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SATELLITE DATA FOR SURFACE-MINE INVENTORY

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SEPTEMBER 1976

GSFC

GODDARD SPACE FLIGHT CENTER
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ABSTRACT

The ability to routinely monitor the progress of surface mining and reclamation is necessary for effective enforcement of state environmental regulations. Many states still lack the quantitative information which is needed to monitor the affected areas. To determine the feasibility of satellite data for surface-mine inventory, particularly as it applies to coal, a case study was conducted in Maryland.

Two digital analysis methods were applied to this problem. The first was a four-band analysis distinguishing various strip-mine-associated classes and conditions. This method proved useful, but has limited extendibility over a seasonal or annual period. In the second approach, a band-ratio method was developed to measure disturbed surface areas, and it proved to be extendible both temporally and geographically.

This method was used to measure area changes in the region over three time periods from September 1972 through July 1974 and to map the entire two-county area for 1973. For mines ranging between 31 and 244 acres (12 to 98 hectares) the measurement accuracy of total affected acreage was determined to be 92%. Mines of 120 acres (50 hectares) and larger were measured with greater accuracy, some within one percent of the actual area.

The ability to identify, classify, and measure strip-mine surfaces in a two-county area (1541 square kilometers — 595 square miles) of western Maryland has been demonstrated through the use of computer processing. On the basis

of these results the use of Landsat* satellite data and multi-level sampling of aircraft and field verification inspections, multispectral analysis of digital data has proven to be an effective, rapid, and accurate means of monitoring the surface mining cycle.

The State of Maryland has incorporated into their monitoring program the results from this rapid and reliable method of large-area inventory from the Landsat band-ratio analysis. Using Landsat-derived maps, the State Geological Survey is attempting to prioritize reclamation needs for orphan (pre-1967) mines and derive information for planning and control of environmental quality in the strip-mine regions. This process is an immediate and cost beneficial response to the need for areal measurement and assessment in a regional planning and management program. As a result of this project a complete mined-land inventory is presently being incorporated into the State of Maryland mined-land inventory and assessment program.

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*Formerly ERTS – The Earth Resources Technology Satellite

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INTRODUCTION

Coal extraction by surface-mining techniques in an economic response to the demand for energy, and new reserves in both the western and Appalachian states are continually being opened or reworked. Effective resource exploitation of these disturbed regions involves a compromise between the need for the resource and the effects of despoilation on the land caused by the mining process. Coal mining is profitable, and the product is a needed energy resource, but its past effects can be viewed as devastating. Activity in these mining areas will increase to reduce our dependence on foreign petroleum imports. To help in this effort, and to keep environmental impacts to a minimum, a process has been developed to inventory surface mines and to monitor reclamation changes. This accomplishment can be observed routinely every 18 days through the use of Landsat (formerly ERTS — The Earth Resources Technology Satellite) multispectral digital data.

The ability to routinely monitor the progress of surface mining and reclamation is necessary for effective enforcement of state mining and environmental regulations. Many states still lack the quantitative information which is needed to monitor the affected areas. However, the use of Landsat satellite data is an effective method of gathering the needed measurements when used in conjunction with aircraft photography and field verification inspections.

Multispectral analysis of Landsat digital data has provided a rapid, accurate, and practical means of observing and monitoring the continuing surface-mining cycle. Numerous studies have examined the feasibility of applying various analog (photographic) and digital techniques to this application and the interpretation of these data. But the complimentary use of multi-level and supplementary remote sensing data has significantly enhanced the capability to monitor surface-mining activities and progressive stages of the affected and reclaimed areas.

The goal of this study was to produce a mined-land inventory of coal strip mining areas of Maryland, which are contained in two counties in western Maryland. The results are to be used by the State Geological Survey and Bureau of Mines in their overall assessment program. Based upon a previous demonstration project [3] involving a 20 square mile area, State officials agreed that the use of Landsat multispectral data was a rapid and accurate means to locate, classify, and provide accurate size surveys of the affected areas. The previously developed analysis technique of band-ratioing two Landsat spectral bands, was extended to include the entire 595 square mile area as viewed on three Landsat images. In the first study the derived signature was used to classify three images of the same 20-square mile area acquired 2 years apart. With the cooperative of State agencies, the previous method was applied to the entire five coal basin regions in Maryland.

