AUTOMATIC MAPPING OF STRIP MINE OPERATIONS FROM SPACECRAFT DATA

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BIOGRAPHICAL SKETCH

Dr. Rogers is a senior staff engineer at Bendix, where he is a Principal Investigator for NASA/ERTS and Skylab/EREP programs. Rogers received his BS from Tri-State College, his MS from Southern Methodist University, and his PhD in EE from Michigan State University. He is a member of the ASP, and his publications number nineteen. Larry Reed is a projects investigator for Bendix and is actively involved in the processing and analysis of data from ERTS, Skylab, and Bendix multispectral scanners. He has seven years of experience as an Air Force image interpreter, using aerial photography, side-looking radar, and infrared imagery. Dr. Pettyjohn received a BA and MA from the University of South Dakota and a PhD in Geology from Boston University. He is a professor in the Department of Geology at Ohio State University. He is a Co-Investigator for the NASA/ERTS Ohio Strip Mine Program. His publications on mining activities and the effects of mining on the environment are extensive.

ABSTRACT

To provide planning and control of strip mining activity, local, state, and federal agencies must have repetitive mapping of mining areas and the capability of rapidly determining the extent of stripping and the success of reclamation activity. Information on the areas reclaimed and the progress or viability of replanted vegetation is needed for establishing a tax base and for releasing bonds. Knowledge of the secondary effects of mining on the environment is also needed. These effects include erosion, vegetative stress, and sedimentation in rivers and lakes.

Computer techniques were applied to process ERTS tapes acquired over coal mining operations in southeastern Ohio on 21 August 1972 and 3 September 1973. ERTS products obtained included geometrically-correct map overlays showing stripped earth, partially reclaimed earth, water, and natural vegetation.

Computer-generated tables listing the area covered by each land-water category in square kilometers and acres were also produced. By comparing these mapping products, the study demonstrates the capability of ERTS to monitor changes in the extent of stripping,

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success of reclamation, and the secondary effects of mining on the environment. NASA C-130 photography acquired on 7 September 1973 was compared with ERTS products generated from the 3 September 1973 tape to establish the categorization and geometric accuracy of mapping strip mine activities from ERTS data.

BACKGROUND

The area encompassed by this investigation is shown in Figure 1. The area includes five counties in eastern Ohio that comprise nearly 7,800 square kilometers (3,000 square miles). The counties; Muskingum, Coshocton, Guernsey, Tuscarawas, and Belmont; have been disrupted by coal mining since the early 1800s. Strip mining, which generally began before the 1920s, has been practiced in all of the counties. The total area of stripping operations in each county was quite large during the period from 1914 to 1947, but was insignificant when compared to the area stripped from 1948 to the present time.

From the earliest days of mining until 1948, little thought was given to the detrimental effects of coal mining on the environment. However, reclamation techniques required by 1948 legislation resulted in some grading and planting of trees and forage on spoil banks although, in some areas, the soil was too toxic for replanting. In view of the stricter laws passed by the state legislature in 1973, reclamation is proceeding, not only more rapidly, but much more effectively.

In addition to large areas that are disrupted to such an extent that they are no longer productive, strip mining has caused severe ecologic effects. These include the erosion of bare or sparsely vegetated spoil banks and the discharge of highly mineralized water. Sediment eroded from mined areas tends to fill streams and reservoirs. This erosion, in turn, leads to flooding, decreased storage area, and the choking of vegetation. Water that discharges from spoil banks and underground mines generally has a low pH and is highly mineralized.

Local, state, and federal agencies must have repetitive mapping of mining areas and the capability for rapidly evaluating each situation. They also must be able to quickly determine areas of mining reclamation and progress or viability of replanted vegetation, at least on an annual basis.

During the Ohio ERTS-1 strip mining investigation (MMC309), a search of records and data revealed that not a single government agency had up-to-date maps or data showing areas that have been disrupted by coal mining operations. Reports available to the public are severely out-dated, commonly inaccurate, and difficult to acquire. This status is understandable since on-site examination of individual mines, and particularly older mines, is hindered by (1) a lack of adequate mine map coverage; (2) deeply eroded, non-existent, or blocked access roads; (3) lack of accurate or adequate records; (4) the great total size of the stripped area; (5) strip mine reclamation planting along roads that obscures adjacent barren land; and (6) dated aerial photographic coverage.

