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A SUBSIDIARY OF THE SINGER COMPANY**4936-F****INVESTIGATION OF COLOR AND COLOR INFRARED
AERIAL PHOTOGRAPHIC TECHNIQUES FOR MINING
AND RECLAMATION PLANNING AND MONITORING**

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Columbia Plaza
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*Submitted By: HRB-Singer, Inc.
Science Park
P.O. Box 60
State College, Pa. 16801*

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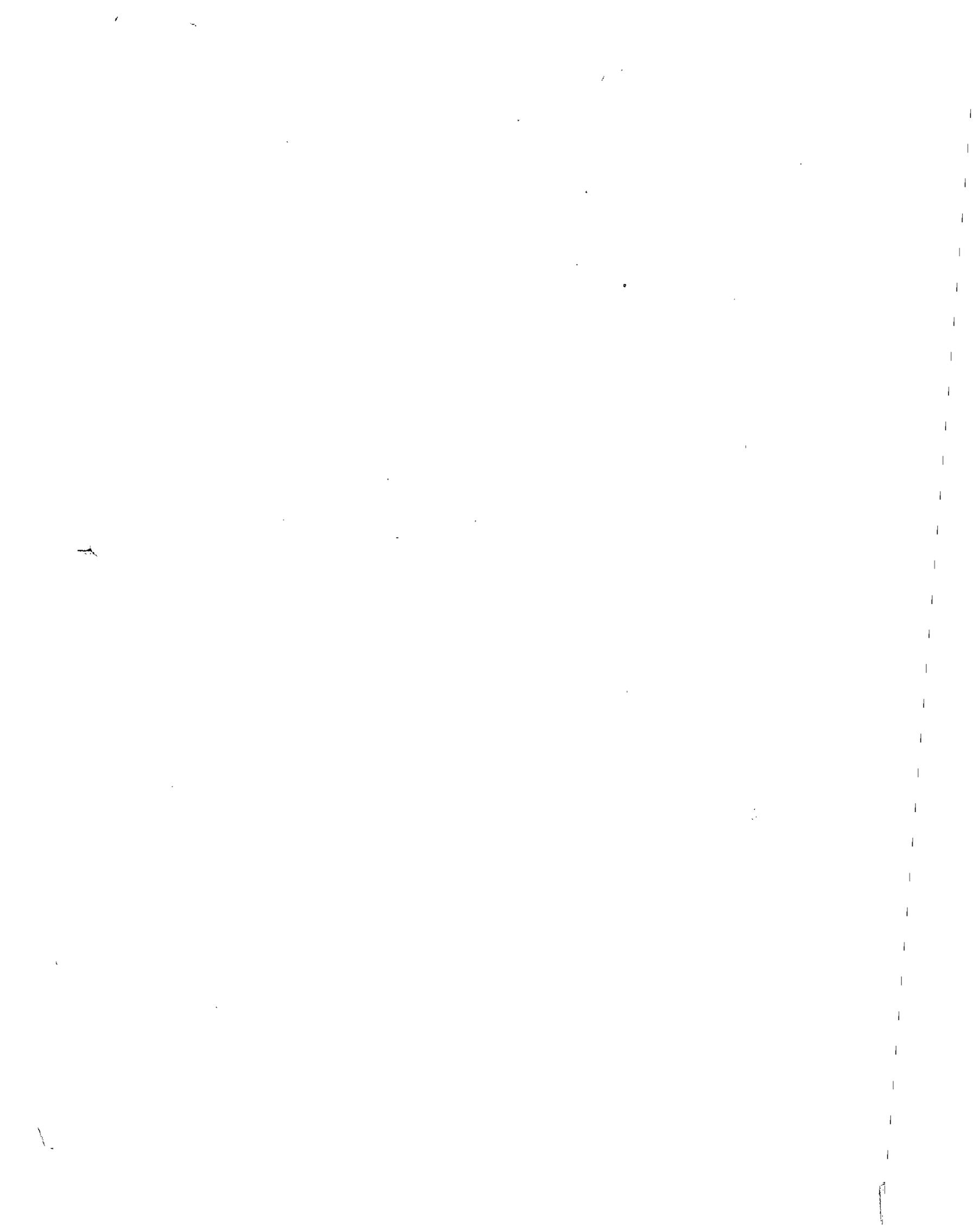
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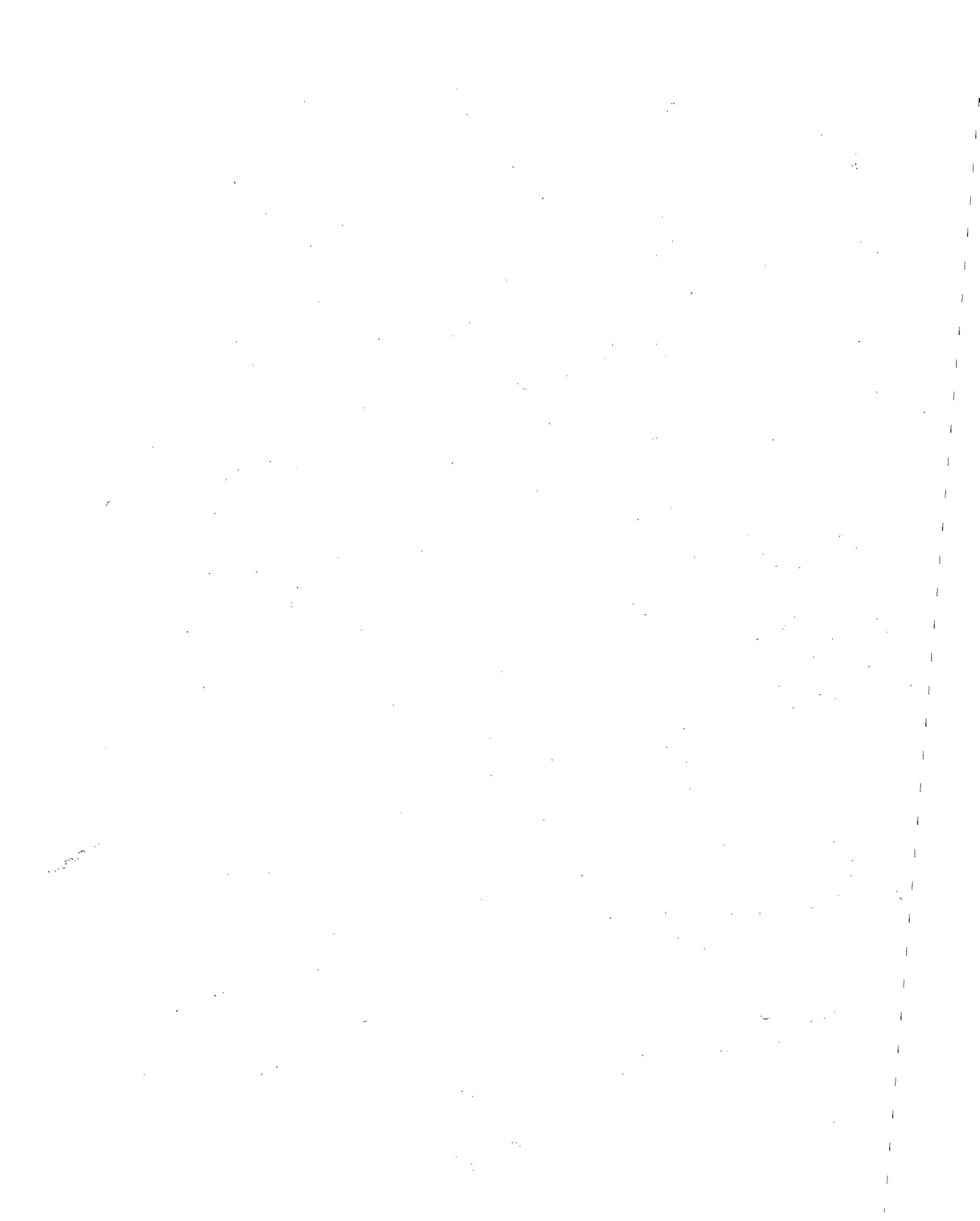
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16. Abstract (Limit: 200 words) The objectives of this study were the evaluation of the technical and economical feasibility of utilizing color and color infrared aerial photography to satisfy some informational needs for premine planning, mine progress monitoring, and reclamation monitoring. Seven aerial data collection missions were conducted within a 2-year period over strip mine sites in Pennsylvania. Scales of 1:6,000; 1:12,000; 1:24,000; and 1:48,000 were flown on the first aerial mission. The 1:12,000 was chosen as the optimal scale for the remaining six flights. An extensive literature and legislative review and discussion with strip mine operators identified the informational parameters that could possibly be obtained from aerial photography. Interpretability accuracies were evaluated for parameters in the broad categories of land use, soils, water, vegetation, and geology. Seasonal interpretation characteristics were noted for infrared photography. Man hours for photointerpretation and costs of aerial data collection were monitored closely and incorporated into a cost benefit analysis. Those parameters that could be mapped, identified, or measured with accuracies ≥ 75 percent were incorporated into a photointerpretation training manual. An additional analysis was performed to determine the applicability of the interpretation methodologies and results developed for Eastern sites to Western surface coal mining sites.			
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FOREWORD

This report was prepared by HRB-Singer, Inc., of State College, Pennsylvania under USMB Contract Number J0155041. The contract was initiated under the Mining Environmental Research Program.

This program was administered under the technical direction of the Division of Environment with Mr. Paul Marcus as the Technical Project Officer. The Western Site Analysis was administered by the Denver Mining Research Center with Ms. Carol Molnia as the Technical Monitor. Mr. A. G. Young was the Contract administrator for the Bureau Mines.

This report is a summary of the work recently completed as part of this contract during the period 30 May 1975 to April 28, 1978. This report was submitted by the authors on September 1978.

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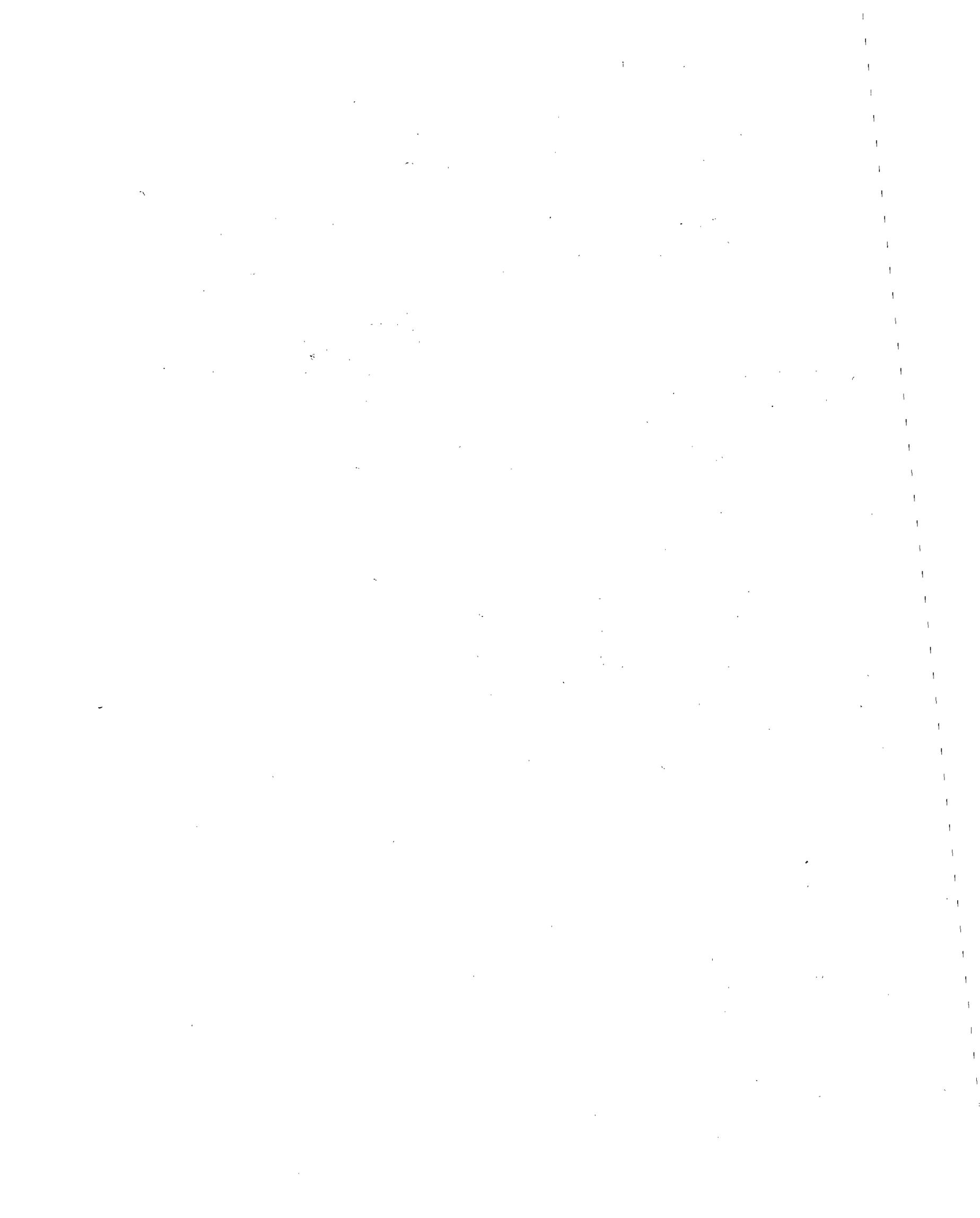


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I. EXECUTIVE SUMMARY

This study was conducted to determine if basic photointerpretation techniques combined with color and color infrared photography could be used in a cost effective manner to satisfy certain informational needs of surface coal mine operators and regulatory personnel. This information is needed for pre-mine planning, mine progress monitoring, reclamation planning, and reclamation monitoring. The evaluation technique consisted of combining photointerpretation accuracies with the costs of photointerpretation and aerial data collection to determine the feasibility of utilizing color and color infrared aerial photography to supplement, expedite and improve present mining and reclamation planning and monitoring.

Test sites in Clarion and Cambria Counties, Pennsylvania were selected for this study. The site in Cambria County encompassed an area of 15 square miles and represented a steep slope contour mining situation. The site in Clarion County encompassed an area of 25 square miles and represented both contour and area mining situations. Within these test sites, six 3/4 square mile test areas were chosen for intensive ground data collection and photointerpretation testing.

A legislative review and discussions with mine operators and regulatory personnel were conducted to determine what kinds of data are needed. Based on past experience and the results of these discussions, a list of surface mine features was produced. In addition, an extensive literature review was conducted to identify which photointerpretive techniques could best be used to evaluate the interpretation accuracies for each surface coal mining feature.

On the initial data collection flight data at scales of 1:6,000; 1:12,000; 1:24,000; and 1:48,000 were collected. Color, color infrared, black and white, and black and white infrared film types were used. An evaluation of interpretation accuracies and data collection costs indicated that color and color infrared film types at 1:12,000 scale were the optimum combinations. These two film types at this scale were used for the next six seasonal data collection missions.

Six photo interpreters evaluated the aerial data collected during each season. Photointerpretation equipment included light tables, lens stereoscopes, tube magnifiers, mirror stereoscopes, planimeters, parallax bar, and engineers scale. Mapped and measured interpretation results were compared to the ground data to produce interpretation ratings and accuracies for each mining feature over all four seasons. Interpretation man-hours were monitored closely by the photo interpreters.

The results indicated that acceptable interpretation accuracies (most features can be mapped or measured with 75% accuracy compared to ground data) could be obtained for a large number of parameters. These parameters included pre-mine land use, water quality, drainage patterns, slopes, and vegetation. Mine progress parameters such as distances from mining, and overburden removal estimates were obtained with acceptable accuracies. Reclamation monitoring parameters such as percent cover, trees/acre, spoil and soil identification, erosion, water quality and slope measurements were obtained with acceptable accuracies.

A western site analysis was conducted to determine if the interpretation methodologies and results developed for eastern sites in this study could be applied to the western surface mining situation. Color and color infrared aerial photography was collected over three mining sites in Montana and Wyoming during June of 1977. Results of the western site analysis indicated that the informational needs of western operators are more detailed than for eastern operators. Some additional interpretation methodologies will have to be developed for vegetation, archaeology, and geology.

This study produced two documents, a final technical report and an aerial photographic interpretation manual for eastern surface mine operators and regulatory personnel.

II. BACKGROUND AND OBJECTIVES

A. BACKGROUND

Many existing state surface mine regulations and, more particularly, newly enacted federal legislation require permit applicants to prepare a comprehensive mining and reclamation plan supported by detailed environmental and physical information. This, in addition to increased emphasis placed by the regulatory authorities and operators on the proper management and monitoring of surface mining operations, has resulted in a need for rapid and accurate data acquisition and interpretation. The gathering of pertinent surface data relating to land use, water, soils, vegetation, and geology can be expedited and enhanced greatly by means of aerial photography supported by limited ground correlation.

The collection of data throughout the mining and reclamation process is an expensive and time-consuming task. To reduce time and costs, black and white aerial photography has been used by the mining community for preparing topographic maps, determining overburden removal volumes, and monitoring the progress of mining. Black and white imagery, however, is limited in its information content relative to certain physical or natural parameters. Color and color infrared aerial photography, on the other hand, can provide additional information relative to physical and natural parameters that are vital to effective mining and reclamation planning.

This information could provide a means for reducing costs and saving time by providing additional planning and monitoring data and reducing field collection for the surface coal mine operators.

B. OBJECTIVES AND SCOPE

The first task of this study was to develop a methodology for determining the utility of color and color infrared aerial photography as a data collection and analysis tool for surface coal mine planning and reclamation monitoring.

After the methodology was developed, the subsequent tasks involved objectives applying the methodology in order to determine the uses of photography, to analyze the cost effectiveness of the photography, and to develop interpretive criteria for operationally using the imagery. Results and recommendations were to be documented in a final technical report and interpretation manual.

The objectives of the study were to:

1. Determine the efficiency of using color and color infrared photographic techniques for mining and reclamation planning and monitoring.
2. Determine the cost-effectiveness relationship of color and color infrared aerial photography in meeting reclamation program objectives.
3. Develop interpretive techniques and criteria for the use of color and color infrared aerial photography by mine operators and regulatory personnel.

III. OVERVIEW OF THE TECHNICAL APPROACH

The technical approach set forth in the initial proposal was used as the basis for the project implementation plan. The final technical approach comprises eight phases as described below and depicted in Figure 1.

Phase I-Literature Review and Discussions

This phase involved identifying the uses and requirements of surface mining and reclamation planning and monitoring for which color and color infrared aerial photography can be utilized.

1. Discussions were held with various operators and state and federal regulatory personnel on current and potential uses of color and color infrared aerial photography.
2. A literature review was conducted to determine the status of research being done in remote sensing which might be applicable to surface mining and reclamation planning and monitoring.
3. A review of eastern states' reclamation regulations was performed with special emphasis placed on revegetation requirements to determine current uses and potential uses of color and color infrared aerial photography.

Phase II-Site Selection

Test sites at which seasonal airborne and ground data would be collected were identified and selected in this phase.

1. The sites were to total no more than 100 square miles and were to contain both contour and area mining with on-going reclamation activities.
2. The sites were to reflect mining at various stages of development and contain several vegetation types in various stages of planting and growth used in reclamation.

Phase III-Data Collection

The definition and collection of ground and airborne data at seasonal intervals for use in subsequent analysis and evaluation phases were performed in this phase.

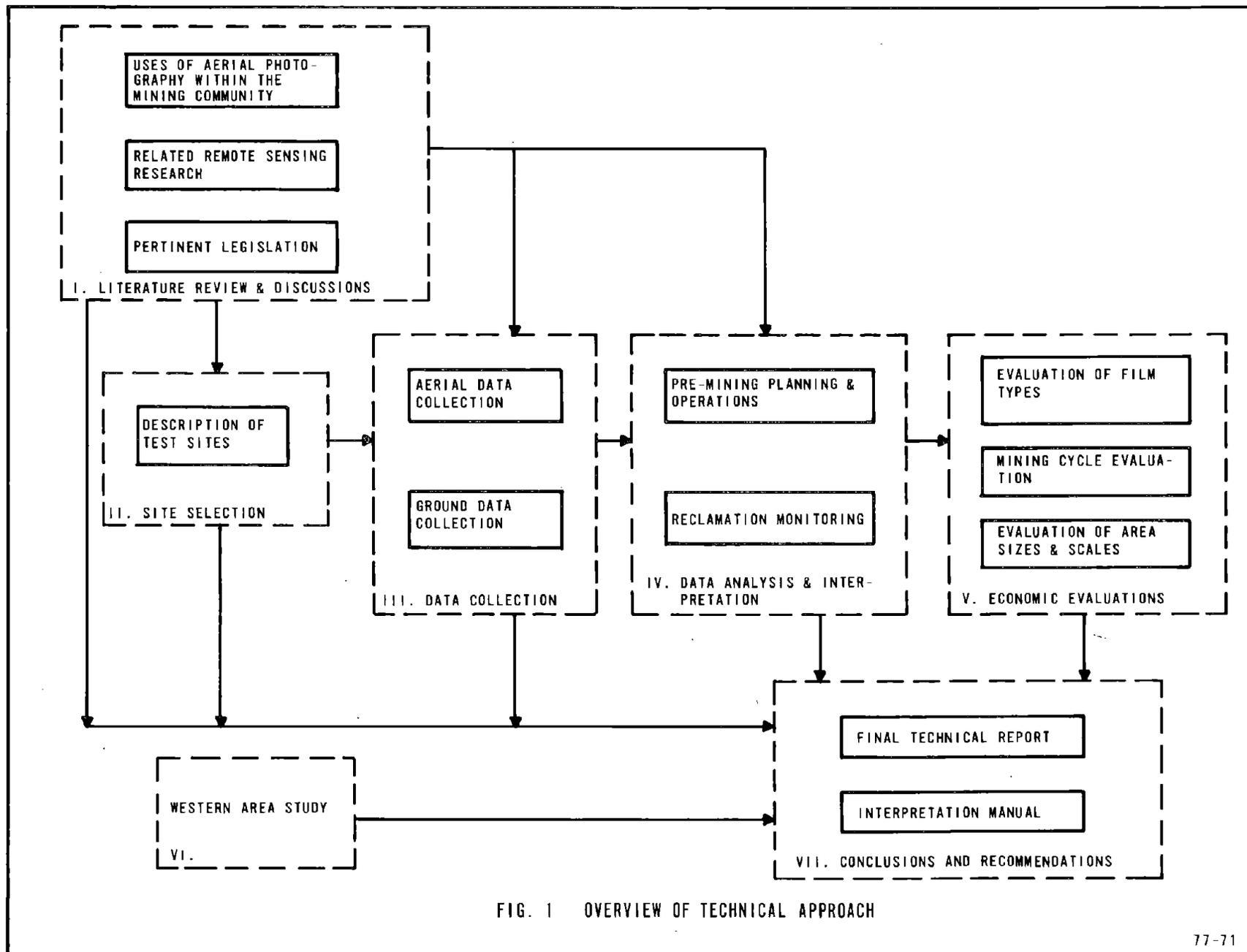


FIG. 1 OVERVIEW OF TECHNICAL APPROACH

1. Those physical features and parameters related to surface coal mining which could be interpreted from the aerial photography were identified.
2. A determination of optimum altitudes and scales for planning and monitoring mining and reclamation activities in the most cost-effective manner was recommended.
3. Ground and aerial data over the sites on a seasonal basis for a period of two years were collected.

Phase IV-Data Analysis and Interpretation

This phase involved analyzing and interpreting the data gained from the overflights and comparing the results with the ground data.

1. A determination of the extent to which color and color infrared aerial photography would aid in surface mine planning and monitoring was made.
2. The extent to which color and color infrared aerial photography could assist in the planning and monitoring of revegetation activities of reclamation was evaluated.
3. The utility of color and color infrared photography in delineating other features and parameters related to the surface mining process was determined.

Phase V-Economic Evaluations

A methodology for performing economic evaluations of the operational use of color and color infrared aerial photography was developed in this phase. In addition, three types of evaluations were performed:

1. Economic evaluation of operational use of the photography for all phases of the surface mining cycle,
2. A determination of the costs and benefits of aerial coverage for areas of various sizes,
3. An economic comparison of the various film types used in this study.

Phase VI-Western Area Study

This phase involved an analysis of interpretation techniques developed in this study as to their applicability to the western surface mining activities.

-
1. The transferability of interpretative techniques developed in this study to the western sites was evaluated.
 2. New parameters that must be interpreted on western sites were identified.

Phase VII-Conclusions and Recommendations

The products resulting from this study consist of this final technical report and appendices and a separately bound document entitled "An Interpretation Manual for Color and Color Infrared Aerial Photography for Surface Coal Mining."

IV. LITERATURE REVIEW AND DISCUSSIONS

A. OBJECTIVES

The objectives of this phase were to identify, review and, to a limited extent, analyze literature relating to remote sensing techniques with possible surface mine applications. Activities also performed in this phase included holding discussions with technical personnel regarding the status of current remote sensing research and regarding the use of aerial photography in surface mine reclamation planning and monitoring. State and federal regulations were reviewed to determine the applicability of aerial photography for monitoring reclamation.

B. APPROACH

To maximize the utilization of the reviews and discussions while minimizing the time involved to complete them, parallel activities in the three areas were conducted simultaneously by different personnel. These areas were: 1) remote sensing research related to surface coal mining, 2) relevance of aerial photography to current surface coal mine legislation, and 3) status of the use of aerial photography in the mining community. All pertinent literature was identified, collected, abstracted and filed in the HRB-Singer library. A review of all literature with possible applications of remote sensing related to surface mining was completed. This literature was classified into four topic categories: 1) vegetation characteristics, 2) water resources, 3) soils and terrain, and 4) geology. A review of the status of remote sensing research was prepared for each topic area.

Surface mining legislation and rules and regulations from each of the eastern and midwestern states were reviewed and analyzed to determine where and how aerial photography could be used with respect to requirements set forth in the legislation.

In addition, informal discussions were held with various coal operators and regulatory personnel in the eastern and midwestern states in order to determine where and how aerial photography could be used for surface coal mining activities. Possible users of aerial photography were determined.

C. RESULTS

The results of this phase are presented in three separate sections below.

SECTION 1. Remote Sensing Research Related to Surface Coal Mining

The objective of this literature review was to examine past and present uses of remote sensing--primarily aerial photography--in order to determine the role it can play most effectively in the surface coal mining cycle. This review addresses the determination of vegetative characteristics, water assessment, soils and terrain evaluation, and those facets of geology that relate to surface mining. In addition, a review of satellite monitoring of surface mine operations and reclamation was conducted. Each review of a topical area is supplemented by a bibliography in Appendix A.

a) Vegetative Characteristics

This section of literature review deals with the remote sensing of vegetation. It is an outline of the types of vegetative characteristics that can be detected remotely. It includes a brief discussion of reflectance factors that make it possible for vegetative characteristics to be detected and evaluated. Table 1 summarizes those vegetative characteristics that can be detected with remote sensors. It also lists the films, scales, time of coverage, type of coverage, and references used for each characteristic.

(1) Reflectance from vegetation

The quality of spectral reflectance from leaves in the visible and near-infrared regions of the electromagnetic spectrum is largely dependent upon chlorophyll content, leaf structure, and water content (Knipling, 1970). Water content is not important when photographic sensing systems are being used because water affects reflectance in the higher infrared wavelengths.

In the visible region, the low reflectance of blue and red light from green vegetation is due to the absorption of these wavelengths by chlorophyll. When chlorophyll is destroyed by stress, reflectance shifts towards the blue and red wavelengths. Chlorophyll is the most important factor affecting reflectance in the visible portion of the spectrum.

In the near-infrared region of the spectrum the most important factor that affects reflectance is leaf structure (Knipling, 1970;

TABLE 1 VEGETATIVE CHARACTERISTICS DETECTED WITH REMOTE SENSORS

77-71

TYPE OF VEGETATION	VEGETATIVE CHARACTERISTICS	FILM	SCALE	SEASON OR TIME OF COVERAGE	STEREOSCOPIIC COVERAGE NEEDED	REFERENCES
GRASSLAND	IDENTIFICATION OF SPECIES	COLOR IR	1:600	SPRING	NO	CARNEGIE 1968
	% COVERAGE	COLOR IR	1:800 TO 1:50000	SPRING	NO	CARNEGIE 1968
	DENSITY AND BIOMASS	MULTI-SPECTRAL SCANNER	NOT INDICATED	SPRING AND SUMMER	NO	PEARSON 1972
	STRESS	B&W INFRARED	1:500 TO 1:9000	NOT INDICATED	NO	COLWELL 1956
SHRUBS	IDENTIFICATION OF SPECIES	COLOR IR	1:500 TO 1:1500	EARLY SUMMER	YES	DRISCOLL AND COLEMAN 1974
	% COVERAGE	COLOR IR	1:800 TO 1:3000	EARLY SUMMER	NO	DRISCOLL 1970, TUNER 1970
DECIDUOUS TREES	IDENTIFICATION OF SPECIES	COLOR COLOR IR	1:500 TO 1:9000	SPRING	YES	SAYN-WITTGENSTEIN 1960 SAYN-WITTGENSTEIN 1961 AVERY 1968
	CANOPY DENSITY	COLOR COLOR IR	1:4000 TO 1:10000	NOT INDICATED	YES	KRUMPE 1971
	HEIGHT AND VOLUME	COLOR IR	1:1000	NOT INDICATED	YES	SAYN-WITTGENSTEIN 1972
	WATER STRESS	COLOR IR	1:6000 TO 1:9000	SUMMER	NO	RHODE AND OLSEN 1970
	DISEASE STRESS	COLOR IR	1:6000 TO 1:9000	SUMMER	YES	MEYER AND FRENCH 1967 MURTHA 1971 PAYNE 1971
	TREE COMPETITION	NOT INDICATED	1:2400	SUMMER OR WINTER	YES	LATHAM 1972
CONIFEROUS TREES	IDENTIFICATION OF SPECIES	COLOR	1:5000 TO 1:9000	NOT INDICATED	YES	PARRY 1969 SAYN-WITTGENSTEIN 1960
	CANOPY DENSITY	COLOR COLOR IR	1:4000 TO 1:10000	NOT INDICATED	YES	KRUMPE 1971
	HEIGHT AND VOLUME	COLOR IR	1:1000	NOT INDICATED	YES	SAYN-WITTGENSTEIN 1972
	DISEASE STRESS	COLOR IR	1:6000 TO 1:40000	NOT INDICATED	NO	MEYER AND FRENCH 1967 MURTHA 1971 FOX 1973
	INSECT STRESS	COLOR COLOR IR	NOT INDICATED	FALL	NO	BAILEY 1973, CIESLA 1974 HELLER 1970 MURTHA 1971
	AIR POLLUTION STRESS	COLOR	1:1500 TO 1:8000	WINTER	YES	HELLER 1969
	COMPETITION	NOT INDICATED	1:2400	SUMMER OR WINTER	YES	LATHAM 1972

Gausman, 1974). A leaf with many intercellular spaces has a greater reflectance than a leaf possessing few intercellular spaces (Knipling, 1970; Gausman, 1969). The refractive index differences between hydrated cell walls and the atmosphere inside the intercellular spaces cause the light to be reflected (Knipling, 1970). If a leaf has few intercellular spaces or if the spaces become filled with cellular contents of water, the leaf becomes a continuous medium that transmits rather than reflects the near-infrared light (Gausman, 1969).

Other factors that affect the reflectance from vegetation are: a) amount and arrangement of leaves; b) stalks, trunks, and limbs; c) background characteristics (soil, amount of leaf litter, etc.); d) solar zenith angle; and e) look angle (Colwell, 1974).

(2) Films and scales

The nominal scales of aerial photographs and imagery are usually separated into four approximate categories:

Large Scale	< 1:4000
Medium Scale	1:4000 - 1:20000
Small Scale	> 1:20000
Space Photography	> 1:150000

Most applications of remote sensing in the plant sciences or in forestry require large-to-medium scale photography because often individual plant species must be viewed and evaluated (Heller, 1971). For example, tree species identification requires a detailed analysis of tree crown characteristics and these characteristics can only be seen on large-to-medium scale photographs (Sayn-Wittgenstein, 1960; Parry, 1969). In other cases, when large vegetative areas are affected by stress, such as insect infestations, scales as small as 1:125,000 can be used to detect the stressed areas (Ciesla, 1974). Space imagery such as the LANDSAT (ERTS) satellite data is usually only useful for delineating broad categories of vegetation or stress which are two hectares in size or larger (Fritz, 1974; Health, 1974).

Success with remote sensors often depends upon the films used (Fritz, 1967). Many reflective differences from vegetation can be detected at the same time by color and color infrared films (Benson, 1967). When color differences appear earlier and more prominently on color infrared films, it can often be traced to the fact that the film emulsion can discriminate more distinctly between foliage and background surfaces and the film has the ability to amplify tonal renditions of visible spectral changes (Knipling, 1969). Often there is no real change in infrared reflectance. The tones on color film can usually be correlated with plant vigor more readily, and more hue discriminations are possible than with color infrared film. Thus, color films are usually better for damage evaluation whereas infrared films are better for detection (Heller, 1969).

(3) Species identification

Trees - Reflectance characteristics in the visible and near-infrared portions of the spectrum can be used to distinguish broad categories of vegetation on color and color infrared photographs. The three categories most often distinguished by reflectance are conifers, which are the least reflective; deciduous trees, which are intermediate in reflectance; and grasses or rangeland, which have the highest reflectance (Fritz, 1967). However, the color characteristics on color and color infrared photos are helpful only in a few cases for identifying individual tree species (Parry et al; 1969). Machine-analyzed multispectral data has provided recognition accuracies of 85 percent for forest tree species (Rhode and Olson, 1972). Machines are capable of making finer discriminations in reflectance than the human eye. In fact, for some species, identification from remotely sensed imagery can be accomplished only by machines.

Recognition of individual tree species by a photo interpreter is usually accomplished by utilizing spatial characteristics of the tree--physical factors such as branching patterns, crown shapes and tree size (Avery 1968, Sayn-Wittgenstein, 1960; Sayn-Wittgenstein, 1961). Large scale (1:1000 to 1:9000) photographs must be used for identifying species because spatial characteristics cannot be determined using small scale photographs. Stereoscopic coverage is also preferred because tree height and crown size and shape can be determined more readily by stereoscopic viewing (Avery, 1968). Black and white panchromatic and infrared films are often used because

they are cheaper, but color is usually preferred because the photo interpreter can relate it more readily to a natural scene (Parry, 1969).

