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APPLICABILITY OF SATELLITE REMOTE SENSING FOR DETECTION AND MONITORING OF COAL STRIP MINING ACTIVITIES

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APPLICABILITY OF SATELLITE REMOTE SENSING FOR DETECTION AND MONITORING OF COAL SURFACE MINING ACTIVITIES

SKYLAB EREP INVESTIGATION 9669

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ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

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1. INTRODUCTION

The objective of this investigation is to evaluate satellite imagery as a means of detecting and monitoring coal surface mines, their environmental effects, and reclamation activities. The satellite imagery employed in the investigation is Skylab EREP S-190A and S-190B from SL-2, SL-3 and SL-4 missions; a large variety of camera/film/filter combinations have been reviewed. This study strives to ascertain whether satellite imagery may be routinely used to assist State and Federal agencies in their monitoring of coal surface mining and reclamation activities. Our results show the answer to be a definite YES!

The investigation includes determining the applicability of satellite imagery for detection of disturbed acreage in areas of surface mining, and the much more detailed monitoring of specific surface mining operations including locating of active mines, inactive mines, highwalls, ramp and access roads, water impoundments and their associated pH, graded areas and type of grading, and reclaimed areas. Techniques have been developed, via this investigation, to enable State and Federal mining personnel to utilize the satellite imagery in a practical and economic manner, requiring no previous photo interpretation background and requiring no purchases of expensive viewing or data analysis equipment.

To corroborate the photo interpretation results, on-site observations were made in the very actively mined area near Madisonville in western Kentucky. Strip Mining and Reclamation officials of the State of Kentucky assisted greatly during the on-site inspection; they also reviewed the results of this investigation and are very enthusiastic about the potential of satellite monitoring to assist them in their duties.

This investigation was funded by NASA/Lyndon B. Johnson Space Center under contract NAS9-13310. The NASA Technical Monitor is Mr. R.E. Joosten.

2. BACKGROUND

Coal is the general name given to naturally occurring, non-clastic sedimentary rock which was derived from the burial and chemical changes of forest type vegetation. This dynamochemical alteration has formed a variety of products with high amounts of combustible material such as: peat, lignite, sub-bituminous, bituminous, anthracite and graphite. Most of the coal in the United States was formed during the Carboniferous period of the Paleozoic era which began about 280 million years ago; being buried under areas covered today by the majority of the nation's contiguous states (see Figure 2.1).

Of all fossil fuels, coal has been in use by human beings for the longest time. In the United States consumption of coal, in a major scale, started around 1850 and it has increased to almost 20 x 10^{15} BTUs/Yr. by 1975 (see Figure 2.2). Coal production in the United States has increased considerably in the past years (see Table 2.1), and statistics show that the country will continue to produce coal for the next several hundred years at current or increased production rates since coal reserves amount to more than 1.5 trillion tons (Wagner, 1974).

TOTAL COAL PRODUCTION IN THE UNITED STATES

year	thousand short tons
1950	560
1960	434
1965	527
1968	557
1969	571
1970	613
1971	561
1972	602

Source: Statistical Abstract of the U.S. Commerce Dept., 1974.

TABLE 2.1

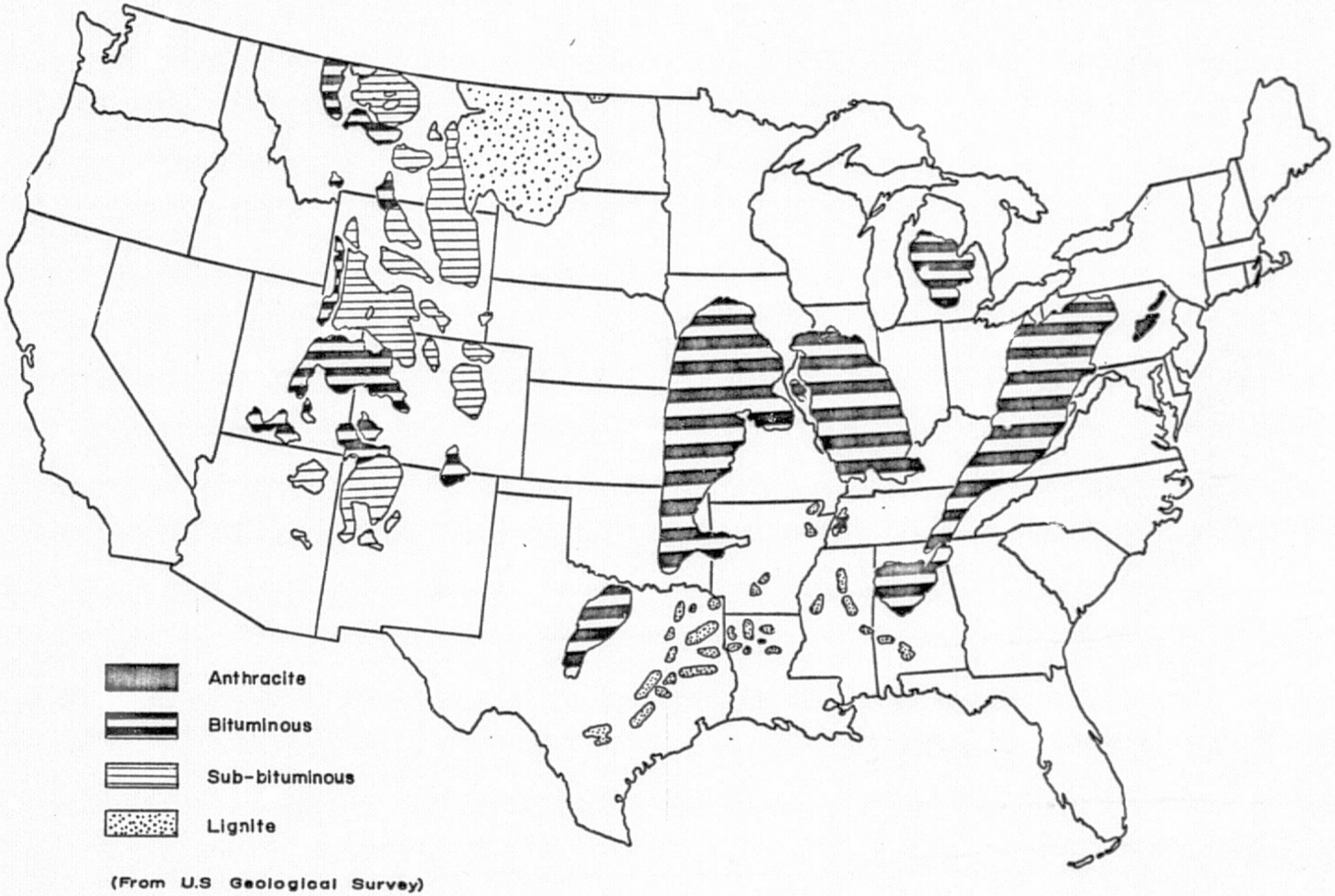
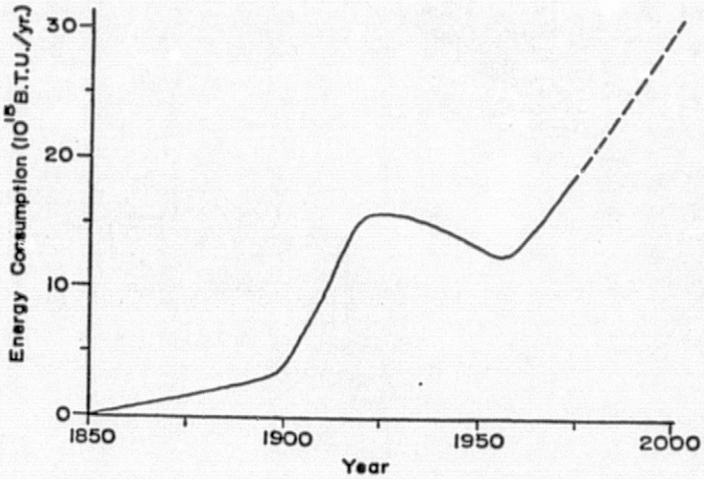


FIGURE 2.1

LOCATION OF COAL PRODUCING AREAS IN THE UNITED STATES



CONSUMPTION OF COAL IN THE UNITED STATES

FIGURE 2.2

Coal mining in the United States has been accomplished in two manners: underground mines and surface mines. When coal beds are a few feet below the surface and in a relatively horizontal position, they can be mined by removing the material on top and shovelling out the coal. Presently over 50% of the total coal production in the United States is by surface mining because it can be done cheapest by using modern machinery

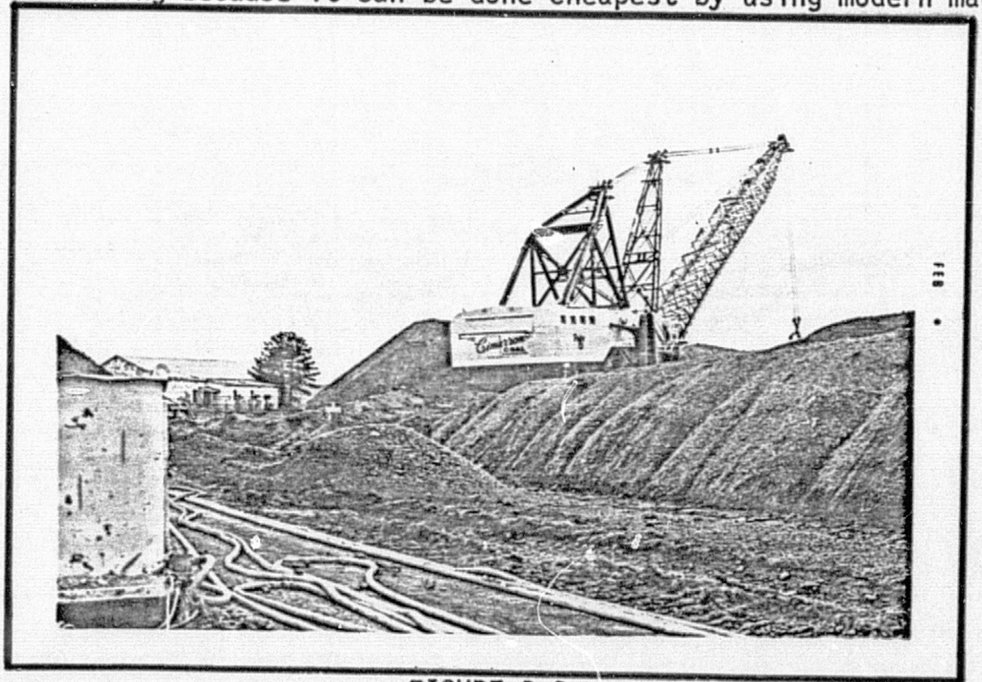


FIGURE 2.3
Cimarron Coal Co. Electric Dragline
Hopkins County, Kentucky

such as gigantic shovels that can remove many tons of material at a time (see Figure 2.3).

2.1 SURFACE COAL MINING

Surface mining in the United States is a relatively modern coal extraction technique. Here and for the remainder of this paper we shall adopt the terms strip mining or stripping because their negative connotation has made the terms popular synonyms for surface coal mining. Basically there are two types of strip mines: area and contour.

2.1.1 Area Strip Mining

Area strip mining is usually practiced on relatively level terrain with flat or only gently dipping coal beds. The technique calls for a first cut or trench which removes the overlying soil and rock, commonly referred to as "overburden" or "spoil," and exposes the coal bed. The first cut may extend to the property boundary or the economical limits of the deposit. After the coal is removed, additional cuts are made paralleling the first. As each cut is made, the overburden is deposited in the cut previously excavated producing narrow, steep ridge-like forms called "spoil banks" and a fairly perpendicular scarp called the "highwall" (see Figure 2.4). After the final cut is made and mining ceases, an open trench or "pit floor" remains, bounded on one side by the last spoil bank and on the other by the undisturbed highwall. The stripped land between the initial and final cut is left to resemble a giant washboard.

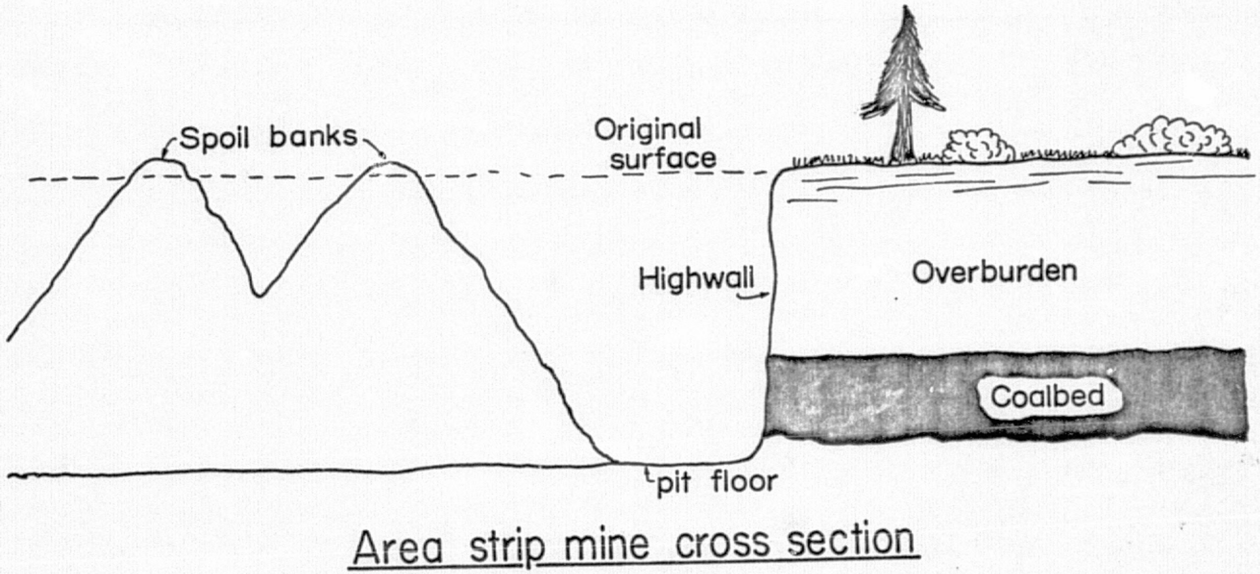

Spoil banks
Original surface
Highwall
Overburden
Coalbed
pit floor
Area strip mine cross section

FIGURE 2.4

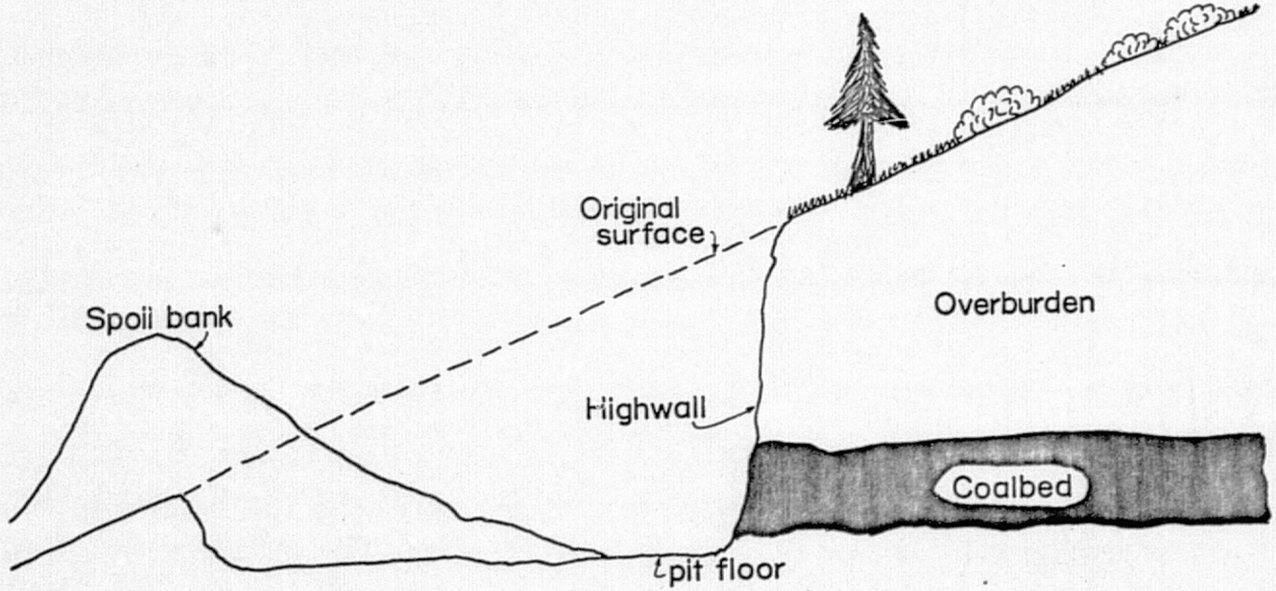
2.1.2 Contour Strip Mining

Where hilly or mountainous terrain makes area stripping uneconomical, contour mining is practiced. Mining advances along the natural contour of a hill being stripped. The first cut is made along the hillside above the coal bed. The hillside is cut back as far as the value of the underlying coal will allow, with the resulting overburden dumped on the downhill slope. Mining proceeds laterally along the slope creating a shelf or terrace in the profile of the hill (see Figure 2.5). Contour stripping leaves a near-vertical highwall above the mining ledge and a steeply inclined spoil ridge.

With advances in modern technology, the area strip mining method is becoming more commonly practiced due to the relatively lower operating costs of stripping machinery. Hills and topographic irregularities do not present insurmountable economic barriers as they did a few years ago. Today strip mining is considered to be more advantageous than underground mining in recovery rates, grade control, economy, flexibility of operation, safety, and working environment.

2.2 RECLAMATION

However, coal strip mines have recently received much adverse publicity. Problems of earth waste, erosion, scenic degradation, acid drainage and general ecological disturbances have plagued strip mining operations. For years strip mines were left untouched after mining operations ceased, leaving un-reclaimed, torn landscapes which have been given the name "orphan areas" (see Figure 2.6).



Contour strip mine cross section

FIGURE 2.5

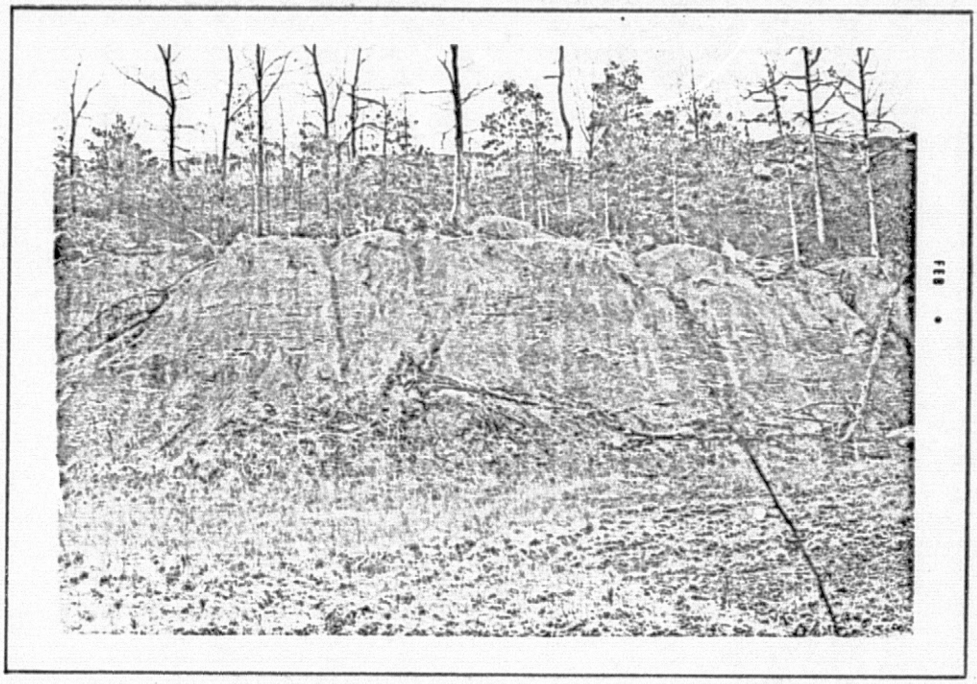


FIG. 2.6 Orphan Area, Hopkins County, Kentucky

Environmental damage is caused long before the coal is extracted when the area is prepared for strip-mining. If the site was previously covered by a forest, it must be cleared thus destroying a natural resource and more importantly destroying the natural habitat of countless wildlife species. Areas devoid of forest cover suffer a similar destruction of habitat as soon as access roads are built and the overburden is stripped. The following is a list of documented environmental effects produced by coal strip-mining (Cubbison and Dunlap, 1972).