Landsat digital data have previously been used to analyze strip mines in Maryland and other coal mining regions (Anderson, et al.,[5] 1975; Anderson and Schubert,[3] 1976; Rogers and Pettyjohn,[7] Amato, et al.,[2] Alexander, et al.,[1] and EPA).[6] Significant reflectance variations among mines, and even for the same mine, were observed in these projects using Landsat data. This variation resulted in several strip-mine sub-categories; active mines, graded and upgraded spoils, and partially revegetated areas in all studies. In at least one study (EPA), it was necessary to calibrate the classification algorithm for each mine site. Overall, the studies reported good qualitative correlation between satellite classifications and large scale aerial photographs of strip mines.

Our previous study (1975) differs in several significant aspects from the other studies, in terms of both the size of the mines and accuracy. Two projects involved strip mines much larger than those analyzed in the present one. The average size of the fourteen mines classified in the Northern Great Plains study[6] was 2,238 hectares; the mines averaged 11,000 hectares in the Ohio study.[7] The average size of the eight test mines in this analysis is about 40 hectares, and the accuracy of classification has been evaluated quantitatively. Area measurements derived from satellite classification were determined to be 92% accurate, when compared to independent measurements from low-level aerial photography. Other studies have not included quantitative evaluation of satellite classification accuracies.

BACKGROUND

The State of Maryland became officially involved in the regulation, monitoring, and reclamation of strip mines in 1967 when the State's coal strip mining law was enacted. This law, amended from 1969 through 1974 had established a Land Reclamation Committee which administers the provisions of the act. Under this act, strip mine operators are required to obtain licenses and permits, submit mining and reclamation plans, procure performance bonds, and periodically report on the amount of land area disturbed. All of the disturbed surfaces, including storage areas for topsoil and spoils, haul roads, and areas disturbed by the movement of equipment, must be reclaimed according to State-approved plans. Mines closed or orphaned (pre-1967) before the law's enactment will be reclaimed by the State, once they have an accurate inventory of all these lands involved.

To assist in the tasks of planning, monitoring, enforcement, and reclamation, the Maryland Bureau of Mines needs information on the location, size, and condition of coal surface mining areas. Five mine inspectors presently report monthly on active mining operations within a 1541-square kilometer area (595 square miles). The new regulations and increased coal production (over 2 million tons per year) will require additional inspectors and more efficient means of data collection.

STUDY AREA

The region of semibituminous coal resources includes five basins in Garrett County and part of the adjacent area of Allegany County in western Maryland (Figure 1). These are the only coal deposits in the State. This region is part of the Allegheny Plateau of the newer Appalachian Range. It consists of gently folded, parallel northeast-southwest-oriented mountains and synclinal basins resulting from differential erosion of sedimentary formations. The coal-bearing strata are of Pennsylvanian age and lie within 200 feet of the surface in the basins. The easternmost basin, Georges' Creek, contains 233 square kilometers (90 square miles) of intensive strip mine activity. Most of the strip mines in this area follow topographic contours and are 75 to 400 meters wide. High walls range from 20 to 45 meters, and the majority of mines are less than 90 hectares (220 acres) in size. It was within the Georges Creek basin that multispectral Landsat data was first used for providing a data base — referred to as a training site. The process was subsequently extended to the entire basin and to the remaining four basins: the Upper Potomac, Castleman, and Upper Youghiogheny and Lower Youghiogheny basins.

METHOD

The 1975 analysis from which the present inventory follows was approached from two interactive computer classification methods. Prior to classification, the first step was planimetering eight test mines using the same time of reference (Sept. 1973) in a 20 square mile area. The mines ranged in size from 18.8 hectares (46.4 acres) to 98.7 hectares (243.8 acres). The planimetry was performed on 1:18,000 low-altitude color infrared photography from the C-54 NASA/Wallops aircraft (Figure 2). Using these accurate area measurements it was possible to quantitatively inventory the area affected by surface mining and verify the accuracy of the satellite inventory. Standard procedures were applied in the measurements, taking into consideration factors such as elevation, viewing angle, distortions, and tilt and aspect angle.

