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# APPLICATION OF LANDSAT-2 DATA TO THE IMPLEMENTATION AND ENFORCEMENT OF THE PENNSYLVANIA SURFACE MINING CONSERVATION AND RECLAMATION ACT


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16. Abstract
The objectives of this investigation were to develop Landsat and aerial photographic interpretation products which will aid the Commonwealth of Pennsylvania in the implementation of their surface mining laws. Computer processing of Landsat data by linear stretching and by 4x computer enlarging resulted in quality imagery of 1:24,000 scale. This imagery was manually interpreted. The areal extent of mines as mapped with Landsat imagery showed an accuracy of about 95%, and general classification on status-of-reclamation into four categories. Imagery and interpretation products from both Landsat imagery and aerial photography were prepared and presented to the appropriate bureaus within the Pennsylvania Department of Environmental Protection. After evaluation, they judged the products as being of no utility in implementing their mining laws.

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# PREFACE

The central objective of this investigation was, through the use of Landsat imagery and aerial photography, to provide information products which would aid the State of Pennsylvania in the implementation of the surface mining laws. A complete mine land information package and instructional material were to be prepared and a system of distribution of these information products was to be established.

Computer enhancement of Landsat imagery was determined to be necessary to produce the quality and scale imagery which had potential of accomplishing the above objectives. Several computer processing techniques were tested and useful Landsat images at a scale of 1:24,000 were produced and interpreted. Area determinations of total mined lands proved to be about 95% accurate and considerable information about status or reclamation was discernible from this imagery. Both the Landsat products and the photo interpretation results were presented to the appropriate bureaus within the State and were judged by them to be of no utility in their activities.

The information requirements of the State are largely at the field inspector level. Information which will aid in his activities must be detailed and timely, factors which are not obtainable with the current basis data distribution system. The information must be in a form that can be readily understood by the inspector. This requires an intermediate interpretation phase which further affects the timeliness of the information.

It is concluded that although useful information can be derived from appropriately processed Landsat imagery and aerial photography, resolution limitations, cost, and timeliness of data severely impact the potential of effectively integrating remote sensing technology into the routine mine land monitoring activities.

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## 1.0 INTRODUCTION

The Federal Energy Administration has established that even with conservation measures the nation's total energy needs by 1990 will be 53% greater than in 1974. Unless a major breakthrough occurs in the harnessing of solar energy or in the development of fusion reactors, coal must provide well over half of these energy needs. In his energy message of April 20, President Carter estimated that by 1985 this country will have to be producing one billion tons of coal a year. Both the Energy Supply and Environmental Coordination Act of 1974, and the Energy Policy and Conservation Act of 1975 mandated that where possible electric power plants must convert to coal. To accomplish this, the quantity of coal mined would need to be doubled, and a major portion would be from surface mines.

While the increase of coal production is essential, consideration for protection of the environment is equally important. Federal legislation to enact standards of reclamation for surface mine lands is now being considered with this objective, and is expected to become law.

Pennsylvania's surface mining laws are generally recognized as being some of the better legislation of the Appalachian region for water quality control and surface mine land reclamation. The enforcement of these laws, however, requires nearly 100 administrative and field personnel, and an annual expenditure of over $2 million. Investigation of methods or techniques which improve law enforcement efficiency should thus be of high priority. Work performed by EarthSat, as well as by others in the ERTS-1 experiments (Wier, 1974, 1976; and Rogers, et al., 1973; Sweet, et al., 1973), indicate considerable potential for using Landsat imagery and small scale aerial photography in monitoring the progress and status of surface coal mining in certain parts of the country. The results of these studies prompted the investigation described here.

A test area in the bituminous coal area of western Pennsylvania was selected for evaluating the utility to the State of Landsat imagery and aerial photography in enforcing surface mining laws. Although much potentially useful information can be derived from both the photography and the Landsat imagery, they were found to be of limited value to the State for law enforcement purposes.

## 2.0 OBJECTIVES

To determine the utility of Landsat data for implementing mining regulations in Pennsylvania, this investigation had the following central objectives:

- To prepare information products for the analysis of Landsat and aircraft imagery to rapidly and effectively implement the regulatory provisions of Pennsylvania's Surface Mining Conservation and Reclamation Act and anticipated Federal Surface Mining Legislation.
- To develop and operationally implement a monitoring system within one or more detailed study sites, which would include surface mine disturbance change detection, reclamation status monitoring, and mined lands inventory updating.
- To provide usable regulatory information products to line-agencies within the Pennsylvania Department of Environmental Resources.

Initial emphasis was to be placed on manual analysis by experienced image interpreters. The utility of large scale digital image reconstructions, selected multispectral signature programs, and classification algorithms were then to be evaluated as an aid to manual image interpretation.

## 3.0 BACKGROUND

Pennsylvania has long been a leading coal producing state. The U.S. Bureau of Mines reports that since 1760 the State has produced over nine billion tons of bituminous coal, and until 1927 was the nation's leading coal producer. The bituminous coal fields, which occur mostly in western Pennsylvania (see Figure 1), cover over 14,000 square miles (36,244 square kilometers), predominately within the watersheds of the Allegheny and West Branch Susquehanna Rivers. A cursory examination of Landsat imagery indicates that the drainage system of approximately one-fourth of this area or about 3,500 square miles (9,061 square kilometers), could currently be adversely affected by improper mining and reclamation procedures.

Mining practices over the last century have left many areas severely affected by excessive sedimentation and acid water producing conditions. However, since the enactment of the Bituminous Coal Pit Mining Conservation Act in 1963, Pennsylvania has made great strides in controlling old problem areas, and their current mining and reclamation laws are considered to be among the more comprehensive.

The laws are administered within the Pennsylvania Department of Environmental Resources, by the Bureau of Water Quality Management and Bureau of Surface Mine Reclamation, as shown on the organizational chart in Figure 2. For administrative purposes, the Bureau of Surface Mine Reclamation has divided the Commonwealth into the Eastern Anthracite and the Western Bituminous Regions. The latter region is extensive and is divided into 18 districts which are monitored by one or more Field Inspectors under the supervision of two Inspectors-at-Large.

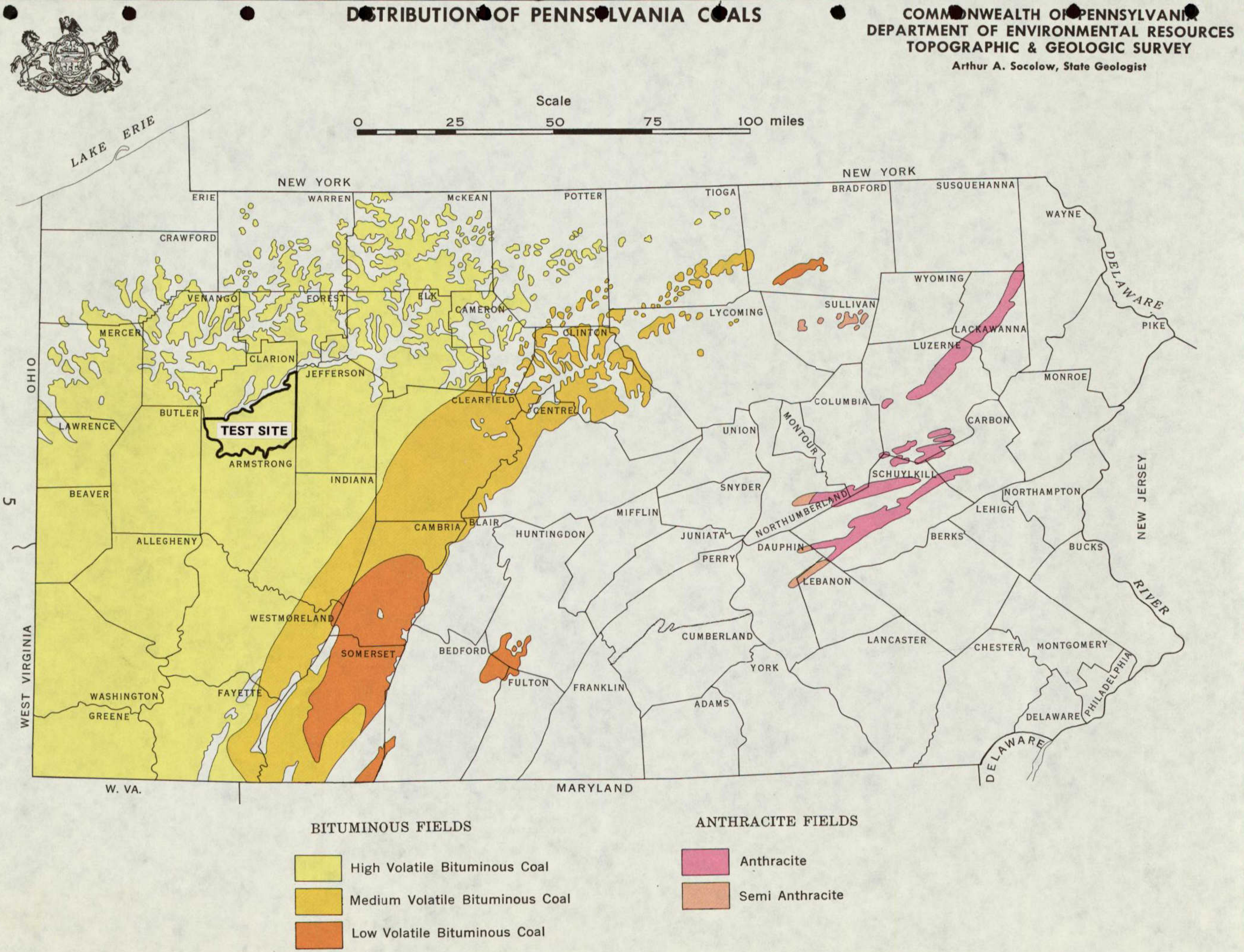



Figure 1. Map showing the investigation site and the distribution of Pennsylvania coal.

The Bureau of Surface Mine Reclamation employs 95 personnel and had an operations budget in 1975 of over $1.6 million. The budget for 1977 is about $2 million, of which over $600,000 will be expended in the Western Bituminous Region.

As of February 1977, there were 1,146 current permits issued, and 972 active surface coal mining operations in western Pennsylvania. The State employs 46 inspectors to monitor these operations. Permits range in size from 25 to 2,000 acres, with the average nearer the lower figure. Depending upon the size of the company, an operator may mine from 60 to 1,000 acres per year. In 1976, nearly 5-3/4 million tons of bituminous coal were produced.

## 3.1 Description of the Bituminous Coal Area of Pennsylvania

The bituminous coal fields in Pennsylvania lie in the western portion of the Commonwealth (see Figure 1) in an area generally referred to physiographically as the Appalachian Plateau. This area lies immediately west and north of the more rugged Valley and Ridge Province of the Appalachian Mountains. The Plateau is in the temperate climatic zone, where August temperatures average about 68°F and February temperatures 25°F. The area has considerable cloud cover and an average rainfall of 40 inches per year, supplemented by 20-50 inches of snowfall. The result of this abundant moisture is a dense forest cover wherever land has not been disturbed by human activities.

Elevations range between extremes of about 2,500 feet in north-central Pennsylvania to about 1,400 feet on the Ohio River at the Ohio-Pennsylvania state line. The area is maturely dissected, characterized by moderate relief and rolling topography, with local elevation differences ranging between 200 and 500 feet. It has been classified by Hammond (1964) as predominately open high hills and low mountains.

Geologically, the area is characterized by highly dissected nearly horizontal to moderately folded strata of shales, sandstones, limestones, and coals, ranging in age from Upper Mississippian (about 325 million years ago) to Lower Permian (about 275 million years ago). Geologic conditions were unique in this time period in that there were repeated minor fluctuations in the land level which caused alternate marine transgressions and regressions to occur in the shallow interior basins, producing a cyclic character to the sedimentation in the basins. A regular sequence of rock types was deposited over and over. Thus, in western Pennsylvania there are several coal beds that are of commercial interest separated by a predictable sequence of other rocks. Although all units of this sequence are not always present, the ideal sequence, beginning at the bottom, consists of:

1. Fine grain micaceous sandstone, locally unconformable on underlying beds;
2. Sandy shale;
3. Freshwater, usually non-fossiliferous limestone;
4. Under clay;
5. Coal;
6. Gray marine shale with pyritic nodules;
7. Impure lenticular fine grained marine limestone;
8. Black laminated shale with limestone concretions or layers;

9. Clean marine limestone;

10. Marine shale with limestone concretions.

The lower part of this sequence is normally freshwater sedimentation, and the upper part was deposited in marine anerobic conditions. A supply of oxygen was lacking in this environment, and the carbon from the organic material was thus preserved. When the concentration of organic material was adequate, coals were formed. Elsewhere, the carbon imparts a black coloration to most of the rock sequence. Such a chemically reducing environment was also ideal for the precipitation of iron sulfide as pyrite or marcasite, which when exposed at the surface during the process of mining for coal, decomposes and contributes to producing acid soil and water conditions.

## 3.2 Surface Coal Mining

Strip mining for coal is more economical than underground mining when the coal bed(s) lie near the surface. Several factors influence to what depth it is practical to strip; however, the production cost and selling price of coal usually determine what is economical to mine by stripping methods. For many years, a general rule-of-thumb in the Midwest was that six meters (20 feet) of overburden could be removed for every foot of coal seam. Today's technology permits stripping to depths greater than 30 meters (100 feet) if the quantity of coal justifies it.

Much of the coal in the United States lies in relatively undeformed strata and the coal seams are roughly parallel to the general land surface. If the terrain is relatively flat and poorly dissected, surface mines can extend continuously over large areas. In such environments, as is much of the Midwest, the stripping is referred to as "area mining." In the highly dissected environment of much of the Appalachian Plateau where slopes are commonly greater than 15°, the stripping operations normally follow the coal seam around the contour of the land. Such mines are narrow and sinuous, and are referred to as "contour mines."

Originally, nearly all the surface mining in western Pennsylvania was contour mining, but with the development of larger and more efficient equipment, current operations may be considered as a combination of contour and area mining.

