LANDSAT INVENTORY OF SURFACE-MINED AREAS USING EXTENDIBLE DIGITAL TECHNIQUES

E-7

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ABSTRACT

Multispectral analysis of LANDSAT imagery provides a rapid and accurate means of identification, classification, and measurement of strip-mined surfaces in Western Maryland. Four band analysis allows distinction of a variety of strip-mine associated classes, but has limited extendibility. A method for surface area measurement of strip mines, which is both geographically and temporally extendible, has been developed using band-ratioed LANDSAT reflectance data. The accuracy of area measurement by this method, averaged over three LANDSAT scenes taken between September 1972 and July 1974, is greater than 93%. Total affected acreage of large (50 hectare/124 acre) mines can be measured to within 1.0%.

INTRODUCTION

Extraction of near-surface coal by surface or "strip" mining techniques is an economically feasible response to the Nation's growing demand for energy. In order to reduce dependence on foreign imports, coal mining activity has increased greatly in the last year, and will continue to do so as new reserves are opened. The Nation's need for energy, however, must be balanced with the environmental consequences of coal exploitation. Surface mining unaccompanied by reclamation renders the land useless for other productive uses. Property near or adjoining mine sites is degraded in value (Ref. 1), and severe erosion, landslides, flooding, air and water pollution may also occur.

Of the estimated 2.2 million acres of land stripped for coal in the United States, only a third has been reclaimed (Ref. 2). Frequent monitoring by regulatory agencies is required to insure reclamation success. National reclamation standards do not yet exist and requirements vary widely among the 23 states which presently regulate strip mining. Thus, information on the location, size, and condition of mines is often lacking or inadequate. In a cooperative NASA/State of Maryland effort, imagery relayed from the NASA Earth resources satellite (LANDSAT-1)[1] was applied to the monitoring information needs of the Maryland State Bureau of Mines. The objectives of this cooperative study were (1) determine the accuracy of satellite data for measuring strip mines of the size common in Western Maryland, and (2) develop an operationally feasible procedure for large area inventorying and monitoring of surface mining.

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 in 1969 and 1971, established a Land Reclamation Committee which administrates 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 surface, 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 before the law's enactment will be reclaimed by the State.

[1]The LANDSAT program is managed by the NASA/Goddard Space Flight Center, Greenbelt, Md.

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To assist in the tasks of planning, monitoring, enforcement, and reclamation, the Maryland State Bureau of Mines needs information on the location, size, and condition of coal surface mining areas. Three 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 will require additional inspectors and more efficient means of data collection.

STUDY AREA

The region studied in this investigation includes most of Garrett County and the adjacent area of Allegany County in Western Maryland. The State's only coal deposits are located in these counties. This region, part of the Allegheny Plateau of the Appalachian Range, consists of gently folded mountains, the result of differential erosion of sedimentary materials which were originally deposited in horizontal layers and were compressed to form a series of parallel mountains and synclinal basins. The co~l-bearing strata are of Pennsylvanian age and lie within 200 feet of the surface in five major basins (Figure 1). 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 (250 to 1300 feet). High walls range from 20 to 45 meters (60 to 150 feet). The majority of mines are less than 90 hectares (220 acres) in size. It was within the Georges Creek basin that multispectral training of LANDSAT data was conducted.

METHODS

Area Measurements

Accurate area measurements from aerial photographs were required for this study in order to quantitatively inventory the area affected by surface mining and verify the accuracy of the satellite inventory. Prior to 1975 the State recorded only the area of coal surface annually exposed. For this study, therefore, total affected area was determined by planimetry of NASA/Wallops low altitude aerial photography taken in October 1973 (Figure 2). The area measurements obtained from these photographs were used to verify the accuracy of the LANDSAT classifications for eight surface mines in the test site.

Obtaining accurate area measurements from low altitude aircraft imagery is a difficult, time consuming task due to a combination of factors: off-nadir viewing, the varying elevation of the mines in this area, and the distortion due to the mountainous terrain. The following procedure was followed in calculating the area of each test mine from aircraft photography:

- The mine areas were planimetered four times with precision among these being greater than 96%. (Readings with a large deviation were rejected.) The average of these readings was used in the calculation.
- A table of photo scale versus aircraft altitude was calculated using the formula:

$$\text{Photo scale} = \frac{\text{Focal length}}{\text{Altitude}}$$

- The table of photo scale was verified and corrected using ground distance measurements on the aerial photographs and topographic maps.
- The camera height was determined by subtracting the mean topographic elevation of the mines from the corrected aircraft altimeter readings. Large mines were segmented into sections of nearly equal elevation.

- Using the appropriate photo scale factor the planimetry values were converted to acres.
- The mine acreage values were corrected for the viewing aspect angle.

The surface area measurements obtained in this manner are shown in Table II which is in the Results Section of this paper. The test mines shown in Figure 2 range in size from 12.7ha (31.4 acres) to 98.7ha (243.8 acres). Surface area values from aircraft photos are 25 to 30 percent larger than the published State figures which at that time related only to the coal surface exposed; the aircraft values are for the total affected area including spoil piles and haul roads. For accurate reclamation projections, the State now requires data on this total disturbed area.

High altitude aerial photographs of the Georges Creek basin are available from NASA/Ames for 1972 and 1974. One of the test mines, Franklin Hill-A was planimetered on these photographs because the entire mine was not included on the 1973 low altitude photos. In general, however, the areas of interest were too small and too near the format edge to permit accurate planimeter measurement.

The high altitude photography did show that most of the test mines changed very little in size during the two-year period between the photos. The only test mines whose areas were significantly different from year to year are those located near Mill Run. Mill Run-B had not been opened in 1972, but was completely stripped by October 1973. In 1974 it was backfilled. The lower section of Mill Run-A was bare in 1972 and almost completely revegetated in 1973 (see Figure 2). The other test mines remained approximately the same size from 1972 through 1974.

Multispectral Analysis

An interactive, multispectral image analysis system[2] was used to perform the digital data processing of LANDSAT computer compatible tapes (CCTs). The system's image analysis console houses a color image display, controls, and a special purpose high speed processing logic. A mini-computer together with peripherals serves as a system process controller and computational device. The user interacts directly with the computer through a graphics entry/display terminal. The graphics terminal also serves to display the quantitative processing results in both numerical and graphic form.