In response to the need for an economical means of generating strip mine and reclamation data on a repetitive basis, the objective of the NASA ERTS-1 investigation MMC309 is to determine the utility of ERTS-1 in detecting and monitoring area strip mining and reclamation. At the third ERTS Symposium held in Washington, D. C. in December of 1973 computer processing techniques were successfully applied to ERTS CCTs acquired on 21 August 1972 to produce maps of the Ohio Power Company's Coal mining operations (Ref 1)*. This paper extends these results by reporting on additional processing results achieved with tapes acquired by ERTS approximately one year later, on 3 September 1973, and the use of the mapping products from the two ERTS coverages to detect and monitor changes in strip mining and reclamation.

TEST SITE

The ERTS-1 test site selected for the investigation consisted of the five counties in southeastern Ohio shown in Figure 1. This area was selected because of the large amounts of mining in the area. Many of the disrupted areas have been reclaimed, but the degree and success of many such operations are largely unknown, partly because of the rapidly increasing area of disruption and concomitant reclamation. To provide detail analysis of the categorization and geometric accuracy of maps generated from ERTS data, the test area was further narrowed to the three specific areas noted as A, B, and C on the ERTS image shown in Figure 2. The portion of the ERTS Band 7 image shown in the figure covers an area 93 by 93 km (50 by 50 n. mi.).

Site A; Ohio Power Company Mine

The area designated Site A in Figure 2 includes a single large strip mine, owned and operated by the Ohio Power Company in the moderately rolling terrain of southeastern Muskingum County. The mine (also shown in the aerial photograph of Figure 3) is very irregular in shape, nearly 14 km (9 miles) long, and as much as 8 km (5 miles) wide. Aerial photographs indicate that there had been no stripping in the area before 1950. By 1965, however, about 1.6×10^7 square meters (4,000 acres) had been disrupted and, by 1971, strip mining had devastated close to 4.5×10^7 square meters (11,000 acres). Reclamation, caused by the more stringent legislation enacted in 1972, is proceeding at a very rapid rate. Aerial photographs of the northern part of this mine were taken in May of 1972. The area was also examined in the course of field work in June of 1973. In several parts of the mine, there was no comparison between the landscapes that appeared on the 1972 photograph and the condition that existed only 13 months later. Many of the strip mine lakes had been filled, much of the area was graded, and various grasses had been planted as part of the reclamation program.

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*References, tables, and illustrations can be found, in that order, at the end of this paper.

Site B; Contour Mining in Coshocton County

An extensive contour mining operation in southeastern Coshocton County is designated Site B in Figure 2. At this site, contour mining is proceeding into the hills along the flanks of seven stream valleys, leaving nearly vertical high walls about 15 meters (46 feet) high. The mine area is about 5.7 km (3.5 miles) long and nearly 3.2 km (2 miles) wide. The entire operation began after 1965. In view of the type of mining operation, the areal extent of disrupted material does not change rapidly. The spoil, blasted from the high walls, is graded toward the centers of the valleys and planted.

Site C; Belmont County Mining

Strip mining started in Belmont County in 1918, most of it in the northwestern part of the county where, in many places, the major coal seams lie at relatively shallow depths below the gently rolling topography. Some contour mining is also taking place. Site C, noted in Figure 2, includes an area about 13 km (8 miles) long and 21 km (13 miles) wide, most of which lies north of highway I-70. Much of the newly disrupted earth in this area is also being rapidly reclaimed.

AUTOMATED MAPPING

The need for a faster and more economical means of generating strip mine and reclamation information has led Bendix into evaluating computer target "spectral recognition" techniques as a basis for automatic target categorization and mapping (Ref 2). These categorization techniques have been under continued development at Bendix for the past eight to ten years, primarily using aircraft multispectral scanner data and, more recently, using ERTS/MSS and Skylab/EREP-S192 data.

The elements of the Bendix data center used to process data for this study include Digital Equipment Corporation 1.5 M-word disk packs, two nine-track 800-bit-per-inch tape transports, a line printer, a card reader, and a teletype unit. Other units are a color moving-window computer-refreshed display, a glow-modulator film recorder, and a computer-controlled Gerber plotter.

The data processing steps used and the results achieved in transforming ERTS CCTs into strip mine and reclamation data are briefly summarized in the following paragraphs.

Establish Map Categories

The first step in the development of the strip mine and reclamation map is to establish the land-water categories that can be feasibly mapped from ERTS data with an acceptable categorization accuracy. The initial study objective was to map stripped earth, partially reclaimed earth, and water with a categorization accuracy that would, as a minimum, satisfy Anderson's first criterium (Ref 3) of 90 percent or more.

The first task was to locate and designate to the computer a number of ERTS picture elements or pixels that best typified the land-water categories of interest, the "training areas". These areas of known characteristics were established from aerial photographs and ground survey data and were located on the ERTS CCTs by viewing the taped data on the TV monitor. The coordinates of the training areas were designated to the computer by placing a rectangular cursor over the desired area and assigning a training area designation, category code, and color code. Several training areas were picked for each category. The color code is used in later playback of the tapes when the computer-categorized data is displayed in the designated colors.