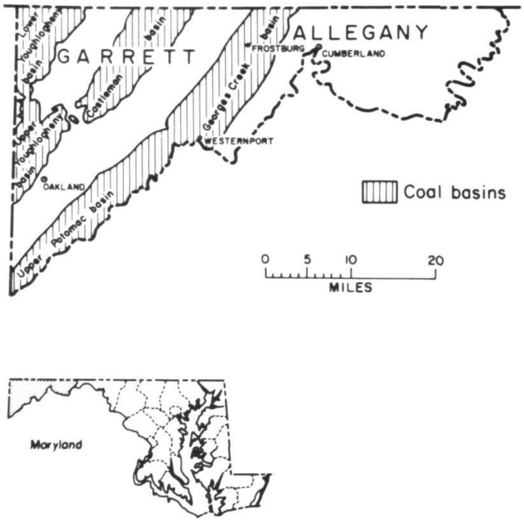

Figure 1. Coal Basins in Garrett and Allegany Counties of Western Maryland

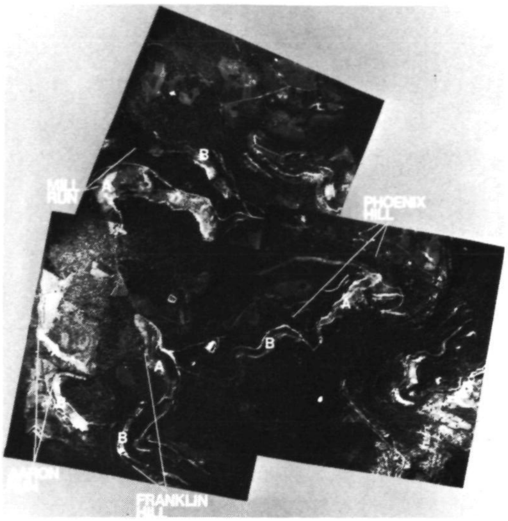

Figure 2. Low Altitude Aircraft Photo Mosaic of Test Site Northwest of Westernport, Maryland

The interactive G. E. IMAGE-100 multispectral image analysis system was used in the study to perform the digital data processing on the Landsat computer-compatible tapes (CCT's). In the operation of the system, a user specified training area is delineated on the image with an adjustable electronic cursor which is displayed on the image monitor and scanned by the system hardware for size and position coordinates. With Landsat multispectral scanner data the gray level values within the training area are automatically measured for each of the four black and white images. The minimum and maximum brightness values in each scanner channel are used to define a four-dimensional parallelepiped in spectral space. Each picture element (pixel) in the entire image is then scanned and compared to the parallelepiped limits. All pixels which lie within the bounds defined by the training data are flagged or alarmed and displayed on the monitor as a color map. This entire process requires less than 5 seconds, so the user may respond in real time, and rapidly go through several training and classification iterations.

The user can respond to a classification by selecting another training site, modifying the parallelepiped limits, or applying other signature extraction and classification algorithms to the same training area. At any time during this process the user can request histograms, grey-level listings, cluster displays, or other statistical reports for the training area. These statistics are displayed on the printer/plotter in real time. Once the desired classification results have been achieved, they are then stored on one of the eight binary theme channels to form a thematic map which can be displayed on the original image CRT display or output as black and white hard copy or digitally processed color images. During the procedure of image processing for inventory of the mined land in this region the following two classification methods were used.

Four-band classification was the first method applied to the 20 square mile area using supervised training and classification performed on the four Landsat spectral bands. Training sites were selected, and the image analysis system identified the spectral reflectance range within the training site in the four Landsat bands simultaneously.

In this study, single-parallelepiped training was applied to areas within the Georges' Creek basin whose surface cover was known from interpretation of the low altitude aerial photography and from field inspection. In certain cases, pixels were classified into more than one category. Aerial photographs were then consulted to determine the proper classification, and the signatures of the overlapping classes were modified to eliminate the conflicts.

The spectral radiance variability among the four-band signatures for various types of strip mining surfaces discourages the use of this type of classification on an operational monitoring basis. A great deal of ground verification data is required, and training must be carried out on each type of surface. This is not only true in western Maryland but other investigators (EPA, Rogers and Pettyjohn) have reported similar differences between mines and even sections of the same mine in the Northern Great Plains and in Ohio.

The band-ratio method through preprocessing of the Landsat multispectral data before classification, provided a means of distinguishing strip mines in a single 4-band classification. The objective of preprocessing is to transform the sensor output to minimize the effects of environmental, observational, and sensor conditions of signature extraction. Other investigators (EPA) have found that band-ratioing techniques minimize systemic errors and decrease temporal and geographical differences. The rationale behind ratioing of spectral signatures is that it reduces the inherent variables and produces an extendible signature to be used in other areas.