Four-band classification. - A portion of LANDSAT-1 scene 1405-15242 (1 Sept. 73) containing the Georges Creek basin was digitally enlarged to fill the system's 512 X 512 picture element color display (Figure 3). The area displayed is approximately 51.8 square kilometers (20 square miles). Supervised training and classification were then performed on the four LANDSAT spectral bands. Training sites were selected with an electronic cursor which is sized and positioned using a joy-stick. The image analysis system's special purpose hardware identifies the spectral reflectance range within the training site in the four LANDSAT bands simultaneously. The minimum and maximum reflectance values in each channel (band) of the training area are then used to define the limits of a 4-dimensional spectral parallelepiped. The picture elements of the entire displayed image are examined pixel-by-pixel. Those pixels lying spectrally within the parallelepiped bounds defined by the training site are identified or "alarmed" on the TV monitor. This entire process requires less than 5 seconds. The system user then has the option of modifying the spectral signature to increase or decrease the alarm through thresholding the parallelepiped boundaries. This procedure is known as single parallelepiped training and classification.

[2] General Electric IMAGE 100 System

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.

Seven classes, five of which describe areas affected by strip mining, were identified. Discussion of these classes and their extension throughout the study region is presented in the Results Section of this paper.

Band-ratio classification.- The great variability among 4-band signatures for various types of strip-mining surfaces discourages the use of this means 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 the Environmental Protection Agency (Ref. 3) has reported great variation among signatures for strip mines studied in Wyoming and Montana. Preprocessing of the LANDSAT multispectral data before classification provides a means of distinguishing strip mines in a single classification. The objective of preprocessing is to transform the sensor outputs to minimize the effects of environmental, observational and sensor conditions on signature extraction. Other investigators (Ref. 4) have found that band-ratioing techniques minimize systemic errors and decrease temporal and geographical differences. The rationale behind ratioing can be illustrated by a simplified model of spectral signal in the narrow bandwidth (i) of a sensor:

$$S_i' = m_i S_i + a_i$$

where S_i' is the observed reflectance and S_i is the reflectance at the surface. If the multiplicative terms are larger than the additive terms and these are approximately invariant over adjacent spectral bands, then when $i+1 = j$, the ratio

$$\frac{S_i'}{S_j} = \frac{m_i S_i}{m_j S_j} = \frac{S_i}{S_j}$$

is not affected by the multiplicative error factors. Hence, multiplicative system errors are minimized in the ratioed signals. Table I , borrowed from Kriegler (Ref. 5), indicates the factors that produce signal variation. Note that most of the factors related to the useful signal are multiplicative. On the other hand, the effects of atmospheric backscatter and noise are additive, and they tend to mask the useful signal.

TABLE I .- GENERAL FACTORS THAT PRODUCE SIGNAL VARIATIONS

Variable Factor	Causes and Dependencies	Type of Factor	
		Multi	Add.
Illumination	Shadows, time of day, clouds, etc	X	
Transmittance	Altitude, haze, aerosols, scan angle	X	
Reflectance	Scan angle, sun angle, species, maturity, vigor	X	
Atmospheric Backscatter	Altitude, haze, aerosols, sun angles		X
Sensor Gain	Different setups, different days	X	
Noise	System components		X (primarily)

Identical portions of the 1 Sept. 73 (1405-15242) and the 6 Sept. 72 (1045-15245) images were preprocessed on the multispectral image analysis system to yield twelve band-ratios for each date. The procedure used to determine the most accurate strip mine classification using these ratios was as follows:

- In both images polygon-shaped training sites were defined to surround each test strip mine.
- Histogram lists of the polygon areas were obtained for all twelve LANDSAT ratios. These provided pixel counts for each mine in several gray level ranges.
- Pixel counts for each mine were converted to surface area. A LANDSAT pixel equals 0.453 hectares (1.12 acres).
- A least squares regression was then calculated for the aircraft area values (y) and the LANDSAT area values (x) for each gray level range, using data from both 1972 and 1973 imagery. The regression resulting in the smallest standard error of estimate was selected as providing the most consistently accurate surface area measurement from both 1972 and 1973 data.

The smallest standard error of estimate, 2.16 hectares, was obtained using the band-ratio of MSS 5/6 (Figure 4). The resulting equation was:

$$y = 0.295 + 0.970\,x + \epsilon$$

where y is the "true" or aircraft area in hectares; x is the LANDSAT area in hectares; and ϵ is the residual. This equation was used to "adjust" the LANDSAT area measurements for the two images. The MSS 5/6 strip mine signature selected by this procedure was applied to a third satellite image, 1729-15164 of 22 July 1974. The pixel counts for each test mine were converted to hectares and adjusted by the factors in the regression equation. The resulting surface area values for all three images are given in Table II.

RESULTS

Four-band Classification

Using the multispectral analysis system, 4-channel training and classification on sites of known surface characteristics resulted in the identification of seven classes: three strip mine surface classes, bare soil, partially revegetated, and two classes of undisturbed land including forest and open fields. Figure 5 demonstrates the results of this classification of the test site on 1 September 1973 LANDSAT-1 imagery.

Field analysis and communication with the Bureau of Mines revealed several additional details about these classes.

- Strip Mine Class 1 corresponds to the exposed subsoil and the spoil piles of relatively light color, particularly from the Franklin and Barton coal seams. The mines in this class were either open or backfilled with spoil material at the time of the satellite overpass.
- Strip Mine Class 2 denotes the open or backfilled mines of darker subsoil, specifically those associated with the Pittsburg coal seam. The overburden of this seam contains a large quantity of burned shale (rashings), which has a characteristic red color, and therefore, a distinct reflectance signature. The red shale is often used as road surfacing material by the mine operators, and some roads are included in this class.
- Strip Mine Class 3 corresponds to strip mines that have been backfilled and graded, some of which are being used as landfill areas. Most of these mines exposed the Upper Bakerstown coal seam and its associated spoils.