Crown density, tree volume, and tree height can also be identified from large scale aerial photos (Aldred and Kippen, 1967; Frumpe, 1971; Sayn-Wittgenstein, 1972).

Shrubs - Identification of shrub species has been accomplished on large scale (1:800 - 1:1500) color infrared photographs (Driscoll and Coleman, 1974). Plant height and crown characteristics are used to identify species on color infrared photographs. Using scales between 1:800 and 1:1500, 85 percent of the shrubs can be identified correctly. The best month of the year for identification is July. Percentage of crown coverage can also be determined from large-scale photographs (Driscoll, 1970; Turner, 1970).

Grasses - Identification of individual herbaceous species is usually not possible except for a few species (Driscoll, 1971). However, measurements such as foliage cover, relative density, and standing crop biomass can be made with densitometric measurements of aerial photographs and machine analysis of multispectral data (Carnegie, 1968; Driscoll, 1970; Driscoll, 1972; Pearson, 1972). Proportions of live vegetative cover to bare soil can be measured on large scale color infrared photographs (Driscoll, 1970).

(4) Vegetative stress

Vegetative stress caused by a variety of factors has been detected by remote sensing techniques. Light to moderate forms of stress are usually detected because chlorophyll is disrupted or because leaf structure has been altered. Detection of severe stress is possible because of disrupted chlorophyll, altered leaf structure, leaf orientation changes, and reduced leaf area and density which allow background surfaces to change the quality and quantity of reflected light.

The following diseases have been detected by utilizing remote sensors: Dutch elm disease, oak wilt, dwarf mistletoe on black spruce (Meyer and French, 1967); nematode and virus problems of citrus trees (Norman and Fritz, 1965); citrus young tree decline (Edwards, 1975); root rot diseases of pecan trees (Payne, 1971); oak decline of live oak (Van Arsdel, 1974); and Fomes annosus root rot of pine (Fox, 1973). With the oak decline disease, detection on

color infrared photographs was obtained three to five years before symptoms could be seen on the ground (Van Arsdel, 1974). The following insect damages have been detected utilizing remote sensing procedures: defoliation of ponderosa pine by the pine butterfly (Ciesla, 1971); defoliation by forest tent caterpillars (Ciesla, 1971); beetle-killed lodgepole pine (Klein, 1973); and beetle-killed ponderosa pine (Heller, 1970). Single tree infestations are detected best on large scale photographs, although multiple tree infestations have been mapped accurately at scales of 1:30,000 and greater (Ciesla, 1974; Heller, 1971).

Pines damaged by air pollution have been detected and evaluated by utilizing color photographs (Heller, 1969). A scale of 1:8000 was used for detection, but scales of 1:1500 and 1:3900 proved best for evaluating the condition of the trees. Color films were used because the natural hues could be related more easily to tree damage.

Moisture-stressed trees have been detected by thermal infrared scanners because the non-transpiring trees were warmer than trees which were transpiring naturally (Rhode and Olson, 1970). The same stress was detected just as readily by using color infrared films. The oak decline condition that can be detected by color infrared film three to five years before symptoms become visible on the ground is actually a moisture stress condition because the pathogen prevents normal translocation of water to the foliage (Van Arsdel, 1974). When plants leaf out under moisture stress, the leaves have few intercellular spaces and transmit rather than reflect infrared light.

Stresses that cause chlorophyll destruction, leaf structure changes, wilting of leaves, and reduced leaf density and area can be detected readily with remote sensors. However, it is important to note that the cause of stress cannot usually be discerned from aerial photographs (Driscoll, 1974). An evaluation of vegetation can be made from remote sensor outputs but causes of vigor decline or increase must usually be determined by field work or from ground truth data.

(5) Utilization of aerial photographs for mine reclamation

Color and color infrared aerial photography can be used to derive information about vegetation types, species percentage of cover, and condition of vegetation in reclaimed strip mine areas. Species identification

can be made when analysts field-check problem areas. Vegetal stress caused by adverse conditions on reclaimed areas can be identified. Medium-scale color infrared photography is best suited for identifying the characteristics above (Garofalo, 1973; Wobber and Amato, 1974). Most mining companies and regulatory agencies that utilize aerial photographs to obtain information on mine reclamation use scales between 1:2400 and 1:9000 (Wobber, 1971).

Listed below are vegetative characteristics and plant responses that can be determined and characterized by utilizing output from remote sensing devices. In compiling this list, consideration was given to: (1) the small number of past studies that utilized remote sensors to evaluate mine reclamation; (2) related uses of remote sensors in other areas of the plant sciences; and (3) some current regulations contained in state reclamation legislation.

- o Type of vegetation
- o Density of vegetation and proportion of live vegetation to bare ground
- o Vegetative vigor
- o Extent of vegetative non-vigor
- o Rate of vegetative growth
- o Planting patterns
- o Species composition
- o Planting method
- o Natural invasion of volunteer species

b) Water Characteristics

Remote sensing provides a unique capability for assessing surface water characteristics in large areas quickly and inexpensively. This type of data collection, however, does not entirely replace the standard ground-based field and laboratory methods. Nevertheless, it does enable the identification of those areas where more detailed field analyses should be undertaken. Table 2 summarizes water characteristics which have been monitored with aerial photography. A bibliography is presented in Appendix A.

(1) Water pollution from strip mining

Mine drainage and sedimentation are the principal surface water problems resulting from strip mining. Marcasite and pyrite

TABLE 2 WATER CHARACTERISTICS DETECTED WITH REMOTE SENSORS

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WATER QUALITY PARAMETERS	RECOMMENDED FILM OR SENSOR	SCALE	SEASON OR TIME OF COVERAGE	REFERENCES
pH (INFERRED BY INDIRECT MEASUREMENT)	COLOR IR MSS (MULTISPECTRAL SCANNER) COLOR	1:4800 1:1020	PERIODS OF LOW FLOW WHEN STREAM IS RELATIVELY FREE OF SEDIMENT EXPOSURES RECOMMENDED FOR ALL SEASONS.	COOPER, 1969 McCAULEY, 1974 JOHNSON AND WILLSON, 1969
FERRIC HYDROXIDE	COLOR & COLOR IR COLOR COLOR IR COLOR COLOR	1:1020 1:8000 TO 1:12,000 LARGE SCALE 1:12,000	EXPOSURES RECOMMENDED FOR ALL SEASONS. EXPOSURES RECOMMENDED FOR ALL SEASONS	JOHNSON AND WILLSON, 1969 SCHNEIDER AND KOLIPINSKI, 1969 AMBIONICS, 1974 WOBBER AND AMATO, 1974 GAROFALO AND WOBBER, 1973
TURBIDITY (SUSPENDED SOLIDS; DISCRIMINATION BETWEEN TURBIDITY AND SUSPENDED SOLIDS W/AERIAL PHOTOGRAPHY IS VERY DIFFICULT).	COLOR COLOR AND COLOR IR COLOR	1:8,000 1:12,000 1:12,000		SCHNEIDER AND KOLIPINSKI, 1969 SCHERZ AND VAN DOMELEN, 1973 GAROFALO AND WOBBER, 1973
STREAM BED SEDIMENTATION (NOT INCLUDING FERRIC HYDROXIDE PRECIPITATES)	COLOR COLOR COLOR	1:1020 1:8,000-1:12,000 1:12,000	EXPOSURES RECOMMENDED FOR ALL SEASONS.	JOHNSON AND WILLSON, 1969 SCHNEIDER AND KOLIPINSKI, 1969 GAROFALO AND WOBBER, 1973
LOCATION OF SEEPS AND OUT-FALLS.	BLACK & WHITE IR COLOR THERMAL IR THERMAL IR	1:24,000 LARGE SCALE 1:62,000 1:12,000	FALL OR WINTER NIGHT TIME WHEN GROUND AMBIENT TEMPERATURE NEAR FREEZING.	PETRUS, 1975 WOBBER AND AMATO, 1974 LEACHTENAURE, HIRSCH, WILLIAMS & TUCKER (1972) FISHER, 1972
LOCATION AND DIMENSIONS OF SURFACE WATER	COLOR IR COLOR & COLOR IR COLOR (DEPTH)	1:1020 1:12,000 LARGE SCALE	EXPOSURES RECOMMENDED FOR ALL SEASONS.	JOHNSON AND WILLSON, 1969 WOBBER AND AMATO, 1974 SCHNEIDER AND KOLIPINSKI, 1969
ALGAL GROWTH ALONG SHORELINES AND STREAMBEDS	COLOR (STREAMBEDS) COLOR IR (STREAM-BANKS) COLOR IR	1:4800 1:4800 1:10,000	PERIODS OF LOW FLOW WHEN STREAM IS RELATIVELY SEDIMENT FREE. PERIODS OF LOW FLOW WHEN STREAM IS RELATIVELY SEDIMENT FREE. BETTER THAN COLOR AT HIGH ALTITUDES IN CONDITIONS OF HAZE.	COOPER, 1969 COOPER, 1969 WELCH, 1969

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distributions (iron disulfides) oxidize during and after mining to produce hydrous ferrous sulfates which are easily dissolved in water to form the associated hydrous iron complexes. Dissolved iron sulfates can hydrolyze to form iron hydroxides. These precipitates impart the characteristic red color of acid mine drainage and discolor the streambed and banks with the well-known "yellow boy" deposits. Sulfates of aluminum, manganese, calcium and magnesium are also present in the water.

(2) Remote sensing of water quality and quantity

Numerous studies have assessed the capabilities of remote sensing techniques for application to water quality problems. For the most part, these studies have been subjective. Although they provide an empirical "feel" for the potential of remote sensing techniques, the application of the techniques to water quality problems is not widespread.

The most probable areas of application of remote sensing techniques to mine water quality are determining physical properties of water and determining selected chemical properties of water.

- o Physical properties of water
 - location of seeps and outfalls
 - physical dimensions and shapes of water bodies
 - sediment deposition and stream sedimentation patterns
 - turbidity and suspended sediments
- o Chemical qualities of water
 - pH
 - Hydrous ferric hydroxide

(3) Physical properties

The location of seeps and outfalls is an important factor in the planning and reclamation stages of strip mining. Black and white infrared and color infrared photography have been shown to be useful for mapping minute seeps as well as large rivers (Parry and Turner, 1971; Leachtenauer, Hirsch, Williams and Tucker, 1972; Petrus, 1975). This is possible because of the large contrast between the shallowest water image and the land image. The physical dimensions and shapes of water bodies can be determined and where the

water is clear, water depth can be ascertained by use of color aerial photography (Schneider and Kolipinski, 1969) and from multispectral scanner data (Brown, et al., 1972).

Color aerial photography is useful for identifying stream sedimentation patterns and for obtaining other subaqueous terrain data, provided that the water is not very turbid (Garofalo and Wobber, 1973; Deely, Russell and Wobber, 1973; Hodder, 1973). Color infrared is less useful for assessing subsurface sediment patterns because of its limited water penetration capability (Garofalo and Wobber, 1973). Color film has a distinct advantage in its ability to penetrate water (Schneider and Kolipinski, 1969) and, according to Johnson and Willson (1969), color film penetration to the stream bottom was "as good when the sky was overcast as when it was clear." The U.S. Geological Survey has found that color film is superior for the registration of bottom conditions as deep as 70 feet below the surface. Color infrared photography is superior, however, for revealing the health of underwater plants (Welch, 1969; Ward, 1973). The presence of these plants indicates fairly high dissolved oxygen content, a tolerable pH range, low sediment or settleable solids load (i.e., the silt is not blocking the light), and the absence of choking bottom sludge.

Color and color infrared photographs have shown considerable potential for studying the turbidity of water bodies. The turbidity of a water is its capacity for absorbing or scattering light. Turbidity levels are determined by the size, character and concentration of suspended solids.

Studies correlating reflectance and the water quality parameters of suspended solids, turbidity, and color have shown that although there is good relationship between reflectance and the parameters of suspended solids and color, the relationship changes from day to day. It was only the correlation between reflectance and turbidity that remained constant (Scherz, 1972; Scherz and Van Domelen, 1973). McCauley (1974) used satellite and aerial photography analyzed with a Macbeth EP-1000 macrodensitometer to relate film density to the following ground-sampled parameters: bicarbonate, carbonate, calcium, magnesium, potassium, sodium, sulfate, chloride, total solids, total heat-stable solids, suspended solids, heat-stable suspended solids and pH. The results showed a strong linear relationship between the red/green radiance ratio and suspended solids. Color infrared film is most sensitive to changes in suspended

sediment concentrations. Use of red or blue filters for measuring density appeared to improve infrared film sensitivity (Blanchard and Leamer, 1973). Blanchard found during an investigation of farm ponds at Chickasha, Oklahoma, that photographic film response appeared to be dominated by suspended sediments. A highly turbid stream will, in fact, mask most other water quality indicators (Cooper, 1969).

Photographic measurement of suspended sediments (or turbidity) requires corrections for atmospheric effects. A reflectance standard should always be present in the photographs to be analyzed (Scherz and Van Domelen, 1973). According to Blanchard and Leamer (1973), measurement of suspended sediments in water is feasible for concentrations up to approximately 75 parts per million. They state that visible and near-infrared light produce misleading results if heavy concentrations of suspended sediment are present.

(4) Chemical properties

Cooper (1969) used color infrared to detect acid stains along a river shoreline through a moderate tree canopy. The acid stains appeared brilliant green on the photography. In some cases, low pH (3.5-4.0) waters appeared green to blue-green. Other waters with comparable pH appeared blue-green to light blue. Cooper ran a correlation analysis on an unidentified number of samples and was able to state only that there appeared to be some relationship between the rise in pH and a change in color from green to blue. A correlation analysis between film densities and pH measurements taken in the field provided no significant relationship between the two (McCauley, 1974).

Results obtained by Johnson and Willson (1969) did not prove a relationship between stream color and stream pH. Neither the color nor the color infrared photography showed the predicted color shift to illustrate changes in pH as recorded on the ground by field tests.

Iron hydroxide precipitates are the most obvious indicator of stream chemical contamination by mine drainage. They impart the characteristic red color of acid mine drainage and discolor the stream bed and banks with the well known "yellow boy" deposits. In 1963, color imagery taken of West Virginia showed streams of high acidity in shades of green and basic streams (pH of 7 or more) in blue. Johnson and Willson (1969) determined that

the color of the acid stain along the banks and on the stream bottom was more easily seen on color film (Ektachrome X) than on color infrared film. Schneider and Kolipinski (1969) also found color aerial photography useful for identifying streams polluted by acid mine drainage. High altitude color photography can be used to identify iron oxide discoloration in streams and ponds over 30 feet wide (Deely, Russell and Wobber, 1973).

Johnson and Willson preferred color to color infrared film for identifying contaminated water bodies. They stated that mine acid drainage registered as "greenish-cream" on Ektachrome infrared film. Ambionics (1974) found a close correlation between "green water" on the false-color infrared photography and waters polluted by acid mine drainage.

The presence of specific kinds of algae in water has been used as an indicator of acid water and a number of aerial photographic surveys have investigated the potential of using remote sensing for detecting algae concentrations and aquatic vegetation (Hom, 1968; Scherz 1969). However, the use of algal growth in streams as a photographic indicator of acid water must be used with extreme caution since similar green algae thrive in neutral water.

Sulfates of aluminum, calcium, and manganese are also present in mine drainage; however, investigations by Blanchard and Leamer (1973) indicated that the mineral content of water is not correlated with film response.

c) Soils and Terrain

Soil and landform characteristics considered in this review are important to mine reclamation efforts. The characteristics include slope and aspect, slope failure (mass wastage), erosion, drainage, soil moisture, surface shape, soil type, and soil texture. Most of the successful procedures listed in this review are directly applicable to aerial photographic evaluations of reclaimed mine areas. Aerial photography is currently being used to determine slope and aspect, slope failure, erosion, drainage patterns, and surface shape. Aerial photographs are also being used as aids in soil surveys. A summary of the above uses of remote sensors and film, scale, time of coverage, type of coverage, and references is given in Table 3.

TABLE 3 SOILS AND TERRAIN CHARACTERISTICS DETECTED WITH REMOTE SENSORS

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SOIL AND TERRAIN CHARACTERISTIC	FILM	SCALE	TIME OF COVERAGE	STEREOSCOPIIC COVERAGE NEEDED	REFERENCES
SLOPE AND ASPECT	PANCHROMATIC COLOR COLOR IR	LARGE TO MEDIUM < 1:4000 - 1:20,000	WINTER EARLY SPRING	YES	AVERY, 1968 KUHL, 1970 MOESSNER, 1964 MOESSNER, 1966 VAN DER BENT, 1969
SLOPE FAILURE	PANCHROMATIC COLOR COLOR	1:2400 TO 1:20,000	WINTER EARLY SPRING	YES	POOLE, 1969 MINTZER, 1966
EROSION	COLOR IR	>1:10,000	NOT INDICATED	YES	FEZER, 1969 POOLE, 1969
DRAINAGE	COLOR IR	1:12,000 TO 1:17,500	LATE SPRING EARLY SUMMER	YES	FEZER, 1969 KUHL, 1970 MINTZER, 1968 PARRY, 1971
SOIL MOISTURE CONTENT	COLOR IR	1:2500 TO 1:5600	PLANT GROWING SEASON OR SPRING	NO	PIECH, 1974 SCHMER, 1970 WERNER, 1971
SURFACE SHAPE	PANCHROMATIC COLOR COLOR IR	NOT INDICATED	WINTER EARLY SPRING	NO	FEZER, 1969 WAEELT, 1970
SOIL TYPE	COLOR COLOR IR MULTI-SPECTRAL SCANNER	1:9600 TO 1:36,000	EARLY SPRING	NO	KRISTOF, 1974 MINTZER, 1968 PARRY, 1969 VALENTINE, 1971
SOIL TEXTURE	COLOR	LARGE SCALE < 1:4000	NOT INDICATED	NO	PIECH, 1974

(1) Slope and aspect

The angle of a slope surface with respect to the horizontal (slope) and the bearing or direction of the slope (aspect) can both be determined from aerial photographs (Avery, 1968; Moessner, 1964; Moessner, 1966; van der Bent, 1969). Slope is determined by measuring the height difference between two points--directly down slope--on stereoscopic pairs of photographs. This measurement is accomplished most easily by the use of a parallax wedge or parallax bar (Moessner, 1964; Moessner, 1966). In past studies on bare soil, correlation coefficients as high as 0.941 have been obtained between measurements made on the ground with Abney levels and measurements made on photographs (Moessner, 1964). In forested and vegetated areas, the correlation coefficients decrease because the slope at the top of the vegetation may not correlate with the slope of the soil. Sometimes this problem can be avoided by using photos obtained when the vegetation was dormant in winter. The scale of photographs that should be used for slope characterization is determined by the size of the slopes that are being evaluated. In most cases medium (1:12,000) to large (< 1:4000) scales are sufficient. Color films are preferred (Kuhl, 1970).

Aspect can be determined easily by drawing a line of true north on the photograph and using it as a reference for presenting slope direction or aspect (Avery, 1968).

(2) Slope failure

Forms of slope failure, including soil creep, rock fall and rock creep, earth flow, slump, debris slide, and rock slide, can be detected from aerial photographs (Mintzer, 1966; Poole, 1969). Analysis indicates that scales smaller than 1:9600 are not adequate for detection of small wastage details and slide-prone areas which average 100 by 200 feet in the proximity of strip mines (Mintzer 1966). Stereoscopic coverage is preferred for detailed analysis and scales should be approximately 1:2400 for this type of analysis (Mintzer, 1966; Poole, 1969). Color and color infrared films are preferred because color contrasts are more pronounced, microsurface characteristics are more readily discerned, and vegetation and soil moisture are better depicted. Winter and early spring are considered to be the optimum seasons for this type of identification, although sometimes older slope failures can be detected in late spring and early summer because of the effect on vegetation patterns.

(3) Erosion

Erosional forms, including sheet wash, rill wash, and gullying, can be delineated on aerial photographs (Fezer, 1969; Poole, 1969). Sheet wash, even in its formative stages, is detectable on large-scale photographs by its mottled appearance. Rill wash is an early stage of gully formation and it is almost impossible to determine from aerial photographs where rill wash ends and gullying begins. Stereoscopic viewing of color and color infrared photographs with a stereoscope at 4x magnification facilitates determining whether rill or gully wash is occurring (Poole, 1969). Scales should generally be larger than 1:10000 to evaluate erosional patterns.

Erosion under tree cover can often be detected because of ground exposure where tree litter was washed away. The amount of exposed soil at the periphery of the trees is also an indicator of erosional processes (Poole, 1969).

(4) Drainage

Various forms of drainage patterns can be detected easily by utilizing aerial photographs (Avery, 1968; Fezer, 1969; Kuhl, 1970; Mintzer, 1968). Single photo interpretations with color and color infrared are more accurate than with panchromatic film. Drainage can be determined with great accuracy from stereo pairs. The input of slope, which can be determined from stereo pairs, aids in determining drainage patterns, especially in areas where soil materials are moderately to slowly permeable and drainage is closely associated with landscape position (Kuhl, 1970). Late spring to early summer is considered the best time for photographing soil drainage (Kuhl, 1970). Color photographs are considered better than color infrared photographs because hues are more similar to what would be seen on the ground (Kuhl, 1970). However, when drainage channels are still moist, color infrared is usually better because of the low infrared reflectance from water (Hunter, 1970). Medium scales (1:12,000) are considered acceptable, but every 2x magnification of the imagery provides seven percent more detection of drainage density on the aerial photographs (Fezer, 1969).

(5) Soil moisture

Relative amounts of soil surface moisture can be determined from aerial photographs (Piech, 1974; Schmer, 1970; Werner, 1971). In some cases color film can be utilized to view vegetative cover which is used as an indicator of soil moisture (Schmer, 1970; Werner, 1971). Photometric information extracted from color imagery can also be used to determine soil moisture (Piech, 1974). With this method, ratios of red to blue reflectance are used to determine relative amounts of moisture. It is important to note, however, that in many cases, even relative amounts of soil moisture can be difficult to determine because other factors such as soil texture and organic matter can affect soil reflectance in the same manner as soil moisture (Mathews, 1973; Piech, 1974).

Microwave radiometry has been used to determine soil moisture (Schmugge, 1974). The microwave emission from soils is a function of radio-meter wavelength and the distribution of moisture in the soil. At a wavelength of 1.55 cm there is little variation of emission below 10-15 percent moisture, but above this value there is a linear decrease in emission for each percentage point increase in soil moisture.

Thermal infrared imaging is useful for identifying areas of relatively high soil moisture. Evaporation contrasts due to variation in soil moisture are responsible for these thermal contrasts.

(6) Surface shape

In addition to slope, ruggedness is another soil surface factor which can be determined quite easily from aerial photographs (Fezer, 1969; Waelti, 1970). Surfaces classified as plane horizontal or sloped, undulant, moderately gullied, heavily gullied or broken, and completely irregular have been determined from aerial photographs for the purpose of forest road planning (Waelti, 1970). Photographs taken during vegetative dormancy are best because soil surface forms can be delineated more readily without vegetal interference. Stereographic format is best for shape characterization and study.

(7) Soil type

Soil series are normally differentiated by both surface and subsurface properties and, therefore, delineation of these series by remote sensing should not be expected in many cases. Any given series has an allowable range of

surface conditions that is capable of causing confusion on remote sensor outputs. There has been limited success in recognizing various soil series using computer-analyzed multispectral scanner data (Kristof, 1974). However, the chief value of this type of detection is the delineation of grosser soil divisions over a large area. The same usually holds true for photointerpretation of aerial photography for soil identification. The basic value of aerial photographs lies in their ability to provide synoptic views that can be used to delineate boundaries of soils that are of different types. These types, however, must usually be identified by field work on the ground (Mintzer, 1968; Parry, 1969; Valentine, 1971).

Boundaries of soil and terrain units in valleys and low wetlands are often more clearly discerned on color infrared photographs (Valentine, 1971). Scales of 1:9600 to 1:36000 can be used for this type of delineation (Parry, 1969; Valentine, 1971). Stereoscopic coverage has been used in many cases but has not been deemed necessary in all cases.

In other studies it has been found that exact correspondence between field and photographic colors as defined by the Munsell Color System could not be obtained (Parry 1969). Also few soils possessed unique color characteristics at the soil series level. When the color variations within a soil series are smaller than the variations among soil series, identification of the series is possible (Cihler, 1972; Kihlblom, 1972; Parry, 1969).

The Soil Conservation Service uses aerial photos for most soil identification work. Generally, a combination of landforms and vegetation assists in defining the spatial extent of a given soil type. Field study is necessary to validate the interpretation and to extend its applicability.

(8) Soil texture

Soil texture is one of the characteristics used to determine soil series. Relative soil textures have been determined by utilizing the ratio of red to blue reflectance (Piech, 1974). Other studies utilizing conventional photointerpretation techniques have not been successful especially when clays were present in varying amounts at the soil surface (Kuhl, 1970; Kihlblom, 1972).

d) Geologic Characteristics

Strike and dip of rock strata and the analysis of photo-geologic linear features (fractures) are important aspects in mine planning and ultimately in mine reclamation. Fractures can affect the drainage, hydrological aspects, and even stability of a given area. Strike and dip of rock and coal strata are important in mine planning. Slope determination of regraded areas, unmined areas, and surface shape are dealt with in the portion of literature review concerned with soils and landforms.

(1) Photogeologic linears

One of the advantages in studying remote sensor outputs is the marked delineation of linear geologic features. The advantage is a direct result of the synoptic view inherent in viewing aerial data. Many alignments or nonalignments that are inconspicuous to the ground observer are readily apparent on photography and other imagery. Linear geologic features may be conspicuous due to their nonalignment with stream valleys, ridges, or uplands which they cross. The most common indicators are alignments of stream segments and small drainage courses.

Most of the linear features are direct or indirect expressions of fractures and are depicted on the aerial data as tonal variations in vegetation alignment, as straight segments of stream courses, as differential solar illumination, or as differential radiant emission due to variations in lithology or moisture.

A new concept and terminology dealing with photo-geologic linears have recently been formulated (Gay, 1973). This new concept is based upon the observation that the earth's continental crust is cut by a number of parallel to subparallel deep fractures in the basement rock. These basement fractures are regional in extent and invariably paired with other sets of fractures orthogonal to them. Photogeologic lineaments observed in the overlying cover rocks which coincide with traces of the basement faults are fracture trace lineaments. The cover rocks may be faulted along the trace lineaments, or they may be unfaulted and strongly jointed. The lineaments are generally several kilometers long. When lineaments are observed in the overlying cover rocks that do not coincide with the traces of basement faults but are caused by joints parallel

to basement faults, they are called joint lineaments. These types of lineaments generally do not exceed one or two kilometers in length.

All of these lineaments can be successfully mapped from aerial photographs and imagery obtained from spacecraft (Gold, 1973; Lattman, 1958; Lattman, 1961; Ray, 1960; Trainer and Ellison, 1967; Wier, 1973A; Wier, 1973B).

Joint lineaments (fracture traces as defined by Lattman) can best be mapped from aerial photographs at scales of 1:20,000 or larger (Lattman, 1958; Lattman, 1961; Ray, 1960). Trainer and Ellison (1967) have shown that lineaments in flat-lying strata more accurately depict the basement fracture pattern than lineaments lying in tilted strata because the fracture patterns from basement fracture lineaments are imprinted onto overlying sedimentary rock strata. Histograms of joint lineaments made from aerial photographs often show maximums closely corresponding to those of prevailing directions of joints (Ray, 1960). However, since imprinting from basement lineaments to sedimentary rock occurs as soon as the sediments are laid down, later deformations and the tilting of strata cause joints to become non-vertical and strike to be changed (Trainer and Ellison, 1967). In areas where dip is greater than 5 degrees, joint lineaments may not be parallel to joint sets and may differ as much as 45 degrees (Lattman, 1961). The close correspondence of joint lineaments with joint directions in horizontal or nearly horizontal strata, however, indicates that aerial photographs can be used to extend mapping of joint sets into areas of no outcrop.

Regional fracture mapping can be accomplished by utilizing satellite data (Gold, 1973; Wier, 1973A; Wier, 1973B). In areas where deep mine roof failure is associated with natural fractures, data from the ERTS satellite has been used to determine high-risk areas (Wier, 1973A; Wier, 1973B). However, the use of satellite data is still limited because subregional smaller concentrations of joint sets are not within the resolution capabilities of the satellite.

(2) Strike and dip

In areas where associated rock strata conform with topographic surfaces, dip is easily determined by measuring the altitude between two points, directly down dip from one to the other (Avery, 1968; Lattman, 1965;

Ray, 1960). The difference in altitude and the horizontal difference between the two points are used in the following equation to determine dip angle.

$$\frac{\text{Vertical Distance}}{\text{Horizontal Distance}} = \text{Tangent of Dip Angle}$$

Rapid estimations of slopes and dips can be made by using comparators which allow direct visual comparison of a natural dip slope with a range of constructed dip slopes overlaid on a portion of the stereo pairs being used (van der Bent, 1969).

Dip angle is hard to measure from aerial photographs when the rock strata do not conform with topographic features (Ray, 1960). A slope which has the same dip direction as its underlying rock units is called a resequent slope. A slope with an opposite direction from that of the dipping rock units is an obsequent slope. When the dip of the rock units is moderate to small (<25 degrees) the obsequent slope is usually steeper than the resequent slope (Miller, 1961). This simple association is sometimes used to roughly estimate slope when the rock strata do not conform with topographical features.

Generally, the strike can be found with a protractor by determining the direction of a line lying between two points of the same altitude on a bed (Avery, 1968). Both strike and dip are difficult to determine where vegetative cover is dense (Miller 1961).

e) Satellite Monitoring of Surface Mine Operations and Reclamation

Conventional photointerpretation and photogrammetric techniques can be successfully applied to space photography when the imagery is sharp (Henkes, 1971). Very accurate linear measurements can be made on ultra-small scale (1:2,050,000 - 1:2,700,000) space photographs, although the accuracy of volumetric measurements is low compared to volumetric data obtained from low altitude large-scale photography. Results obtained from photographic systems on board the Gemini and Apollo spacecraft indicate that outputs from these systems could be used to accurately determine total surface area being mined (Henkes, 1971). Repetitive coverage of this type could be used to monitor the success of revegetation efforts for large areas. However, evaluation of vegetative vigor and small areas of vegetative failure could not be made from this type of imagery.

The recent development of multispectral scanners capable of sensing many spectral bands and recording them simultaneously on magnetic tape has led to new methods of data analysis. The bottleneck of rapid information extraction (the photo interpreter) is bypassed as man-machine analysis provides a more rapid quantitative interpretation of spectral data. The multispectral scanners on board the ERTS (LANDSAT) satellites have been proved capable of detecting and delineating strip mined areas (Alexander, 1973; Chase, 1973; Schubert, 1973; Thompson, 1973; Wier 1973). Repetitive coverage of large areas provides monitoring capabilities, although in certain areas this advantage is offset by cloud coverage during a major portion of the year. A second disadvantage is resolution which is .456 hectares (1.27 acres) and not practical for evaluating small areas.

Studies in Ohio have shown that the amount of surface area being mined can be detected rapidly and efficiently by machine analysis of the ERTS data (Chase, 1973; Pettyjohn, 1973). It is claimed that strip mine and reclamation maps that now take months to produce from aerial photography could be produced in a matter of days at one-tenth the current cost by utilizing automatic mapping techniques with the ERTS data (Pettyjohn, 1973). Vegetation affected by acid mine drainage has also been detected and mapped (Alexander, 1973). Small lakes that are a product of the mining operation are easily detected by utilizing the infrared channel from the ERTS scanner (Pettyjohn, 1973).

Unreclaimed stripped land and in some cases reclaimed land can be distinguished from natural and agricultural vegetation on negative and positive transparencies of ERTS-1 imagery (Ambionics, 1974; Ahmad, 1973). Positive transparencies of mined areas can be projected onto 7.5 minute topographic maps and the mined areas can then be delineated on the maps (Ambionics, 1974). The procedures and equipment needed for this type of analysis are relatively inexpensive and uncomplicated as compared to the equipment and methods used for machine analysis of computer-compatible tapes. This method could provide government agencies with an inexpensive accurate means of updating records pertaining to surface mining activity.

The studies that have been completed to date strongly indicate that current aerospace and computer technology can be utilized to rapidly and efficiently produce maps of the gross features of strip mined areas. Repetitive coverage permits monitoring changes in mining operations including revegetation of mined areas. However, reclamation characteristics such as vegetation type, species composition, vegetative vigor, percent slope, and planting method are not within the resolution capabilities of the satellite sensors. Therefore, the satellite data would not be useful for determining compliance to specific reclamation legislation. It should be restated that satellite monitoring of surface coal mining areas has been used to discriminate strip mined lands; however, detailed differential between types of strip mined lands (i.e., reclaimed or unreclaimed) has not been demonstrated conclusively.

f) Summary

In considering the applicability of remote sensing to surface mining and reclamation, emphasis must be placed upon the techniques of information acquisition. Objectives of gathering data must be clearly delineated. Film, film-filter combinations, time of day, altitude and many other factors must be carefully calculated to effectively monitor surface mining. Finally, it must be kept in mind that remote sensing information is best used to complement, assist, or reduce field data collection rather than replace it.

SECTION 2. Relevance of Aerial Photography to Current Surface Coal Mine Legislation*

a) Introduction

Color and color infrared aerial photography is currently being used only to a limited extent to aid mine operators in meeting strip mining legislative requirements, although there are many potential users for these tools. This section reviews those portions of existing strip mine legislation where the suggested or required use of aerial photography is made explicit. Following the review, some of the potential uses of color and color infrared photography are explored.

* To facilitate identification of sources, pertinent legislation is cited in footnotes throughout Section 2.

There are explicit references to aerial photography in the legislation or regulations in the states of Alabama, Illinois, Maryland, Pennsylvania, Tennessee, and West Virginia. In most cases, aerial photographs are a suggested substitute for one of the maps required by the laws. In only one state, Illinois, are aerial photographs a part of the sampling scheme for revegetation inspection.

