed by July 1975, and most of the barren area had been revegetated by August 1976. All of the 1973 barren area had been reclaimed by April 1978. The revegetation of the July 1975 barren area is shown in figure 16(b), and the revegetation of the August 1976 barren area is shown in figure 16(c). The potential use of satellite data for monitoring revegetation progress on an annual basis is evident, but additional development is required before an accurate technique is available.

A critical factor in the routine, repetitive application of satellite data for annual monitoring of surface mines is the need for accurate scene-to-scene or scene-to-map registration. Many of the surface changes that occur in mining operations on an annual basis occur for areas of less than 10 acres. If changes in such small areas are to be detected accurately, it is necessary to register scenes to within single-pixel accuracy.

In addition to using satellite data to monitor surface changes, the computer analyses can be used for routine inventory purposes to establish the extent of the area affected by the mining operations or to determine the area associated with a specific land-cover type. The simplest and most accurate inventory procedure to use with the computer techniques is a direct pixel count, as used for the data in figure 10 or table I. However, if the area to be inventoried cannot be accurately outlined within the computer data base, it is possible to use thematic imagery and more conventional planimeter or optical area measurement techniques. For year to year comparisons where only satellite imagery is available, such conventional methods are appropriate, and noncritical needs can be met by using band-ratio or possibly single-band imagery. Inventory measurements for barren and revegetated areas made with computer-classified, band-ratio 5/6 and band 5 thematic imagery are compared in table III. The table III data were obtained for the four Landsat scenes over a common 5478-acre area (60 pixels by 83 scan lines) that included the primary test site.

The use of band-ratio or single-band imagery for inventory purposes is somewhat qualitative and subjective in that the cutoff levels associated with a specific land-cover class are not clearly defined. It is necessary to rely on the capability and experience of the person performing the measurements to estimate the cutoff levels appropriately.

The data in table III indicate that either band ratio 5/6 or band 5 imagery can be used to inventory barren areas within an accuracy of ±20 percent of the computer-classified data. The data from April 14, 1978, are not as accurate as the other data because of the lack of contrast between barren and vegetated areas due to seasonal conditions. Using band ratio 5/6 or band 5 imagery to inventory revegetated areas introduces significant differences from computer-classified data. Other band-ratio or single-band imagery may be more appropriate for revegetated areas, but this evaluation was not pursued.

Other computer systems are available that can be used for the statistical classification of multispectral scanner data. The MDAS developed by the Bendix Corp. of Ann Arbor, Michigan, is one such system. The MDAS is a dedicated minicomputer system that has interactive analysis capability and a color video display for real-time evaluation of the classification results. The results of such an analysis for the August 1976 test-site scene are shown in figure 17. Figure 17 is a level I, seven-class, seven-color, supervised classification of the scene from training-site data that were selected from the general scene area. Because of the small size of the test site, it was difficult to obtain good training-site data directly from the test area, and it was necessary to rely on training-site data that could be obtained from larger mines outside the general area. The final classified image is an acceptable description of the mine area, but the results are not considered to be as accurate or directly applicable to the mine as are the results obtained from the more intensive LARSYS analysis. The MDAS analysis, however, was made in a much shorter time with significantly less effort. The resulting classification may be a useful compromise for many applications.

Aircraft Multispectral Scanner Data

The images that have been shown at a scale factor of 100 000 illustrate the detail obtainable from satellite data for a typical surface mine. The images could have been presented at a scale factor of 50 000, or even magnified to 24 000 if large-scale images were desired. However, if additional surface detail related to land-cover or surface activity is required, other higher resolution data base systems, such as aircraft multispectral scanner systems, should be considered. Aircraft multispectral scanner systems are capable of much higher spatial as well as spectral resolution and can be used to describe land cover in much greater detail (ref. 15). There is, however, a significant increase in the cost, time, and effort required to acquire and analyze aircraft data.

Three examples of single-band aircraft multispectral imagery obtained during an overflight of the test area for October 1976 are shown in figure 18. The data were obtained with a Bendix 11-channel multispectral scanner (ref. 11) at an altitude of 3000 meters. The spatial resolution of the data at nadir at the 3000-meter altitude is 7.5 meters. The resulting single-channel imagery in figure 18 is much more detailed than the satellite imagery in figure 4. The aircraft scanner data bands 4, 6, and 9 correspond approximately to the satellite data bands 4, 5, and 7 but with a much narrower spectral bandpass. With experience, photointerpretation techniques can be used to provide useful information from single band 4 or band 6 imagery. The additional information content that can be obtained from three-band (4, 6, and 9), false-color imagery is shown in figure 19. The false-color image is useful primarily for identifying revegetated areas.

The primary advantage of aircraft multispectral data is the improved spatial resolution, which permits more detailed analysis of land-cover classes. The results of a supervised classification of the mine are shown in figure 20. The computer classification consisted of 23 different land-cover classes that were further combined and represented by 16 colors in the color-coded images. The locations of the training sites used for the supervised classification are shown in figure 21. The training-site descriptions and spectral radiometric data are shown in table IV. A band-ratio representation of the classes is shown in figure 22 to illustrate the radiometric separation that exists between the various classes. The analysis of high-resolution aircraft scanner data permits the statistical separation of the data into many different classes - frequently, more classes than can be quantitatively defined or color coded to present an interpretable image. Even with careful color selection it is difficult to comfortably study or analyze an image with more than 16 colors.

CONCLUDING REMARKS

The application of Landsat data and imagery to describe site-specific land cover of a surface strip mine in eastern Kentucky has been presented. Original black-and-white, 1 000 000-scale-factor, single-band imagery obtained from the EROS Data Center can be used to locate and detect mines that have at least 100 acres of disturbed area. Landsat band 5 imagery is the most suitable band for this purpose. A scale factor of 100 000 is a useful working scale for studying mine changes. Computer-enhanced imagery produced from computer-compatible digital data tapes can provide an improved product that can be electronically magnified to any desirable scale.

Band ratio 5/6 imagery provides a greater contrast range and improved separation between level I land-cover classes than single band 5 imagery. Although band-ratio data have the potential application for level II class separation, the gray level limitations of black-and-white image products cannot accommodate the improved contrast range of the band-ratio data. The resulting band-ratio image is only a slight improvement over a simple band 5 image. Either band 5 or band ratio 5/6 data can be used to effectively follow the temporal changes in the surface-mine features.

A false-color composite image produced from three data bands is useful for specific applications such as the location and selection of homogeneous areas for training sites to be used for four-band, supervised, statistical classifications. Although the direct application of three-band-superposition, false-color imagery for land-cover classification is possible, there does not appear to be any advantage over band-ratio imagery.

The statistical, computer classification of four-band data has the potential of providing the maximum information regarding the various land-cover characteristics but considerable training, experience, and computer equipment are required.

Although either supervised or nonsupervised techniques can be used for classification, supervised techniques are recommended if suitable ground-survey data are available. Nonsupervised techniques are presently limited by the spatial resolution of the Landsat multispectral scanner system and the small areas associated with surface-mining activity. This combination introduces many "border pixels" into the clustering process and can introduce mixed classes that have little significance for land-cover information. Supervised analysis techniques are the recommended procedure but are also somewhat limited by the sensor resolution and require care in the selection of training-site areas. Pertinent mine-related areas frequently consist of groups of only four to six pixels and require the accurate location of known homogeneous areas to insure accurate training sites. Geometric registration is also an important factor and techniques that provide scene-to-scene or scene-to-map accuracies of 1 pixel are required if mine features compatible with a scale factor of 50 000 or greater are to be identified and compared.

Single-theme, black-and-white images of computer-classified, barren areas have been found to be an effective presentation format for following mining progress (i.e., barren areas) if registration accuracies within 1 pixel can be obtained. However, the comparative mapping of annual revegetation changes is not as direct or quantitative as mapping of the barren area changes. Although revegetation changes were mapped during the 5-year study period for the specific test site, the year-to-year changes are considered only approximate and additional effort is required to develop this application.

The computer classification of the mine is considered to be 90 percent accurate for forested and barren areas and 60 percent accurate for revegetated areas.

High-altitude-aircraft multispectral scanner data are more readily suited to provide site-specific information for features consistent with a scale factor 50 000 or larger. The time, effort, and funds required to acquire and analyze these data are significantly more than those required for satellite data.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 20, 1979,
663-01.