- The Bare Soil Class identifies strip mine surfaces which have been backfilled with the spoil, graded and covered with topsoil. The soil is brighter than subsoil material in all four LANDSAT spectral bands and therefore this class is distinct from the three described above. Some of the mine surfaces included in this class have been seeded but are not yet revegetated.
- The Revegetated Class relates to surfaces which are similar in cover to the sparsely grassed-over airstrip on Franklin Hill, which is an old strip mine that has been approved as revegetated by the State. The boundaries between open strip mines and forests or fields are sometimes falsely included in the revegetated class. This is due to the fact that the average reflectance of the field of view of these boundary pixels is similar to that of sparse vegetation on closed strip mines.
- Open Field refers to unforested land, chiefly crop and grazing land, which has never been stripped.
- Forest refers to areas covered by dense trees and scrub vegetation.

The signatures derived for these seven classes were applied to the entire study area which contains the adjoining areas of Garrett and Allegany Counties in Maryland, and Grant and Mineral Counties in West Virginia. The resulting regional classification is shown in Figure 6.

Certain surfaces are falsely alarmed (classified) when the multispectral signatures are extended over a larger area. For example, the town of Keyser, Maryland, located to the right of center in Figure 6, is classified as strip mine. Apparently the vegetated/non-vegetated contrast in reflectance of the town is similar to that of the mines. Another false alarm includes the railroad yard west of Keyser. The dark railroad bed material is classified in the second strip mine class. The bare soil classification correctly identified areas other than backfilled spoils. Along the west bank of the North Branch of the Potomac River, the construction site of a new rail cut located adjacent to the river was classified as bare soil.

Band-Ratio Classification

Using band-ratioed data and linear regression analysis it was possible to extend a single signature to three LANDSAT images covering a time span of two years. Of the 12 LANDSAT band-ratios, the ratio of MSS 5/6 proved to provide the most consistently accurate results when compared to aircraft planimetry. Using the linear regression equation the standard error of estimate is less than 5 pixel-sized units. The correlation coefficient (r) of the linear regression is 0.997. The results of the band-ratio classification of the Sept. 72, Sept. 73, and July 74 LANDSAT data are presented in Table II and Figure 7.

The average difference from the aircraft photography is $\pm$ 6.9% for all three years. The largest errors occur in the July 1974 image; six of the eight mines are underestimated by an average of 12%. Comparison of the 1974 classification with the 1973 and 1972 classifications and with available air photos suggests that most of this change is due to natural revegetation around the edges of inactive mines. The two Phoenix Hill mines (Figure 2) ceased operations before the passage of the Maryland Strip Mining Bill in 1967. They are void of topsoil, and natural revegetation is progressing slowly. This natural recovery is seen in the continued decrease of the 1972 through 1974 satellite area measurements. The two Aaron Run mines are also revegetating. These mines were forfeited to the State unreclaimed prior to 1972. The State has backfilled and planted these areas, but the LANDSAT data indicates that reclamation has not been as successful as in other parts of the test site.

State records indicate 137 acres of coal were exposed and 157,000 tons of coal removed from the Mill Run-A mine (Figure 2) during the period monitored by the LANDSAT images. Aerial photography taken in October 1973 shows that the total affected area was 217.9 acres, 14.5 acres of which was partially reclaimed. The Sept. 73 LANDSAT classification identified 198.3 acres of unreclaimed area affected by surface mining, a 2.6% difference from the aerial interpretation. More reclamation had occurred by the time of the 1974 LANDSAT image which shows 191.7 acres in Mill Run-A. The 1972 LANDSAT image shows the full extent of the mine (222.1 acres) before reclamation.

Mill Run-B was opened in 1973. Prior to that the satellite data identified several pixels in the 1972 image in areas where roads had been cleared in preparation for strip mining. The 1973 aircraft and LANDSAT images indicate approximately 65 acres of land had been affected by stripping operations. The mine was backfilled and seeded during the next year, reducing the 1974 acreage to 53 acres.

The mines on Franklin Hill (Figure 2) were operative throughout the period covered by this investigation. High altitude photography of the region in 1972 and 1974 shows that these mines did not alter significantly in surface area over that period, even though 100 thousand tons of coal were extracted from these mines in 1973 alone. The Franklin Hill mines were opened before 1972 and the same areas have been restripped several times. The increased area identified in the 1974 LANDSAT image is due to new spoil piles and enlarged haul roads.

Figure 8 shows the band-ratio classifications applied to the same study area as Figure 6. The results demonstrate the geographic extendibility of the ratio signature. False-alarms are similar to those resulting from the 4-channel classification. Misclassifications of this sort are not generally serious since the locations of most of the mines are well known.

CONCLUSIONS

This study has demonstrated the feasibility of strip mine monitoring with LANDSAT multispectral data to within 2 hectares (5 acres). The average accuracy of classification is greater than 93% for LANDSAT images from three dates. Using band-ratioing techniques it is possible to extend signatures over a large geographic area and temporally to other LANDSAT images.

The procedures developed in this study could be incorporated into a comprehensive monitoring program to provide, in a rapid and inexpensive manner, accurate information on the location, size, and condition of areas affected by surface mining. Multispectral analysis of satellite digital data would be useful in validating operators' reports on the size and status of mining operations, locating abandoned and unrevegetated mines, and assessing reclamation costs and requirements.

REFERENCES

1. Board on Unreclaimed Strip Mined Lands, State of Ohio. Land Reborn, Jan. 1, 1974.

2. Council on Environmental Quality. Annual Report 1974.

3. Office of Enforcement, Environmental Protection Agency, An Application of ERTS Technology to the Evaluation of Coal Strip Mining and Reclamation in the Northern Great Plains. EPA-330/3-75-001; Feb. 1975.

4. Goetz, A.F.H. and Billingsley, F.C., "Digital Image Enhancement Techniques Used in Some ERTS Applications Problems", in Proceedings of the Third Earth Resources Technology Satellite-1 Symposium; Vol. I, Section A. NASA SP-351; 1974.

5. Kriegler, F.J., et al., "Preprocessing Transformation and Their Effects on Multispectral Recognition", in Proceedings of the Sixth International Symposium on Remote Sensing of the Environment. University of Michigan, Willow Run Laboratories, Ann Arbor, Michigan, October 1969.