In normal mining operations, after the vegetative cover has been removed and the overburden has been "shot" or blasted adequately to fracture the strata, a drag line removes the loosened material to expose the coal, as shown in Figure 3. A drag line differs from a shovel in that a drag line has the earth-moving bucket on a cable rather than on a solid beam. The drag line, equipped with a large boom which may be as much as 90 meters (300 feet) long, remains on the original ground surface and opens a trench down to the coal seam wide enough to permit shovels and large trucks to operate in the bottom to dig and remove the coal.

Once the overburden, often referred to as "spoil," has been removed, it is piled in a ridge on the side of the trench opposite the drag line. As the trench is widened to expose more coal, the mined-out portion is filled-in with the removed overburden.

Environmental problems, other than aesthetics, arise from erosion of the loosened rock material and decomposition products of

Figure 3. This aerial view of Clarion County, Pennsylvania illustrates a typical strip mining operation for coal. The drag line in the foreground removes the earth overlying the coal bed and piles it to one side of the open trench. The coal is loaded onto trucks by power shovels or, as in this photograph, by large front-loaders. Drilling in the center-background is for blasting to break and loosen the rock strata so that drag line can remove it. As that loosened rock is removed, it will be piled in the existing ing trench. Thus, the elongate trench and highwall will move to the left across the area. The rock material pile on the right will be leveled to the approximate original contour of the land. The top soil, which was removed and stock piled prior to mining, will be replaced after regrading. The land will then be revegetated as forest-grassland or developed as farmland.

minerals exposed at the surface (see Figures 4 and 5). Most of the strip mining legislation enacted by states and the federal government are directed at minimizing or eliminating these problems.

Figure 4. Past reclamation practices were not always successful. In this area, which was mined at least 15 years previously, the re-establishment of a suitable ground cover was only partially successful. The barren areas are continually being eroded, severely in some places as can be seen in Figure 5. The responsibility of the mine operator for proper reclamation has no doubt lapsed and the problem of rehabilitation of the land now lies with the state or federal government.

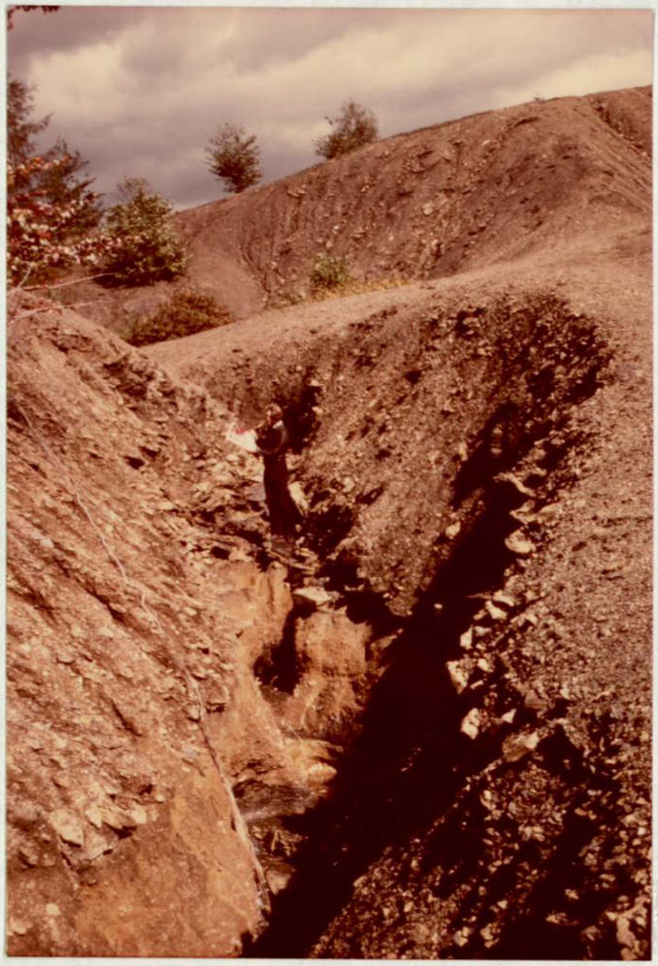


Figure 5. This gully eroding into old mine spoil lies just to the left of the area in Figure 4. Portions of the sediment from this area are being deposited on the adjacent farmland. However, the drainage from the major tributaries such as shown above soon enter the Clarion and Allegheny Rivers.

minimize erosion and the threat of siltation. The top soil must be preserved and re-used as much as possible. A detailed timetable and cost estimate must be included.

The operator must post a bond for the land affected as surety that provisions of the "Clean Streams Law" will be met and that the reclamation will be performed. The size of the bond, which has recently been raised from $500 to $1,000 per acre, is held during the period of mining operations and for five years thereafter, unless released sooner.

The enforcement of the laws is the responsibility of field inspectors assigned to Mined Land and Water Conservation Districts.

## 4.2 Field Inspector Function

The duties of the field inspectors are varied. They are responsible for enforcing proper safety equipment and procedures which are used on the mine sites. They must monitor the operator mining and reclamation procedures for adherence to the plan approved at the issuance of the mining permit. They inspect for stream pollution and determine if the sediment ponds and water treatment facilities are adequate. They monitor backfill procedures and graded lands for proper contour. They inspect topsoil stock piles to insure that they are properly protected from erosion. Finally, they determine if reclamation has been adequate for release of bond.

The inspectors advise mine operators on proper procedures and encourage them to conduct their mining activities within the framework of the current regulations. Citations may be written and an examiner may assess large fines; however, the inspectors attempt to assist the operator in correcting infractions promptly without resorting to legal procedures.

### 4.3 Federal Surface Coal Mining Laws

Existing federal laws are similar in scope and nature to those of the State of Pennsylvania, but apply only to mining on federally-owned lands.

New mining legislation presently being considered by Congress shows much similarity to the Pennsylvania regulations, but is more comprehensive and is designed with flexibility so it can be applied in all areas of the country.

The House Bill, H.R.2, and the Senate Bill, S.7., are similar. The bills establish a program of federal and state cooperation to regulate coal strip mining and reclamation. They recognize the state's primary responsibility to regulate surface mining, but set federal standards for state programs and provide a strong federal back-up for enforcement. Under the bills, the Interior Department will be responsible for approval of state regulatory programs which must meet or exceed the federal standards, provide grants to the states for development of their programs, administer a federal program for the reclamation of abandoned mines, and take primary responsibility for regulating strip mining on federal lands.

The bills outline in considerable detail the standards for strip mining operations designed to reduce environmental damage. They provide for the protection of the rights of surface owners as well as farmers and ranchers whose interests, such as water rights, may be affected by the mining operations. They allow for public input through hearings on prospective mining and reclamation operations. The bills also allow the states or the federal government to designate lands that are unsuitable for strip mining.

A review of the House Bill, H.R.2, reveals several areas where remote sensing, either with satellite data and/or aerial photography, can be of utility. Only those portions of the bill are summarized (Mikva, 1977).

Title IV of the House Bill establishes an Abandoned Mine Reclamation Fund to finance the reclamation of abandoned strip mine lands. Money for the fund would be derived primarily from fees set at the rate of 35¢ per ton for the surface mine coal and 15¢ per ton of deep mine coal. A special fee of 5% of the value of the coal or 35¢ per ton, whichever is less, is set for lignite or brown coal.

Section 404 of Title IV dictates that each state may submit an abandoned mine reclamation program to the Secretary, showing a schedule of projects to be undertaken and criteria for ranking them in priority. Once a state program has been approved, projects may be submitted on an annual basis for funding. The federal share of each project cost cannot exceed 90%.

Under Section 406, the Secretary of Interior is required to make a thorough study of potential reclamation sites, select lands for purchase according to certain priorities, and prepare a cost benefit analysis for each project.

Section 507 states that mine operators must submit the following information as part of the required mining and reclamation plans:

- Identification of all corporations and officials involved;
- Historical information regarding the applicant;
- A demonstration of compliance with public notice requirements;
- Maps of the proposed mining area;
- Description of the mining methods;
- Listing of past mining permits;

- Schedules and methods for compliance with environmental standards;

- Full description of the hydrologic consequences of mining and reclamation;

- Results of test boring;

- A soil survey if the mine will be located on "prime agricultural land;"

- Complete reclamation schedule;

- A complete blasting schedule.

Under Section 510 of the law, specified findings are required demonstrating that the operation will not interrupt, discontinue, or prevent farming on alluvial valley floors where land is naturally sub-irrigated by groundwater, nor damage the water systems that supply the floors.

Section 515 contains the specific performance standards required for surface coal mine operations. The major performance standards in which remote sensing can be of utility are as follows:

- The operator is required to return the site to its approximate original contour; highwalls are to be eliminated. Regraded slope must be shaped to assure stability and minimize erosion.

- The operator must preserve and re-use the top soil taken from the mine site, protecting it from erosion and contamination. In areas of prime agricultural land, the operator must provide in the final regraded surface, a soil root zone of comparable depth and quality to that which existed in the natural soil.

- The operator must revegetate with a cover native to the area, and must assume responsibility for revegetation for five years after the last seeding or planting. An exception is provided for areas of annual precipitation of less than 26 inches; in these cases, an operator's period of responsibility is ten years.

- The operator is required to minimize disturbance to the hydrologic balance, and to the quality and quantity of surface underground water systems by avoiding acid and toxic mine drainage, preventing suspended solids from entering the stream flow, cleaning out and removing temporary settling and siltation ponds, and preserving hydrologic functions of alluvial valley floors in arid areas of the country.

- Water impoundments are allowed as a part of reclamation if they meet set standards including government safety standards, and if the embankments are graded so as to provide safe access for water users.

- The operator may mine the top of a mountain without being required to regrade it to its original contour, and may leave a plateau or rolling slope with no high walls.

- Mining on steep slopes (any slope above 20%) is subject to strict standards including the prohibition against placing spoil (even from the first cut) on the down slope below the bench, and a requirement that any high walls be back-filled.

Section 517 establishes that inspections on each surface mining operation are to be carried out no less than once a month and must be done without notice to the operator. This section also places tight restrictions on the financial interests any regulatory authority the employee may have in coal operations.

Under Section 522, states are required to establish plans to designate lands where reclamation is not economically or physically feasible as unsuitable for strip mining. Other areas may be so designated if:

1. Strip mining would be incompatible with government objectives;

2. The lands are fragile or historic;

3. The site is a natural hazard area where development could endanger life or property;

4. The area contains renewable resources where development would result in a loss of long-range productive capacity.

In addition, no strip mining operation will be permitted in the National Park System, the National Wilderness System, the Wild and Scenic River System, or Custer National Forest. Strip mining operations will also be prohibited if they will damage lands and water used by the public, or are within 400 feet of a public road or within 300 feet of an occupied building.

Title VI establishes that federal lands may be declared unsuitable for mining of minerals other than coal if the lands are:

1. Predominantly urban or suburban;

2. Used for residential purposes;

3. Located where mining would damage cultural, scientific, or esthetic values or endanger human life or property.

No land may be so designated if mining operations exist at the time of enactment of this bill.

## 5.0 IMAGERY ACQUISITION, PROCESSING, AND ANALYSIS

Although three test sites were tentatively selected for investigation, southern Clarion County, an area of intensive surface coal mining activity, was selected as the prime site for this study (see Figure 1).

### 5.1 Remote Sensor Program Support

Remote sensor data support to the program was provided by NASA in the form of Landsat film and computer compatible tapes and small scale aerial color and color infrared photography.

Aerial photographic support was provided by Ames Research Center, Moffett Field, California. 1:120,000 scale color photography and 1:60,000 scale color infrared photography was acquired from the U-2 platform on 11 April 1975, 23 October 1975, and 19 July 1976. The quality of this photography ranged from fair to good, and was an invaluable aid to the project.

Landsat-1 (formerly known as ERTS, or the Earth Resources Technology Satellite) launched in July of 1972 was joined by a second satellite, Landsat-2, in January of 1975. Both satellites operated at an altitude of approximately 960 kilometers and acquire four simultaneous images of the Earth's surface with a multispectral scanner system (MSS). Each of the satellites passes over a particular point on the Earth's surface every 18 days. The orbits were established such that Landsat-2 passed over a particular point nine days after Landsat-1. Thus, the two satellites provide repetitive coverage of a given point about six times every two months. Each frame of imagery is 100 nm wide and 97 nm long, with a resolution of approximately 80 meters depending upon the contrast of an object and its surroundings. A mirror oscillating perpendicular to the spacecraft's orbital path scans the Earth and the image is formed six scan lines at a time. Data is acquired in four spectral bands; two in the infrared and two in the visible image. These bands are designated by numbers 4, 5, 6, and 7, and scan the approximate spectral ranges of 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 μm.

### 5.2 Aerial Photography

Photographic coverage of portions of western Pennsylvania were acquired with the NASA U-2 aircraft in support of this program. Three flights were made as follows:

Flight No. 75-037B on 11 April 1975

Flight No. 75-183 on 23 October 1975

Flight No. 76-108 on 19 July 1976

Color and color infrared photography acquired at approximate scales of 1:125,000 and 1:60,000 respectively, were used as supplemental "ground truth" in conjunction with field investigations. The color infrared photography was particularly useful as compared to color film, not only from the point-of-view of larger scale and better resolution, but from better scene contrast and vegetational enhancement.

