Arthur T. Anderson
Jane Schubert†
Goddard Space Flight Center
Greenbelt, MD 20771

ERTS-1* Data Applied to Strip Mining

ERTS-1 analog and digital data were used to delineate strip-mine areas in western Maryland and West Virginia.

Abstract: *Two coal basins within the western region of the Potomac River Basin contain the largest strip-mining operations in western Maryland and West Virginia. These are at the Georges Creek and the Upper Potomac Basins, which lie within the Georges Creek (Wellersburg) syncline. The disturbed strip-mine areas were delineated with the surrounding geological and vegetation features by using ERTS-1 data in both analog (imagery) and digital form. The two digital systems used were (1) the ERTS-Analysis system, a point-by-point digital analysis of spectral signatures based on known spectral values, and (2) the LARS Automatic Data Processing System. The digital techniques being developed later will be incorporated into a data base for land-use planning. These two systems aided in efforts to determine the extent and state of strip mining in this region. Aircraft data, ground verification information, and geological field studies also aided in the application of ERTS-1 imagery in order to perform an integrated analysis that assessed the adverse effects of strip mining. The results indicated that ERTS can both monitor and map the extent of strip mining to determine immediately the acreage affected and indicate where future reclamation and revegetation may be necessary.*

Introduction

The effective exploitation of mineral resources involves a compromise between the need for the resource and the effects of despoilation on the land caused by strip mining. For example coal mining is extremely profitable, and the product is a needed energy source; but, its effects can be devastating. This point was best summarized by Jane Stein (1973). With the improved mechanical methods of strip mining, coal is easily available and the percentage of affected areas is increasing throughout the United States. At this time, 24 states are affected by strip mining. Emphasis on the discovery of additional deposits has increased due to the current energy crisis. Newspapers and magazine articles have predicted finds of 1400 trillion kg (1.5 trillion tons) of coal within 1800 m (6000 ft) of the surface. Perhaps more practical is the estimate of 90 trillion kg (100 billion tons) of coal in seams 6 to 76 m (21 to 250 ft) below the surface that can be recovered quickly through strip-mining techniques. Such possibilities are being investigated with the new discoveries of significant amounts of coal such as those in Mon-

* ERTS-1 is now designated LANDSAT-1.

† Now employed in Canada.