TABLE II.- SURFACE AREA MEASUREMENTS FROM LANDSAT MSS 5/6 CLASSIFICATION AND LEAST SQUARES REGRESSION

Strip Mine	Aircraft Photography 10/16/73		LANDSAT Imagery												
			6 Sept. 72				1 Sept. 73				22 July 74			
	ha	acres	pixels	ha	acres	resid. ha	pixels	ha	acres	resid. ha	pixels	ha	acres	resid. ha
Mill Run-A[a]	88.2	217.9	204	89.9	222.1	1.7								
	82.4	203.4					182	80.3	198.2	-2.1	176	77.6	191.7	-4.8
Mill Run-B	22.8	56.4	6	(b)			59	26.2	64.7	3.4	48	21.4	52.9	-1.4
Aaron Run-A	12.7	31.4	34	15.2	37.5	2.5	30	13.5	33.3	0.8	23	10.4	25.7	-2.3
Aaron Run-B	18.8	46.4	42	18.7	46.2	-0.1	45	20.1	49.6	1.3	39	17.5	43.2	-1.3
Phoenix Hill-A	45.0	111.1	98	43.4	107.2	-1.6	95	42.0	103.7	-3.0	82	36.3	89.7	-8.7
Phoenix Hill-B	51.3	126.7	116	51.2	126.5	-0.1	115	50.9	125.7	-0.4	107	47.4	117.1	-3.9
Franklin Hill-A	98.7	243.8	224	98.8	244.0	0.1	230	101.4	250.4	2.7	239	105.4	260.3	6.7
Franklin Hill-B	42.7	105.5	91	40.3	99.5	-2.4	90	39.9	98.5	-2.8	99	43.7	107.9	1.0

[a]The acreage of Mill Run-A was reduced for '73 and '74 to exclude revegetated areas identifiable on the air photos.

[b]Mill Run-B was not opened until 1973.

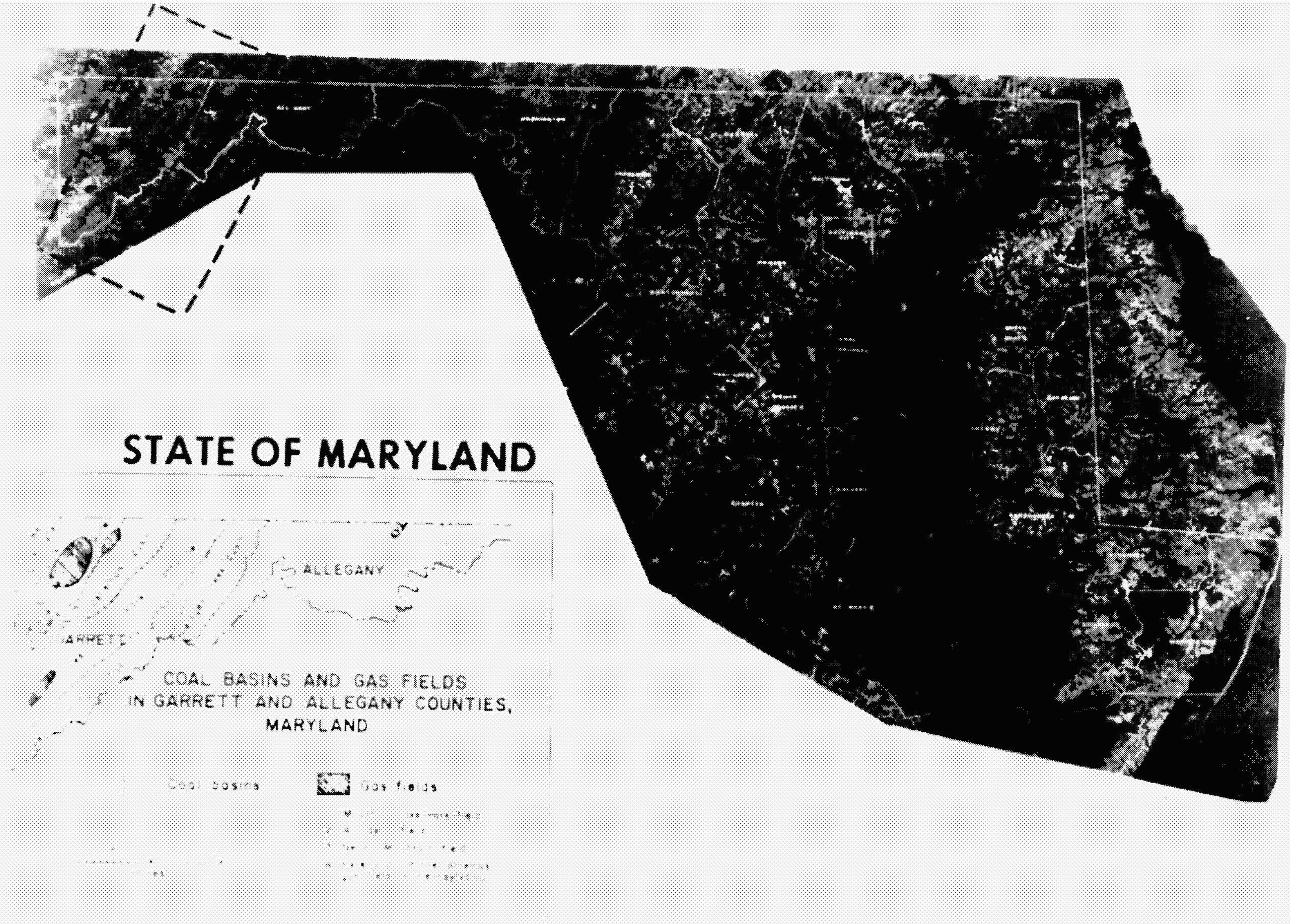

Figure 1. LANDSAT mosaic of Maryland with the test site and larger study region outlined; insert map of coal basins (from Vokes and Edwards, 1968).