In all, various states require six different kinds of maps: prospecting maps, permit application maps, reclamation plan maps, mining plan maps, progress maps, and final maps. All of the states require some reclamation of prospected areas (unless mining immediately follows prospecting, in which case reclamation follows the mining), so, in many states, a map must be provided detailing the area to be prospected. In some states, permit application maps which show the existing conditions prior to mining must be presented. Reclamation and mining plan maps, if required, are usually prepared as a part of the permit application. They are generally the most detailed maps prepared by the operator, and include such information as location of the operation, boundaries of the affected area, the location of natural waterways and waterways to be constructed, and the location of utilities in the affected area. Progress maps include all the updated versions of the reclamation and mining plan maps, that show such features as the actual area mined during a given period, an area to be substituted for the mined area for reclamation, and areas already reclaimed. Final maps, prepared after the completion of all mining and reclamation in an area, must show all the areas that were mined and later reclaimed.

b) Explicit References to Aerial Photography

The Tennessee law and regulations specify that aerial photographs may be used in place of prospecting permit maps and mining and reclamation plan maps.^{1,2} The regulations further specify that the aerial photo must be at a scale of 1" = 500'.

¹Tennessee, The Tennessee Surface Mining Law, Laws of 1974 (1974) Public Chapter No. 1547, Sec. 6 (b) with amendment of May 1974.

²Tennessee, Regulations Pertaining to Surface Mining (1974), Regulation 0400-3-4-.01.

In Maryland, an aerial photo may be employed as a permit application map. It may also be used in place of an annual mining and progress report map and a completion report map.^{3,4}

The Pennsylvania "Surface Mining Conservation and Reclamation Act" requires a mining permit application map. The law states that aerial photographs "shall also be provided if such photographs are required by the secretary,"⁵ but there is no indication that the photos may be substituted for the maps.

Aerial photographs may be the base for permit application, progress, and final maps, according to the laws of West Virginia.⁶ The details of map and aerial photograph format are specified in the regulations.⁷

In Illinois, there are two distinct uses for aerial photographs in the mined land reclamation process. First, an aerial photo may be used for the "affected acreage map," a type of progress map. Second, an aerial photograph must be used as part of the sampling procedure to monitor the establishment of pasture or row crops.⁸

³ Maryland, Natural Resources Strip Mining Law. Title 7, Subtitle 5, (1974), 7-505(c).

⁴ Maryland, Rules and Regulations, (Bituminous Coal Strip Mine and Auger Mine Regulations), 08.06.01.02.

⁵ Pennsylvania, Surface Mining Conservation and Reclamation Act, Pennsylvania Statutes Annotated, (1971), Title 52, Mines and Mining, Chapter 1396; approved 1945 as Pennsylvania Bituminous Coal Open Pit Mining Conservation Act; Public Acts of 1963, 1968; Public Act No. 147, 1971, Section 4.a.(1).

⁶ West Virginia, Surface Mining Act, West Virginia Code, Volume 8, (1970), Replacement Volume, Chapter 20-Natural Resources, Sections 2, 5-11, 14-17, and 30; Section 20-6-9.

⁷ West Virginia, Surface Mining Reclamation Regulations. Chapter 20-6 Series VII, (1971), Section 10.01-10.05.

⁸ Illinois, Rules and Regulations Pertaining to the Surface-Mined Land Conservation and Reclamation Act, (1972), Chapter XVI, Rule 1601-Rule 1606.

There are no other explicit references to the use of aerial photography in any of the surface mining laws, rules, and regulations of the eleven coal mining states east of the Mississippi River. However, there are many potential areas for the further use of color and color infrared aerial photography.

c) Potential Uses of Aerial Photography

Color and color IR photography is useful primarily for showing landscape features; therefore, only that legislation which relates to the effects of mining on the landscape is pertinent to aerial photography. For this reason, certain sections of surface mining legislation were reviewed in detail, while other sections were given only a cursory examination. For example, some of the sections of the Kentucky law given complete review are those entitled:

Permit Required; Content of Application; Map;
Fee; Bond; Reclamation Plan; Requirements;
Approval; Dumping Regulations; Backfilling and
Grading; Alternative Impoundments; Bond Release.
Vegetative Cover Requirements.

Those sections of little importance to aerial photography include, among others:

Suspension of Permit; Bond Forfeiture;
Denial of Future Permits.
Succession of One Operator by Another.

The current discussion compares the more lenient requirements of some states with the more stringent requirements of other states for each item. A stringent reclamation requirement is one which requires a mining operator to spend a relatively great amount of time, money, and other resources in restoring the land to its original condition or in improving the land for a "higher" land use.

A stringent requirement is not necessarily the best or most suitable regulation for every state. In fact, the strict rules in effect in some of the states would be impossible to enforce in other states for reasons of climate, topography, geology (including structure of the coal beds), and settlement patterns. For example, in Illinois, the rules for land reclaimed for row-crop agriculture state:

The top 24 inches of newly placed materials shall contain no rocks larger than 6 inches in diameter, and shall not contain more than 20% rock by volume. The two to four foot layer of newly placed materials shall contain no rocks larger than 10 inches in diameter and shall not contain more than 50% rock by volume.⁹

There are many places in Illinois where topsoil depth prior to mining is many feet thick, so it is reasonable to require that two feet of topsoil be replaced. However, in many parts of Pennsylvania there are only a few inches of topsoil, so all of the soil must be saved in order to comply with the following requirement of 12 inches of cover:

⁹ Illinois, Rules and Regulations, Rule 1104.

All topsoil and sufficient sub-soil shall be removed segregated, and stored in a readily accessible location to insure ample material for a cover of at least 12 inches after backfilling has been completed.¹⁰

An outline of the types of items that were reviewed in detail is shown below:

- Types of mining covered by laws and regulations
- Inspections; frequency and techniques
- Mine planning requirements
 - a. Prospecting maps; items included
 - b. Permit application maps; items included
 - c. Reclamation plan maps, mining plan maps; items included
 - d. Areas restricted from mining
- Mine monitoring requirements
 - a. Progress maps, final maps; items included
 - b. Monuments, markers
- Reclamation requirements
 - a. Backfilling
 - b. Grading
 - c. Drainage control, including impoundments
 - d. Access roads, fire lanes
 - e. Removal of debris

¹⁰ Pennsylvania, Requirements Accompanying Permits Authorizing the Operation of Surface Coal Mines (1972), Subchapter D, 77, 92, f.(5).

- f. Revegation
- g. Other land use
- h. Overall time for reclamation

(1) Types of mining

The reviewed laws of several states cover only the surface mining of bituminous coal. The Maryland law is designed to effect the "improvement of areas of land affected in the mining of bituminous coal by the open-pit strip mining, or auger mining method."¹¹ The Ohio law covers the strip mining of coal, including the auger method. The "control (of) present and future problems associated with the surface mining (strip, auger, or other surface methods) of coal resources and the reclamation of disturbed lands"¹² is the objective of the Virginia law. The remaining states have more generally applicable surface mining laws. For example, the Illinois law applies to coal, sand, gravel, silica, shale, clay, and limestone. The Michigan law controls the mining of "coal, gypsum, stone, metallic ore, . . . and other material to be excavated for commercial, industrial, or construction uses. It does not include clay, gravel, marl, peat, or sand."¹³ The Indiana law governs coal, clay, and shale mining. The Pennsylvania law includes reclamation requirements for "limestone, dolomite, sand, gravel, rock, stone, earth, fill, slag, iron ore, zinc ore, vermiculite clay, and anthracite and bituminous coal."¹⁴

Since several states have surface mining laws applicable to minerals other than coal, utilization of aerial photography in those states should be noted.

Although the legislation in many states is identical for several minerals, there are specific regulations for various minerals that take into account the unique physical properties of the substances. In Pennsylvania there are separate planting regulations following the mining of bituminous and

¹¹Maryland, Natural Resources Strip Mining Law, 7-502.

¹²Virginia, Coal Surface Mining Law, Code of Virginia, (1975), Title 45.1, Chapter 17, 45.1-198(d).

¹³Michigan, Mine Reclamation Act (1972), Sec. 1.(h).

¹⁴Pennsylvania, Surface Mining Conservation and Reclamation Act, Section 3.

anthracite coal, because anthracite spoils and soils are quite different from those of the bituminous areas of Pennsylvania and the same species of vegetation will not grow well on both types of spoil.

(2) Inspection: frequency and techniques

All of the states require that a state mining inspector visit each mining site at some time during the operation. The frequency and rigor of inspections varies considerably from state to state.

The West Virginia law and regulations provide for the strictest inspection schedule. The "Duties of surface-mining reclamation inspectors" include the assurance of complete compliance with the conditions of the mining permit, "inspections . . . of each active surface mining operation at least once every fifteen days,"¹⁵ and the reporting of all violations to the director. Surface mine inspection reports must be filled out every 15 days until the backfilling and grading are completed. All water discharged from the permit area must be monitored daily, and the Reclamation Division receives a monthly report of water quality. The final inspection of revegetation takes place at least two years after planting and the reclamation bond is released if there is a satisfactory vegetative cover at that time.

None of the other states requires a scheduled inspection of mining sites with a particular frequency (at least the laws and regulations do not require this). One of the documents which mentions inspections only in the most general way is Alabama's law. The Alabama law dictates:

Any member of the Commission, director or their staff may enter upon the affected lands at any reasonable time for the purpose of inspection to determine whether the provisions of this act have been complied with.¹⁶

The law also mentions inspections when certain milestones are reached, such as at the completion of all reclamation. The final inspection must be made by a registered forester.

Discussions with state reclamation bureau personnel indicate that all the states attempt to make regular inspections using a

¹⁵ West Virginia, Surface Mining Act, 20-6-5.

¹⁶ Alabama, Surface Mining Reclamation Act of 1975, Section XII.

set of standard techniques and reporting procedures. However, nearly all the state inspection teams are understaffed. Any of the applications of color and color IR aerial photography which would make more frequent inspections possible would be welcomed by the bureaus.

(3) Mine planning requirements

The remaining requirements of surface mining laws are reviewed in roughly sequential order with respect to the mining operation. Prospecting maps, permit application maps, and reclamation plan maps must all be prepared previous to beginning mining. Also areas within the general permit area in which mining is to be prohibited must be determined before mining commences.

(a) Prospecting maps

Maryland, Tennessee, Virginia and West Virginia require prospecting maps. Pennsylvania requires a detailed description of prospected areas but no map. The prospect mining map in Maryland must be a USGS topographic map, 7 1/2 minute series, at a scale of 500 feet to the inch, showing the location of each prospect and property line, adjacent ownership, and route of access. Information which need not be mapped but must be described verbally includes area disturbed, depth of overburden, and name and thickness of seam to be mined.

In Tennessee, three topographic maps or aerial photos must be submitted as part of the permit application, showing tract boundaries, the contour on which prospecting will occur, and the location of surface disturbance. The requirement in Virginia is quite similar; there a USGS topographic map must show the crop line and name of the seams to be prospected. A USGS topographic map showing the crop line and name of the seams must be presented to the Department in West Virginia. A plan for reclamation of a prospected area in West Virginia must include a reclamation plan map identical to that prepared for a mined area (see Section C, Reclamation plan and mining maps).

(b) Permit application maps

Nearly all of the state laws require permit application maps. One of the most detailed application maps is the one which must be prepared in Ohio. A strip mining license, rather than a permit, is issued in Ohio, so that the map discussed in this section is actually a license application map. It must be submitted in triplicate, at a scale not to exceed four hundred feet to the inch. It may be a USGS topographic map enlarged to the given scale with the information superimposed upon it.

The complete list of information required on the Ohio map indicates several features which would be displayed well on aerial photographs:

Required Information: Ohio License Application Map

Boundaries of affected area
Boundaries of subjacent and adjacent deep mining; active,
inactive, mined out
Name of the applicant

Names of surface and mineral owners of area and within five
hundred feet of area
Names and locations of streams, creeks, other water bodies,
roads, railroads, utility lines, buildings, cemeteries, oil
and gas wells, in area and within five hundred feet of area
County, municipality, township, and section names
Drainage plan; existing and proposed
Location of test borings
Date of preparation, north point, quadrangle sketch
Locational monuments in area and within five hundred feet of area
Locational coordinates (Universal Transverse Mercator Grid
Coordinates)

Aerial photographs provide current information on the location of such man-made features as roads, railroads, buildings, and locational monuments. Color infrared photography, in particular, displays the existing drainage pattern, including the beds of minor, intermittent streams whose channels have changed since previous mapping.

No permit application maps are required in Alabama or in Michigan, although an accurate description of the location of mining areas must be kept on file with the inspectors in these states.

(c) Reclamation plan and mining plan maps

The reclamation and mining plan map requirements were quoted in the previous pages (since they included references to aerial photography) for the states of Maryland, Pennsylvania, Tennessee, and West Virginia. Two other states, Indiana and Michigan, have particularly interesting reclamation plan requirements.

The Indiana reclamation plan maps must indicate . . .

the location of the operation, the name of the applicant and date, the boundaries of the area of land affected, the drainage plan on and away from the area of land affected, all utility and other easements on the area of land affected¹⁷

The Indiana Plan of Reclamation Form (R-501-A) requires the operator to specify the land use objective for the proposed area to be mined. The slope and soil conditioning requirements for various land uses appear on the form itself. The proposed vegetation must be indicated as a part of the plan; therefore, the revegetation types must be considered much sooner in the mining process in Indiana than in many of the other states. Other information such as the techniques and types of equipment used for grading must be presented in a similarly detailed fashion.

The Mine Reclamation: Proposed Rules of the Geological Survey Division of Michigan (not yet ratified as of this writing) would provide for a dynamic process for determining the reclaimed land use. The rules state that "upon request of the supervisor, an operator shall submit his long range environment plan for the mining area."¹⁸ Once the plan is accepted, it is termed the reclamation plan. It may be updated at any time, and "may be conditioned to periodic review in light of new research and changed reclamation technology."¹⁹

¹⁷Indiana, An Act Regulating Surface Mining, House Enrolled Act No. 1789 (1968), Section 1.(c).

¹⁸Michigan, Mine Reclamation: Proposed Rules (1974), Rule 8. (1).

¹⁹Ibid., Rule 9. (3).

(d) Areas restricted from mining

Most of the laws restrict certain areas from mining to prevent erosion, pollution of streams, and encroachment on scenic areas. There are also regulations against mining if physical conditions would demand that the mining operation be unusually expensive, or if such conditions would render reclamation impossible.

The Kentucky law clearly bans mining from many areas:

No application for a permit shall be approved by the division if . . . there is no probable cause to believe that the proposed method of operation, backfilling, grading, or reclamation of the affected area can be carried out consistent with the purpose of this chapter. If the division finds that the overburden . . . shows that substantial deposition of sediment in stream beds, landslides or acid water pollution cannot feasibly be prevented, the division may delete such part of the land described in the application upon which such overburden exists.²⁰

Strip mining may not take place in Kentucky if it would be a hazard to any house, public building, school, church, cemetery, commercial or institutional building, public road, stream, lake, wild river, park, or other public property. No strip mining area can be within 100 feet of any public road, stream or lake.

The Maryland law requires similar restrictions, and also states that no operator shall maintain a highwall within two feet for every foot of vertical highwall to an adjacent property line. Maryland, as of this writing, has proposed a regulation to ban most mining from the scenic corridor of the Youghiogheny River.

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Kentucky, Strip Mining Law, Kentucky Revised Statutes (1973), Title XXVIII - Mines and Minerals, Chapter 350 - Strip Mining, Section 350.085.

In Ohio, no mining may take place closer than 50 feet in horizontal distance to a public road, and no excavation may be high above an adjacent road. The Virginia regulations state that the Director of the Department of Conservation and Economic Development may, at his discretion, limit any one contiguous strip mining area to 250 acres.

(4) Mine monitoring requirements

The two remaining types of mining maps, progress (or operating) maps and final maps, must be prepared by the operator in order to keep an accurate, updated description of the mining operation on file with the state reclamation agency. State officials are aided in comparing proposals for mining with actual areas of land affected because they require monuments delimiting the permitted area.

(a) Progress and final maps

Progress (or operating) maps are called for in the legislation of most of the states. In Indiana, Kentucky, Maryland, Pennsylvania, Virginia, and West Virginia, these maps, usually prepared annually, are updated versions of permit application maps. In Tennessee, an annual report map must show planted, regraded, and non-reclaimed mined lands, each item color-coded. Similarly, in Ohio the progress map is to show affected and reclaimed land.

In Michigan, (according to proposed regulations) the most detailed map prepared throughout the duration of the mining operation is the annual operation map. It must show the location of the operation; the name of the operator and date of map preparation; the boundaries of the affected area including the location of surface overburden, waste rock, and stockpiles of coal; the locations of tailing basins and other constructed drainageways; utilities; adjacent owners; previously mined areas; acreage currently disturbed; abandoned workings; and anticipated changes in the mining area in the coming year.

As mentioned previously, aerial photography may be used as progress maps in Illinois.

A few states require a "final map," as distinguished from a progress map, to be prepared at the completion. In most states, however, inspection of the reclaimed land is much more important than the submittal of a final map as a criterion for the approval of reclamation.

(5) Reclamation requirements

Color and color infrared aerial photographs have already been assessed as useful tools in monitoring the degree of success of clay mining reclamation.²¹ The ability of these tools to sense landscape scarring and erosion, vegetation destruction, shifts in vegetation, wildlife habitat destruction, water pollution and undesirable afteruse (land use) should also prove valuable in satisfying the coal mining mandates for monitoring backfilling, grading, drainage control, access roads, debris removal, revegetation, other land uses, and meeting the time limitations for reclamation. Each of the types of coal mined land reclamation rules is reviewed in detail below.

(a) Backfilling

All of the states except Michigan (whose requirements are currently undergoing revision) require the backfilling of toxic material by at least two feet, and in some cases four feet, of "clean fill."

(b) Grading

Grading requirements vary extremely from state to state. Several states, such as Kentucky, Ohio, Tennessee, and West Virginia, require area mined land (where the method of operation does not produce a bench)

²¹Donald Garofalo and Frank J. Wobber, "Remote Sensing for Environmental Studies in Mined Areas," Photographic Applications in Science, Technology, and Medicine, (September 1974): 22.

to be returned to its approximate original contour. Each of the laws has a specific interpretation of "approximate original contour." The Kentucky law specifies that complete backfilling should take place from the top of the highwall to the toe of the spoil bank with no depressions to accumulate water. All highwalls and spoil peaks are thus eliminated. Diversion drainage ditches may also be required.

The other states encourage various methods of minimizing erosion and enhancing the usefulness of reclaimed land. In Alabama, grading must be done to "reduce peaks and ridges to a rolling topography."²² The Indiana law says that "grading shall be carried out . . . so as to reduce peaks and ridges, and diminish depressions between such peaks and ridges, to a rolling, or sloping, or terraced topography consistent with the land-use objectives stated in the plan of reclamation."²³

On the Indiana Plan of Reclamation form, the operator must specify the proposed land use for the affected area. If the land is to be reclaimed as row crop acreage, the maximum graded slope is eight percent; for pasture and hay acreage, the maximum graded slope is 25 percent; and for forest or range land, it is 33 1/3 percent.²⁴

Most of the states have separate grading requirements for contour mining. States which do not have such rules are states in which very little contour mining takes place.

One state where contour mining is very common is West Virginia. The law and regulations charge the operator with regrading a bench so that it slopes toward the reduced highwall. If auger or deep mining is performed, the grading must be a Georgia Type V Ditch.²⁵

²² Alabama, Surface Mining Reclamation Act of 1975, Section III.

²³ Indiana, An Act Regulating Surface Mining, Section 6.

²⁴ Indiana, "Plan of Reclamation" (Form R-501-A), Item 10.

²⁵ A Georgia Type V Ditch and other configurations for regrading are explained in Elmore C. Grim and Ronald D. Hill, Environmental Protection in Surface Mining of Coal, EPA Environmental Protection Technology Series, (1974), Section IX, "Backfilling, Grading and Revegetation."

However, the Kentucky law demands that contour, auger, and highwall mines be regraded by terrace backfilling. The steepest slope of the reduced or backfilled highwall and of the outer slope must be less than 45 degrees. The table portion of the restored land must slope toward the highwall at less than ten degrees. There are also restrictions on the maximum solid bench width of the first cut.

Most of the states have a time limitation or a distance limitation on when backfilling must take place. In Illinois, all grading must be completed within one year after the mining permit expires. In Maryland, grading must be underway within two spoil ridges of the active pit and within 1500 feet of the pit. Tennessee requires that backfilling take place within 15 days and 1500 feet of the pit, unless augering is to follow stripping. In this case augering must be begun within 60 days of stripping. Further, all backfilling and grading for any type of surface mining in Tennessee must be completed within 180 days from the time that soil is first disturbed in the area.

(c) Drainage control, including impoundments

The regulations for drainage control are voluminous. In fact, several of the states have separate laws governing certain aspects of drainage control (for example, Pennsylvania, The Clean Streams Law, [1937] as amended). Other states have separate "how to" manuals to explain techniques to mining operators (for example, the Tennessee Drainage Handbook for Surface Mining). This review, however, will be limited to discussions of drainage control found in the strip mining legislation and regulations.

In Kentucky, there are separate regulations for water quality and for impoundments. The water quality regulation stipulates that no water shall be discharged "into the waters of the Commonwealth from the area of land affected, the pH of which is less than 6.0 or greater than 9.0."²⁶ The

²⁶ Kentucky, "Water Quality Criteria," (402 KAR 1:055), Section 2 (3).

measure of pH and the measure of iron concentration (not to exceed 7 milligrams per liter) cannot, of course, be made by remote sensing means. However, color and color infrared photography are potentially useful for indicating subaqueous buildups of sediments and the differences in sediment buildups between main and tributary streams. Therefore, violations of the Kentucky regulation, which disallows suspended matter in excess of 330 ppm, or 2,200 ppm following precipitation, could at least be suggested by the interpretation of aerial photographs of the site. The regulation also requires treatment facilities to be built and operated if the water quality would be substandard without them. Kentucky also demands that intermittent streams be kept free of spoil material, no drainage be discharged into underground mines, and no sudden release of water be made onto the outer slopes of spoil banks.

The Kentucky regulation governing impoundments says that "the operator shall construct water retarding structures, sediment dams, or sediment ponds in those drainage areas to be immediately affected by the operation" (once his drainage plan is approved).²⁷ There are time, depth and revegetation restrictions on such impoundments.

Ohio has similar mandates, and this excerpt from its law also serves as an example of statements in most of the strip mining laws about alternative reclamation of impoundments.

Affected land must be contoured, unless "the area of land affected (is used) for water impoundments, water-oriented real estate development, recreation area development"²⁸

(d) Access roads, fire lanes

Most of the states have some regulations concerning the construction of access roads to the mining operation and fire lanes. The regulations focus on three areas: 1) that an access road have safe grades, 2) that it be composed of non-toxic materials, and 3) that it not impede the flow of water.

²⁷ Kentucky, "Sediment Control Planning," (402 KAR 1:060), Section 1 (b).

²⁸ Ohio, Strip Mine Law, (1972), 1513.16 (C) (1).

The more detailed specifications in the Tennessee regulations are similar to those in some other states. No road may be constructed near enough to a stream channel so that eroded material from the road could cause sedimentation. Tennessee has strict requirements dealing with the grading of roads. For example, there may be no sustained grades of greater than ten percent; there may be no grades of greater than 15 percent for 300 feet; on temporary roads between benches; grades may not exceed 20 percent; the surfaces of roads must be insloped at 1/2 inch per foot of surface width; and cut slopes may not exceed 45 degrees, except in stable rock.

All of the states require the regrading and revegetation of abandoned haulage roads. Virginia requires the entire road surface to be vegetated following abandonment. In Kentucky, abandoned haulageways must be adequately drained and planted; "in the eastern Kentucky coal field, seeding shall be done . . . including access roads, within fifteen days after grading" ²⁹

(e) Removal of debris

Color and color infrared aerial photography may prove to be extremely useful for inspecting a formerly mined area in order to determine whether debris has been removed from the site. Garofalo ³⁰ suggests the use of color aerial photography to recognize the distribution of trash, old equipment, and abandoned buildings, whereas color infrared photography is particularly well-suited to identify abandoned equipment.

Several of the states specify that debris and equipment must be removed before termination of the mining operation. In Indiana, the law states that all debris must be removed or buried before completion of reclamation. Ohio, Pennsylvania, and West Virginia have similar rules.

²⁹Kentucky, "Revegetation Requirements," (402 KAR 1:040).

³⁰Garofalo and Wobber, Ibid.

(f) Revegetation

Color and color infrared aerial photography can be especially useful in monitoring the progress of revegetation. This investigation into the use of color and color infrared photography for mine planning and reclamation monitoring tested the usefulness of these tools for monitoring revegetation. Therefore, the sections of the legislation and regulations which deal with revegetation are reviewed here in greater detail.

Revegetation plans must be filed in every state, either as separate documents or as a part of another document. Most of the plans are filed at the same time as (or as part of) the permit application. In Illinois, the reclamation plan requires a specification of the areas to be reclaimed as forest, pasture, cropland, horticultural cropland, homesites, recreation areas, industrial sites, and wildlife shelter or forage lands.

The Tennessee revegetation plan, filed concurrently with the permit application, must include: 1) a schedule for planting; 2) a listing of plant species; 3) the types of fertilizer to be used; 4) the rate of seeding; 5) the spacing of seedlings; and 6) the approximate dates for planting.

West Virginia mine operators must file a planting plan within 60 days after grading of the affected areas is approved. Several of the states also demand a planting report either as soon as the planting is finished or within one season of planting.

In most of the states, both plant species native to the state and non-native plant species proven to be adapted to the state are permissible. All of the states allow revegetation with trees, shrubs, grasses, or legumes. In every case, tree seedlings are much preferred because of their greater survivability. Trees are generally required in highly erosive areas accompanied by a nurse crop of annual grasses. The operator usually has the right to choose the type of vegetation he wishes to plant in other areas. In at least one state (Pennsylvania), any one plant species may not cover more than 50 percent of the acreage of any operator.

The general standards for survivability of trees, grasses, and legumes in some of the states appear below:

SURVIVABILITY OF VEGETATION AFTER ONE YEAR

	<u>Trees/Acre</u>	<u>Grasses & Legumes/Coverage</u>	<u>Mixture</u>
Alabama	435	75%	
Illinois	450 *	85%*	
Kentucky	600	85%	
Ohio	900	85%	
Pennsylvania	900	--	600 trees/80% grass/legumes
Tennessee	**	80%	
Virginia	800	***	
West Virginia	600	80%*	60% trees/60% grass or legumes

*After second growing season

**Must be planted on a 6' by 7' grid; survivability requirement is vague

***Specified as percent germination of original weight of seed planted

Several of the state regulations specify the minimum pH level for planting of each type of vegetation. For example, in Kentucky the soil's pH must exceed 6.4 for the planting of grasses and legumes, and the pH must exceed 5.5 for the planting of other types of vegetation.

All of the states specify a planting schedule, depending upon the type of species to be planted. Planting must be done as soon after grading as it is practical.

(g) Other land use

The revegetation requirements outlined above are classified according to the proposed land use following reclamation. Some of the states allow land to be reclaimed for other uses which cannot fall within the jurisdiction of any of the standard revegetation rules. Such land uses are subject to state approval as individual, special cases.

For example, in Alabama:

The applicant may elect to reclaim the land for range, agricultural or horticultural, homesite, recreational, industrial, or commercial use, or other uses.³¹

In any of the states, proposed land uses are subject to zoning and other land use-related ordinances of the counties. Illinois' surface mining law clarifies the county's influence over land use in affected areas:

The county boards of each county containing lands to be affected may propose the use for which such lands within its county are to be reclaimed, and such proposal shall be considered by the Department ...

³¹ Alabama, Surface Mining Reclamation Act of 1975, Section IX, E.

If requested by a county board of a county to be affected under a proposed permit, a public hearing to be conducted by the Department shall be held in such county on the permit applicant's proposed reclamation plan . . .

The Department's approval of a plan shall be based upon the advice of technically trained experts . . . the Department shall consider written testimony from county boards . . .

The Department shall consider the short and long-term impact of the proposed mining on vegetation, wildlife, fish, land use, land values, local tax base, the economy of the region and the State, employment opportunities, air pollution, water pollution, soil contamination, noise pollution, and drainage.³²

(h) Overall time for reclamation

All of the states require the establishment of planting before the reclamation bond can be released. In most states, bond release occurs as a single repayment of the entire sum upon approval of the revegetation after a specified time period.

Kentucky provides for bond release "in its full amount less two hundred dollars per acre at the completion of backfilling, grading, and the attainment of acceptable soil pH levels." The remaining two hundred dollars per acre is retained until two years after the planting of vegetation. Vegetation is inspected at the end of the first and second growing seasons after planting; if it is satisfactory, the remaining bond is released at that time. If it is not satisfactory, the remaining bond is forfeited.³³

The Tennessee regulations permit vegetation to be inspected and evaluated at least 12 months after planting. If the vegetation cover is approved, the performance bond will be released when the parcel has been reclaimed; the remainder of the permitted area may be planted, inspected, and approved at another time.

Most of the states require revegetation to be completed within three years after the termination of mining and require at least two years after the planting of vegetation before the reclamation bond is released. The Indiana law permits the bond to be released within two years of revegetation planting, with the times varying slightly depending upon whether row crops, range,

³² Illinois, Surface Mined Land Conservation and Reclamation Act (1971), Section 5. (f), (g).

³³ Kentucky, Strip Mining Law, (1973), Section 350.093(6).

pasture, hay, or forest cover were planted. However, if upon inspection, an unsatisfactory vegetative cover exists, the operator must continue revegetation work and monitoring until satisfactory vegetative cover is established, or for 15 years. In the other states, the bond is usually either released or forfeited within five years, at the most.

d) Summary

The review of the legislation and regulations on the previous pages was complete as of November 1977. However, strip mining regulations are rapidly changing as demands are made increasingly for productive and aesthetically pleasing reclaimed land.

Several of the laws and regulations quoted in the report are currently being updated. The current versions of the Pennsylvania planting regulations and the Ohio strip mining regulations were mentioned, although new regulations are being written currently. The proposed Michigan and Maryland regulations, not yet in effect, were mentioned. Further, in Indiana, regulations can be changed rather quickly, as they are non-promulgated.

This review was not intended to be an exhaustive analysis of every state statute relating to reclamation. The review was conducted primarily to determine to what degree of detail reclamation must be monitored and to what degree remote sensing tools could be used for monitoring purposes.

SECTION 3. Status of the Use of Aerial Photography in the Mining Community

Thirty-three surface coal mine operators were contacted or visited to discuss the operators' usage of aerial photography in various aspects of the surfacemining cycle. Table 4 presents the results of these informal discussions with the surface mine operators.

The results of these discussions indicated that some 60 percent of the operators contacted used black and white aerial photography in some aspects of their operations. The majority used this photography for such applications as overburden removal volume estimates and for monitoring progress of mining activity. All companies contracted out the aerial data collection and analysis and only received a final product. None did its own interpretation or calculations.

Nine percent of those operators contacted used color aerial photography but always in conjunction with black and white photography, not

TABLE 4 RESULTS OF DISCUSSIONS WITH MINE OPERATORS

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ANNUAL PRODUCTION (TPY)				
STATE	OVER 1 MILLION	500,000 - 1 MILLION	0-500,000	TOTAL
ALABAMA	2	1	0	3
ILLINOIS	3	1	0	4
INDIANA	0	1	0	1
KENTUCKY	1	2	2	5
OHIO	0	1	4	5
PENNSYLVANIA	2	3	3	8
TENNESSEE	0	0	2	2
WEST VIRGINIA	1	1	3	5
TOTAL	9	10	14	33

A. DISTRIBUTION AND SIZE OF OPERATOR WITH WHOM DISCUSSIONS WERE HELD.

TYPE OF PHOTOGRAPHY					
STATE	BLACK & WHITE	COLOR	COLOR IR	NONE	TOTAL
ALABAMA	2	0	0	1	3
ILLINOIS	4	0	0	0	4
INDIANA	1	1	0	0	2*
KENTUCKY	1	0	0	4	5
OHIO	4	1	0	1	6*
PENNSYLVANIA	5	1	0	3	9*
TENNESSEE	0	0	0	2	2
WEST VIRGINIA	3	0	0	2	5
TOTAL	20	3	0	13	36*
% OF TOTAL	61%	9%	0%	40%	

*USED COMBINATION OF BLACK & WHITE AND COLOR PHOTOGRAPHY. % OF TOTAL BASED ON 33 RESPONDENTS.

B. USAGE OF AERIAL PHOTOGRAPHY FOR PORTIONS OF MINING CYCLE.

in place of it. No companies contacted used color infrared photography. Although some have considered it, they lacked an understanding of its potential usefulness. Generally the larger producing operators used aerial photography, whereas the smaller operators felt it was not cost effective for them to utilize it. Only one company contacted in the east (a large operator) had any personnel trained in aerial photointerpretation; however, a number of surface operators in the west have trained photo interpreters on their staffs. This is discussed in more detail in Section X, Western Area Study. Suffice it to say that the more detailed environmental assessments and monitoring required at the western operations has led to the operators' increased use of photointerpretation.

Of the 33 surface coal mine operators contacted, 28 indicated that they would be willing to have one of their personnel trained in basic manual photointerpretation. The results of these discussions agreed with the contractor's earlier perception of the use of aerial photography by coal mine operators.

Regulatory personnel were contacted in 11 eastern and midwestern states to determine their usage of aerial photography for monitoring purposes. Only two states make any use of aerial photography. One state used aerial photography to monitor disturbed and reclaimed acreages and also for making preliminary assessments of vegetative cover. A second state utilized large-scale polaroid or 35 mm aerial photography taken from a helicopter to have a record of potential problem areas that should be ground checked by inspectors.

Both these states had personnel trained in photointerpretation. Most state regulators were aware that aerial photography might be used for reclamation monitoring but generally felt it was too expensive and felt their inspection personnel lacked interpretation experience.

In summary, there is minimal usage of aerial photography within the mining community. Where it is used, it is used for photogrammetric purposes. The lack of trained personnel, unfamiliarity with film types and capabilities, and cost have made aerial photography less widely used in the surface coal mining industry than in many other land-intensive industries such as forestry.

V. SITE SELECTION

A. OBJECTIVES

The objectives of this phase were to select a test site or sites which met the criteria established by the Bureau of Mines Personnel. Those criteria included:

1. The site should not be less than 1 but not more than 100 square miles in area.
2. The site(s) should contain both contour and area strip mining with on-going reclamation activities.
3. The test site was to contain mining at various stages of development and several vegetation types used in reclamation at various stages of planting and growth.
4. If two test sites were selected, they should not total together more than 100 square miles and they should be in close proximity to each other.

With these objectives in mind, HRB-Singer entered into a detailed site selection process.