Noise pollution due to blasting
Tension cracks in rock due to blasting
Spoil banks slippage, loss of soil stability
Landslides
Avalanches of rock and mud
Houses washed downhill
Topsoils lost at bottom of spoil bank
Exposed saline sub-soils
Exposed shales, baked and impervious
Soil sterility

Continual cutting-and-filling erosion cycle
Siltation
Excessive silt pavements of stream beds
Redistribution of sub-surface waters
Lower water retention capacities of watersheds
Reduced storm-carrying capacities of rivers
Flash floods
Acid and mineral seepage into the water table
Loss of oxygen in water
Loss of aquatic invertebrates
Loss of spawning areas
Sparse vegetation
Exotic and vulnerable plant species artificially induced
Replacement of diverse rich hardwood forests by fast-growing but vulnerable monocultures

Due to the vast acreage of strip mined areas and increased public concern, coal strip-mine reclamation legislation has been enacted in many states resulting in the reclamation of considerable acreage (see Table 2.2).

Coal strip mining reclamation consists mainly of returning the land to the best ecologic, topographic and aesthetic conditions since it would be impossible to return to the original landscape. Reclamation usually begins well before the mining operation starts by requiring mine operators to file a "Plan of Reclamation" in which they must document how they will attempt to restore the areas disturbed. Actual reclamation practices start before the mining operation has ceased. The usual procedure is to bulldoze the spoil banks into the floor of the pit (see Figure 2.7). Regulatory contract provisions usually require backfilling to reach the top of the highwall and to be graded to the original contour; elimination

TABLE 2.2

	Total State area in acres	Mined area in acres[1]	Reclaimed area in acres
Alabama	32,678,000	52,600	28,500
Alaska	365,482,000	25,850	10,600
Arizona	72,688,000	61,500	6,850
Arkansas	33,599,000	24,880	9,040
California	100,207,000	162,100	43,900
Colorado*	66,486,000	35,950	14,000
Connecticut	3,135,000	10,910	3,410
Delaware	1,266,000	1,211	370
Florida	34,721,000	81,800	17,100
Georgia*	37,295,000	29,020	9,650
Hawaii	4,106,000	4,270	1,160
Idaho*	52,933,000	20,680	8,660
Illinois*	35,795,000	264,800	188,000
Indiana*	23,158,000	164,300	113,000
Iowa*	35,860,000	48,400	18,300
Kansas*	52,511,000	35,470	21,500
Kentucky*	25,512,000	195,000	150,000
Louisiana	28,868,000	16,160	5,210
Maine	19,848,000	9,520	3,170
Maryland*	6,319,000	22,360	9,170
Massachusetts	5,035,000	18,150	5,610
Michigan	36,492,000	81,700	24,100
Minnesota	51,206,000	110,200	13,000
Mississippi	30,223,000	9,570	3,310
Missouri*	44,248,000	70,800	41,400
Montana*	93,271,000	36,300	10,600
Nebraska	49,032,000	11,480	3,720
Nevada	70,264,000	23,100	4,020
New Hampshire	5,769,000	4,770	1,590
New Jersey	4,813,000	23,090	7,470
New Mexico	77,766,000	33,500	9,800
New York	30,681,000	68,400	24,600
North Carolina	31,403,000	30,660	9,640
North Dakota*	44,452,000	34,050	23,900
Ohio*	26,222,000	269,400	181,000
Oklahoma*	44,088,000	31,700	16,500
Oregon	61,599,000	27,390	8,940
Pennsylvania*	28,805,000	285,500	186,000
Rhode Island	677,000	2,100	540
South Carolina	19,374,000	12,140	4,110
South Dakota	48,882,000	13,880	4,650
Tennessee*	26,728,000	52,800	23,400
Texas	168,218,000	67,300	20,500
Utah	52,697,000	38,100	6,390
Vermont	5,937,000	3,730	1,200
Virginia*	25,496,000	55,700	28,900
Washington*	42,694,000	30,970	9,740
West Virginia*	15,411,000	127,100	105,000
Wisconsin	35,011,000	41,030	12,400
Wyoming*	62,343,000	23,840	8,890
TOTAL	2,271,304,000	2,903,000	1,460,000

*States with reclamation laws

[1]Includes both active and inactive mines

Source: Bureau of Mines Information Circular IC 8642, June 1974.

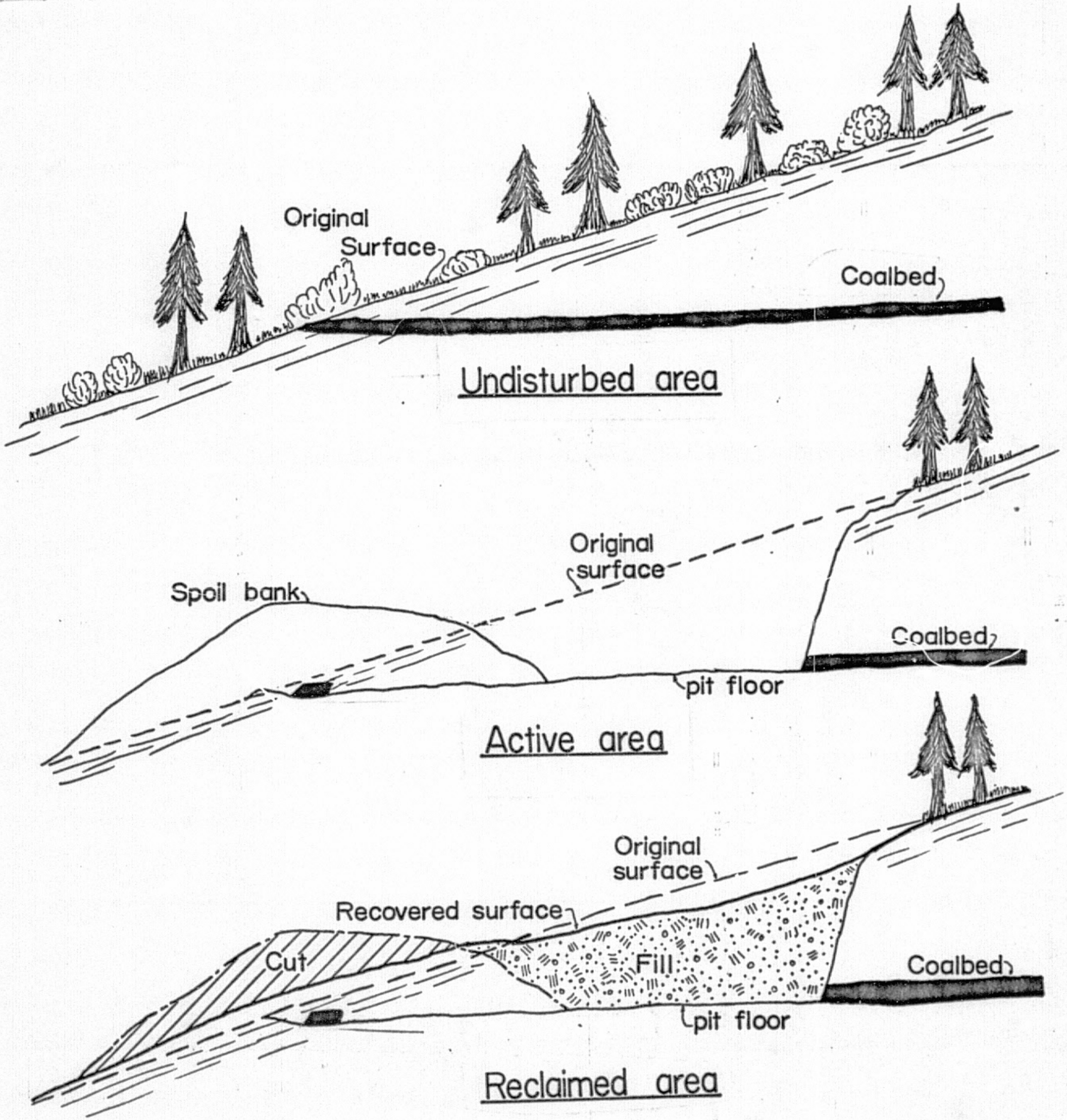

Original
Surface
Coalbed
Undisturbed area
Original
surface
Spoil bank
Coalbed
pit floor
Active area
Original
surface
Recovered surface
Cut
Fill
Coalbed
pit floor
Reclaimed area

FIGURE 2.7

of spoil peaks; impoundment of water; filling of pit floor to a depth of 4-5 feet; burying of all debris; neutralization of acid forming materials; and revegetation resulting in acceptable growth (see Figures 2.8, 2.9, 2.10). The pictures in these three Figures were taken within 100 yards of each other, and depict pre-mine, active mining, and post-mining landscapes.

At present, 20 states have set up laws and regulatory agencies to monitor strip-mines and to enforce regulations (see Table 2.3). Most laws require the mining operator to file a reclamation plan, to backfill and grade the areas stripped, to replant with acceptable vegetation and to submit periodic reclamation reports. Each agency enforces these regulations by periodic inspections and fines if necessary. However, the large areal extent and a shortage of mining and reclamation inspectors cause an excessive work load for these agencies.

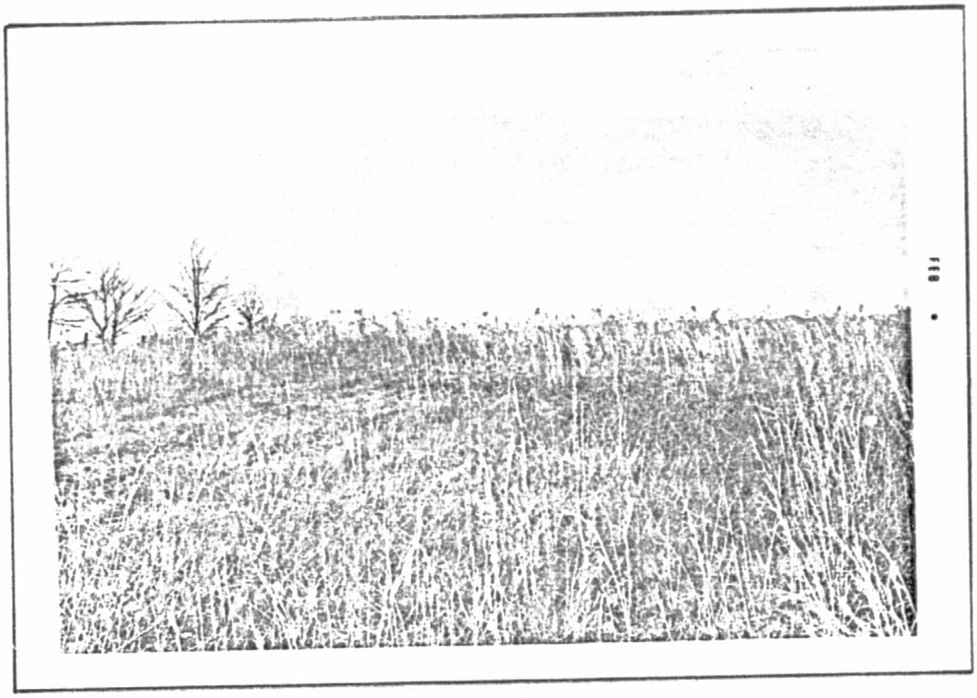


FIGURE 2.8
Undisturbed Area
Sextet Mine, Hopkins County, Kentucky

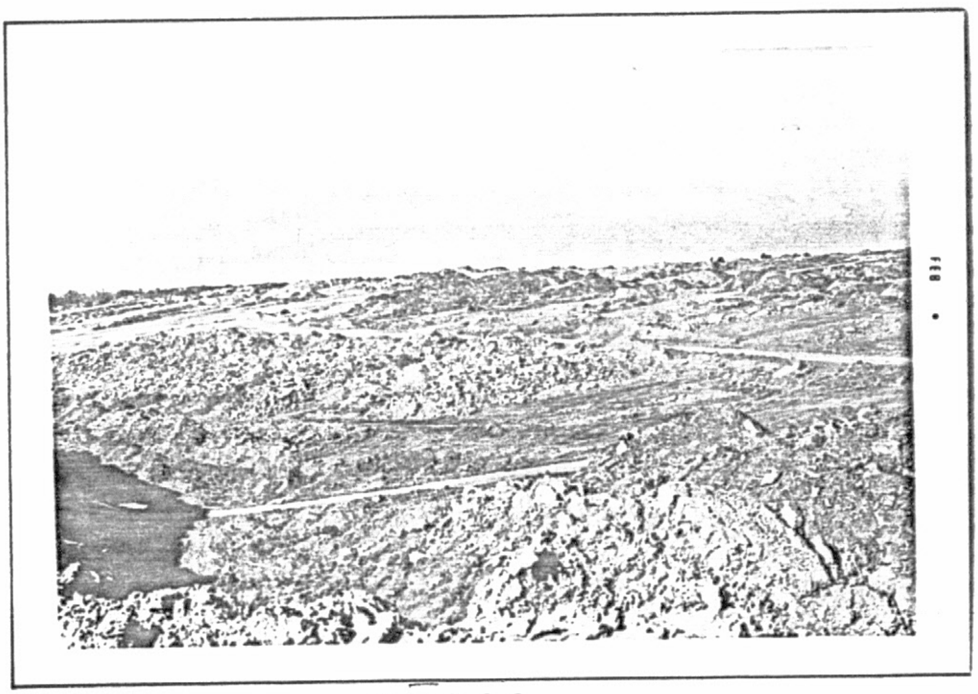


FIGURE 2.9
Active Area
Sextet Mine, Hopkins County, Kentucky

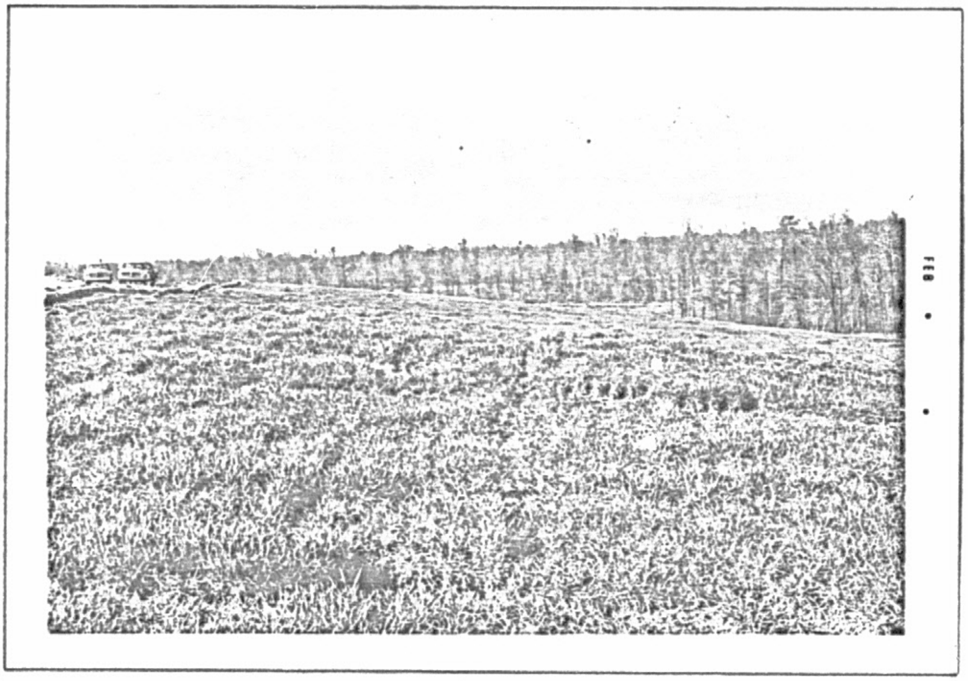


FIGURE 2.10
Reclaimed Area
Sextet Mine, Hopkins County, Kentucky

SUMMARY OF STATE COAL STRIP MINING RECLAMATION LAWS

State	Law and State	Regulatory Agency	A	B	C	D
Colorado	Open Cut Reclamation Act, 1969	Department of Natural Resources		x	x	x
Georgia	Surface Mining Act, 1968	Surface Mined Land Use Board	x	x		
Idaho	Surface Mining Act, 1971	Board of Land Commissioners	x	x	x	
Illinois	Surface Mined Reclamation Act, 1961 (amended 1963, 1967)	Department of Conservation		x	x	x
Indiana	Chapter 344 of the Act, 1941 (amended 1963, 1967)	Department of Natural Resources	x	x	x	x
Iowa	Senate File 279, 1967	Department of Mines and Minerals		x		x
Kansas	Mined Land Conservation Reclamation Act, 1968	Mined Land Conservation and Reclamation Board	x	x	x	x
Kentucky	Chapter 350, Revised Statutes, 1954 (revised 1966)	Department of Natural Resources	x	x	x	x
Maryland	Article 66C, Sec. 657-674, 1967	Bureau of Mines	x	x	x	x
Missouri	Land Reclamation Act, 1971	Land Reclamation Commission	x	x	x	x
Montana	Chapter 245, Session Law, 1967	Bureau of Mines and Geology		x		
North Dakota	Chapters 38, 01-14 Century Code, 1919 (revised 1970, amended 1971)	Public Service Commission	x	x	x	x
Ohio	Chapter 1513, Revised Code, 1965	Division of Forestry and Reclamation	x	x	x	x
Oklahoma	Open Cut Land Reclamation, 1968	Department of Mines and Mining	x	x	x	x
Pennsylvania	Act 418, Public Law 1198, The Bituminous Coal Open Pit Mining Conservation Act	Department of Mines and Mineral Industries	x	x	x	x
Tennessee	Strip Mine Law, 1967	Department of Conservation	x	x	x	x
Virginia	Chapter 15, Strip Mining Act, 1966	Department of Labor and Industries	x	x	x	x
Washington	Title 76, R.C.W., 1971	Board of Natural Resources	x	x	x	x
West Virginia	Article 6, Chapter 20, State Code, 1967	Department of Natural Resources	x	x	x	x
Wyoming	Open Cut Land Reclamation Act, 1969	Commissioner of Public Lands	x	x	x	x

NOTES: A = Filing of Reclamation Planning
B = Backfilling and Grading Required
C = Planting Required
D = Reclamation Reports Filing

Source: U.S. Bureau of Mines, Information Circular 8531, Jan. 1972.

TABLE 2.3

3. THE STUDY AREA

For the analysis of strip mining and reclamation monitoring by satellite imagery it is necessary to choose a representative region. First, the region must have a long history of intensive strip coal mining so that a proper study of pre-law and post-law areas can be made. The area must presently be mined and ideally several stages of reclamation be present. Secondly, the region should have ample Skylab coverage and this coverage should include a variety of film/camera/filter combinations.

The Western Kentucky Coal Fields meet these requirements (see Figure 3.1) These are horizontal to gently sloping strata of bituminous coal of Pennsylvanian age. Coal production from this field started more than 100 years ago and at present more than 33 million short tons are extracted yearly (see Table 3.1)

PRODUCTION AND ACREAGE OF BITUMINOUS COAL, WESTERN KENTUCKY

Year	Production*	Acreage
1965	26,537,294	4,463
1966	27,104,309	4,442
1967	29,740,962	4,220
1968	28,325,046	3,697
1969	28,167,862	4,852
1970	33,281,946	6,392

*short tons

Source: Surface Mining and Reclamation in Kentucky
Kentucky Division of Reclamation, 1972.