The ERTS spectral measurements within the training area boundaries were edited by the computer from the computer compatible tape (CCT) and processed to obtain a numerical description (Ref 4) to represent the "spectral characteristics" (computer processing coefficients) of each land-water category. To test the computer's capability to use these spectral characteristics, they were first applied to categorize data from known areas. The processed results were viewed on the TV monitor, and output in the form of accuracy tables similar to those shown in Table 1.

Selection of training areas, generation of accuracy tables, and evaluation of processing results using computer printouts and the TV monitor were iterative operations. To obtain accurate categorization of stripped earth, partially reclaimed earth (less than 70 percent grass), natural vegatation, and water, subcategories with corresponding training areas were established and then merged in the computer to form the desired four categories. Although this paper reports on mapping results achieved with the four merged categories, the subcategories could have been mapped as well. The stripped earth category was composed of subcategories; newly stripped, which had a very rough texture; intermediate stripped, which contained dirt in large mounds piled up prior to smoothing and planting; and very smooth earth, which was in the process of planting. The category desginated partially reclaimed earth included land which had been planted with grass. This category was subdivided into three "density"-related grass categories. The natural vegetation category was composed of rangeland, farmland, and two density-related tree categories. Water was composed of three categories related to sedimentation concentration.

When satisfaction with the categorization accuracy was achieved on the four merged categories, the processing coefficients were placed into the computer disk file and used to process that portion of the CCT covering the three study areas. This first step in the categorization processing resulted in new or categorized CCTs; where each ERTS pixel is represented by a code designating one of the four categories. This tape was later used to generate categorized map overlays and as a medium to store the interpreted information on the study areas. Computer-generated area measurement tables were also edited from this tape to determine areal extent of stripping and reclamation at the three test sites.

Categorize Map Overlays

To produce stripping and reclamation data that will directly relate to a map, the categorized CCTs were submitted to a second stage of processing. In this stage, new tapes were generated that had data corrected for earth rotation, and whose format was compatible with the Gerber plotter. These tapes, when played back by the computer, caused geometrically-corrected map overlays of a specified target category to be drawn on film at a scale specified by the operator. The film, when removed from the plotter and photographically processed, provided transparent overlays which were used directly to overlay maps and aerial photographs, as illustrated in Figures 4 through 6, or processed further to produce transparent color-coded overlays. Color-coding permitted multiple overlays to be used simultaneously over the base map.

Area Measurement Tables

Computer-generated area measurement tables were produced from the categorized data tapes to determine stripping and reclamation in the three test areas. To accomplish this step (Ref 5), the categorized data tapes were used to produce printouts, showing each of the mining areas. In this case, the symbols on the printout designated the categories. The printouts were used to locate the coordinates (scan line number and resolution element number) of a regular polygon(s) which defined the boundary of the mining areas of interest. Inputting these coordinates in turn to the computer yielded, immediately, the desired area measurement table, as shown in Table 2. The table quantifies the amount of land stripped and partially reclaimed in each mining zone of interest. These tables were rapidly produced for each of the three test areas for the 21 August 1972 and 3 September 1973 time period. The data resulting from these printouts, summarized in Tables 3, 4, and 5 show the extent and changes in stripping and reclamation activity in the test areas.

ANALYSIS

Comparisons and analysis of the map overlays and area printout tables generated from the August 1972 and September 1973 ERTS CCTs establish ERTS capability to monitor the extent and changes in stripping and reclamation at each of the three test sites.

Site A; Southeastern Muskingum County

Figure 4 shows the stripped earth and partially reclaimed earth overlays mapped from the 3 September 1973 ERTS tapes at a scale of 1:250,000. These transparent overlays are shown over an AMS map of the same scale. The characteristic shape of the Ohio Power Company Mine, observed in these overlays, can be compared with the NASA photograph of Figure 3. The overlay technique was found to be particularly useful for updating base maps and, more importantly, for detecting and identifying changes between the overlays and the base map; i.e., change detection. Whereas the overlays provide the location of the stripping and reclamation activity, the area printout shown in Table 2 provides a quantitative measure of the amount of land that is stripped, partially reclaimed, etc. at the test site.

Map overlays of the stripped earth category were also generated to match the scale (1:40,000) of the NASA C-130 aircraft photograph acquired on 7 September 1973, as shown in Figure 5.