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TABLE I. - RADIOMETRIC AND INVENTORY DATA OBTAINED FROM LARSYS III

ANALYSIS OF AUGUST 19, 1976 LANDSAT SCENE

Class	Description	Spectral data-band				Band ratio		Total pixels classified
		4	5	6	7	5/6	7/4	
		Mean radiometric values						
Unsupervised analysis								
1	Barren - limestone, active operations	42	43	43	16	1.00	0.39	44
2	Barren - limestone and shale, graded	35	32	32	12	1.01	.33	145
3	Barren - Shale, graded	30	24	27	10	.90	.35	116
4	Revegetated - less than 30 percent	36	33	39	16	.85	.44	86
5	Revegetated - less than 50 percent	29	24	35	16	.67	.54	135
6	Revegetated - greater than 50 percent	28	20	42	21	.49	.74	113
7	Forest - hardwood, sunny	24	15	48	26	.31	1.08	173
8	Forest - hardwood, sunny	23	14	41	22	.33	.99	700
9	Forest - hardwood, shade	23	14	36	19	.38	.83	423
10	Forest - hardwood, shade	22	13	30	15	.43	.68	669
Supervised analysis								
1	Barren - limestone, active	44	45	44	16	1.02	0.37	93
2	Barren - limestone and shale, graded	36	32	31	11	1.04	.31	144
3	Barren - shale, graded	29	24	26	9	.91	.32	134
5	Revegetated - less than 50 percent	29	23	35	15	.66	.53	196
6	Revegetated - greater than 50 percent	27	19	42	20	.45	.76	124
7	Forested, hardwood, sunny	25	16	50	27	.32	1.07	166
8	Forested, hardwood, sunny	23	13	42	23	.32	1.00	750
9	Forested, hardwood, shade	22	13	35	19	.37	.85	418
10	Forested, hardwood, shade	21	12	28	14	.44	.65	540

TABLE II. - CLASSIFICATION DATA FOR THREE LANDSAT SCENES

Scene	Description of class	Spectral data-band				Band ratio	
		4	5	6	7	5/6	7/4
		Mean radiometric values					
July 12, 1973	Limestone	49.6	53.4	56.8	25.6	0.94	0.52
	Limestone and shale	41.2	40.0	37.8	15.7	1.07	.38
	Revegetation, less than 50 percent	33.6	30.0	46.1	24.4	.65	.73
		28.1	21.8	39.7	21.7	.55	.77
	Revegetation, more than 50 percent	27.2	20.2	54.3	33.5	.37	.81
		37.0	28.9	57.2	32.0	.51	.86
	Forest, sunny	24.1	13.8	64.2	42.4	.22	.57
		23.0	13.7	57.1	37.8	.24	.61
	Forest, shady	22.7	13.1	52.6	33.6	.25	.68
		22.5	12.8	46.7	29.1	.27	.77
July 29, 1975	Limestone	39.6	46.4	62.6	25.7	.74	.65
	Limestone and shale	38.8	43.0	54.1	21.0	.79	.54
	Shale	35.8	36.7	47.9	18.5	.77	.517
	Revegetation, less than 50 percent	32.0	30.7	47.9	20.8	.64	.65
	Revegetation, more than 50 percent	35.7	38.4	59.7	25.3	.64	.71
	Forest, sunny	30.6	26.8	59.8	31.1	.45	1.02
		37.8	34.5	62.1	29.3	.56	.78
	Forest, shady	27.8	23.1	57.7	29.9	.40	1.08
		30.1	26.2	53.1	25.3	.49	.84
April 14, 1978	Limestone	37.5	50.5	51.8	20.1	0.98	0.53
	Limestone and shale	32.1	41.0	41.3	15.6	.99	.49
	Shale	27.1	33.6	34.5	13.2	.97	.49
	Revegetation, less than 50 percent	26.7	34.3	50.5	23.3	.68	.87
		26.3	31.8	42.4	18.4	.75	.70
	Revegetation, more than 50 percent	22.1	26.3	46.1	22.8	.57	1.03
	Forest, sunny	20.3	27.8	38.3	19.6	.73	.97
		18.9	24.2	33.7	16.6	.72	.88
	Forest, shady	16.6	20.3	28.7	14.0	.71	.84
		15.1	16.7	22.0	10.1	.76	.67

TABLE III. - INVENTORY OF 5478-ACRE AREA OF LANDSAT DATA,

TAKEN WITH SCANNING DENSITOMETER

Landsat scene	Computer-classified data	Band ratio 5/6	Band 5	Computer-classified data	Band ratio 5/6	Band 5
	Barren area, acres			Revegetated area, acres		
Apr. 14, 1978	548	422	872	893	1030	1450
Aug. 19, 1976	425	402	483	733	1180	1200
July 29, 1975	476	583	583	590	1175	1258
July 12, 1973	250	226	299	1108	1185	1493

TABLE IV. - TRAINING-SITE DATA USED FOR MDAS ANALYSIS OF AIRCRAFT MULTISPECTRAL

SCANNER DATA (OCT. 23, 1976)

Class	Description	Color	Color code	Spectral data band							Band ratio	
				4	5	6	7	8	9	10	6/9	10/4
				Mean radiometric values								
1	Barren limestone	White	777	127	123	97	99	101	129	126	0.76	0.99
2	Barren limestone bench	White	777	123	118	94	95	95	121	117	.78	.96
3	Barren limestone haul road	Light gray	666	124	115	90	91	93	121	118	.75	.95
4	Barren spoilbank	Brown	433	115	109	86	85	83	105	98	.82	.85
5	Barren limestone, active	Brown	433	119	113	89	89	86	109	102	.82	.85
6	Barren limestone, active	Gray	555	91	88	71	69	66	86	83	.83	.91
7	Barren spoilbank, shale	Dark gray	333	71	71	57	54	49	65	60	.89	.84
8	Revegetated spoilbank	Red	700	80	76	61	59	86	148	161	.41	2.02
9	Revegetated spoilbank	Red	700	81	76	61	59	85	153	153	.40	1.89
10	Revegetated graded hollow	Yellow	770	78	75	60	59	78	130	139	.47	1.78
11	Revegetated graded hollow	Yellow	770	75	72	58	56	75	126	134	.46	1.78
12	Revegetated spoilbank (SE)	Light green	070	87	85	68	58	80	119	125	.57	1.44
13	Revegetated spoilbank (NW)	Turquoise	064	65	65	53	50	63	102	107	.52	1.63
14	Revegetated graded hilltop	Dark yellow	050	75	74	59	58	67	103	106	.58	1.42
15	Revegetated spoilbank	Dark red	500	82	81	65	63	70	101	101	.65	1.24
16	Revegetated graded hilltop	Dark turquoise	044	69	70	58	56	60	89	96	.65	1.38
17	Forest, hardwood, sunny	Green	050	72	74	62	62	77	120	140	.52	1.97
18	Forest, hardwood, sunny	Green	050	64	67	56	55	63	99	113	.57	1.78
19	Forest, hardwood, shady	Dark green	030	58	60	50	48	49	74	79	.68	1.37
20	Forest, hardwood, shady	Dark Green	030	58	60	49	46	48	70	73	.70	1.26
21	Highwall shadow	Dark gray	222	73	71	58	54	48	63	59	.92	.82
22	Highwall shadow	Dark gray	222	62	64	53	49	45	60	57	.88	.91
23	Water, sediment pond	Blue	005	92	88	69	65	57	68	57	1.02	.62

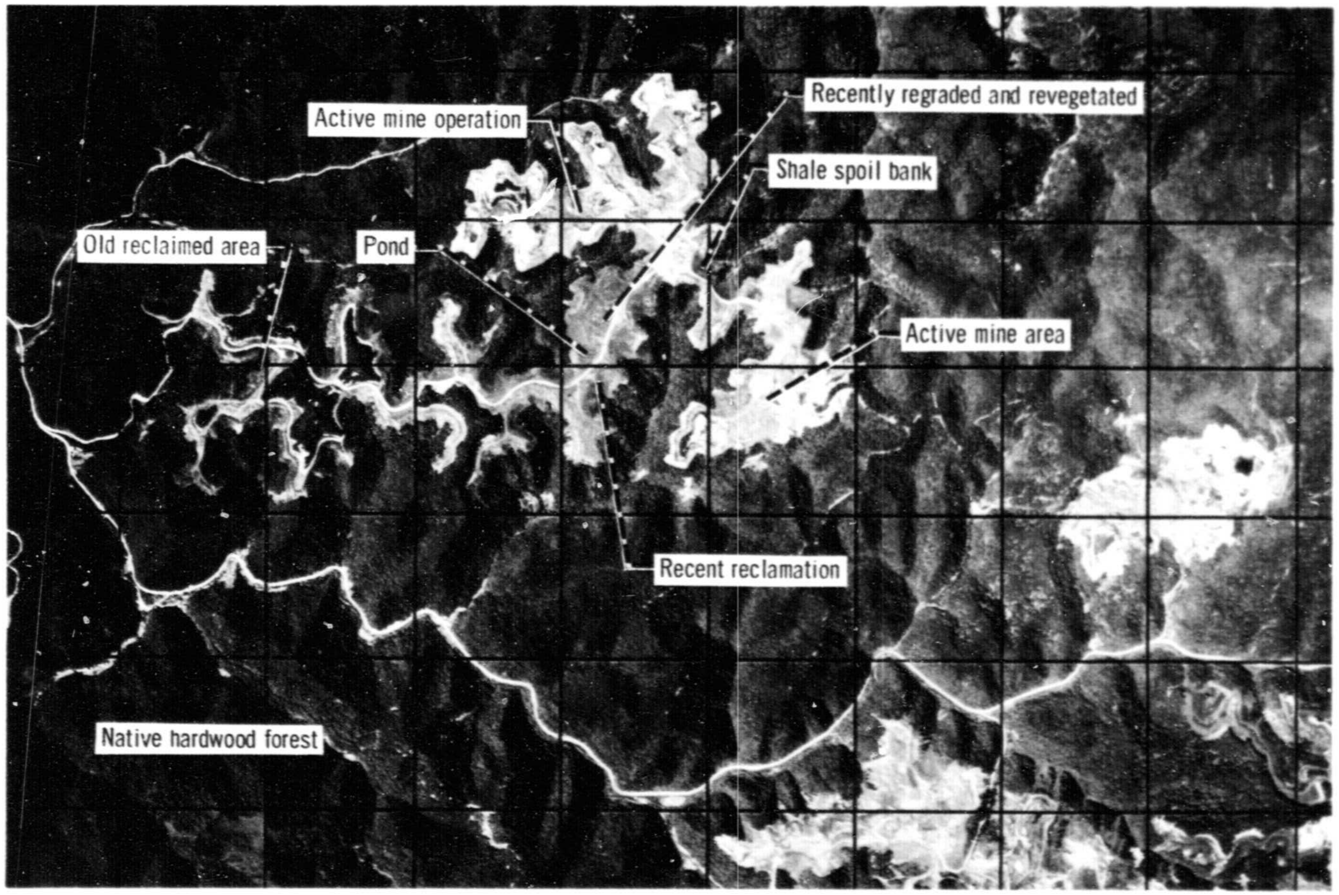
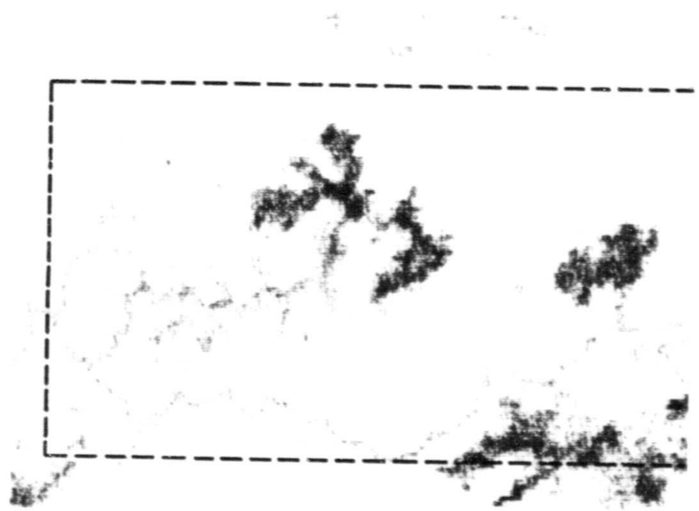