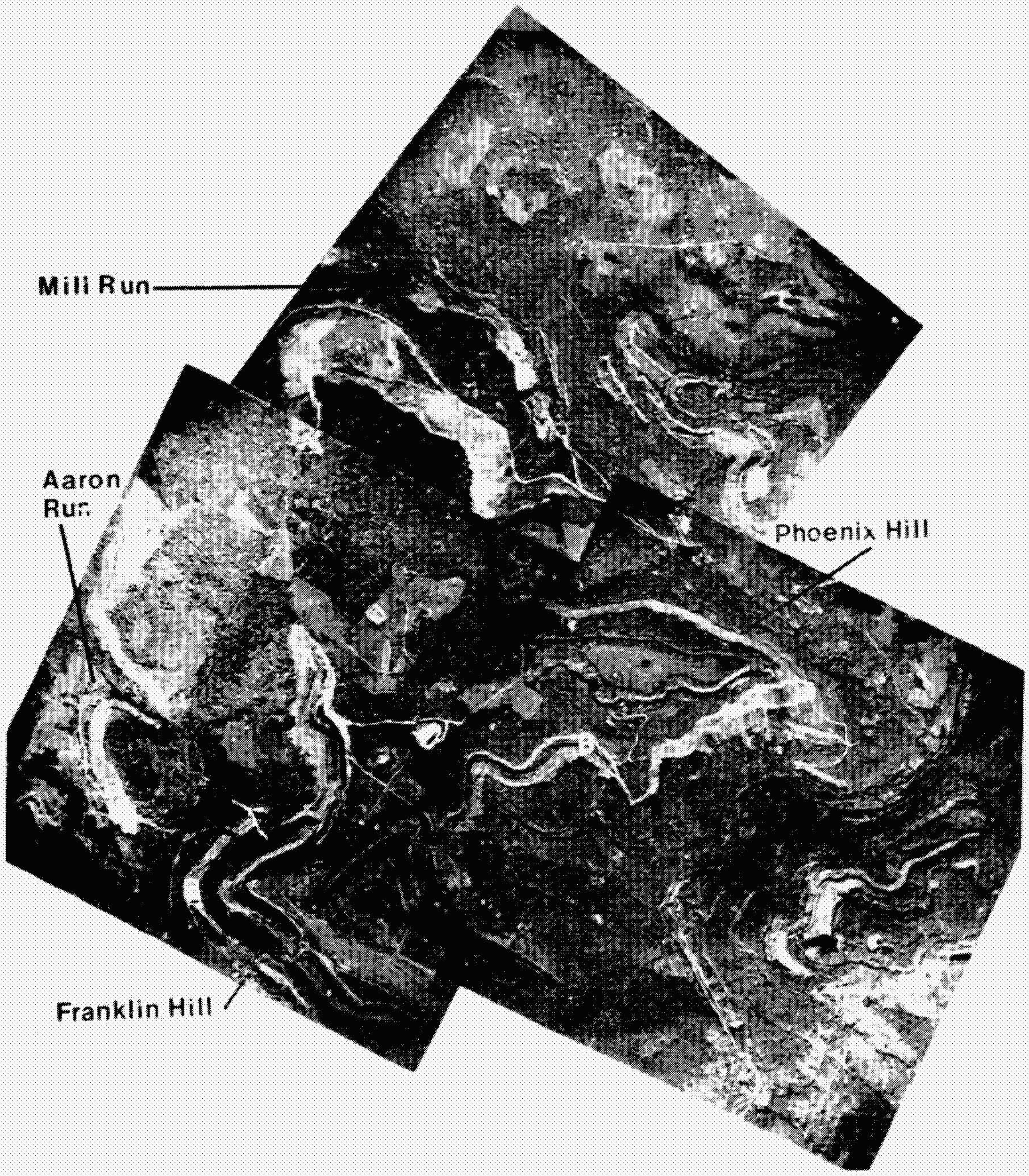

Figure 2. Low altitude NASA/Wallops aircraft photo-mosaic, taken 10/16/73, showing the 51.8 sq. km. test site with test strip mines identified.

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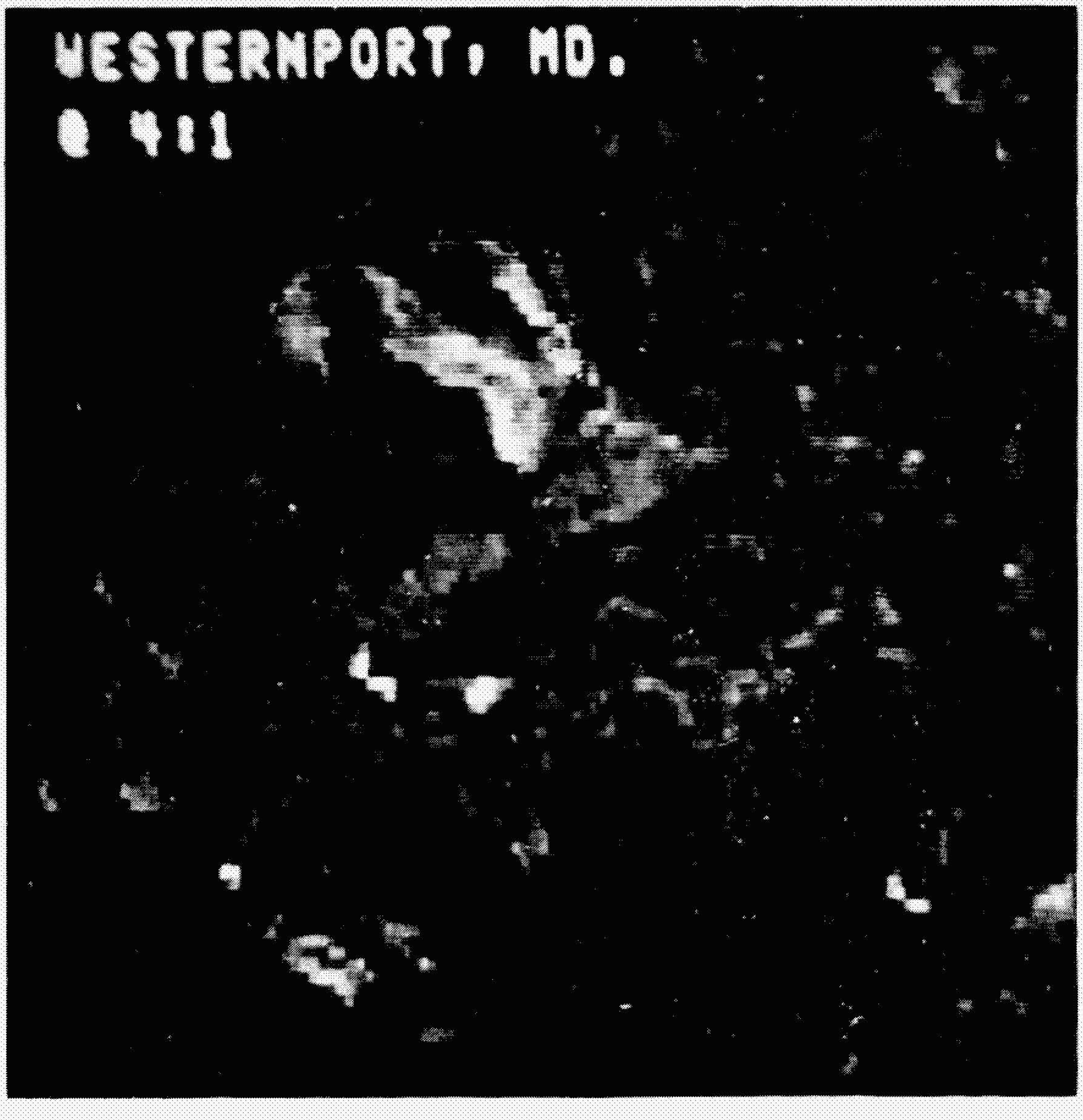