TABLE 3.1

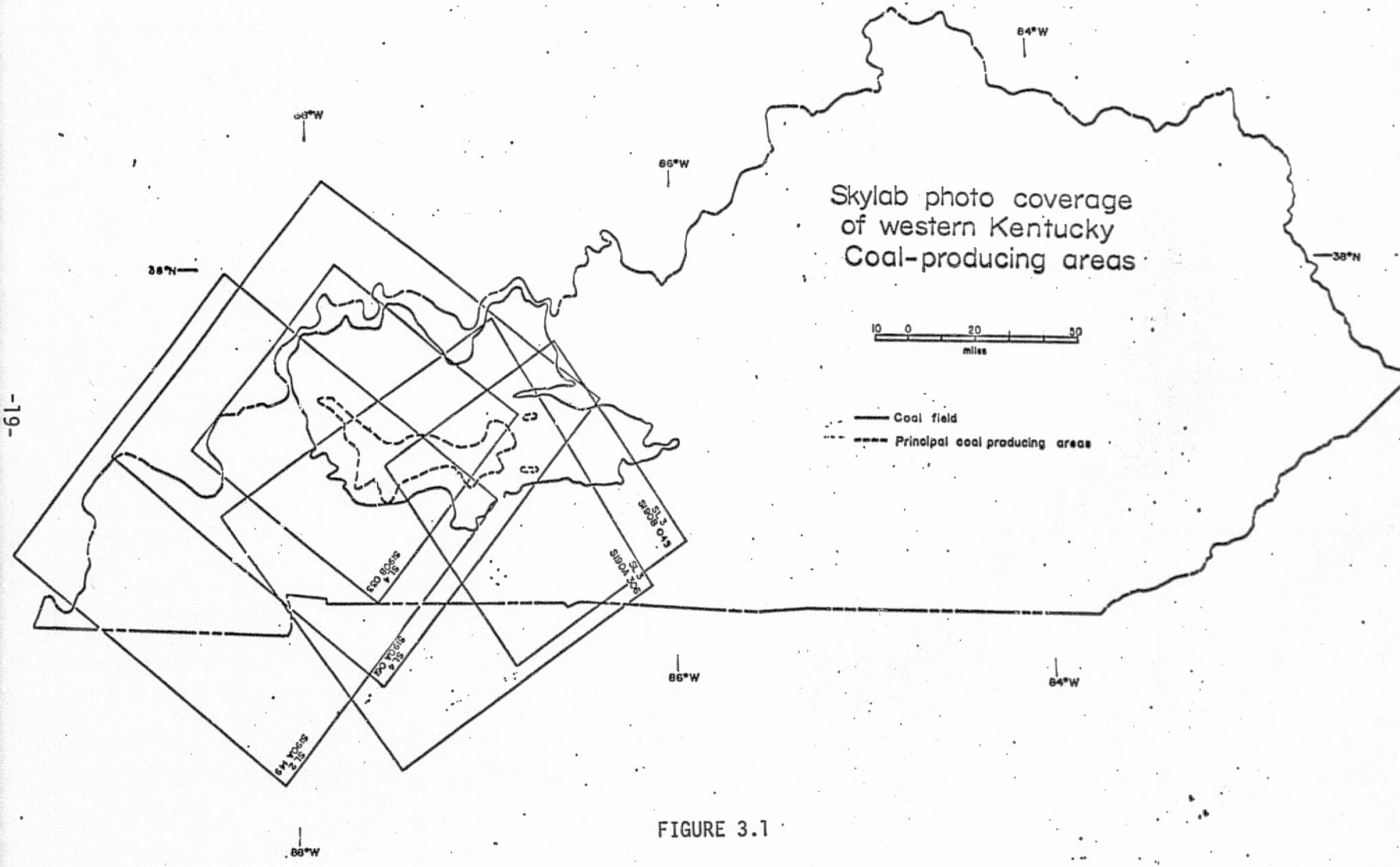

Skylab photo coverage
of western Kentucky
Coal-producing areas
10 0 20 30
miles
Coal field
Principal coal producing areas
84°W
86°W
88°W
38°N
SL 3 SI90B 043
SL 3 SI90A 306
SL 4 SI90B 033
SL 2 SI90A 149

FIGURE 3.1

Strippable bituminous coal resources in the Western Kentucky coal fields are estimated at more than 4 billion tons, particularly centered around Muhlenberg and Hopkins counties (see Table 3.2).

STRIPPABLE RESOURCES AND RESERVES OF BITUMINOUS COAL IN WESTERN KENTUCKY, JANUARY 1st, 1968 (by county)

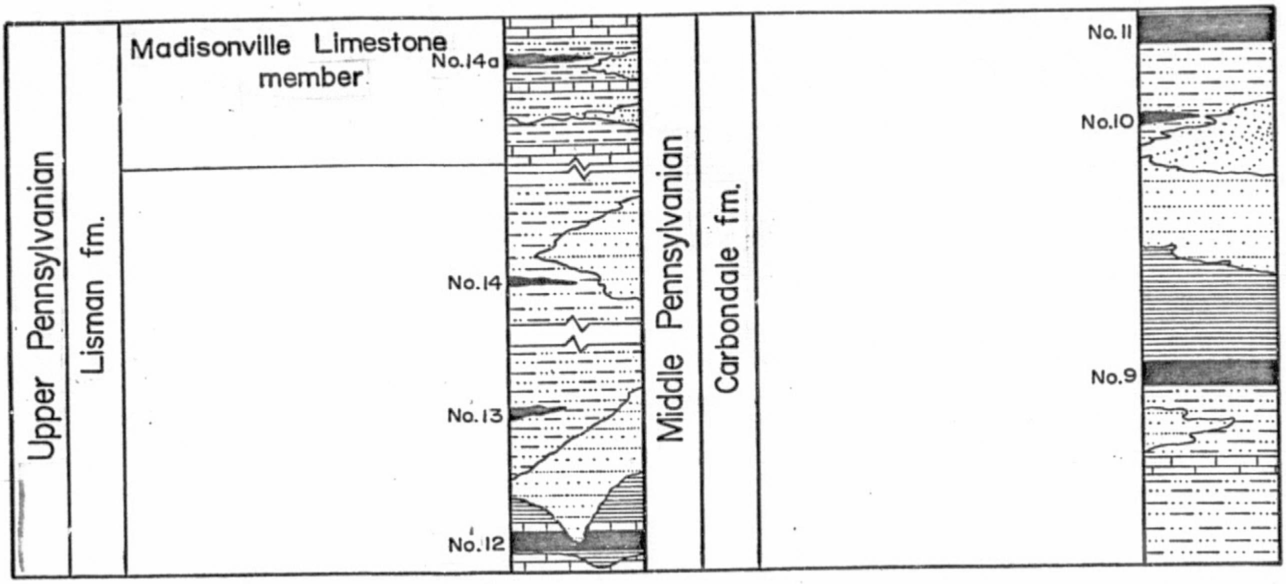
County	Strippable Resources*	Strippable Reserves*
Butler	206,000	39,000
Christian	32,000	7,000
Crittenden	4,000	7,000
Daviess	346,000	69,000
Edmonson	58,000	9,000
Grayson	7,000	1,000
Hancock	75,000	14,000
Henderson	670,000	165,000
Hopkins	687,000	152,000
McLean	173,000	43,000
Muhlenberg	1,070,000	258,000
Ohio	700,000	161,000
Union	117,000	25,000
Webster	126,000	27,000
Total	4,271,000	977,000

* in thousand short tons.

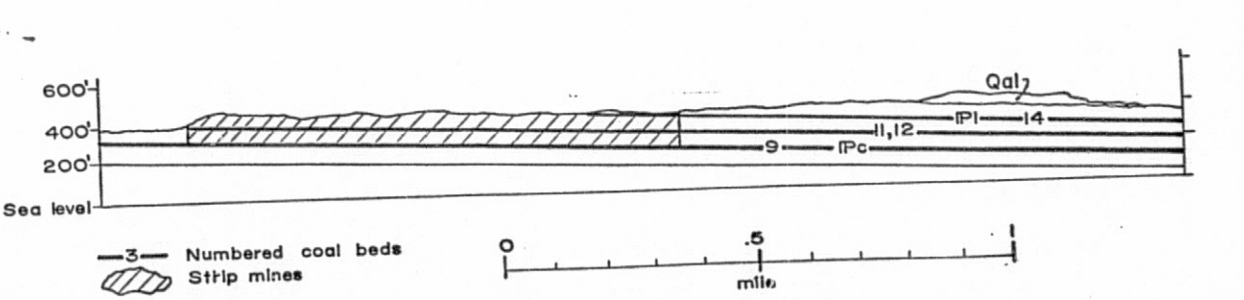
Source: Bureau of Mines Information Circular 8531, January, 1972.

TABLE 3.2

At present, the Nos. 9, 11, 12 and 14 (see Figure 3.2) coal beds of this field are being strip mined. A small amount of Nos. 14 and 15 coal beds have been extracted. No. 9 coal bed contains the largest recoverable resources. It has been extensively mined, but large reserves still remain in the northern parts of the coal field where the coal bed dips too much under the surface.



GENERALIZED LITHOLOGY AND PROFILES
WESTERN KENTUCKY COAL FIELDS



SOURCE: U.S. GEOLOGICAL SURVEY, GEOLOGIC MAPS

FIGURE 3.2

In 1964 the first effective Reclamation Law was passed in the State of Kentucky.. Prior to this law more than 700,000 acres had been mined in the Western Kentucky Coal fields. Area strip mining left spoil ridges; whatever little vegetation is present was natural growth under these harsh conditions since no effort was made to cover the acid producing materials. Presently there are more than 40,000 acres of these "orphan areas" in Western Kentucky (see Figure 3.3). Since the 1964 law and particularly since the newer, more effective law of 1966 orphan areas have not been produced. It should be noted here that no one is responsible to reclaim pre-law orphan areas and the State of Kentucky is in dire need of funds to put reclamation practices in effect in these aesthetic and ecologic eyesores. The purpose of the law was to create the Division of Reclamation in the Department of Natural Resources and Environmental Protection, Bureau of Land Resources. The main goal of this agency is the "minimization of

FIGURE 3.3
Orphan Area, Hopkins County, Kentucky

the impact of surface mining upon the environment." (Kentucky, Division of Reclamation, undated brochure).

One of the principal field offices of this newly created agency is located in Madisonville, Kentucky, and some of the specifications that this office must check using the present means of its jurisdiction are:

- Check reclamation plan, determine damage to public roads and streams.
- Check breakthrough of acid waters.
- Check the extent of ponded runoff waters.
- Check dumping and piling of overburden.
- Check to see if proper backfilling is completed.
- Check vegetative cover requirements.
- Check type of planting or seeding.
- Check date of planting or seeding.
- Check the area of land planted or seeded.
- Check the effectiveness of planting or seeding.

The law also gives the director of the Division of Reclamation the power to suspend a permit and thereby halt all operations for non-compliance with the regulations. In addition to suspension, the operators must pay fines ranging from $100 to $1000 per day of non-compliance. The mine operators are also required to post a bond of $100 to $500 per acre which is forfeited if the area is not reclaimed properly.

The mine inspection usually takes place without notice by one of the ten to twelve mine inspectors from the field office. It should be noted here that one mine inspector may be responsible for up to ten mines ranging in sizes from a few acres to thousands of acres plus being responsible for the continued surveillance of the landscape against small, illegal operators. Any fast, accurate monitoring technique, such as that presented here, is a welcome relief.

4. AVAILABLE PHOTO COVERAGE

Material for this study consisted of photographs taken with the S-190A multispectral photographic sensor and the S-190B earth terrain camera carried aboard the Skylab orbital workshop. These cameras, using six film types (see Table 4.1) in conjunction with different filters, produced a wide spectrum of exposures.

Film Number	Sensor	Type
EK 2424	S-190A	Aerial black and white infrared film
EK 2443	S-190A	Aerial color infrared film
SØ 356	S-190A	Aerial color film
SØ 022	S-190A	Aerial black and white film
EK 3443	S-190B	Aerial color infrared film
SØ 242	S-190B	Aerial color film

TABLE 4.1

The photographs, in the form of both 9" x 9" and 70 mm transparencies were reviewed and the frames providing the coverage of the Madisonville, Kentucky, area were chosen for analysis. These study frames, shown earlier in Figure 3.1, were contained in 14 rolls of film from the S-190A camera and 2 rolls of S-190B film spanning the three Skylab missions. General information on the transparencies used for the analysis is given in Table 4.2.

TABLE 4.2

IMAGERY DESCRIPTIONS

Pass Description	Camera	Camera Station	Roll #	Frame #	Film Type	Filter	Wavelength (in)	Remarks
SL-2 EREP Pass 6	S-190A	1	07	141	EK2424	CC	.7-.8	
9 June 1973		2	08	141	EK2424	DD	.8-.9	
15:09:26 GMT		3	09	149	EK2443	EE	.5-.88	underexposed, high contrast
		4	10	149	SØ356	FF	.4-.7	underexposed, high contrast
		5	11	141	SØ022	AA	.5-.6	underexposed, very high contrast
		6	12	141	SØ022	BB	.6-.7	
SL-3 EREP Pass 42	S-190A	1	37	306	EK2424	CC	.7-.8	1 positive & 1 negative transparency
15 September 1973		2	38	306	EK2424	DD	.8-.9	1 positive & 1 negative transparency
16:33:30 GMT		3	39	306	EK2443	EE	.5-.88	
		4	40	306	SØ356	FF	.4-.7	
		5	41	306	SØ022	AA	.5-.6	1 positive & 1 negative transparency
		6	42	306	SØ022	BB	.6-.7	1 positive & 1 negative transparency
	S-190B		87	048/049	SØ242	4		2 photographs needed to cover study area
SL-4 EREP Pass 54	S-190A*	3	51	061	EK2443	EE	.5-.88	overexposed, haze obscuring study area
30 November 1973								
16:36:21 GMT		4	52	061	SØ356	FF	.4-.7	overexposed, haze obscuring study area
	S-190B		90	032	SØ242	NONE		

*Film from S-190A camera stations 1, 2, 5 and 6 were not received.

5. VIEWING TECHNIQUES

A number of techniques were studied for analyzing the Skylab transparencies including standard photo enlarging equipment, stereoscopes, magnifying reticles used with a light table, and Map-O-Graph.

The best method for viewing the imagery was found to be a simple overhead transparency projector, since transparencies of this type (9" x 9" copy) having scales approximately 1/475,000 (S-190B) and 1/725,000 (S-190A) are too small to be viewed without enlargement. The less expensive overhead projector models using a plastic fresnel collimating lens were found to be unsatisfactory as the resolution of the projected image tends to be too poor for analysis. The overhead projectors of a type similar to the Transpaque Auto Level Model 20400 used in this study, (see Figure 5.1) however, use a parabolic reflector in their optical system and produce pictures which are perfectly suitable for this type of study. This type of projector is readily available at a cost of approximately $500. This projector when used with a smooth white screen, such as poster board, can produce high resolution images in any type of darkened viewing area. The screen should be mounted on a flat rigid surface to eliminate distortions in focus. The 9" x 9" format is necessary as the 70 mm photo format was found to be unsuitable for this type of projection because of its small size.

The image produced by the overhead projector has the advantages of being viewable by any number of people, can be studied closely and features can be easily traced when projected onto a suitable paper. The scale is infinitely variable just by changing the distance from the screen to the projector. The S-190B transparencies were enlarged to a scale of

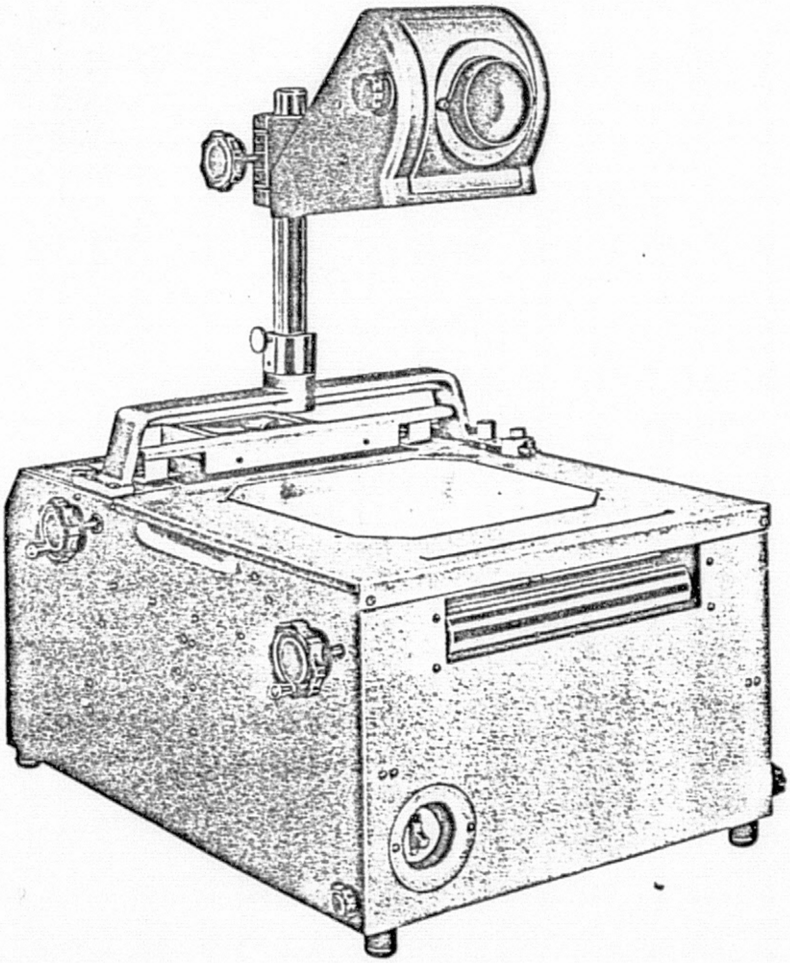


FIGURE 5.1
Transpaque Auto Level Overhead Projector

1:18,000 for detailed area studies and could be enlarged further with little loss of resolution. Most of all the technique is simple, efficient and produces excellent images which can be used by laymen with no photo-interpretation experience.

6. IDENTIFICATION OF DISTURBED AREAS

The first analytical section of this study is to determine the applicability of satellite imagery for the overall recognition of coal strip mined areas. The general aim is to be able to distinguish this type of land-use from all others. Due to the physiographic and climatic elements of western Kentucky, the land use types generally fall in the following categories:

Farming

Urban areas

Lakes, streams and reservoirs

National Parks

Natural Forests

Strip Mines

Highways and Railroads

The procedure followed for this analysis is similar to that explained in Chapter 5; each transparency was viewed independently through the overhead projector at scales ranging approximately around 1/100,000 so that the entire photo area could be viewed at one time. At this scale it is difficult to recognize some of the features peculiar to strip-mines such as pits, ramp roads, etc. Therefore an initial recognition of the sites disturbed by strip-mining is necessary. Individual transparencies were viewed and visual inspections of land-use patterns were made, and recorded.

The two most applicable transparencies were: SL-3, S-190A camera station 2 B & W IR (negative transparency) and SL-3, S-190B, color infrared imagery. The following are notes from each of these photo types.

6.1 SL-3, S-190A, CAMERA STATION 2 IMAGERY

Two transparencies from Mission SL-3, Camera S-190A, camera station 2 in black and white infrared film (see Table 4.2 for more detailed information on film and filter) were obtained; one positive and one negative. The lower 1/4 of the photo is almost totally obscured by clouds, fortunately however, the strip mines are located in the upper right sector where cloud cover is minimal.

Figure 6.1 is an annotated print of the negative transparency. As can be seen, the most outstanding feature in this print is the elongated, U-shaped feature formed by the Kentucky and Barkley Lakes. It should be noted here that this large water body proved to be a valuable feature in the initial recognition and orientation of the transparencies. Medium sized lakes such as Lake Beshear and Lake Malone were also identified. It was decided to use the negative transparency because it afforded better tonal contrasts. In the negative transparency, even small lakes such as Peewee Lake, Pleasant View Lake, and Loch Mary Reservoir appear as very distinct light features contrasting with darker tones surrounding them. The area disturbed by strip-mining is distinguished by its light tone, and by the series of lighter toned lines representing the highwalls of the area strip mines. These lighter tones are due to the lower infrared reflectance of these barren and exposed surfaces. Please notice the almost perfect correlation between the outline of strip mines in this Figure 6.1 and the outline of the western Kentucky coal producing


STRIP MINE DISTURBED AREA
Ohio
Lake Malone
Lake Beshears
Barkley Lake
Kentucky Lake

FIGURE 6.1

areas shown in Figure 3.1, which represents the southernmost outcrop of the coal bearing beds in the regional structure.

6.2 SL-3, S-190B IMAGERY

The transparencies from Mission SL-3, Camera S-190B, in color-infrared (see Table 4.2 for more detailed information on film and filter) proved to be also of good quality for overall strip mine recognition. Since these photos were taken during the same Mission as SL-3, S-190A, camera station 2 discussed above, the area is under the same cloud cover conditions.

