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Coal Refuse Site Inventories

An operational survey of coal refuse sites was performed for the State of Indiana using small scale color-infrared photography.

Abstract: *Since 1973, the Indiana State Legislature has debated proposals to reclaim coal refuse sites and to find the costs required for their reclamation. Information concerning the number, size, location and environmental effects of refuse sites was developed in a timely manner by using aerial color-infrared photographs at 1:120,000 scale. Over 200 coal refuse sites were located and environmentally assessed. Remotely derived physical and environmental data combined with industrial and state statistics were used to compute the cost of reclamation for each site. Tabulations of site acreage, capsulated descriptions of site conditions, and cost of reclamation are summarized on two 1:250,000-scale Coal Refuse Inventory Maps. The results of the survey revealed that a high degree of accuracy had been achieved by using small scale imagery. The survey was completed in 90 days and served as a practical demonstration of the cost effectiveness and efficiency of remote sensing. The techniques can be used to support the legislative decision-making process in other coal producing regions. Program data are now being used by the Board of Directors, Indiana Coal Association, various State and Federal Agencies, and the Indiana State Legislature.*

Introduction and Background

Increasing reliance on coal as an energy source has focused public attention on the environmental effects of coal mining including active and orphaned coal refuse sites.* Legislative attention is therefore being given both to the past and to anticipated impacts of coal mining on the environment; the coal industry also is responding with increasing efforts for refuse site reclamation.

Approximately 23 per cent of the raw bituminous coal mined in the United States is ultimately discarded as refuse material. Processing of coal (washing and screening) removes unwanted coal debris and rock material which is separated into two fractions; a relatively coarse boulder-to-pebble-sized "gob" fraction and a fine-pebble-to-clay-sized particles containing abundant coal debris. The "gob" fraction is discarded in large

* Terminology: Coal refuse sites collectively refer to coal refuse banks and slurry ponds. Coal refuse banks or "gob piles" refer to sites for disposal of coarse coal waste, and slurry ponds for disposal of the fine coal waste fraction.

banks close to the preparation plant; these banks may be miles long and several tens of feet high. The fine debris, called slurry, is usually piped to depressions created by mining or specially constructed impoundments.

In 1973, the Indiana State Legislature passed an amendment which provided for the "acquisition of abandoned and unclaimed mined areas for reclamation purposes."* While authority for acquisition and restoration of such lands was given, funding questions remained to be addressed by future legislative sessions.

In the past several years there has been considerable discussion among members of the Indiana State Legislature's Conservation Advisory Committee, State Agencies, and the coal industry regarding the need for an inventory of coal refuse sites (coal refuse banks and slurry ponds). An inventory was required to establish a basis for agreement among legislative committees, the coal industry, and state agencies. All parties recognized the difficulty and cost of acquiring the data by comprehensive field surveys. Even with the necessary financial resources, the inventory could not have been completed in time for use by the spring 1974 session of the State Legislature. Without a reasonable estimate of site acreage and cost of reclamation, legislative planning would be hindered and differences of opinion between the State and industry would be difficult to resolve. Furthermore, the inventory would aid the state in complying with the requirements set forth in proposed Federal surface mine legislation.

The State Legislature, Indiana Geological Survey, Indiana Division of Reclamation, and Indiana coal producers determined that the available data based was insufficient. It was recognized that some coal refuse sites were acid-producing; other sites had been leached out or have burned out through the years, thereby eliminating acid runoff. Breaching of impoundments with associated sediment pollution is a common local problem (Figure 1). Some "neutral sites" only could be classified as lacking asthetic value. Once the location, acreage, and environmental elements of problem areas were fully understood, field surveys could be conducted within those areas classified as highest reclamation priority. Estimated reclamation costs might then be refined by field survey.

In November 1973, the Indiana Geological Survey and Indiana Coal Association conducted a NASA-supported high-altitude aerial inventory program to meet the critical information needs of the state.