Figure 1. - Color, infrared aerial photograph of eastern Kentucky strip-mine test site. (June 1976 scene; scale factor, 50 000.)

(a) Original imagery. (Scale factor, 1 000 000.)

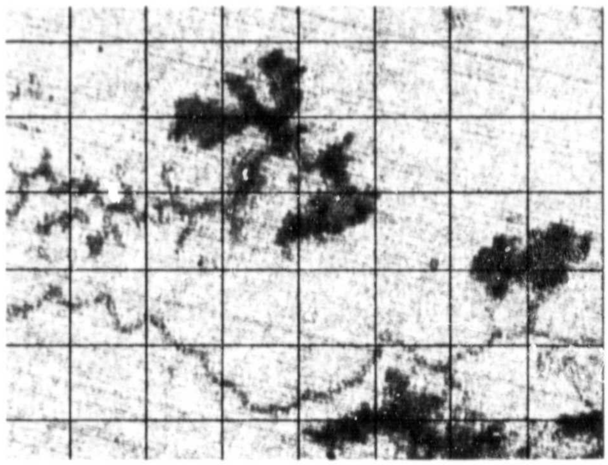
(b) X4 magnification. (Scale factor, 250 000.)



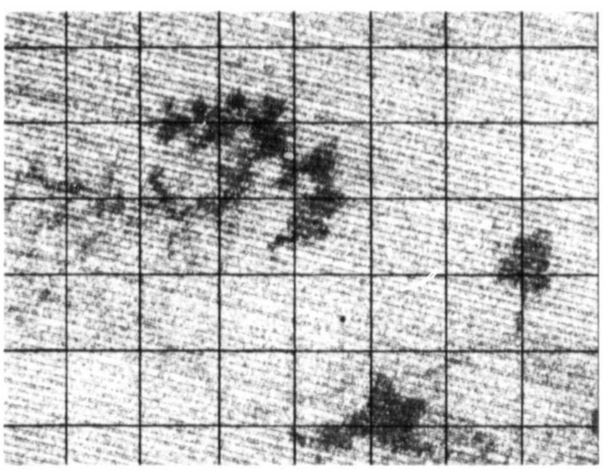
(c) X10 magnification. (Scale factor, 100 000.)

(d) X20 magnification. (Scale factor, 50 000.)

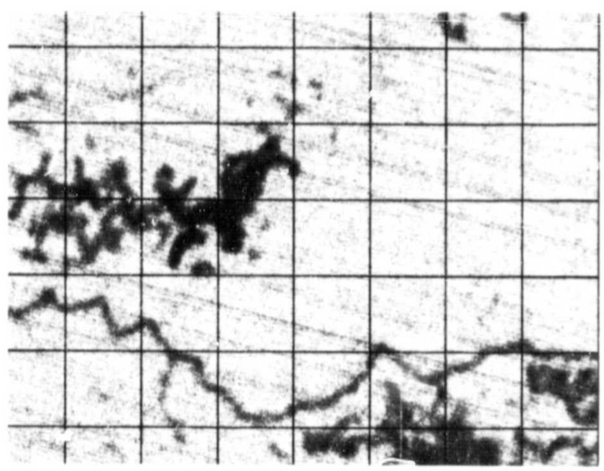
Figure 2. - Landsat band 5 negative print of test site. (Aug. 19, 1976 scene.)



(a) August 19, 1976 scene.

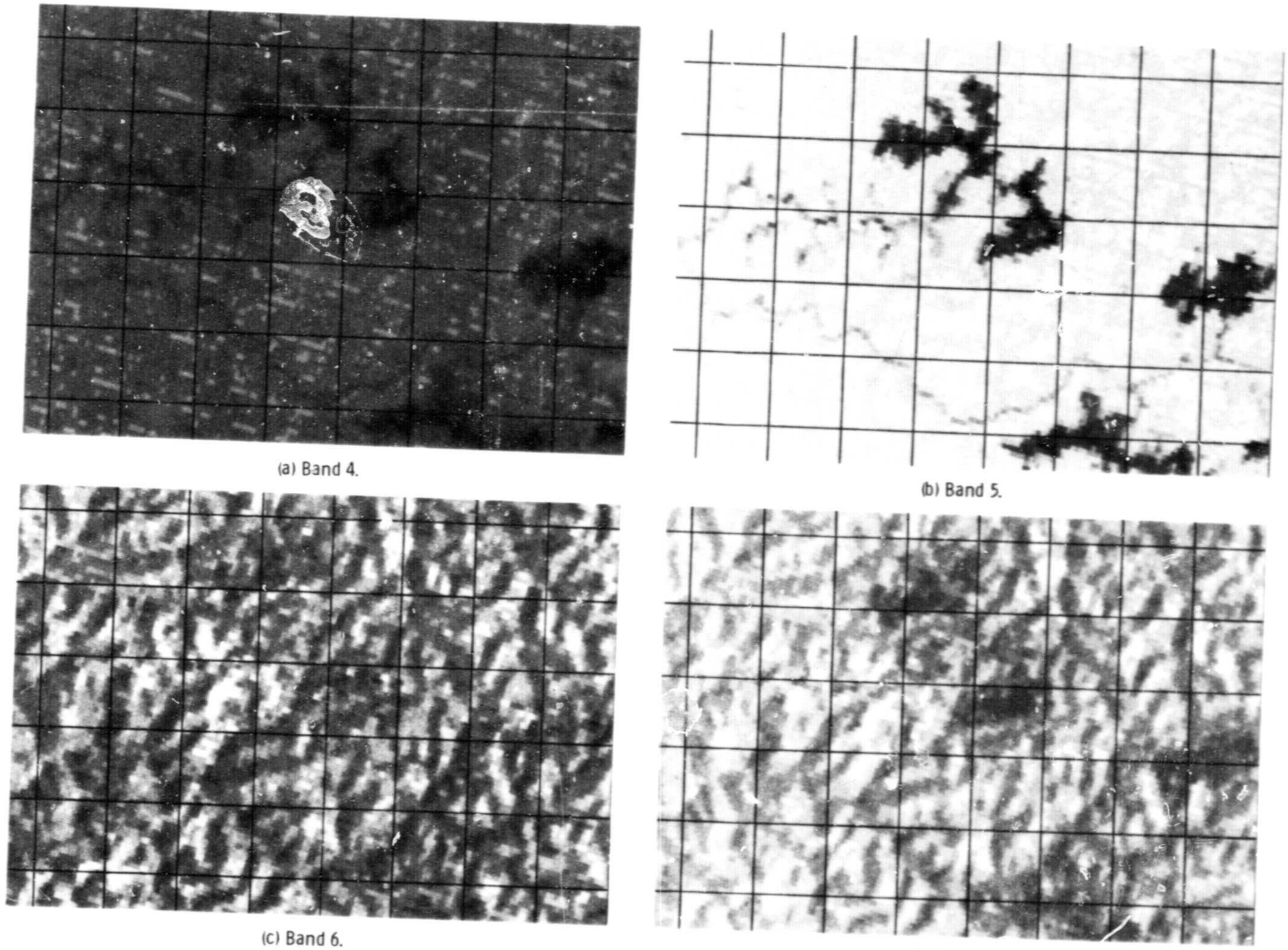


(b) July 29, 1975 scene.



(c) July 12, 1973 scene.

Figure 3. - Landsat band 5 imagery for three scenes. (Scale factor, 100 000.)