Figure 6.2 is an annotated print of this imagery; notice that, of course, the area covered is somewhat smaller and at a much larger scale (1/370,000 compared with approximately 1/604,000 in Figure 6.1). The detail is greater here, not only due to a larger scale but also due to the film's higher spectral resolution. Unfortunately the large water body of the Kentucky/Barkley Lake falls outside the photo; yet, highways appear prominently as light white lines and they serve well for orientation purposes. The Western Kentucky Parkway, U.S. 41, U.S. 231, and U.S. 31W were recognized and traced. Medium sized water bodies such as Rough River and Norlin River Reservoirs were easily identified by their dark blue color and characteristic shape. Small water bodies are not readily seen due to the confusion in color and size with the clouds' shadows. However streams such as the Green and Barren Rivers are discernible due to their dark blue color and linearity. It should be noted that the Mammoth Cave National Park's boundary were very well defined since it

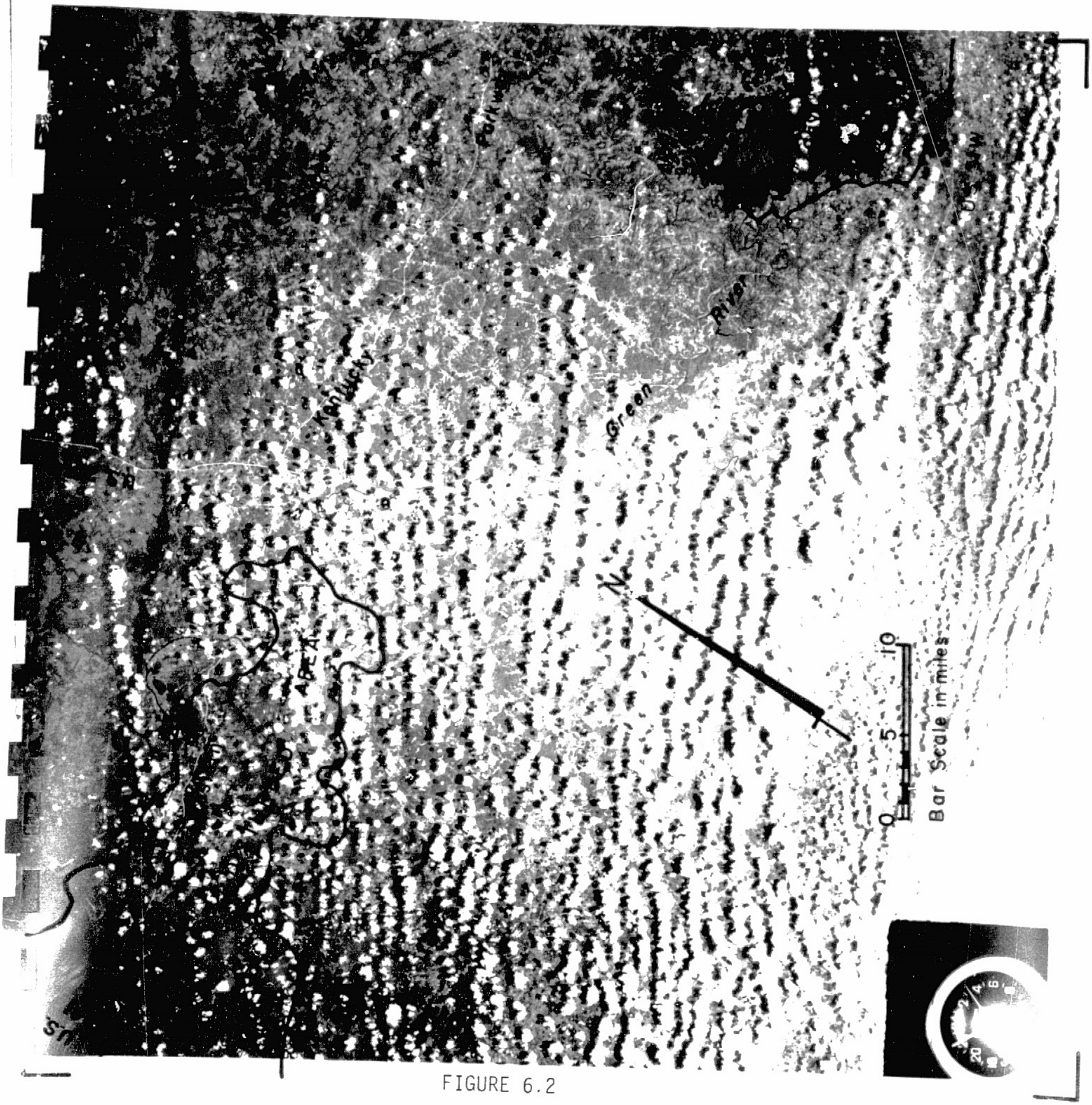


FIGURE 6.2

represented a change in red color perhaps due to the completely different land-use types between the Park and the farming area surrounding it. Strip mines were prominent, appearing as the only light blue tones in the photograph due to the low reflectance in the infrared wavelengths of the disturbed areas. Again the correlation between the western Kentucky coal fields depicted in Figure 3.1 and the outline of strip mine area plotted here correspond rather well.

Prints as shown in Figures 6.1 and 6.2 are representations of the transparencies; the transparencies are the better interpretation medium.

6.3 SUMMARY

All available imagery were analyzed for the identification of strip-mine disturbances and the results are presented in Appendix "A". The best film/filter combinations for overall strip mine recognition appear to be those obtained from sensor S-190A, camera stations 1, 2, and 3. It is important to note here that all these camera stations used infrared film (black and white or color). Due to the larger scale and thus a resultant smaller area coverage, imagery from sensor S-190B is not considered ideally suited for regional overall recognition of strip mined areas.

Since the satellite passes are all in the morning, there is an important lack of spectral reflectance in the infrared wavelengths from disturbed mined areas. Strip mines appear light blue in the color infrared and appear as a light tone (negative copy) in black and white infrared. These differences in color and tone from the surrounding fields and forests (which have higher spectral reflectance at these wavelengths) makes identification of strip mines feasible. For these reasons it is felt that the infrared films are best suited for this analysis.

7. DETAILED MONITORING

Detailed monitoring of coal strip mines is performed using the same equipment and procedures as presented in Section 5. The main viewing difference is that the overhead projector was placed farther from the screen to obtain larger scales 1/36,000 for S-190A and 1/18,000 for S-190B. Since mapping the entire 9" x 9" original transparency at this scale would be a time consuming effort, it was decided to choose a representative area. The area is bounded on the north by the Illinois Central Railroad, on the west by U.S. 41, on the south by the Western Kentucky Parkway and on the east by the edge of the photo coverage. This area contains farming fields, a river, naturally vegetated areas, active strip mines, reclaimed areas, and inactive strip mines (orphans). It should be noted here that the transparency was almost entirely masked by a black, heavy-weight paper with 2" x 2" cut out, so as to allow only the area selected to be projected on the screen. This procedure enhanced viewing because it eliminated the projector's light except on the study area resulting in an image which appears sharper to the eye.

All the imagery received were viewed and analyzed in detail as reported in Appendix "B". The analysis proceeded as follows: once the image was projected onto the screen, a general reconnaissance was performed aided by the topographic and geologic maps of the area. Then tracing of the different shapes and tones was performed by placing a tracing sheet over the screen and pencilling the tonal boundaries as projected. A classification of different tones was done using a Kodak gray scale (see Fig. 7.1) for black and white imagery and a classificatory code was devised for the color and color infrared imagery (see Table 7.1). The

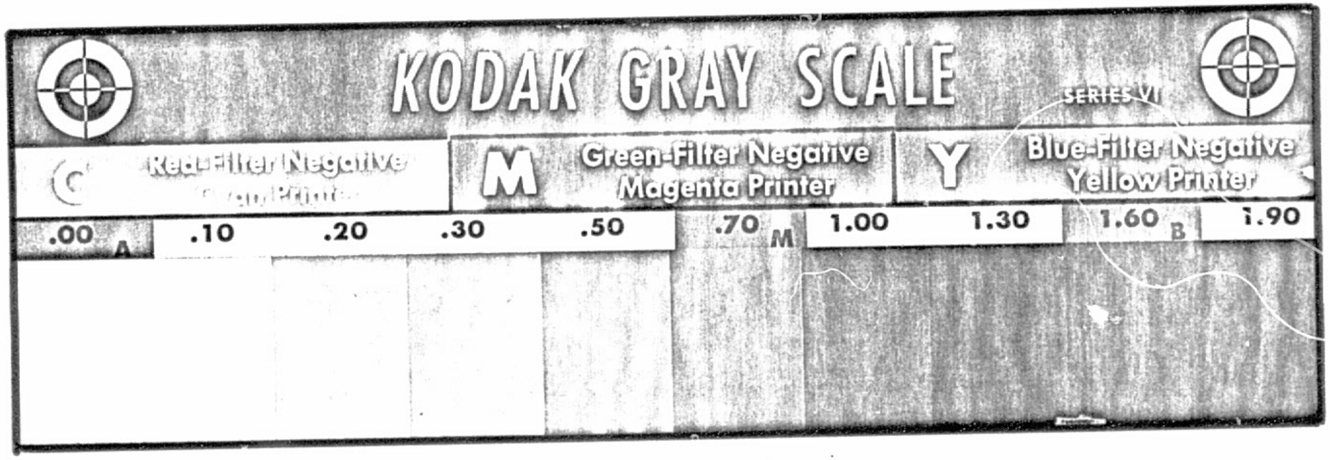


FIGURE 7.1

Kodak Gray Scale

applicability of three selected transparencies for detailed monitoring is described in the following sections.

Color Classificatory Coding
Used for Color and Color Infrared Imagery

Code	Color	Code	Intensity
1	Red	a	Very light
2	Blue	b	Light
3	White	c	Medium
4	Brown	d	Dark
5	Black	e	Very dark

TABLE 7.1

7.1 SL-2, S-190A, 6 (B/W Positive) IMAGERY

This transparency is underexposed by 1/2 f-stop and this seems to be partly responsible for its poor quality, as it can be seen in Figure 7.2 which is an annotated print of this transparency. A variety of tonal patterns were discernible and traced (see Figure 7.3) yet this is somewhat misleading because similar features often had different tonal characteristics. Close inspection revealed that light tones (0 - .2) or areas of high reflectance, usually represent south-facing highwalls (see Figure 7.4), ramp roads and presently (at time of satellite pass) active mines; medium tones (.3 - 1.5) usually represent orphan areas, reclaimed areas and farming land; dark tones (1.6 - 1.8) usually represent the pit of orphans or active mines, the corona of trees in countour mined areas, and water impoundments; and very dark tones >1.9 or areas of low reflectance usually represent natural vegetated areas (see Figure 7.5). A

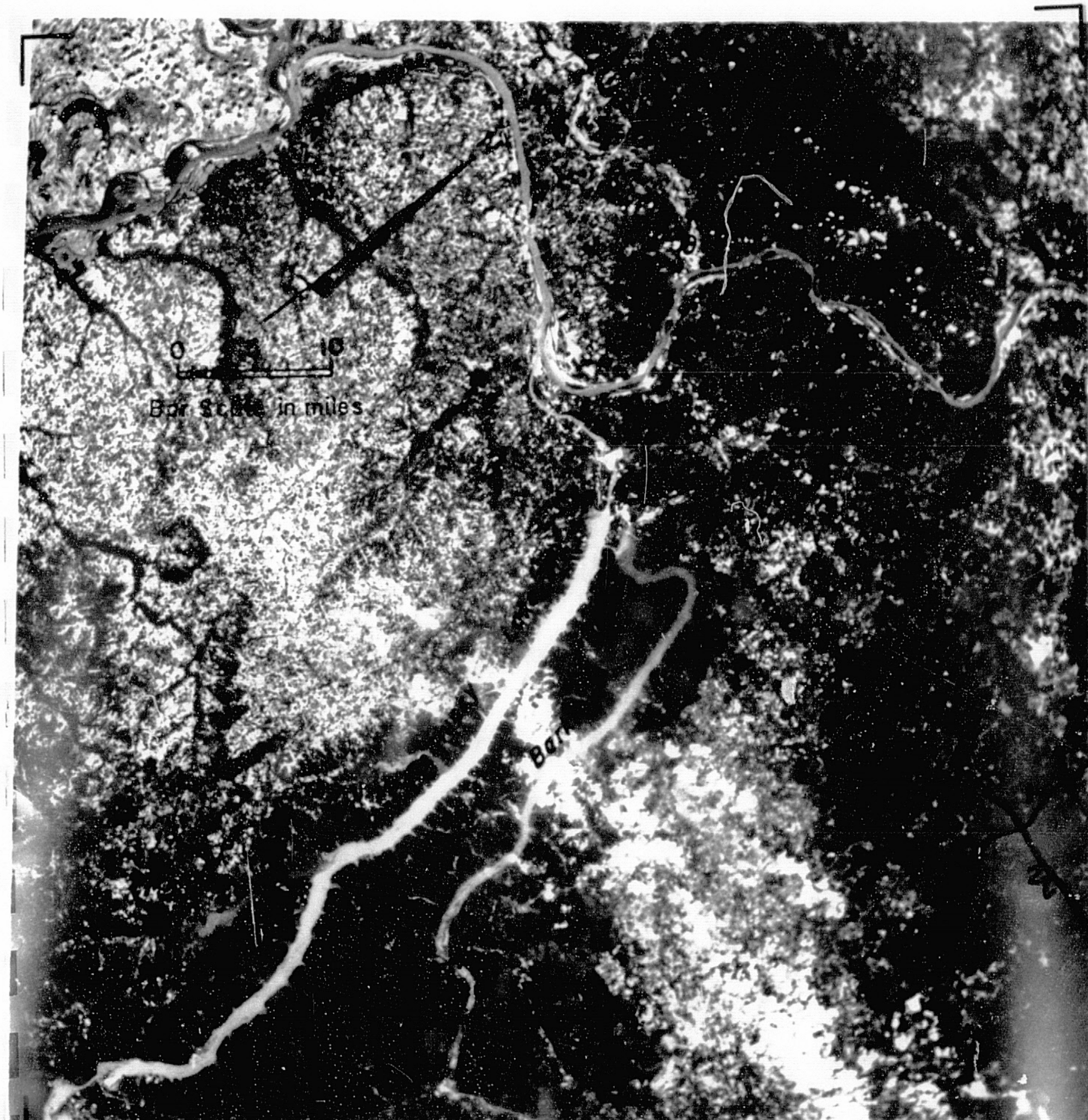


FIGURE 7.2

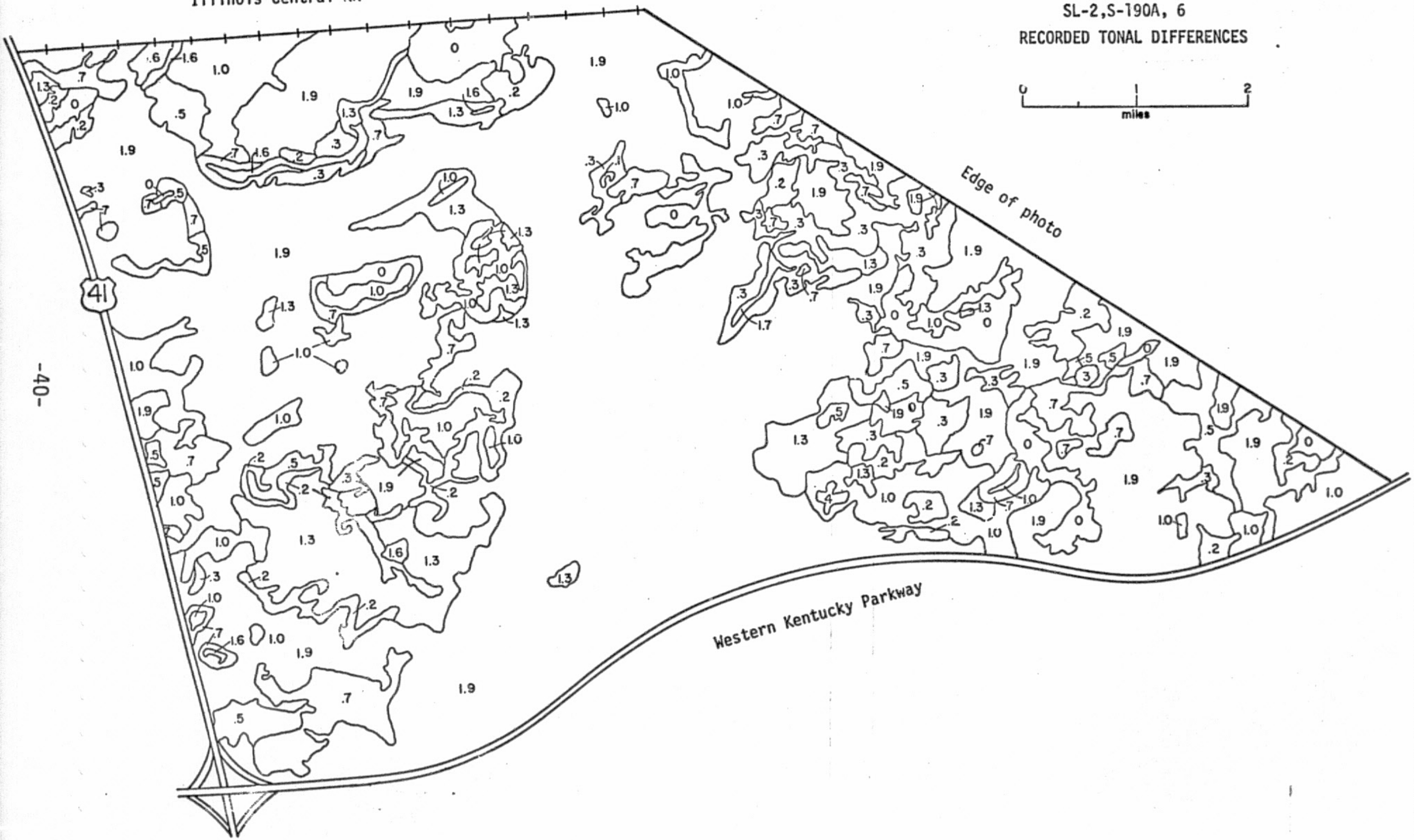


FIGURE 7.3
SL-2,S-190A, 6
RECORDED TONAL DIFFERENCES

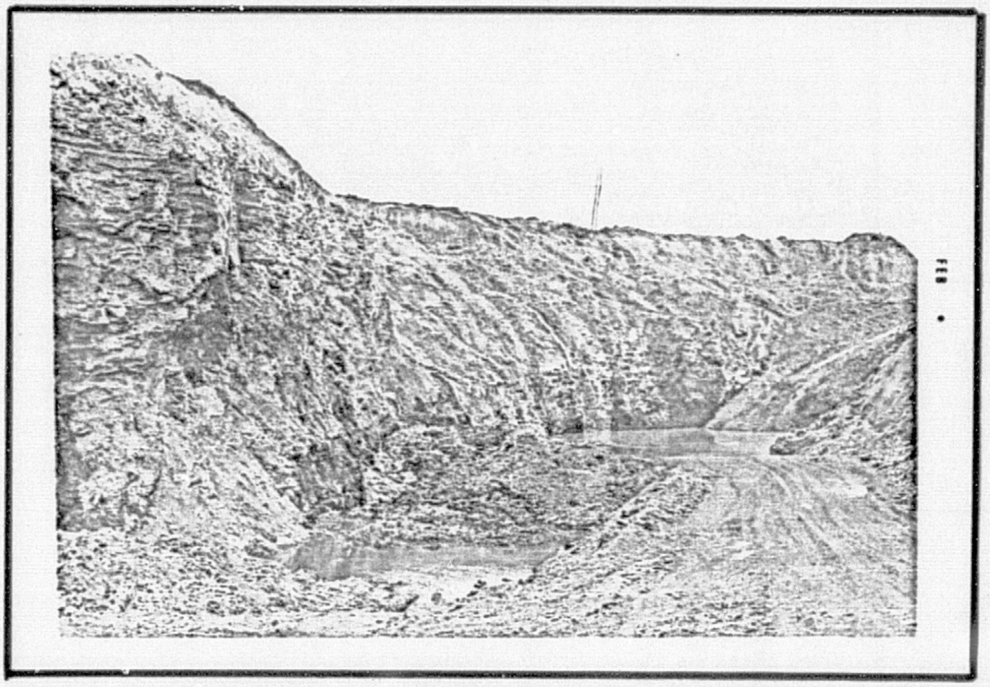


FIGURE 7.4
South facing highwall, Cimarron Coal Co., Hopkins County, Kentucky.