B. APPROACH

A number of potential test sites were presented in our technical proposal and in May 1975, HRB-Singer personnel visited the potential sites. Based on the previously mentioned criteria, four candidate test areas were selected. An initial analysis indicated that two areas in close proximity to each other were prime candidates in that they met all criteria. These sites were submitted to the Bureau of Mines Technical Monitor as the recommended test sites.

In late May 1975, the recommended test sites were visited by HRB-Singer and the Bureau of Mines personnel. The Bureau of Mines personnel concurred with the recommended test sites. Discussions were held with personnel from the two surface mining companies: Mr. Peter Chernicky, President, (since retired), and Mr. James Kindel, Chief Engineer of the C&K Coal Company,

Clarion, Pennsylvania and Mr. Halden Johnson, President and Mr. Donald Johnson, Vice President of K&J Coal Company of Lanse, Pennsylvania. Both companies agreed to co-operate in the study and made available their lands and various information. Both companies have been involved in utilizing black and white aerial photography for monitoring their operating pits and expressed an interest in this study.

It should be noted that without the cooperation and help provided by these operators this study could not have been conducted as smoothly as it was. They were always willing to provide any information requested and candidly answered questions we put forth. In addition, we were able to visit the test sites at any time and collect data. We feel fortunate to have had such cooperation.

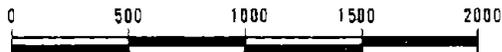
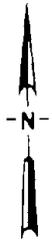
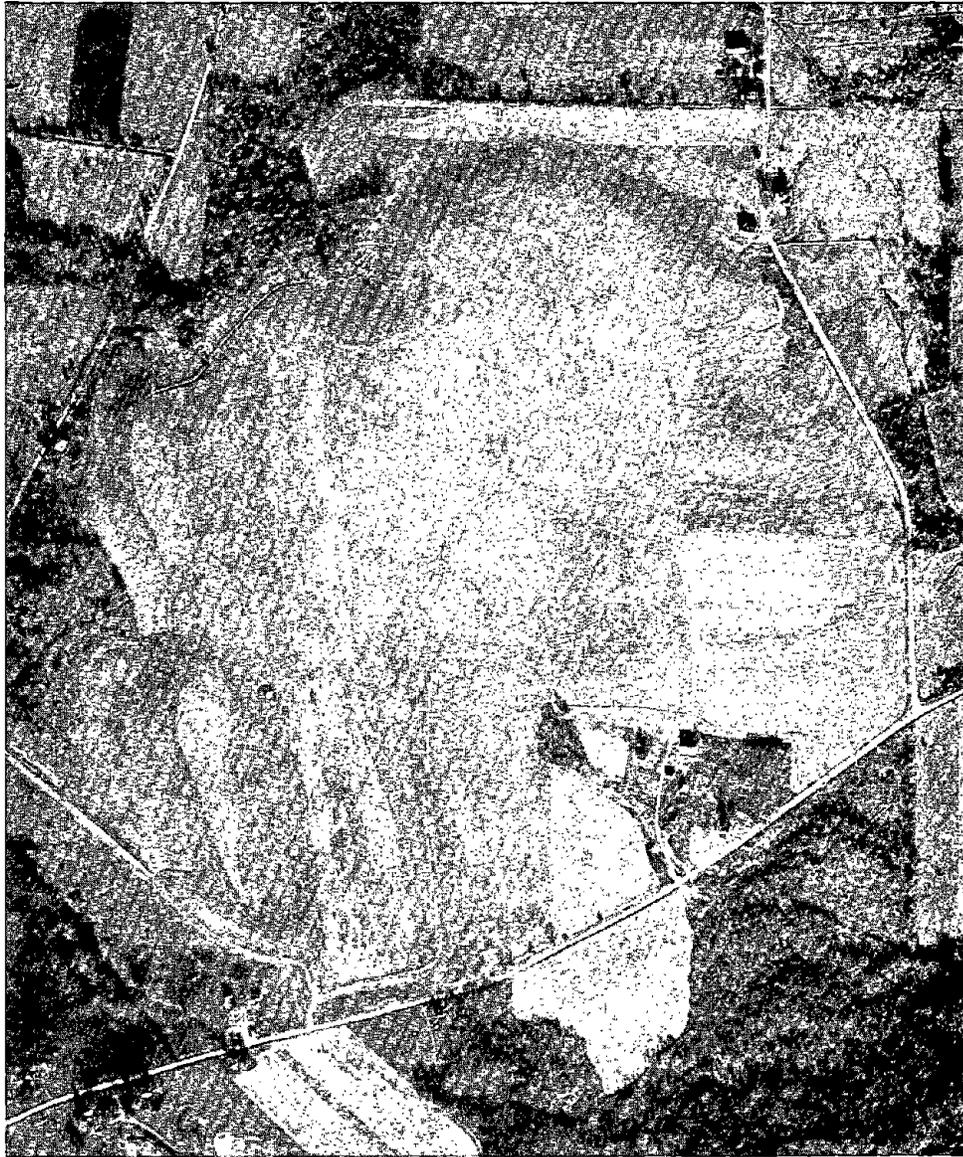
C. DESCRIPTION OF THE TEST SITES

The test sites selected are located in Clarion and Cambria Counties, Pennsylvania. Figure 2 shows the location of the test sites.

Test Site 1 is approximately 25 square miles in size. A series of four 3/4 square mile test areas were selected on which detailed ground truth was collected. These four areas were selected because they contain a variety of mining and reclamation activity. The test areas were located on C&K Coal Company land. An aerial photograph and description of each test area are presented in Figures 3 through 6. Site 1 was considered to have the most diversity of any of the sites. It is estimated that over 70% of the 25 square mile area has been disturbed by past and present surface mining activity.

Site 1A is an area of approximately 1 square mile within which a small area (area 5) was being utilized as a controlled test plot for tree planting on a reclaimed surface mine. This area was included for its possible use in detecting tree growth with the aerial photography. Figure 7 shows this site and describes test areas.

Site 2 is an area in Cambria County, Pennsylvania. It encompasses about 15 square miles. Initially one test (test area 6) was selected for detailed ground truth in that it contained mining and reclamation on steep slopes. Figure 8 shows that area and describes it. As the project



SCALE IN FEET

THIS AREA IS A RECLAIMED MINING SITE WHICH HAS BEEN RETURNED TO AGRICULTURE. CROPS GROWN INCLUDE OATS, HAY AND CORN. THE SITE GENERALLY HAS A HIGH PERCENTAGE OF GROUND COVER. THERE ARE SEVERAL AREAS OF STEEP SLOPES (15-20%) WHERE THE HIGHWALL EXISTED. MODERATE EROSION IS PRESENT ON THE RECLAIMED HIGHWALL SLOPES. RECENT MINING ACTIVITY IS ENCRDACHING IN SOUTHWESTERN CORNER. THERE ARE SEVERAL AREAS IN THE WESTERN MARGIN ALONG THE OLD HIGHWALL WHERE ACID MINE DRAINAGE IS OCCURRING.

FIG. 3 SITE 1 AREA 1

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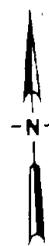


0 500 1000 1500 2000
SCALE IN FEET

THIS SITE IS CHARACTERIZED BY A SIGNIFICANT AMOUNT OF MINING AND ON-GOING RECLAMATION ACTIVITY. ACTIVE CONTOUR MINING IS TAKING PLACE AND AREA MINING USING A 45 YD³ DRAGLINE IS PROGRESSING. MAJOR CHANGES ARE OCCURRING IN THIS AREA AS CONCURRENT RECLAMATION IS TAKING PLACE, IN THE CENTER. THE LIGHTER TONED AREAS IN THE EASTERN PORTION OF THE SITE ARE AREAS RECLAIMED RECENTLY TO GRASSES AND TREES. NUMEROUS MINING RELATED IMPOUNDMENTS ARE ON THE SITE. SEVERAL STANDS OF WHITE PINES ARE LOCATED SOME OF WHICH ARE AFFECTED BY WHITE PINE BORER. A STAND OF VIRGINIA PINE IS PRESENT. THIS SITE CONTAINED A DIVERSITY OF ACTIVITY WHICH CONTINUALLY CHANGED DURING THE STUDY PERIOD.

FIG. 4 SITE 1 AREA 2

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SCALE IN FEET

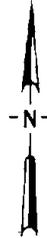
THIS SITE CONTAINS NO ACTIVE MINING OPERATIONS BUT HAS A VARIETY OF TYPES AND AGES OF VEGETATION IN RECLAIMED AREAS. IN ADDITION, THERE ARE AREAS OF PAST MINING ACTIVITY IN WHICH NO ATTEMPT TO RETURN THE HIGHWALLS TO ORIGINAL CONTOUR WAS REQUIRED. TWO IMPOUNDMENTS ARE LOCATED ON THE AREA. NORTH OF THE IMPOUNDMENTS IS A LARGE ABANDONED REFUSE BANK.

THE EASTERN PORTIONS OF THIS SITE CONTAIN NUMEROUS AREAS OF RECLAMATION INCLUDING TREES (CONIFEROUS AND DECIDUOUS) AND GRASSES.

FIG. 5 SITE 1 AREA 3

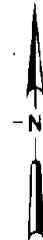
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THIS AREA IS CHARACTERIZED BY A SIGNIFICANT AMOUNT OF WATER (BOTH STREAMS AND STANDING WATER). THERE ARE AREAS OF ACTIVE MINING. ACTIVE RECLAMATION IS TAKING PLACE. NUMEROUS PLANTINGS OF TREES ON RECLAIMED AREAS ARE LOCATED ALONG THE EASTERN EDGE OF THE AREA.

FIG. 6 SITE 1 AREA 4



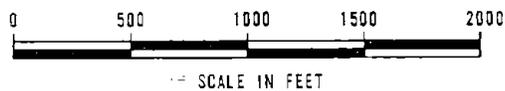
SCALE IN FEET

THIS SITE WAS SELECTED BECAUSE THE MINED AREA IN LOWER CENTER HAS BEEN RECLAIMED AND PLANTED BY THE U.S. FOREST SERVICE IN A CONTROLLED MANNER. 70 DIFFERENT TREE SPECIES HAVE BEEN PLANTED (5/75) AND THE GROWTH PATTERN WAS MONITORED OVER THE PROJECT PERIOD.

FIG. 7 SITE 1A AREA 5

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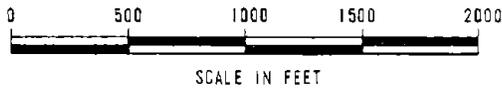
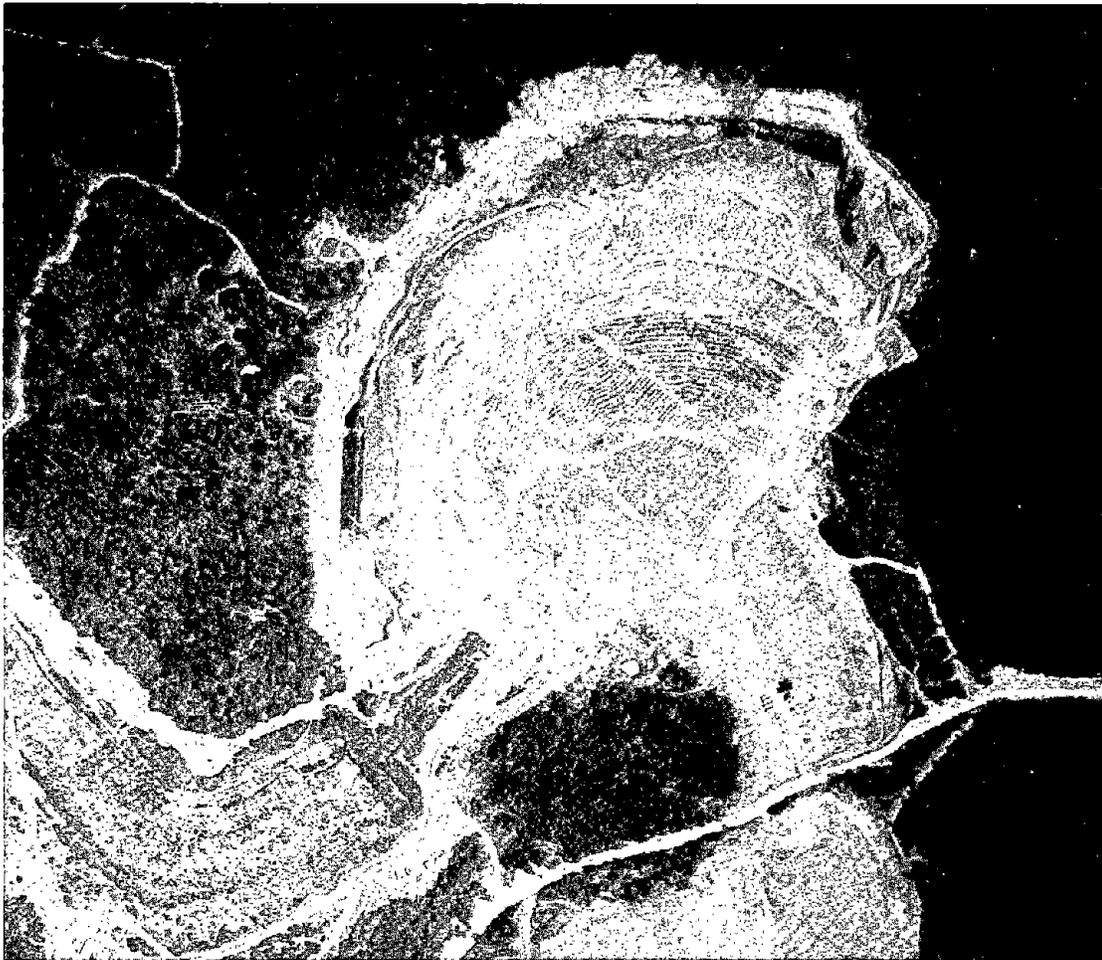




THIS SITE IS CHARACTERIZED BY AREAS OF STEEP SLOPES IN EXCESS OF 20%. A VARIETY OF RECLAMATION AND MINING ACTIVITY IS TAKING PLACE. IN THE NEAR FUTURE, THE SITE WILL BE REMINED USING A MOUNTAINTOP MINING TECHNIQUE TO REMOVE COAL FROM DEEPER SEAMS.

FIG. 8 SITE 2 AREA 6

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THIS SITE IS CHARACTERIZED BY A VARIETY OF TREE PLANTINGS ON OVERBURDEN MATERIAL AS PRESCRIBED BY PRE 1971 STATE LEGISLATION. IN ADDITION ACTIVE CONTOUR MINING IS OCCURRING ALONG THE NORTHERN PERIMETER OF THE AREA. NUMEROUS IMPOUNDMENTS ARE IN THE FOREST ADJACENT TO THE ACTIVE MINING.

FIG. 9 SITE 2 AREA 6A

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progressed another area within Site 2 became of interest to us. This area was added because of the diversity of older reclamation and active mining with associated impoundments. This area was designated as area 6A. It is shown in Figure 9 along with a general site description. Both test areas at site 2 were on K&J Coal Company land.

These areas (Figures 3-9) served as the major ground truth and training sites throughout the program. They were considered ideal for the types of data required in the study.

VI. DATA COLLECTION

A. OBJECTIVES

The objectives of this phase were to collect both aerial and ground data at the selected test sites which would provide adequate data for subsequent analysis and interpretation. This effort was to include seasonal data on a variety of ground features related to the surface coal mining process. Aerial and ground data collection efforts are discussed separately in the following sections. It should be noted, however, that these efforts were closely coordinated to ensure comparability of data.

B. APPROACH

The planned approach was to acquire aerial and ground data for two years beginning in the summer of 1975. Data collection was to be on a seasonal basis, except the second winter effort was to be omitted. Table 5 shows the scheduled and actual data collection periods. Generally data was collected according to schedule with the exception of the last two data collection efforts, which had to be rescheduled for later dates due to weather conditions that prevented data acquisition in the fall of 1976. The aerial and ground data collection methodologies and results are discussed in the following sections.

C. AERIAL DATA COLLECTION

The aerial data collection missions were planned on a seasonal basis as shown in Table 5. The areas to be flown coincided with the test sites shown in Figure 2 which total approximately 40 square miles. The first aerial data collection flight consisted of color, color infrared, black & white, and black and white infrared aerial photography at a variety of scales, and two different 9" format aerial cameras were used. Table 6 summarizes the aerial data collection parameters of with the initial flight.

TABLE 6 AERIAL DATA COLLECTION PARAMETERS - FLIGHT 1 - AUGUST 1975

CAMERA SYSTEM	ALTITUDE ABOVE TERRAIN	PHOTO SCALE	FILM TYPE 1,2	FLIGHT LINE MILES OF PHOTOGRAPHY		
				TEST SITE 1	TEST SITE 2	TOTAL
ZEISS RMKA 15/23 6" FOCAL LENGTH 9" FILM FORMAT	3000'	1:6000	COLOR	24	42	66
			COLOR IR	24	42	66
	6000'	1:12000	COLOR	16	21	37
			COLOR IR	16	21	37
	12000'	1:24000	COLOR	8	14	22
			COLOR IR	8	14	22
	24000'	1:48000	COLOR	4	7	11
			COLOR IR	4	7	11
			BLACK & WHITE	4	7	11
			BLACK & WHITE IR	4	7	11
	TOTAL			112	182	294
	WILD RC-9 3 1/2" FOCAL LENGTH 9" FILM FORMAT	1750'	1:6000	COLOR	24	42
COLOR IR				24	42	66
3500'		1:12000	COLOR	16	21	37
			COLOR IR	16	21	37
7000'		1:24000	COLOR	8	14	22
			COLOR IR	8	14	22
14000'		1:48000	COLOR	4	7	11
			COLOR IR	4	7	11
TOTAL			104	168	272	

1-COLOR FILM - KODAK AERO NEGATIVE 2445-COLOR IR FILM-KODAK AEROCROME IR 2443
BLACK & WHITE FILM - KODAK DOUBLE X 2405
BLACK & WHITE IR FILM - KODAK AEROGRAPHIC 2424

2-FILTERS UTILIZED
COLOR FILM - CLEAR ANTIVIGNETTING
COLOR IR FILM - CLEAR ANTIVIGNETTING
BLACK & WHITE FILM - MINUS BLUE
BLACK & WHITE IR - RED OR 'D)

The data resulting from this flight were evaluated for interpretability. After considering interpretability, scales normally flown for aerial photography, and cost tradeoffs of various scales, it was determined that subsequent flights would collect only color and color infrared with the ZEISS RMKA15/23 aerial camera at a scale of 1:12000. The results of this analysis are shown in Tables 7 & 8. Table 7 shows the average interpretability of various film types and scales of photography collected during the initial flight. These data indicated that interpretability of all film types increased as the scale increased. Color and color infrared photography were consistently rated higher than other film types in interpretability at each scale. Therefore, it was determined to utilize the largest scale photography possible considering cost constraints of data collection and to discontinue use of black and white films.

Table 8 shows the cost comparisons of various film types and scales based on 1975 cost estimates of aerial data collection. These data showed that the cost of data collection increases as the scale increases. The greatest cost increase was between 1:12,000 and 1:6000 scale photography. For a 100 square mile area, it was 2.88 times as expensive to collect 1:6000 scale than 1:12,000 scale color aerial photography. Similarly, it was 2.48 times as expensive to collect 1:6000 scale than 1:12,000 scale color infrared aerial photography. Thus cost and interpretability indicated a 1:12000 scale photography was optimum. In addition, our discussions with the mining community indicated that this scale was commonly used. Examples of various film types at a scale of 1:12000 are shown in Figure 10. The aerial photography was collected by Kucera & Associates of Cleveland, Ohio and was consistently of high quality.

As indicated in Table 5, all aerial photography was collected within the scheduled time frames with the exception of the last two flights. Because of an unusually warm September and October at the test sites, the fall 1976 flight was scheduled for November. Conditions radically changed in November. Temperatures turned significantly colder (the coldest November on record), and more importantly there were no cloud free days (<10% cloud cover) during this month. Although all available weather data indicated that October and November would have the most number of cloud free days for aerial data collection, this particular year was a departure from the norm.

TABLE 7 AVERAGE INTERPRETABILITY OF DATA AT ALL SCALES - FLIGHT 1 - SUMMER 1975

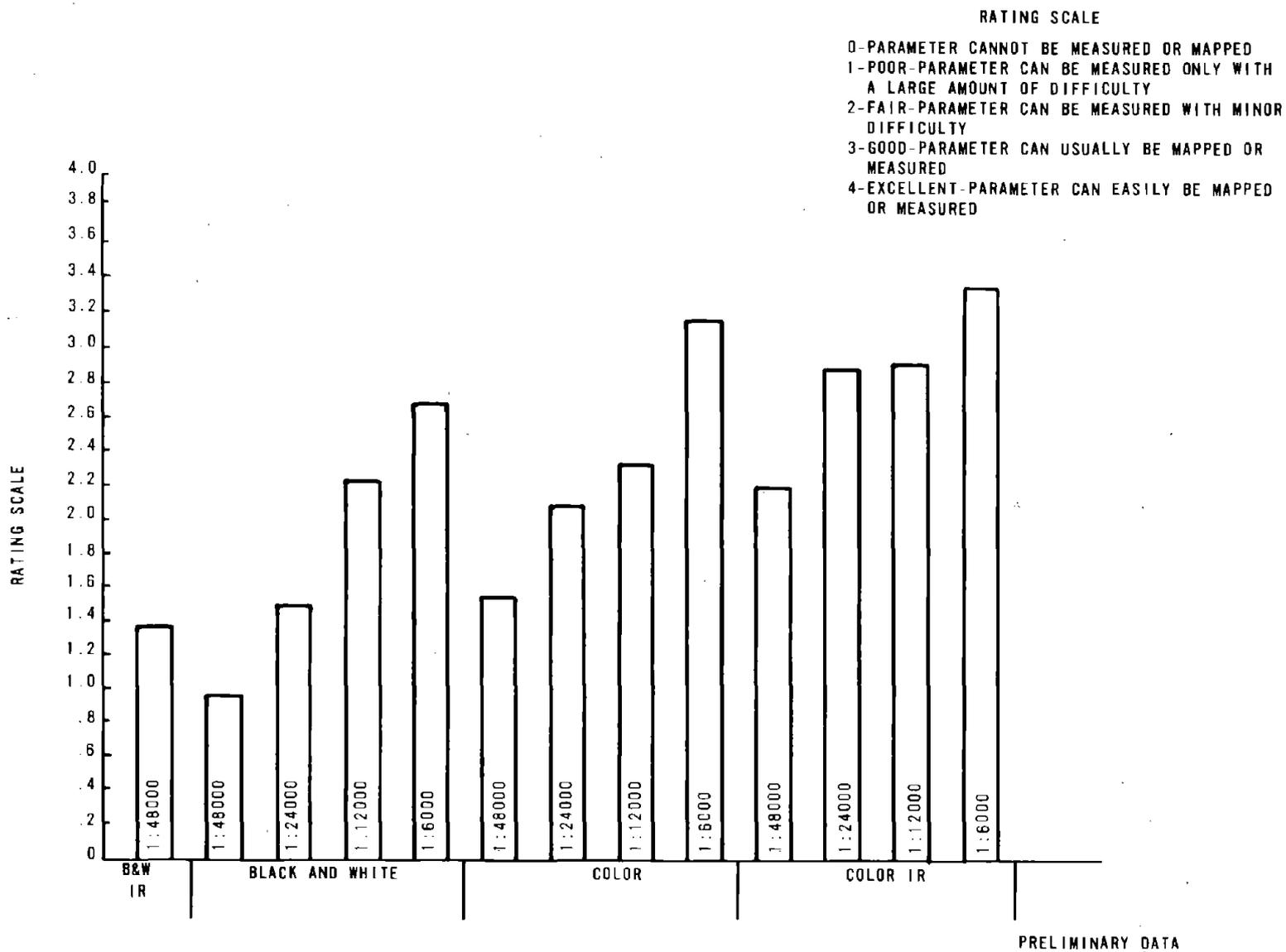
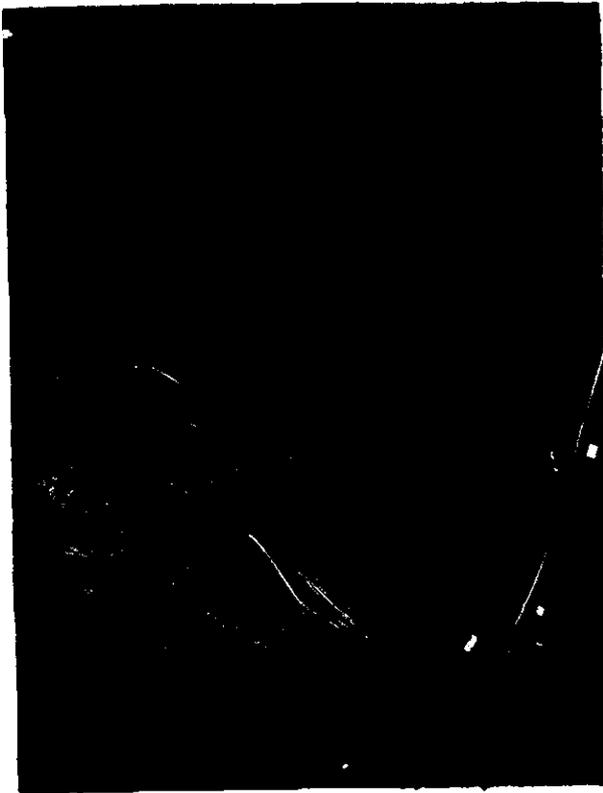


TABLE 8 TOTAL COST AND COST PER SQUARE MILE OF AERIAL PHOTOGRAPHY (BASED ON 1975 DATA)

77-71

SCALE		1:6000		1:12000		1:24000		1:48000	
		COST (UNITS=DOLLARS)							
COVERAGE	FILM TYPE	TOTAL	SQ. MI.	TOTAL	SQ. MI.	TOTAL	SQ. MI.	TOTAL	SQ. MI.
1000 SQ. MI.	COLOR	60200 ⁽¹⁾	60	17600 ⁽¹⁾	18	8260 ⁽¹⁾	8	4060	4
	COLOR IR	38500 ⁽¹⁾	39	12200 ⁽¹⁾	12	5470 ⁽¹⁾	5	2819	3
	B&W	23800 ⁽¹⁾	24	6800 ⁽¹⁾	7	3580 ⁽¹⁾	4	1980	2
	B&W IR	24500 ⁽¹⁾	25	8825 ⁽¹⁾	9	3670 ⁽¹⁾	4	2020	2
100 SQ. MI.	COLOR	6680	67	2320	23	1300	13	1120	11
	COLOR IR	4410	44	1780	18	1150	12	965	10
	B&W	2900	29	1140	11	950	10	860	9
	B&W IR	2900	29	1443	14	1000	10	860	9
10 SQ. MI.	COLOR	1900	190	880	88	870	87	870	87
	COLOR IR	1500	150	820	82	790	79	790	79
	B&W	1180	118	760	76	760	76	760	76
	B&W IR	1180	118	763	76	766	77	760	76
1 SQ. MI.	COLOR	736	736	718	718	718	718	718	718
	COLOR IR	724	724	712	712	712	712	712	712
	B&W	712	712	706	706	706	706	706	706
	B&W IR	717	717	708	708	708	708	708	708

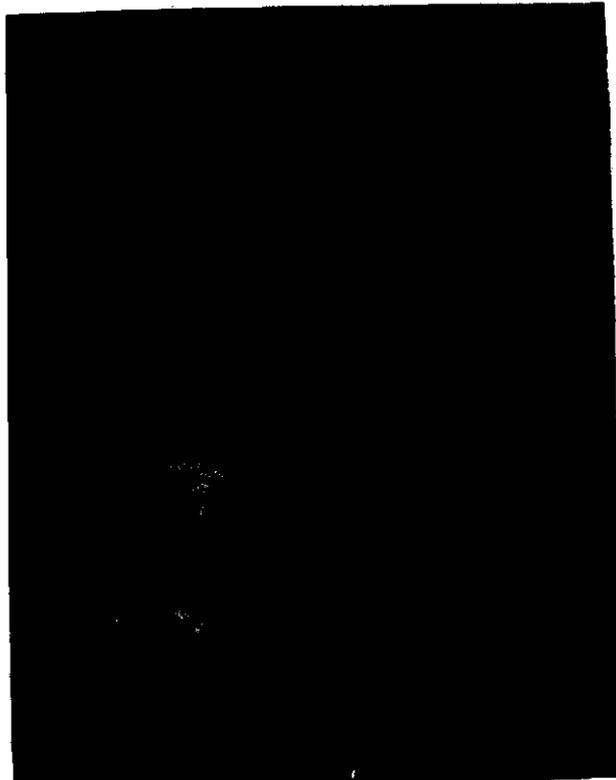
(1) INCLUDES MOBILIZATION FOR TWO DAYS FLYING, REMAINING FIGURES BASED ON MOBILIZATION FOR ONE FLYING DAY.



BLACK AND WHITE



COLOR



COLOR INFRARED

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FIG. 10 EXAMPLES OF 1:12000 SCALE AERIAL PHOTOGRAPHY AUGUST 1975, SITE 1

It is important to note when planning a seasonal aerial data collection mission, one must realize that cloud cover could preclude the collection of the data. This is especially true in the Appalachian Region where cloud buildup due to topography is common and weather systems are prone to move very rapidly or stagnate over the region.

After consulting with the Bureau of Mines personnel, it was decided to shift the flight schedule so that flight 6 was conducted in April of 1977 and the final flight was completed during July 1977.

In addition, a separate aerial data collection flight using a helicopter platform was conducted in May 1977. This flight collected 70 mm and 35 mm color and color infrared oblique photography. The purpose of collecting this data was to determine the utility of this type of data collection and to provide oblique views of the test areas. Samples of this photography are shown in Figure 11.

In conclusion, the aerial data collection generally proceeded smoothly with excellent quality photography obtained on each flight.

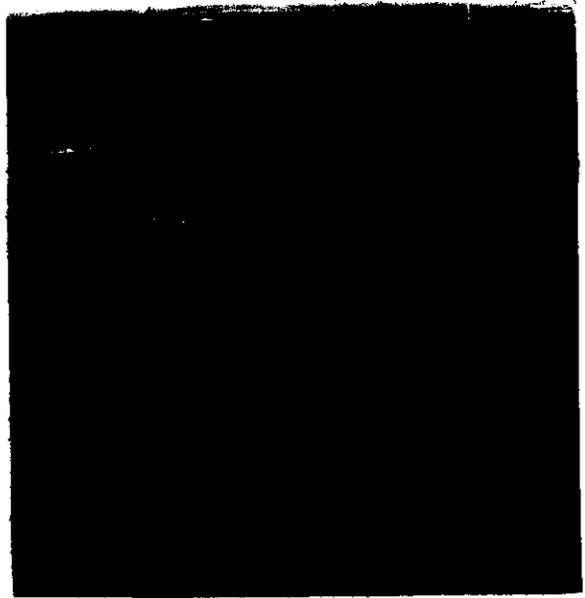
D. GROUND DATA COLLECTION

Ground data collection was planned to coincide with aerial data collection as shown in Table 5. The purpose of the ground data collection was twofold: 1) to document in detail the existing conditions on the ground in the 3/4 square mile test areas and 2) to determine the time and cost of collecting a variety of data by on-ground methods.

During the planning process, consultations with various surface mine inspectors and surface mine operators, and the results of the remote sensing literature review, enabled us to determine a list of features associated with surface coal mining on which information could be in some degree derived from interpretation of color and color infrared aerial photography. These features were classified into five general categories. They were 1) land use, 2) soils and terrain, 3) vegetation, 4) water and 5) geology. Within those categories each specific feature was classified as to whether it was to be



SITE 1 AREA 4
SUMMER 1977



SITE 2 AREA 6
SUMMER 1977



SITE 1 AREA 4
SUMMER 1977, 70MM

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FIG. 11 EXAMPLES OF AERIAL PHOTOGRAPHS TAKEN FROM A HELICOPTER

mapped, measured, or both. In this report map means to locate and identify a feature and plot it on a known coordinate base or bounded area, and measure means to quantify certain properties of a feature such as length, width, height, or area. In addition, each feature was evaluated as to its applicability to various stages of the surface mining cycle (pre-mining, operations, and reclamation). Table 9 shows the features on which ground data was collected.

Pertinent features found within each 3/4 square mile test area were mapped, and their parameters were measured on the ground. The distribution of each feature within each 3/4 square mile test area was mapped. For parameters, a number of quantitative ground measurements such as soil and water pH, suspended solids, and soil moisture were made.

In order to have the large amount of ground data collected in some order for use in interpretation and analysis, a base aerial photograph with grid was produced for each 3/4 square mile test area. A sample photograph with grid is shown in Figure 12. Each grid represents an area 500 feet on a side. For mapped features such as forest land, their distribution was mapped directly on the photograph and grid. This distribution was then updated during each ground data collection trip. The photograph and grid were also especially useful in locating areas where measurements were taken. For example, slope measurements in the field were located by grid number and the slope measured was plotted on the base photograph. This allowed rapid correlation of the ground data collection sheets with actual ground locations of the various measured parameters. A number of ground data collection sheets were developed relating to the general categories discussed previously. These ground data collection sheets along with photographs and grids enabled the large amounts of ground data to be analyzed and filed in a systematic manner to be used in other ground data collection efforts and for comparison with results of interpretation of the aerial photography.