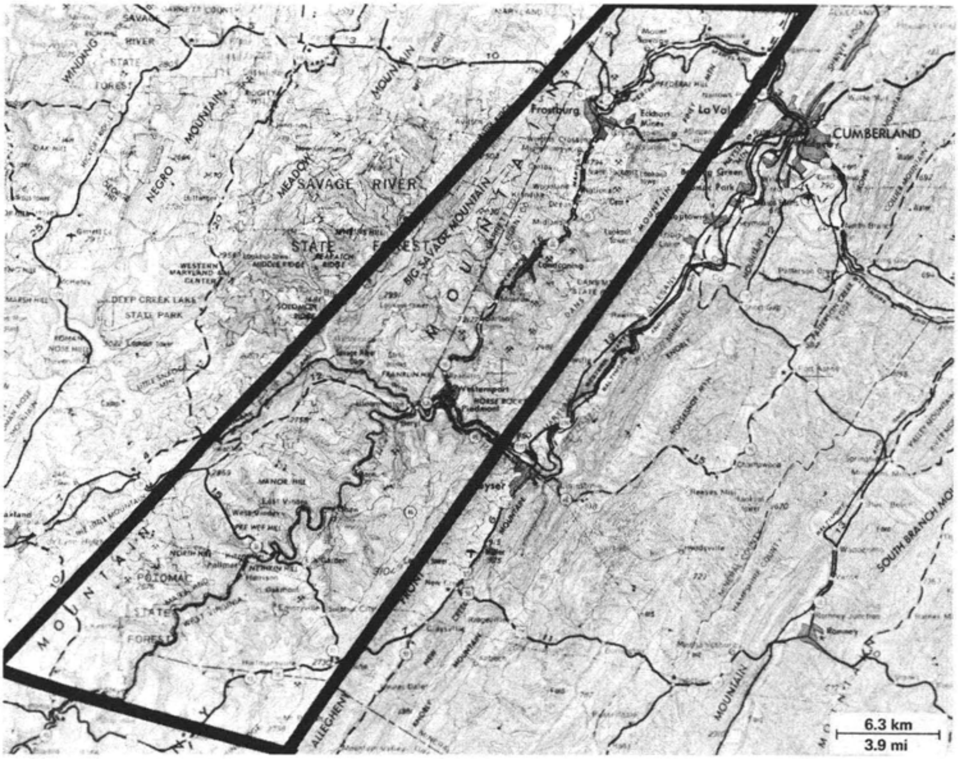


FIGURE 1. Outline of the Georges Creek and Upper Potomac Basin study area encompassing parts of western Maryland and West Virginia.

tana, Wyoming, and North Dakota where an area covering over 3 per cent of this tri-state region (about half the size of Rhode Island) has been found to contain coal. However, the abundance of coal and the need for the resource are impacted by national and state regulations to limit the yearly output of coal for ecological reasons, a conflict facing many areas of the nation today.

Considering this situation in terms of smaller, local, and immediate problems, the area of western Maryland and West Virginia within the Potomac River Basin was studied by using the Earth Resource Technology Satellite (ERTS-1) imagery and digital data. The principal purpose of this experimental study was to demonstrate the utility and application of ERTS-1 data in an integrated analysis, both to map and monitor strip mining, and to develop the needed methods and techniques in order to provide a data base for future land-use planning. For example, Georges Creek Basin and the Upper Potomac Basin in Garrett and Allegany counties of western Maryland were examined by means of an analog technique (photographic interpretation) and digital analysis. This area is now producing over 90 per cent of the 1.45 billion kg (1.6 million tons) of coal mined each year in Maryland. These two counties are comprised of 3,044.76 km^2 (721,376 acres). Using aircraft photographs of these same counties 25.16 km^2 (6216 acres) were categorized as extractive (strip mines) according to the land use classification of 1973 by the State Planning Commission.*

STUDY AREA

The strip mine study area is outlined on a 1:250,000 scale map (Figure 1). The area in western Maryland borders the Garrett/Allegany county boundary from Frostburg and extends southward, paralleling Georges Creek and North Branch main-stream-head waters of the Potomac and ends in Steyer, Maryland. This area is within the great Appalachian coal region which extends from Pennsylvania to Alabama. Physiographically, the Maryland area encompasses the Georges Creek Basin to the north and upper Potomac Basin to the south, divided by the right-angle bend of the Potomac. These two divisions are purely artificial and together constitute a

* Thomas, E., *et al.*, private communication, 1973.

single structural unit of the Georges Creek (Wellersburg) syncline.

The overall area is a gentle, elongated, shallow syncline which trends northeast-southwest between Dan's Mountain and the Allegheny front on the east and both Big Savage and Backbone Mountains to the west. The mountain ranges form the flanks of the gently dipping syncline within the eastern border region of the Allegheny Plateau and contain geologic formations of Permian and Pennsylvanian age. Located here are the only coal-bearing seams in Maryland. The formations are the Dunkard, Monongahela, Conemaugh, Allegheny, and Pottsville groups. Although these formations are approximately 518 m (1700 ft) thick, about 18.9 m (62 ft) contain usable coal in seams ranging from 0.3