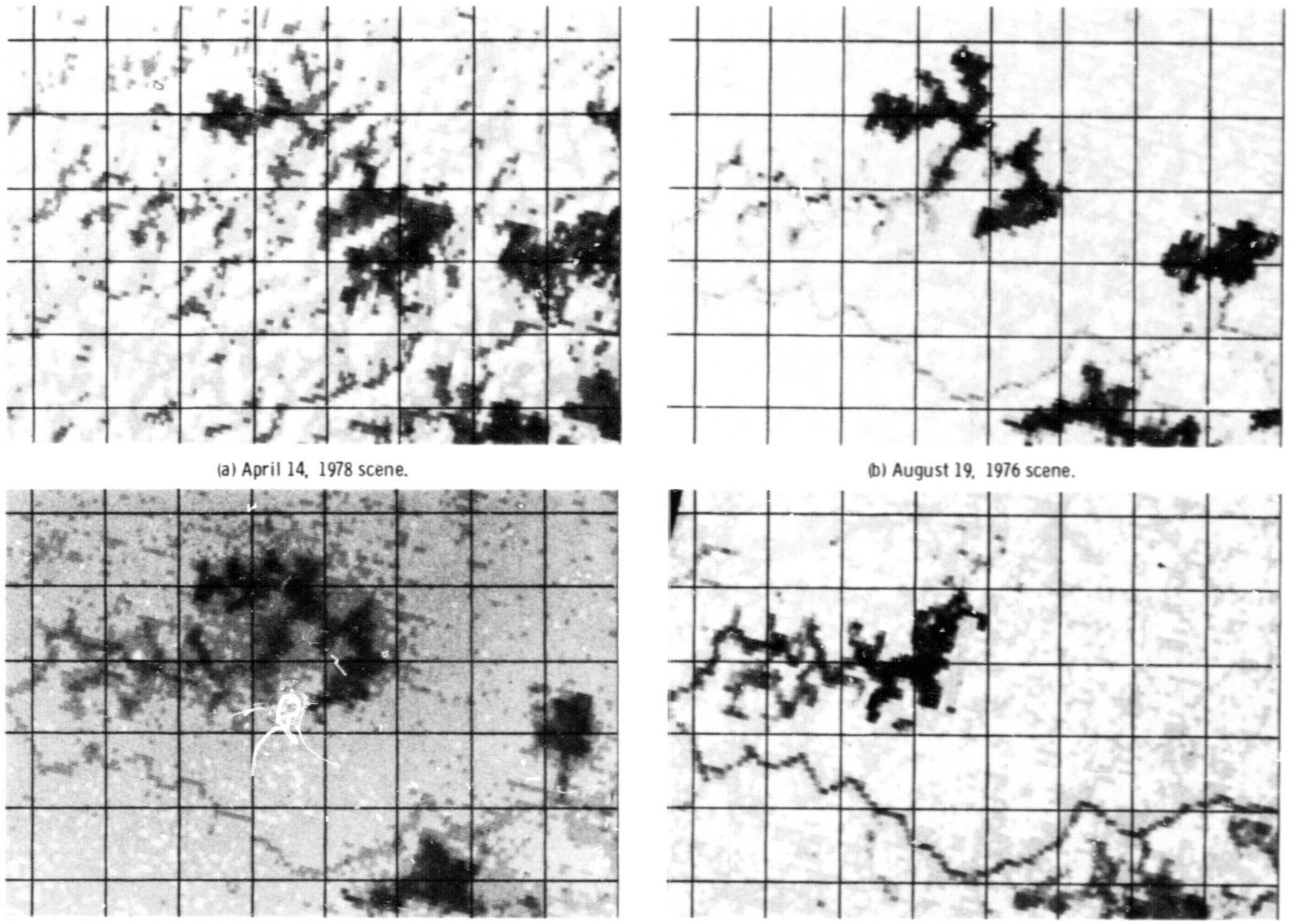
(a) Band 4.

(b) Band 5.

(c) Band 6.

(d) Band 7.

Figure 4. - Computer-generated Landsat imagery. (Aug. 19, 1976 scene; scale factor, 100 000.)



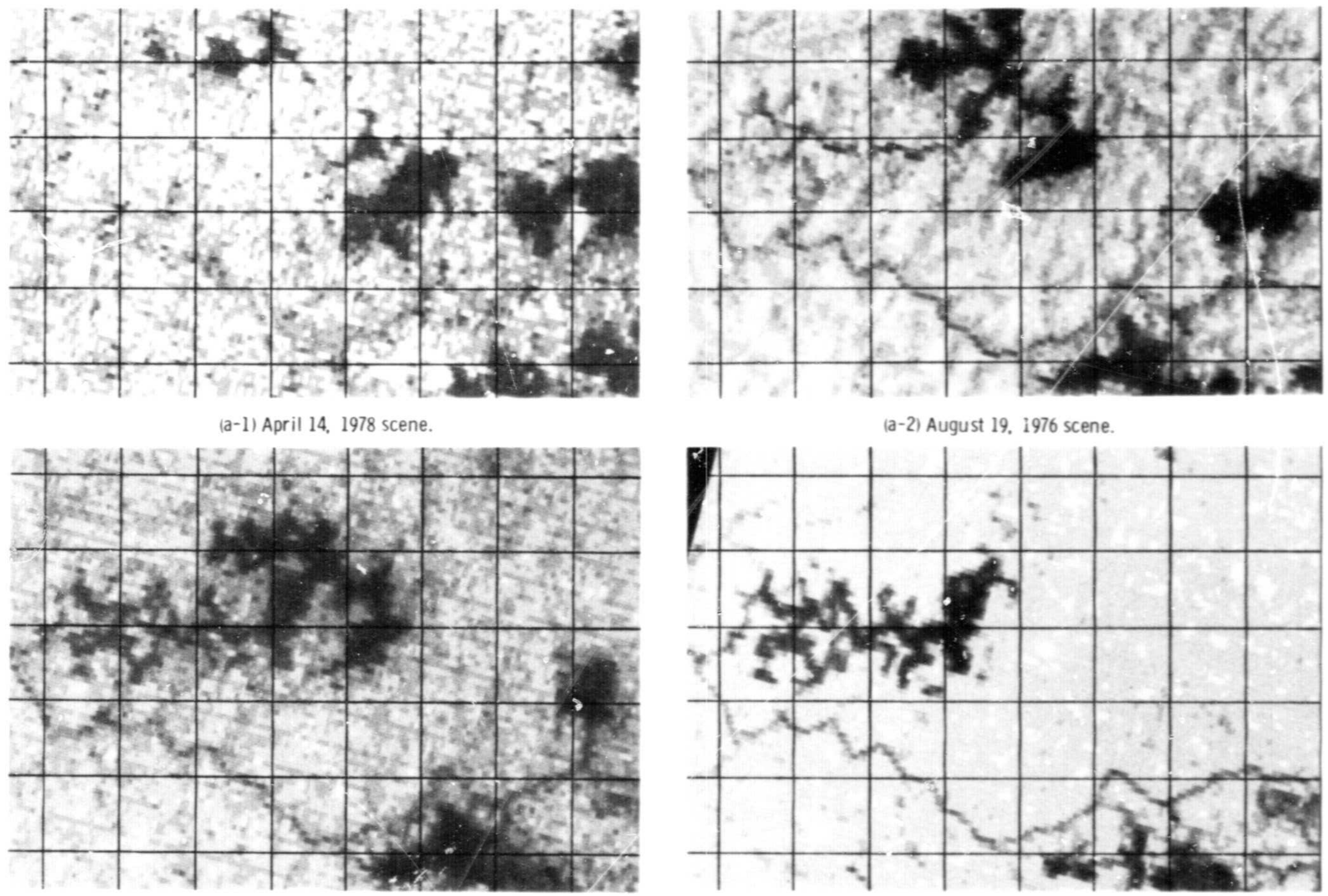
(a) April 14, 1978 scene.

(b) August 19, 1976 scene.

(c) July 29, 1975 scene.

(d) July 12, 1973 scene.

Figure 5. - Computer-generated Landsat band 5 imagery. (Scale factor, 100 000.)



(a-1) April 14, 1978 scene.

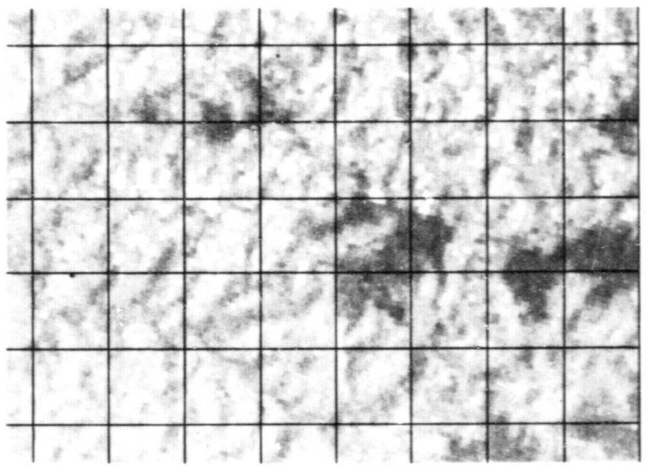
(a-2) August 19, 1976 scene.

(a-3) July 29, 1975 scene.

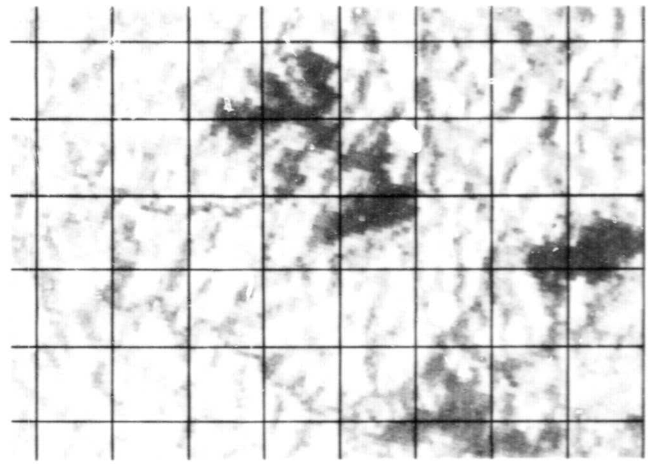
(a-4) July 12, 1973 scene.