The overlay mapped from the 3 September 1973 ERTS overpass, when compared with the NASA photograph acquired at approximately the same time, shows good agreement in both geometric and categorization accuracy. Comparison in Figure 5 of the stripped earth overlays generated from the August 1972 and September 1973 ERTS tapes readily shows changes in stripping in the Ohio Power Company Mine. Areas noted as Areas 1 and 2 in Figure 5, not stripped in 1972, are shown stripped in 1973. The area noted as Area 3 in Figure 5 was stripped in 1972 and partially reclaimed in 1973. Table 3, produced from area printout tables generated from 1972 and 1973 tapes, give a quantitative measure of these changes.

A brief analysis of the area and area change data in Table 3 indicates that, between 21 August 1972 and 3 September 1973, an additional 3.5 square kilometers (868 acres) was stripped at this test site. Partially reclaimed land also increased 1.6 square kilometers (401 acres) during this period. That the mine is still growing or spreading out is indicated by the loss of 3.9 square kilometers (965 acres) of natural vegetation and the fact that the new stripping is occurring at about twice the rate of the reclamation. The loss of 1.2 square kilometers (304 acres) in surface water was not considered significant since it only confirmed, in this case, that 1973 was a much drier year than 1972.

Site B; Coshocton County Contour Mining

The areal extent of stripped and partially reclaimed earth at Site B, mapped from the 3 September 1973 ERTS CCT, is shown in Figure 6 at a scale of 1:24,000. At this scale, a single ERTS pixel 57 by 79 meters (187.5 by 259.7 ft) appears as a small rectangular box 3 by 4 mm (0.125 by 0.18 inch) on the overlay. Many investigators prefer this map scale, and the category overlays will directly overlay a 7.5-minute topographic base map. Table 4 summarizes the areal extent and the changes in the areal extent of mining between 21 August 1972 and 3 September 1973 at Site B. In view of the contour mining technique at this site, the areal extent of stripped earth, as noted in the table, does not change much (plus 0.78 square kilometers or 193 acres). It is also apparent from the table that the new stripping is being extracted from the previous year's (1972's) partially reclaimed category. Analysis of aerial photography reveals that the partially reclaimed areas are not being re-stripped for coal but are being re-graded for additional reclamation efforts. Although this mine is not growing significantly in areal extent, a major environmental problem at this test site is the discharge of highly mineralized acid water from nearby abandoned underground mines.

Site C; Mining in Belmont County

The changes in the areal extent of mining in northwestern Belmont County are shown in Table 5. This table indicates a loss of over 16.2 square kilometers (4,000 acres) of natural vegetation to mining activity within a one-year period. At the end of the year, about half of the land lost to mining remained divided between stripped earth and partially reclaimed earth. Analysis of the corresponding map overlays shows that this new stripping is proceeding eastward and also south of highway I-70 in Belmont County.

CONCLUSION

This investigation has demonstrated the feasibility of using ERTS-1 CCTs as a basis for mapping and monitoring strip mining and reclamation. Similar techniques could be used for a wide variety of other purposes where an economical means of mapping land use and land use changes are needed. The methods described herein are rapid and accurate, and are believed to be inexpensive when compared to standard methods using aerial photographs and ground teams. It is estimated that stripping and reclamation maps at 1:24,000 to 1:250,000 scales can be produced from ERTS CCTs at a tenth of the cost of conventional mapping techniques. Since these maps can be produced quickly and economically, it is now feasible to monitor changes in stripping and reclamation activity at least on an annual basis.

REFERENCES

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2. R.H. Rogers and L.E. Reed; Automated Land Use Mapping from Spacecraft Data; Proceedings of the 40th Annual Meeting of the American Society of Photogrammetry at St. Louis, Mo. in March of 1974.

3. J.R. Anderson; Land Use Classification Schemes; Photogrametric Engineering, Vol XXXVII, No. 4, April 1971, pg 379.

4. R.H. Dye, D.S. Hanson, and C.L. Crawford; Signature Data Processing Study; Bendix Report, BSR 2949, NAS 9-9848, August 1970.

5. R.H. Rogers, L.E. Reed, N.J. Shah, and V. Elliot Smith; Automatic Classification of Eutrophication of Inland Lakes from Spacecraft Data; proceedings of Ninth International Symposium on Remote Sensing of Environment at Ann Arbor, Mich., ERIM Publication, 15-19 April 1974.