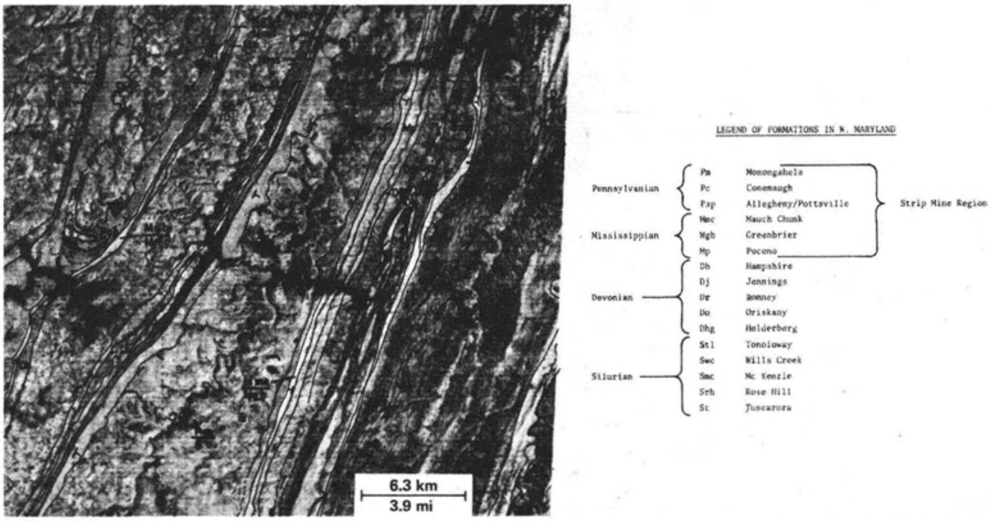


FIGURE 2. Geologic interpretation from ERTS-1 MSS band 7 imagery from September 7, 1972. Strip-mine areas, noted by dark contour lines in the central area, lie within the Monongahela-Pottsville groups.

TABLE 1. ERTS MSS SIGNATURE ANALYSIS FOR INTERNATIONAL BIOLOGICAL PROGRAMME (IBP) VEGETATION CLASSES (FROM SCHUBERT AND MACLEOD, 1973)

Corrected Digital Tape Values	MSS 5 (0.6 μm to 0.7 μm) Reflectance Measurements			
	55	34−50	15−34	15
MSS-7 (0.8 μm to 1.1 μm) Reflectance Measurements	No Vegetation	Sparse Vegetation (IBP Class 3)	Open Vegetation (IBP Class 2)	Closed Vegetation (IBP Class 1)
0−3	Water (·)	Water (·)	Water (·)	Water (·)
4−6	Sand-flat in or near water (−)			Organic mud-flat (/)
7−10	Sand-flat in or near water (−)			Seasonal short grass (orthophyll marsh) IBP-1M2-2 (M)
11−14	Bare soil or sand (open) ( )	Scrub over sand IBP-3B (:)	Scrub IBP-2B (;)	Evergreen forest (narrow sclerophyll) IBP-1A1 (E)
15−21	Bare soil or sand (open) ( )	Scrub over sand IBP-3B (:)	Scrub IBP-2B (;)	Scrub IBP-1B (B)
22−26	Bare soil or sand (open) ( )	Herbs, grasses over sand IBP-3C (+)	Steppe (herbs and grasses) IBP-2G (#)	Seasonal grasses IBP-1L2 and 1M2 (G)
27−36	White beach or desert sand (−)	Herbs, grasses over sand IBP-3C (+)	Steppe (herbs and grasses) IBP-2G (#)	Deciduous forest IBP-1A2 (D)

to 4.3 m (1 to 14 ft) in thickness. Specifically, the major coal seams in this area are the Pittsburg, Barton, Franklin, and Sewickley seams.

METHOD

During the preliminary examination of strip-mine regions, the first step in this study was to demonstrate the utility and application of the ERTS imagery for a multilevel analysis of immediate problem areas and for future planning of land-use management. With this in mind, it was determined that the use of map-related data, imagery, geologic analysis, and computer processing techniques would provide a more accurate and complete assessment of strip mines for both a total acreage figure and for determining active, inactive, or reclaimed mining areas. It should be noted that strip mines go through various stages of development and reclamation in a period of three months to one year and that some inferences (with the assistance of the Maryland Geological Survey) had to be made in projecting backward in time to determine the approximate stage of development in larger mines. In this context, the study used the September 7, 1972 (1046-15301), ERTS imagery. This imagery provided the best delineation of the strip mines.