(a) Band ratio, 5/6.

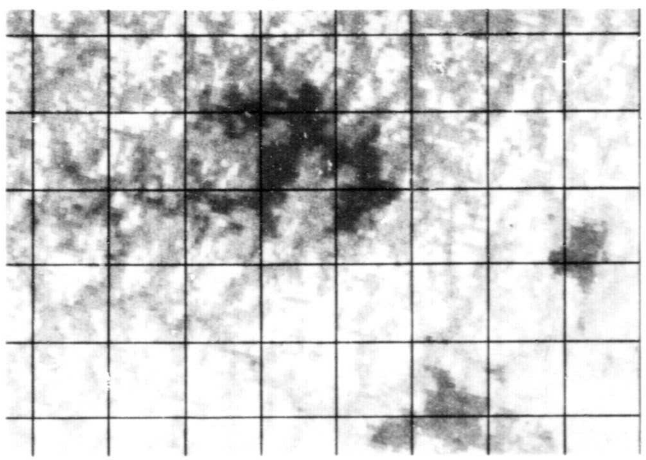
Figure 6. - Computer-generated Landsat band-ratio imagery. (Scale factor, 100 000.)



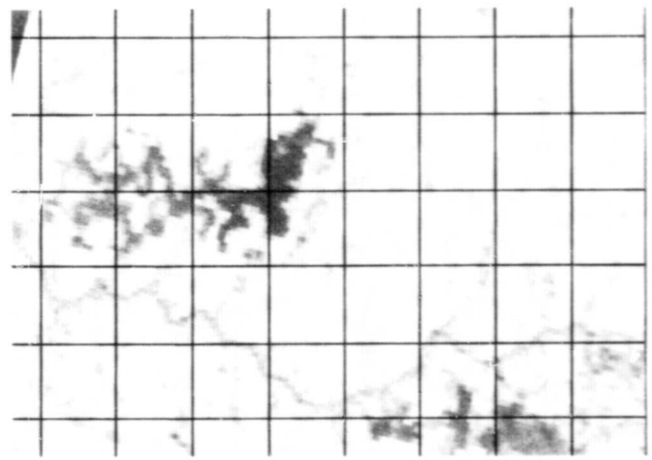
(b-1) April 14, 1978 scene.



(b-2) August 19, 1976 scene.



(b-3) July 29, 1975 scene.



(b-4) July 12, 1973 scene.

(b) Band ratio, 7/4.

Figure 6. - Concluded.

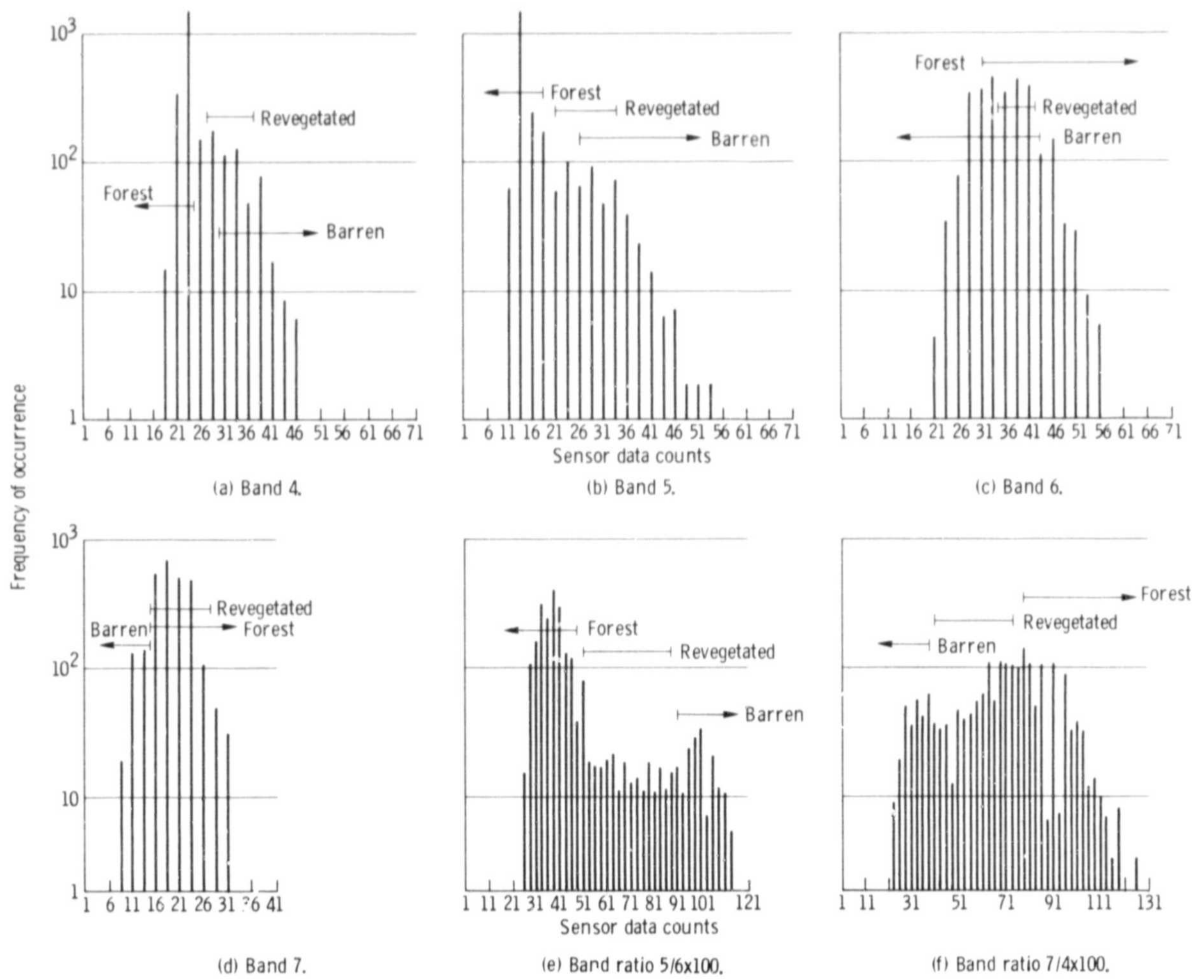


Figure 7. - Histogram of August 19, 1976 data for test site.

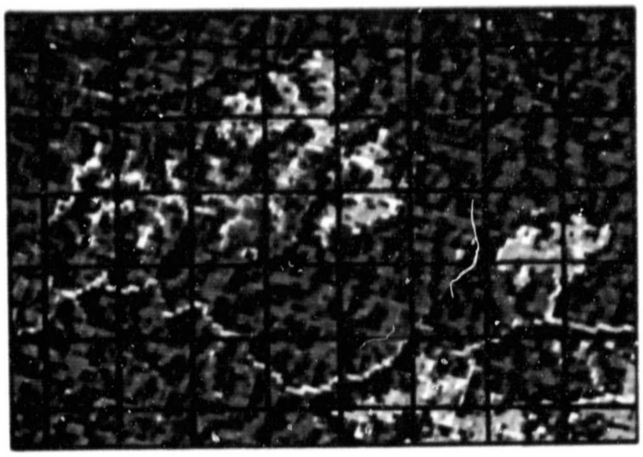


Figure 8. - Three-band false-color image. (Aug. 19, 1976 scene.) (Scale factor, 100 000.)

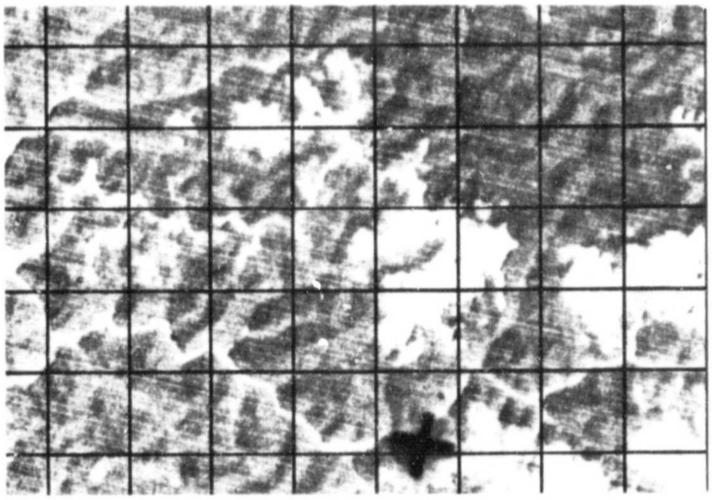
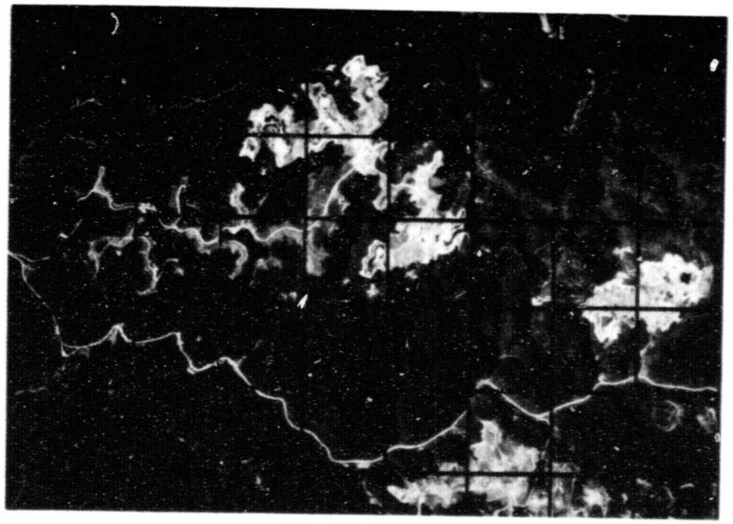
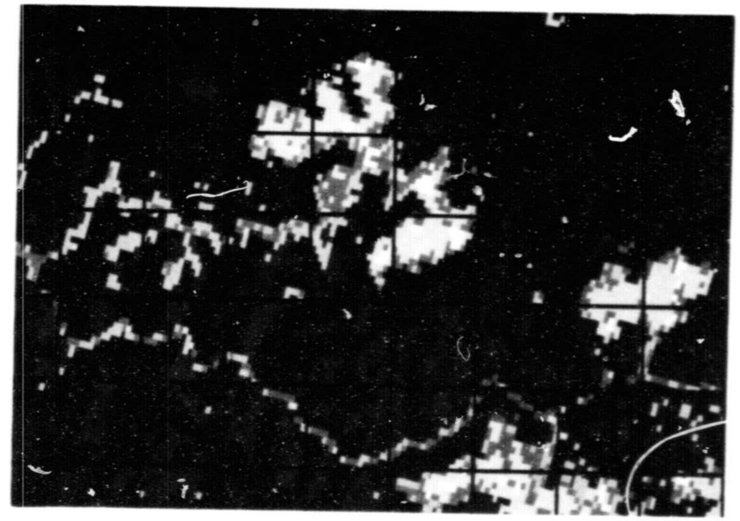