Figure 3. Computer output from video monitor showing test site from 1 September 1973 scene (1405-15242).

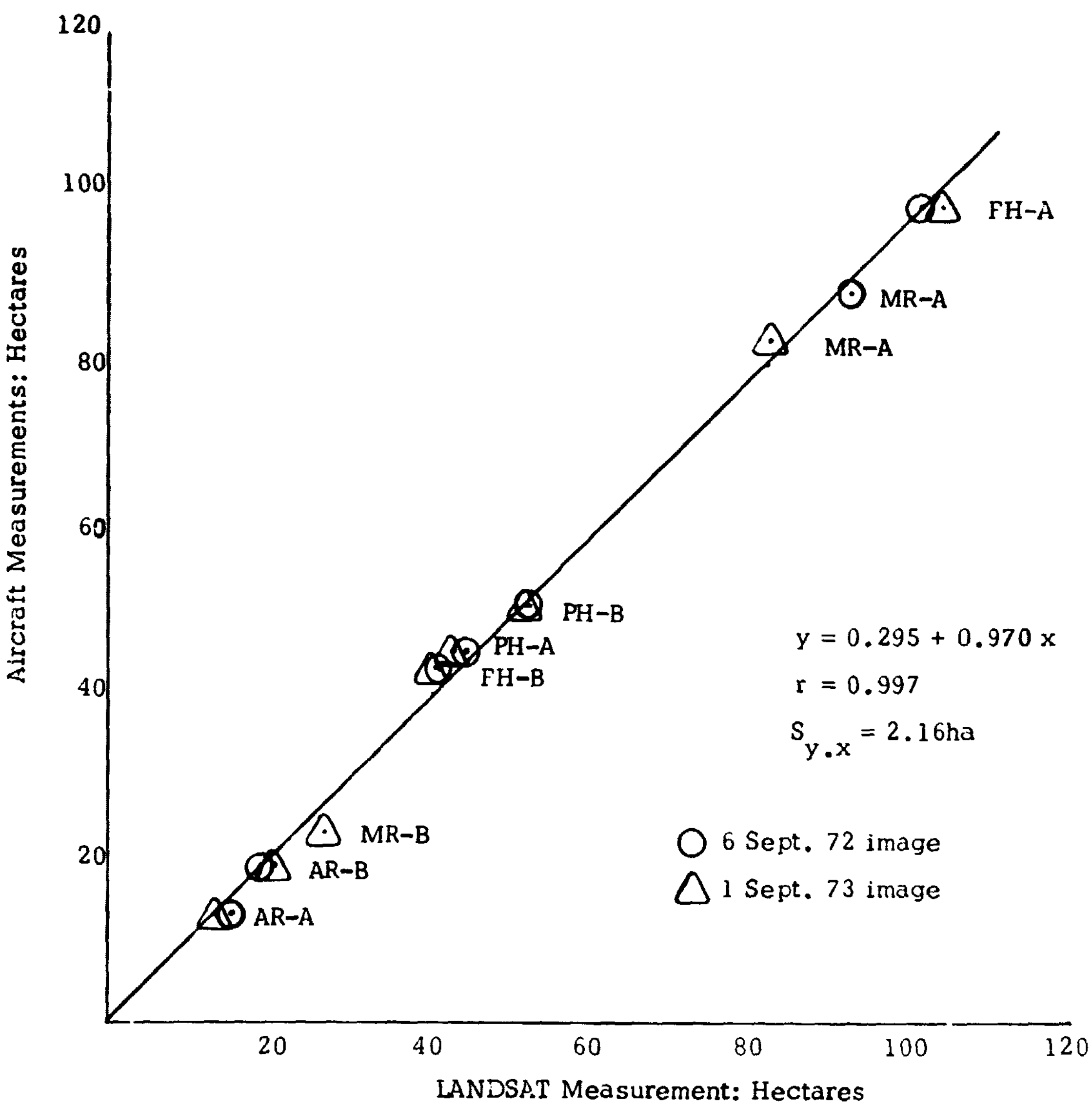

Figure 4.- Linear Regression Analysis of MSS 5/6 Strip Mine Classification