Based on this imagery, a photogeologic interpretation of the area was compiled in the form of a geologic map (Figure 2) which contains both the Georges Creek to the north and Upper Potomac Basin south of the Potomac River bend. This analysis was made on an enlargement of a portion of an original ERTS frame at a scale of 1:125,000 by using the

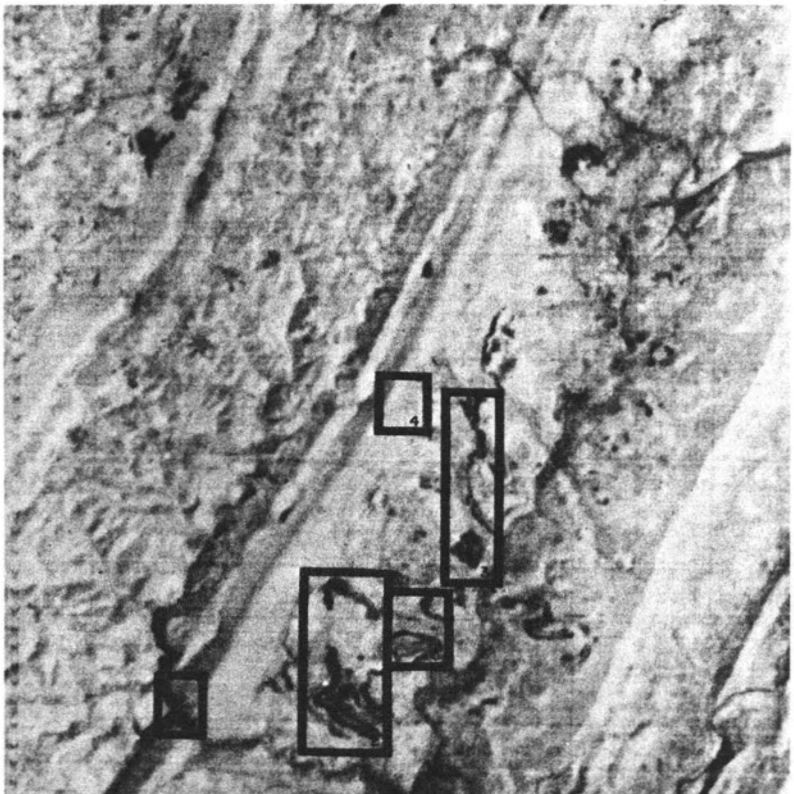


FIGURE 3. Five sample areas chosen for LARSYS2 clustering analysis and classification, representative of the study area.

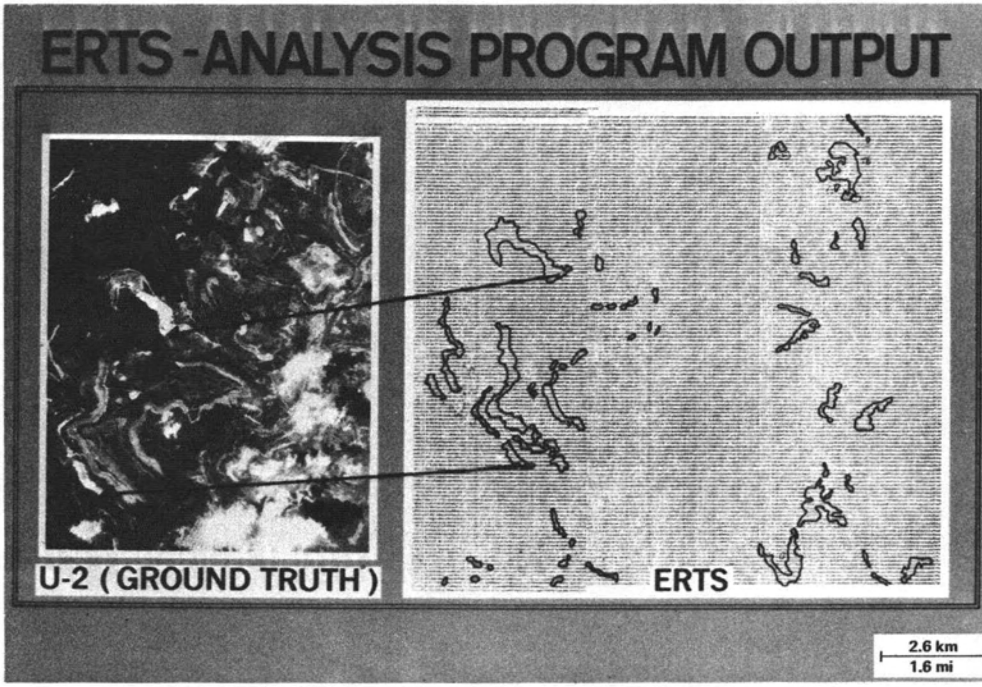


FIGURE 4. ERTS-Analysis output and U-2 photography which were verified in the field.