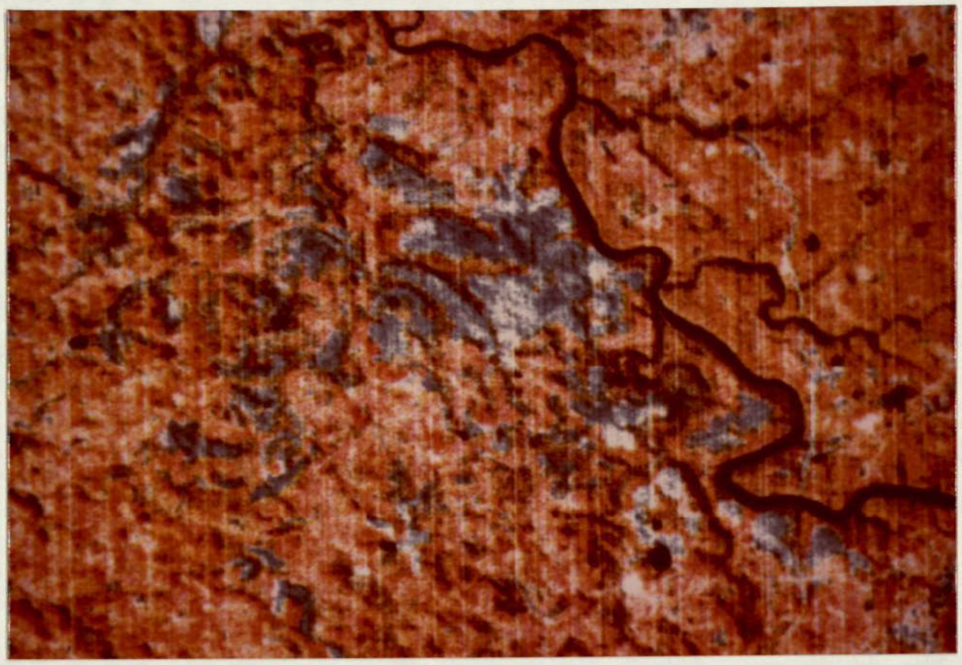
### 5.3 Landsat Imagery

The initial evaluation of the Landsat imagery was made on black-and-white enlargements and color composites of bands 5 (0.6-0.7μm) and 7 (0.8-1.1μm) prepared from 70mm film products. A number of color combinations were tested for interpretability, and imagery which portrayed surface mine lands in shades of red and tan, and vegetation in green was deemed the most interpretable (Figures 6A and 6B). Inequalities in Landsat system response degrades the quality of much of the imagery to the extent that scales larger than 1:125,000 are impractical. At a scale of 1:125,000 most mines were visible, but were too small for the manual extraction of data which could be used by the field inspectors.

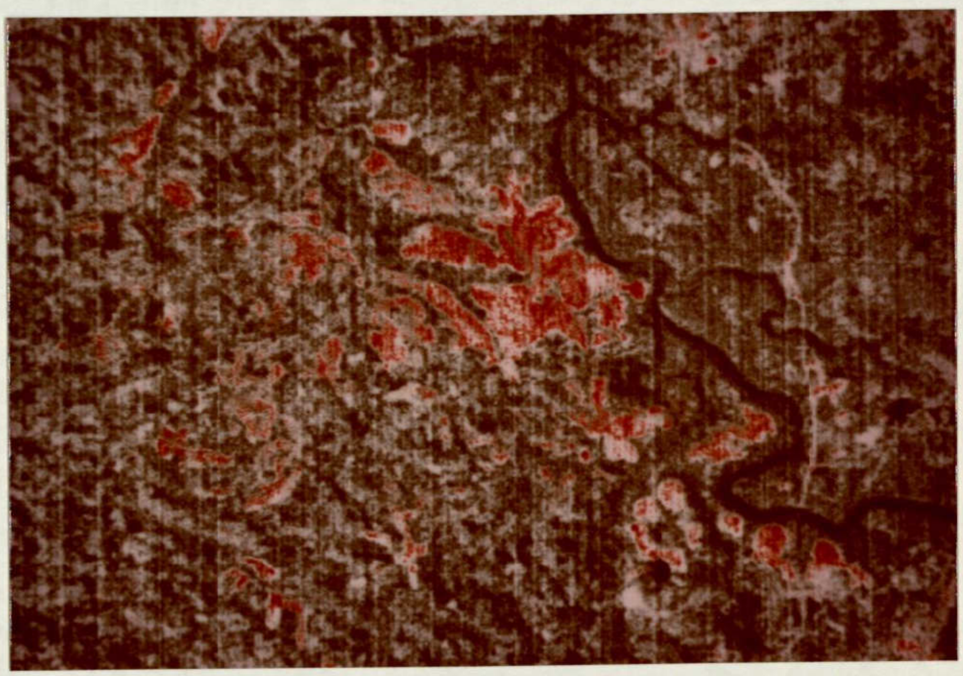
Although the potential exists for available Landsat imagery every nine days, atmospheric conditions adversely affect the quality of imagery produced. Western Pennsylvania receives about 40 inches of rainfall per year. This weather is accompanied by extensive cloudy and hazy periods, resulting in much poor quality or unusable imagery. Figure 7 is a graph showing the percentage of cloud cover for imagery of the Clarion County, Pennsylvania area over a two-year period. Only five frames were cloud-free. Although weather conditions vary from year-to-year, the probability is small for acquiring adequate Landsat imagery for a monitoring program based on an update interval of less than one year.

## 5.4 Computer Processing

The objective for computer processing the Landsat data was to increase the usable scale and improve the interpretability of the imagery. Processing Landsat digital data directly from computer compatible tapes (CCT's) provides two major advantages in evaluating surface mines which cannot be realized by photographic processes. First, the digital data provides a means for direct



**A**



**B**

Figure 6. Two-band color composite images of Landsat frame no. 5072-10571 (30 June 1975) prepared from 70mm film negatives furnished by the EROS Data Center. Different color combinations were tested to determine which was best for manual interpretation of surface mined lands. The decision of the analysts was that mines portrayed in reddish tones on the green vegetational background, Figure B, was superior to other combinations tested.

quantification of surface mines using computer technology. Additionally, digital data can be manipulated by the computer to provide enhanced data to produce photographically processed images for refined interpretations of the surface mined areas.

Although automatic classification of Landsat data is attractive because of the potential time and cost saving, and some effort was expended with this objective, the major direction of this investigation toward production of imagery which would improve the results of a manual interpretation of surface coal mines. The processing steps performed for the surface mine investigations were:

1. Scan line removal;
2. Geometric rectification;
3. Analysis;
4. Enhancement processes;
5. Enlargements.

5.4.1 Scan Line Suppression

A major source of recurring noise seen in much Landsat imagery consists of a noise effect seen as a sixth line banding, which results from a difference in sensor gain and offset voltage. This is evident in Figures 6A and 6B. Since the Landsat scanner simultaneously acquires six lines of data from six detectors in each scan, the imbalance is seen as a six-line phenomena. This effect produces a striped image which is difficult to interpret, particularly when the area to be analyzed is spatially small. This effect also "confuses" classification techniques. Computer processing to remove the majority of this effect was performed by the computer program SCANLINE*.

### 5.4.2 Geometric Rectification

Landsat digital imagery contains several inherent geometric distortions. The two major distortions affecting interpretation are: skew introduced by Earth rotation, and spot size difference between the along-scan direction (57 meters) and the across-scan direction (79 meters).

Correction of these geometric distortions is performed by the computer program GEOMTRY. GEOMTRY utilizes the LANDSAT heading and altitude information to calculate a line-dependent correction for skew and scale. Correction of skew is accomplished by a calculated line offset and correction of scale by insertion of averaged lines when necessary. After this process, images produced from the resulting data are a close approximation of ancillary data sources, such as quadrangle maps or rectified aerial photography. The scanline-free geometrically corrected image provided the base image for the interpretive analysis.

### 5.4.3 Data Analysis By Computer

Delineations of the surface mines produced by the applications scientists, supported with the appropriate ground truth, were the basis for computer data analysis. The digital

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* A proprietary program developed by Earth Satellite Corporation.

data were initially displayed as "shade prints" (Figure 8) or as actual numeric reflectance values (Figure 9). Examination of these displays over a small area (test site) provides insight into the digital data character of the surface mines. Histograms (Figure 10) of the reflectance values of the areas disturbed by mining allow an examination of the mines to be made within the context of the scene from which the data is displayed.

The primary test site was shade printed in band 5 and count values displayed for the four MSS bands. The histograms of typical surface mines were produced and examined, and their reflectance response evaluated manually. Results of the manual examination showed the surface mines exhibit a high intensity response in bands 4, 5, and 6, and tended to be of relatively low intensity in band 7 (Table 1).

Table 1 - Manual Evaluation of the Reflectance of Surface Coal Mines Using Numeric Prints (Landsat Frame 2169-15242)

| MSS Bands | 4 | 5 | 6 | 7 |
|---|---|---|---|---|
| Minimum Gray Value | 22 | 17 | 43 | 0 |
| Maximum Gray Value | 127 | 127 | 127 | 26 |

An unsupervised cluster analysis (CLUSTER program) was used to produce a multi-classed classification not influenced by interpretive bias. Two broad classes designated 4 and 6 (Table 2) were produced which were readily identifiable as surface mines and which exhibited spectral signatures similar to those previously selected from the multi-band analysis.

Figure 8. Producing computer shade prints is a rapid imaging method for preliminary assessment of data. In this shade print of MSS band 5 of Landsat frame no. 2169-15242, the surface mines in the primary test site are readily identifiable. Tonal differences within the mined area result from different stages of mining, grading, and revegetation.

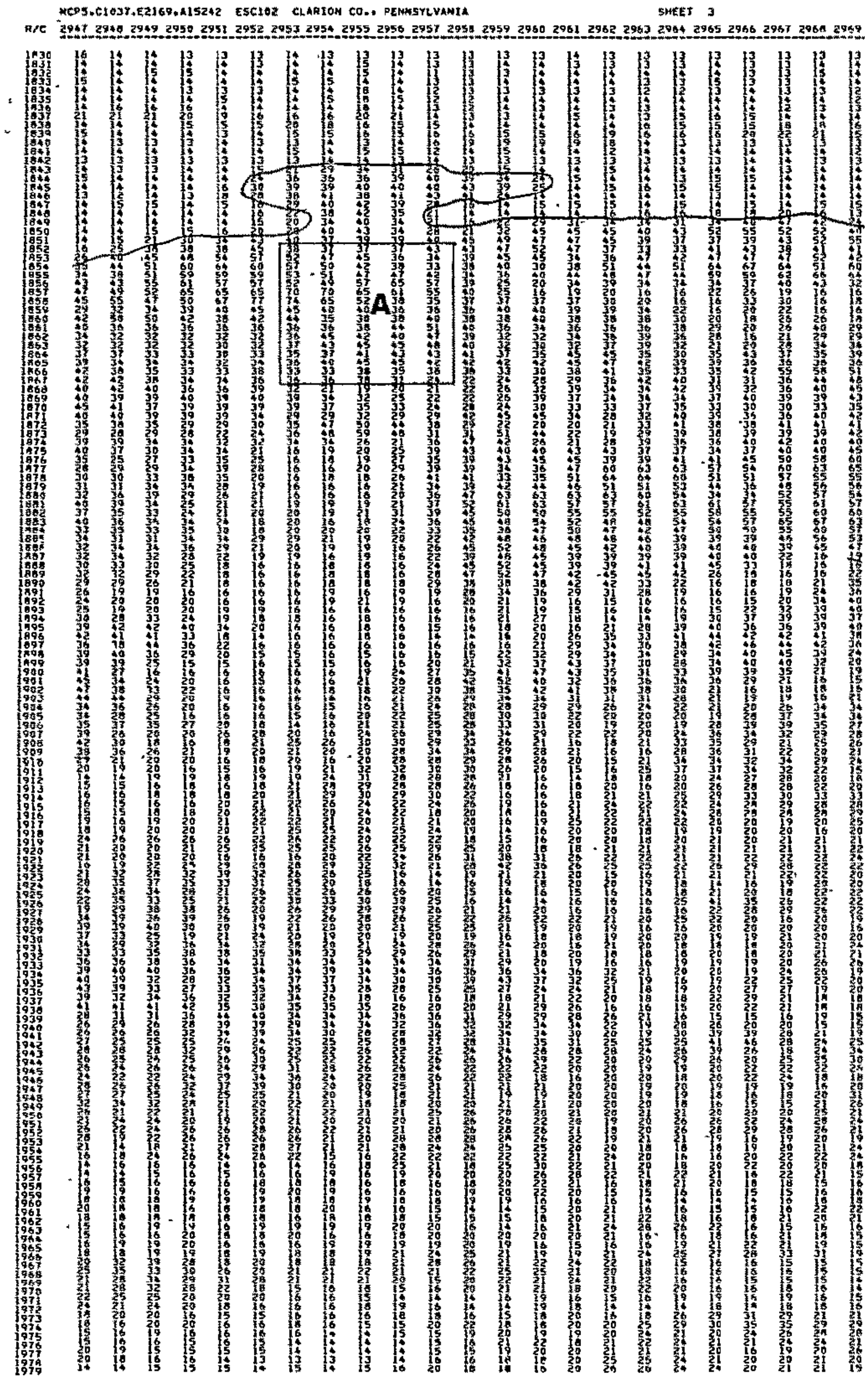
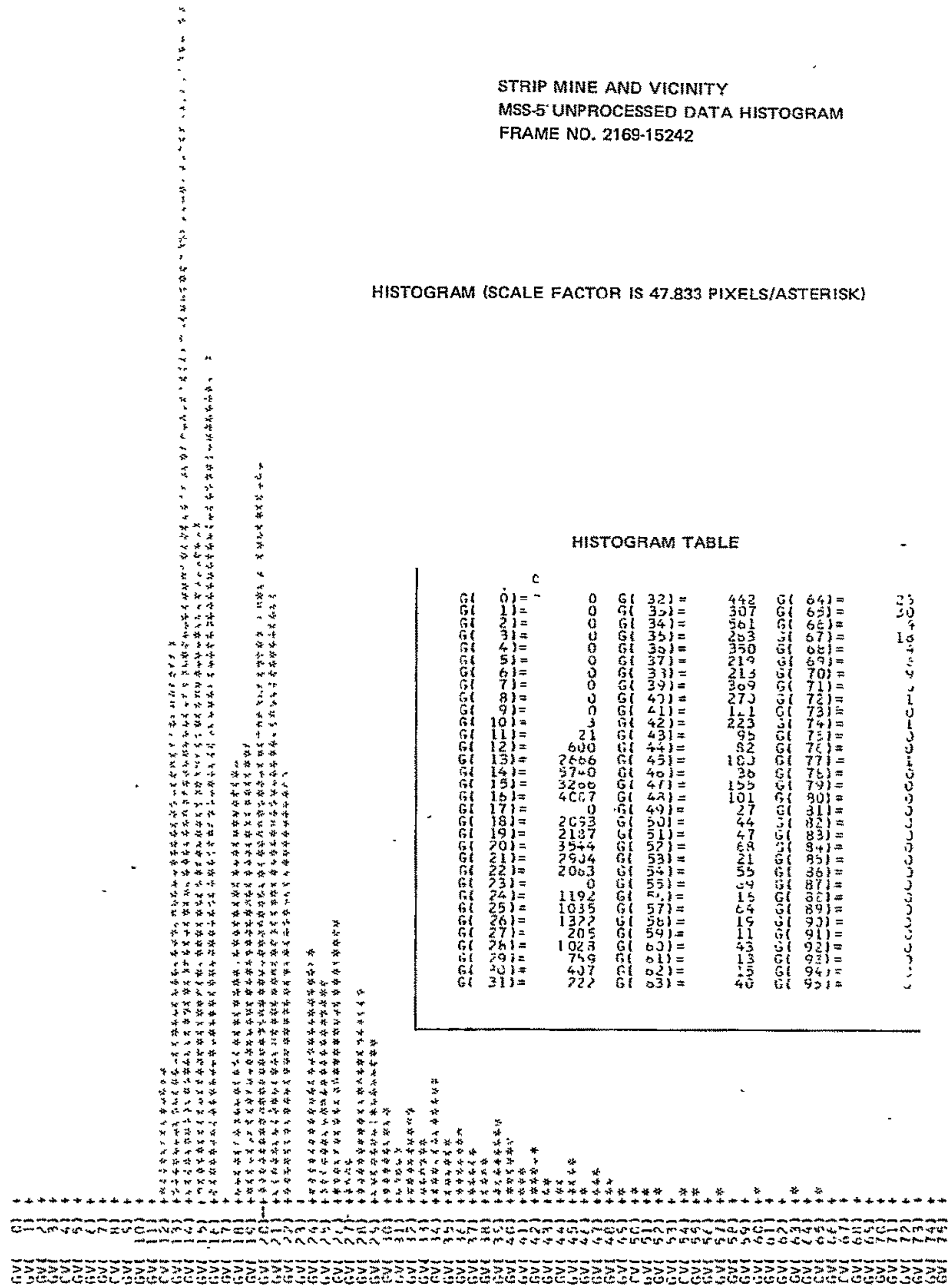