* Indiana Senate Enrolled Act #10, 98th Indiana General Assembly.

Objectives

The primary objective of the investigation was to locate and evaluate coal refuse banks and slurry ponds within the Indiana portion of the Eastern Interior Coal Basin, and to estimate the cost of reclamation for each site. Presentation of inventory data in a convenient and easily understood format was essential.

A secondary objective was to apply multilevel remote sensing data to address an immediate operational problem, i.e., timely data to meet the needs of the Spring 1974 session of the Indiana General Assembly. The investigation could also provide information to NASA concerning the use of integrated satellite and aircraft remote sensing for legislative and management decision making by state agencies.

Remote Sensing Procedural and Analysis Summary

Physical and environmental analysis of coal refuse sites

Satellite (ERTS) computer compatible tapes were analyzed by using computer processing techniques. Testing was conducted in Warrick County, Indiana (Figure 2) where coal refuse banks and slurry ponds of various sizes and spatial distribution occurred. The objective was to provide the investigators with rapid regional estimate of the location of all refuse sites; once located, follow-up using high-altitude aircraft imagery would permit acquisition of environmental data.

The computer-assisted investigation was conducted in two phases: statistical training and positional calculations. Statistical analyses revealed that coal refuse and water were not statistically separable. Other ERTS investigators report some success in differentiating coal refuse and water under different geological conditions and for larger refuse sites.

The second phase of the investigation involved the refinement of an algorithm to calculate latitude-longitude given an input pixel and certain satellite parameters.† Testing revealed that positional accuracies amounting to 1700 ± 800 meters could be derived by using ERTS imagery. These results are generally consistent with those obtained by other investigators but were insufficient for use by coal producers and the State.

† These parameters are those provided with an image print, i.e., coordinates of the center point and orbit azimuth. These data provided are not precise enough to permit positioning accurate to better than one mile.

FIG. 1. Example of an environmental problem which may be associated with abandoned coal refuse. This slurry pond was breached during heavy rains and impounded refuse was carried into nearby streams.

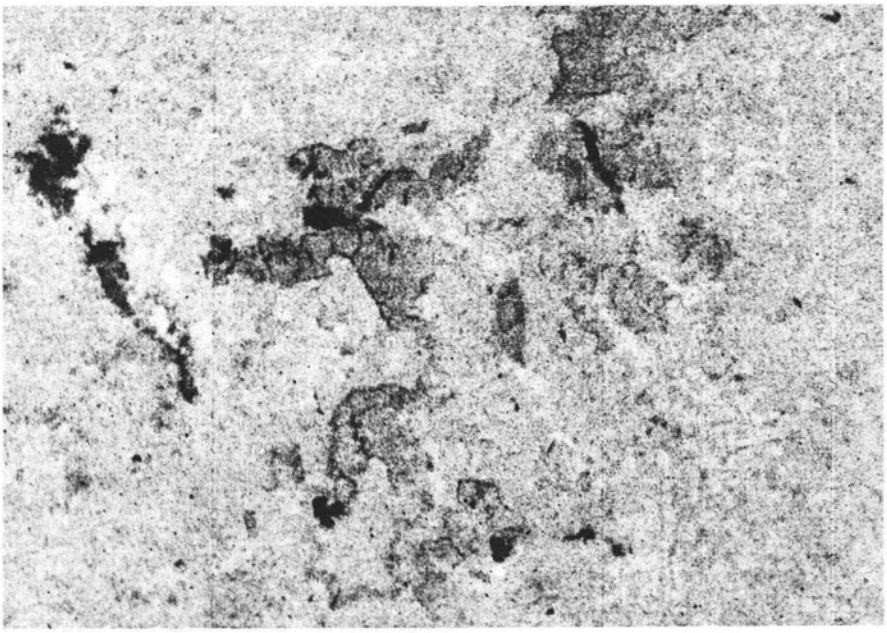


FIG. 2. Enlargement of an ERTS-1 (Earth Resources Technology Satellite) image of Southern Indiana. Mined lands are shown as dark grey areas; a major coal refuse bank (black) can be identified near the center of the image.