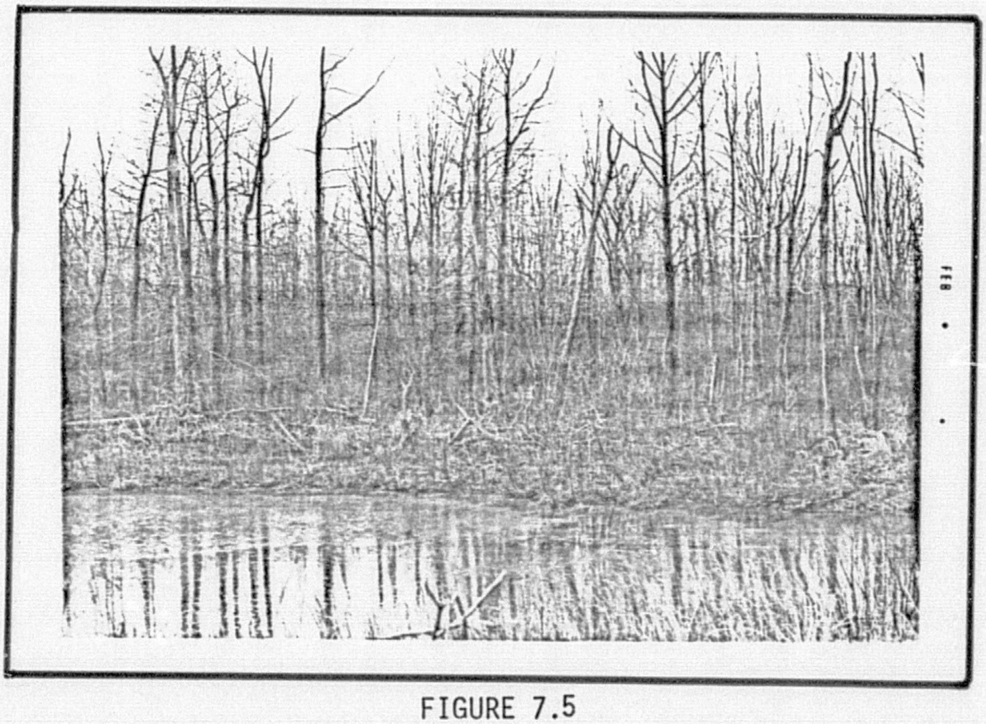


FIGURE 7.5
Natural vegetation, Pond River Floodplain, Hopkins County, Kentucky.

generalization of tones was made and the resulting boundaries were traced (see Figure 7.6). It is necessary to note here that this is of medium quality for monitoring purposes because, for example, there is no difference between south-facing highwalls and ramp roads which places an impediment in accurate recognition and surveillance.

7.2 SL-2, S-190A, 3 (Color IR) IMAGERY

Similar procedures, as noted above, were used to analyze this imagery. Again, there is a great variation; in this case of colors and intensities rather than gray tones as it can be seen in Figure 7.7 which is an annotated print of this transparency. Different colors and intensities were also recorded and traced for the area described above. The resulting patterns appear in Figure 7.8. Generally, naturally vegetated areas appeared as dark reddish colors (1E, 1D, 1C); it should be noted that vegetational differences were evident, for example timbers growing in the floodplain of Pond River were of different red intensity (1D) than those in the interfluvial areas (1C). Generalizations were necessary in this imagery also, because the variety of colors and intensities tend to obstruct rather than enhance recognition of the maps presented here, a generalized map is shown in Figure 7.9. The following generalizations tend to conform rather well to these characteristics:

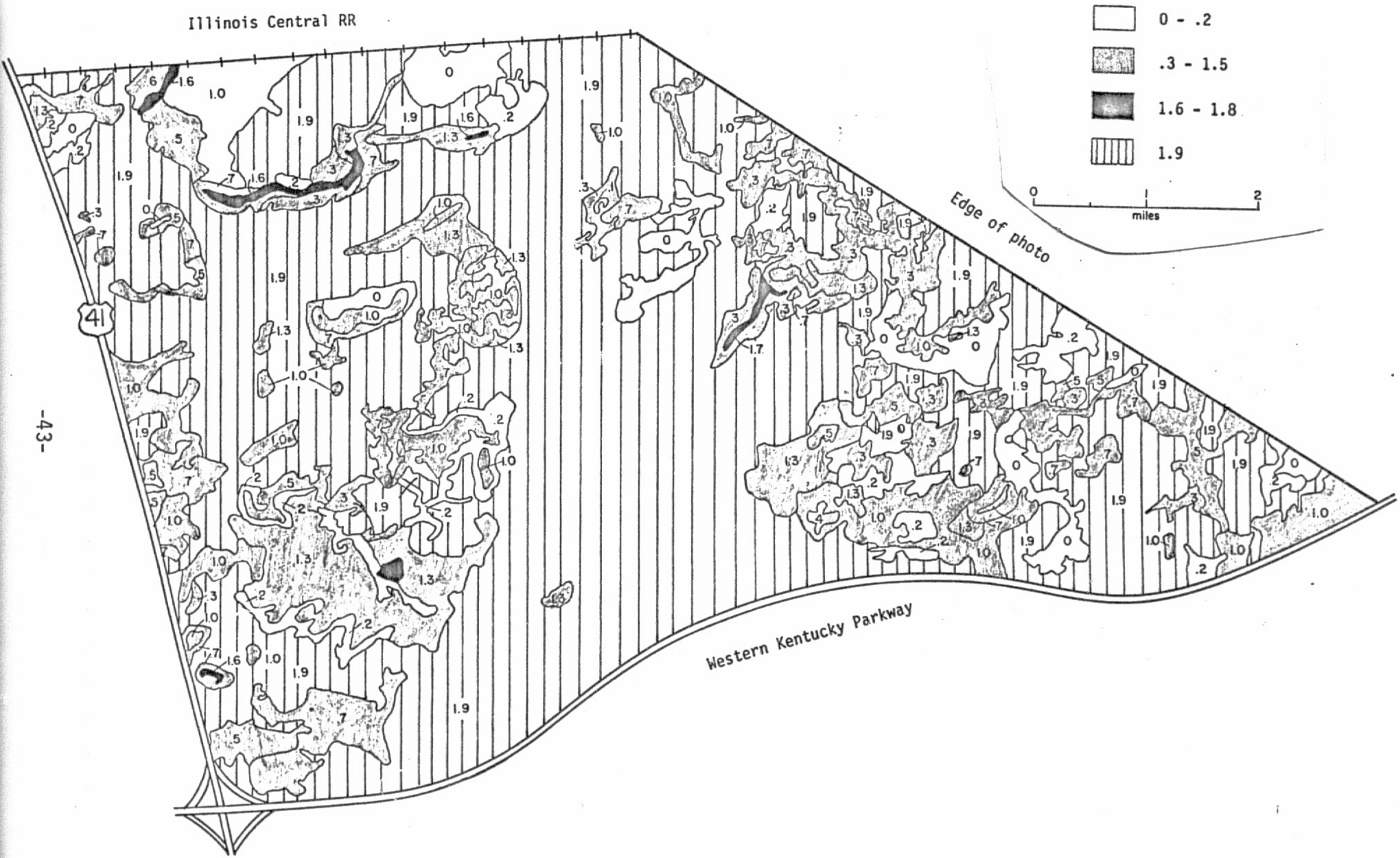
1A, 1B (very light to light reds)-undifferentiated farming or natural grasses appear in these intensities of red.

1E, 1D, 1C (very dark to medium reds)-represent naturally vegetated areas, notice that the timbered corona of contoured strip mines now appears discernible from pit floors.

FIGURE 7.6

SL-2, S-190A, 6

GENERALIZED TONAL DIFFERENCES



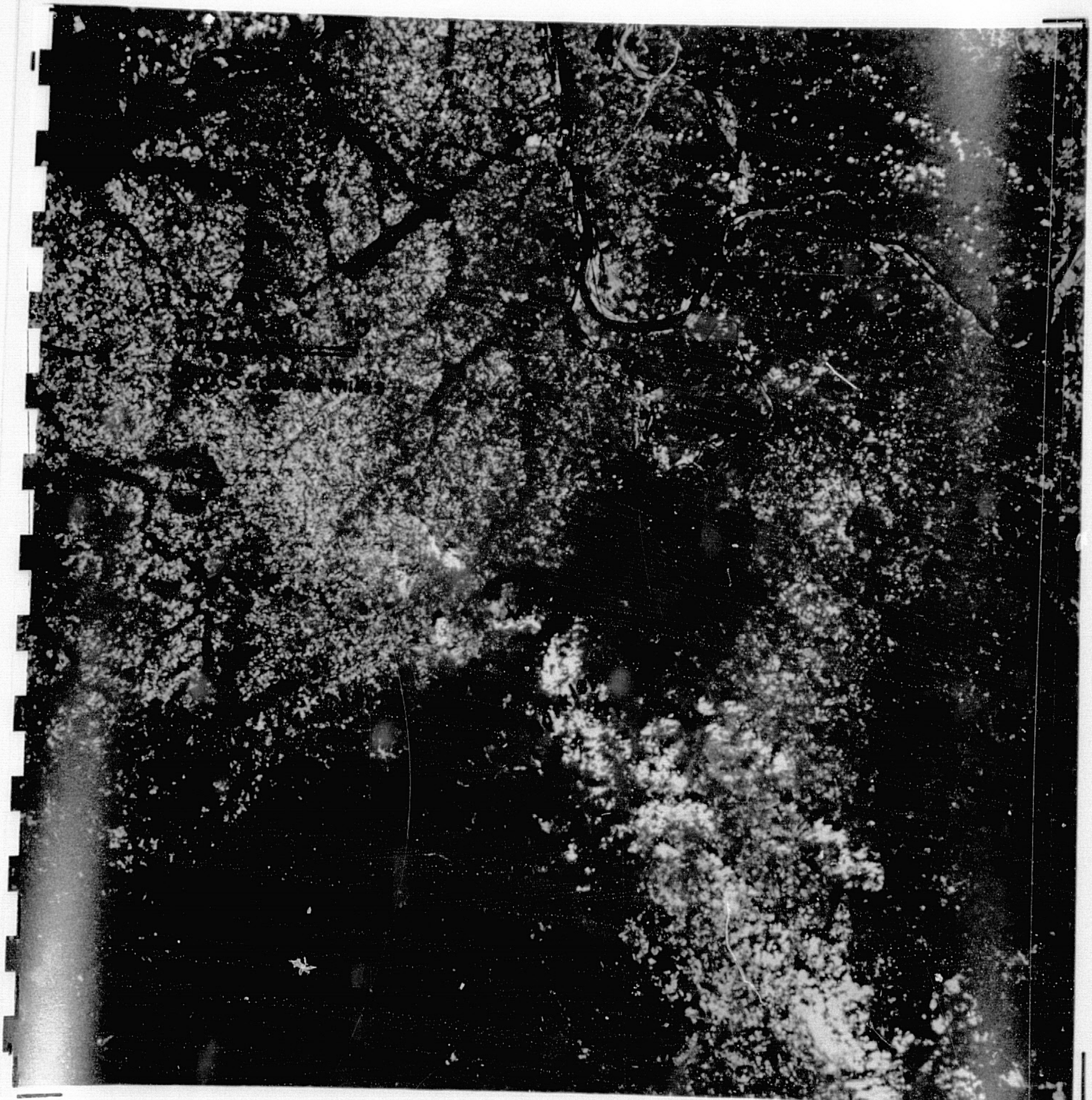


FIGURE 7.7

FIGURE 7.8

[redacted]2, S-[redacted], 3

RECORDED COLOR DIFFERENCES

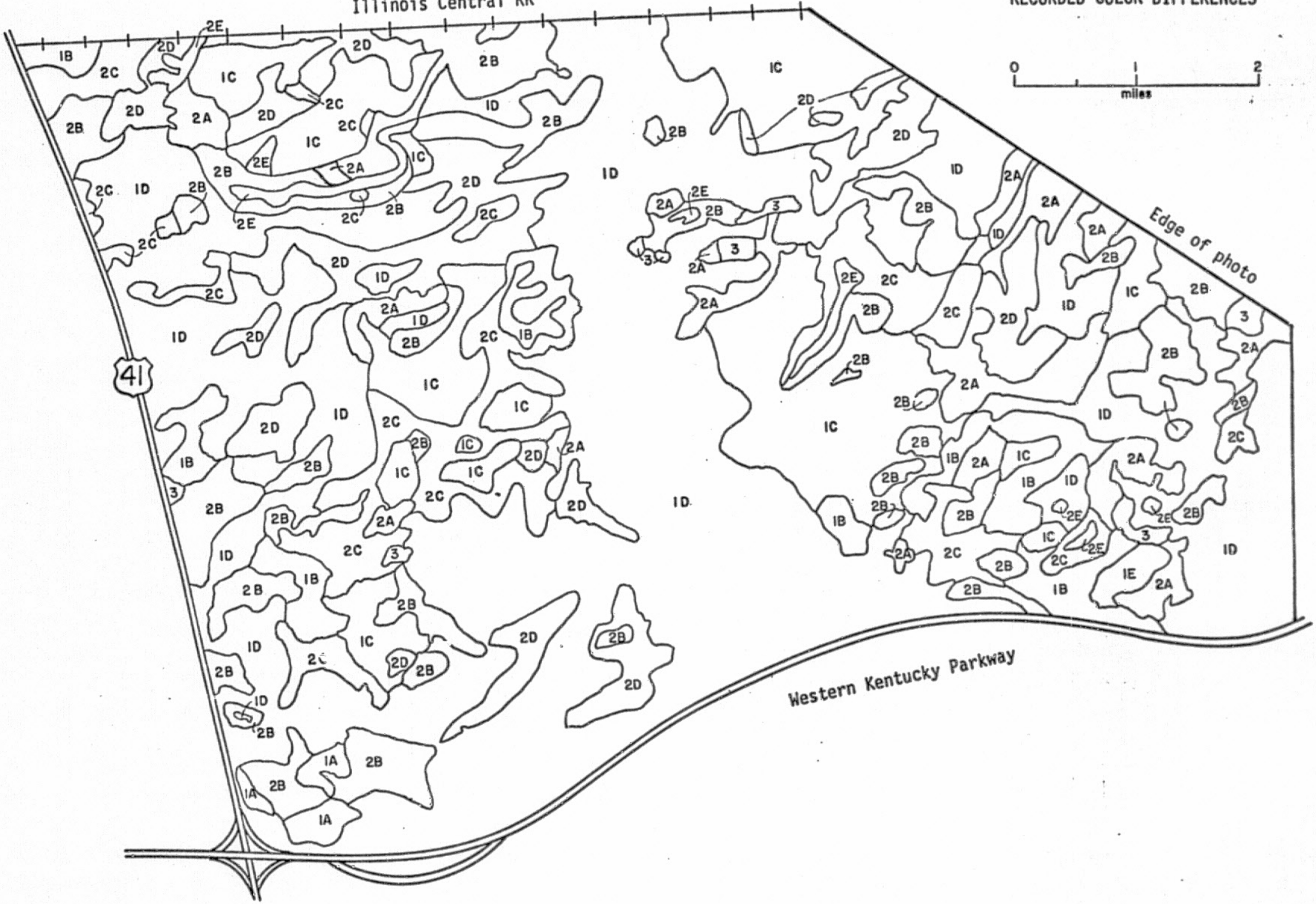
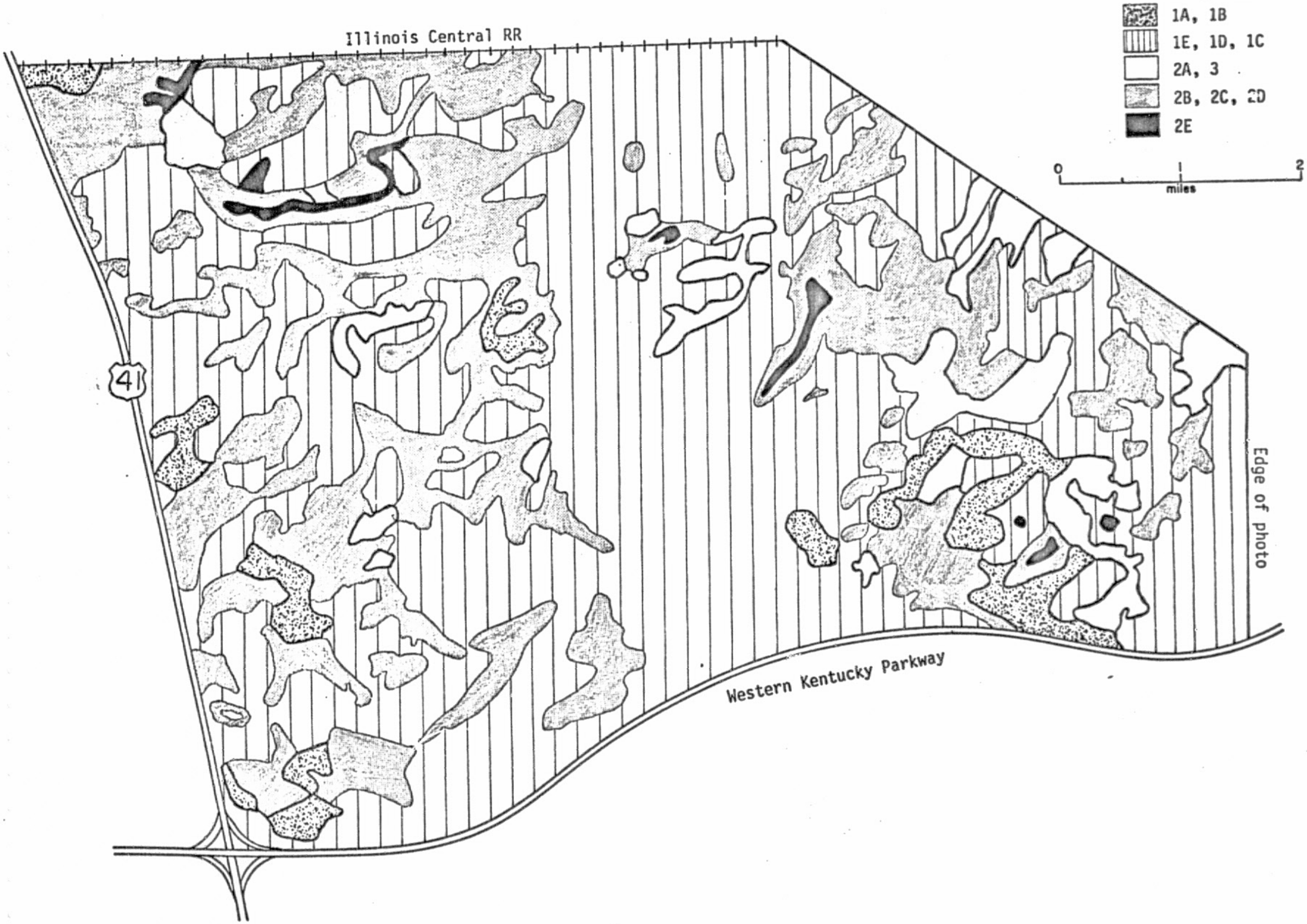


FIGURE 7.9

SL-2, S-190A, 3

GENERALIZED COLOR DIFFERENCES



2A, 3 (very light blue, white)-exposed highwalls and active sections of strip mines, particularly those with broad shallow pits appeared in these colors and intensities.

2B, 2C, 2D (light to dark blues)-represent strip mines in all stages of activity and reclamation; notice the very close correlation between these intensities of blue (at time of exposure, 9 June, 1973) and the areas depicted in the U.S.G.S. topographic sheet (1963), although map and photo are at least ten years apart (see Figure 7.10).

2E (very dark blue) the deep pit floors of large mines were observed to be very dark blue. These are prominent and their contrast with highwalls or reclaimed areas is sharp so that their recognition is enhanced.

7.3 SL-4, S-190B COLOR IMAGERY

This is by far the outstanding photograph for monitoring coal strip mines. Its sharpness and high resolution are truly amazing as it can be seen in Figure 7.11 which is an enlarged portion of this transparency. It is felt that since there is a greater variation of colors (whites, blues, reds, browns) and intensities, it is best to depict the general observations made using this imagery and then to devote a few sections of this report to examples of detailed areas.