Multispectral Scanner System (MSS) band 7 (0.8μm to 1.1μm). This band enhances water features and carbonaceous mine areas (both dark) due to the absorption of energy within this band. The strip mines can be seen as dark contour line segments on the topography in the center of the image. Observing this region in one synoptic view, the geology of the north-east plunging Georges Creek-Upper Potomac syncline and the adjacent anticlines are evident. The cities of Cumberland, Frostburg, Westernport, and others, along with the Potomac, Georges Creek, and the Potomac North Branch drainages, also are evident. Field trips to the area northwest of Westernport were made in July and September of 1973 to examine the region first-hand and to study the mine operations in a 38.84-km^2 (15-mi^2) area northwest of Westernport, Maryland, for later analysis and comparison with the ERTS-Analysis and LARS computer analysis programs.

The first step in the computer analysis was to obtain digital values of the reflectance levels by using the computer-compatible tapes (CCTs) of the image. In order to obtain the desired digital reflectance levels from the CCTs, the ERTS-Analysis computer system (Schubert and MacLeod, 1973) was used on an IBM 360/75 computer to extract the information and return the results at a remote terminal in a form that could be rapidly interpreted. A pixel*-by-pixel (57 × 80 m) analysis of spectral signatures based on known spectral values using the International Biological Program (IBP) vegetation classification system was used to examine the affected areas. Table 1 shows the signature analysis of combining MSS bands 5 (0.6μm to 0.7μm) and 7 (0.8μm to 1.1μm) of previously designated reflectance measurements into 55 and 36 values, respectively, in order to identify the stripped, open, and various vegetation areas in the two basins.

The other computer system used is located at the Laboratory for Application and Remote Sensing (LARS) at Purdue University and is called LARSYS2. This system is accessed by a remote terminal at Goddard Space Flight Center connected to an IBM 360/67 at Purdue using previously reformatted ERTS CCT's. Dr. Al-Abbas at GSFC assisted in use of LARSYS2. A gray-scale output of bands 5 and 7 was first generated to select sample areas within the overall areas under study for a clustering analysis technique using the combined bands. The best spectrally separable clusters were selected, and it was found that 12 spectral signatures seemed to best assess the existing ground condition of the five sam-

* picture element

ple image-enlargement areas chosen from the area of study. These five areas shown in Figure 3 were checked and verified in the field, and the 12 different spectral signatures were identified. Finally, a multispectral classification of bands 5 and 7 based on the identified classes was completed, using pattern recognition techniques developed at LARS.