NASA high-altitude color-infrared aerial photography (May, 1971) was used as the principal data source to inventory and environmentally evaluate Indiana's coal refuse sites (Figure 3). Positive transparencies at a scale of 1:120,000 were analyzed to (a) locate coal refuse banks and slurry ponds; (b) assess local environmental impacts (if any) and par-

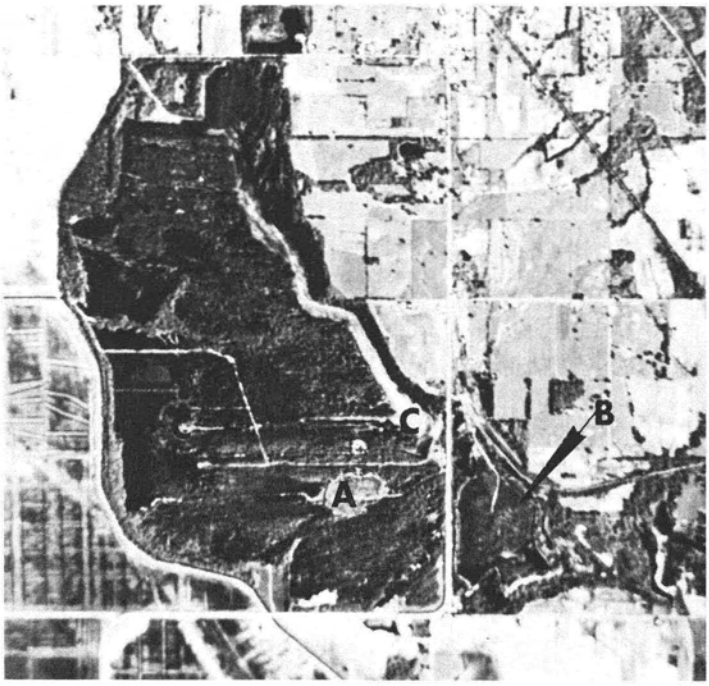


FIG. 3. Black and white enlargement from high altitude color infrared photograph of coal refuse site GR-11 in Green County. Areal data derived from ground survey and the coal industry was compared to remote sensing derived data: Site A - ground survey, 10. acres; remote sensing analysis 10.0 acres. Site B - ground survey, 67.1; remote sensing analysis 66.8. Slurry can be seen at C.

ticularly impacts on water resources;† (c) categorize type of site (e.g., refuse from underground or surface mining); (d) compute the areal extent of each coal refuse site; and (e) make a volume class estimate for each site. Many of these data contributed to cost-of-reclamation estimates.

The inventory was limited to coal refuse sites with an areal extent of approximately two acres. Sites smaller than two acres were mapped, but not tabulated, on the Coal Refuse Inventory Maps; smaller sites (sometimes naturally vegetated) were judged to be of minimum near term significance for legislative and reclamation planning and were not competely mapped.

Quality control of data derived from small-scale color-infrared aerial photography involved spot checking of 1:20,000-scale color and color-infrared aerial photography, field observations, and light aircraft observations. For sample sites, the comparison of remote sensing-derived and industry-supplied areal statistics showed that accuracies of approximately 95 per cent were achieved.