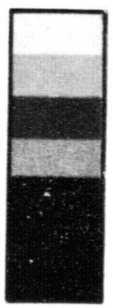
Figure 9. - Return-beam, vidicon-camera image. (Apr. 14, 1978 scene. Scale factor, 100 000.)



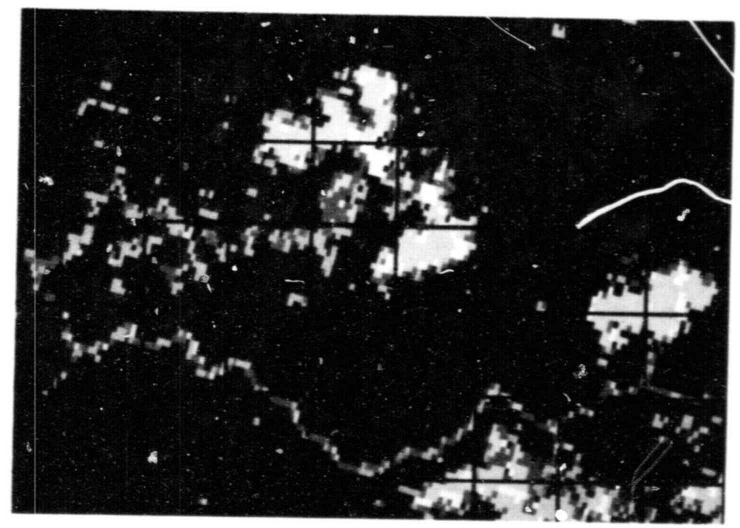
(a) Color, infrared aerial photograph.



(b) LARSYS III unsupervised classified image.



Class	Inventory (pixels)	Unsupervised
Barren limestone	44	93
Barren shale	261	278
Revegetated, < 50%	221	196
Revegetated, > 50%	113	124
Forest, sunny	873	916
Forest, shady	1092	958
Unclassified	- - - -	39
Total	2604	2604



(c) LARSYS III supervised, classified image.

Figure 10. - Color-coded, computer-classified imagery comparing LARSYS III images with aerial photograph. (Aug. 19, 1976 scene. Scale factor, 100 000.)

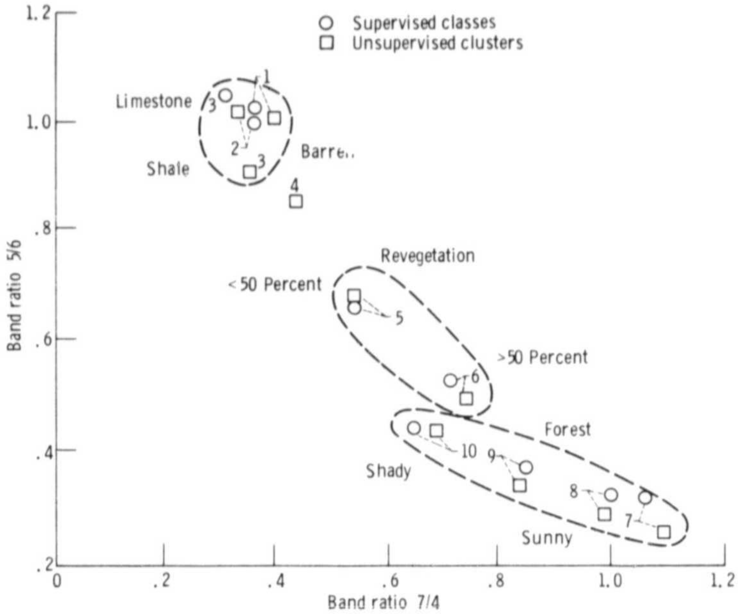
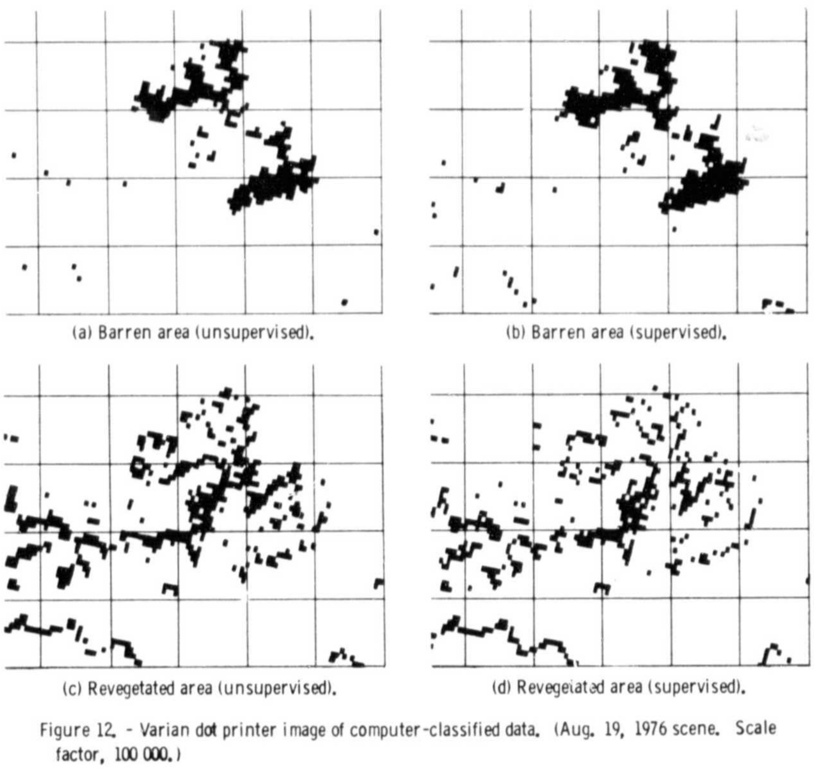


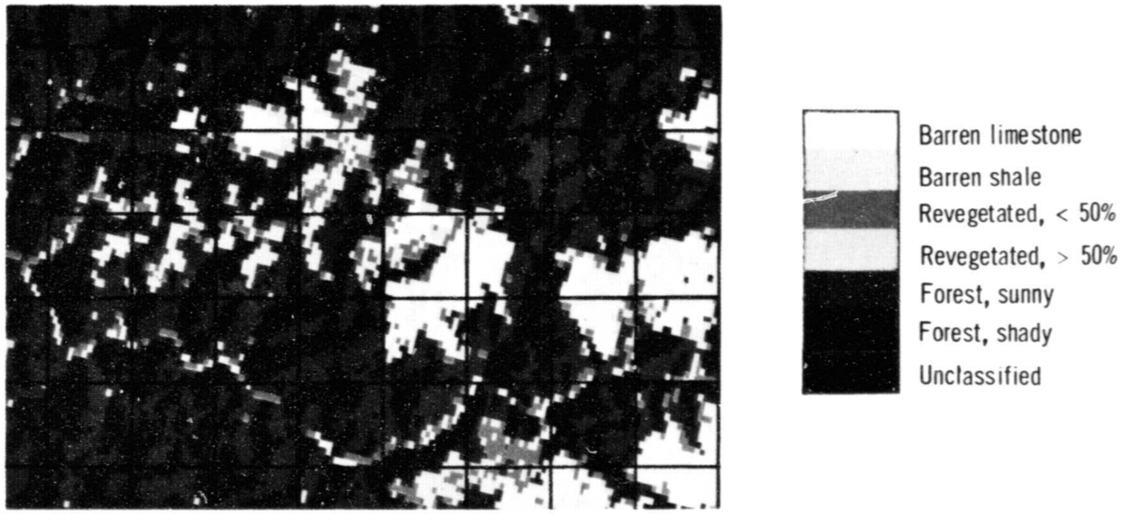
Figure 11. - Classes or clusters used for computer analysis. (Aug. 19, 1976 scene.)



(a) Barren area (unsupervised). (b) Barren area (supervised).