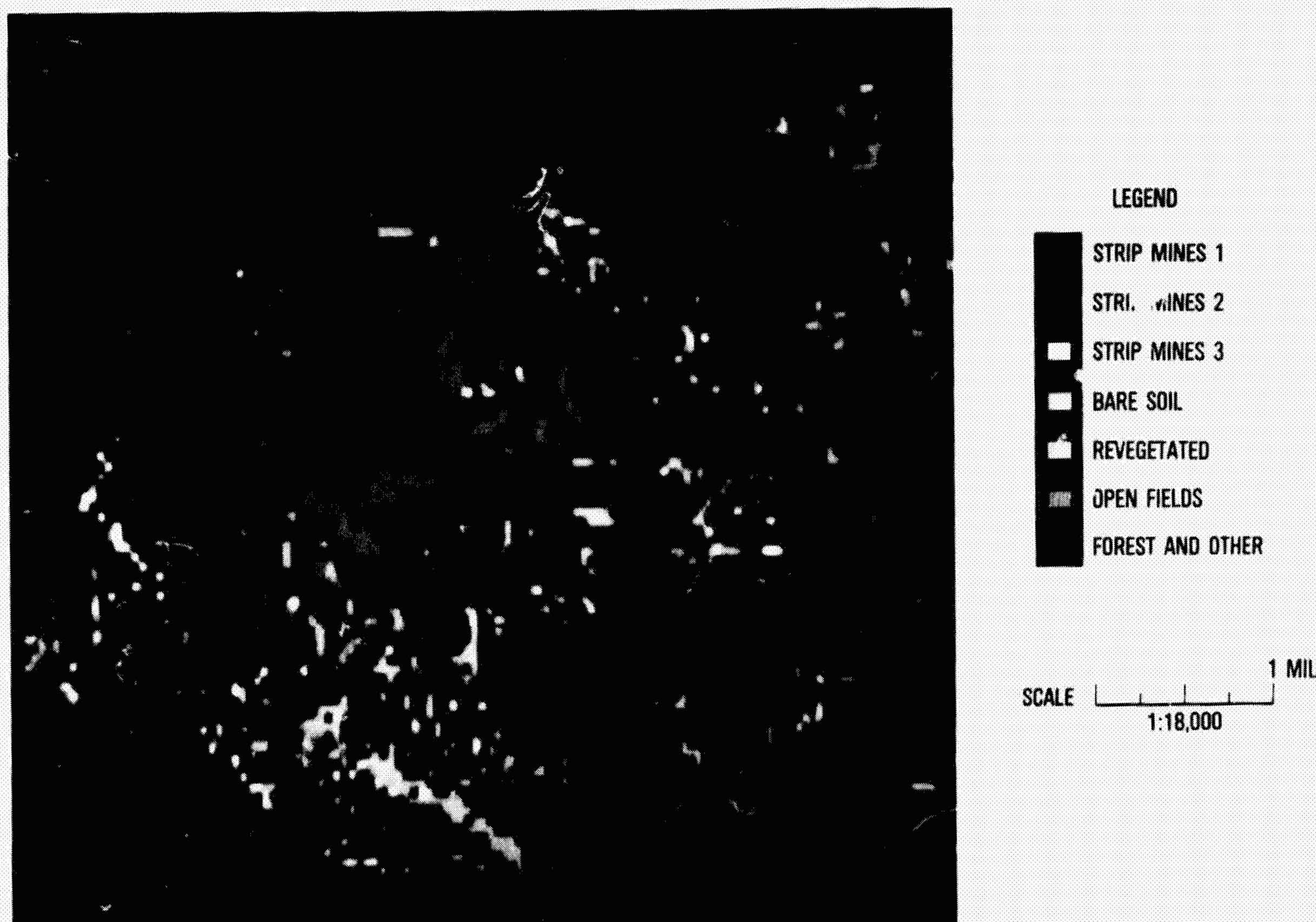

Figure 5. Interactive computer system output showing 4-band classification of test site.

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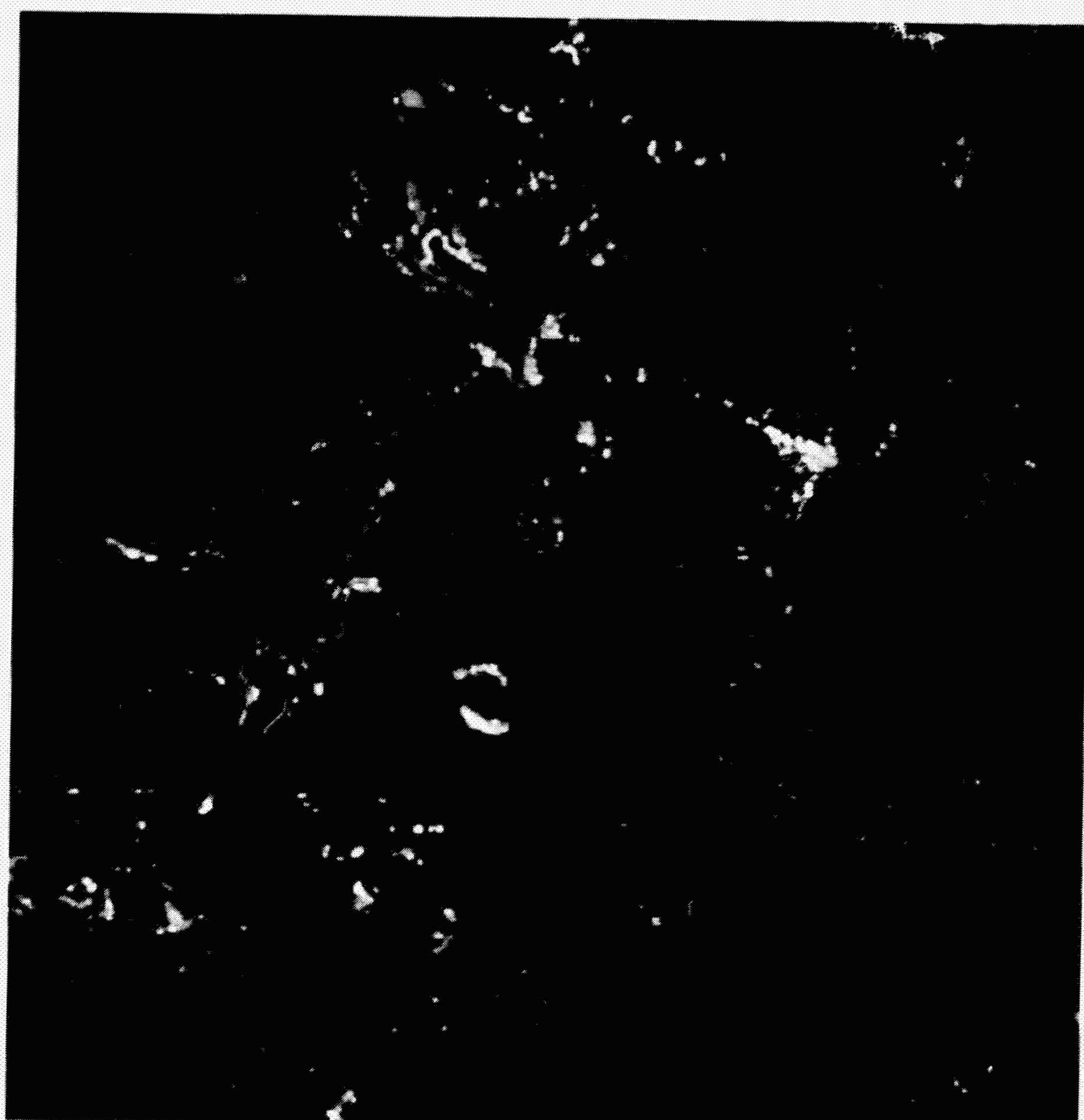