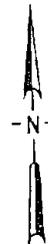
TABLE 9 GROUND DATA COLLECTION FEATURES

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CATEGORY	FEATURES AND PARAMETERS	MAPPED	MEASURED	APPLICABILITY TO MINING PHASE
LAND USE	AGRICULTURAL LAND	X		1
	FOREST LAND	X		1
	GRASS/FALLOW LAND	X		1
	RESIDENTIAL	X		1
	ACTIVE STRIP PIT	X	X	1,2
	INACTIVE STRIP PIT	X		1
	ABANDONED STRIP PIT	X		1,3
	PREPARATION FACILITIES	X		2
	STORAGE FACILITIES	X		2
	SPOIL BANKS	X	X	1,2,3
	SHIPPING AREAS	X		2
	EQUIPMENT	X		2,3
	SOIL BANKS	X	X	2,3
	ACTIVE RECLAMATION	X	X	3
	COMPLETED RECLAMATION	X	X	3
	IMPOUNDMENTS	X	X	1,2,3
	DRAINAGE DITCHES	X	X	2,3
	CULTURAL FEATURES	X	X	1,2
	UTILITY LINES	X		1,2
	STREAMS	X		1,2,3
MINE PROGRESS	X	X	2	
HEIGHT OF HIGHWALL	X	X	2,3	
OVERBURDEN ESTIMATES	X	X	2	
HAUL ROADS	X		2,3	
GEOLOGY	DIP ANGLE		X	1,2
	DIP DIRECTION		X	1,2
	MAPPING ROCK UNITS	X		1,2
	FRACTURE TRACE	X		1,2
	SURFACE LITHOLOGY	X		1,2
	SURFACE DEPOSITS	X		1,2
VEGETATION	SPECIES TYPE	X		1,3
	TREES/ACRE		X	3
	SPACING OF TREES		X	3
	NUMBER ROWS/SPECIES		X	3
	SIZE OF PLANTING		X	3
	PERCENTAGE OF COVER		X	3
	PERCENTAGE OF DEAD TREES		X	3
	DYING & DEAD VEGETATION	X	X	3
	VEGETATION DEC LINE	X	X	3
WATER	PONDS	X	X	1,2,3
	STREAMS	X	X	1,2,3
	SEEPS	X	X	1,2,3
	IMPOUNDMENTS	X	X	1,2,3
	STANDING WATER	X	X	1,2,3
	SEDIMENTATION	X		2,3
	YELLOWBOY (AMD)	X		1,2,3
	DRAINAGE DITCHES	X	X	2,3
SOILS	REFUSE	X		1,2,3
	STORED TOPSOIL	X		2
	REGRADED TOPSOIL	X		3
	SOIL TEXTURE	X		1,3
	SOIL COLOR	X	X	1,3
	EROSION CLASS	X		1,3
	SLOPE CLASS	X	X	1,3
	SLOPE ASPECT	X		1,3
	SILT COLLECTION AREAS	X		2,3
MINING PHASES	1 - PREMINING	2 - OPERATIONS	3 - RECLAMATION	

0 500 1000 1500 2000

SCALE IN FEET



AREA # _____ | _____ SITE # _____ | _____ FEATURE MAPPED _____

TEAM # _____ DATE _____

FIG. 12 BASE AERIAL PHOTOGRAPHY WITH GRID FOR GROUND DATA COLLECTION

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Three teams of two people each comprised the ground data collection teams. Each team was assigned two test areas. Generally one day was allotted to each test area for ground data collection. In addition, time was allocated for the teams to generally delineate and map features in the vicinity of the test areas. Various types of field data collection tools were utilized. These included abney levels, soil test kits, water test kits, range finders and brunton compasses. The ground data collection effort proceeded with only minor difficulties such as heat and rain encountered.

VII. DATA ANALYSIS AND INTERPRETATION

A. OBJECTIVES

The objectives of this task were threefold. The first objective was to organize the ground truth data into a format that could be easily compared with photointerpretation results. The second objective consisted of the actual photointerpretation. The final objective consisted of rating the interpretability of each feature and parameter. These three objectives represented a logical progression for evaluating the uses of aerial photography in the mining cycle.

B. METHODOLOGY

The problem of formatting the ground truth data for rapid comparison with interpreted results was partially solved by utilizing dual purpose data collection forms. As stated earlier, the elements of mining that were to be interpreted were divided into two broad categories -- those that need only be mapped or identified and those that could be measured by some basic photogrammetric technique. Data collection forms reflected this broad division of landscape features. Data collection forms were formulated for land use, vegetation, soils, water, and geologic mapping. Separate forms were also produced for land use, vegetation, soils, water, and geologic parameters to be measured.

Figure 13 is an example of the data collection form for mapped land use features. This form was taken into the field by the personnel collecting ground truth. The field crews would check "yes" if ground truth was collected for a specific feature. The location(s) of the features were noted by recording the grid coordinates of the field location photographs. In addition, the location and outline of features were delineated directly on the base aerial photograph. The remainder of the data collection form was used by the interpreters to record interpretability ratings.

Figure 14 is an example of measured land use data collection form. Measurements made in the field by the ground truth data collection teams were recorded directly into these forms. Measurements made by interpreters from the photographs were also recorded directly on these forms. This dual purpose data collection format simplified the comparison between ground truth and interpretation data.

CAMERA SYSTEM AREA/SITE NO.				FLIGHT INTERPRETER		LAND USE		
FEATURES	MEASURING UNIT	GROUND TRUTH		LOCATION	COLOR		COLOR IR	
		YES	NO		COMMENT	RATING	COMMENT	RATING
AGRICULTURE	MAPPED							
FOREST								
GRASSLAND/ FALLOW								
RESIDENTIAL								
ACTIVE STRIP PIT								
INACTIVE STRIP PIT								
ABANDONED STRIP PIT								
TREATMENT FACILITIES								

FIG. 13 INTERPRETATION ANALYSIS FORM FOR LAND USE MAPPING

CAMERA SYSTEM AREA SITE NO.				FLIGHT INTERPRETER				LAND USE	
FEATURES	MEASURING UNIT	GROUND TRUTH		LOCATION	COLOR		COLOR IR		
		YES	NO		COMMENT	RATING	COMMENT	RATING	
PREPARATION FACILITIES	MAPPED								
STORAGE FACILITIES									
SPOIL BANKS									
SHIPPING AREAS									
EQUIPMENT									
SOIL BANKS									
ACTIVE RECLAMATION									
COMPLETED RECLAMATION									

FIG. 13 INTERPRETATION ANALYSIS FORM FOR LAND USE MAPPING(CONT'D)

CAMERA SYSTEM AREA SITE NO.				FLIGHT INTERPRETER		LAND USE		
FEATURES	MEASURING UNIT	GROUND TRUTH		LOCATION	COLOR		COLOR IR	
		YES	NO		COMMENT	RATING	COMMENT	RATING
IMPOUNDMENTS	MAPPED							
DRAINAGE DITCHES								

FIG. 13 INTERPRETATION ANALYSIS FORM FOR LAND USE MAPPING(CONT'D)

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		CAMERA SYSTEM AREA/SITE NO.			FLIGHT INTERPRETER				LAND USE			
DISTANCES FROM MINING	PARAMETER	MEASURING UNIT	GROUND TRUTH		LOCATION	GROUND TRUTH DIMENSION	COLOR			COLOR IR		
			YES	NO			INTERPRETED DIMENSION	RATING	COMMENT	INTERPRETED DIMENSION	RATING	COMMENT
	BUILDINGS	FEET										
	CEMETERIES	FEET										
	PUBLIC ROAD	FEET										
	RAILROADS	FEET										
	UTILITY LINE	FEET										
	TRANSMISSION	FEET										
	PIPELINE	FEET										
	STREAMS	FEET										

FIG. 14 INTERPRETATION ANALYSIS FORM FOR PARAMETER MEASUREMENTS

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		CAMERA SYSTEM AREA/SITE NO.			FLIGHT INTERPRETER					LAND USE		
PARAMETER	MEASURING UNIT	GROUND TRUTH		LOCATION	GROUND TRUTH DIMENSION	COLOR			COLOR IR			
		YES	NO			INTERPRETED DIMENSION	RATING	COMMENT	INTERPRETED DIMENSION	RATING	COMMENT	
DISTANCES FROM MINING	CREEKS	FEET										
	WATER BODIES	FEET										
	PUBLIC PROPERTY	FEET										
	MINE PROGRESS	AREA IN FEET										
	MINE PROGRESS	DISTANCE TO RECLA- MATION FEET.										
	SPOIL BANK	PEAK WIDTH										
	SPOIL BANK	BANK AREA										
	SOIL BANK	PEAK WIDTH										

FIG. 14 INTERPRETATION ANALYSIS FORM FOR PARAMETER MEASUREMENTS (CONT'D)

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HERB. SINGER, INC.

		CAMERA SYSTEM AREA/SITE NO.			FLIGHT INTERPRETER				LAND USE		
PARAMETER	MEASURING UNIT	GROUND TRUTH		LOCATION	GROUND TRUTH DIMENSION	COLOR			COLOR IR		
		YES	NO			INTERPRETED DIMENSION	RATING	COMMENT	INTERPRETED DIMENSION	RATING	COMMENT
SOIL BANK	BANK AREA										
IMPOUNDMENT SIZE	SQ. FEET										
IMPOUNDMENT DISTANCE TO NEAREST DWELLING	FEET										
IMPOUNDMENT DISTANCE TO NEAREST STREAM OR POND	FEET										
IMPOUNDMENT DISTANCE TO NEAREST WELL	FEET										
IMPOUNDMENT DAM WIDTH	FEET										
IMPOUNDMENT DAM LENGTH	FEET										
DRAINAGE DITCH WIDTH	FEET										

FIG. 14 INTERPRETATION ANALYSIS FORM FOR PARAMETER MEASUREMENTS (CONT'D)

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Six interpreters were used to photointerpret each flight.* Each interpreter did two of the six test areas. Not all features were present on all of the test areas. Interpretations were made on photographic coverage outside of the six main test areas for some uncommon features such as cemeteries, transmission lines, coal preparation plants. It was necessary to do this to provide a statistical sample of photointerpretations of the uncommon features. Highwall heights and slopes were measured by three interpreters who possessed the stereoscopic vision capability necessary for using a parallax bar. Overburden removal estimates were tested in a similar manner because height determinations are part of the procedure.

Interpreters were provided with stereoscopic coverage of both the color and color infrared photographs for two test sites. Interpretations were made while viewing the photographs stereoscopically and/or with magnification. Measurements were made with basic photogrammetric instruments. The instruments that were used during the interpretation procedure consisted of the following:

- light table
- pocket stereoscope
- mirror stereoscope
- tube magnifier 7X
- tube magnifier 10-35X
- engineers scale
- parallax bar
- planimeter

Interpretations and ratings were recorded directly onto the data collection forms.

Throughout the photointerpretation effort each interpreter maintained a record of man hours spent interpreting in the three major categories of land use, vegetation, and water. For both color and color infrared photography a time record form was provided to the interpreters for this purpose. This data served as input into the statistical and economic analysis task.

* Each interpreter was not a skilled photointerpreter but was familiar with photointerpretation techniques and surface coal mining procedures.

Utilizing each film type separately, the interpretability of features and parameters were rated by the interpreters using a scale from zero to four.

- 0 - feature cannot be mapped
- 1 - feature can be mapped only with a large amount of difficulty and low accuracy (25%)
- 2 - feature can be mapped with minor difficulty and 50% accuracy.
- 3 - feature can be mapped with minimal difficulty and 75% accuracy.
- 4 - feature can be mapped easily with 100% accuracy.

Interpretability of each mapped feature was rated subjectively by each interpreter by comparing ground truth to the interpreted results and assigning a rating.

Ratings were assigned to the measured parameters in a quantitative manner. The difference between an interpreted measured value and a value obtained by ground truth measurements was expressed as % error. This % error was subtracted from 100 to find % accuracy. Percent accuracy was multiplied by 4 to convert to the same rating scale used for the mapped features. For example, if a slope is measured at 17.6° on the ground and the measurement from the photograph is 16.1° the difference is 1.5° or 8.5% error from the ground truth measurement. The accuracy is $100\% - 8.5\%$ or 91.5%. By multiplying $.915 \times 4$ a rating of 3.6 is obtained which is consistent with the zero to four rating scale which is used for mapped features. The ratings provided by the interpreters served as a major input into the statistical and economic analysis.

C. RESULTS

The interpretation results were tabulated and utilized to provide the data used to perform the economic statistical and economic analyses and to determine the aerial data applications for various aspects of the surface coal mining cycle.

VIII. AERIAL PHOTOGRAPHIC APPLICATIONS FOR SURFACE COAL MINING PROCESSES

A. INTRODUCTION

This section presents the interpretability results for each individual feature by seasons. Interpretation characteristics for each feature are discussed for both color and color infrared photography. The optimal season for interpretation is also discussed. The interpretability ratings and discussions pertain specifically to 1:12,000 scale photography. Identification accuracies and measurement accuracies will in most cases increase with larger scale photography or decrease with smaller scales. The reasons for the selection of the 1:12,000 scale were discussed in Section VI.

1. Interpreter Performance

The interpreters that were used throughout the study have various educational and experience background including geology, botany, geography, and soil science. Three of the six key interpreters had extensive past experience with aerial photographic interpretation. The other three interpreters had some basic experience with aerial photographs but they did not have any formal training in interpretation techniques and they were not experienced interpreters. All of the interpreters had basic knowledge concerning strip mining processes. Despite varied interpreter backgrounds and different levels of interpretation experience a statistical analysis showed no significant difference in interpretation accuracy among interpreters in the areas of land use, vegetation, water, and general soil characterization. Significant differences in interpretation accuracy and ability did occur in the areas of geology and soils typing. Our results indicated that significant amounts of training and extensive experience are necessary to accomplish geologic characterization and soils typing from aerial photographs. For this reason these two areas were evaluated separately by experienced interpreters with extensive backgrounds in geology and soils.

Interpretation accuracies increased slightly after the first flight was interpreted and then remained constant for the remaining six flights. Apparently familiarity with the area and the initial interpretation experience did have a slight effect between the first two flights. Interpretation experience did affect interpretation time. During the first few flights interpretation times of the less experienced interpreters were almost double the times of the experienced interpreters. For the sixth and seventh flights interpretation times did not vary significantly among interpreters.

The ability to measure heights on the photographs did vary significantly among the six interpreters. Three of the six interpreters possessed stereoscopic vision capabilities that enabled them to accurately measure heights with a parallax bar. The other three interpreters could see the three dimensional model when viewing stereo pairs with the stereoscope, but they could not maintain a fused dot when using a parallax bar. The ability to measure heights did not vary over the time length of this study.

B. AERIAL PHOTOGRAPHIC APPLICATIONS FOR PRE-MINE PLANNING AND MINE PROGRESS MONITORING

1. Introduction

This section presents interpretability results for features and parameters of pre-mine planning and mine progress monitoring. These include land uses and land covers for pre-mine planning and features that must be recognized for mine progress monitoring such as coal preparation facilities, coal storage facilities, shipping areas, mining equipment, impoundments, and drainage ditches. In addition, ratings for photogrammetric techniques necessary to monitor mine progress are presented in this section. These techniques include linear measurements, area measurements, highwall height measurements and overburden removed measurements. The remaining discussions in this section pertain to water, such as, drainage pattern mapping, standing water recognition, and yellowboy (iron oxide) identification.

2. Ratings for Pre-Mine Planning and Mine Progress Interpretability

The average rating obtained by the interpreters for selected features and parameters by season and film type are presented in Table 10 along with an overall average for all seasons. The methods for establishing these ratings are discussed in Section VII.

Some seasonal averages represent five or less observations because ground truth data was limited or because only a few examples of the feature were present on the test sites. These include overburden removed estimates (3 observations), cemeteries (4 observations), and preparation facilities (4 observations). For the remainder, the average number of observations for each seasonal average is 19.

The interpretability and interpretation characteristics for the selected features and parameters listed in Table 10 are discussed in detail in the following sub-sections.

a) Agriculture

Agricultural land use types, including pasture, row crops, and orchards were identified with accuracies ≥ 87 percent with both film types in spring, summer, and fall. Rows are the key identifier for row crops; they are visible even in grain fields on 1:12,000 photography. Pastures can be identified by the presence of grazing animals, the smooth texture, and the high reflectance in the green and infrared wavelengths. The high reflectance is caused by continuous grazing and cutting of pastures which stimulates fresh growth that appears bright green on color photographs and bright red on color infrared. Orchards are distinguished by the regular spacing of trees growing on cut grassland. Identification of agricultural land uses was slightly more difficult in winter.

b) Forest

This type of land cover is easy to identify and accuracies obtained by the interpreters were close to 100 percent. The feature is identified usually by texture and height. Native forests can be distinguished from older quality tree reclamation because trees on the reclaimed sites are usually a

	SUMMER		FALL		WINTER		SPRING		AVERAGE	
	COLOR	COLOR IR	COLOR	COLOR IR	COLOR	BLACK & WHITE	COLOR	COLOR IR	COLOR	COLOR IR
AGRICULTURE (MAPPED)	97.5	97.5	98.0	98.5	87.5	77.5	99.5	98.5	95.8	98.1
FOREST (MAPPED)	99.2	99.0	98.5	98.7	97.2	93.7	99.5	99.2	98.0	99.0
RESIDENTIAL (MAPPED)	97.5	98.7	98.0	98.2	97.2	91.2	97.5	99.0	97.5	98.5
ABANDONED STRIP PIT (MAPPED)	98.2	98.0	98.5	97.7	99.0	70.0	96.0	97.5	97.7	97.7
AREA MEASUREMENTS - AGRICULTURE, FOREST, RESIDENTIAL, ABANDONED STRIP PIT	95.2	96.3	97.3	97.0	95.7	90.0	98.1	98.1	96.5	96.4
UTILITY LINES (MAPPED)	75.2	79.0	75.0	83.0	74.2	87.8	77.7	80.5	75.5	80.7
TRANSMISSION LINES (MAPPED)	87.5	91.7	87.0	84.7	84.2	83.3	85.7	89.5	86.0	88.5
TRANSMISSION LINES - DISTANCE FROM ACTIVE STRIP PIT	96.1	91.2	93.4	96.1	94.1	87.4	95.4	90.2	94.7	92.5
ROADS (MAPPED)	96.7	97.7	97.5	95.5	98.2		96.2	98.7	97.0	96.5
ROADS (WIDTH)	99.6	98.9	96.2	99.1	97.1	73.5	88.7	92.5	95.4	96.8
CEMETERIES (MAPPED)	98.5	99.2	99.5	98.7	97.2	97.1	90.2	99.0	99.2	99.0
DRAINAGE PATTERNS (MAPPED)	75.5	79.2	91.0	97.2	97.7	87.2	75.2	77.7	86.0	84.7
PREPARATION FACILITIES (MAPPED)	99.5	99.7	99.2	99.7	99.5	99.3	99.7	99.7	99.5	99.5
STORAGE FACILITIES (MAPPED)	99.0	99.2	99.2	99.0	98.2	97.4	99.2	99.2	99.0	99.0
SHIPPING AREAS (MAPPED)	99.2	99.0	97.7	98.2	98.5	97.6	98.7	99.2	98.5	99.0
MINING EQUIPMENT (MAPPED)	76.7	82.5	75.0	85.2	80.0	71.3	80.7	90.0	79.0	85.7
IMPOUNDMENTS (MAPPED)	89.7	96.5	92.7	97.2	87.5	80.0	90.0	94.0	90.0	95.7
IMPOUNDMENTS (LENGTH)	80.0	95.0	90.0	97.5	91.2	81.2	88.7	90.0	87.5	94.1
IMPOUNDMENTS (WIDTH)	82.5	95.0	87.5	95.0	90.5	80.0	90.0	88.7	87.6	82.9
IMPOUNDMENTS (AREA)	87.5	95.0	95.0	95.0	92.7	90.2	80.0	81.2	88.8	90.4
DRAINAGE DITCHES (MAPPED)	78.0	79.7	70.0	80.0	81.2	72.5	83.5	82.5	78.7	82.2
DRAINAGE DITCH (LENGTH)	82.5	72.5	82.5	77.7	87.5	70.1	91.2	93.7	85.9	81.3
DRAINAGE DITCH (WIDTH)	50.0	67.5	52.5	70.0	54.2	47.2	56.2	60.0	53.2	65.8
PUDDLES (MAPPED)	80.5	82.2	80.2	83.5	75.0	69.1	80.0	91.2	78.7	86.5
YELLOWBOY (MAPPED)	78.7	85.2	90.5	82.5	66.7	42.3	92.7	80.7	86.5	82.7
SLOPE MEASUREMENTS ²	87.7	---	92.5	---	90.5	---	91.5	---	90.7	---
HIGHWALL HEIGHT ²	94.0	---	92.2	---	89.5	---	95.2	---	92.7	---
OVERBURDEN REMOVAL ESTIMATES ³	---	---	---	---	---	---	80.2	---	---	---
ACTIVE RECLAMATION (MAPPED)	85.5	96.5	97.7	96.7	97.5	92.3	95.5	97.7	96.6	97.7
COMPLETED RECLAMATION (MAPPED)	90.5	85.2	85.7	90.0	85.2	81.2	92.7	92.5	88.5	89.2
REFUSE MATERIAL (MAPPED)	92.7	96.0	92.0	93.0	94.7	89.7	92.7	96.0	93.0	95.0
TOP SOIL PILES (MAPPED)	95.2	86.5	94.0	92.7	87.5	84.1	94.7	90.0	93.0	89.7
TOP SOIL, REGRADED (MAPPED)	86.5	87.7	88.2	89.5	85.2	81.3	85.0	88.5	86.7	88.5
SPOIL PILES (MAPPED)	88.0	85.2	88.5	89.2	87.7	88.4	90.5	97.0	89.0	93.7
SPOIL, REGRADED (MAPPED)	82.7	85.2	88.0	90.2	86.7	83.8	90.7	92.7	87.0	89.6
AREA MEASUREMENTS - ACTIVE RECLAMATION, COMPLETED RECLAMATION, REFUSE MATERIALS, TOP SOIL PILES, REGRADED TOP SOIL, SPOIL PILES, REGRADED SPOIL	91.2	93.1	94.7	95.1	93.2	89.9	89.2	91.3	92.0	93.0
RILL EROSION (IDENTIFICATION)	79.0	80.2	81.7	81.0	80.2	74.2	80.7	83.5	80.5	81.5
GULLY EROSION (IDENTIFICATION)	92.7	91.2	94.7	92.7	91.7	86.3	93.5	92.5	93.2	92.2
SHEET EROSION (IDENTIFICATION)	61.7	57.7	57.7	56.0	53.5	52.3	58.0	60.5	57.7	59.5
RILL EROSION (LENGTH MEASUREMENT)	85.5	79.2	83.2	81.7	83.2	89.4	85.2	83.0	84.2	81.2
GULLY EROSION (LENGTH MEASUREMENT)	85.7	80.2	86.7	85.5	87.7	83.2	87.2	81.5	87.0	82.5
RILL EROSION (WIDTH MEASUREMENT)	50.2	54.2	49.2	52.5	52.7	40.9	50.7	49.0	50.7	52.0
GULLY EROSION (WIDTH MEASUREMENT)	66.7	67.7	83.0	85.2	61.7	57.5	84.5	65.2	64.0	66.0
RILL EROSION (DEPTH) ²	22.7	---	10.5	---	8.5	---	17.7	---	16.6	---
GULLY EROSION (DEPTH) ²	21.1	---	8.0	---	11.7	---	23.0	---	16.2	---
CONIFEROUS TREE IDENTIFICATION	75.0	92.5	88.7	97.7	87.0	70.1	57.5	84.0	77.0	91.0
DECIDUOUS TREE IDENTIFICATION	77.5	89.2	89.2	98.2	88.0	89.4	78.2	82.5	83.2	80.0
RECLAMATION SPECIES IDENTIFICATION	84.0	92.0	85.0	92.5	58.2	67.4	77.5	86.7	90.4	75.6
LEGUMES IDENTIFICATION	79.2	80.2	82.5	79.2	50.0	74.1	75.2	77.7	71.7	79.0
TREES/ACRE MEASUREMENT > 18" CROWN DIAMETER	78.5	80.2	82.7	79.2	76.0	71.2	79.5	85.5	79.2	81.7
PERCENT COVER GRASSES & LEGUMES	80.5	79.5	81.2	80.0	30.2	26.4	82.0	81.7	68.5	80.5
VEGETATIVE VIGOR	50.2	54.2	50.0	30.2	---	N/A	45.5	48.5	48.5	50.7
VEGETATIVE DISTURBANCE (ACIDITY/SEDIMENT)	79.2	90.5	53.2	60.2	---	N/A	78.7	87.2	69.7	79.2

1. LOW SUN ANGLE PRECLUDED THE COLLECTION OF COLOR IR IMAGERY IN WINTER, HOWEVER, BLACK AND WHITE IMAGERY WAS COLLECTED AND INTERPRETED.
2. MEASUREMENTS WITH THE PARALLAX BAR WERE ONLY CONDUCTED WITH COLOR IMAGERY.
3. OVERBURDEN REMOVAL ESTIMATES WERE ONLY DONE DURING ONE SPRING SEASON BECAUSE GROUND TRUTH DATA SUPPLIED BY COOPERATING COAL OPERATORS WAS ONLY AVAILABLE DURING THIS SEASON.

TABLE 1Q AVERAGE % ACCURACIES FOR SELECTED PRE-MINE PLANNING, RECLAMATION, AND MINE PROGRESS FEATURES AND PARAMETERS

monoculture or strips of monocultures planted on a regular spacing, therefore, the canopy appears very regular and even on aerial photography seasonal differences in accuracies are minimal and both film types work equally as well.

c) Residential

Residential units were identified with accuracies \geq 97 percent with both film types over all seasons. The features which indicate that a building is a residence are garages, lawns, and driveways. The test sites were almost totally rural and very few business buildings were present on the test sites. Because of the lack of businesses in the study areas the 97 percent accuracy is probably inflated and lower accuracies would be anticipated in less rural areas.

d) Abandoned Strip Pit

This parameter was identified with accuracies \geq 96 percent for all seasons with both film types. The key identifier is the presence of the old highwall and pit with no mining machinery present. Spoil piles are also usually present, but they may not be visible because of dense tree cover. Most old abandoned strip mines in the test areas are contour mines and they have the distinctive "snake" shape. Most of the spoil piles have 0-50 percent vegetative cover.

e) Utility lines

Utility lines were identified and mapped with accuracies \geq 75 percent. The actual lines are too small to see and the vertical view of the utility pole is just barely visible at 1:12,000 scale. The key feature used to identify utility lines is the shadow cast by the utility poles. When pole shadows are cast onto fields or highways they are obvious; however, shadows cast in forested areas are not visible. Color infrared photography is slightly better for this purpose because shadows are more distinct on this film type.

f) Transmission Lines

Transmission lines were mapped with accuracies of ≥ 84 percent over all seasons with both film types. The key identifier is the cleared right-of-way through forested areas with steel towers which are visible at 1:12,000 scale and 1:24,000 scale

g) Roads

Roads are obvious features on aerial photographs. They can be distinguished because of their long linear shapes. Paved roads can be distinguished from unpaved quite easily. However, it can be difficult to determine if unpaved roads are private or public. Old haul roads to abandoned mines were quite visible, however. These roads were being traveled by four wheel drive vehicles which helped prevent vegetation establishment. Roads were identified with accuracies of 95 percent or greater over all seasons with both film types.

h) Cemeteries

Cemeteries were identified with accuracies ≥ 95 percent over all seasons with both film types. The key feature used to identify cemeteries in the presence of the evenly spaced rows of tombstones.

i) Drainage Patterns

The interpretability of drainage patterns was found to vary with the seasons. Accuracies after leaf drop in fall and winter average ≥ 95 percent. In spring and summer accuracies average 77 percent. There is no significant variation between film types. Stereo viewing is absolutely necessary to map drainage features. Intermittent small streams and drainage channels are difficult to see but their presence can be inferred by noting slope aspect and low areas when viewing photographs in stereo. The microtopography is more visible in fall and winter when vegetation is dormant, and this facilitates the mapping of drainage patterns.

j) Preparation Facilities

These were identified with almost 100 percent accuracy in every season with both film types. The presence of covered conveyor belts, settling ponds, and the distinctive shape of crusher/washer buildings are key identifiers.

k) Storage Facilities

Storage areas were identified with near 100 percent accuracy in all seasons with both film types. The distinctive features are the coal piles. Often diversion ditches and treatment ponds are present for water runoff.

l) Mining Equipment

Mining equipment was identified with an average accuracy of 82 percent for both film types over all seasons. Drills, draglines, haulage trucks, bulldozers, front-end loaders, pans, and scrapers can all be identified. Scrapers and pans appear similar and are sometimes confused. Some models of bulldozers and front-end loaders also appear similar on the vertical view.

m) Impoundments

Mining related impoundments were identified with accuracies \geq 87 percent with both film types over all seasons. Accuracies were slightly better with color infrared photographs. Identification features include the rectangular shape and the earth breastworks which are usually quite visible.

n) Drainage Ditches

Drainage ditches were identified with slightly better accuracies on the color infrared photographs. Accuracies averaged 78 percent for color photography and 82 percent with color infrared photography. Drainage ditches were slightly easier to identify when they were wet; therefore, identification on spring photographs is slightly better. Small drainage ditches (< 1 ft. wide) made by a single tine deep bottom plow were

difficult to recognize unless the sun angle caused a shadow in the ditch. The key identifier was the thin linear shapes parallel to the contour of slopes.

o) Puddles

When present puddles larger than 3 ft in diameter were identified with accuracies of ≥ 75 percent on both film types throughout all seasons. Puddles are quite common features on reclaimed strip mines. They sometimes become acid drainage collection areas. Many puddles are transitory features that evaporate in dry periods. On color photography puddles can be recognized by their tan color and smooth texture. On color infrared the color is light blue.

p) Yellowboy

Yellowboy (iron oxide precipitates) in water bodies was identified with good accuracy on color photography from the spring and summer seasons. Accuracies ≥ 92 percent were obtained. Accuracies with color infrared were somewhat lower, ≥ 85 percent for the spring and summer season. Color infrared photography is less effective than color photography because it does not penetrate water very well and yellowboy is a bottom phenomenon. Yellowboy displayed an interesting seasonal variation. During the summer the yellowboy appears bright orange on color photography and lime green on color infrared. During spring and fall the yellowboy color is a brownish orange on color photography and green blue on color infrared. In the winter evidence of yellowboy almost disappears in most water bodies. When it is visible in the winter it is a brown color with just a slight hint of orange on color photography. Accuracy of identifying yellowboy on color photography collected during the winter season dropped to 66 percent. The reasons for the lower visibility of yellowboy in winter could not be completely determined. In streams the visibility is partially dependent on water level. Bottom visibility is less during high flow periods because the water is deeper and contains more sediment which partially screens stream bottoms. However, some large acid seeps appeared bright orange on the summer photographs and lost the orange color in winter even though flow remained constant. This

indicates that other factors are active in determining the visibility of yellowboy. It is possible that some temperature dependent chemical reactions are partially responsible for the color changes. If the visibility differences between winter and summer are temperature related the seasonal visibility difference will probably diminish in the southern Appalachian states.

q) Linear Measurements

Linear measurements such as distances from strip pit to buildings, roads, houses, and streams, and length of drainage ditches, etc. were measured with accuracies ≥ 75 percent with both film types over all seasons. Measurements were made with an engineers scale. In areas where the terrain slopes are $35-40^{\circ}$ errors for linear measurements on unrectified photographs will be between 10-20% because of the geometry of a vertical view and scale changes caused by terrain height differences.

r) Area Measurements

Area measurements of spoil banks, regraded areas, impoundments, etc. were measured with accuracies ≥ 93 percent with both film types over all seasons. Measurement accuracies were obtained only after features were positively identified. Area measurements were made with a polar planimeter. Errors can be large when the boundaries of the area being measured is not distinctly visible. The border between ungraded and graded spoil is often nebulous. Water body boundaries such as impoundments are distinct especially on color infrared photography.

s) Highwall Height

Highwall heights were measured with a parallax bar. Accuracies ≥ 89 percent were obtained with color photography. Highwall heights were difficult to measure when the highwall shadows fall across the bottom of the pit. For this reason height measurements were less accurate in winter because the low sun angle increases the likelihood of shadows in the pit. Height measurements were not made on color infrared photography because of the difficulty of marking principal points and conjugate principal points.

t) Volume Estimates

Volume estimates for spoil piles, coal stock piles, stored top soil piles and overburden removed were derived by manual photogrammetric techniques from the color aerial photography. Accuracies for spoil piles, stored topsoil, and coal stock piles were very poor. However, overburden removed estimates were accomplished with an average accuracy of 90 percent with spring photography. This type of measurement was only conducted during the spring season because ground truth was available from the mining company only at this time.

u) Soils Typing

Soils typing consists of determining which soil series a particular parcel of soil belongs in based on the 7th approximation soil classification system currently in use in the United States. The taxonomic properties used to classify soils are zonation, clay and mineral content, particle size, temperature regime, depth of soil, moisture, and color. Almost all of these characteristics must be known for a particular soil before that soil can be classified. Many of these characteristics cannot be determined from aerial photographs. For this reason soils typing from aerial photographs is always done in conjunction with ground truth data.

The process that was used for soils typing in this study is similar to the soil mapping method used in the Soil Conservation Service (SCS) county offices throughout the United States. Ground truth was collected at scattered points throughout the area to be mapped. The ground truth consists of the soils characteristics listed above. The soils at the sampling points are classified based on the characteristics.

The sampling points were located on the aerial photography. Boundaries were drawn around the soils types during the photointerpretation process. The boundaries are drawn based on vegetative patterns, knowledge of

the types and location of rock units, drainage patterns, slopes, and land use. This is an extremely difficult task for interpreters without soils training and experience with soils mapping.

Our interpreters without soils mapping experience could not delineate the soil types on the aerial photographs. Spring and summer photography was used because vegetative patterns are more visible during these two seasons. Our experienced interpreter, who had worked for SCS, could produce soil maps similar to the maps already produced by SCS. Maps produced from black and white, color, and color infrared photographs were all similar; however, the interpreter preferred color photography because vegetative patterns are easier to see on color photography.

Soils mapping is difficult and time consuming. In the eastern United State SCS has already produced soils maps for most of the counties that have strippable reserves.

v) Geology

The use of aerial photography to obtain qualitative and quantitative geologic information is termed photogeology. Detailed analysis of stratigraphy, hydrology, or geomorphology generally requires professional training in geology, although a skilled photo interpreter lacking formal training in geology may develop proficiency in identifying certain geologic features from aerial photography. In eastern United States the lush vegetative cover and relatively thick soils tend to mask many geologic features and even make ground geological reconnaissance somewhat difficult. However, it is possible to observe certain geologic features and these will be discussed.

Drainage patterns can be used as rough indicators of the types of rock units present. Major streams and tributaries may be constructional (responsible for the deposition of the land form) or destructional (erosive agents). Destructional tributaries and streams reflect the character and structure of underlying rock units. By analyzing the density and geometric shape of drainage patterns with aerial photographs an experienced photogeologist can make broad generalizations about the underlying rock units (e.g., shale, limestone-shale, sandstone-shale, etc.).

Basic rock types in the region were determined to be shale with some sandstone present. This was inferred from drainage pattern analysis. The results were the same for all three film types. The drainage pattern analysis was easier with winter photography because small tributaries and gullies are more visible after deciduous tree leaf drop.