Color-infrared (1:120,000 scale) photography was analyzed in order to locate areas of environmental degradation. Stream pollution was detected primarily from color variations; refuse-derived coal sediments in streams, evidence of vegetative stress and/or "yellow boy" in water bodies were detected. The terminology adopted to summarize the broad environmental and physical conditions at each coal refuse sites is *contained, affected areas, filled strips,* and *floodplains.*

The term *contained* refers to the fact that stream pollution and/or vegetation damage was minor or not identified in small-scale aerial photography. Minor occurrences of acid or sediment pollution were identified during field checking and low-altitude observations within some contained areas but were not evident on the aerial photography. *Affected area* refers to the fact that major stream sedimentation was visible, or that vegetation damage was identified; serious sources of environmental degradation were judged to be high-priority reclamation

† Generally environmental degradation caused by coal refuse in Indiana has been limited to orphan sites; current reclamation practices have reduced pollution from banks associated with operating mines.

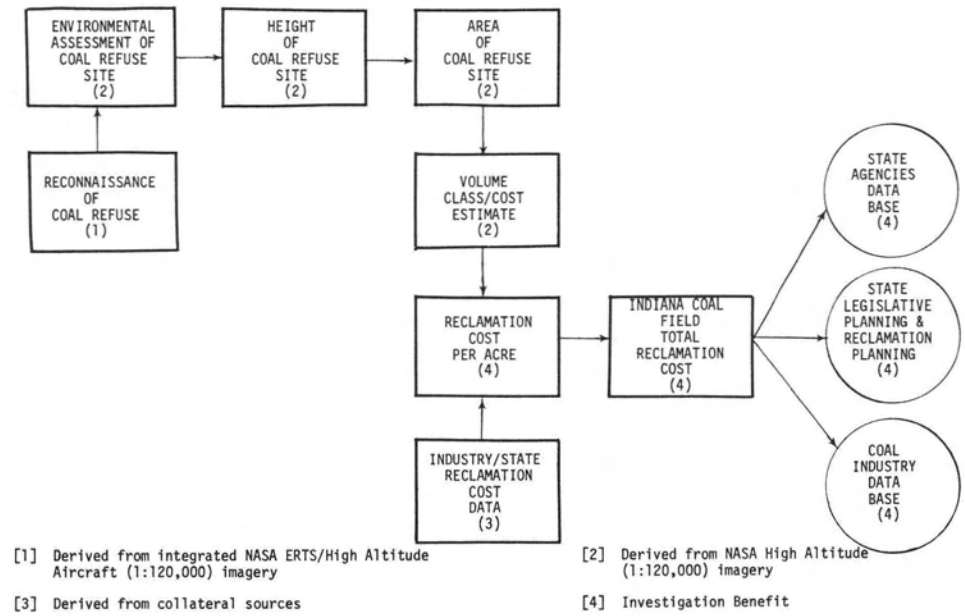


FIG. 4. Procedures for the Indiana Coal Refuse Site Inventory with outputs.

targets. The term *filled strips* indicates that mining operations had back-filled unused strip pits with refuse material; these sites were generally contained and showed little or no environmental damage. The sites included numerous small areas of refuse that were combined within total acreage figures. *Floodplain* indicates that the coal refuse site encroached upon the floodplain.

COST OF RECLAMATION ESTIMATE

Reclamation cost per acre was computed by integrating remote sensing-derived refuse classes with historical reclamation cost statistics based principally upon coal industry and state sources* (Figure 4). Reclamation costs for Illinois and Kentucky and U.S. Bureau of Mines' data for Kentucky and Pennsylvania also were used. Cost of reclamation estimates for each class site assume (a) shaping and compacting of each site, and covering with 2-3 feet of soil; (b) soil preparation, fertilization, and seeding; and (c) local materials and labor.

Reclamation cost estimates assume reclamation effort which ensures neutralization of acidity and long-term revegetation of the coal refuse sites.

Estimates of site acreage, height, and general condition were determined by using small-scale aerial photography. Refuse sites were divided into three classes (Table 1) based on refuse type and estimated maximum height. These classes correspond to the general natural three-fold class of sites in Indiana. These data were integrated with a generalized per-acre cost of reclamation statistic in order to compute statewide reclamation costs (see Table 2).

* State subcontracted reclamation efforts may increase the industry based reclamation cost figures cited in this report by several times.