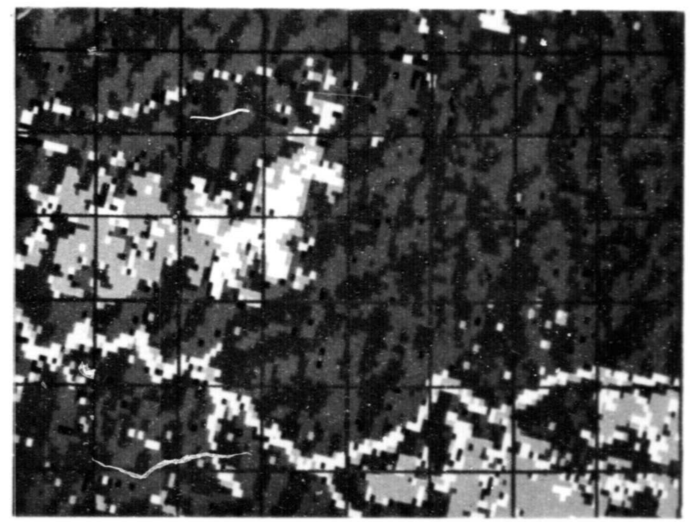
(c) Revegetated area (unsupervised). (d) Revegetated area (supervised).

Figure 12. - Varian dot printer image of computer-classified data. (Aug. 19, 1976 scene. Scale factor, 100 000.)



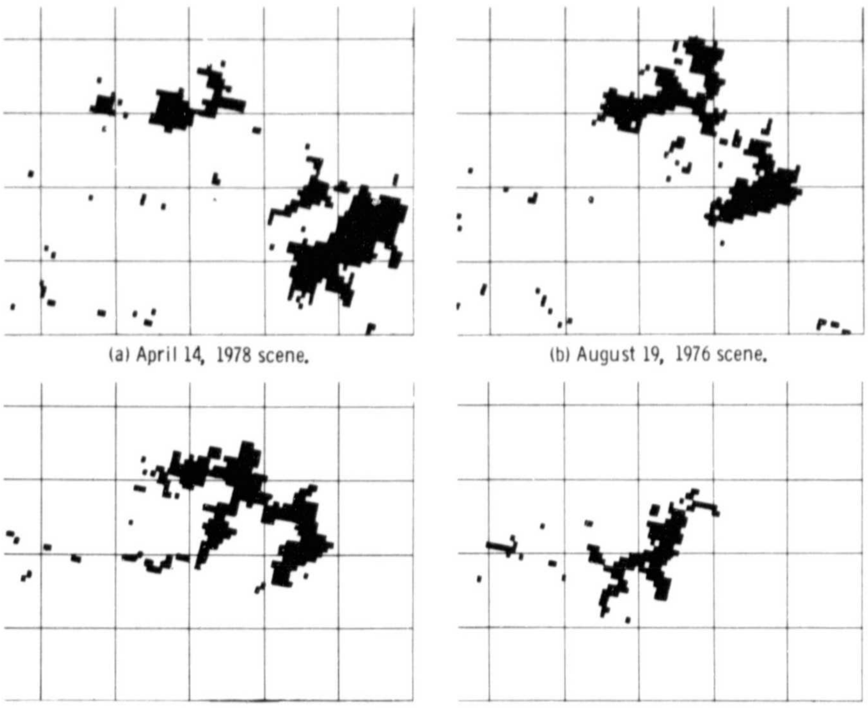
(a) April 14, 1978 scene.

(b) July 29, 1975 scene.



(c) July 12, 1973 scene.

Figure 13. - Color-coded computer-classified imagery of three scenes. (Scale factor, 100 000.)



(a) April 14, 1978 scene.

(b) August 19, 1976 scene.

(c) July 29, 1975 scene.

(d) July 12, 1973 scene.

Figure 14. - Varian dot printer imagery for barren area from LARSYS III classification. (Scale factor, 100 000.)

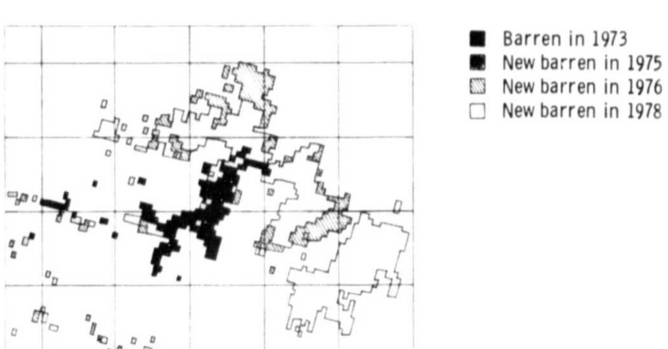
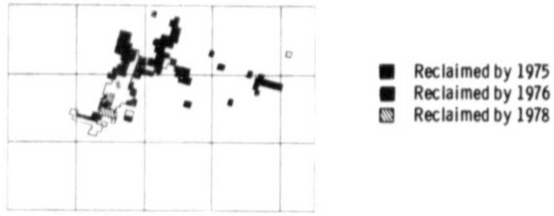
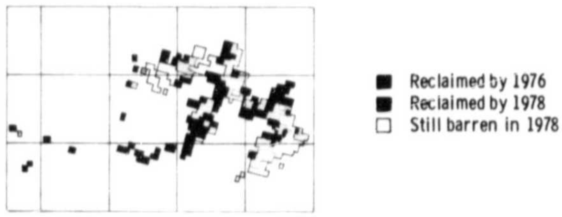


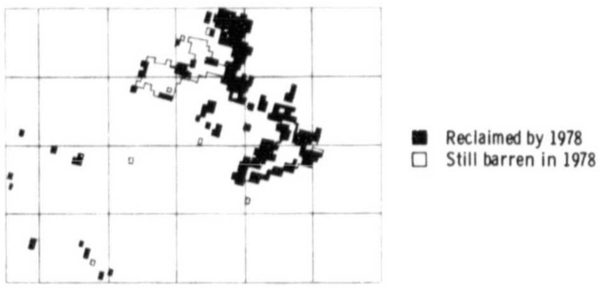
Figure 15. - Barren area changes between July 12, 1973, and April 14, 1978. (Scale factor, 100 000.)



(a) Reclamation of 1973 barren areas.



(b) Reclamation of 1975 barren areas.



(c) Reclamation of 1976 barren areas.

Figure 16. - Reclamation progress of barren areas. (Scale factor, 100 000.)

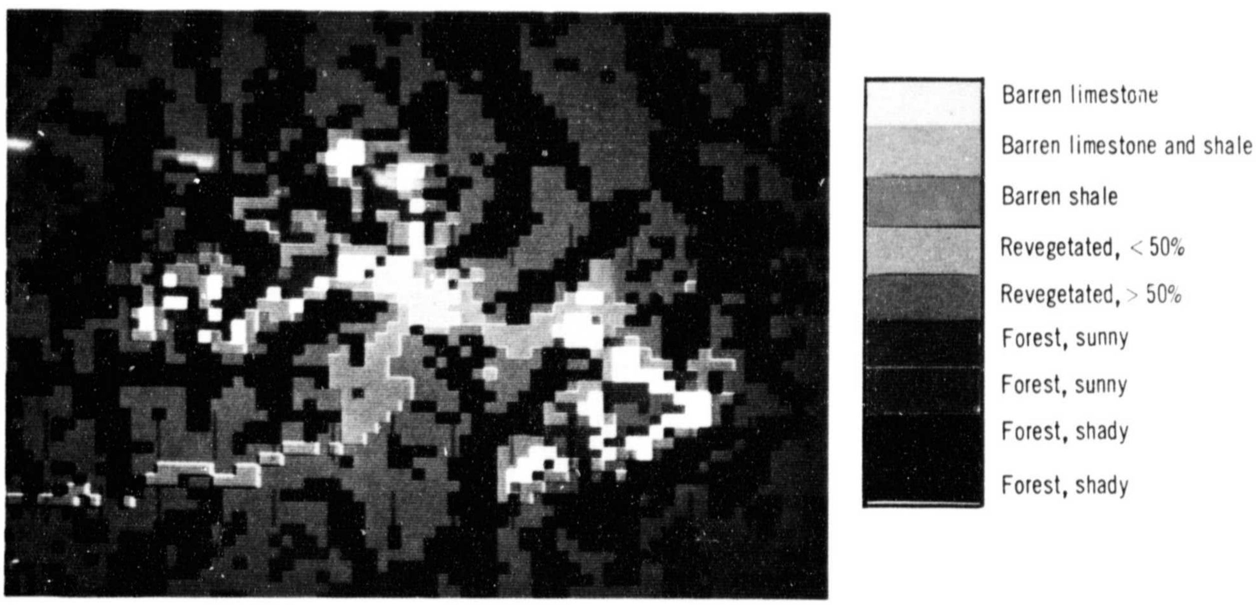
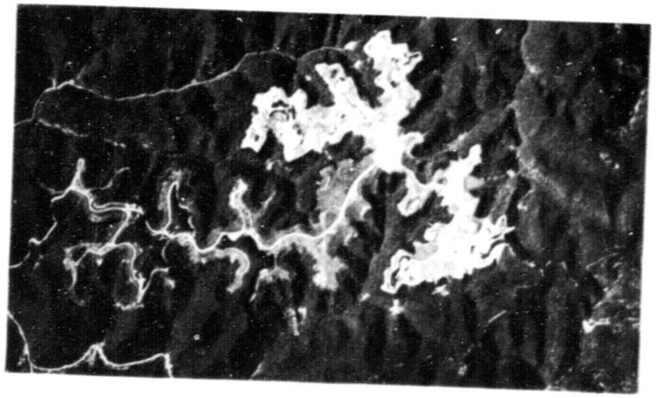
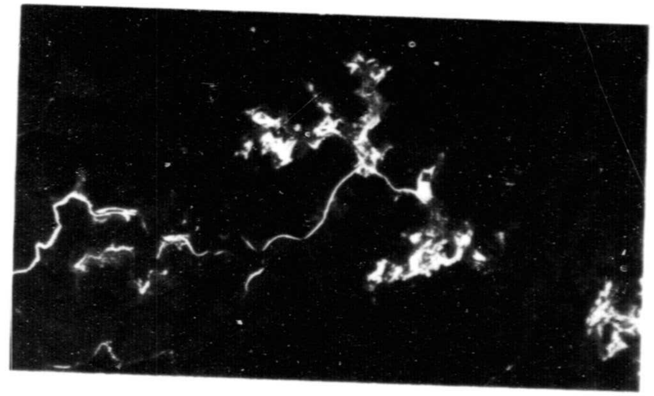