Structural geologic features such as faults and anticlinal and synclinal structures may be observed on aerial photography with some proficiency. For example, an offset in a ridge or change in elevation across a linear feature of fracture track is a good indication of faulting. It is possible to plot anticlinal and synclinal axes and estimate dip angle. Identification of these features can be an aid in exploration and mine planning.

Mapping lithologic units or geologic formations can be accomplished from aerial photography. Changes in slopes or benches along a hillside that can be traced along a ridge or across a valley are valuable aids in mapping certain rock units.

Sometimes marker beds may outcrop fairly consistently throughout an area and if the rock units that occur above and below this bed are known, the bed can be used to map the rock units above and below. In areas where abandoned mined lands are numerous, the old highwalls can often be used as marker beds.

The mapping of lithologic units, specifically coal seams, was attempted on 1:24,000 black and white, color, and color infrared. This mapping was extremely difficult because soil and trees cover the rock units on the test sites. Numerous abandoned strip pits were used as marker beds because breaks in slope did not occur at coal outcrops. The coal outcrops maps made from aerial photographs were similar to maps prepared by the mining company. The maps were the same with all three film types. No seasonal differences were noted because outcrops are covered by soil. Dip of coal beds was calculated and the values were within 90% of the values calculated from maps provided by the mining company.

Fracture traces as seen on aerial photographs are the linear surface expression of a zone of high fracture or joint density in the underlying rocks. Linear features, undetected by the ground observer, may be conspicuous on aerial photography. Fracture expression on aerial photography may appear as tonal variation in soils, vegetation alignment, straight segments of stream courses, or differential solar illumination. Fractures, especially intersection of two fracture traces, in rocks provide excellent conduits for water and, therefore, may be an indication of possible stability problems if disturbed.

Fracture traces were mapped by an experienced photogeologist using black and white, color, and color infrared photographs. The fracture trace patterns were similar on all three film types; however, more fracture traces were noted on color infrared photographs. Accuracies could not be determined because fracture traces are usually not evident on the ground.

Solifluction lobes are tongue shaped features resulting from the slow down-slope movement of waterlogged soils. Solifluction lobes have a steep front and relatively smooth upper surface. These lobes serve as an expression of more rapid movement on certain parts of the slope as a result of either change in gradient or moisture content of the soils. Again, if the lobe is disturbed, slope stability problems may arise.

Solifluction lobes, colluvial deposits, faults and synclinal/anticlinal structures were not present on the test sites.

Colluvial deposits is a general term applied to loose heterogeneous material or incoherent masses of soil and rock fragments usually deposited at the base of steeper slopes. The colluvium is deposited by unconcentrated surface runoff or sheet erosion and may form fan shaped features or simple buildup of material at the bottom of slope that may be identified on aerial photography. These deposits may be several feet thick and cause stability problems.

Photogeologic results were similar with all three film types; however, the interpreter expressed a preference for black and white photographs because he felt varied color tones can be distracting. Winter season is the best because there is less vegetation to obscure geologic features and indicators. A scale of more synoptic view than larger scales, the 1:48,000 scale presents a good regional picture, however, some small features were not visible on this scale.

C. AERIAL PHOTOGRAPHIC APPLICATIONS FOR RECLAMATION PLANNING AND MONITORING

1. Interpretability Ratings for Reclamation Features and Parameters

The average ratings obtained by the interpreters for reclamation features by season and film type are presented in Table 10.

A minimum of twelve data points was used to derive the seasonal interpretability averages in most cases. Some seasonal averages are represented by as many as 40 data points and a few averages were obtained with less than twelve points. The average number of data points used to compute the reclamation ratings is 23. Features that were identified or parameters that were measured with less than 75 percent accuracy in any season are not discussed individually in following sections.

2. Discussion of Reclamation Features and Parameters

a) Active Reclamation

Active reclamation, (including backfilling, grading, and planting) was recognized with a 95 percent accuracy or greater in all seasons. Key identification features include machinery for grading and planting, and tracks left by this machinery in the soil or spoil. Ease of identification is uniform throughout all seasons. The separate steps of backfilling, grading, topsoiling, and planting can be recognized on the aerial photography. Features can be identified and their parameters measured with the same accuracy on both color and color infrared photography.

b) Completed Reclamation

Completed reclamation was recognized by the interpreters with an 85 percent accuracy or greater for all seasons and film types. No seasonal trends were noticed in the identification. The shape of the area is a key identifier. Contour mine reclaimed sites are long narrow shapes parallel to ridge tops. Area mine reclaimed sites are usually more irregular in shape

than fields and pastures. Straight fence rows and boundaries are often absent. Older reclaimed sites with invader weeds and shrubs are often confused with fallow fields of irregular shape. Light soil tones and smooth texture are usually indications that topsoil has been spread, and reclamation is near completion. However, it is difficult to determine if revegetation has occurred until vegetation with a uniform height distribution appears. Identification accuracies were similar with both color and color infrared photography. In general, the interpretability of completed successful reclamation decreases with age of the reclamation work after the first two or three growing seasons.

c) Coal Refuse Material

Coal refuse material was identified with a 92 percent accuracy or greater with both film types and in all seasons. Refuse is the black "fines" washed out of the coal at the preparation plant. In drying beds it is easy to recognize because of the black color and flat appearance when viewed stereoscopically. Refuse is usually disposed of in the bottom of strip pits. The refuse is usually dumped from the top of a highwall. This operation is easy to recognize because it is not similar to other mining operations. Refuse is sometimes confused with shadows at the bottom of the pit.

d) Topsoil Piles

Topsoil piles were recognized with an accuracy of ≥ 86 percent in all seasons with both film types. They are identified by the rectangular shape of the pile composed of a material with a lighter color than the surrounding spoil. During the growing season the storage piles are usually covered with weeds, or seeded annuals. Plant cover slightly increases interpretation accuracy when topsoil is stored in unvegetated areas and slightly decreases the accuracy when topsoil is stored in vegetated areas.

e) Topsoil, Regraded

Regraded topsoil was recognized with an accuracy ≥ 85 percent for all seasons and film types. The color of the topsoil is usually lighter than spoil and the surface is much smoother than regraded spoil. The tonal differences between spoil (usually darker) and topsoil (usually lighter)

is enhanced on color infrared photography. If spoil and topsoil are the same color the smooth texture of the topsoil is the key indicator. This relationship between tone and texture of spoil and topsoil is generally the same throughout the Appalachian coal region.

f) Spoil Piles

Spoil piles were identified with an accuracy ≥ 87 percent of all seasons and film types. The dark tones, rough texture, and proximity to the pit are key identifiers. In addition, the curved adjacent piles typical of a dragline operation are unmistakable.

g) Spoil, Regraded

Regraded spoil was identified with an accuracy ≥ 82 percent with all film types and seasons. The tones are darker than regraded topsoil and the surface is usually quite rough. Dozer tracks and blade marks are usually very visible and large rocks can be present.

h) Rill Erosion (identification)

Rill erosion was identified with an accuracy ≥ 79 percent. Rill erosion appears as groups of very fine parallel lines on moderately steep slopes. Rill erosion is not wider than 6 inches. Very often rills widen into gullies at the mid and lower sections of a slope. There is much confusion between gullies and rills if the gullies are small (6-12 inches wide). Identification of rills is easier if they are wet. However, no real seasonal identification differences were found.

i) Gully Erosion (identification)

Gully erosion was identified with an accuracy > 90 percent for all seasons with both film types. Gullies are larger than rills and are not necessarily in groups. Large gullies are unmistakable and can be identified with 100 percent accuracy.

j) Sheet Erosion

Sheet erosion is not very visible on aerial photography at this scale. Sediment build-up at the bottom of slopes with no rill or gully erosion is evidence that large amounts of soil are being moved by sheet erosion. This sediment is usually fine textured and lighter than the surrounding topsoil. The effects of sheet erosion are visible only when large amounts of soil moved by this process accumulate in an area visible on the photograph. In such cases an interpreter can indicate with 100 percent accuracy that sheet erosion is occurring on unprotected soil.

k) Length Measurements - Rill & Gully Erosion

Rill erosion measurements were made with accuracies ≥ 79 percent for all seasons with both film types. Gully erosion length measurements were made with accuracies ≥ 82 percent with both film types over all seasons. Measurements were made with engineers scales, and errors occurred largely because the starting points for the erosion channels are sometimes difficult to identify.

l) Width Measurements - Rill & Gully Erosion

Larger gullies (> 5 ft wide) were measured with acceptable accuracies (> 75 percent), however, smaller rills and gullies could not be measured with acceptable accuracies on either film type during any season.

m) Depth Measurements - Rill & Gully Erosion

Depth measurements could not be accurately made with either film type.

n) Coniferous & Deciduous Tree Identification (Reclamation Plantings)

Trees with crowns under 18 inches in diameter cannot be identified very well individually on either film type. Conifers > 3 ft tall can be distinguished from deciduous species by the former's regular conical shape.

In the fall and winter coniferous species were identified with an accuracy ≥ 87 percent because except for larch they retain their foliage. No significant difference was noted between film types for the fall season. During summer and mid to late spring identification accuracies on color photography are low because color differences between deciduous and coniferous species are minimal and only shape can be used as an identifier. On color infrared photography spring and summer identification accuracies were ≥ 84 percent because on the color infrared transparencies coniferous species appear in hues of purple and magenta while the deciduous species are more bright red. This relationship decreases toward the end of summer, and by fall all trees appear about the same; however even then some discrimination (at lower accuracies) is possible because the crowns of deciduous trees appear to be irregular and "fluffy" while still in leaf.

o) Reclamation Grasses & Legumes Identification

On color photography grasses generally appear in lighter shades of green than legumes which are dark green in late spring through late summer. Late summer appears to be the optimum time for determining if legumes are present in grass mixtures on reclaimed areas. At this time the grasses have gone to seed and appear on color photographs in shades of tan while the legumes still retain a dark green appearance. On color infrared the legumes are a bright magenta color in the fall which can be distinguished from the grey-purple hues of the grasses. During the spring and early summer grasses and legumes are hard to distinguish with both film types unless the legumes are concentrated in almost pure stands. When this occurs legumes appear much darker than the surrounding grasses on both color and color infrared photography. Accuracies for identifying legumes and grasses in late summer and early fall are ≥ 79 percent with color photographs and ≥ 89 percent with color infrared photographs.

p) Trees/acre Measurements

This parameter was measured with an accuracy ≥ 76 percent for all seasons with both film types. Coniferous trees and deciduous trees in leaf must be at least 18 inches in crown diameter to obtain this accuracy.

Inaccuracies occur in dense deciduous tree plantings because individual trees are difficult to distinguish. When individual trees are visible accuracies are close to 100 percent. Small deciduous trees are difficult to see during the winter season after leaf drop.

q) Percent Cover, Grasses & Legumes

Percent cover for grasses and legumes was estimated from the aerial photographs by comparing areas with unknown percent cover to a percent cover key. The percent cover key is comprised of portions of aerial photographic images of grasses and legumes with known percent cover. The known percent covers on the key represent 0, 25, 50, 75, and 100 percent cover. By placing this key alongside areas on a photograph of unknown percent covers, interpreters were able to classify the unknown areas into one of four categories, 0-25, 25-50, 50-75, or 75-100 percent cover. Accuracies were ≥ 80 percent with all film types during spring, summer, and fall. Winter accuracies were very poor. Both film types worked equally well for measuring this parameter.

r) Vegetative Vigor

Chronic symptoms of toxicity caused by acidity and certain free ions in the root media were visible on the leaves of grasses and legumes, however, these symptoms were not manifested in the tonal variations on either the color or color infrared photography. The best indication of vigor was the annual increase in percent cover. In an area which remains static with no percent cover increase the vegetation is generally of low vigor. In tree plantings the percent dead or missing trees is an indication of vigor, however this percentage can only be obtained from an aerial photograph when trees are planted in rows with regular spacing.

s) Vegetative Disturbance Caused by Acidity and Sedimentation

Vegetative decline caused by the sudden appearance of acid seeps or sediment build-up from erosion can be identified quite easily. Reclamation species have high tolerances to acidity problems and respond to low pH situations with static or declining growth patterns. This type of acidity problem can be

difficult to determine from aerial photography. Natural vegetation adjacent to mining areas is typically intolerant of low pH situations and when a sudden acid influx occurs in these areas destruction of plants occurs which is visible on aerial photography. This is especially easy to see when the affected vegetation is comprised of deciduous trees. Dead grasses and legumes affected by sudden increases of acidity are dark brown to black on both color and color infrared aerial photography.

When trees are affected by acidity, sedimentation, or both the dead leafless trees are easily visible on aerial photographs. It is not possible to determine if the tree damage is a result of sedimentation or acidity. The symptoms and effects of sedimentation and acidity appear similar on the aerial photography and observations were made of damage areas where the sediment was visible on the aerial photography but the actual damage was caused by acid waters that carried the sediment to that location. Living trees bordering an affected area may display autumn colors of red or yellow even in early spring. Border trees may also have fewer leaves than healthy trees.

Vegetative decline and damage to grasses, legumes, and trees were recognized with an accuracy ≥ 87 percent with color infrared photography collected in the spring and summer. The accuracy for color photography during the same seasons was ≥ 76 percent.

t) Slope Measurements

Slope measurements were made only on color photography because principal points and conjugate principal points are difficult to mark on transparencies. Horizontal measurements were made with an engineers scale

and vertical measurements were made with a parallax bar. The average accuracy for slope measurement was greater than 90 percent.

D. CONCLUSIONS

The features and parameters discussed in parts B and C represent some of those features which can be identified and mapped with a minimum amount of training and technical background. Most of the identification and measuring accuracies are ≥ 75 percent. These features represent a majority of the total number of features tested in this study (Appendix B). The data collection and interpretation costs for one flight with color photography collected at a scale of 1:12,000 over one square mile amounts to 3.7 cents per ton of coal if all the features and parameters discussed above are interpreted (Assuming: three foot coal seam mined with 85 percent recovery, \$8.00 hourly rate for interpreter, 1977 data collection costs). The cost per ton is less when larger areas are involved because aerial data collection costs per square mile decrease as photographic coverage increases when the same camera and lens focal length are used.

Some seasonal considerations must be made when attempting to monitor vegetation, features covered by vegetation, highwall height, and yellowboy. All other features discussed in parts B and C above can be monitored effectively throughout the year.

Some seasonal considerations are due to sun angle. In areas north of 40° North latitude during the months of November, December, and January there is less than 30° maximum solar altitude and shadows occur on aerial photographs taken during this time. This same effect occurs when aerial photographs are taken in early morning or late afternoon during spring, summer, and fall. Some features like geomorphology are enhanced by low sun angle and shadows. However, most of the features discussed in parts B and C are not enhanced by shadows. In fact, many features may be obscured by shadows. Low sun angles are not desirable for most features related to strip mining.

Linear and area measurements from 1:12,000 color and color infrared aerial photography can be made with good accuracies if the features being measured are visible and not located in terrain with large relief differences. Photographs can be rectified (rectification is the process of removing the effects of relief, tilt, dip, and other distortions that can occur on aerial photographs). Linear and area measurements made on rectified photographs are extremely accurate, usually within 1-2 percent of actual ground measurements. However, complete rectification is only done with black and white photography and the cost is between \$100 and \$200 per photograph. Rectification for just tilt and dip of the camera when the photograph was taken costs \$50 for a single photograph. The cost decreases to around \$20 per photograph when a large number of photographs are rectified for tilt and dip. Rectification is not cost-effective for the mining parameters discussed above. If extremely accurate measurements are needed ground measurements are usually more cost effective.

Features relating to geology and soils typing must be interpreted by personnel with extensive training in the fields of geology and soils. The geologic and soils interpretations made by our interpreters who were not trained in these fields were very inaccurate and improvements were minimal throughout the course of the study.

The results indicate that aerial photographic techniques are effective methods for obtaining pre-mining information pertaining to land use, land cover, surface drainage, roads, utilities, and residential unit locations. Mine progress including area measurements and overburden removal estimates can be monitored accurately. In addition reclamation progress and effectiveness can be evaluated by identifying and mapping regraded spoil, regraded soil, planting, reclamation vegetation types, erosion and percent cover. Because of low costs of aerial photography, and the large amounts of information available from the photography, mine operators should utilize aerial photographs to meet their information needs.

IX. STATISTICAL AND ECONOMIC EVALUATIONS

A. OBJECTIVES

The objective of this phase was to perform an economic evaluation of the operational use of color and color infrared aerial photography for the following purposes:

- Pre-mine planning
- Monitoring the revegetation aspect of reclamation
- Monitoring all aspects of the reclamation process
- Monitoring the entire mining process from planning to release of bond following reclamation.

B. METHODOLOGY

In order to perform an economic evaluation of the operational use of color and color infrared aerial photography, a cost-effectiveness model had to be developed. The model was developed in three steps: 1) information required was defined^{a)}; 2) the method of data collection was specified, for example, the accounting of costs for each type of aerial data collection and time spent for photointerpretation for each type of data collection was determined; and 3) the quantitative measures of cost-effectiveness for evaluating the performance of alternative methods of aerial data collection for mine planning and reclamation monitoring were developed. The measure of cost-effectiveness for the evaluation of each technique of aerial data collection and interpretation was based on the variance of interpretability ratings of color and color infrared photography for producing the relevant data and a cost function for each film type based on both collection and interpretation costs.

The equations^{b)} for calculating the variance and mean of the estimator for each type of aerial data collection and interpretation are specified

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- a) Information required is discussed in Section VI, Data Collection, and Section VII, Data Analysis & Interpretation.
- b) The estimation of the variance of the estimator of operational performance (expressed in interpretability ratings) is based on the theory of simple random sampling. This appears realistic because a photograph for a site consists of a population of land use, vegetation and water parameters. Each parameter category has an equal chance or probability of being delineated by the interpreter in deriving the ratings.

in equations (1), (2) and (3). The specification and definition of the applicable cost function to derive the effectiveness criterion for rating the efficiency of the operation performance of each type of aerial photography follow in equation (4).

Interpretability ratings for mining related features and parameters are represented by the following symbols:

X_{ic} - interpretability ratings for mining related subjects from color photos
 X_{icIR} - " " " " " " " color infrared
 X_{iBW} - " " " " " " " black & white photos

Then the mean and variance of the ratings for each type of photograph are equal to

$$\bar{X}_j = \sum_{i=1}^N X_{ij} / N \quad (1)$$

$$Sx_j^2 = \sum_{i=1}^N (X_{ij} - \bar{X}_j)^2 / N-1 \quad (2)$$

$$V(\hat{u}_j) = Sx_j^2 / n \quad (3)$$

where

(i = 1, 2 N number of features and/or parameters in a category)

(j = represents film types, 1 for color; 2 for color infrared and 3 for black and white

\bar{X}_j is an estimate of the population mean (\hat{u}_j) of interpretability rating for mining related subjects per site

Sx_j^2 is an estimate of population variance per site

$V(\hat{u}_j)$ is an estimate of the variance of \hat{u}_j (simple random sampling estimator) for all sites included in the study.

n is number of sites included in the study in square miles.

The cost function applicable for each j method of data collection and interpretation is expressed in equation (4) below.

$$TC_j = CO_j + n (CD_j + CI_j) \tag{4}$$

where

TC_j is total cost for each method

CO_j is total fixed cost which is equal to cost of flight mobilization for this analysis, in dollars.

CD_j is total cost of data collection which includes the cost of flying time and film processing, in dollars.

CI_j is total cost of interpretation derived from time expended (average of six interpreters) in identifying features and measuring parameters from the photograph by site, in dollars or hours.

n = number of sites in square miles.

Equation (5) or (5a)^{c)} defines the effectiveness criterion that is useful to measure the efficiency E_j of the operational performance of each j type of aerial data collection and interpretation. It is derived from the variance shown in equations (2) and (3).

$$E_j = 100 \sqrt{V(\hat{u}_j) / \hat{u}_j} \tag{5}$$

$$= 100 \sqrt{\frac{Sx_j^2 / n}{\bar{x}_j}} \tag{5a}$$

where

E_j is the standard deviation (derived from the relative variance) of the jth estimator expressed as a percent of the mean.

The cost function (equation 4) can be incorporated into the efficiency equation (5a) to determine the best method^{d)}. The best method is the one that

c) M. H. Hansen, W. N. Hurtwitz, W. G. Madon, Sample Survey Methods and Theory New York: John Wiley and Sons, 1966, pp. 110-178.

d) A. H. Aldred, "Decisions on Combining Data From Several Sensors," First CDN Symposium on Remote Sensing, 1972.

minimizes E_j subject to a budgetary constraint imposed by the cost function defined in equation (4). In order to show how the relative efficiencies of each method or operational use of color and color IR for data collection for mine planning and reclamation monitoring vary with the cost function, the cost function can be substituted in the efficiency equation in (5a). The cost function can be rewritten as:

$$n = TC_j - CO_j / CD_j + CI_j \quad (6)$$

When it is substituted into equation (5a) it yields equation (7)

$$E_j = 100 \sqrt{\frac{Sx_j^2 / n}{\bar{x}_j}} = 100 \sqrt{\frac{Sx_j^2 (CD_j + CI_j) / TC_j - CO_j}{\bar{x}_j}} \quad (7)$$

where Sx_j^2 , CD_j , CI_j , CO_j and \bar{x}_j are known values and TC_j is the variable for each type of data collection and interpretation. Equation (7) is applied in the empirical analysis to derive the efficiency rating for each method of aerial data collection and interpretation.

Two sets of data were collected for this task. One set pertains to the actual costs incurred in the operational use of color, color infrared, and black and white photography in monitoring four surface mining activities defined previously. The data collected included three major cost items: (1) Aerial data collection; (2) photo processing; and (3) interpretation. These data were expressed not only in monetary units, but also in terms of time spent, especially on interpretation. Data on time spent for interpretation were compiled by interpreter per square mile site by major feature and parameter categories for each type of film.

The other set of data collected includes the evaluations of operational performance of color, color infrared and black and white photographs for interpreting vegetation, land use and water data on each mining activity defined in the scope of work^{e)}. The operational performance of each type of photography is quantified in terms of a scale that reflects the success with which the data

e) Appendix B lists specific parameters in each category.

were derived from the photographs. The quantification was done by means of a 1, 2, 3, 4 interpretability rating scale^(f). The data on interpretability ratings were compiled by subject, by site, by interpreter, by season, and by film types. The rating scale is formulated so that on the scale 4 is a 100 percent feature placement or measurement from the photographs.

The analysis of costs for each film type by season and the analysis of the data on performance accuracy (interpretability ratings) were integrated to determine the cost-effectiveness of the operational use of each film type for mine planning and reclamation purposes.

Fixed and variable cost estimates used in the analysis were compiled for the data collection and interpretation activities by season and by three major landscape categories: land use, vegetation, and water. The measure of operational performance or accuracy of each film type was derived from the interpretability ratings.

Sample data on calculated percent accuracy for each type of sensor by season and by the three major landscape categories are shown in Table 10 on Page 95. The data on interpretability ratings were converted into percentage accuracy ratings as a measure of operational performance. The conversion was made by dividing the indicated rating by 4 and multiplying by 100. The calculation of these accuracy percentages was based on a scale on which 4 represents 100 percent feature delineation (mapped or measured) from color photos or from color infrared transparencies.

Analysis of variance was used for analyzing data on performance accuracy to test statistically if there were significant differences in the variation of accuracy ratings between color and color infrared films by season and by landscape feature categories.

(f) Description of Rating Scale

- 0- feature cannot be measured or mapped
- 1- poor - feature can be measured only with a large amount of difficulty
- 2- fair - feature can be measured with minor difficulty
- 3- good - feature can usually be mapped or measured
- 4- excellent - feature can easily be mapped or measured.

The cost-effectiveness model was used to perform economic evaluations of the operational use of color and color infrared photography. Separate analyses were included to address the economical use of aerial photography in each of the four mining and reclamation activities defined previously:

1) pre-mine planning, 2) the revegetation aspect of reclamation, 3) all aspects of the reclamation process, and 4) the entire process from planning to release of bond following reclamation. The cost-effectiveness criterion used indicates that the operational use of one method of aerial photography for mining and reclamation planning and monitoring is more efficient than another if under specified conditions one yields more reliable results (minimizes relative error) per unit cost than the other.

C. RESULTS

Results of the economic evaluation are presented in four subsections. Each subsection corresponds to a surface mining and reclamation planning activity. In the discussion of the results for each activity, the cost estimates presented are based on coverage of one, ten, one hundred, and one thousand square mile areas.

Data on time spent and cost per square mile per flight or season are given in Appendix D. The cost of data collection (which includes charges for film, flying time over the data collection site, film processing, labor and profit) plus the cost of flight mobilization are fixed for both color and color infrared. Mobilization costs are costs incurred by an aerial survey company for aircraft preparation, camera preparation and testing, plotting of flight lines, and flying time to and from the data collection site. In this study, the per square mile estimated fixed cost for color photography, excluding mobilization costs, was \$18.00. For color infrared, it was \$12.00 per square mile. The variable cost includes charges for data interpretation. The cost estimate per square mile for data interpretation was based on an average labor rate of \$8 per hour and the average time spent by six interpreters delineating (mapping and measuring) key parameters from color photography and color infrared transparencies on six sites.

1. Pre-mine Planning

Analysis of the data focused on the estimated cost and interpretability ratings compiled from the mapping and measuring of parameters related to pre-mine planning included in each category listed in Appendix B.

The estimated total costs per one, ten, one hundred, and one thousand square miles to monitor pre-mine planning are given in Table 11. The data show that it costs more to collect and interpret data from color prints than from color infrared transparencies. On a square mile basis, the cost differential is approximately \$10 in summer and fall and about \$5 in spring. This differential could be significant if the area coverage was several thousand square miles. It should be noted that the interpretation of color infrared transparencies requires the use of a light table for viewing. This cost to the user may reduce slightly the cost advantage of color infrared transparencies.

The cost of photo interpretation for mine planning purposes also differs between the two films by season. It costs approximately \$3 to \$4 more per square mile to interpret pre-mining data from color prints than from color infrared transparencies in the summer and fall but the cost in the spring is slightly higher for color infrared transparencies than for color prints. The estimated cost of interpretation in this case is most likely influenced by the training and skills of the interpreter and by the numbers of the specific features to be looked at.

It is interesting to note, also, that the costs of photointerpretation of films showed a similar pattern of variation. That is, the costs for both are higher in the summer than in the spring, and likewise the cost estimates for spring are slightly higher than the fall and winter costs.^(g) Seasonal differences in costs are a function of the seasonal differences in the ease of interpretation and the number of items to be interpreted and measured.

^(g) For winter the comparison is between color and black and white photography.

TABLE 11 COST OF SURVEYING MAJOR FEATURES RELATED TO PRE-MINE PLANNING BY FILM TYPE AND SEASON WITH 1:12000 SCALE PHOTOGRAPHY (IN DOLLARS)

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COST ITEM	SUMMER		FALL		WINTER		SPRING		AVERAGE OF GROUND SURVEY
	COLOR	COLOR IR	COLOR	COLOR IR	COLOR	BLACK AND WHITE	COLOR	COLOR IR	
\$/SQUARE MILE									
INTERPRETATION (a)	47.36	43.76	38.16	35.28	39.60	39.36	39.04	40.08	
AERIAL DATA COLLECTION (c)	18.00	12.00	18.00	12.00	18.00	6.00	18.00	12.00	
SUBTOTAL	65.36	55.76	56.16	47.28	57.60	45.36	57.04	52.08	
AERIAL MOBILIZATION (d)	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	
TOTAL	765.36	755.76	756.16	747.28	757.60	745.36	757.04	752.08	640
\$/ACRE	1.20	1.18	1.18	1.17	1.18	1.16	1.18	1.17	1.00
\$/TON OF COAL (f)	.0016	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0012
\$/10 SQUARE MILES									
INTERPRETATION	473.60	437.60	381.60	352.80	396.00	393.60	390.40	400.80	
AERIAL DATA COLLECTION	180.00	120.00	180.00	120.00	180.00	60.00	180.00	120.00	
SUBTOTAL	653.60	557.60	561.60	472.80	576.00	453.60	570.40	520.80	
AERIAL MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	
TOTAL	1353.60	1257.60	1261.60	1172.80	1276.00	1153.60	1270.40	1220.00	6400
\$/ACRE	.21	.20	.20	.18	.20	.18	.20	.19	1.00
\$/TON OF COAL	.0003	.0003	.0003	.0002	.0003	.0002	.0003	.0002	.0012
\$/100 SQUARE MILES									
INTERPRETATION	4736.00	4376.00	3816.00	3528.00	3960.00	3936.00	3904.00	4008.00	
AERIAL DATA COLLECTION	1800.00	1200.00	1800.00	1200.00	1800.00	600.00	1800.00	1200.00	
SUBTOTAL	6536.00	5576.00	5616.00	4728.00	5760.00	4536.00	5704.00	5208.00	
AERIAL MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00	
TOTAL	7236.00	6276.00	6316.00	5428.00	6460.00	5236.00	6404.00	5908.00	64000
\$/ACRE	.11	.10	.10	.09	.10	.08	.10	.09	1.00
\$/TON OF COAL	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0012
\$/1000 SQUARE MILES									
INTERPRETATION	47360.00	43760.00	38160.00	35280.00	39600.00	39360.00	39040.00	40080.00	
AERIAL DATA COLLECTION	18000.00	12000.00	18000.00	12000.00	18000.00	6000.00	18000.00	12000.00	
SUBTOTAL	65360.00	55760.00	56160.00	47280.00	57600.00	45360.00	57040.00	52080.00	
AERIAL MOBILIZATION (g)	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	
TOTAL	66760.00	57160.00	57560.00	48680.00	59000.00	46760.00	58440.00	53480.00	640000
\$/ACRE	.10	.09	.09	.08	.09	.07	.09	.08	1.00
\$/TON OF COAL	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0012

(a) ASSUME \$8.00 HOURLY RATE FOR INTERPRETER.

(b) COLOR IR NOT COLLECTED DURING WINTER BECAUSE OF LOW SUN ANGLE.

(c) INCLUDES FLYING TIME, PHOTO PROCESSING AND INDEXING.

(d) BASED ON SITE WITHIN 300 MILES OF BASE (1 DAY DATA COLLECTION)

(e) AERIAL DATA COLLECTION COSTS BASED ON AVERAGE OF SEVERAL AERIAL SURVEY COMPANIES.

(f) ASSUME A 3' SEAM OF COAL IS TO BE MINED WITH A 85% RECOVERY RATE. AERIAL COVERAGE IS 5 TIMES MORE THAN AREA TO BE MINED.

(g) BASED ON TWO DAYS MOBILIZATION - NORMALLY ABOUT 500 SQUARE MILES CAN BE COVERED PER DAY AT 1:12000 SCALE WITH 6" MAPPING CAMERA, 7" FORMAT.

For example, in winter, there were less vegetation features that could be delineated on black and white photography. On the other hand, those vegetation features that could be interpreted were more difficult than color and took more time to interpret. Operational performance or percent accuracy of feature and parameter identification and measurement from color and color infrared films was also analyzed. The performance analysis and cost analysis are integrated to determine the cost-effectiveness of the operational use of both films. In general, the performance or percent accuracy rating for color infrared is higher than for color photography for interpreting pre-mining features in summer, fall, and spring. The mean accuracy ratings for land use and vegetation interpretation calculated for each season by film type are shown in Table 12 below:

TABLE 12 MEAN VALUES OF PERFORMANCE ACCURACY FOR INTERPRETING LAND USE AND VEGETATION FOR PRE-MINE PLANNING BY FILM BY SEASON USING 1:12000 SCALE AERIAL PHOTOGRAPHY 77-71			
FILM TYPE AND SEASON		PERCENT ACCURACY	
		LAND USE	VEGETATION
COLOR	SUMMER	80.71	83.75
	FALL	88.08	79.07
	SPRING	88.21	76.77
COLOR IR	SUMMER	91.50	78.61
	FALL	94.35	86.32
	SPRING	90.58	81.18

For land use interpretation, 10-12 percent more accuracy can be gained from color infrared transparencies over color photography in summer and fall. The gain is only approximately three percent in the spring. However, for interpreting vegetation features, the gain in using color infrared film is about 15 percent in summer, eight percent in the fall and approximately three percent in the spring.

Data used for calculating means were analyzed statistically using an analysis of variance technique called multi-factor classification.^(h) This analysis was done to test the hypothesis that there were no significant differences in the relative performance of the two types of films by seasons and by land use and vegetation categories.

Results of the analysis of variance are shown in Tables 13 and 14. Table 13 shows the analysis of variance by film type and season for land use interpretation. Table 14 shows the same for vegetation. The results indicate that for monitoring land use and vegetation, the differences in the performance accuracy between color and color infrared are statistically significant at a one percent level.⁽ⁱ⁾ These results are attested to by the highly significant F-ratios^(j) calculated for each film type in Tables 13 and 14. It can be noted, further, that the seasonal variation for each film type is also statistically significant at the one percent level. This observation is also supported by the mean values shown in Table 12. In summary, the results show that the gain in accuracy from use of color infrared is significant for three seasons for interpreting both land use and the vegetation aspects of pre-mine planning.

The results of the cost-effectiveness analysis for rating the relative efficiency (percent error) of color and color infrared photography for mine planning are shown in Table 15. For the purpose of interpreting the results, a method is said to be more efficient than another if under specified conditions it yields more reliable results per unit cost. The results show that for mine planning purposes it is more efficient to use color infrared than color photography regardless of the season in which land use and vegetation

(h) R.G.D. Steel and J. H. Toorie, Principles and Procedures of Statistics, New York: McGraw-Hill New York, 1960, Chapter 8. The analysis of variance technique applied in the data analysis followed randomized complete block design concept.

(i) This implies that the chance or probability of including the feature under investigation in a random sample is 99 percent out of 100.

(j) F ratio is associated with an F-distribution. The F distribution is the test statistic applied to establish the significance test of no differences between or among variances.