Discussion

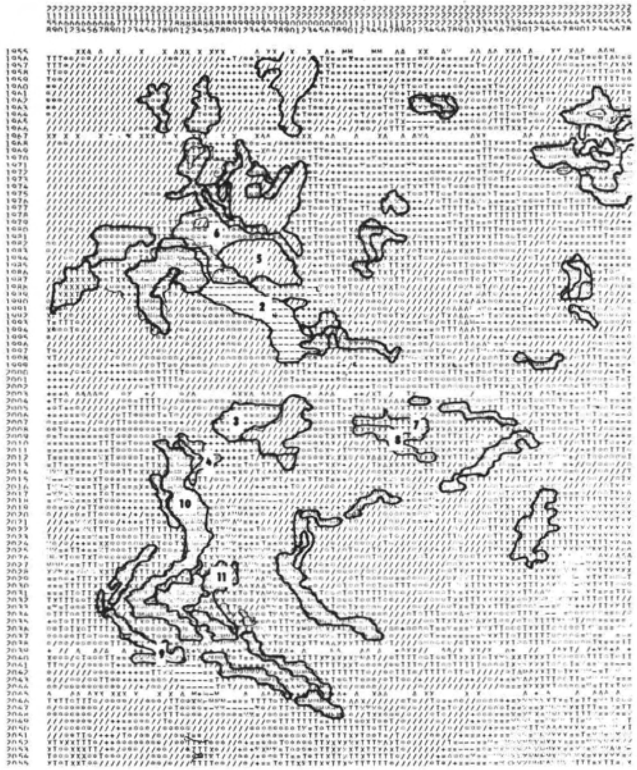
The ERTS assessment of the areas affected by strip mining was performed in a two-part analysis through the use of manual image-interpretation techniques and the ERTS-Analysis and LARS computer systems using the CCT's. First, in using manual techniques with ERTS imagery enlarged to 1:125,000 scale, there were limitations due to scale and, consequently, only the boundaries of the geologic formations could be defined in relation to the specific strip mines under investigation. No attempt was made to extract the total acreage of strip mines. These areas are too small in scale to show the desired detail with ERTS-1 imagery; they were no more than 80 to 300 m(260 to 1000 ft) across. This technique was not accurate enough for the purposes of this study to quantify the entire affected areas by planimetry means, the features being too small. The use of the ERTS computer-compatible tapes with both the ERTS-Analysis and LARSYS2 systems provided more reliable answers in the detection and inventory of strip mines. The results of the ERTS-Analysis output can be seen in Figure 4. Results from the computer output were correlated with the U-2 photograph; there was excellent size agreement with the printout. The U-2 photograph was then verified in the field.

Figure 5 presents a compilation of the final results from the ERTS-Analysis technique in identifying strip-mine areas in the two basins using this program, and shows a sample output registered to a topographic map. This sample output includes the Franklin Hill area which lies northwest of Westernport and outlines the local strip mines. The analysis, computer time, and statistical listing, compiled in approximately eight hours, identified 140 strip mines totaling 12.58 km² (3109 acres) of disturbed land within the two basins and adjoining area. The stripped, soil-covered, and high-wall boundaries could be delineated on the output. The table in Figure 6 also shows the size, number, and percentage of strip mines in the study area, the majority of which are less than .089 km² (22 acres) in size. In addition, the ERTS-Analysis computer output in transparency form registered to the topographic base at 1:24,000 (Figure 5) has already proved to be extremely useful for reclamation studies as a rapid

- **377,929 Acres, Surveyed and Analyzed in 8 Man-Hours**
- **140 Mines, 3109 Acres, Surveyed by ERTS, - Only 58 Mines, 568 Acres, Surveyed Routinely by the State of Maryland (1972)**
- **Total Number of Strip Mines**

Size (Acres)	Number
0 - 11.3	68
11.4 - 22.6	39
22.7 - 33.9	11
34.0 - 45.2	3
45.3 - 56.5	4
56.6 - 67.8	3
67.9 - 79.1	5
79.2 - 90.4	3
90.5 - 101.7	1
101.8 - 124.3	1
158.2 - 169.5	1
271.2 - 282.5	1

FIGURE 5. Tabulation of results in the study area and a sample output transparency registered to topographic base for quantitative studies.



1.0 km
0.6 mi

AREA 2 AND 5 CLUSTER ANALYSIS

CLUSTER	SYMBOL	IDENTIFICATION	# POINTS
1	(OPEN)	Missing Data	229
2	-	Bare Soil	220
3	+	Agriculture	551
4	=	Agriculture	1099
5	/	Low Trees	2366
6	*	High Trees	1978
7	T	High Dense Trees	1319
8	x	High Dense Trees	807
9	\	Grass/Spoil	689
10	M	Strip Mines	620
11	A	Low Dense Trees	323
12	W	Water	

FIGURE 6. LARSYS2 clustering output, showing the outline and delineation of the strip-mine areas and 12 cluster areas, for sample areas 2 and 5 from Figure 3.

method to show the overall extent of the acreage affected at one specific time, according to James Coffroth of the Maryland Geological Survey (private communication, 1973).