Figure 6. Four-band classification of strip mines and partially revegetated mines in entire study region.

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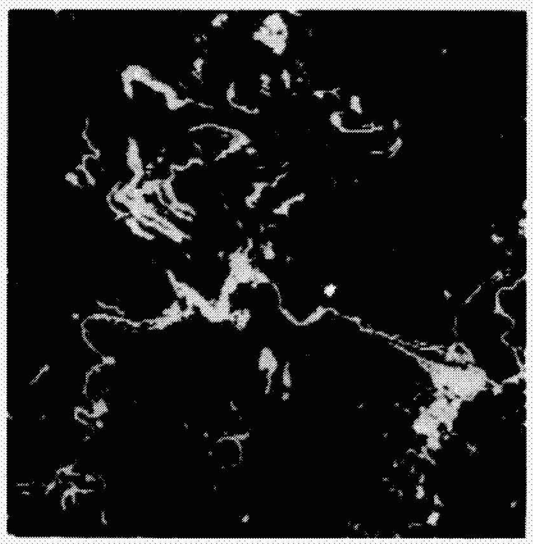

(a) 6 September 1972

(b) 1 September 1973

(c) 22 July 1974

Figure 7. Strip mines identified on three LANDSAT images from same spectral signature in band 5/6 ratio.

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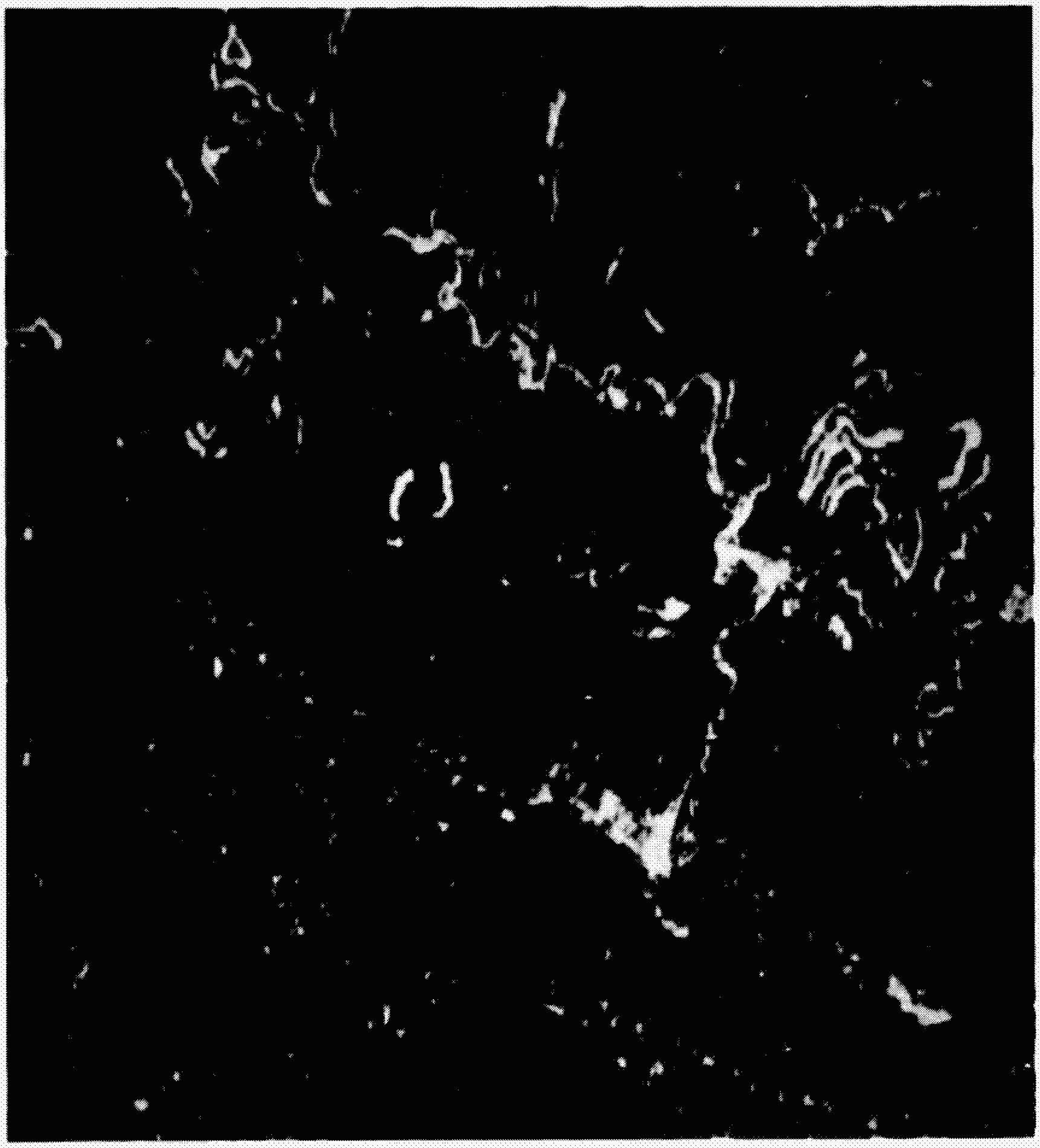

Figure 8. Band-ratio classification of strip mines for the study region, 1 September 1973.

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