TABLE 1. VOLUME CLASS/COST CATEGORIES.

Class I	Includes refuse banks from underground mining and large surface-mining refuse banks with a maximum height in excess of 40 feet as determined from aerial photography stereoscopic analysis, ground checking, and topographic map checking. Such sites require intensive grading and reclamation work. Industry experience shows that reclamation costs approximate $5800/acre.
Class II	Intermediate sites, including coal refuse sites (as cited above) with maximum heights of 10 to 40 feet. Historical industry records show that reclamation costs approximate $4000/acre.
Class III	Includes active slurry ponds, old dissected slurry impoundments and coal refuse banks which lack appreciable height (<10 feet). An average cost of reclamation of $2600/acre was derived from state, federal, and coal industry sources.

TABLE 2. COUNTY STATISTICAL SUMMARY.

County	Acres[a] GOB	Acres[a] Slurry	Reclamation Cost Estimate County[b]
Clay	123	94	$ 800,000
Daviess	31	12	132,000
Dubois	8	0	21,000
Fountain	6	0	16,000
Gibson	34	10	117,000
Greene	248	313	1,458,000
Knox	405	47	2,098,000
Martin	5	0	16,000
Owen	15	0	39,000
Pike	363	217	1,860,000
Spencer	11	0	29,000
Sullivan	361	410	2,714,000
Vermillion	58	11	203,000
Vigo	468	53	2,386,000
Warrick	443	464	2,634,000
STATE TOTAL:[c]	2579	1631	$14,523,000

[a] Individual site acreage was rounded to the nearest whole acre and then totalled.

[b] Rounded up ($500 or more) or down (less than $500) to the nearest $1000.

[c] Refuse areas greater than 2 acres in areal extent.

SUMMARY OF REMOTE SENSING OBSERVATIONS

The spatial detail provided by high-altitude aircraft imagery proved essential to the classifying of coal refuse sites, and the acquiring of primary elements of the environmental information needed to establish priorities for reclamation.

Automated data processing techniques applied to ERTS imagery of Indiana proved unsuccessful for distinguishing water bodies from slurry ponds, some of which were covered by shallow water. Some coal refuse sites of 20 acres or more were located by using ERTS imagery but the required environmental assessments, e.g., evidence of sediment pollution within drainage systems, was generally beyond the resolution limits of the satellite imagery. Almost all coal refuse banks and slurry ponds from old mining operations were too small (several acres) or too densely vegetated to be distinguished from nearby vegetated lands with ERTS imagery.

A comparative cost analysis showed that high-altitude (1:120,000 scale) aircraft had a distinct cost benefit over ERTS-1 imagery for inventory programs of this kind. For a cost of less than $2.00/square mile, including field checking, coal refuse sites were accurately located and environmentally analyzed by using high-altitude aircraft imagery. The cost of locating refuse sites and conducting general areal measurements following analysis of ERTS imagery and digital tapes approximated $3.00/square mile, not including field checking.

STATISTICAL SUMMARY OF REFUSE SITES

A compilation of remote sensing-derived refuse site data in Indiana shows there are 149 major coal refuse sites in the coal field. An estimated 2579 acres of gob and 1631 acres of slurry were identified. The total cost for reclaiming these sites as derived from remote sensing data for sites in excess of 2 acres is over $14.5 million. This figure reflects basic cost of reclamation; additional reclamation for environmentally degraded areas, hydrological improvements, supplementary land acquisition, or state subcontracting costs are not included.