Most open water features such as Peewee Lake appear as medium blue with intensities varying according to depth of water. Siltation, sedimentation and general flow of sediments are identified by their brownish color. This is probably of great importance for studies of the environ-

FIGURE 7.10
COMPARISON BETWEEN SL-2, S-190A, 3
AND TOPOGRAPHIC SHEET

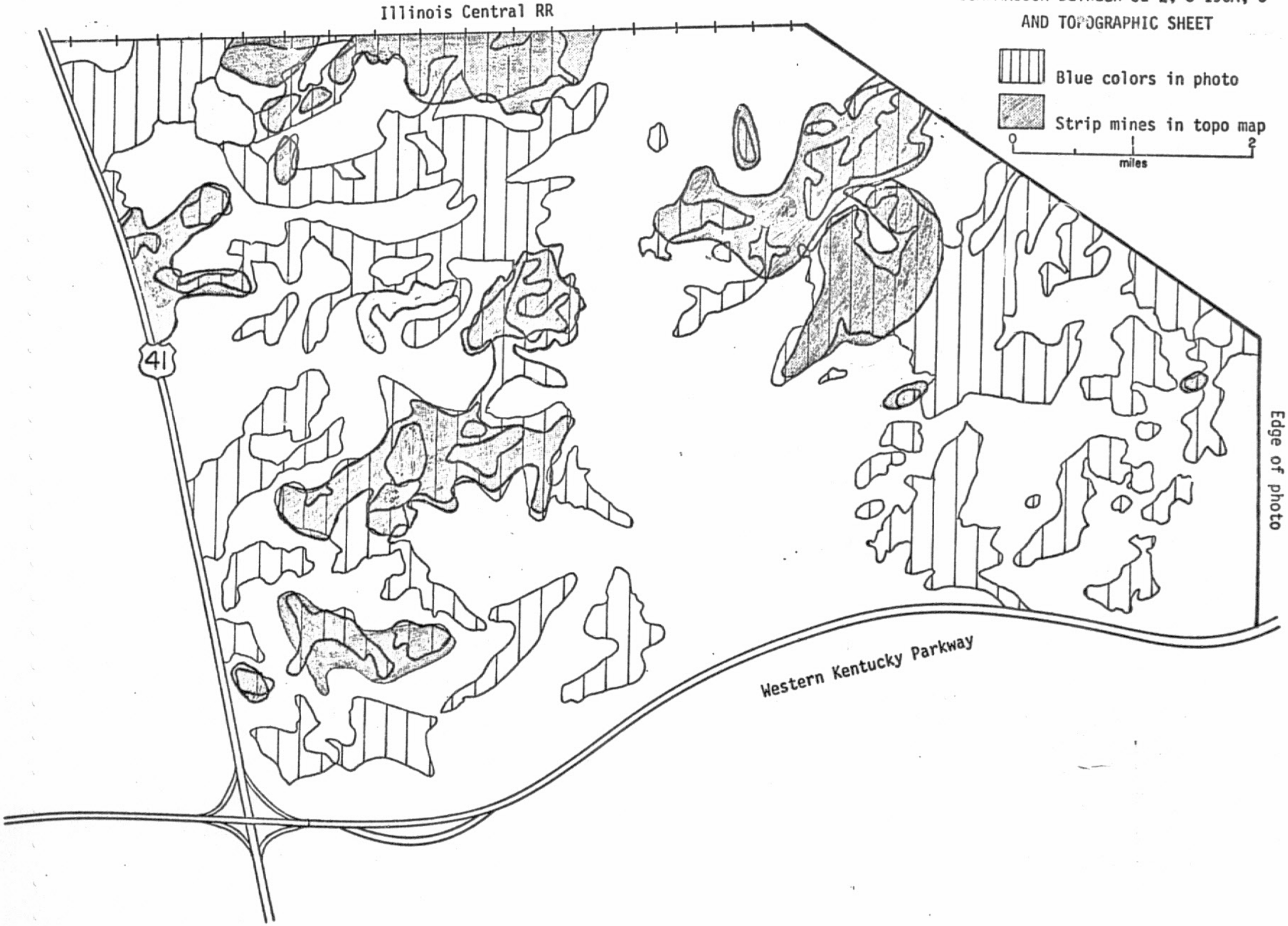


FIGURE 7.11

mental impact of strip mines. Highways, regardless of their width and composition (black top, gravel, etc.) appear as very sharp thin lines. Because roads are so clear this type of imagery is most helpful to mine inspectors for locating purposes. Railroads are also discernible and so is the Madisonville airport. Very fine detail is readily recognized in the town of Madisonville, streets, golf courses, trailer parks, major buildings, etc.; such fine detail is impossible to recognize in any of the other imagery.

A general recognition was easily accomplished for the representative area as seen in Figure 7.12 due to the high degree of resolution. Strip mines show in bluish colors, highwalls as white linear features, pits as dark blue (if water present) or black. This is important in determining active vs. orphan areas. In orphan areas there are numerous highwalls and these appear as such; active areas usually have one or two highwalls and large adjacent areas in different stages of reclamation. Reclaimed areas appear in bluish and brownish colors depending on the type of reclamation practices (grasses=blue; trees=brown) or their stage of reclamation (recently planted trees=blue; successful tree growth=brown) (see Figure 7.13).

Naturally vegetated areas as in river floodplains appear as light brown with a smooth texture, other naturally vegetated areas also appear in a brown color but darker and of coarser texture. These differences represent variations in terrain from flat floodplain to gently rolling to hilly uplands.

Farmed areas appear with unique rectangular fields varying in color from light reddish-brown to bluish, depending on the stages of cultivation.

FIGURE 7.12
SL-4, S-190B
GENERALIZED PATTERNS

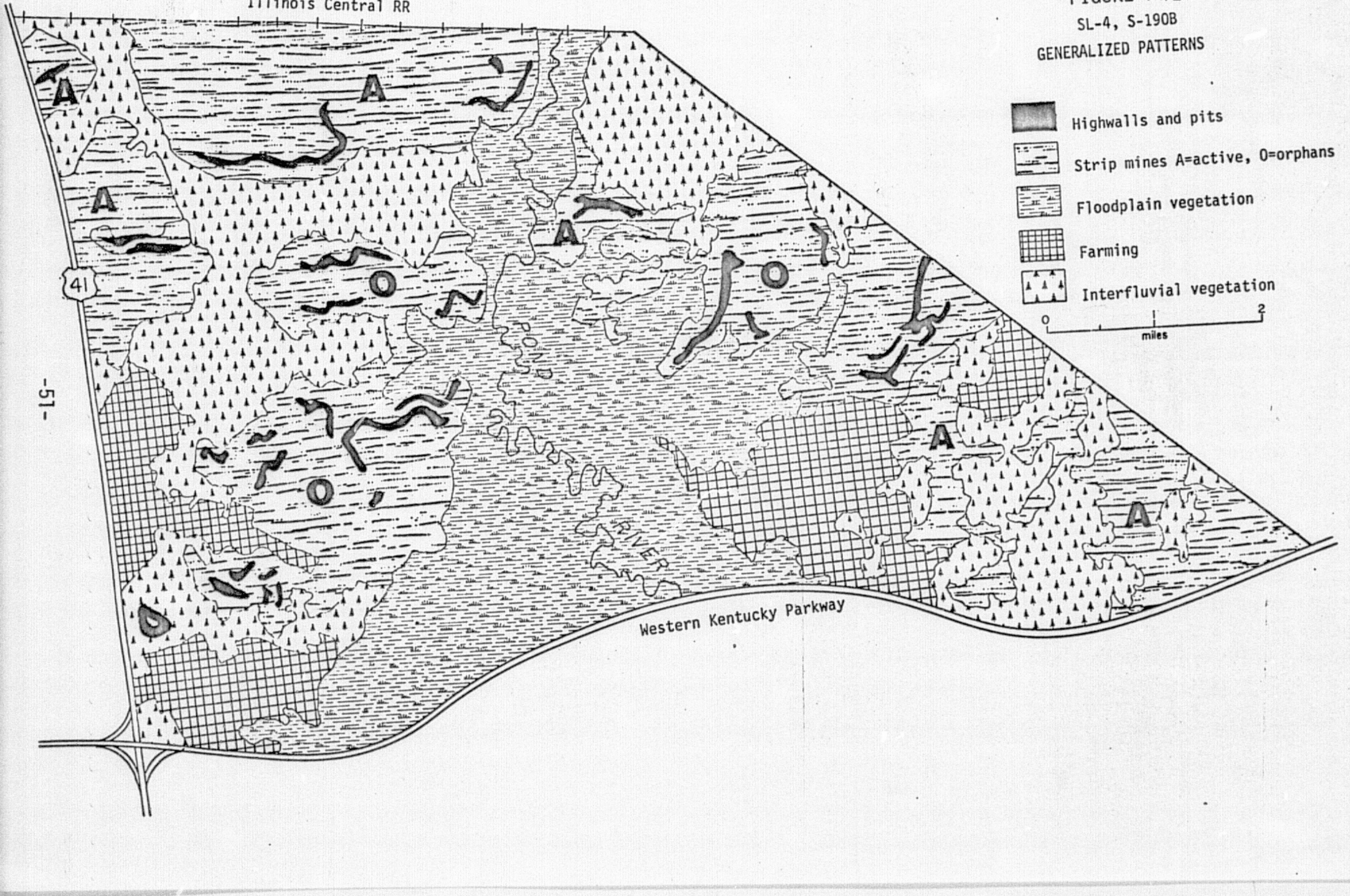
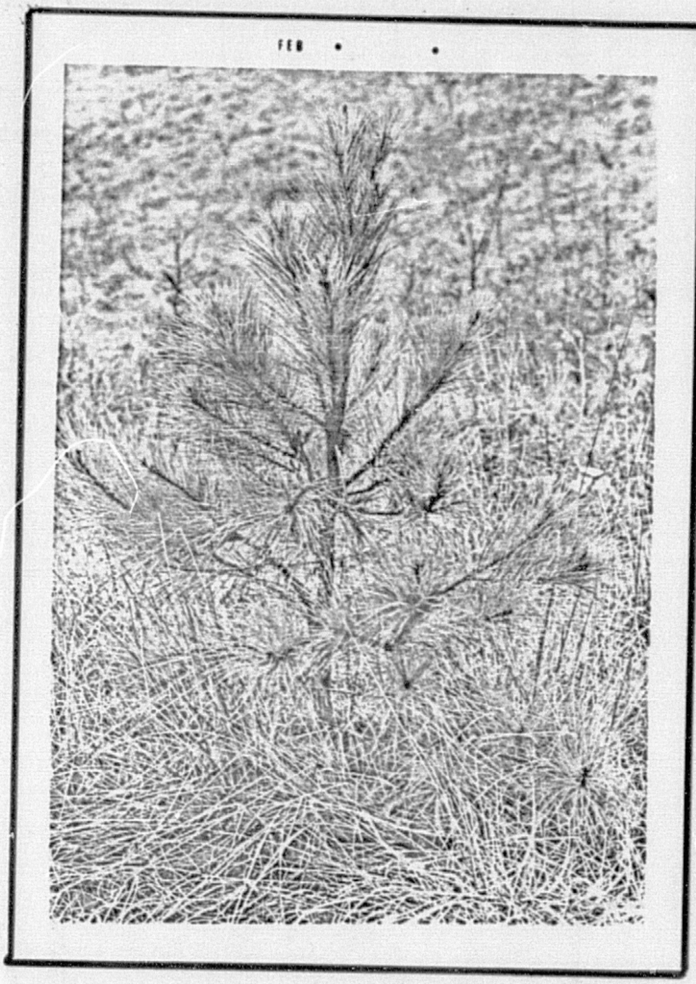


FIGURE 7.13

Loblolly pine and fescue grass on recently reclaimed area, Hopkins County, Kentucky.



The fine detail observed in this transparency is of such high resolution and thus resultant applicability to satellite monitoring of strip mines that it was decided to include a few specific examples of its capabilities.

7.4 MINIMUM ACREAGE IDENTIFIED

The outline of strip mines obtained from this imagery corresponds exactly with the boundaries of said mines at time of satellite pass, an indication of the high resolution of the transparency and sharp boundary recognition. Furthermore, an analysis was made to determine the boundaries of the smallest strip mine that could be recognized. This resulted in the boundaries obtained for Knob Mine, (see Figure 7.14). The boundaries can be sharply defined from the imagery and their resultant dimensions are .35 mile by .20 mile or a total surface of 45 acres. It is important to note here that this is perhaps the minimum size for coal strip mines since mines smaller than 40-50 acres are not profitably exploitable.

7.5 INACTIVE PRE-LAW CONTOUR MINE

Both types of strip mining methods (as described in Chapter 2) can be recognized. Inactive contour strip mining in an area just east of U.S. highway 41 and just north of the Western Kentucky Parkway is identified. The rough circular features identified in Figure 7.14 are local topographic highs produced by domal structures of sediments. These are old pre-law mines now inactive. Please notice the variation in colors and intensities (see Table 7.1 for description of color and intensity codes). Code 2E represents the corona of trees that have been left undisturbed on top of the domes; these are areas above the bedding planes of the coal seams. The disturbed areas appear as 2D and the remaining part of the highwalls appear as a grayish 4C. Notice also that the outstanding parts of the highwalls are facing south and thus, with higher solar exposure and less moisture availability, it has not been naturally reclaimed.

7.6 COLONIAL COAL COMPANY AREA MINE

Area strip mines are also readily identified. A large feature

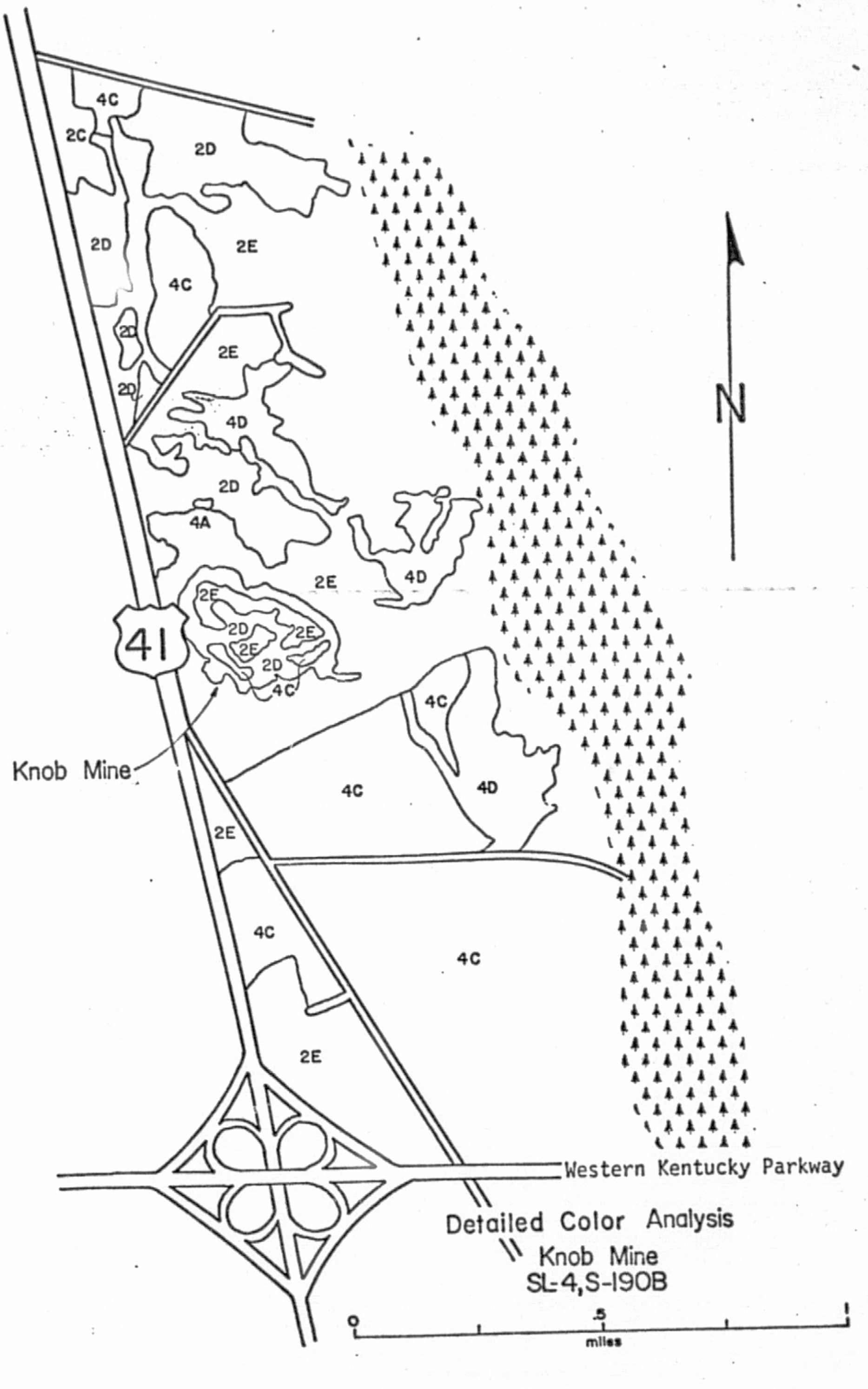

4C
2C
2D
2D
2E
4C
2D
2E
2D
4D
2D
4A
4D
2E
2E
2D
2E
2E
2D
4C
41
Knob Mine
4C
4C
4D
2E
4C
4C
2E
N
Western Kentucky Parkway
Detailed Color Analysis
Knob Mine
SL-4, S-190B
0
.5
1
miles

FIGURE 7.14

immediately recognized as a strip mine in this photograph is the area mine operated by Colonial Coal Company just west of Madisonville, Kentucky (see Figure 7.15). This Figure is a further enlargement of the same SL-4, 190-B color transparency. This mine presently consists of a large north-south trending pit (identified as 2A) which is being worked in an easterly direction. A series of ramp roads are leading into the pit and trending east-west (identified as 3) and built on top of a series of spoil ridges. The area west of the present pit has been reclaimed as the operations progress. Notice the gradation in intensities of blue (2E, 2D, 2C) indicative of successive stages of reclamation. It should be noted here that the area coded 2E has been recognized in the field as a reclaimed area in which army-worm infestation has drastically altered the reclaiming process. This specific example of Colonial Coal Company is a dramatic indication of the outstanding capabilities of this type of imagery.

77. OFF-STRIKE GRADING

Another interesting detail observed from this imagery is the off-strike grading practiced at Cimarron Coal Company Mine. Off-strike grading consists of a series of parallel ridges of reclaimed spoil trending perpendicularly with the strike of the coal bed (see Figure 7.16 and 7.17). In this totally reclaimed area (see Figure 7.18), the off-strike grading is readily apparent as subtle linear changes in color 2C. Notice that the tipples in background of Figure 7.16 appear as two small white (code 3) features in the photo.