Table 1 Categorization Accuracy Table (Units Percent)

Category	1	2	3	4
1 Stripped Earth	96	4	0	0
2 Partially Reclaimed Earth	0	98	2	0
3 Natural Vegetation	0	8	92	0
4 Water	0	0	0	100

Table 2 Area Printout Table Test Area A, ERTS 3 September 1973

Category	Percent of Total	Square Kilometers	Acres
Stripped Earth	15.54	15.44	3,814
Partially Reclaimed	11.86	11.79	2,913
Natural Vegetation	72.08	71.6	17,692
Water	0.53	0.52	129

Table 3 Site A Area and Area Changes

Category	21 Aug 1972 Acres	3 Sept 1973 Acres	Difference (1973 - 1972) Acres
Stripped Earth	2,948	3,814	+868
Partially Reclaimed	2,512	2,913	+401
Natural Vegetation	18,657	17,692	-965
Water	433	129	-304

Table 4 Site B Area and Area Changes

Category	21 Aug 1972 Acres	3 Sept 1973 Acres	Difference (1973 - 1972) Acres
Stripped Earth	411	604	+193
Partially Reclaimed	991	787	-204
Natural Vegetation	2,993	3,053	+60
Water	65	16	-49

Table 5 Site C Area and Area Changes

Category	21 Aug 1972 Acres	3 Sept 1973 Acres	Difference (1973 - 1972) Acres
Stripped Earth	2,988	5,076	+2,088
Partially Reclaimed	7,897	10,557	+2,660
Natural Vegetation	52,640	48,345	-4,295
Water	1,139	686	-453