These data were examined by comparing September 1, 1973 and September 6, 1972, images. They were preprocessed to yield twelve band-ratios for each date. Then to determine the most accurate surface mine classification and best ratio, an assessment of each mine and ratio was made. The analysis was conducted by outlining a polygon on a mine, scanning the histogram of pixel count and gray level range, making a pixel count on each mine and converting to surface acreage, and performing a least squares regression between the aircraft and Landsat values for each gray level range using data from both 1972 and 1973. The regression for the ratio of the red band (band 5) and the near infrared (band 6) resulted in the smallest standard error of estimate, and was then used in providing the most consistent area surface measurement. The ratio 5/6 signature for surface mines was then applied to a July 1974 scene of the same area and consistently accurate values were extended and generated. Pixel counts were converted to hectares and adjusted by the factors in the regression equation. An example of these comparisons and the resulting surface area appear in Figure 3.

The Maryland Geological Survey expressed a definite need to immediately obtain a complete inventory of all mined-land in the two county area. This inventory was to be part of the assessment plan for the State's program to be completed this year. Of great concern to the State is an overall inventory of past (pre-law 1967) and present affected acreage. The need for this information is urgent to fill the information data base because there are no accurate records on pre-law mine acreage and this information is required to determine the total disturbed acreage in the State. Post-1967 records exist on mines, but due to the minimal reclamation the pre-law mines, the State must now have accurate quantitative values. Also the State is in the process of establishing systematic procedures by which the older mines must be rehabilitated.

To help satisfy these needs the band-ratio technique derived in the Lower Georges' Creek Basin 20 square mile training site of the original study was extended to the entire 595 square mile region. Also included was a 5-10 mile boundary region including West Virginia and Pennsylvania (Figure 4). From the original study a single band-ratio signature was used to classify three Landsat images acquired 2 years (1972-74) apart over the same test area and study region. It was determined from extendibility of the derived strip mine and reclaimed signature that temporal and geographic extension was possible. The two-county area was divided into six areas, which were situated within the corner sector of three overlapping Landsat scene images from two consecutive days. Images used were from September 1, and 2, 1973 (1405-15242, 1406-15294 and 15300). Frame 1405-15242 had been used previously to develop the band-ratio technique. The eight strip mines used as ground truth controls in the previous study were contained in the overlap region of all three images.

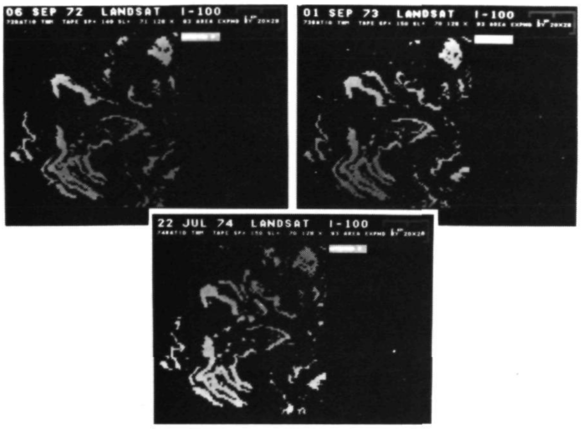

Figure 3. Band-Ratio Classification of Test Site for 1972 Through 1974

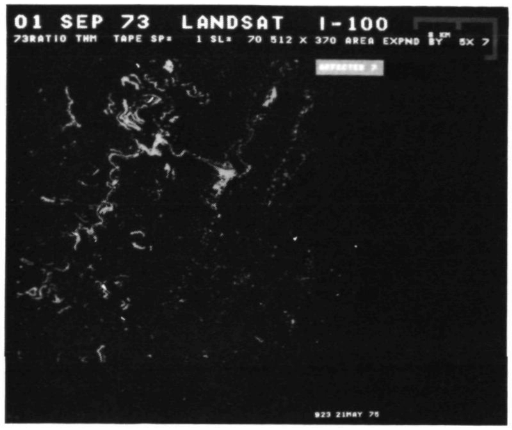

Figure 4. Thematic Classification of Study Region Located at the Boundary of the Georges' Creek and Upper Potomac Basin

Because the ratio signature can be geographically extended only throughout a single image, band 5/6 ratio signatures were calibrated for each image in a manner similar to the method used to select the signature in the earlier study. Pixel counts were obtained for the eight test mines over a series of signature ranges. Regression analysis was performed to determine the signature range which produced the "best fit" of the Landsat area measurements to the "actual" area measurements derived from aerial photographs. This procedure resulted in selection of the signature ranges listed in Table 1.