The LARSYS2 multispectral clustering and classification system proved to be very reliable in detecting and identifying various ground-surface conditions and ground cover of the existing strip mines and vegetation in the study area. The various spectral classes identified in Figures 6 and 7 provide important land-use information for future planning and for incorporation into a useful data base. As seen in Figure 6, the 12 clusters of vegetation density and soil cover can be extrapolated spectrally as depicted in the outlined clustered areas. The sampled areas in Figure 3, areas 2 and 5, outline that area shown in Figure 6. This output from LARSYS2 subdivides the 2.86 km² (707 acres) (620 pixels) of strip mines (M) in the area (Figure 6). In addition, the classification in Figure 7 resulting from the clustering analysis correlates with the detailed strip-mine state topographic map of the area and the previous ERTS-Analysis output. The results of this classification depict the stripped areas (C in Figure 7) and the soil cover overlying the backfilled spoils (open regions in Figure 7).

The analysis of the digital data, compared to manual techniques, proved most advantageous in the evaluation of the strip mines. As determined from the computer analyses, the reclaimed areas which were grassed over within a period of two years or less are somewhat difficult to distinguish from the recently

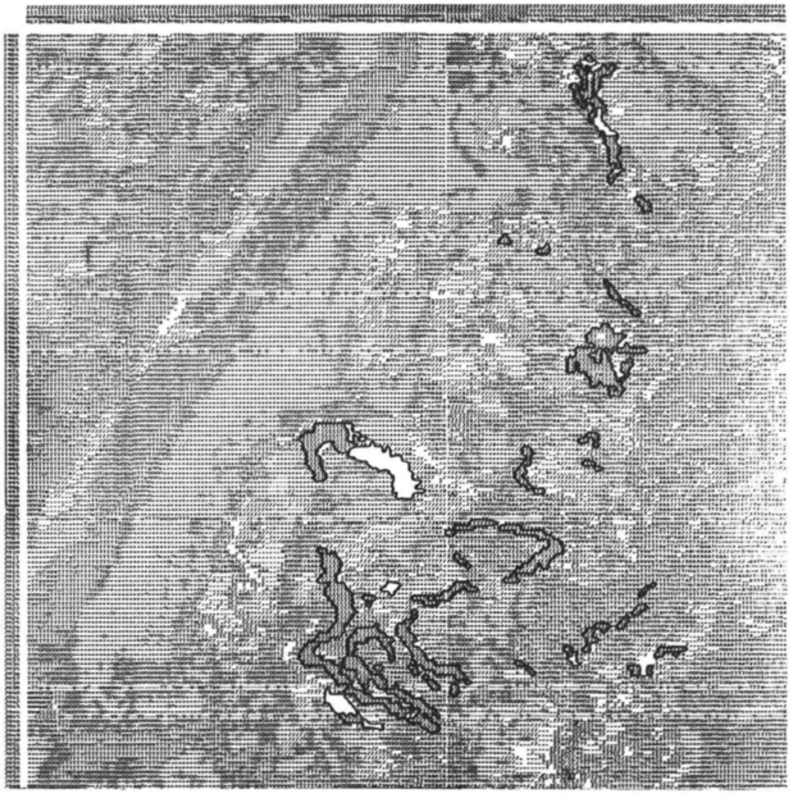


FIGURE 7. LARSYS2 classification output sample, verified with aircraft and field studies, delineating the strip mines (C) and bare soil (reclaimed area) which is open.

recovered and seeded grass regions. This was due mainly to two factors: the spoil material in the reclaimed areas contains a high degree of carbonaceous content mixed into the original soil cover, and the grass was not dense enough to change the spectral response. Digital computer analyses of affected strip-mining areas can be quantitatively examined by applying the advantages of both systems, ERTS-Analysis and LARSYS2. These data reduction and interpretation techniques will provide an added tool and rapid means of strip-mine assessment.