Figure 1 Geologic Map of Ohio, Showing
Five-County Study Area

Figure 2 ERTS Band 7 Image of Test Sites

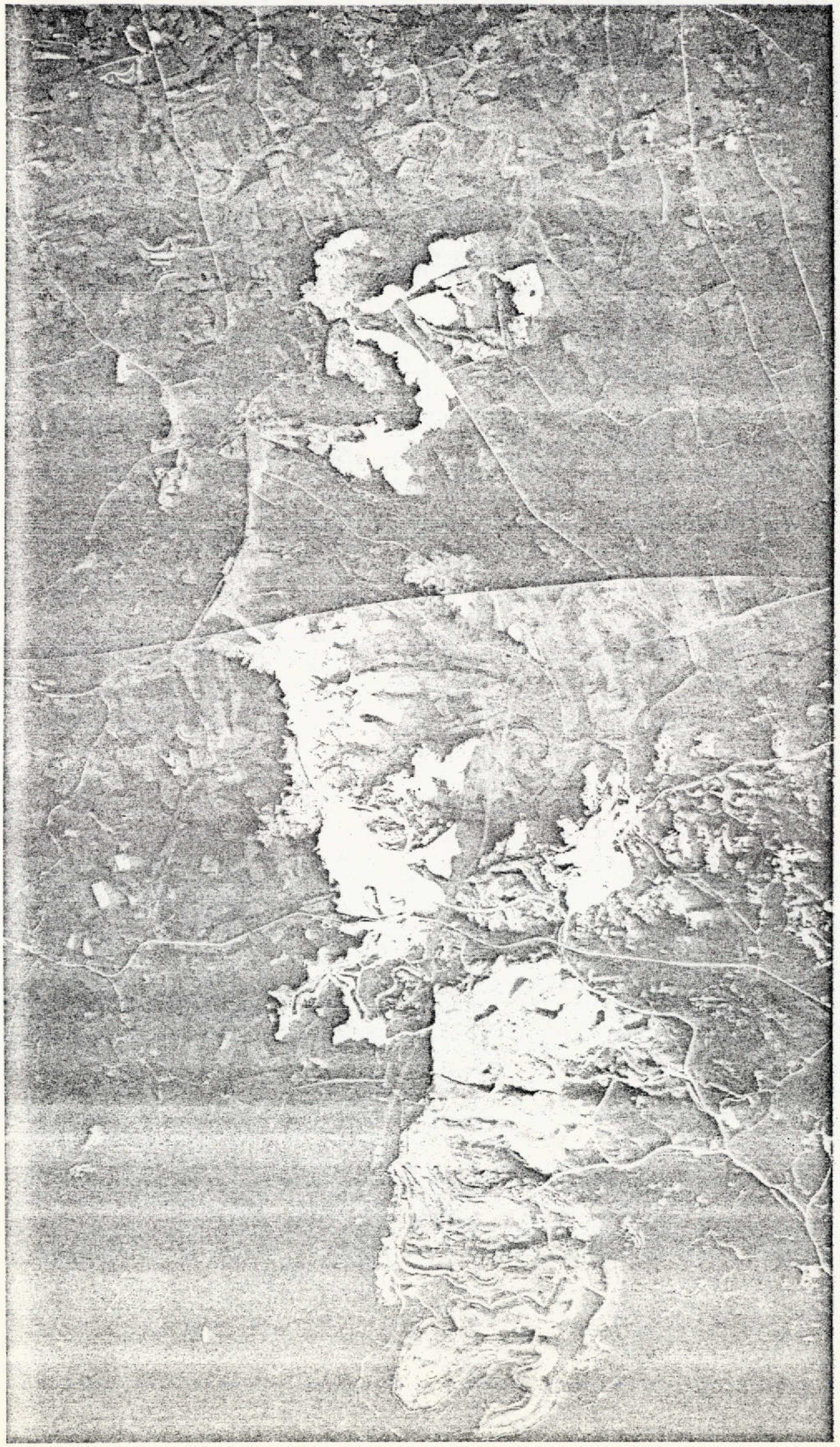
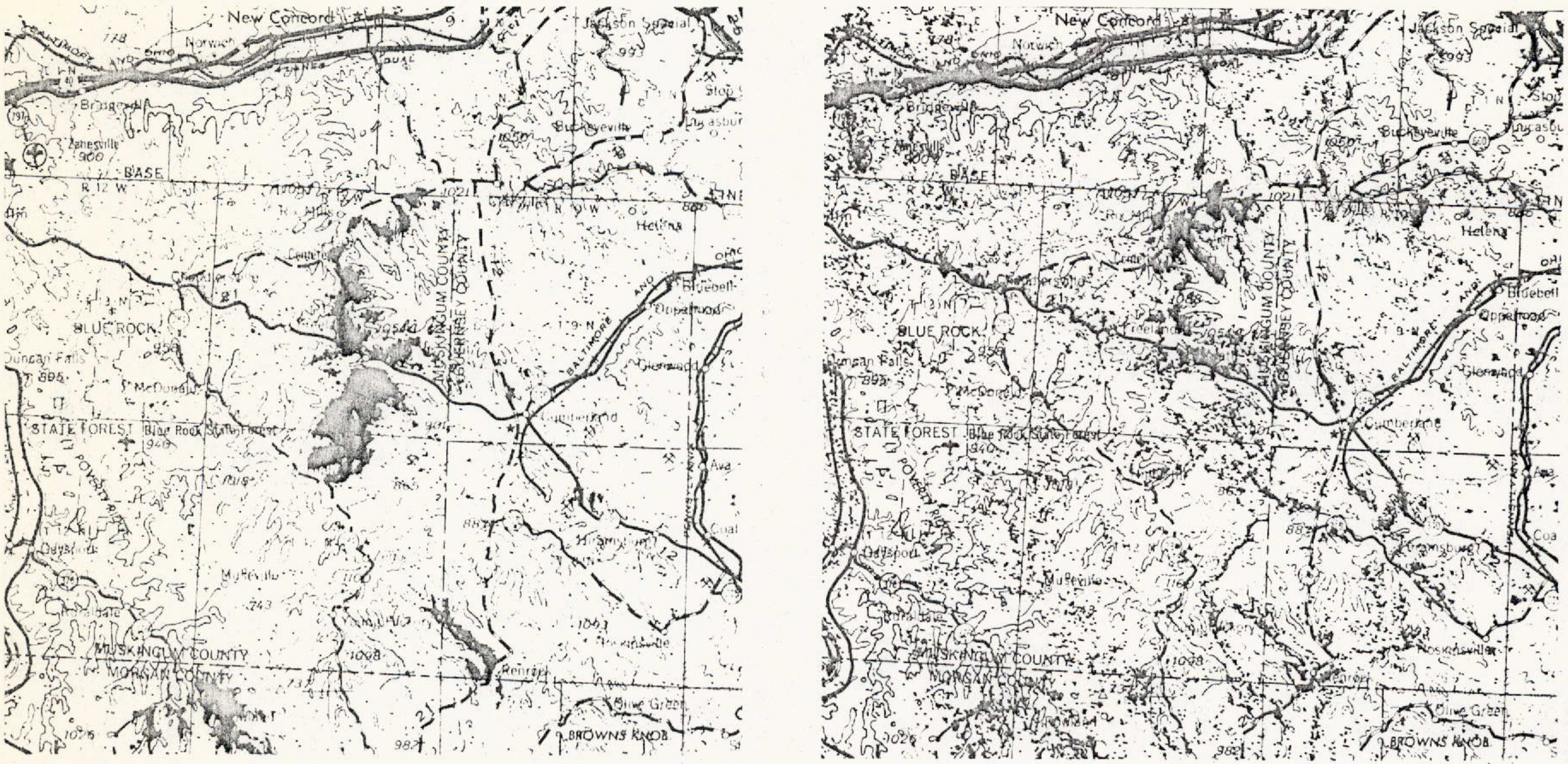