Figure 9. Area A of this numeric print of pixel values from MSS band 5 of Landsat frame no. 2169-15242 was chosen for manual evaluation of surface mined land reflectances. The four-band evaluation is shown in Table 1.



STRIP MINE AND VICINITY
MSS-5 UNPROCESSED DATA HISTOGRAM
FRAME NO. 2169-15242

HISTOGRAM (SCALE FACTOR IS 47.833 PIXELS/ASTERISK)

HISTOGRAM TABLE

| | | | | | |
|---|---|---|---|---|---|
| G( 0)= | 0 | G( 32)= | 442 | G( 64)= | 23 |
| G( 1)= | 0 | G( 33)= | 307 | G( 65)= | 30 |
| G( 2)= | 0 | G( 34)= | 561 | G( 66)= | 4 |
| G( 3)= | 0 | G( 35)= | 263 | G( 67)= | 16 |
| G( 4)= | 0 | G( 36)= | 350 | G( 68)= | 4 |
| G( 5)= | 0 | G( 37)= | 219 | G( 69)= | 4 |
| G( 6)= | 0 | G( 38)= | 213 | G( 70)= | 4 |
| G( 7)= | 0 | G( 39)= | 309 | G( 71)= | 0 |
| G( 8)= | 0 | G( 40)= | 270 | G( 72)= | 1 |
| G( 9)= | 0 | G( 41)= | 111 | G( 73)= | 0 |
| G( 10)= | 3 | G( 42)= | 223 | G( 74)= | 1 |
| G( 11)= | 21 | G( 43)= | 95 | G( 75)= | 0 |
| G( 12)= | 600 | G( 44)= | 82 | G( 76)= | 0 |
| G( 13)= | 2666 | G( 45)= | 100 | G( 77)= | 0 |
| G( 14)= | 5740 | G( 46)= | 36 | G( 78)= | 0 |
| G( 15)= | 3266 | G( 47)= | 155 | G( 79)= | 0 |
| G( 16)= | 4007 | G( 48)= | 101 | G( 80)= | 0 |
| G( 17)= | 0 | G( 49)= | 27 | G( 81)= | 0 |
| G( 18)= | 2053 | G( 50)= | 44 | G( 82)= | 0 |
| G( 19)= | 2187 | G( 51)= | 47 | G( 83)= | 0 |
| G( 20)= | 3544 | G( 52)= | 68 | G( 84)= | 0 |
| G( 21)= | 2904 | G( 53)= | 21 | G( 85)= | 0 |
| G( 22)= | 2063 | G( 54)= | 55 | G( 86)= | 0 |
| G( 23)= | 0 | G( 55)= | 34 | G( 87)= | 0 |
| G( 24)= | 1192 | G( 56)= | 15 | G( 88)= | 0 |
| G( 25)= | 1035 | G( 57)= | 64 | G( 89)= | 0 |
| G( 26)= | 1372 | G( 58)= | 19 | G( 90)= | 0 |
| G( 27)= | 205 | G( 59)= | 11 | G( 91)= | 0 |
| G( 28)= | 1023 | G( 60)= | 43 | G( 92)= | 0 |
| G( 29)= | 759 | G( 61)= | 13 | G( 93)= | 0 |
| G( 30)= | 407 | G( 62)= | 15 | G( 94)= | 0 |
| G( 31)= | 722 | G( 63)= | 40 | G( 95)= | 0 |

Figure 10. Typical histogram of the MSS band 5 response of the test site. Note the peaks at gray values 34 and 39 which are associated with the reflectance characteristics of coal strip mines.

TABLE 2 - MEANS AND STANDARD DEVIATIONS FOR EACH CLASS AND SPECTRAL BAND AS DETERMINED BY THE CLUSTER PROGRAM

MEANS

| | Band 4 | Band 5 | Band 6 | Band 7 |
|---|---|---|---|---|
| Class 1 | 17.849 | 15.554 | 55.751 | 30.772 |
| Class 2 | 23.328 | 24.256 | 54.545 | 26.616 |
| Class 3 | 19.469 | 18.132 | 43.864 | 21.807 |
| Class 4 | 37.119 | 52.348 | 62.468 | 24.323 |
| Class 5 | 20.456 | 18.552 | 64.041 | 34.612 |
| Class 6 | 28.825 | 34.689 | 44.284 | 17.029 |

STANDARD DEVIATIONS

| | Band 4 | Band 5 | Band 6 | Band 7 |
|---|---|---|---|---|
| Class 1 | 1.427 | 1.984 | 3.029 | 2.369 |
| Class 2 | 1.957 | 3.788 | 3.436 | 2.467 |
| Class 3 | 2.544 | 3.717 | 6.080 | 4.336 |
| Class 4 | 3.407 | 7.898 | 6.834 | 3.143 |
| Class 5 | 2.128 | 2.783 | 3.451 | 2.488 |
| Class 6 | 2.643 | 4.801 | 5.394 | 3.169 |

The total area affected by surface mining is well portrayed as shown in Figure 11, but detail within the disturbed area is not accurately portrayed by the two classes. Compare Figure 11 with Figures 20, 21, and 22. However, the selection by CLUSTER of these two classes was encouraging evidence that enhancement through automated techniques is possible.

5.4.4 Data Enhancement

The above data analysis guided the processing of the Landsat digital data to enhance the detail within the surface mined areas, with resultant relatively low contrast in the remainder of the scene. Three primary computer techniques were selected: multi-band supervised linear stretch, ratioed images, and maximum likelihood images.

Figure 12 shows the imaged results of computer processing with supervised linear stretch on two bands of data (5 and 7) which were photographically combined to produce a false color composite. This technique maximizes the gray levels available for surface mines in each MSS band before display on the film recorder. These data are combined photographically into a false color composite, then interpreted by the imagery analysts.

5.4.5 Pseudo-Ratios

Two-band combinations of these data were displayed in a single image with the program RATIO. This program does not produce a true ratio, but a result which is obtained from

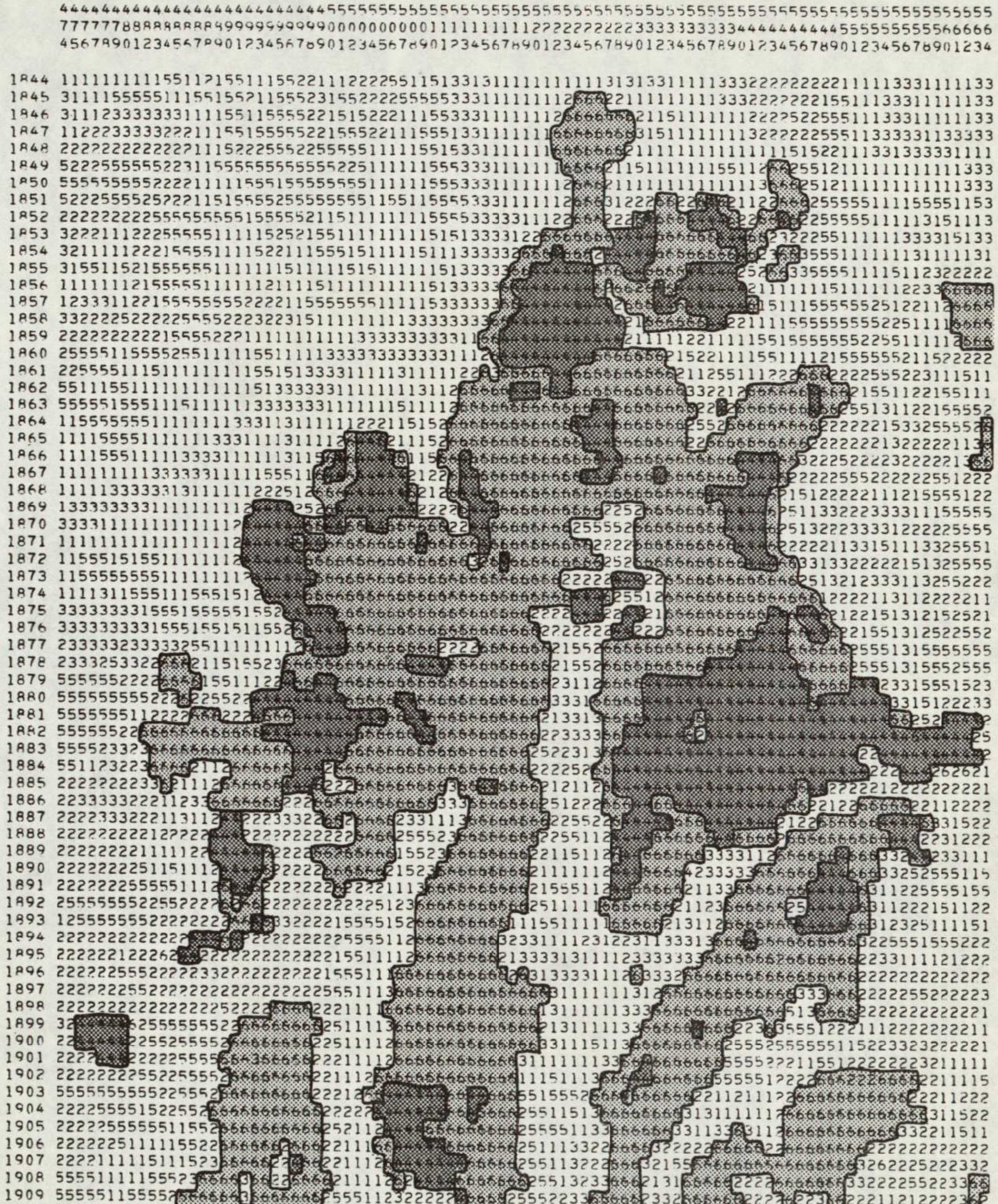


Figure 11. This assignment map represents an unsupervised cluster analysis classification of the surface mined lands and test area of southern Clarion County. Classes 4 and 6 effectively outline the majority of the lands affected by surface mining. Compare this illustration with Figures 20 and 21.

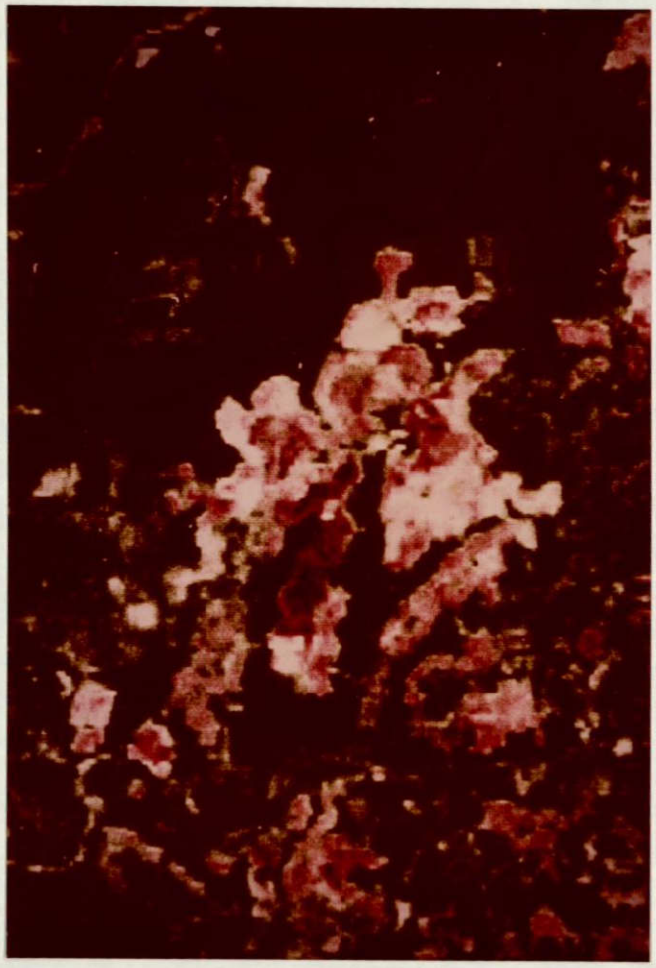


Figure 12. Color composites of computer enhanced Landsat data (MSS bands 5 and 7 of frame no. 2169-15242) has maximized the tonal detail within the mined area. Darker red areas are newly mined. The lighter areas have been fertilized and reseeded. The greenish areas indicate degrees of revegetation; the darker the green color, the more dense the vegetation. The general background of dark green indicates undisturbed land or completely revegetated mined lands.

processing the two-dimensional data matrix (Figure 13) and constructing a look-up matrix which is data dependent. This technique transforms the ratio data into an output range of 0-255 counts for display on a film recorder.