The regression equations were used as before to "adjust" the initial area determination made by converting pixels to acres by the nominal pixel area of 1.12 acres/pixel.

RESULTS

The classification results using the above signatures are presented in Figure 5. Each of these sub-images includes an area of approximately 325 square miles. When made into a mosaic, a map of the western Maryland surface mining coal areas is produced. From these images the Maryland Bureau of

Table 1

Strip Mine Signatures Used in Western Maryland Inventory

Image	Date	MSS 5/6 Spectral Signature Range	Regression Equation	Standard Error of Estimates-hectares (acres)
1405-15242	9/1/73	72-158	$y = 0.728 + 0.970x$	2.16 (5.34)
1406-15294	9/2/73	79-158	$y = 1.02 + 1.009x$	3.13 (7.73)
1406-15300	9/2/73	76-158	$y = 1.59 + 0.964x$	3.07 (7.59)

y = surface mine areas from aerial photos in acres

x = classified Landsat pixels x 0.45 hectares (1.12 acres)/pixel

Mines can identify operative, inactive, unrevegetated surface mine areas, and refuse piles from deep mines. It should be noted that certain non-vegetated surfaces which are not mine related are classified in the sub-images. Examples are the city of Cumberland and a new construction site (Route 48). Such "false alarms" are not confusing to the user; surprisingly they were of assistance in making a 1:62,500 scale overlay of the theme classified area on to the county and geological map base, knowing the boundaries of the five coal basins.

Figure 6 is an alpha-numeric computer print-out showing the thematically classified pixels of the eight test mines. In the alphanumeric printouts, each character represents one classified pixel. The area of individual mines areas and mine spoil piles can be determined by counting the classified pixels, multiplying the pixels by the nominal hectare pixel conversion (0.45), and applying the appropriate regression equation (Table 1). This procedure was applied to the eight test mines as classified in the three images. For less accurate estimates of mined surface area, calculation by the regression equation is unnecessary. Simple conversion by the nominal pixel area, 0.45 hectares per pixel, is a method which is generally applicable to all three images. Surface areas using this conversion will be slightly underestimated when using pixel counts from image 1406-15294 and overestimated by 1-2% when pixel counts from the other two images are applied.

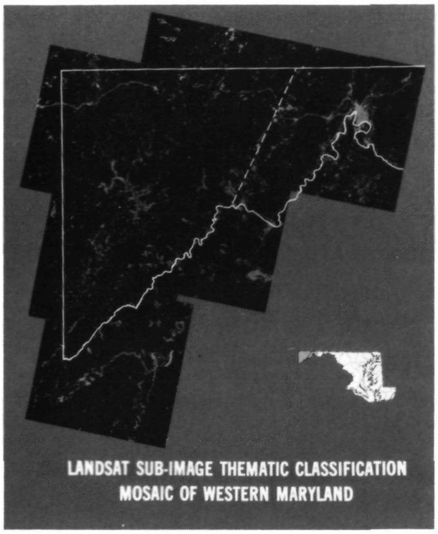

Figure 5. A Band-Ratio Classification Mosaic of Six Sub-Images From Three Landsat Images

Figure 6. Example of Alphanumeric Printout of the Franklin Hill Area

The error in the two September 2, 1973, images is slightly greater than that in the September 1 image. The standard errors of estimate of the regression analyses are 2.16, 3.13 and 3.07 hectares for the 1405-15242, 1406-15294 and 1406-15300 images, respectively. The average accuracy of all measurements in the three images is better than 92%. Again, as in the initial study small mines have the greatest (percent) error. The average accuracy of mines greater than 100 acres is 97%.

After deriving the signature and refining the bounds for each scene, the six overlapping sub-scenes of the area were digitally processed. The output products produced for each sub-area were: photo product which was registered to a map at 1:62,500 after enlargement, an alphanumeric printout for each of the six 325 square mile areas, and the regression line for the averaged pixel to acreage conversion. The entire area was thematically portrayed on an overlay registered to the 1:62,500 scale base maps. These are being used by the State of Maryland to exactly locate each unknown observable mine from the Landsat thematic surface mine alarmed areas as seen in Figure 7. Each mine that was two acres or more in size, whether opened, active, orphaned, inactive, and reclaimed or partially revegetated, which could still be determined to have spoil material or soil on part of the surface was identified. If a mine was fully vegetated by natural tree cover, due to the 9 year lapse since the laws were initiated, the area was not alarmed, but this only occurred in a small number of cases. Since only part of the mine was covered, and the boundary was usually recognizable, they were able to be spectrally discerned from the surroundings.