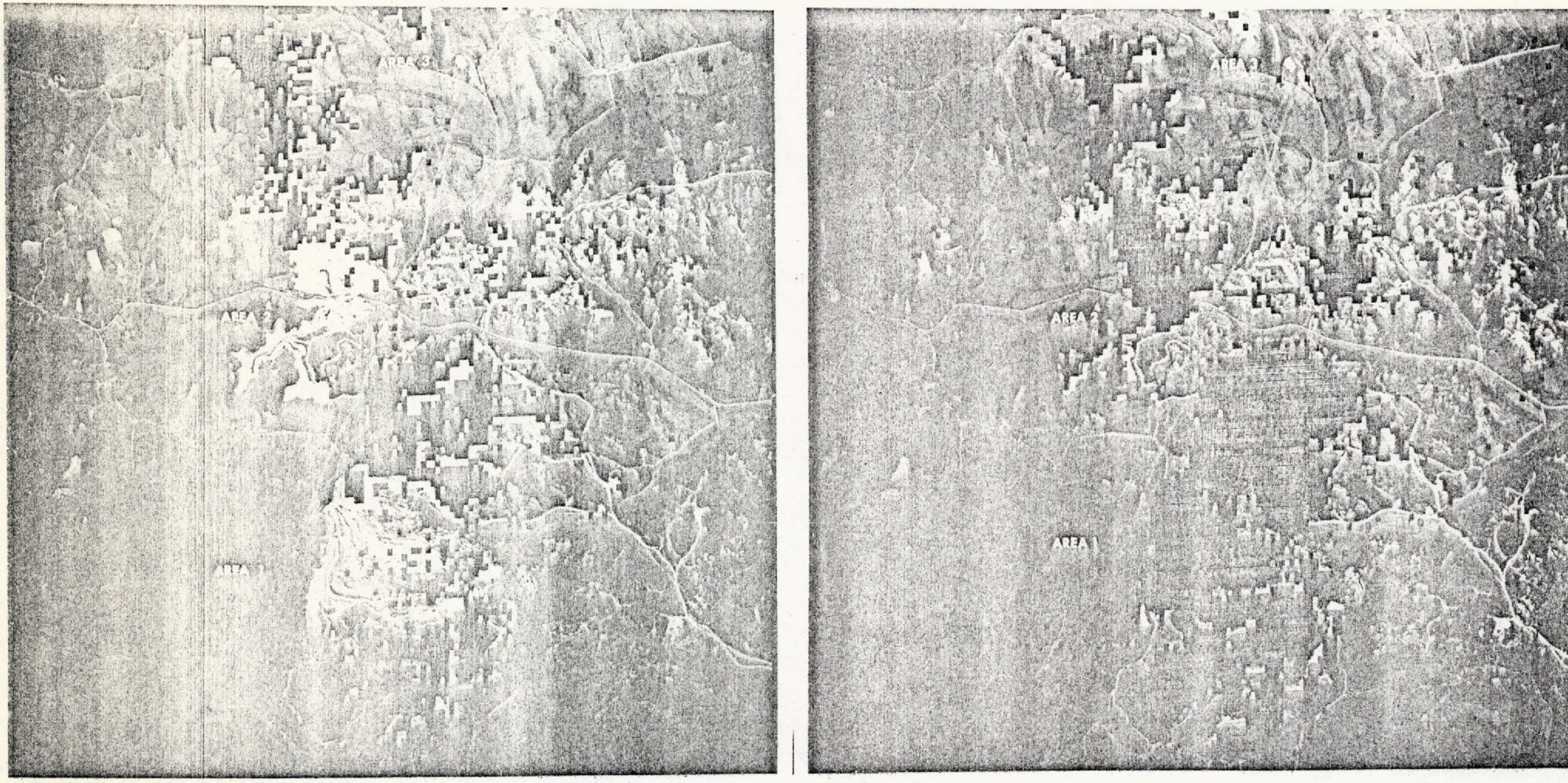
Figure 3 Aerial Photo-Mosaic, Showing Site A Ohio Power Company Strip Mine in Southeastern Muskingum County, Ohio. Acquired by NASA C-130 Aircraft Photography on 7 September 1973.