5.4.6 Maximum Likelihood

Although the emphasis in this investigation was on manual interpretation, a maximum likelihood subroutine of EarthSat's ratio program was tested on the mined land data. This subroutine was designed to calculate output gray values as a function of:

1. Input gray values G1 and G2 from two MSS bands; and
2. Class statistics from CLUSTER analysis.

The success of this procedure was limited and no thorough investigation was made of alternate means of calculation or of possible adjustments to the probability algorithm. The principal problems encountered on the final photographic products generated by the maximum likelihood (MLH) ratio routine involve upper class confusion, errors of commission, and an overall salt-and-pepper image quality which did not highlight satisfactorily the active surface mined areas.

In its present configuration, the MLH algorithm is dependent on the statistical inputs generated by the CLUSTER program. Spectral classes delimited during the clustering procedure (Figure 14) and their associated means standard deviations, variances, and co-variances were used in the calculation of parameters for probability functions in the MLH

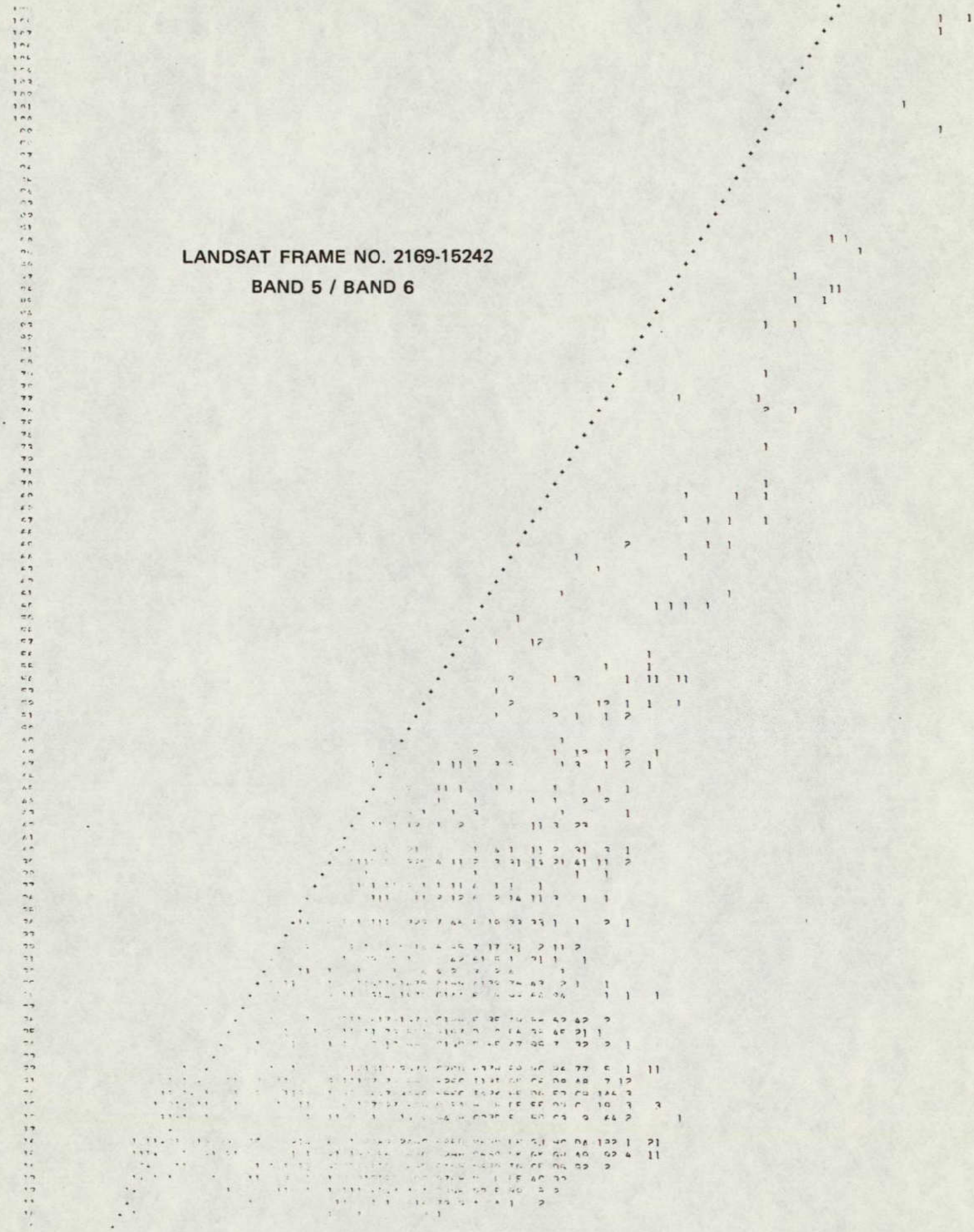



Figure 13. Two-band (MSS-5/MSS-6) histograms were processed to produce a look-up matrix table. Subsequent processing with maximum likelihood identified a subset (Figure 15) of this matrix which has the highest probability of representing strip mines.

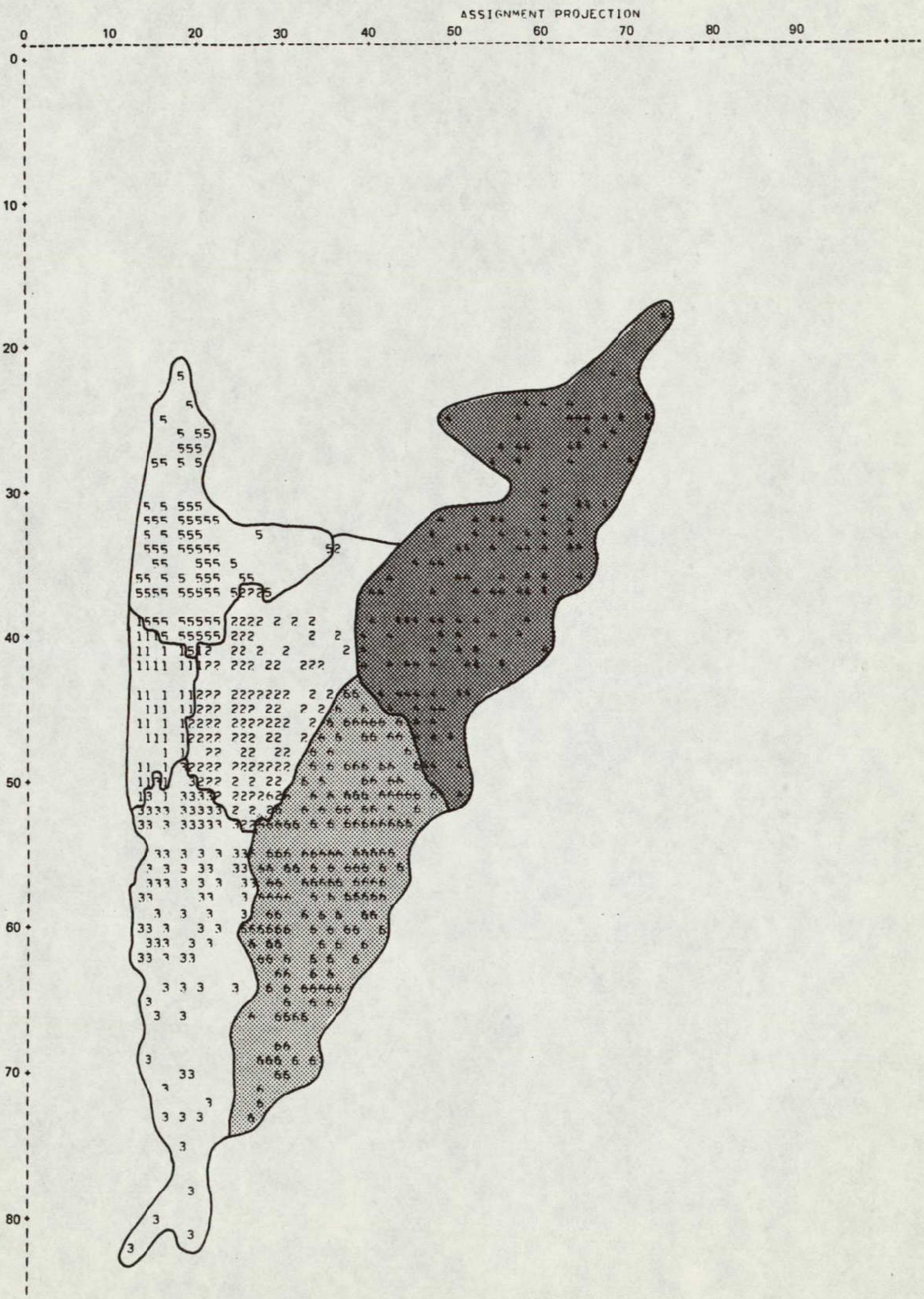



Figure 14. Histogram plot of the spectral classes delimited by the clustering program, showing generally good spatial grouping indicating valid classes.

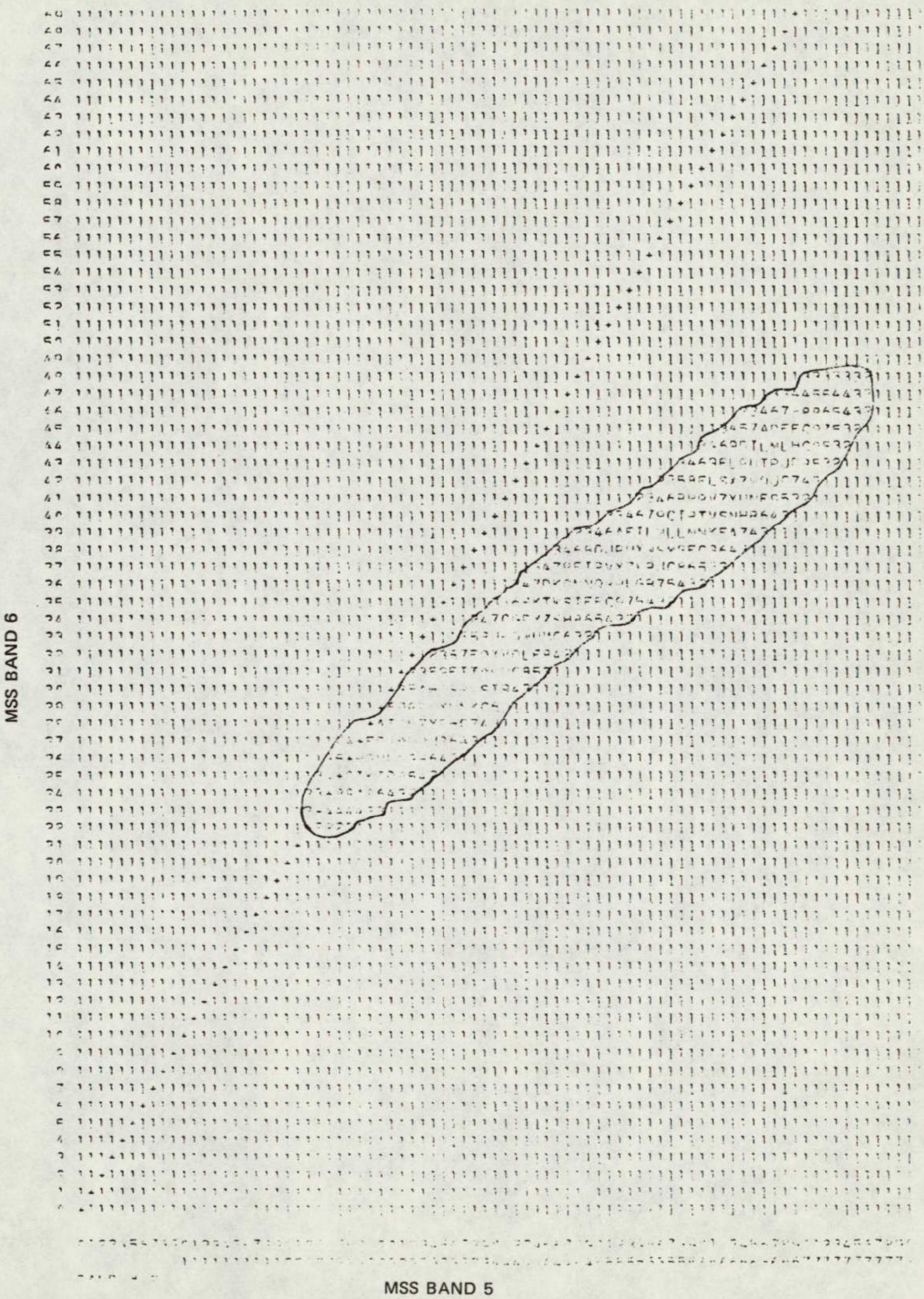
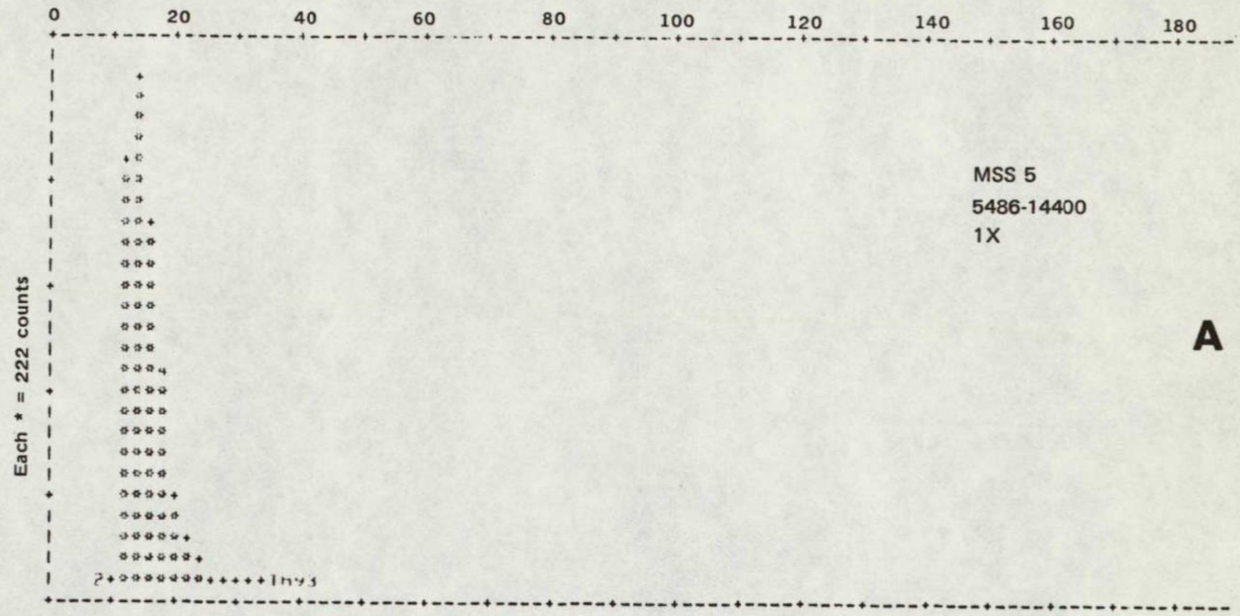



Figure 15. Two-space (MSS bands 5 and 6) surface mine reflectance distribution plot derived using class statistics extracted by CLUSTER and produced by a maximum likelihood algorithm. Each "non-1" data point represents a band combination which is displayed in the resulting image.