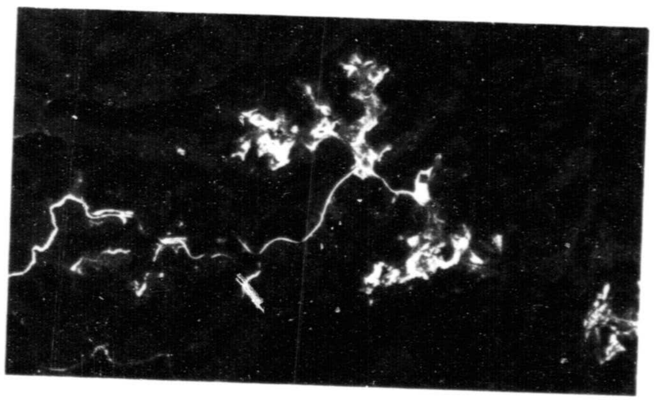
Figure 17. - MDAS, color-coded, computer-classified image. (Aug. 19, 1976 scene. Scale factor, 50 000.)



(a) Color, infrared photograph.



(b) Multispectral scanner, band 4.



(c) Multispectral scanner, band 6.

(d) Multispectral scanner, band 9.

Figure 18. - Aircraft multispectral scanner imagery. (Altitude, 3000 m; October 22, 1976 scene; scale factor, 76 000.)

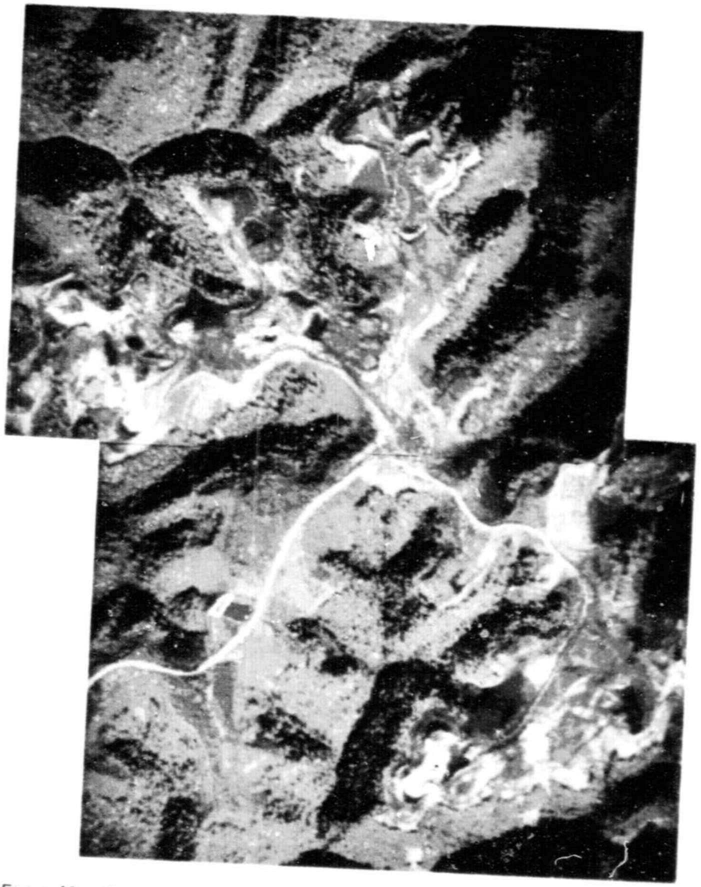


Figure 19. - Three-band, false-color composite of aircraft scanner channels 4, 5, and 7.

Figure 20. - MDAS, color-coded, computer-classified image of aircraft multispectral scanner data. (Oct. 22, 1976 scene.)

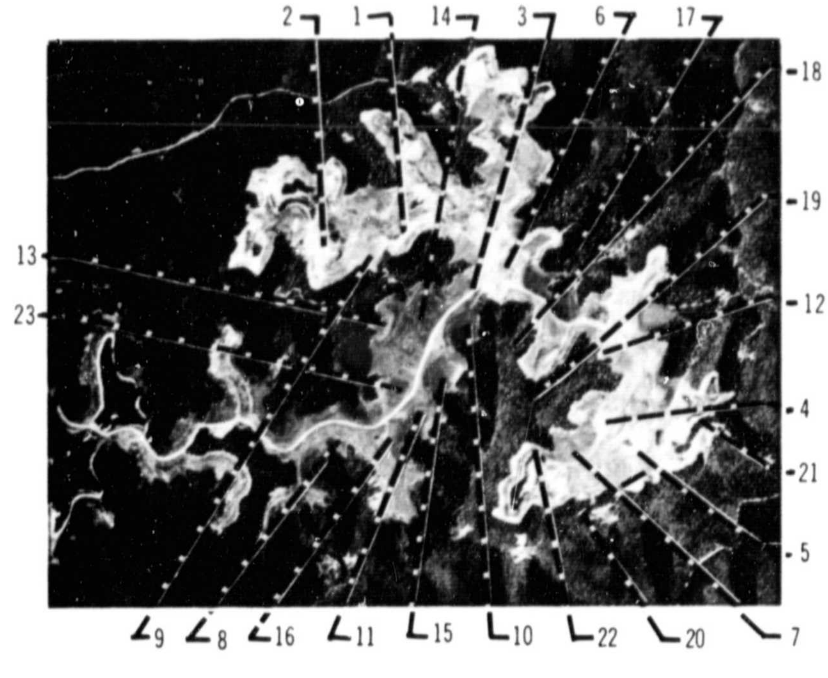


Figure 21. - Training-site locations used for MDAS classification of aircraft multispectral scanner data. (Numbers denote classes shown in table IV.)

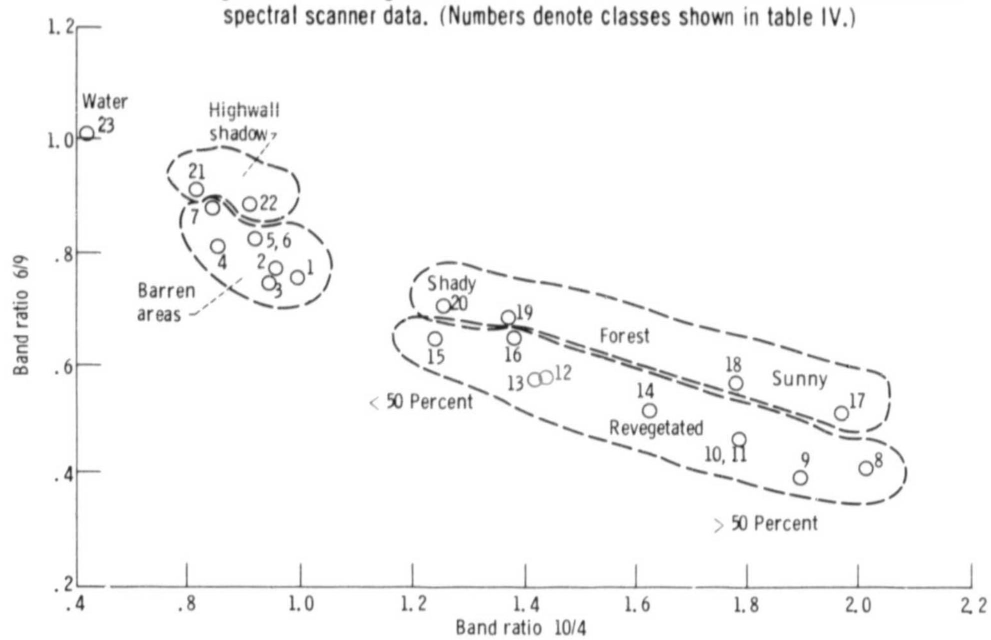


Figure 22. - Partitioning of aircraft-data training sites for MDAS classification.

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16. Abstract

The application of Landsat multispectral scanner data to describe the mining and reclamation changes of a hilltop surface coal mine in the rugged, mountainous area of eastern Kentucky is presented. Original single-band satellite imagery, computer-enhanced single-band imagery, and computer-classified imagery are presented for four different data sets obtained over a 5-year period in order to demonstrate the land-cover changes that can be detected. Data obtained with an 11-band multispectral scanner on board a C-47 aircraft at an altitude of 3000 meters are also presented. Comparing the satellite data with color, infrared aerial photography and ground-survey data shows that significant changes in the disrupted area can be detected from Landsat band 5 satellite imagery for mines with more than 100 acres of disturbed area. However, band-ratio (bands 5/6) imagery provides greater contrast than single-band imagery and can provide a qualitative level I classification of the land cover that may be useful for monitoring either the disturbed mining area or the revegetation progress. However, if a quantitative, accurate classification of the barren or revegetated classes is required, it is necessary to perform a detailed, four-band computer classification of the data. Either supervised or non-supervised statistical analysis procedures can be used. If current aerial photography or ground-survey data are available to guide the analysis, supervised classification procedures are recommended for greater accuracy.

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