Stripped Earth and Major Sources of Erosion

Partially Reclaimed Earth and Minor Sources of Erosion

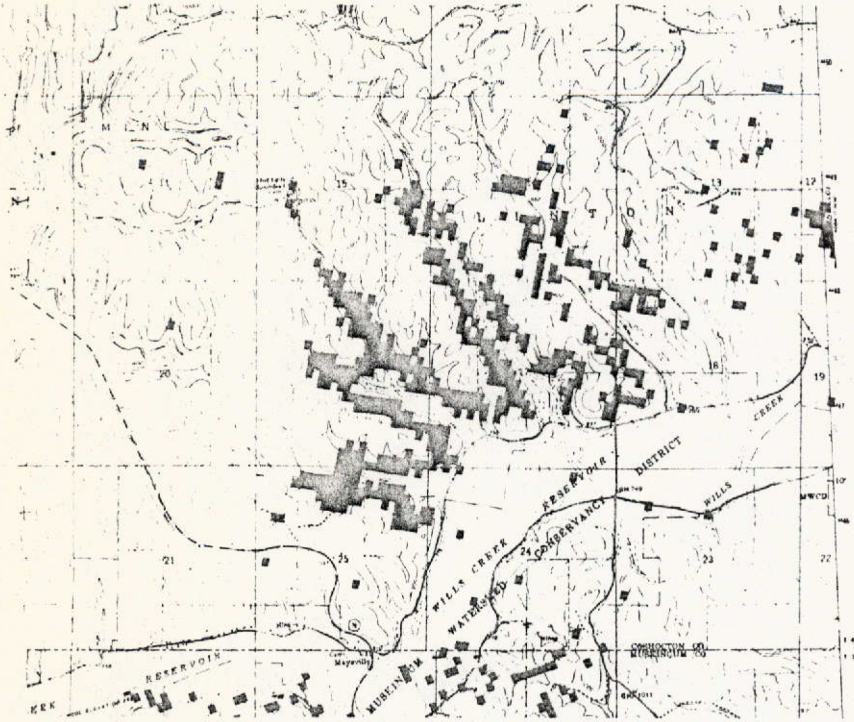
Figure 4 Computer-Generated Overlays on AMS 1:250,000 Scale Map.
Mapped from ERTS Data Acquired on 3 September 1973.
Site A, Ohio Power Company Mining Operation in Muskingum County, Ohio.



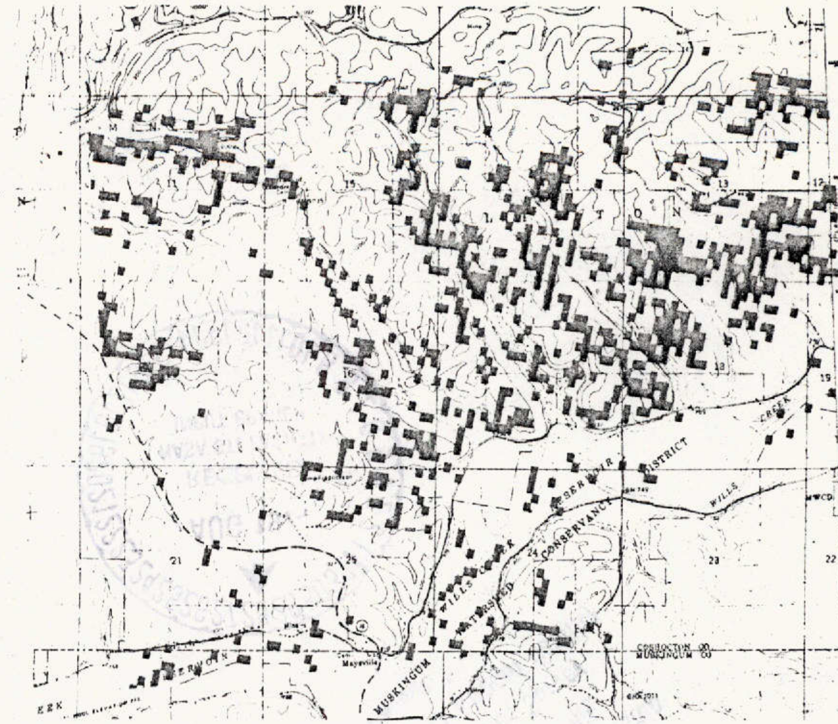
21 August 1972
Stripped Earth

3 September 1973
Stripped Earth

Figure 5 Stripped Earth Category Mapped from 1972 and 1973 ERTS Data Overlaying NASA Photograph Obtained on September 1973. Approximate Scale 1:40,000. Site A, Ohio Power Company Mine in Muskingum County, Ohio.



Stripped Earth and Major Sources of Erosion



Partially Reclaimed Earth and Minor Sources of Erosion

Figure 6 Computer-Generated Overlays on AMS 1:24,000 Scale Map. Mapped from ERTS Data Acquired on 3 September 1973. Site B, Contour Mining Operation in Coshocton County, Ohio