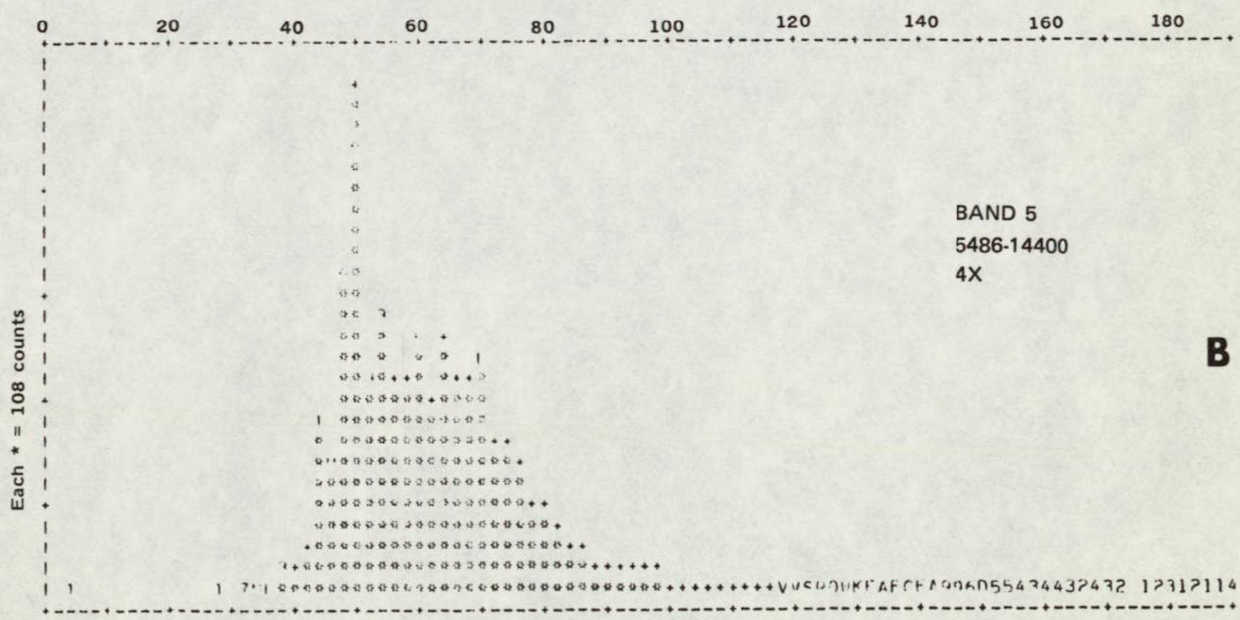




Figure 16. Figure A is a histogram of the data distribution and reflectance information pertaining to mined lands prior to image enlargement. Figure B is the histogram after processing to a 4X digital enlargement. Both histograms represent the data before the "gray-scale stretch" has been applied for maximum enhancement of the surface mined lands.

## 5.5 Imagery Interpretation and Analysis

The initial analysis of the surface mined land in the test area was from 1:125,000 scale CIR aerial photography. A map showing the aerial extent and distribution of mined land was prepared at a scale of 1:62,500 and submitted to the Pennsylvania Department of Environmental Resources for evaluation. Figure 17 is a reduced scale version of this map. After evaluation, the State judged the map to be of no utility in the implementation of their mining legislation.

Emphasis was then given to larger scale, more detailed mapping from both aerial photography and Landsat imagery. Tests were initially conducted on 1975 Landsat scenes; but with the acquisition of good quality aerial photography on July 19, 1976 and cloud-free Landsat imagery only one month later on August 17, 1976 (frame #5486-14400) computer data processing was shifted to this scene. A series of processing techniques, as described in Section 5.4, were tested to produce useful imagery at a scale of 1:24,000.

The Landsat numeric data were manually evaluated to identify the spectral range within each band that was associated with strip mine areas. Once the spectral range was identified, these Landsat data were linearly stretched across the 255 gray values of the output device (OPTRONICS) to provide maximum tonal discrimination within the mined lands. Although black-and-white prints were made and interpreted, two color composites from MSS bands 5 and 7 provided substantially more information.

A problem in producing extreme enlargements of Landsat data is the deterioration of the photographic image quality. Figure 18 is

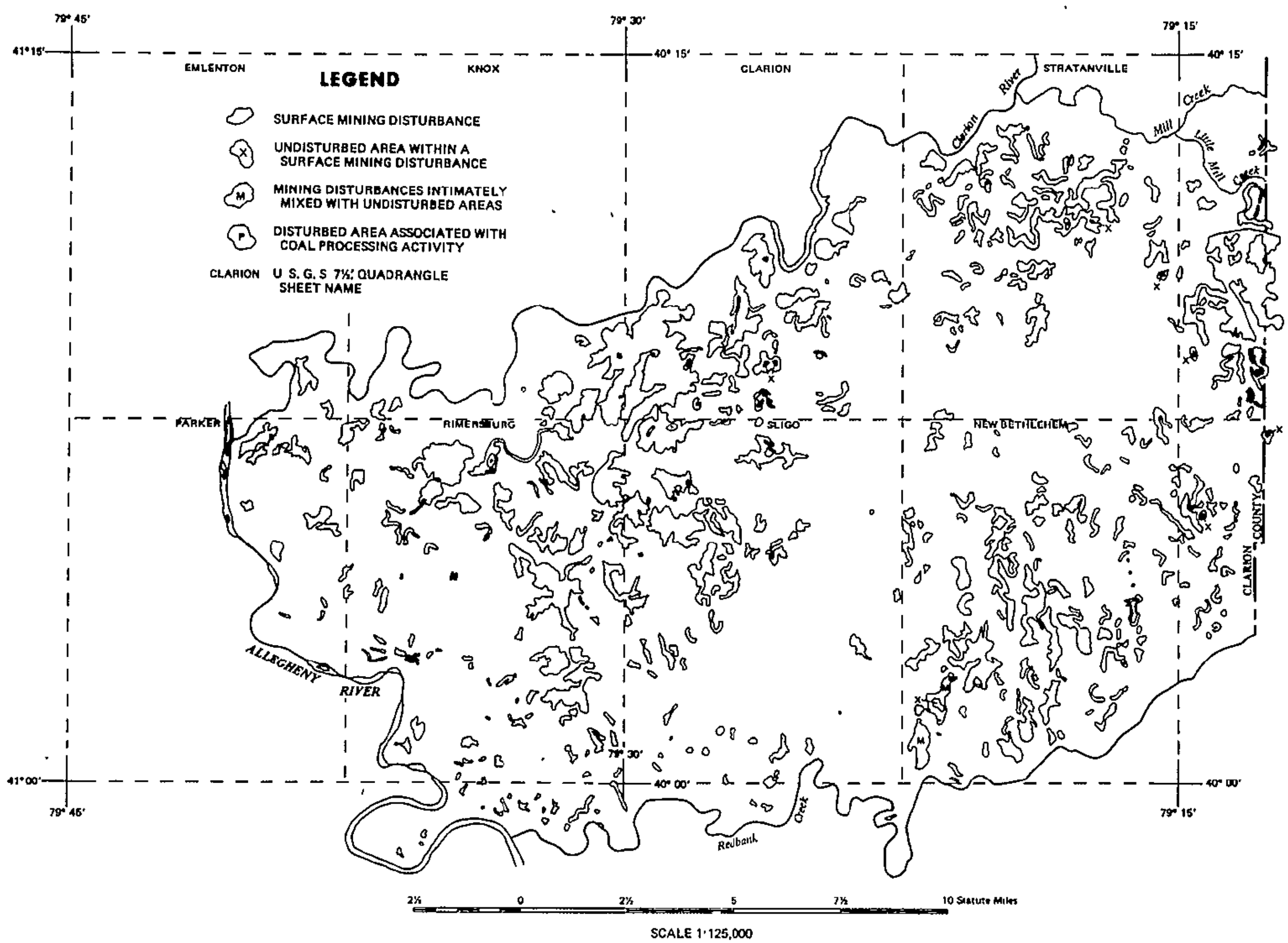



Figure 17. Surface mined land disturbance inventory of southern Clarion County, Pennsylvania prepared from the interpretation of 1:125,000 scale aerial photography flown by NASA-Ames Research Center on 22 February and 11 April, 1975. The original scale of the map was 1:62,500.

an example of such an image enlarged to 1:24,000 scale. Each pixel was originally reproduced on a film recorder with a 100μm spot size for a negative scale of approximately 1:550,000. This image required a 23x photographic enlargement to attain the desired scale. Although useful information is present, the blurred image introduces uncertainty in delineation of tonal boundaries. To improve image quality by reducing the photographic enlargement requirement, the computer enlargement algorithm discussed in Section 5.4.7 was used to produce a 2x computer enlargement. This reduced the photographic enlarging requirement to about 12.5x. The resulting image is shown in Figure 19 at a scale of approximately 1:31,000. Although a substantial improvement over Figure 18, this image is neither sharp nor esthetically pleasing.

The computer processing was incremented a step further to make a 4x digital enlargement, thus producing 16 pixel units for each original Landsat pixel. To produce a 1:24,000 scale image from this Landsat data, only a 6x photographic enlargement was required. The results were both valid and pictorially crisp as is illustrated in Figure 20.

The image interpretation and analysis of the Landsat imagery was "validated" by ground truth obtained by visits to the test site and by interpretation and analysis of the aerial photography. Figure 21 is an example of the 1:60,000 scale color infrared photography enlarged to 1:24,000.

To insure accuracy in measurements both area delineations and land classification, high-altitude (1:125,000 scale) color stereoscopic photography acquired by NASA on July 19, 1976, was used to

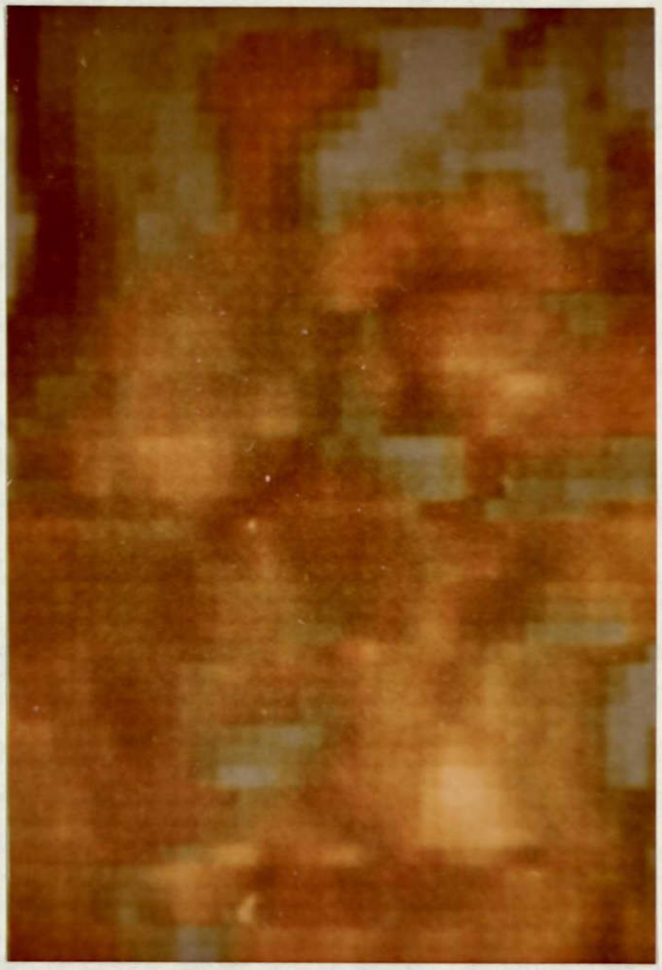


Figure 18. To produce this Landsat image (no. 5486-14400) at 1:24,000 scale, required a 23X photographic enlargement of the computer generated film image. Although considerable mined land detail is discernible, the image is generally unsatisfactory.