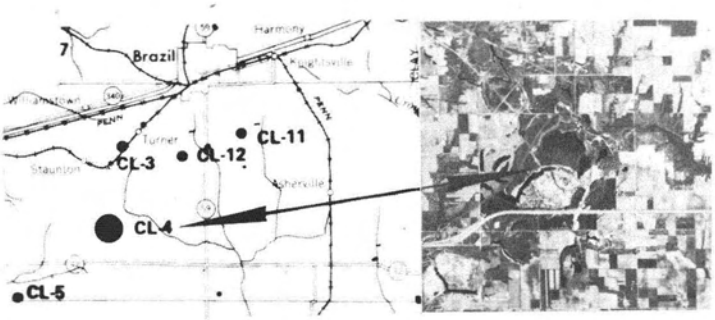
Principal environmental damage was detected at 16 sites; a majority of coal refuse sites as evaluated with aerial photographs were identified as contained; i.e., not contributing to significant environmental degradation.

The cost of reclamation for coal refuse sites for the State of Indiana may be greater than that estimated during the inventory. Cost data summarized on the Coal Refuse Inventory Maps are derived largely from industry data; other factors including state engineering surveys, drainage control, supporting services from the State Public Works Department, contracting with private firms, and reclaiming border strips adjacent to refuse sites will increase costs. The final cost, according to the Indiana Division of Reclamation, may exceed $40 million.

UTILITY OF THE INVENTORY TO THE STATE

Indiana has become the first state to complete a statewide coal refuse site inventory using integrated high-altitude aerial and orbital techinques. The magnitude of the problem of reclaiming the various coal refuse sites throughout the State, and funding limits required to meet statewide reclamation needs have been identified for the first time. The program provided an important statistical data base for use by various State agencies. This statistical record includes the location and classification of all coal refuse areas of approximately two acres or greater in size, a cost reclamation estimate, and an environmental assessment for each site.

Coal Refuse Inventory Maps (Figure 5) were delivered during the 1974 Session of the General Assembly. The Indiana General Assembly did not, however, debate a funding bill for reclamation of coal refuse sites in the 1974 Session. It is anticipated that other bills



Tabulation

CLAY COUNTY

Site Number	Location T.	R.	Sec.	Type of Mine	Remarks	Area (acres) G	Sl	Volume Class Estimate	Reclamation Cost (total cost of site)
CL-1	13N	7W	11 NE1/4	S,i	contained	7.8		III	$ 20,280
CL-2	13N	6W	5 NW1/4	S,i	contained	2.9		III	7,540
CL-3	12N	7W	10 SE1/4	S,i	contained	3.2		III	8,320
CL-4	12N	7W	28,27	S,a	affected area	73.0	94.0	I,III	667,800
CL-5	12N	7W	32 NW1/4	S,i	contained	2.4		III	6,240
CL-6	11N	6W	18 NE1/4	S,i	filled strip	5.5		III	14,300
CL-7	11N	6W	11 NE1/4	S,i	contained	1.8		III	4,680
CL-8	10N	6W	15 NE1/4	S,i	contained	3.0		III	7,800
CL-9	9N	7W	30 NE1/4	U,i	contained	13.7		III	35,620
CL-10	9N	7W	29 SE1/4	U,i	contained	1.7		III	44,200
CL-11	12N	6W	8 NE1/4	S,i	contained	5.6		III	14,560
CL-12	12N	7W	12 SE1/4	S,i	contained	1.8		III	4,680

FIG. 5. Portion of Coal Refuse and Reclamation map showing an area in Clay County, Indiana. Insert is a black and white reproduction of a 1:120,000 color scale infrared aerial photograph from which tabulated data was generated for site CL-4. Site CL-4 in Clay County, Indiana within Township 12 North, Range 7 West, Sections 27 and 28. It is an active surface mine with 73 acres of Class I gob refuse and a 94 acre slurry pond. The mining has produced some environmental damage and would cost $668,000 to reclaim.

to fund reclamation of coal refuse sites will be introduced in the near future.

The statistical data developed from the inventory were distributed to the Conservation Advisory Committee. This is a standing committee of the Indiana State Legislature which is responsible for drafting reclamation bills for the next legislative session. The State already has authority to acquire mined lands, to restore them, and to resell them as required but lacks the necessary funds for acquisition. The inventory will prove central to identifying the required funds to reclaim coal refuse sites.