TABLE 13 ANALYSIS OF VARIANCE ON LAND USE INTERPRETATION FILM TYPE BY SEASON

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SOURCES OF VARIATION	DEGREES OF FREEDOM	SUM OF THE SQUARES	MEAN SQUARE	F-RATIO
(B) FILM TYPE (COLOR VS COLOR IR)	1	1759.90	1759.90	38.59*
(A) SEASON WITHIN FILM TYPE	4	1244.85	311.21	6.82*
INTERACTION OF A WITH B	(2)	(499.38)		
(C) LAND USE INTERPRETATIONS	27	14758.09	548.59	
EXPERIMENTAL ERROR	135	6156.35	45.60	
INTERACTION OF A WITH C	(54)	(4289.84)		
INTERACTION OF B WITH C	(27)	(1143.99)		
INTERACTION OF A WITH B AND C	(54)	(722.47)		
TOTAL	167			

*SIGNIFICANT AT 1% LEVEL

TABLE 14 ANALYSIS OF VARIANCE ON VEGETATION INTERPRETATION BY FILM TYPE SEASON

SOURCES OF VARIATION	DEGREES OF FREEDOM	SUM OF THE SQUARES	MEAN SQUARE	F-RATIO
(B) FILM TYPE (COLOR VS COLOR IR)	1	2226.0	2226.0	17.45*
(A) SEASON WITHIN FILM TYPE	4	3180.14	795.03	6.23
INTERACTION OF A WITH B	(2)	(556.27)		
(C) VEGETATION INTERPRETATIONS	18	43858.96	2436.60	
EXPERIMENTAL ERROR	90	11478.4	127.53	
INTERACTION OF A WITH C	(36)	(9738.04)		
INTERACTION OF B WITH C	(18)	(650.29)		
INTERACTION OF A WITH B AND C	36	(1090.07)		
TOTAL	113			

TABLE 15 RELATIVE ERROR VARIANCES FOR RATING THE EFFICIENCY OF COLOR AND COLOR IR TO SURVEY LAND USE AND VEGETATION

FILM TYPE AND SEASON		PERCENT ERROR	
		LAND USE	VEGETATION
COLOR	SUMMER	6.65	14.00
	FALL	4.70	9.15
	SPRING	3.10	6.90
COLOR IR	SUMMER	3.75	11.50
	FALL	2.70	6.85
	SPRING	2.60	6.80

IN STATISTICAL PARLANCE, THIS IS ONE STANDARD DEVIATION EXPRESSED IN A PERCENT OF THE MEAN ACHIEVED WITHIN THE BUDGET OR COST ALLOCATED

(A) - SPRING, SUMMER, FALL UNDER COLOR AND COLOR IR

(B) - COLOR VS COLOR IR

(C) - SAMPLE FEATURES USED IN INTERPRETATION

are surveyed. The seasons considered were spring, summer and fall. Aerial surveys of vegetation are not practical in the winter; nor is the collection of color infrared data feasible because of the low sun angle.

The relationship between percent error and cost of interpreting land use and vegetation for mine planning is shown in Figure 15. Although the relationship between percent error and cost can be expected to be a curvilinear function, the graph illustrates it in linear form because of the limited number of data points used in the analysis. For purposes of comparison, A and D represent the relationship between percent error and cost for monitoring land use in the summer using color infrared (A) and color (D) photography. It can be seen that percent error (3.75 percent) and cost (\$1270) for A is much lower than D (6.65 percent with \$1355). This relationship is based on ten square mile coverage. The same relationships hold for the comparison of B and E for fall and C and F for spring. For surveying vegetation, the comparison is between G and I for summer, and H and J for fall. The relationship in spring is almost identical for both color infrared and color photography.

Geological interpretation ratings were similar for black and white, color, and color infrared film types. If the major emphasis for pre-mine planning is geological information black and white aerial photography can be used. Data collection costs (Table 11) are much less for black and white imagery than for color and color infrared imagery. Interpretation costs for geologic information will be more expensive than land use or vegetation interpretations because an experienced geologist must perform the interpretations.

2. Monitoring the Revegetation Aspect of Reclamation

The economic evaluation of the operational use of color and color infrared aerial photography to monitor the revegetation aspect of reclamation is based on the assumptions that the interpreter (operator or inspector) is familiar with the natural vegetation of the area and has inspected the area once immediately after revegetation. Aerial inspection of the same area after revegetation is done to insure successful and timely reclamation revegetation.

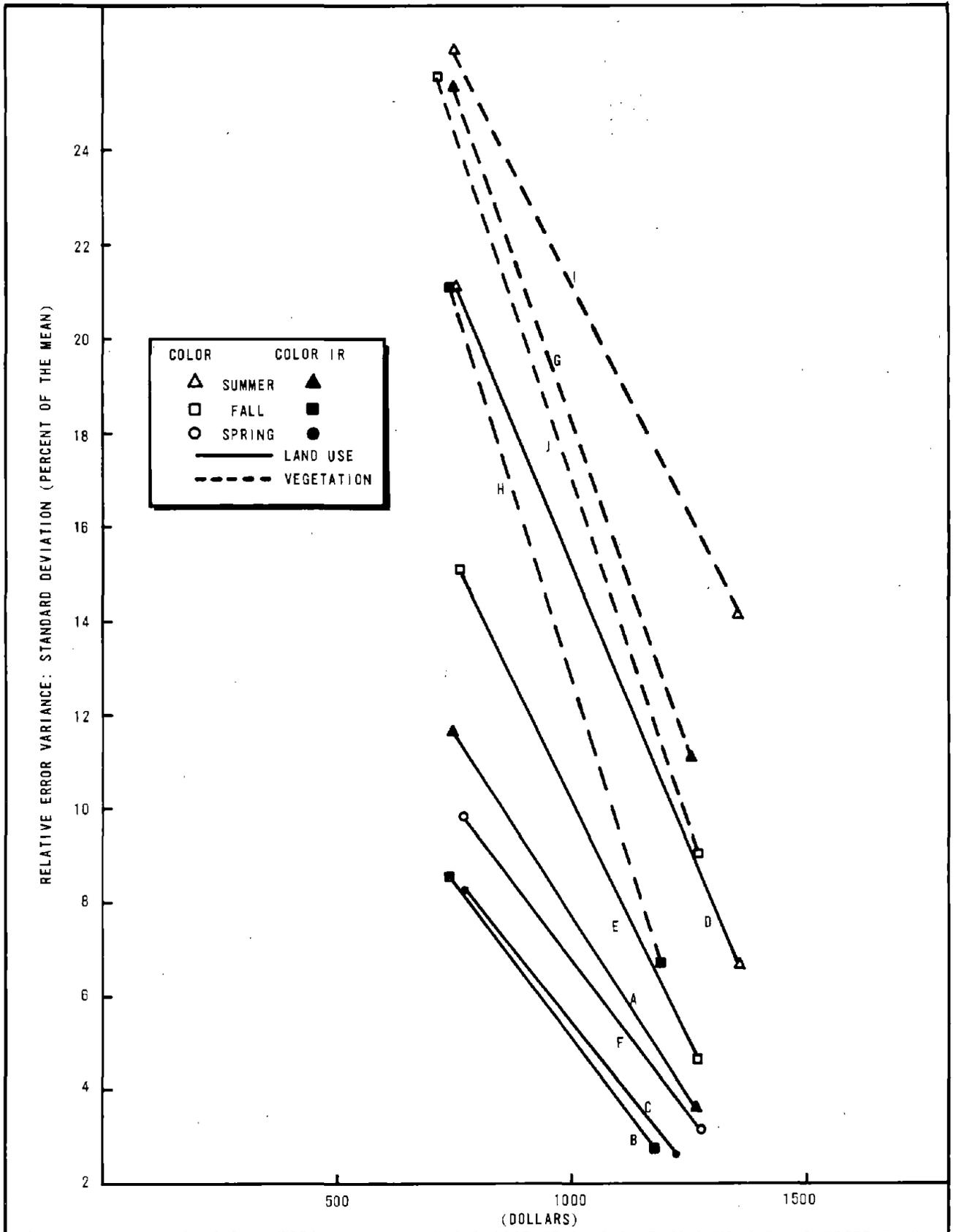


FIG. 15 RELATIONSHIP BETWEEN THE ACCURACY AND COST OF INTERPRETING LAND USE AND VEGETATION BY COLOR AND COLOR IR PHOTOGRAPHY (10 SQ. MILE)

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Sample data on interpretability ratings for mapping and measuring vegetation are given in Table 10 on page 95. The mean value calculated from these data by type of film by season and analysis of variance results are shown in Table 14. The results of the analysis show that the performance of color infrared is significantly better than color photography at a one percent level.

The results of the analysis of variance in Table 14 show the difference in the performance accuracy between color and color infrared photography to monitor vegetation parameters is significant at the 1.0% level. The cost differential between the two films is approximately \$5.00 in the summer and spring and about \$6.00 in the fall. The total cost estimate (Table 16) for a square mile showed that it is less expensive to use color infrared than color photography for all growing seasons for monitoring the revegetation aspect of reclamation. This conclusion is also supported by the relationships between cost and relative efficiency shown in Figure 15. In the spring, however, the efficiency ratings of color and color infrared are about the same.

3. Monitoring All Aspects of the Reclamation Process

For monitoring all features of the reclamation process, the analysis included data on cost and performance accuracy for mapping features and measuring parameters of land use and water as well as vegetation. Data compiled on estimated total costs of one, ten, one hundred, and one thousand square mile coverages are given in Table 17. The total cost estimates for each film by season suggest that it costs more to monitor all aspects of the reclamation process by color photography than by color infrared photography. For a one square mile area, the total cost differential is approximately \$4.50 in the spring, \$5.50 in the summer, and \$8.00 in the fall.

TABLE 16 COST OF MONITORING THE REVEGETATION ASPECT OF RECLAMATION BY FILM TYPE AND SEASON WITH 1:12000 SCALE PHOTOGRAPHY (IN DOLLARS)

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COST ITEM	SUMMER		FALL		WINTER		SPRING	
	COLOR	COLOR IR	COLOR	COLOR IR	COLOR	BLACK AND WHITE	COLOR	COLOR IR
\$/SQUARE MILE								
INTERPRETATION	14.08	14.96	15.68	15.52	15.76	16.80	16.00	16.88
DATA COLLECTION	18.00	12.00	18.00	12.00	18.00	6.00	18.00	12.00
SUB-TOTAL	32.08	26.96	33.68	27.52	33.76	32.80	34.00	28.88
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
TOTAL	732.08	726.96	733.68	727.52	733.76	732.80	734.00	728.88
\$/ACRE	1.14	1.14	1.15	1.14	1.15	1.15	1.15	1.14
\$/TON OF COAL	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015
\$/10 SQUARE MILES								
INTERPRETATION	140.80	149.60	156.80	155.20	157.60	168.00	160.00	168.80
DATA COLLECTION	180.00	120.00	180.00	120.00	180.00	60.00	180.00	120.00
SUB-TOTAL	320.80	269.60	336.80	275.20	337.60	228.00	340.00	288.80
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
TOTAL	1020.80	969.60	1036.80	975.20	1037.60	928.00	1040.00	988.80
\$/ACRE	.16	.15	.16	.15	.16	.15	.16	.16
\$/TON OF COAL	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002
\$/100 SQUARE MILES								
INTERPRETATION	1408.00	1496.00	1568.00	1552.00	1576.00	1680.00	1600.00	1688.00
DATA COLLECTION	1800.00	1200.00	1800.00	1200.00	1800.00	600.00	1800.00	1200.00
SUB-TOTAL	3208.00	2696.00	3368.00	2752.00	3376.00	2280.00	3400.00	2888.00
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
TOTAL	3908.00	3396.00	4068.00	3452.00	4076.00	2980.00	4100.00	3588.00
\$/ACRE	.06	.05	.06	.05	.06	.05	.06	.06
\$/TON OF COAL	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
\$/1000 SQUARE MILES								
INTERPRETATION	14080.00	14960.00	15680.00	15520.00	15760.00	16800.00	16000.00	16880.00
DATA COLLECTION	18000.00	12000.00	18000.00	12000.00	18000.00	6000.00	18000.00	12000.00
SUB-TOTAL	32080.00	26960.00	33680.00	27520.00	33760.00	22800.00	34000.00	28880.00
MOBILIZATION	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00
TOTAL	33480.00	28360.00	35080.00	28920.00	35160.00	24200.00	35400.00	30280.00
\$/ACRE	.05	.04	.06	.05	.06	.04	.05	.05
\$/TON OF COAL	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001

TABLE 17 COST OF MONITORING ALL ASPECTS OF THE SURFACE MINE RECLAMATION BY FILM TYPE AND SEASON WITH 1:12000 SCALE PHOTOGRAPHY. (IN DOLLARS)

77-71

COST ITEM	SUMMER		FALL		WINTER		SPRING	
	COLOR	COLOR IR	COLOR	COLOR IR	COLOR	BLACK AND WHITE	COLOR	COLOR IR
\$/SQUARE MILES								
INTERPRETATION	61.36	62.00	50.48	48.56	60.40	60.32	60.08	61.68
DATA COLLECTION	18.00	12.00	18.00	12.00	18.00	6.00	18.00	12.00
SUB-TOTAL	79.36	74.00	68.48	60.56	78.40	66.32	78.08	73.68
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
TOTAL	779.36	774.00	766.48	760.56	778.40	766.00	778.11	773.68
\$/ACRE	1.22	1.21	1.20	1.19	1.22	1.20	1.22	1.21
\$/TON OF COAL	.0016	.0016	.0015	.0015	.0016	.0015	.0016	.0016
\$/10 SQUARE MILES								
INTERPRETATION	613.60	620.00	504.80	485.60	604.00	603.20	600.80	616.80
DATA COLLECTION	180.00	120.00	180.00	120.00	180.00	60.00	180.00	120.00
SUB-TOTAL	793.60	740.00	684.80	605.60	784.00	663.20	780.80	736.80
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
TOTAL	1493.60	1440.00	1384.80	1305.60	1484.00	1363.20	1480.80	1436.80
\$/ACRE	.23	.23	.22	.20	.23	.21	.23	.22
\$/TON OF COAL	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003
\$/100 SQUARE MILES								
INTERPRETATION	6136.00	6200.00	5048.00	4856.00	6040.00	6032.00	6000.00	6168.00
DATA COLLECTION	1800.00	1200.00	1800.00	1200.00	1800.00	6000.00	1800.00	1200.00
SUB-TOTAL	7936.00	7400.00	6848.00	6056.00	7840.00	6632.00	7808.00	7368.00
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
TOTAL	8636.00	8100.00	7548.00	6756.00	8540.00	7332.00	8508.00	8068.00
\$/ACRE	.14	.13	.12	.11	.13	.12	.13	.13
\$/TON OF COAL	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002
\$/1000 SQUARE MILES								
INTERPRETATION	61360.00	62000.00	50480.00	48560.00	60400.00	60320.00	60080.00	61680.00
DATA COLLECTION	18000.00	12000.00	18000.00	12000.00	18000.00	6000.00	18000.00	12000.00
SUB-TOTAL	79360.00	74000.00	68480.00	60560.00	78400.00	66320.00	78080.00	73680.00
MOBILIZATION	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00
TOTAL	80760.00	75400.00	69880.00	61960.00	79800.00	67720.00	79480.00	75080.00
\$/ACRE	.13	.12	.11	.10	.13	.11	.12	.12
\$/TON OF COAL	.0002	.0002	.0001	.0001	.0002	.0002	.0002	.0002

It can be noted that for a coverage of a ten square mile area, the total cost estimate for the operational use of color infrared transparencies is about the same for the summer and spring (\$1440 and \$1436). However, total cost estimate is about a hundred dollars less (\$1305) in the fall. This seasonal cost difference in the use of color infrared is due to the difference in the costs of data interpretation between fall and summer transparencies and between fall and spring transparencies which resulted because, in general, fall data was easier to interpret than spring or summer data.

The analysis of variance on accuracy ratings (interpretability ratings) for mapping water features and for measuring their parameters are given in Table 18. The analysis shows that the difference in the performance accuracy of color and color infrared is statistically significant at the five percent level. The mean values of performance accuracy in monitoring all aspects of reclamation process by film type and by season are given in Table 19.

The results of the cost-effectiveness analysis for all aspects are shown in Table 20. In summary, it can be stated that it will be more cost-effective to use color infrared for monitoring all reclamation aspects in the spring, summer, and fall.

Black and white imagery is not very useful for vegetation monitoring because black and white film has a low sensitivity to green light. Regrading and topsoiling operations can be identified on black and white photographs. Percent vegetative cover cannot be measured accurately with black and white. Because black and white imagery is not good for vegetation monitoring it is not recommended for reclamation monitoring.

4. Monitoring the Entire Mining Process from Planning to Release of the Bond

In this section, highlights of the results observed in the previous three sections are integrated because the sum of activities in these three sections constitute the whole of required monitoring activities of the surface mining cycle. Although the data used for the analysis on cost

TABLE 18: ANALYSIS OF VARIANCE ON WATER INTERPRETATION BY FILM TYPE BY SEASON

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SOURCES OF VARIATION	DEGREES OF FREEDOM	SUM OF THE SQUARE	MEAN SQUARE	F-RATIO
(B) FILM TYPE (COLOR VS COLOR IR)	1	1547.36	1547.36	4.77***
(A) SEASON WITHIN FILM TYPE	4	12938.25	3234.56	9.97*
INTERACTION B&A	(2)	(12847.88)		
INTERACTION OF A WITH B	(2)	(80.37)		
(C) WATER INTERPRETATION	18	42857.46	2380.97	
EXPERIMENTAL ERROR	90	29179.4	324.21	
INTERACTION OF A WITH C	(36)	(23370.28)		
INTERACTION OF B WITH C	(18)	(2284.40)		
INTERACTION OF A WITH B & C	36	(3524.72)		
TOTAL	113			

* SIGNIFICANT AT 1% LEVEL

*** SIGNIFICANT AT 5% LEVEL

TABLE 19: MEAN VALUES OF PERFORMANCE ACCURACY TO MONITOR ALL ASPECTS OF THE RECLAMATION PROCESS

FILM TYPE & SEASON		PERCENT		
		LAND	VEGETATION	WATER
COLOR	SUMMER	80.71	83.75	52.76
	FALL	88.08	79.07	72.96
	WINTER	85.44	59.50	78.38
	SPRING	88.21	76.77	73.88
COLOR IR	SUMMER	91.50	78.61	57.69
	FALL	94.35	86.32	80.98
	SPRING	90.58	81.18	83.02
BLACK AND WHITE	WINTER	76.74	48.20	61.05

TABLE 20: RELATIVE ERROR VARIANCE FOR RATING THE EFFICIENCY OF TYPE OF FILM TO MONITOR ALL ASPECTS OF THE RECLAMATION PROCESS BY SEASON

FILM TYPE & SEASON		- PERCENT ERROR -		
		LAND USE	VEGETATION	WATER
COLOR	SUMMER	6.65	14.00	20.60
	FALL	4.70	9.15	10.32
	WINTER	5.58	13.62	7.66
	SPRING	3.10	6.90	8.48
COLOR IR	SUMMER	3.75	11.50	18.25
	FALL	2.70	6.85	9.62
	SPRING	2.60	6.80	4.57
BLACK AND WHITE	WINTER	6.31	16.77	12.01

and interpretability ratings are for only two years, generalization can be made with respect to the overall duration of the entire mining process from planning to release of bond following reclamation. This period can vary from a year to two or more years depending upon the duration of the mining operation and the state and local regulations. The frequency of monitoring or inspection of the mine area also varies because of differences in requirements of state surface mining laws. Periodic inspections as frequently as twice monthly may be required while mining is in progress. When mining is completed, it is likely that inspection or monitoring will be conducted less frequently, for example, once a year. Such inspections continue until an inspector has determined that reclamation has been accomplished successfully, and in some cases until the operator's bond is released.

The results in this study of the economic evaluation of the data on cost and performance accuracy of color and color infrared films for different seasons can be applied to periods of two or more years assuming similar conditions⁽ⁱ⁾ under which the data are collected.

For planning purposes, the results of the analysis of the data on cost and performance for mine planning can be applied. The results of the data analysis suggest that it is more cost-effective to use color infrared photography than color photography to monitor land use and vegetation for mine planning in three seasons: spring, summer, and fall. Spring is considered to be the optimum season for delineating the maximum number of parameters. Thus, for optimum reclamation, a mine plan based on a site monitored in spring is advisable. The estimated cost for monitoring a ten square mile site for planning in the spring is between the costs estimated for summer and fall. The respective cost estimates are \$1220 for spring, \$1257 for summer, and \$1172 for the fall (see Table 11).

(i) These conditions are pertinent to the listed items below:

- Fixed data interpretation requirements.
- Prevailing unit cost of mobilization, flying time, and photo processing.
- Prevailing labor rate for photo interpreters.
- Skill and training of photo interpreters.

These data can be used by prospective users for estimating costs so long as allowances are made for different conditions from those under which the data in this study were generated. In summary, the cost will vary with the frequency or the season that the mine is monitored. In general, if the user relies on aerial surveys to monitor the entire mining process from planning to the release of bond, it will be more cost effective if color infrared transparencies are used.

5. Relationships Between Estimated Cost and Aerial Coverage Per Overflight

Cost estimates presented in this section are based on the following conditions or assumptions:

- (1) The cost of data collection (which includes flying time and film processing) by film type was based on rates quoted for these activities by six aerial survey firms. The charge per flight (mobilization) was also obtained from these six firms.
- (2) The cost of data interpretation was based on the average time spent by six interpreters each examining two of the six sites. No charge for equipment and related supplies for interpretation are included in the cost estimates. The cost of equipment would be part of the initial capital investment and is not included as costs associated with on-going interpretation activity.

Figure 16, 17, 18 show relationships between total estimated cost and the amount of area covered for color and color infrared photography for three seasons. In general, total estimated cost for color infrared photography is relatively lower than for color photography in all seasons for the areas considered. The same comparison holds for estimated

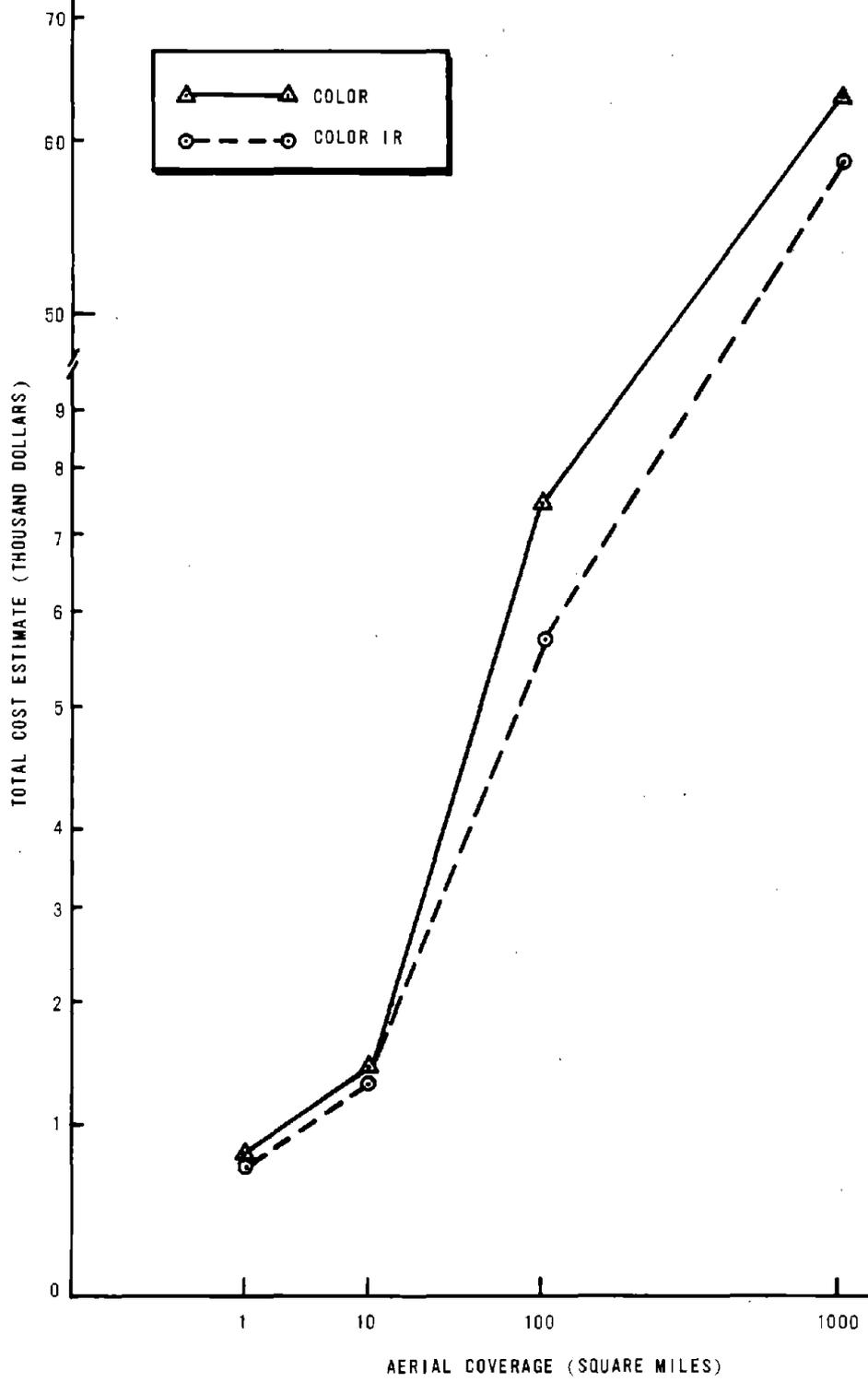


FIG. 16 RELATIONSHIP BETWEEN TOTAL ESTIMATED COST AND AREA COVERED PER FALL OVERFLIGHT

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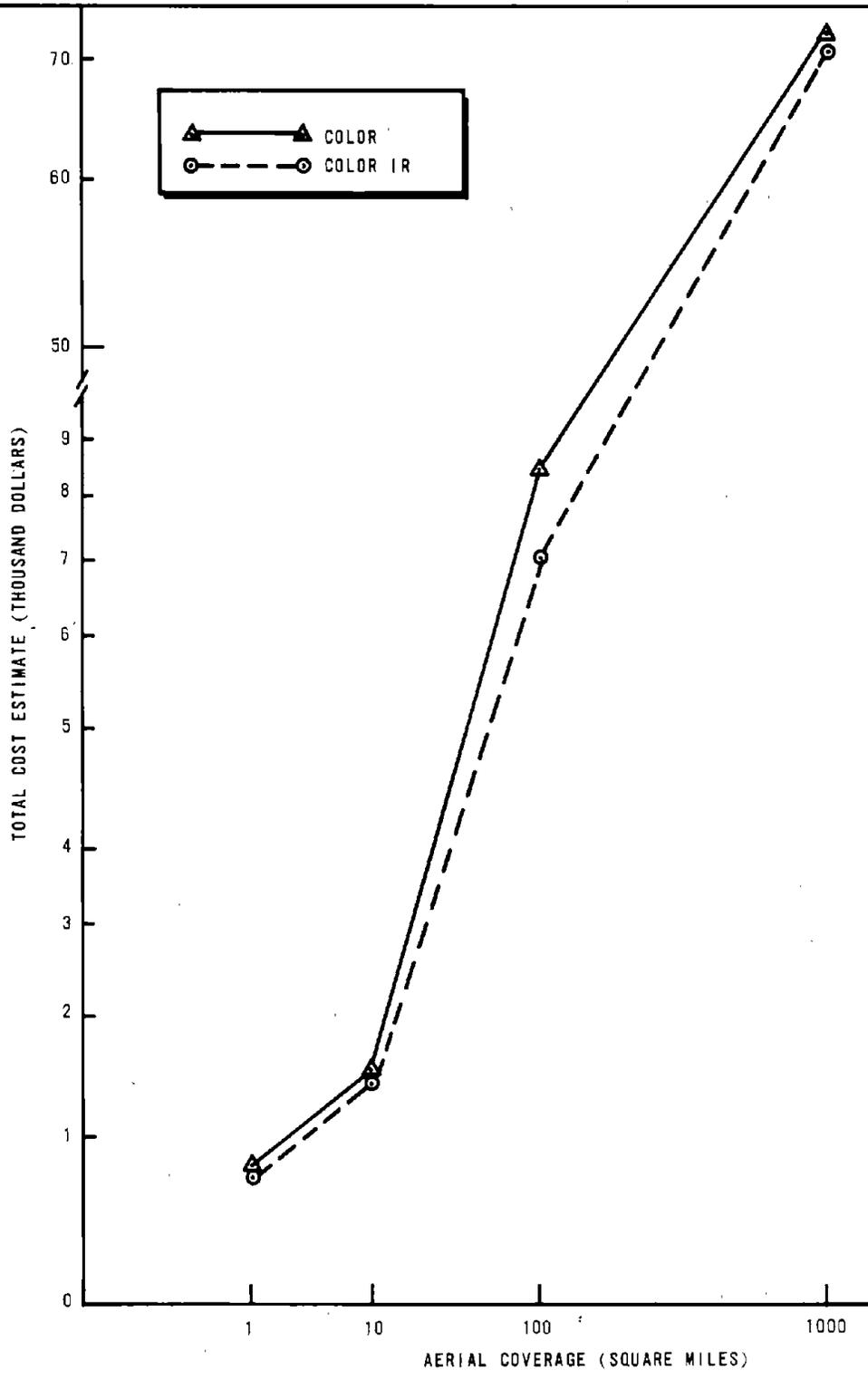


FIG. 17 RELATIONSHIP BETWEEN TOTAL ESTIMATED COST AND AREA COVERED PER SPRING OVERFLIGHT

77-71

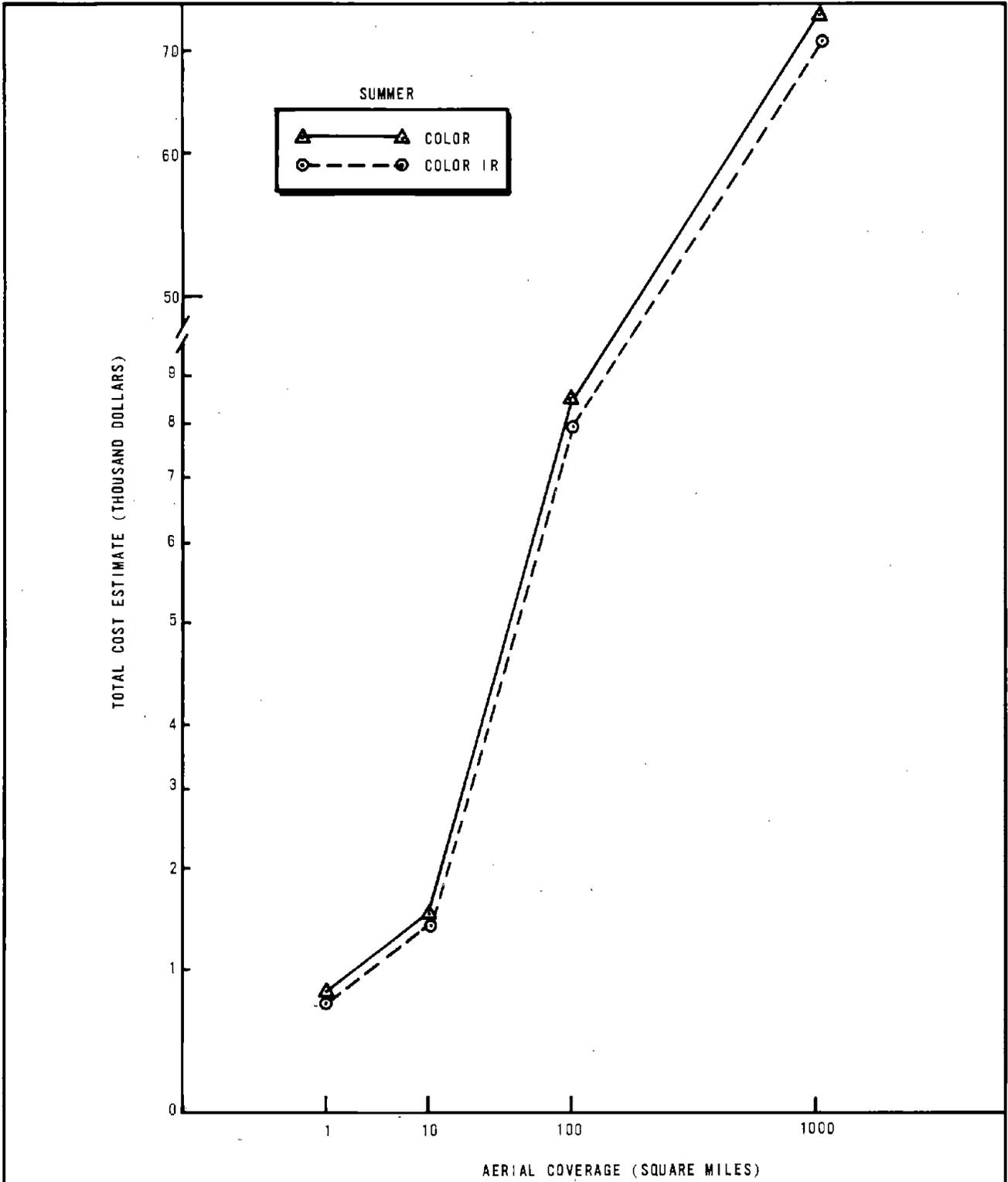


FIGURE 18 RELATIONSHIP BETWEEN TOTAL ESTIMATED COST AND AREA COVERED PER SUMMER OVERFLIGHT

costs per square mile as given in Figure 19, 20, and 21. All three figures suggest curvilinear relationships. It can be noted that as the area increases from one square mile to 1000 square miles, the cost per unit area decreases. It appears that beyond the 1000 square miles coverage the cost per unit area levels off.

Percentages of total cost were also calculated according to major cost elements as shown in Table 21. Percent charged for mobilization decreased as the area coverage increased while the percentage for both interpretation and data collection increased with the increase in area covered. The percentage of the total cost for interpretation is higher for color infrared than for color for all seasons. However, for all seasons, the percentage of the total cost for data collection is lower for color infrared than for color photography.

Estimates of the cost for specified area coverage were based only on tangible cost items such as costs of flying time, film processing, and interpretation. However, in the choice of film types to use, the prospective user must also take into account the intangible factors that are difficult to quantify. For example, for field work, color prints are easier to use than color transparencies.

Some aerial data collection firms have the capability to collect color and color infrared imagery during the same flight with tandem mapping cameras. With this system mobilization costs are only slightly higher than mobilization costs for collecting imagery of a single film type. Basically both film types (color and color IR) can be used to adequately collect information concerning the same features. The advantages of collecting both film types are that a print format is available for efficient use in the field, and the color infrared transparencies provide slightly higher interpretation accuracies than color prints. However, the use of both film types will not significantly increase the amount of information that can be obtained solely from aerial photographs.