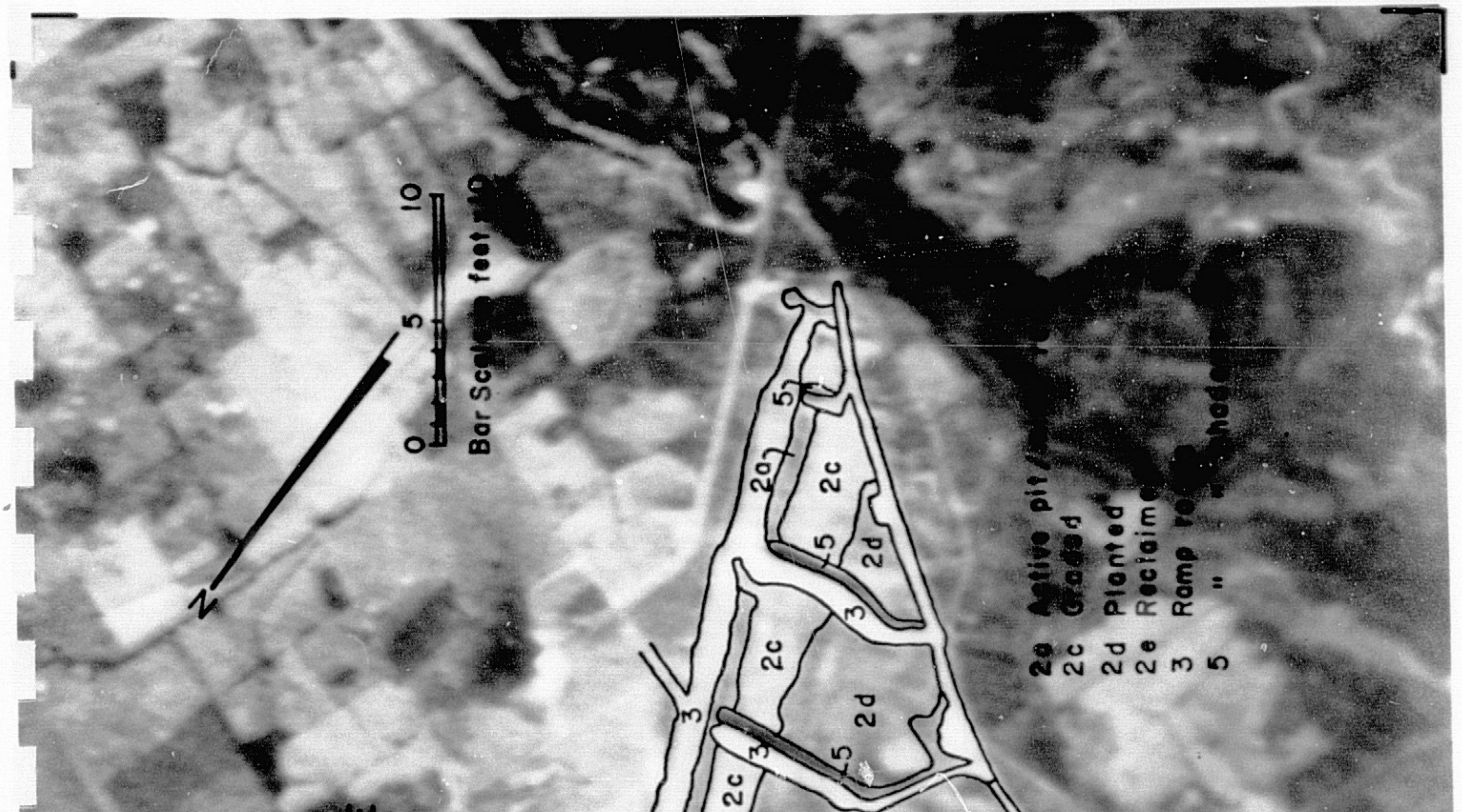

COLONIAL
N
0 5 10
2a Active pit
2c Graded
2d Planted
3 Ramp
2a
2c
2d
2e
3
5

FIGURE 7.15

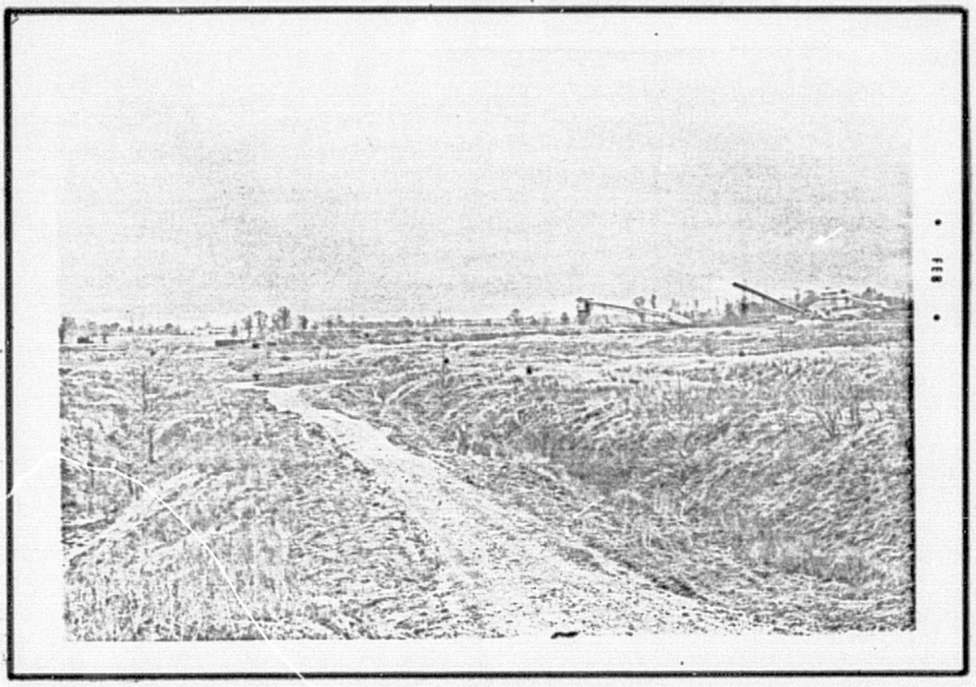


FIGURE 7.16
Off-strike grading, showing tipples, Cimarron Coal Co.
Hopkins County, Kentucky.

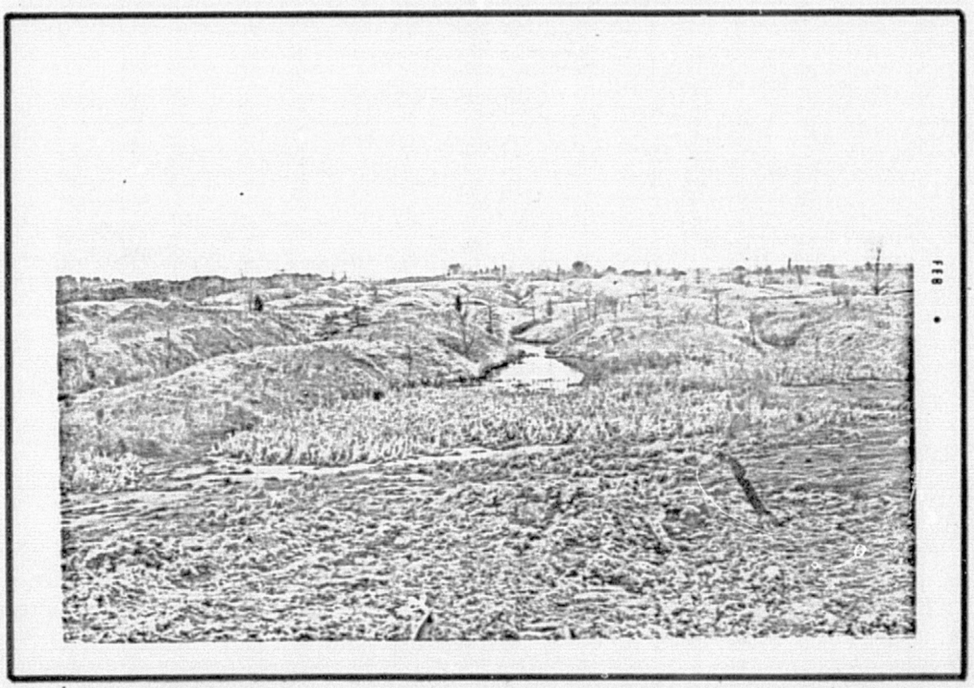


FIGURE 7.17
Off-strike Grading, Cimarron Coal Co., Hopkins County, Kentucky.

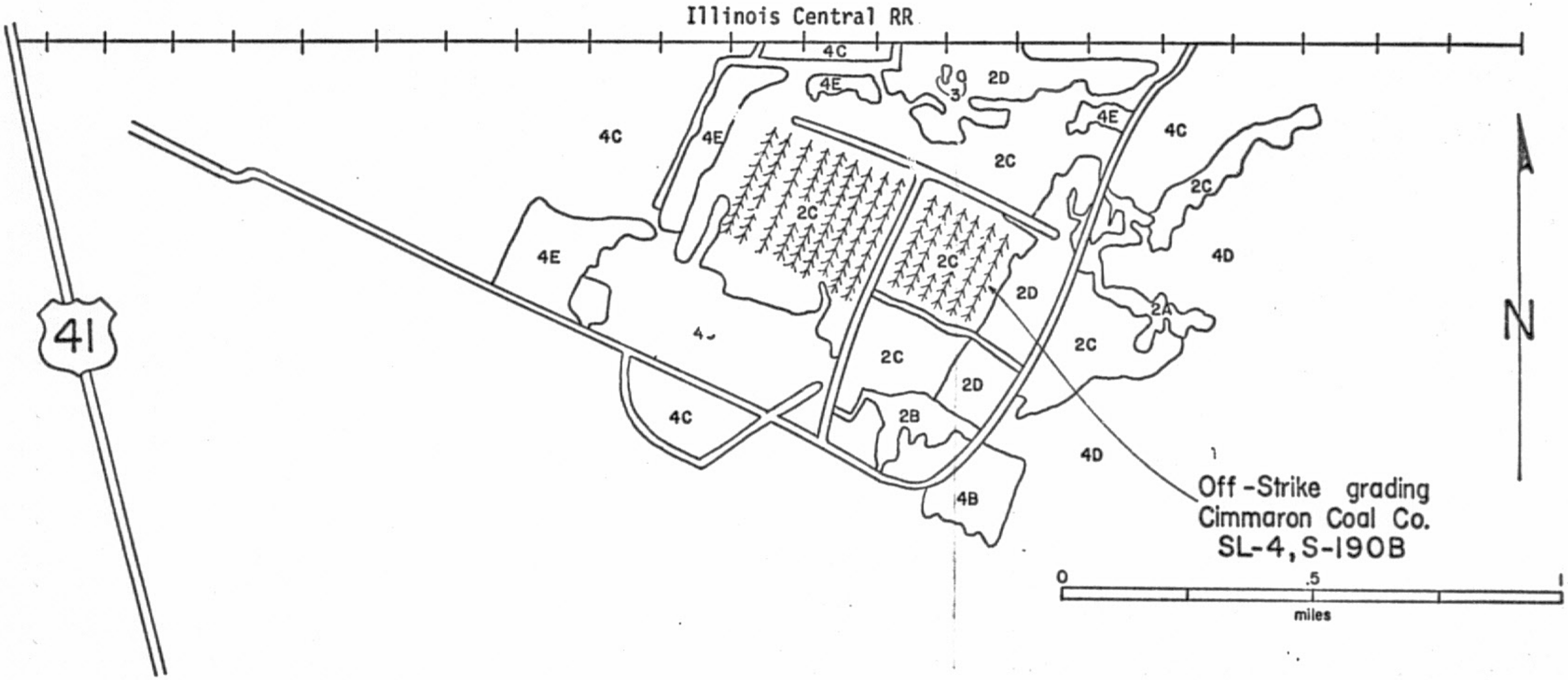

Illinois Central RR
41
4C
4E
2C
2D
3
4D
2A
2B
4B
N
Off-Strike grading
Cimmaron Coal Co.
SL-4, S-190B
0
.5
1
miles

FIGURE 7.18

7.8 DETECTION OF ACID WATERS

Last, it should be noted here that this imagery is also capable of detecting concentrations of iron oxides known as "Yellow boy" at different water impoundments. There is an un-named lake (herein referred to as Red Lake) west of Madisonville, Kentucky (see Figure 7.11) which appears quite red in the imagery obtained from SL-4, S-190B. Further field investigations revealed that this water impoundment has a truly reddish color due to high iron oxide concentrations (see Figure 7.19). Mine inspectors have tested Red Lake water and found it to have a pH of 4.5, an indication of acidity and probable environmental detriment.

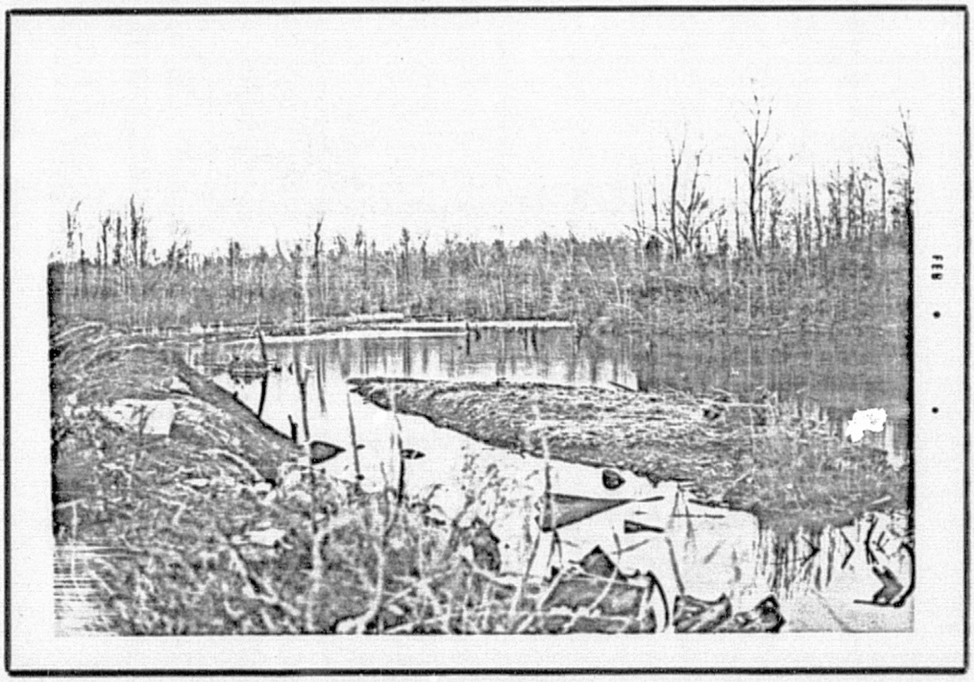


FIGURE 7.19
Red Lake, Hopkins County, Kentucky.

7.9 On-Site Verification

For the purpose of verifying the results of our photo interpretation, two trips were made to the Madisonville, Kentucky, area.

The initial trip was for gathering general information. Liaison was established with the officials of the Kentucky Department for Natural Resources and Environmental Protection, Division of Reclamation at Madisonville. Mr. Claude Downing, Jr., and Mr. Baird Cook of that office provided a ground inspection tour of the area. They provided mine census information and topographic maps of some of the mining operations. Ideas were exchanged on the potential benefit of satellite imagery providing large-area monitoring.

During the inspection tour, we were shown pre-law orphan areas with remaining high walls and poor grading; and we also saw post-law stripping methods and much improved reclamation techniques.

The Madisonville office's jurisdiction includes 14 counties in western Kentucky. The inspectors' duties include the investigation and approval of strip mining permits, and ground monitoring of the strip mining and reclamation activities to insure that they are within the Kentucky laws. Due to the increasing demands for coal, the permit investigations are consuming more of their working days. If a practical satellite monitoring system were available, it would assist them greatly in the performance of their duties.

Subsequent to this initial visit, the Skylab imagery was carefully scrutinized for correlation with the ground-observed features such as:

a) high walls

b) mining pits parallel to the high walls

c) access roads

d) different colored water in the impoundments

e) differences in tone and texture between active and inactive mines

f) advancing vegetation in previously stripped areas

To ensure that our photo-interpretation was correct and that we were not "over-interpreting," we reported our preliminary findings to the Kentucky officials and asked if they would review our analysis and verify them if possible. They agreed and plans were made for our second trip to Madisonville.

The Skylab imagery was taken to Madisonville for our second visit. The imagery, via overhead projector, was reviewed by the mining inspectors and Mr. Kenneth D. Ratliff who journeyed from the state capital at Frankfort to meet with us. Mr. Ratliff is the Assistant Director of the Bureau of Land Resources for the State of Kentucky.

These gentlemen, although not accustomed to the scope of coverage by satellite imagery, verified all our preliminary findings as listed above within the first thirty minutes. More importantly, the mine inspectors who were intimately familiar with the various mines pointed out that the photographs revealed much more information than any of us dared hope.

The inspectors verified the interpretations of high walls, mining pits, and access roads. They stated that the various impoundments did indeed contain different color water; their experience had taught them they could deduce the approximate acidity of the water by its color due to the presence of "yellow boy" or certain-colored algae which thrive at discrete pH levels. An important conclusion we reached at that time was that S-190B color imagery could be utilized to monitor water acidity in the impoundments.

The inspectors also verified our differentiation between active and inactive mines. They agreed that the progress of re-vegetation was observable from the satellite imagery; moreover, they pointed out on the photographs specific reclamation problem areas they had encountered in the field. One particular reclaimed area had been seeded with grasses, but army worms had eaten the roots. This infested area showed up very clearly as a dark area on the S-190B color photograph surrounded by lighter vegetation (see Figure 7.15). Reclaimed areas subsequently affected by water erosion also could be differentiated on the S-190B photograph.

The inspectors also pointed out that the newly graded mine areas were highly reflective. The off-strike grading pattern is easily identifiable on the S-190B color photographs.

The office viewing of the imagery was followed by a detailed ground inspection of examples of what we had distinguished on the photographs. The ground inspection included the following:

a) the pre-law Knob Mine where the highwall, volunteer revegetation, and the corona of trees were observed. This area has changed very little in the last several years.

b) the active Cimarron Coal Company Mine wherein various types of grading, including off-strike grading, were observable. The area of off-strike grading was existent at the time of the Skylab imagery. Various stages of reclamation were present in this large mine area.

c) Red Lake which had the same reddish tint as observable on the Skylab imagery.

d) Orbit Mine which included several stages of reclamation involving grasses and trees.

e) Sextet Mine; at this mining area the land was being relatively rapidly reclaimed so that the undisturbed areas, active mine, and reclaimed areas were all within 100 yards.

Mr. Ratliff's personal opinion of the usefulness of this type of imagery for the monitoring required by the State of Kentucky is expressed in a letter he has sent to us which is reproduced here as Figure 7.20. Speaking for the State of Kentucky, he is desirous of having satellite imagery made available to the Kentucky mining inspectors on a regular basis.

John S. Hoffman
Secretary

Julian M. Carroll
Governor

COMMONWEALTH OF KENTUCKY
DEPARTMENT FOR NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION
BUREAU OF LAND RESOURCES
Billy S. Lewis
Commissioner
FRANKFORT, KENTUCKY 40601

March 7, 1975

Mr. Ronald L. Brooks, Assistant Manager
Range Engineering Department
Wolf Research and Development Corporation
3241 Fairway Drive
Las Cruces, New Mexico 88001

Dear Mr. Brooks:

The Skylab photographs reviewed on February 21, 1975, with Wolf Research and Development Corporation, representative Ronald Brooks and New Mexico State University faculty member Carlos Parra, would be a most useful tool for environmental law enforcement and resource surveys provided nominal cost and regular photograph intervals could be maintained.

The photographs revealed remarkable detail on surface mined areas thus providing the expectation that on the ground surface mine reclamation inspections could be supplemented by referring to the Skylab imagery for an overall impression or review of any given mining site. Progress on reclamation grading and degree of vegetative cover would be readily apparent.

The imagery could be utilized for local, regional or state wide surveys of surface mine disturbance and reclamation, for locating all types of surface disturbance, and for surveying or monitoring the water quality of streams and impoundments within surface mining districts or throughout the state. These are only a few of many applications of the Skylab imagery that could be mentioned.

The Kentucky Division of Reclamation is honored to have been asked to review the Skylab imagery for the western Kentucky coal field and looks forward to the time when such photographic material will be available on a continuing basis.

Sincerely,

Kenneth D. Ratliff
Kenneth D. Ratliff
Assistant Director

KDR:rp

FIGURE 7.20

8. CONCLUSIONS AND RECOMMENDATIONS

The results obtained in this study prompt us to make the following conclusions and recommendations. It is our sincere belief that satellite monitoring should be regarded as a useful tool not only to strip mining inspectors but also to the many industrial, environmental and other groups associated with coal strip mining.

8.1 RECOGNITION OF STRIP-MINE DISTURBED AREAS

The recognition of areas which have been disturbed by strip mining is a task which can be well aided with the use of satellite imagery. The large areas covered by orbital photography allows the user to estimate the acreage of strip mining activity from a few frames. The major feature of such imagery is the ease of differentiation between strip mining and all other land uses. Infrared photography both in color and black and white transparencies was found to be the best suited for this purpose.

The infrared imagery viewed was taken from both the S-190A and the S-190B sensor packages. They are considered to be superior to the black and white and/or color non-IR transparencies because the observed contrast between the spectral reflectance of the strip mined areas and that of forested, farmed, and other cultural landscapes was greater in the wavelengths received by the infrared film/filter combinations. The disturbed areas appear as the only clear tones (except for water bodies and roads) in the black and white infrared negative imagery and as the only turquoise blue on the color infrared imagery.

It is definitely an asset for Strip Mining and Reclamation agencies to use Skylab imagery to assess the extent of coal operations at a given time. The speed and accuracy of delimiting acreage using these tranpa-rencies can only mean a great savings compared with present procedures. For the benefit of users as well as NASA, Table 8.1 is a "Suitability Ranking" of the transparencies used in this study; the more detailed assessment of the transparencies appears in Appendix A. These evalua-tions will aid in the choosing of the best available film/filter combina-tions for such analysis.

8.2 DETAILED MONITORING OF STRIP-MINING OPERATIONS

Skylab-type imagery is of great potential benefit to those concerned with monitoring strip mining activities and their associated effects. The availability of this imagery to government (state and federal) mining officials and operators of large mines would result in considerable savings in terms of man-power and costs. In addition to these savings, the monitoring would be more complete and more accurate, and a reference file of photographic coverage could be established to document temporal changes in each mining area. This type of imagery provides the following general information concerning strip-mining operations:

a) spatial locations of active and inactive mines, including highwalls, pits, access roads, water impoundments, newly graded areas, types of grading, and reclaimed areas.

b) temporal changes in re-vegetation of mined lands and advances of the highwalls from which one could estimate coal tonnage.

c) detection of acid waters; this is possible due to the colora-tion of the water from "yellow boy" and from algae of differing

APPLICABILITY OF SKYLAB IMAGERY FOR IDENTIFICATION

OF STRIP-MINE DISTURBED AREAS

Suitability Rank	Mission	Camera	Station	Comments
1	SL-3	S-190A	2	See comments in section 6.1
1	SL-2	S-190A	2	Similar to above
3	SL-3	S-190B		Area covered is small
3	SL-4	S-190B		Area covered is small
5	SL-3	S-190A	3	Overexposed
5	SL-3	S-190A	4	Overexposed
7	SL-2	S-190A	1	Underexposed
8	SL-3	S-190A	1	Cloud cover not penetrated
9	SL-2	S-190A	3	Underexposed
10	SL-2	S-190A	4	Underexposed
11	SL-2	S-190A	3	Cosmetically enhanced
12	SL-4	S-190A	4	Underexposed
13	SL-2	S-190A	5	Too high contrasts
13	SL-3	S-190A	5	Too high contrasts
15	SL-2	S-190A	6	Much too high contrasts
15	SL-3	S-190A	6	Much too high contrasts

TABLE 8.1

colors which thrive at discrete pH levels.

d) siltation effects on nearby streams and lakes; these effects are readily apparent on this imagery.