The products prepared by using aerial and orbital remote sensing techniques were enthusiastically received by the Committee as basic information of continuing value to the States. The State Legislature, the coal industry, and State agencies agreed that all will benefit from understanding the number and distribution of sites and any associated pollution problems.

The inventory has provided the State Division of Reclamation with a primary data bank vital to future statewide reclamation planning. Priorities for refuse site reclamation can now proceed with the information that the program provided. The statistical data will serve as a basis for responding to Federal inquiries regarding Indiana's mined land problems.

UTILITY TO INDIANA'S COAL INDUSTRY

The Coal Refuse Inventory Maps were made available at the Annual Meeting of the Board of Directors of the Indiana Coal Association in February, 1974. Coal company representatives acknowledged that the data constituted a contribution to understanding coal refuse site problems throughout the State; up to this time, the industry was unaware of the location of all coal refuse banks and to what extent they contributed to serious pollution problems.

The Indiana Coal Association acknowledged that the maps will serve as a basis for working closely with State Offices. In the future, the State and Indiana Coal Association will have the necessary data to deal with

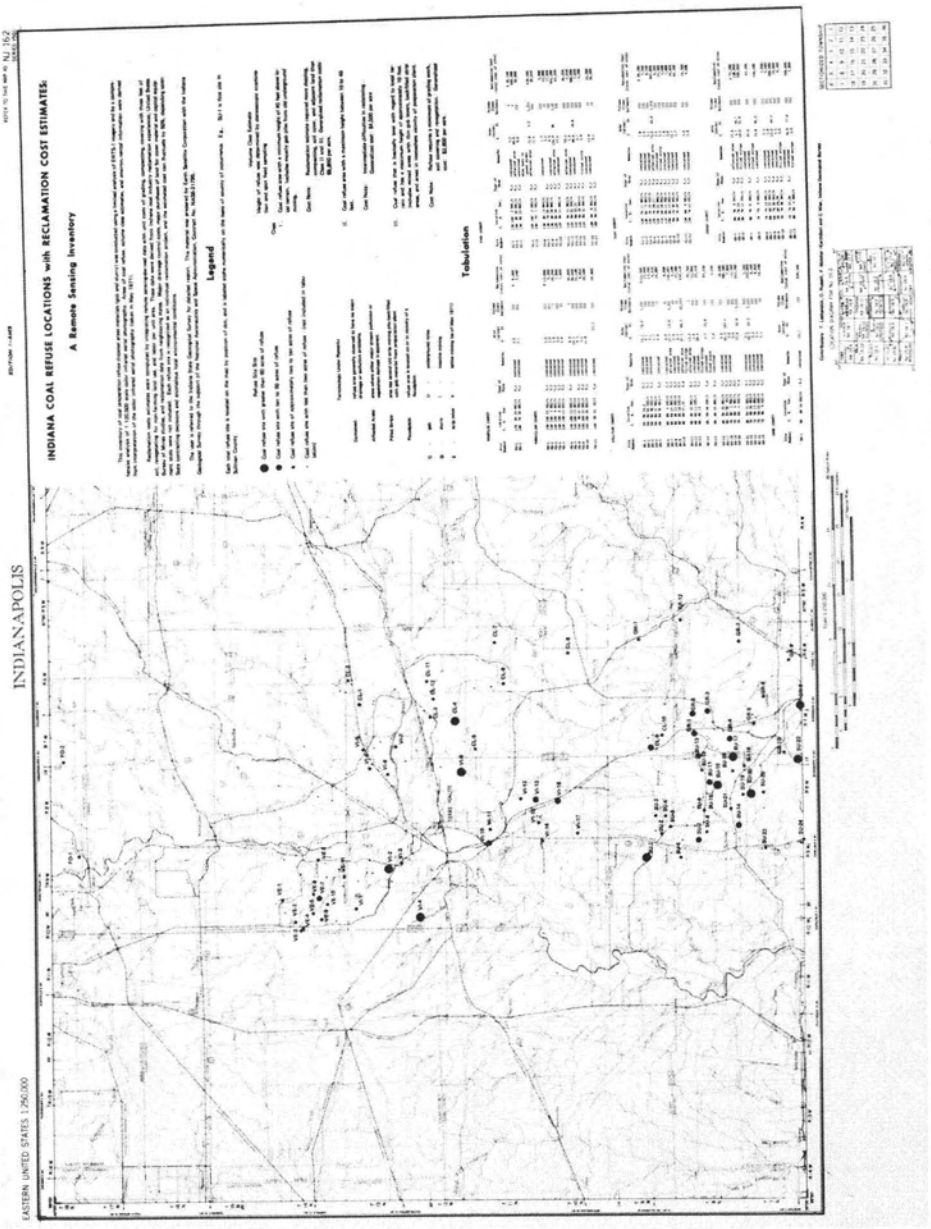


FIG. 6. Coal Refuse Inventory Map Product prepared principally from high altitude aerial photography. The maps are being used throughout Indiana as a primary reference base for coal refuse site planning.

the specifics rather than the generalities of the problem.

CONCLUSIONS

Remote-sensing derived data provided timely information to State agencies, the coal industry and the State Legislature which otherwise only could be obtained by costly and time-consuming ground surveys. Site analyses and reclamation cost estimates were completed in less than 90 days by using remote sensing techniques.

Inventorying major coal refuse piles and slurry ponds with satellite imagery is feasible, but the costs are not competitive with high-altitude aerial color-infrared photography. Color-infrared photographs at 1:120,000 scale provided the required location of coal refuse sites and sufficient environmental and physical information needed to compute cost of reclamation.