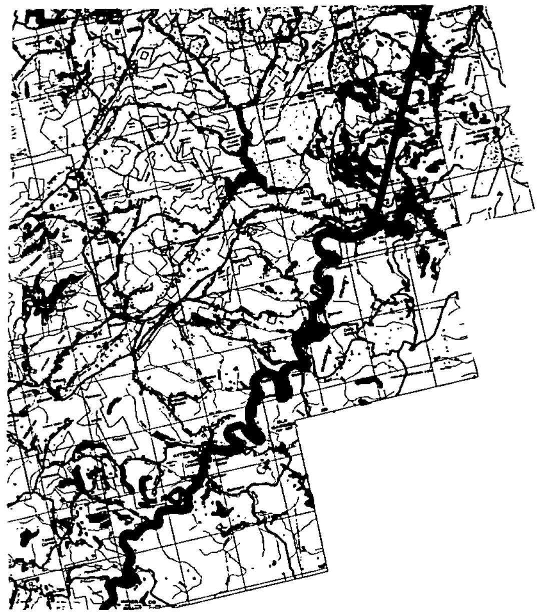

Figure 7. Example of Final Classification Showing One Sub-Image Superimposed on the Garrett County Base Map in the Lower Georges' Creek Coal Basin Region

CONCLUSIONS

The Maryland State Bureau of Mines presently monitors strip mines throughout the five coal basins in Garrett and Allegany Counties. This activity is performed in conjunction with personnel from other State agencies including the Geological Survey, the Forestry Service, and Water Resources and Conservation Department. Through the Land Reclamation Committee, all of these agencies are involved in the review and approval of mine operators' requests for permits, reclamation plans, reports, and reclamation practices. Before 1975, inspectors from the Bureau of Mines measured on a monthly basis only the active coal bench surface area. At present, however, as a direct result of this cooperative study, the inspectors inventory total affected acreage to provide more realistic estimations of the effects of the mining operation for the reclamation and bond release process. The State geologist assigned to the coal region has judged that the monthly and yearly compilations of area measurements are probably not more accurate than 90 percent. Accuracy of State measurements is better for small mines than for mines of 80 hectares (200 acres) or more. In this study, Landsat data were processed to yield total affected area measurements of surface mines on three scenes with an average accuracy of 92 percent for the entire region. Percent accuracy of measurement by the Landsat method increases with the mine size. Thus, Landsat compliments the present inspection system by providing accurate measurement of large mines, as well as verification of area measurement of small mines.

The State has initiated an inventory and mapping program for all strip-mined land in the two counties. The principal purpose for this undertaking is to determine the extent, cost and procedures necessary for reclamation of the inactive and orphan land. The locations and extent of mines which were closed before 1967 are not accurately known. The extension of the Landsat band-ratio signature to the region is a rapid and relatively inexpensive means of locating and measuring the pre-law mines. The satellite data are capable of detecting most barren or partially revegetated surfaces. The Bureau of Mines personnel do not consider the false alarms to be a serious detriment to the mined land inventory since the locations of the coal-bearing corridors are known. Field inspection of surfaces identified as strip mines on a single Landsat image would be a much more efficient process than location of such strip mines at ground or even aerial level.

Landsat images also yield valuable qualitative information on operational mines. Areas where revegetation efforts have not been successful are classified as stripped land. Information on the success of revegetation is useful to both the State and the coal companies who must achieve at least 80 percent revegetation on stripped land for two growing seasons before bonds are released.

This study has demonstrated the feasibility of strip mine inventory and monitoring with Landsat multispectral data to within 2 to 3 hectares. The average accuracy of classification is greater than 92% for Landsat images from 1973. Using band-ratioing techniques it is possible to extend signatures over a large geographic area and temporally to other Landsat images within the same orbit. The procedures developed are now being incorporated into a comprehensive State monitoring and inventory program to provide, in a rapid and inexpensive manner, accurate information on the location, size, and condition of areas affected by surface mining.

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