Skylab-type imagery could open a new era in monitoring strip mining operations because of the inherent cost-savings, time-savings, broad coverage, and wealth of information it portrays. Of paramount importance to the effective utilization of this imagery, however, is the ease of information extraction by mining officials who do not have extensive photo-interpretation backgrounds, expensive scanning equipment, or computer-oriented experience. The fact that the only equipment required is a normal lecture-hall type of overhead projector makes satellite imagery ideal for this application.

Table 8.2 is the resultant suitability ranking for the various transparencies provided by NASA for this study. Detailed assessments of each transparency appear in Appendix B. S-190B imagery is highly recommended for satellite monitoring of strip-mining operations.

8.3 RECOMMENDATIONS

It is recommended that S-190A and S-190B sensors be incorporated into future space Earth resources data collection systems, to acquire imagery of strip mining areas utilizing the herein recommended film types. The imagery and this report should then be forwarded in a timely manner to concerned federal and state officials, as a demonstration project, so that they may have the opportunity to review the imagery as it pertains to their assigned strip mined areas.

APPLICABILITY OF SKYLAB IMAGERY FOR STRIP-MINE DETAILED MONITORING

Suitability Rank	Mission	Camera	Station	Comments
1	SL-4	S-190B		Very high resolution
2	SL-3	S-190B		Next best
3	SL-3	S-190A	4	Underexposed but excellent
4	SL-3	S-190A	2	A little grainy but good
4	SL-2	S-190A	2	Subtle differences in tone
4	SL-3	S-190A	1	A little grainy but good
4	SL-3	S-190A	3	A little grainy but good
8	SL-2	S-190A	1	Lakes easily discernible
9	SL-2	S-190A	3	
10	SL-2	S-190A	4	Underexposed
10	SL-4	S-190A	3	
10	SL-4	S-190A	4	
13	SL-2	S-190A	5	Too high contrasts
13	SL-3	S-190A	5	Too high contrasts
15	SL-2	S-190A	6	Much too high contrasts
15	SL-2	S-190A	6	Much too high contrasts

TABLE 8.2

Eventually, satellite photo coverage of strip mining areas should be forwarded to mining officials at intervals of about three months.

BIBLIOGRAPHY

Cubbison, E. and L. Dunlap Stripping the Land, Only the Beginning, COALition Against Strip Mining-Friends of the Earth, Feb. 1972.

Kentucky Department for Natural Resources and Environmental Protection Title XXVIII: Mines and Minerals Chapter 350 Strip Mining.

Kentucky Department of Commerce and Kentucky Geological Survey, Mineral Resources and Mineral Industries of Kentucky (map) 1962.

Kentucky Division of Reclamation Surface Mining and Reclamation in Kentucky, 1972.

Menard, H.W., Geology, Resources and Society, W.H. Freeman and Co., 1974.

NASA/JSC Sensor Performance Report for SL-2 and SL-3, Principal Investigations Management Office, Sept. 1973.

NASA/JSC Sensor Performance Report Vol. I, S-190A System Analysis and Integration Office, Sept. 6th, 1974.

"Skylab's Bird's Eye View of the Earth's Resources" Optical Spectra, April, 1973.

Projection Optics Co. Inc. Instruction Manual for the Transpaque Autolevel Model 20400 and 20401.

US Bureau of Mines I.C. 8406, 1969.

US Bureau of Mines I.C., Jan. 1972.

US Bureau of Mines I.C. 8642, June 1974.

US Bureau of Mines I.C. 6772, 1966.

US Commerce Department Statistical Abstract of the U.S., 1974.

US Geological Survey Geologic and Topographic Maps.

Wagner, Richard H., Enrivonment and Man, W.W. Horton and Co., Inc., 1974.

Wolf Research and Development Corporation, Technical Proposal Applicability of Satellite Remote Sensing for Monitoring Surface Mining Activities, March 1972.

A P P E N D I X   A

"Applicability of Imagery for Identification of Disturbed Areas."

The following are a few notes about the applicability of the rest of the imagery used for this study (see Table 4.2) for overall identification of strip mines.

- SL-2, S-190A, 1 - Topographic differences are well determined in this transparency by differences in texture and tone. The hillier, rougher parts appear as somewhat coarse texture and darker toned. The strip mined areas can be recognized because they appear as darker and coarser areas within the rougher terrain, and the multitude of water impoundments appear as dark tones.

- SL-2, S-190A, 2 - The only difference between this transparency and the one just mentioned above is that a different filter is used. Its applicability for strip mine recognition is similar; much of the same characteristics also apply.

- SL-2, S-190A, 3 - In this underexposed color infrared photo water bodies are readily recognized by their blue color. Farming areas appear as light red/bluish colors, large fields have a characteristic rectangular pattern. Natural vegetation appears in a red color. It is quite difficult to recognize strip mines since they tend to blend with the red/bluish color of the less intensive farming areas where large rectangular fields are not so common; apparently the spectral reflectance at this wavelength for these two figures is similar.

- SL-2, S-190A, 4 - This is also an underexposed photo in color. Here again there are variations in colors and tones that are indicative of differences in terrain. Farming areas can be identified as they appear lighter than natural vegetated areas, however, there is almost no difference between natural vegetated areas and strip mines, again due to similar spectral reflectance.

- SL-2, S-190A, 5 - In this high contrast black and white photograph the only features that can be identified are the large water bodies. This is totally unsuitable for any finer recognition.

- SL-2, S-190A, 6 - This photograph is black and white and has such a large tonal variation that it appears extremely variegated and thus it is almost impossible to recognize any feature other than the large water bodies.

- SL-3, S-190A, 1 - We have received two transparencies from this series, a positive and a negative. The general characteristics are the same as SL-2, S-190A, 1 since they both are using the same film and filter combination. Although the negative print is somewhat better due to higher contrast, both transparencies are difficult to assess since they have quite a considerable cloud cover.

- SL-3, S-190A, 2 - See particular description in Section 6.1

- SL-2, S-190A, 3 - This color infrared photograph is similar to SL-3, S-190A, 3, since they both use the same film/filter combination. The one exception is that this photo is not underexposed. There is a large amount of clouds as in all SL-3 photos yet many features can be identified. Strip mines show a very distinct light blue (almost turquoise) color which is not observable anywhere else, an indication of a unique spectral reflectance of the disturbed areas. The blue of water is much darker. Farming areas also appear as blue but a more grayish tone.

- SL-3, S-190A, 4 - This color photograph is again similar to SL-2, S-190A, 4; but it is not underexposed and is of a good overall quality for broad strip mine recognition. They are easily recognized by their bluish color.

- SL-3, S-190A, 5 - Photographs from this camera station (and also camera station 6) are unsuitable for overall land-use recognition perhaps due to the high contrast produced by the film/filter combination.

- SL-3, S-190A, 6 - (see SL-3, S-190A, 5).

- SL-3, S-190B - See particular description in Section 6.2.

- SL-4, S-190A, 3 - This is an overexposed color photograph. The area is under heavy cloud cover and perhaps the overexposure tends to cut down the haze but not sufficiently. It is also cosmetically enhanced. Due to the overexposure and heavy cloud cover it is impossible to give a proper evaluation.

- SL-4, S-190A, 4 - Both a negative and a positive transparency were studied. Here again we have an overexposed photo of a cloud covered area. Since this transparency uses the same film/filter combination as SL-3, S-190A, 4 we assume that it should be suitable for broad strip mine recognition; however the overexposure renders it unsuitable.

- SL-4, S-190B - This color photograph is outstanding and it is useable for detailed strip mine analysis. However it is not ideally suited for broad, overall strip mine recognition because there is not enough contrast between colors. The high resolution of this photo places a burden on the recognition of disturbed areas since so many features are observable that it makes it difficult to identify them at a small scale. This is not the case, as it can be seen in Chapter 7, for detailed studies.

APPENDIX B

"Applicability of Imagery for Detailed Monitoring"

The following are a few notes about the applicability of the rest of the imagery used for this study (see Table 4.2) for detailed monitoring.

- SL-2, S-190A, 1 (B/W IR Negative) - This transparency appears as a very grainy photograph. The most salient features are undoubtedly the water bodies which show clearly as very dark black colors. The man-made parallel lakes show up prominently as black and water moisture appears dark. Highways and roads along with the outlines of strip mines are not discernible.

- SL-2, S-190A, 2 (B/W IR Positive) - This transparency appears very grainy with a variation of tones. Possibly due to the higher resolution for dark tones, water bodies are more easily detectable than in previous photographs. Overall, because the subtle differences in tones tend to confuse rather than clarify the images, this transparency is worse for detailed monitoring than for the determination of the outlines of the strip mines.

- SL-2, S-190A, 3 (Color IR)
  (See particular comments above in Section 7.2).

- SL-2, S-190A, 4 (Color) - This transparency was 1/2 f-stop under exposed. The highways appear as sharp, thin, white lines. The mines are discernible with some highwalls quite obvious. Natural vegetation shows up as dark blue to green color especially around Pond River. However, due to the under exposure, the area appears blurry. Because of the under exposure, there seems to be very little advantage of this over the previous black and white transparency studied. It was concluded here that SL-2 imagery resolution was not as good as that of SL-3 and SL-4. However, the region of study was closer to the edge of the transparency for SL-2 than it was for either SL-3 or SL-4.

- SL-2, S-190A, 5 (B/W Positive) - Since the transparency was under exposed by 1/2 f-stop, true analysis of its characteristics is not possible. This transparency has extremely high contrast; in fact, due to such a high contrast, the location of strip mines and other cultural features is not readily possible. Due to the fact that the clouds and the active mines are the same light tones, differentiation between the two is practically impossible. The only real definable characteristic between the two is the linearity of strip mines as opposed to the more circular pattern of the clouds. The major highways, like the Western Kentucky Parkway and the U.S. Highway 41, show up as very sharp lines. Railroads can easily be recognized. Also easily recognized is the highwall of the Colonial mine. Generally speaking, this transparency does not readily serve the interpretive purposes required.

- SL-2, S-190A, 6 (B/W Positive)
  (See particular comments above in Section 7.1).

- SL-3, S-190A, 1 (B/W IR Positive) - This transparency also appears grainy, but dealing with black and white, not as grainy as the previous one. Water bodies again appear prominently as very dark, almost entirely black features. Cloud shadows show up as being somewhat lighter than the water, however, they could be confused with the water objects. Disturbed areas associated with the strip mines appear as a dark tone.

- SL-3, S-190A, 1 (B/W IR Negative) - Since this photo and the previous one are the same, one positive and one negative, it is recommended that they be viewed as a pair. Water bodies appear as extremely light colors. Anchor Lake and Peewee Lake show up as very light whites. Clouds appear as very dark, black tones. The shadows of clouds now show up as white, however, not as light in tone as do the water bodies. No roads appear. Fully vegetated areas in the swamps or, perhaps, in the forest around the swamps, appear as slightly darker tones than other vegetated regions. There is an ideal gradation of tones in this transparency. If the resolution of this transparency were increased, perhaps roads, highways and reailroads could be better viewed. The entire transparency is somewhat more pleasant to view than the positive image.

- SL-3, S-190A, 2 (B/W IR Positive) - Water is visible, however, the degree of contrast between water and land is not very great. But, large water bodies such as Peewee Lake appear as very dark, and very sharp features. Clouds show up as white, while their shadows appear to have a tone very similar in darkness to that of water. Due to the pattern of different tones, strip mines show up very clearly. Disturbed land appears to have somewhat darker tones than the rest of the land, however, the tones are not as dark as the water bodies. Farming appears very light in tone and the natural vegetated areas show up with an intermediate or medium gray tone.

- SL-3, S-190A, 2 (B/W IR Negative) - This transparency, though quite grainy, does not seem to be as bad as the previous ones with the similar condition. This and the previous transparency,the negative and the positive, should be viewed together, since they tend to complement each other. The negative shows clearly the disturbed areas, whereas the positive shows more clearly the water bodies. The lightest tone on the transparency is water. The outlines of Peewee Lake and Anchor Lake are very prominent. Clouds are very dark, in fact, they are almost black. The shadows of the clouds appear as a light tone, although, not as light as does water. Inactive strip mines don't appear as readily discernible as the active strip mines. About the only noticeable difference between active and inactive mines is that the active mines, which appear more heterogeneous, have a series of small linear lakes, whereas the inactive mines, which are more homogeneous, don't have the white tones of these linear lakes. The disturbed land, with outlines quite recognizable, appear as light tones.

- SL-3, S-190A, 3 (Color IR) - This transparency appears to be grainy. Water bodies show up as being dark blue, almost black. Clouds appear white while their shadows are a very dark blue, almost black. Due to the similar color characteristics of water bodies and cloud shadows, differentiation between the two is difficult except that water bodies have a more defineable shape arrangement. The highways within the area are visible with ramp roads near Anchor Lake showing up prominently as they did in the other transparencies. All mines have a very distinct shade of blue. Stripped areas appear quite blue and are well defined. Overall mine analysis is quite good. There is a great variation, arrangement and intensity in tones of red which are probably responses to different types of reclaimed areas--some with trees, some with grasses--and different ages of reclaimed regions. Partially reclaimed land appears as blue with red interspersed indicating orphan areas intermixed with reclaimed areas. The vegetated region of Pond River shows up as a purplish red rather than the crimson dark red in the previous transparency. Some farming regions appear as a very light to scarlet red. This transparency was taken later in the day at a slightly higher sun angle than the previous one.

- SL-3, S-190A, 3 (Color IR Original) - There are three transparencies taken for this camera/film/filter combination. The first is a color IR print which was exposed without the filters and, thus, enhanced cosmetically. This imagery was badly over exposed causing the appearance of a "haze" over the transparency. Highways can be discerned to some extent. The mines are almost impossible to distinguish from the surrounding landscape. As an example, the area within Cimarron Mine has the same tonal characteristics as the naturally vegetated area on the Pond River close to the Western Kentucky Parkway and is almost impossible to distinguish between the two. In general, this transparency is unusitable for the analysis purposes.

  The second transparency is a B/W Positive of the original cosmetically enhanced transparency. This, which was developed with a red filter, has numerous streaks and the haziness observed on the previous transparency is present. Highways can be determined but differentiation between mines and, as an example, farming, is impossible.

  The third transparency is a B/W Negative of the first artificially enhanced imagery. It appears to be under exposed and out of focus. The highways show up as dark lines and the mines are not discernible.

- SL-3, S-190-A, 4 (Color) - Underexposure is at a minimum in this transparency resulting in readily recognizable characteristics. Detail has been greatly improved. Lakes, however, do tend to blend in with surrounding natural vegetation, and the red lake (described in Chapter 8) does not appear as its natural red color but tends to have much the same color as the other lakes. Clouds show up as being white with almost black shadows which are similar in darkness to the lakes. Definition in roads is very good, with the double lane east of the clover leaf in the Western Kentucky Parkway readily observed. Ramp roads around Anchor Lake appear as a light to medium gray. The improved detail allows for the easy viewing of the Madisonville airport. The mines now show up as a tan color. The pit of Cimarron appears bluish, darker than the highwalls which have the previously mentioned tan color. The highwalls of the active mines have a wide pattern, whereas the highwalls of the inactive mines, as an example, Knob Mine and the old Peabody Mine, show up as a thin pattern. Some of the vegetation of the reclaimed areas can be observed. Farming patterns appear very distinct with a variation in colors indicating different crops or different techniques in farming. In general, this imagery is quite suitable for recognition.

- SL-3, S-190A, 5 (B/W Positive) - This transparency does not appear to be as grainy as some of the previous ones. Tone contrast is not as high as in the others, especially when compared with the last one. The highways, which are not as light and discernible as in the previous transparency, can still be detected. Strip mines are somewhat lighter in tones with the characteristic outlines discernible in the active strip mines. Inactive strip mines are totally undefinable and differentiation between the inactive strip mines and farmed areas is practically impossible.

- SL-3, S-190A, 5 (B/W Negative) - Although Anchor Lake is readily recognizable, most water areas such as Peewee Lake are not as easily definable since they tend to blend in with the shadows and other white features in the landscape. Clouds appear dark and their shadows show up as white. Due to the undefinable contrast with the clouds and shadow, much of the imagery is lost and undetectable. The highways appear distinct as dark linear features. Small mines, such as Knob Mine can be discerned and old mines appear as "bacteria infested" regions. The light-toned, naturally vegetated regions of the swamp of Pond River, can be recognized. Farming patterns with their linearity and rectangularity are extremely easy to recognize. These farming lands tend to be characterized more easily in black and white than in the previous black and white infra-red transparencies.

- SL-3, S-190A, 6 (B/W Positive) - This transparency does not appear to be very grainy. Clouds show up as being very light, almost totally white. The cloud shadows appear as dark tones which are somewhat darker than the natural vegetative regions and about the same darkness as water bodies. It is almost impossible to distinguish Peewee Lake from a nearby dark cloud shadow. Highways, in particular, the Western Kentucky Parkway and the U.S. Highway 41 appear as linear grayish tones which are very discernible. Strip mines, though not sharp, can be defined. Outlines of strip-mined areas, however, tend to be difficult to define. Characteristically, this transparency and the previous one are similar. The last two transparencies of SL-2 and SL-3 should be used side by side for comparison of the advancement of strip mining and reclamation.

- SL-3, S-190A, 6 (B/W Negative) - Lakes and water in this transparency are not the same color as they were in the black and white IR, because the B/W IR transparency picked up more differences in reflected light than this B/W transparency. Due to its pattern and shape, Anchor

Lake can be picked out from the background. Clouds appear as dark colors while their shadows are white. The cloud shadows are somewhat darker than the whiteness of water when compared with Peewee Lake for example. Highways appear very prominent as medium grayish to dark grayish tones. The stripped or disturbed areas can be seen, though they are not easily discernible. These regions seem to have a somewhat darker pattern than the natural vegetated area of the Pond River. Farming areas, though not as prominent in this transparency as in previous other ones, can be seen. This negative does not seem to be as good for analysis as the B/W IR Negatives that were viewed before this transparency.

- SL-3, S-190B, (Color IR) - Water bodies, with very distinct outlines, appear as dark blue tones. Clouds show up as white and their shadows, which are darker than the water bodies, are almost black. Highways show up as light white lines and some ramp roads are very easily distinguished. The disturbed areas appear as light to medium blue and some highways are slightly visible with a somewhat lighter pattern. A gradation of tones in the reclaimed regions can be seen. This gradation probably indicates advance of revegetation in some old mines. Natural vegetated areas of the Pond River flood plain are scarlet-looking indicating fields. In general, vegetation appears as a very dark red, almost crimson. Some farm patterns are distinguishable. Due to such fine detail, bands of trees, especially in Knob Mine, can be defined.

- SL-4, S-190A, 4, (Color Original) - Four black and white transparencies were made from the basic color transparency. The first is a B/W Positive transparency with no under exposure and high resolution. Water bodies are not distinct while highways as white lines, are very discernible. The two-lane part of the Western Kentucky Parkway appears prominent. Roads in virgin areas show up distinctly while the roads within the strip areas are lost in the tones. Railroads can be located. The highwalls of the active mines appear as white and quite outstanding.

  The second transparency is a B/W Negative and does not appear to be as suitable as the positive. Roads show up as dark lines and strip mines are most difficult to locate.

  The third transparency is a B/W Red Filter (RF) Positive. Due to the red filter, the resolution is slightly off and it seems somewhat underexposed. The highways appear as prominent white lines. There is very little basic differences between the black-and-white with red filter and the previous black-and-white without the red filter. It should be noted that this plus the previous black-and-white positive transparency show relief within the region very well.

  In the fourth transparency, a B/W RF Negative, roads show up as dark distinct lines. Growth outlines of the disturbed areas can be seen in this transparency and relief is noticeable. This imagery is not suitable for analysis purposes.