Analysis of aerial color-infrared photographs at 1:120,000 scale provided dependable and accurate data by which to locate and

environmentally assess nearly 200 coal refuse banks and slurry ponds. Physical and environmental site data acquired from high-altitude aerial remote sensing records served a basis for evaluating cost of reclamation. Statewide cost of site reclamation based on industry statistics were identified as exceeding $14 million and were distributed to interested groups throughout the state.

The inventory constitutes an important new data base within the Indiana Division of Reclamation and the coal industry. Both groups now have comprehensive reference for establishing priorities for coal refuse site reclamation and for complementing future field surveys.

ACKNOWLEDGMENTS

This program was completed with the sponsorship of the National Aeronautics and Space Administration (NASA) in cooperation with the various Indiana state agencies and the Indiana Coal Association. Dr. Charles Wier, Dr. Frank J. Wobber and Mr. T. Leshendok, were jointly responsible for carrying out the program. Earth Satellite Corporation was responsible for image interpretation. The guidance of Indiana coal producers, Mr. William Beeman of the Indiana Coal Association, and Mr. R. McNabb of the Indiana Division of Reclamation is gratefully acknowledged.

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Obituary

Professor R. S. Halonen

REINO SAKARI HALONEN, 1976 Congress Director and member of the Council of the International Society for Photogrammetry, died July 2, 1975 at his summer home in Aitoo, Finland. Professor Halonen was the head of the Institute of Photogrammetry, Helsinki University of Technology in Otaniemi. He was 60 years old.

His death was a shock to his family and to all his friends. His loss will be felt greatly by photogrammetrists in Finland where he led in the development of and education in his field for a generation.

Professor Halonen impressed the other members of the Council of ISP at their annual meeting in Helsinki in May, 1975, as he demonstrated the excellent organization for the coming Congress. Certainly his leadership will be missed. However, the Council is confident that the Congress will proceed as scheduled, thanks to the Professor's thoughtful preparations.

Professor Halonen is survived by his wife, children, and grandchildren.

—G. C. Tewinkel