Figure 19. Computer enlargement by generating four new pixels for each original pixel has reduced the photographic enlargement requirement to 12.5X to produce a 1:24,000 scale image. Although the image provides much information concerning mined lands, attempts were made to improve image quality.

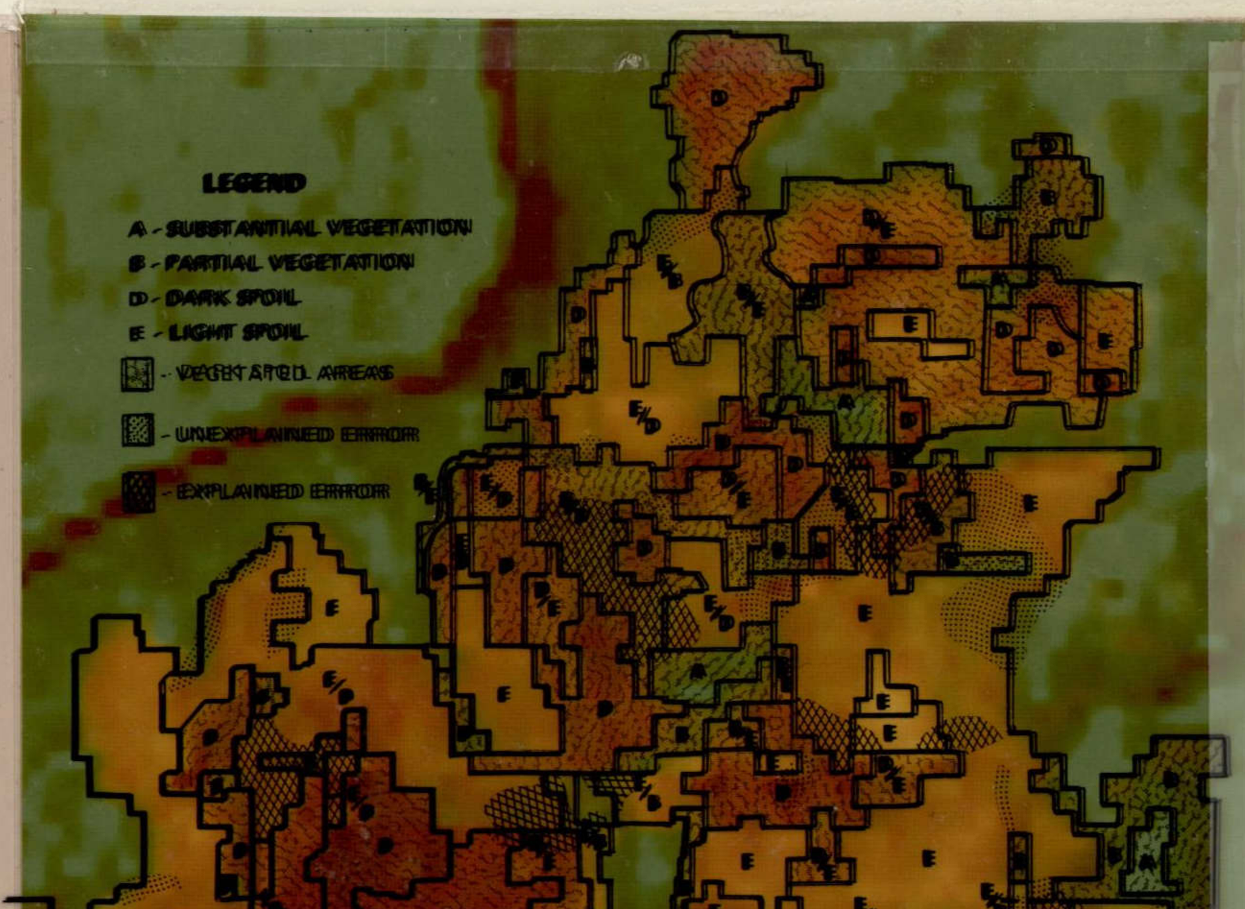



Figure 20. A 4X digitally enlarged, two-band (bands 5 and 7) color composite image of Landsat frame 5486-14400 enlarged to 1:24,000 scale.

OVERLAY A. Delineation of surface mined lands interpreted from Landsat imagery.

OVERLAY B. Vegetated areas interpreted from Landsat and compared with the air photo interpretation.

OVERLAY C. Dark spoil areas interpreted from Landsat imagery and compared with the air photo interpretation.


Figure 21. A high altitude, 1:24,000 scale color infrared aerial photograph of the study area.

OVERLAY A. Delineation of surface mined lands categories interpreted from aerial photography.

OVERLAY B. Delineation of surface mined lands from Landsat imagery.

anomalous color tones occurred in some portions of the mined area shown on Landsat that were later identified as active mining operations, haul roads, and reclamation practices. These activities were not uniform reflectances throughout the study area, so consequently could not be reliably categorized.

The color composite images were subdivided into five separate areas conforming to the subdivisions of the mined area on the aerial photograph and planimetered - separately and then as a total configuration. These measurements were compared to those taken from the aerial photograph and the differences were considered "Landsat error." The ratioed images were only planimetered as total mined area due to the lack of internal detail.

A regression and correlation analysis was performed on the results to determine whether the size of the disturbed area influenced the amount of error that occurred in the Landsat/aerial photograph comparison, and whether the amount of error was predictable. In this analysis, the size of the mined land (in hectares) was plotted on the X axis as the independent variable; the "Landsat error" (in hectares) was plotted on the Y axis as the dependent variable. It was supposed that the amount of error would decrease as the size of the mined area increased, yielding a reverse or negative correlation. It was also hoped that one method of computer enhancement would prove to yield superior accuracy.

However, the results of this analysis (Table 3) were inconclusive. The five subdivisions ranged in size from 141.7 hectares to 610.9 hectares. The regression coefficients were (-.03), (-.03), and (-.01) for the 1x, 2x, and 4x enlargements, respectively. The average percent errors for the three enlargements were 5.9%, 6.8%, and 5.6% for the 1x, 2x, and 4x enlargements.

TABLE 3

Results of Correlation - Regression Analysis

| LANDSAT Enlargement Process | Regression Coefficient | Standard Error (ha) | Average Error |
|---|---|---|---|
| 1x | (-.03) | 2.3 | 5.9% |
| 2x | (-.03) | 14.3 | 6.8% |
| 4x | (-.01) | 9.4 | 5.6% |

The results of the total disturbed area measurements yielded more positive results (Table 4). The 1x enlargement showed a 3.3% error; 2x showed .6%, 4x showed .2% and the 5/6 and 5/7 ratios showed .6% and 1.5% errors, respectively.

The 1x and 2x digital enlargements proved to be unsatisfactory for internal classification except for large homogeneous areas with uniform spectral reflectances. The 4x enlargement, however, was satisfactory for internal classification. Mined land detail that was not apparent on the other enlargements was easily discernible with the 4x enlargement.

Precise boundary line placement and interpretation from Landsat is not possible due to the resolution capabilities of the Landsat MSS which has an instantaneous field-of-view (IFOV) of an area 57 meters by 79 meters (about .5 ha). Individual pixel values will be an average of all the separate reflectances from the ground within the IFOV. Therefore, detailed and absolute line placement will rarely correspond exactly with what is seen from an aerial

TABLE 4 - RESULTS OF STATISTICAL ANALYSIS OF AREA DELINEATION

| Image Type | Mine #1 Area (ha) | Mine #1 Error (ha) | Mine #1 Percent Error | Mine #2 Area (ha) | Mine #2 Error (ha) | Mine #2 Percent Error | Mine #3 Area (ha) | Mine #3 Error (ha) | Mine #3 Percent Error |
|---|---|---|---|---|---|---|---|---|---|
| Aerial Photo | 141.7 | | | 506 | | | 610.9 | | |
| 1x Enlargement | 160.6 | 19 | 13.4 | 509.4 | 3.4 | .7 | 615 | 4.8 | .7 |
| 2x Enlargement | 144.6 | 3 | 2 | 466.2 | 89.8 | 7.9 | 611.2 | .3 | .1 |
| 4x Enlargement | 167.7 | 26 | 18.3 | 503.8 | 2.2 | .5 | 594.1 | 16.5 | 2.7 |

| Image Type | Mine #4 Area (ha) | Mine #4 Error (ha) | Mine #4 Percent Error | Mine #5 Area (ha) | Mine #5 Error (ha) | Mine #5 Percent Error | Total Mined Land Area (ha) | Total Mined Land Error (ha) | Total Mined Land Percent Error |
|---|---|---|---|---|---|---|---|---|---|
| Aerial Photo | 173.3 | | | 229.4 | | | 1661.2 | | |
| 1x Enlargement | 190 | 16.8 | 9.6 | 240.9 | 11.5 | 5 | 1715.8 | 54.6 | 3.3 |
| 2x Enlargement | 161.4 | 12 | 7.0 | 268.4 | 39 | 17.1 | 1651.9 | 9.3 | .6 |
| 4x Enlargement | 169.2 | 4.1 | 2.3 | | (Not Measured) | | 1431.9* | 3.8 | .2 |
| 5/6 Ratio** | | | | | | | 1651.5 | 9.7 | .6 |
| 5/7 Ratio** | | | | | | | 1686.1 | 24.9 | 1.5 |

\+ Hectare
* Area of mines 1-4 only
** Measured only for total mined land

photograph. In spite of these limitations, however, it is possible to place boundaries that indicate the extent of differences within the mines, if not their exact shape and area. A comparison between the mined land overlays from Landsat imagery and the color infrared photography will demonstrate that generally the classification of the Landsat image follows the pattern of classification of the aerial photograph. There are actually very few omissions of detail on the 4x Landsat enlargement when compared to the U-2 photograph. Most of these (see Figure 20, overlay-omissions) are areas of partial vegetation (B) and are smaller than five hectares each. There are several cases of misidentification that can be found when comparing the dominant designators of the two images. These incorrectly designated areas range in size from about 21 ha to about 3 ha. However, since strictly manual interpretation was employed, most of these errors can be traced to the interpreter's subjectivity in identifying dominant tonal characteristics, and should easily be minimized with experience with the local mining practices and landscape.

To test the accuracy of the internal classification, overlays of the study area from Landsat and the aerial photography were compared for similarities in classification. This is illustrated on Figure 21 with overlays A and B[1/]. Due to the aforementioned differences in the two remote sensing systems, exact boundary matches were not sought out. Instead, trends and overall config-

1/ This is not a rectified photograph and the Landsat interpretation overlay may require slight shifting for the best fit.

urations that approximated one another and were comparable were the goals of the study.

Areas on the 4x enlargement that generally matched similar areas on the aerial photography were considered as accurate delineations even though their outlines did not necessarily match exactly. When the two overlays were compared, dominant categories that did not match their counterparts were indicated on the Landsat overlay (B) as an error. In numerous instances, the corresponding category was a secondary one in a combination. When this occurred, the error was considered as an "explained error" - meaning that the desired category was imaged on Landsat, but other factors caused it to be listed as a secondary category rather than a primary one. If the desired category had not been interpreted at all, the error was considered an "unexplained error."

Using this approach, a study of the vegetated categories (A and B) within the mined area was conducted. A "total error" (determined by combining explained and unexplained errors) of 5.8% of this total could be explained by subjective reasons, because the vegetation categories were imaged on Landsat as subordinate to some non-vegetated category. The "unexplained error" or totally incorrect Landsat interpretation was only 3% of the total mined area studied for this phase.

The same procedure was then applied to the dark spoil category (D) with similar results. The total error was 12.2% of the area but the unexplained error was only 5.5%.

Anderson and others (1975) in conducting automated imagery analysis of surface mined lands in Maryland, found that the best delineation of total mined lands was obtained with a MSS 5/MSS 6 ratio. To test this observation on mined lands in Pennsylvania, MSS 5/MSS 6 and MSS 5/MSS 7 ratios (Section 5.4.5) were made. The resulting images shown in Figure 22 confirm Anderson's observations. The MSS 5/MSS 6 ratio portrays total disturbed lands in sharp contrast to the background area. It is apparent, however, that any farmland not densely vegetated would also be portrayed as mined lands. The MSS 5/MSS 7 ratio shows some tonal detail within the disturbed areas which can be correlated with stages of reclamation. The boundary between mined lands and non-mined lands, however, is in places indistinct creating areas of arbitrary decision in boundary placement.