Conclusion

The use of the ERTS-1 data has been shown to provide an immediate application in detecting, mapping, and inventorying the effects of strip mining in the Upper Potomac and Georges Creek Basins of Maryland and West Virginia. These data will provide the states with a better means of detecting and monitoring future reclamation projects. With the increased needs for fuel, it is estimated that the 1.435 billion kg (1.6 million tons) of annual coal production in Maryland will increase by 10 per cent or more in 1974. Through use of the described methods, this increase in strip mining can be monitored throughout the disturbed regions. Also, at the same time, the progress of backfilled, planted, and reclaimed acreage throughout the state can be monitored, which will result in a minimum of ecological impact.

Acknowledgments

The authors wish to express their appreciation to those who assisted in and offered suggestions during the preparation of this paper; in particular, Dennis McFadden, Mike Hoffman, Nick Karlow, James Coffroth, and Dr. Hasan Al-Abbas were most helpful.

References

Jokes, Harold E., "Geography and Geology of Maryland," *Maryland Geological Survey Bulletin # 19*, 1968, (Revised) pp. 105-111.

Josephy, Alvin M., Jr., "Plundered West: Coal is the Prize," *Washington Post*, August 26, 1973, pp. C-1, 6.

Maryland Bureau of Mines, "Strip Mining Laws of the State of Maryland," Bureau of Mines Publication, 1971, pp. 1-10.

Schubert, J.S., and MacLeod, N.H., "ERTS-Analysis, A Remotely Accessed Computer System for Analysis of ERTS Data," NASA Contract Report NAS5-21892, June 1973, p. 29.

Stein, Jane, "Coal is Cheap, Hated, Abundant, Filthy, Needed," *Smithsonian Magazine*, Vol. 3, No. 11, 1973, pp. 19-26.

Toenges, Albert L., *et al.*, "Investigation of Lower Coal Beds in Georges Creek and North Part of Upper Potomac Basin, Allegany and Garrett Counties, Md.," U.S.D.I. Technical Paper 725, 1949, pp. 1-28.

BOOK REVIEW

Phototriangulation, by Sanjib K. Ghosh, The Ohio State University, Columbus, Ohio; Lexington Books, D.C. Heath and Company, Lexington, Mass., Toronto, London, Hard cover, 6½" × 9½", 241 pages, 79 illustrations. Price $22.50.

Numerous articles and most books contain some information on the subject, but until now no book explicitly on phototriangulation existed. This gap has finally been filled with Dr. Ghosh's very informative volume. Although primarily intended as a college textbook, the book is written in such a fashion that from it any photogrammetrist can benefit.

Divided into 13 chapters, it covers the whole spectrum of aerotriangulation with considerable depth and many practical examples. An appendix with two very useful computer programs is given.

After a brief historical review and classification, single-model triangulation, aeropolygon, aerolevelling, independent models, and computational (analytical) phototriangulation is covered. A rather clear breakdown is given, indicating various stages, such as preparation, instrumentation, computation, and adjustment. Using the aeropolygon as major approach, error sources and error propagation as well as different adjustment methods are presented.

The subject areas concerning geodetic control, auxiliary data, block triangulation accuracy, and economic considerations also are briefly dealt with.

The mathematical formulations presented are clear, understandable, and amply supported by illustrations and examples.

Too much emphasis appears to be placed on instrumental methods, sequential adjustments, etc., while rigorous simultaneous adjustments, though mentioned, do not receive the detailed treatment their practical importance deserves. Further, the whole area of simultaneous block adjustments with independent models (e.g., PAT-M-43, published in 1970; SPACE-M, published in 1973), the simultaneous use of auxiliary data including lakes, and the concept of self-calibration within phototriangulation systems (published in 1971) is not discussed. A considerable reduction in geodetic control, which is possible for all simultaneous block adjustments, could be incorporated into the study on economic aspects, because an increased phototriangulation cost may very well represent a considerable saving in ground survey expenses and therefore the total project cost.

Nevertheless, the book is extremely valuable and gives a list of selected references, which include articles on the above-mentioned subjects. Written in a well organized manner, and stressing practical aspects more than theoretical ones, it provides a welcome source of information for practical photogrammetrists and students alike.

—Dr. Wolfgang Faig
University of New Brunswick
Fredericton, N.B., Canada