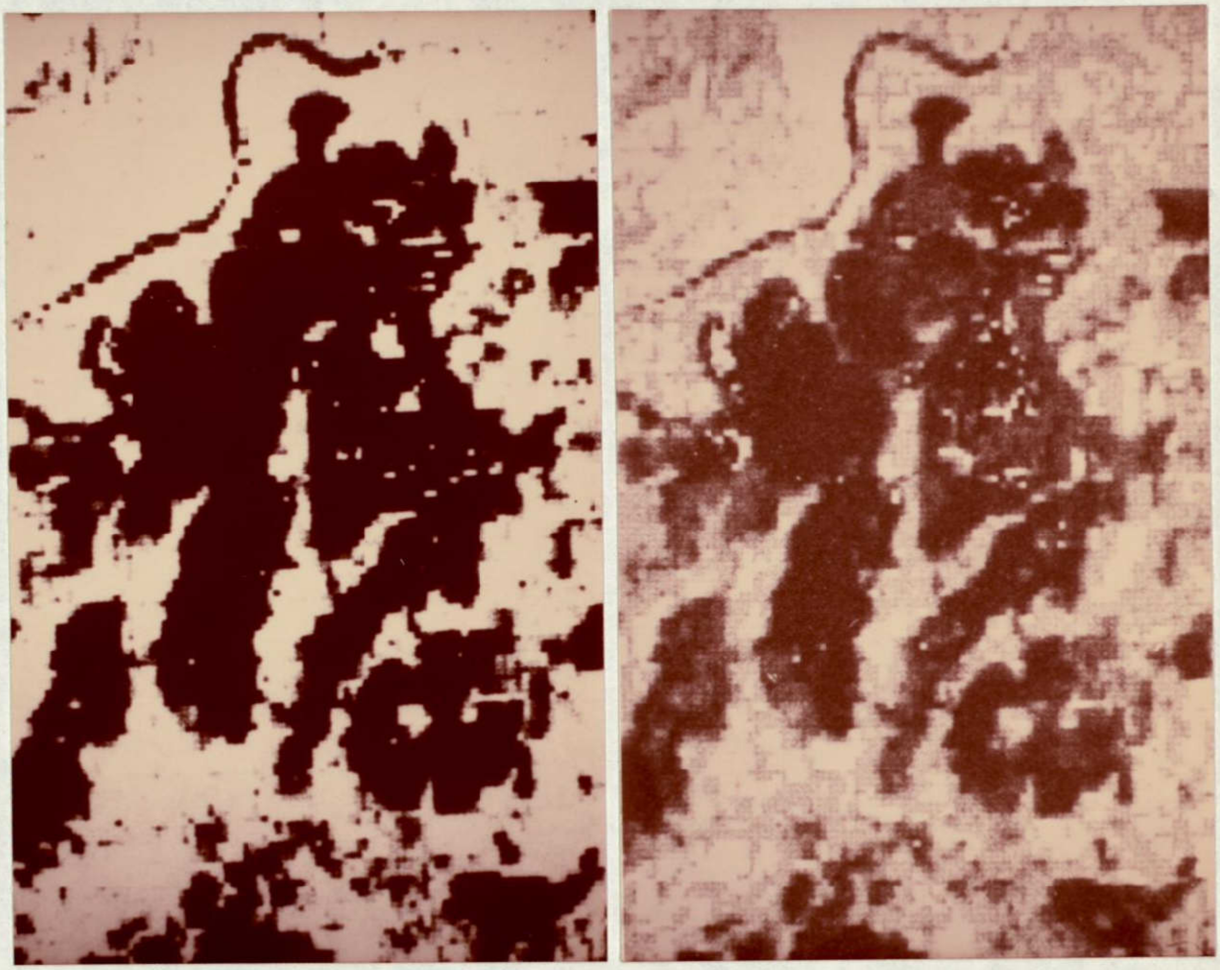


Figure 22. The ratioing of MSS bands 5/6, image A, renders the strip mined areas in sharp contrast to the surrounding vegetated area. Image B is a ratioed image of MSS bands 5/7. In this scene, there is more detail and tonal variation within the mined areas, but also more confusion as to the mined land boundaries. For identifying total disturbed lands, the 5/6 ratio is superior.

2. Older, probably graded and reseeded land.

3. Partially revegetated.

As the vegetational growth covers the mine lands and as plant cover increases, the mined lands blend with the undisturbed lands and become unrecognizable.

No meaningful judgments are possible from the Landsat imagery as to existing water quality or potential water quality problem areas.

A statistical evaluation of the significance of the area size to the reliability of interpretation indicates that, although the regression coefficients derived are not significant, the error in using Landsat to determine the size of the mine tends to decrease as the size of the mine increases. Furthermore, the relative accuracies in measurements of the total mined areas tends to support this contention. It was not determined, however, if there is or is not a particular size for the mined area that will yield optimum results.

There does not seem to be any superior computer enhancement for accurate area measurements based on this study. Although the 4x computer enlargement reflects the lowest percent error for the total disturbed area (2%) and the lowest mean percent error for the five subdivisions (5.6%), the sample size is statistically too small to draw valid conclusions.

The close similarity between the Landsat and CIR air photointerpretation (as shown in Figure 21) demonstrates that there is potentially useful information about surface mining obtainable from Landsat imagery. However, meetings with Pennsylvania Department of Environmental Resources during and near the end of this project failed to identify any application which would aid the state in implementing mining laws.

## 7.0 COSTS AND BENEFITS

Portions of four Landsat frames will provide complete coverage of the bituminous coal area. Computer compatible tapes (CCT) can be acquired at the nominal cost of $1,000. Reliable costs for the production of 1:24,000 imagery similar to that shown in Figure 20 are more difficult to determine. It is, in part, dependent upon whether the State or organization has, or prefers to develop, the in-house capability for the appropriate computer processing, image print-out, and color photographic laboratory facilities necessary to produce the enhanced, two-color, Landsat image enlargements.

Initial capital costs could range from $50,000 to $500,000. A staff of two to four technical personnel qualified in computer and photographic processing would be required. If a regional inventory of mined lands using Landsat imagery is performed on an annual basis, this staff would be fully dedicated to his effort for only two to six weeks. Commercial facilities for the necessary computer processing and photographic image production are limited, and rates may differ substantially. Earth Satellite Corporation's rates for the processing of imagery with the algorithms used to produce Figure 20 are probably representative. They are based on materials, labor, and CPU time. Assuming portions of four Landsat frames must be processed, the cost to produce computer-enlarged, black-and-white negatives of MSS bands 5 and 7 would be approximately $20,000.

Two-band color photographic processing of Landsat data of the bituminous coal field area of Pennsylvania at a scale of 1:24,000, not area-matched to 7-1/2 minute quadrangle sheets, would be approximately $15,000.

Once the imagery is processed, a staff of qualified image interpreters is required to extract the desired information from the imagery. The analysts should be knowledgeable in surface mining and reclamation procedures and have access to current "spot" photography for verification purposes or be permitted to make "field checks" periodically.

The number of analysts required will be dependent upon the State's requirements on timeliness of the data. Annually updating a mine land inventory in western Pennsylvania would require, at a minimum, the full-time services of two image analysts. If State requirements dictate the inventory be completed in shorter time periods, the interpretation staff must be increased appropriately. Salaries for two analysts are estimated at $25,000 to $35,000 per year, and associated costs for field trips are estimated at $3,000.

The imagery interpretation by consulting firms would require comparable time intervals at costs approximately double to triple these above-labor costs.

The acquisition costs of aerial photography are reasonably well-established and reliable budgetary estimates can be developed. The square mile costs of aerial photography, however, are influenced by image scale (a function of flying height and camera-lens system) and general weather conditions which normally prevail within the area of interest.

Two options are open to a state if there is no state-owned aerial photographing capability. These are commercial firms and NASA. Although commercial prices will vary somewhat, costs for 1:60,000 scale color infrared (CIR)[1/] stereoscopic photography will range from about

1/ For small scale aerial photography, color infrared film is recommended.

$5.00 to $6.00 per square mile. NASA currently quotes U-2 flying services at $2,900 per hour. If the U-2 aircraft is on site, 1:60,000 scale photographic coverage of large areas can be acquired for about $3.50 per square mile.[2/] If the aircraft must mobilize to the East Coast from California (the home base), and all mob-demob costs are applied to a single project, an additional $15,000 must be pro-rated to total costs. For the 14,000 square miles of the Pennsylvania bituminous coal area, this would increase costs by at least $1.00 per square mile. Thus, 1:60,000 CIR photographic coverage of the area acquired with the U-2 aircraft may cost as much as $65,000. Unless large areas are flown, commercial firms may be more economical.

If the surface mined land inventory and assessment is made using 1:60,000 scale, stereoscopic, aerial photography, such as represented in Figure 21, imagery acquisition costs will be nearly twice that of using Landsat imagery. However, the resolution of the photography will be on the order of 3 meters (10 feet) as compared to 80 meters (262 feet) for Landsat. Consequently, the information derived from the aerial photography will be more detailed and reliable. Analysis time for the photography will be higher than for the satellite imagery unless the detail of mapping is held to a comparable level. The production of a large quantity of photographic enlargements is not essential, as the interpretation can be plotted directly onto quadrangle maps with appropriate optical-mechanical plotting equipment. Depending upon the sophistication of the equipment acquired, costs can range from $10,000 to $50,000 each.

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2/ If the required level of detail of the photographic analysis is not high, 1:120,000 scale photography may be adequate and acquisition costs may be reduced by half.

Table 5 summarizes the costs estimated for making a mined land inventory of western Pennsylvania.

These costs must be evaluated with the benefits derived. The maps produced will identify the areal extent and geographic distribution of surface mines, plus estimates of the status of reclamation of the disturbed lands. No water quality information can be derived from the Landsat data, and only gross water pollution problems can be observed on the small aerial photography. Comparisons of the imagery on an annual basis will reveal changes in the concentration of mining activities and the progress, or lack thereof, of successful reclamation.

In the final analysis, it is the potential user that must evaluate the utility of the data for his activities. Without consideration to the cost of systematically mapping the bituminous coal region of the Commonwealth, the Pennsylvania Department of Environmental Resources could find little benefit or use for the type of information obtainable from either aerial photography or Landsat imagery.

TABLE 5 - COST ESTIMATES OF CONDUCTING A SURFACE MINED LAND INVENTORY WITH LANDSAT IMAGERY OR AERIAL PHOTOGRAPHY

| | LANDSAT | | Aerial Photography | |
|---|---|---|---|---|
| | In-House[1] | Commercial Firm | In-House[1] | Commercial Firm |
| Imagery Acquired | $ 1,000 | | $20,000-$40,000[2] | $70,000-$84,000 |
| Processing | $ 5,000[2] | $ 35,000 | - | - |
| Technicians (Photographic and Computer) | $5,000-$8,000 | - | - | - |
| Capital Equipment Costs | $50,000-$500,000 | - | $10,000-$50,000 | - |
| Photointerpreters | $30,000 | $150,000 | $45,000 | $200,000 |
| Draftsmen | $25,000 | - | $25,000 | - |
| Misc. Costs | $ 5,000 | - | $ 5,000 | - |

1/ Facility costs are not included.

2/ This figure is only an estimate. Actual costs depend upon how the State accounts for operational expenses.

3/ It can be assumed that due to the limited requirement for this staff, they will be used on other programs and the salary costs distributed accordingly.

## 8.0 CONCLUSIONS AND RECOMMENDATIONS

The use of Landsat data by field inspectors in the routine implementation of Pennsylvania's mining laws is not practical due to the poor resolution of the imagery and the delays in data delivery and interpretation. However, such imagery can provide a record of the status of disturbance of surface lands at an instant in time; a record which may be valuable at the state or federal level.

The monitoring required for enforcement of surface mining regulations may be considered to occur at two levels: detailed observations of the mining procedures by field inspectors in their daily activities, and the regional overview at the headquarters level.

The potential utility of remote sensing to aid in the operations at these two levels is varied. The field inspector cannot be eliminated; therefore, remote sensor data can only be used to make his efforts more efficient and effective. Many of the observations made by the inspectors are detailed, and could only be complimented by high resolution imagery (± 1 foot). The conditions within an area disturbed by mining are continuously changing; thus, current information is necessary for most monitoring requirements. <u>It is only in those areas where the observations are less time dependent that remote sensing will be of the most value</u>. From the standpoint of the field inspector, the usefulness of remote sensing is largely limited to assuring that mining is confined within the permitted area, that grading is done to the appropriate contour, and that revegetation is progressing suitably.

The resolution of Landsat imagery limits the judgments that can be made relating to any of these above-mentioned phases of mining. Aerial photography, even at a relatively small scale (e.g., 1:60,000), can be of considerable utility in these functions, but the cost of acquiring and interpreting the imagery precludes most states from using it to supporting their field inspectors.

At the Bureau level, where the regional aspects of the status of surface mining lend themselves to the use of remote sensing techniques, both Landsat and aerial photography have greater potential application. Landsat imagery can provide estimates for total disturbed lands to approximately 95% accuracy in areas such as western Pennsylvania. General assessments can be made as to the amount of vegetation cover, and when the interpretations made are compared on a periodic basis, the lack of reclamation progress can be detected. The use of Landsat data for such evaluations in western Pennsylvania is not practical on less than a yearly basis because of the limited quantity of cloud-free imagery that would be available. Also, data processing and analysis by manual interpretation methods do not appear economically favorable.

The quantity and level of detail of information available from small scale aerial photography is substantially greater than from Landsat imagery, but the cost for acquisition and interpretation are also greater.

If the federal strip mining legislation is passed, there are several instances in which a mined land inventory with aerial photography will be valuable. It is easy to identify "orphan" or old, unreclaimed mined areas, with small scale to medium scale photography. Title IV of the House Bill establishes that some lands may be declared unsuitable for mining for several reasons, but only if mining does not exist in those areas at the time of the enactment of the bill. Stereoscopic aerial photography acquired on or about the date would document mining status.

An interpretation and evaluation made from this photography would provide the most practical means to determine those areas that should be declared unsuitable for mining. Also, aerial photography can be of great value in the assessment of potential hydrological impacts resulting from mining.

The major conclusions of this study are:

- Cost of processing Landsat data to a scale usable for manual interpretation is comparatively high.
- Landsat imagery can be used to periodically update mined land inventory maps if accuracies of areal measurements of about 95% are acceptable.
- The resolution of Landsat imagery makes it marginally useful for monitoring the status of surface mine lands and areas where mines are of small areal extent and where intricate boundaries exist.
- Weather conditions in western Pennsylvania are such that usable Landsat data is normally obtained only in summer and fall seasons.
- Timeliness of Landsat data is critical to its utility. Information only a few days old is greatly diminished in value for many applications.
- Aerial photography provides higher resolution imagery than Landsat but acquisition and interpretation costs are higher.
- Aerial photography can be of particular utility in implementing several phases of the federal legislation now under consideration.

The results of this investigation indicate that although useful information about surface mining activities can be derived from Landsat imagery, the utility is diminished by the extended time interval between imagery acquisition and delivery of interpretation results to the final user. Efforts should be made to reduce both the time period of delivery of CCT's and the interpretation. The latter should be most readily accomplished by automated or semi-automated data interpretation systems equipped with a interactive video display. Improvements in the resolution of satellite systems will improve the potential utility of data; however, it is doubtful that the planned 30-meter resolution of Landsat-D will greatly improve the usefulness of the resulting imagery to the field inspectors.

The assessment of this investigator is that the combination of image resolution, timeliness of the information, and data acquisition and interpretation costs largely preclude the use of current remote sensor technology from routine implementation of mining laws in Pennsylvania or other states. However, the inventory and evaluation of surface mine lands can be done effectively on an annual basis if the utility of the information will be of economic benefit to the State.

## 9.0 NEW TECHNOLOGY

No new technology reportable items were made during the performance of work under this contract.

10.0 REFERENCES

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