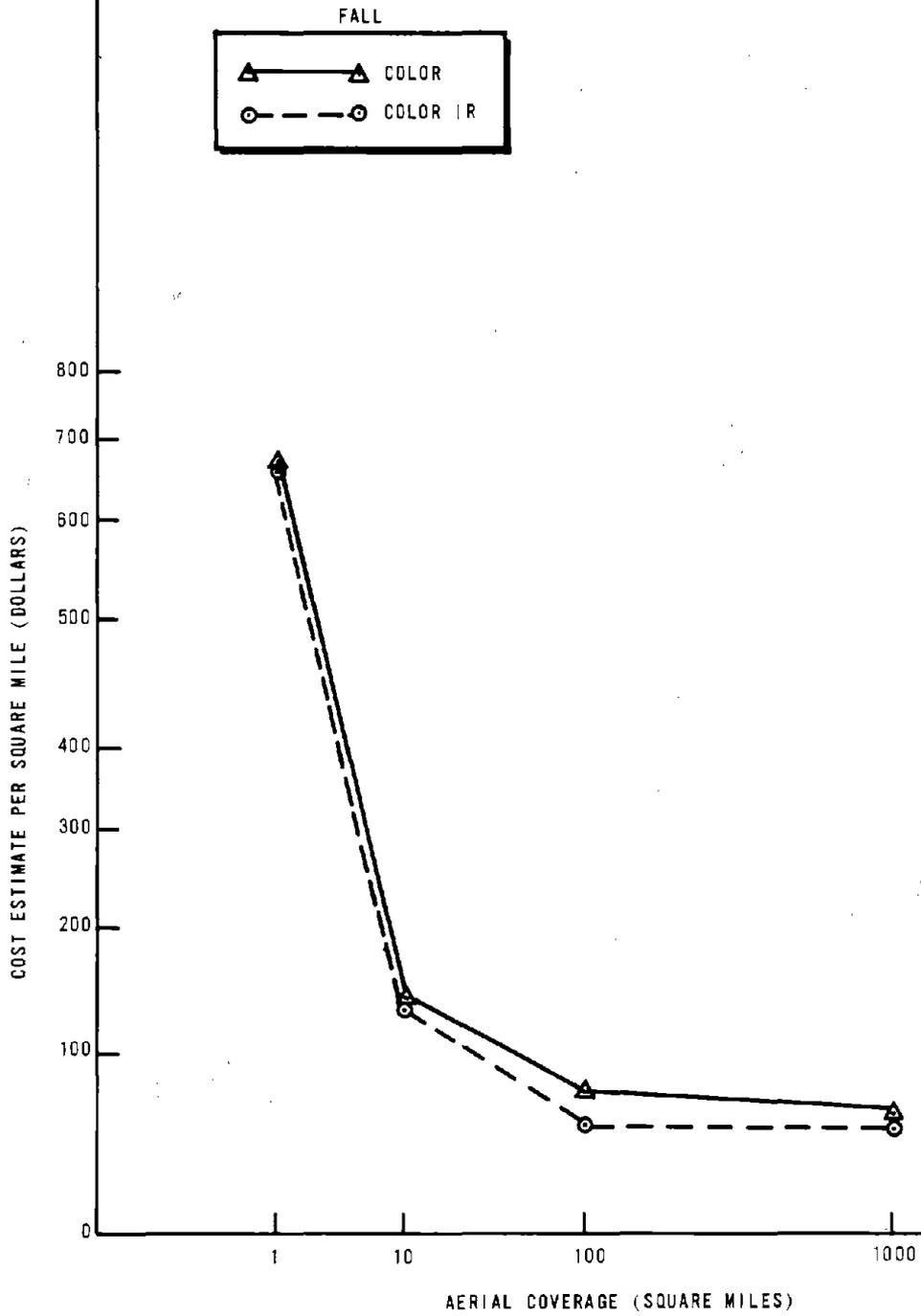


FIG. 19 COST ESTIMATE PER SQUARE MILE AS A FUNCTION OF AREA COVERED PER FALL OVERFLIGHT

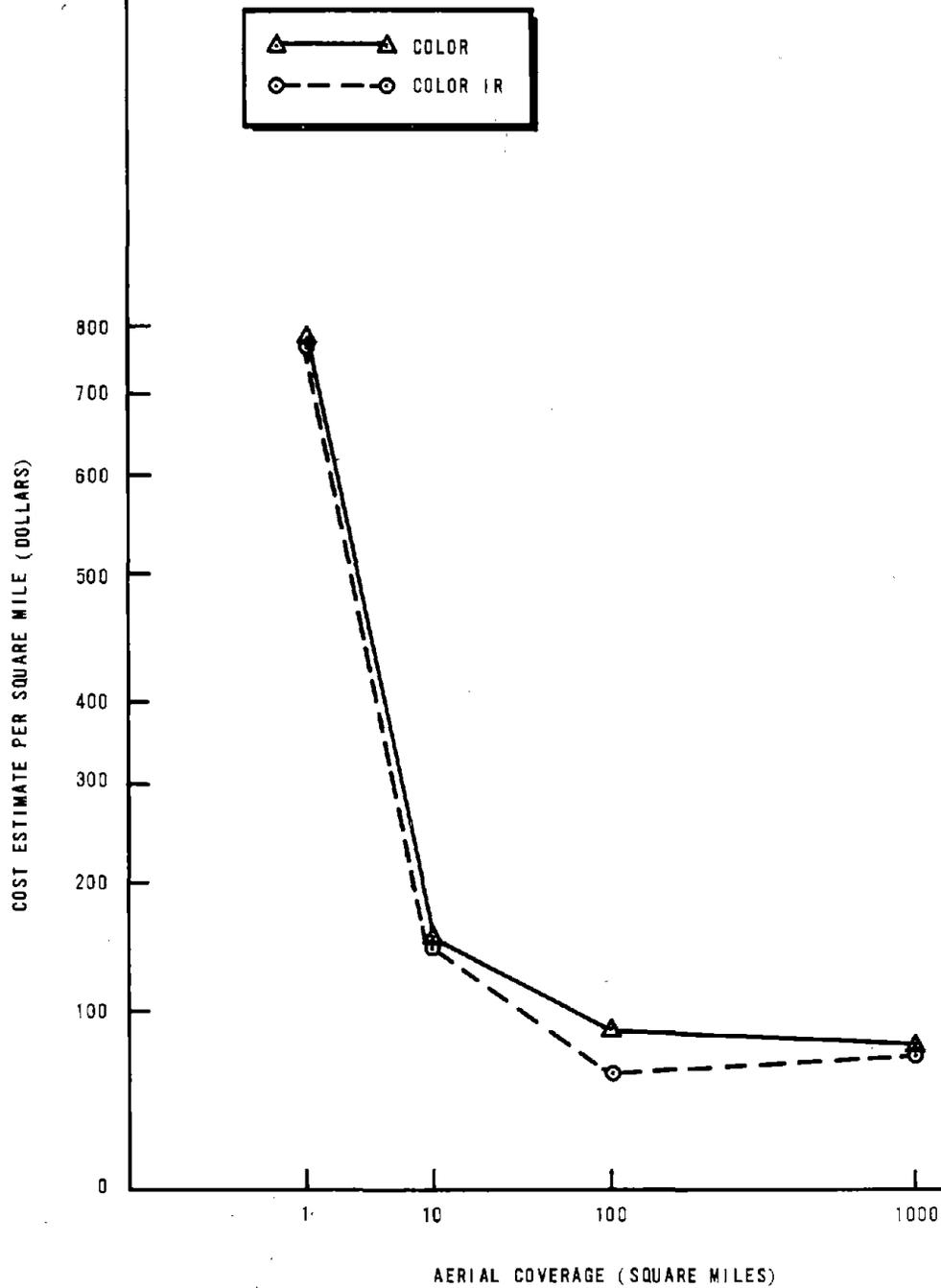


FIG. 20 COST ESTIMATE PER SQUARE MILE AS A FUNCTION OF AREA COVERED PER SPRING OVERFLIGHT

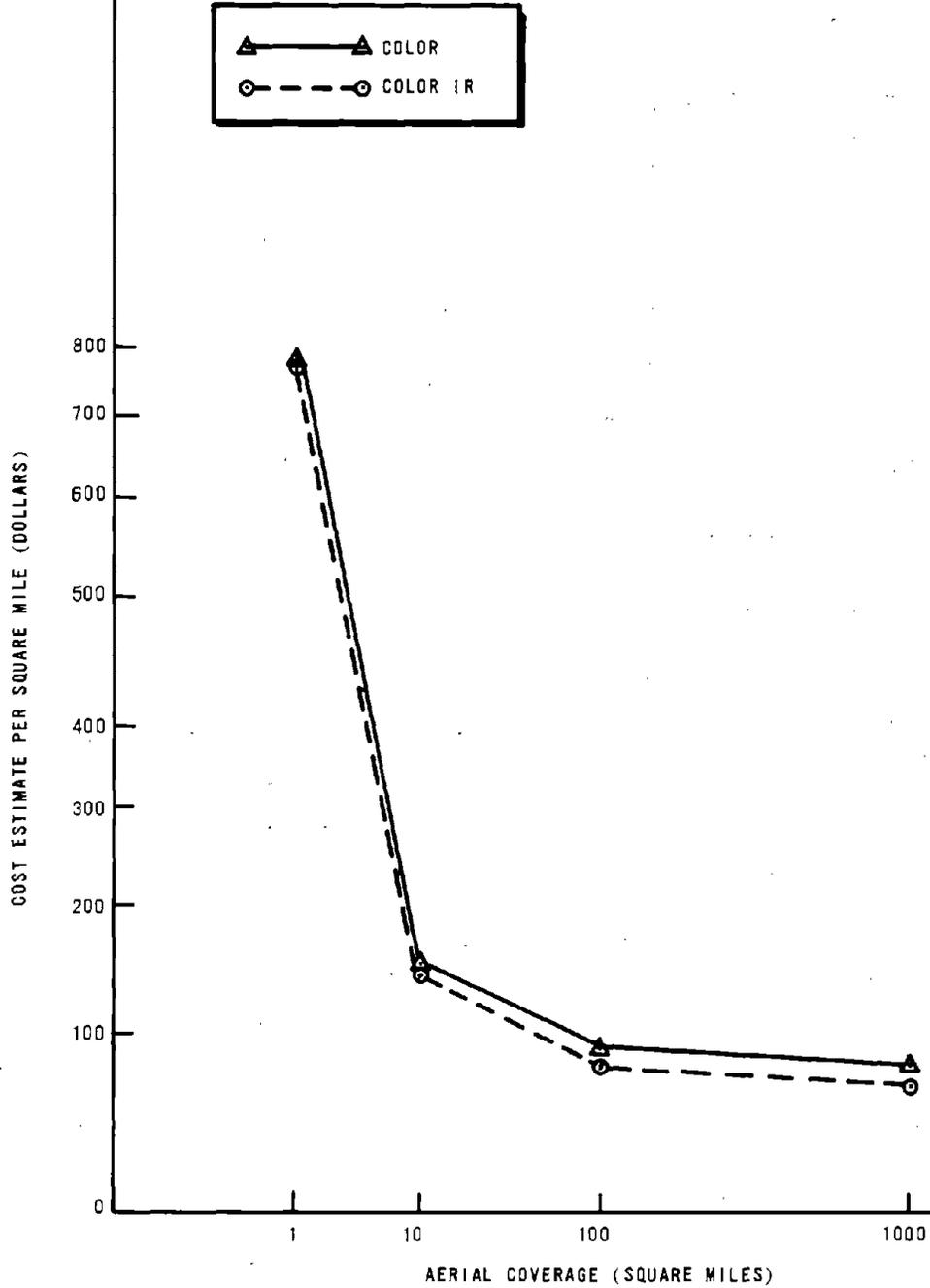


FIG. 21 COST ESTIMATE PER SQUARE MILE AS A FUNCTION OF AREA COVERED PER SUMMER OVERFLIGHT

TABLE 21 COMPONENTS OF TOTAL COST ESTIMATE FOR 1, 10, 100 AND 1000 SQ. MILES (PERCENT OF TOTAL) BY SEASON AND FILM TYPE.

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COST ITEMS	SUMMER		FALL		WINTER		SPRING	
	COLOR	COLOR IR	COLOR	COLOR IR	COLOR	BLACK AND WHITE	COLOR	COLOR IR
1 SQUARE MILES								
INTERPRETATION	7.85	8.00	6.55	6.40	7.75	7.85	7.75	7.90
DATA COLLECTION	2.30	1.55	2.35	1.60	2.30	.80	2.30	1.55
MOBILIZATION	89.85	90.45	91.10	92.00	89.95	91.35	89.95	90.55
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10 SQUARE MILE								
INTERPRETATION	41.05	43.05	36.40	37.15	40.70	44.25	40.55	42.90
DATA COLLECTION	12.05	8.35	13.00	9.20	12.15	4.40	12.15	8.35
MOBILIZATION	46.90	48.60	50.60	53.65	47.15	51.35	47.30	48.75
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100 SQUARE MILE								
INTERPRETATION	72.55	77.70	68.50	73.15	72.25	82.95	72.15	77.60
DATA COLLECTION	19.15	13.55	22.00	16.30	19.35	7.40	19.45	13.60
MOBILIZATION	8.30	8.75	9.50	10.55	8.40	9.65	8.40	8.80
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1000 SQUARE MILES								
INTERPRETATION	83.35	86.50	80.50	83.40	83.15	91.25	83.05	86.55
DATA COLLECTION	15.65	12.50	18.40	15.40	15.90	7.80	15.95	12.45
MOBILIZATION	1.00	1.00	1.00	1.20	1.00	1.05	1.00	1.00
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

As far as the amount of information obtainable from aerial photography neither film type presents a distinct advantage. The amount of ground work needed to collect information that cannot be obtained from aerial photography is similar when either film type is used.

X. WESTERN SITE ANALYSIS

A. OBJECTIVES

The objective of this analysis was to determine the applicability of the interpretation methodologies and results developed for eastern sites in this study to western surface mining sites. Furthermore, any additional interpretation requirements resulting from regional differences such as climate, vegetation, geology, and mining methods were to be identified for western surface coal mining sites. Finally, recommendations were to be developed concerning further study efforts in aerial data collection and analysis for western surface coal mining sites.

The western site analysis was divided into five major elements as shown in Figure 22. The methodology and result of each element are discussed in the following sections.

B. STATUS OF AERIAL PHOTOGRAPHIC USAGE

In order to determine the status of aerial photographic usage in the western surface coal mining community, a selected number of surface coal mine operators and state regulatory authorities were contacted. A total of seven surface coal mine operators were contacted. Their operations were in Arizona, Colorado, Montana, New Mexico and Wyoming. Regulatory authorities in Arizona, Colorado, Montana and Wyoming were contacted.

From these discussions, various current uses of aerial photography for surface coal mining planning and monitoring were determined, as were those potential uses envisioned by the western surface mining community.

It was found that almost all of the western surface coal mine operators utilize aerial photography for analysis and/or monitoring of various aspects of the surface coal mining cycle. Most of the operators utilize black and white aerial photography to monitor the progress of mining, calculate the volume of overburden removed, and make estimates of coal production. Several mine operators are currently using color infrared aerial photography

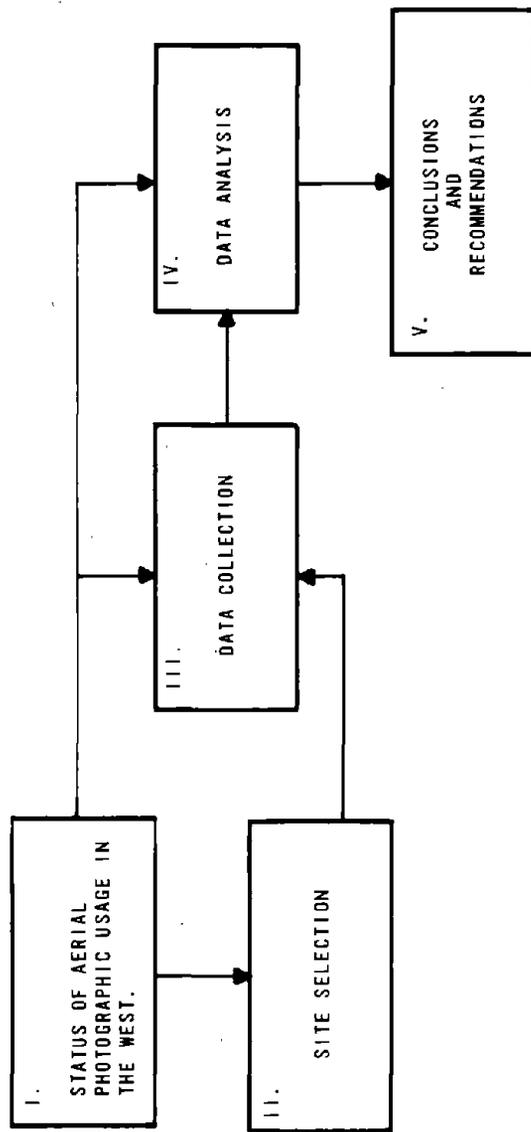


FIG. 22 ELEMENTS OF THE WESTERN SITE ANALYSIS

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as a method of documenting the success of revegetation and reclamation efforts. One operator was using color aerial photography to map surface geologic features. Many of the operators felt that aerial photography could be used more extensively than it presently is, especially for pre-mine planning and assessments related to vegetation mapping, geologic mapping, surface hydrology mapping, land use and archaeological studies. With this possible increased usage in mind, several mining companies have on their staffs a trained photographic interpreter.

In general, western surface coal mine operators are utilizing aerial photography more so than eastern operators and plan to utilize aerial photography for additional applications in the future. Although black and white photography is the most commonly used film type, emphasis is being placed on color and color infrared aerial photography as the operator becomes more involved in photographic interpretation. The major areas of interest for using color and color infrared aerial photography are in vegetation and archaeological studies.

The primary reasons for the widespread use of aerial photography by western surface coal mining operators as compared to the East are diverse.

- Western surface mining operations are characterized by large operators with single sites producing a large amount of coal. A single site usually will be producing for long periods (20 years or more). The large operator has the resources to fully utilize aerial photography. Also, repetitive coverage over the sites is valuable on a long-term basis. In the East, surface mining operations are characterized by small- or medium-sized operators with a large number of sites which are active for very short periods (some less than 2 years). Therefore, repetitive coverage is not as useful.
- The more stringent pre-mining environmental assessments required of the western operator are expensive and time-consuming and have caused him to look at various data collection alternatives to standard ground data collection. This is especially true of vegetation assessments.

- The fact that aerial photography has been utilized in the pre-mining assessments has allowed the operator to become familiar with the capabilities of aerial photography, and he has continued to use it as a data collection tool during mining and reclamation. As this occurred he usually has added an interpreter to his staff.
- Vegetative cover, especially tree canopy, is much less dense over many areas in the West. Thus, surface features are often more clearly visible in aerial photographs of western sites.

The discussions held with the various state regulatory personnel indicated that in three states, Montana, Wyoming, and Colorado, aerial photography was utilized to some extent in monitoring of surface coal mining activity. In Montana color and color infrared are being used experimentally to monitor revegetation at mined sites and to compare the new vegetation to original vegetation type and density. In Wyoming and Colorado, aerial photography was being considered as a monitoring tool, but it was not being currently used on an operational basis. It was generally felt that aerial photography, especially color and color infrared photography, could be utilized more as a compliance monitoring tool; however, the lack of trained photographic interpreters has hampered these efforts. It was felt that as mining activity increases in the West, aerial photography will become an increasingly important monitoring tool.

In general, the operators and regulators considered vegetation assessment, geologic mapping, surface hydrology, operations monitoring, revegetation monitoring and archaeology as the most useful actual and potential applications of color and color IR aerial photography in monitoring the environmental and reclamation progress of western surface mines.

C. SITE SELECTION

In order to determine the utility of color and color infrared photographs in western surface mining situations, several western test sites were selected. A large amount of literature was reviewed related to a number of western surface mining sites. The review was geared toward sites with a variety of reclamation practices and a variety of mining activity. As a result of this review and discussions with Bureau of Mines personnel, the choices were narrowed down to two surface mines in the Powder River Basin of Wyoming and Montana. These surface mines were the Peter Kiewit Sons Company's Decker Mine near Decker, Montana and the Amax Coal Company's Belle Ayr Mine near Gillette, Wyoming. Before the final selection was made, these sites were visited and discussions were held with various personnel at each mine. As a result of these discussions, it was decided to utilize both these surface mines as test sites. Discussions with Peter Kiewit personnel indicated that their Big Horn surface mine near Sheridan, Wyoming, should also be considered as a test site in that it contained a wide variety of vegetation types encountered in the Powder River Basin. Therefore it was decided to include the Big Horn Mine as the third test site. The locations of the test sites are shown in Figure 23. A brief description of each site is included below.

1. Decker Mine

The Decker Mine is located 20 miles north of Sheridan, Wyoming, near Decker, Big Horn County, Montana. It is located near the western edge of the Powder River Coal Region. The mine started production in 1972. A solid 52 ft. coal seam (Dietz) is being mined. Production from this mine (10.2 million tons) made Decker the largest surface coal mine in the United States in 1976. The coal is mined using an area mining method consisting of a series of parallel semicircular cuts outward from the center of the mining complex.

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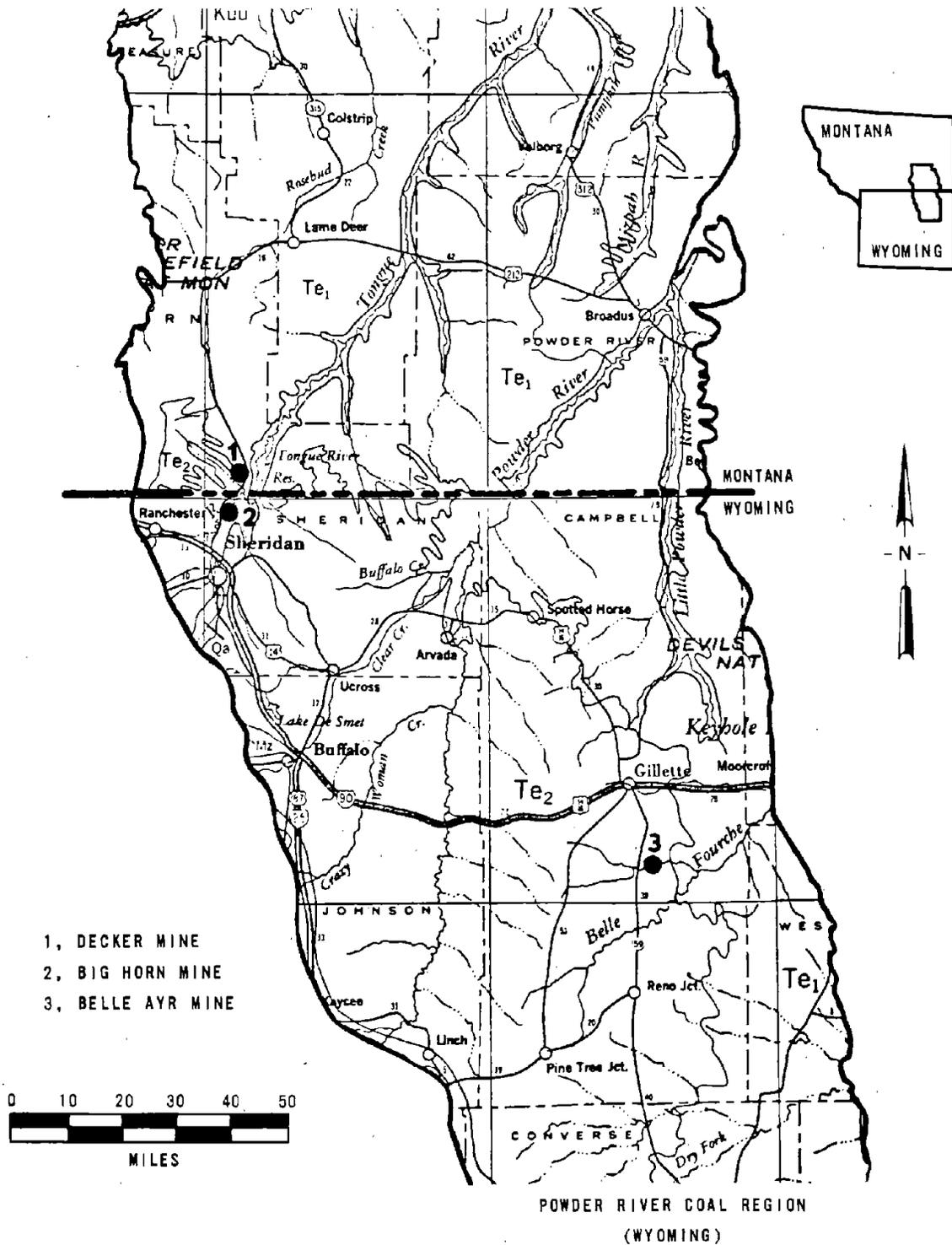


FIGURE 23 LOCATION OF THE WESTERN TEST SITES

The site is characterized by gently rolling land with some benchland. The site is adjacent to the Tongue River Reservoir, which has typical riparian vegetation bordering the river.

The Decker Mine is located in semi-arid prairie country, with mainly grassland/sagebrush vegetation. Because of the delicate rainfall balance, mine revegetation is dominantly with native grass species.

2. Big Horn Mine

The Big Horn Mine is located 12 miles north of Sheridan, Sheridan County, Wyoming. It is located near the western edge of the Powder River Coal Region. The mine started production in the 1950's. The 44 ft. Monarch coal seam and the 12 ft. Armstrong coal seam are presently being mined. Production from this mine totaled 750,000 tons in 1976. The coal is mined using the open pit mining method.

The site is characterized by gently rolling hills. The Tongue River traverses the site and has been diverted to allow for mining.

The Big Horn Mine is located in semi-arid transition country between the arid grassland prairie and the more humid forestlands. This location provides the right conditions for a wide diversity of native vegetation, ranging from ponderosa pine to silver sagebrush. Peter Kiewit Sons personnel have identified over 300 vegetation species at this site. Almost all species encountered in the Powder River Coal Region are present at this site.

3. Belle Ayr Mine

The Belle Ayr Mine is located some 15 miles south of Gillette, Campbell County, Wyoming. It is located near the

center of the Powder River Coal Region. The mine started production in 1972. The 68 ft. Smith-Roland coal seam is being mined. Production from this mine was 7.4 million tons in 1976. Increased production figures indicate that the mine may surpass the Decker Mine in production in the near future. The coal is mined using an open pit mining method.

The site is characterized by gently rolling terrain, with Caballo Creek traversing the area. The stream has been rechanneled past the active mining area.

The Belle Ayr Mine is located in arid prairie country, with mainly grassland/sagebrush vegetation. Because of the lack of rainfall, mine revegetation is mainly with native grasses, except along Caballo Creek where tree planting has been attempted.

D. DATA COLLECTION

This task was divided into two related efforts: 1) Ground Data Collections and 2) Aerial Data Collection. These efforts were conducted within the same week to ensure compatibility and reliability of the data.

It should be noted that the western site analysis was not intended to be as comprehensive as the eastern study and was somewhat limited and experimental in scope. For example, only one aerial data collection flight was conducted (no seasonal comparisons were attempted) and ground data collection was less detailed than the eastern study.

1. Ground Data Collection

As a result of actual site visits, and discussions with various western surface coal mine operators and regulatory authorities, it was determined to concentrate the ground data collection efforts on mapping and delineating vegetative, geologic, and hydrologic parameters. These

parameters were considered most promising for data collection by aerial photography. Although considered of lesser importance, conditions related to soils, land use and archaeology were also documented during the ground data collection.

Recent black and white aerial photography of the sites was obtained from the mining companies, and base photography was produced to be used for field mapping and delineation for the various parameters. Because of the diversity of vegetative, geologic, hydrologic, land use and archaeological conditions known to be present at the two Peter Kiewit Mines (Decker and Big Horn), detailed ground data was collected and/or reviewed at these sites. Because soils conditions were similar at the three sites, soil data was collected only at the Decker site.

Ground data collection consisted of compiling existing data from published sources and from mine company field data collection efforts, and of actual field ground data collection. Two teams of HRB-Singer personnel, accompanied by the Bureau of Mines technical monitor, spent a total of eight man days collecting the ground truth data. A geologist and vegetative technician from Peter Kiewit accompanied HRB-Singer personnel for a total of six man days. In addition, the Peter Kiewit personnel provided a large amount of ground data related to vegetation, land use, geology and archaeology, which they had previously collected.

Ground truth data collection for soils consisted simply of checking the regional maps that had been obtained from the Montana State University and delineating local variations. All sites were dominated by the Bainville-Midway soil association. These soils are light colored, and shallow to moderately deep over sandstone, shale, and siltstone. Grazing is the most important use of land with these soils. The only local variation that was noted in the field was the presence of alluvial soils along some streams in the area. The surface of these soils were dark, from organic material accumulation.

Vegetation mapping for ground truth was concentrated at the Decker site. Information at Big Horn was already available to us; and a detailed ground survey was not required at Belle Ayr, since the native vegetation

consists of only one plant community, 10 percent big sage on short grass prairie. Several plant communities, including sagebrush-steppe, grassland-sagebrush, mid-short-grass prairie, Ponderosa pine, badlands and riparian were mapped based on dominants or co-dominants at Decker. This was accomplished by walking across the area and delineating the plant communities directly on a current (July 1976) black and white aerial photograph. Vegetation experts from the mining company helped to identify species.

Archaeology ground truth consisted of confirming the presence of sites which had been identified during Environmental Impact Statement (EIS) preparation for the mining operation.

Geology ground truth was collected by mapping on 1:24,000 quadrangle maps the general surface geology at the sites. The field data was supplemented by some previous field mapping by Peter Kiewit geologists.

Surface drainage, alluvial valleys, and surface water bodies were delineated from visual inspection of the site and from existing data from EIS preparation.

Land use data was collected from existing maps and the base photography. Changes were noted during the field effort.

Less detailed ground data was collected at the Belle Ayr site because of the similarity of the site to conditions at Decker, and because of time constraints related to the ground data collection effort.

The major types of ground data collected for each of the parameters is presented below:

A. Vegetation Parameters

1. Species Type
 - a. Trees
 - b. Shrubs
 - c. Grasses
2. Trees/Acre
3. Shrubs/Acre
4. Percentage of Grass Cover
5. Vegetation Stress

- B. Geologic Parameters
 - 1. Rock Units (Mapping)
 - 2. Faults and Fractures
 - 3. Surface Lithology
 - 4. Unconsolidated Surface Deposits
- C. Hydrologic Parameters
 - 1. Surface Drainage
 - 2. Alluvial Valleys
 - 3. Surface Water Bodies
- D. Soils
 - 1. Erosion
 - 2. Type
 - a. Coal Refuse
 - b. Spoil material
 - c. Stored top soil
 - d. Regraded top soil
 - 3. Slopes
 - 4. Sediment Areas
- E. Land Use
 - 1. Grassland
 - a. Grazed
 - b. Overgrazed
 - c. Ungrazed
 - 2. Residential
 - 3. Agriculture
 - 4. Forest
 - 5. Badlands
 - 6. Abandoned Mine Land
 - 7. Active Strip Pit
- F. Archaeology
 - 1. Trails
 - 2. Habitations
 - 3. Lookouts
 - 4. Buffalo Kills

2. Aerial Data Collection

As a result of discussions with surface mine operators and regulatory personnel, and from previous experience, an aerial data collection flight utilizing color and color infrared photography was conducted during the week of June 27, 1977. This time frame coincided with the greening period of native grasses on the Northern Great Plains.

All the sites were overflown by Kucera and Associates of Cleveland, Ohio, using a ZEISS RMKA 6" mapping camera. The sites were covered completely with 1:12,000 scale aerial photography. This scale corresponds to the scale used over the eastern test sites. In addition, one line of 1:6,000 scale aerial photography was collected over a portion of the Decker site, because there were indications that for detailed vegetation analysis, this scale might be better than smaller scale photography. It was decided to make such a scale comparison for this parameter during the data analysis element.

Both the color and color infrared photography were of excellent quality and flight coverage was very precise. The photography was cataloged and utilized during data analysis.

E. DATA ANALYSIS

Data analysis of the western test sites consisted of two distinct efforts: 1) determine the compatibility of interpretation methodologies used for the eastern sites to perform similar activities for western surface coal mining sites, and 2) determine unique requirements for western sites and discuss utility of color and color infrared aerial photography in providing data to meet those requirements. The methodologies and results of each of these efforts are described in the following sections.

1. Compatibility of Interpretation Methodologies

This effort involved a detailed interpretation of western site aerial photography of 1:12,000 scale similar to that methodology described in Section VII B of this report. These interpretation results were compared to the average interpretation ratings obtained for the eastern sites to determine those interpretation methodologies which apply to both eastern and western surface mining situations. Most of the eastern methodologies could be directly utilized for the western surface mining sites. There were, however, unique requirements and conditions for western surface mining sites which are discussed later in this section. The following is a discussion of the comparison of eastern and western site interpretation results.

a. Comparison of Interpretability Ratings for Reclamation Features and Parameters

The average rating¹ obtained by the interpreters for each reclamation parameter and film type for the eastern and western sites during the spring season is presented in Table 22. A spring season comparison was made, as only a spring flight was conducted for the western site analysis.

As can be seen in the ratings, it was generally easier to perform interpretations on the western sites than on the eastern sites; therefore, the ratings for both color and color IR aerial photography were higher. The average rating for reclamation parameters using color aerial photography was 2.99 for the eastern sites and 3.16 for the western sites. The average rating for the reclamation parameters using color infrared aerial photography was 3.02 for the eastern sites and 3.14 for the western sites.

¹The interpreters used a rating scale between zero and four. The ratings were:

- 0 - feature cannot be mapped
- 1 - feature can be mapped only with a large amount of difficulty and low accuracy (25%)
- 2 - feature can be mapped with minor difficulty and 50% accuracy
- 3 - feature can be mapped with minimal difficulty and 75% accuracy
- 4 - feature can be mapped easily with 100% accuracy

TABLE 22 AVERAGE INTERPRETABILITY RATINGS FOR RECLAMATION PARAMETERS SPRING SEASON

77-71

PARAMETER:	AVERAGE EASTERN SITES		AVERAGE WESTERN SITES	
	COLOR	COLOR IR	COLOR	COLOR IR
ACTIVE RECLAMATION	3.82	3.91	3.91	3.95
COMPLETED RECLAMATION	3.71	3.70	3.75	3.74
REFUSE MATERIAL	3.71	3.84	3.74	3.84
TOP SOIL PILES	3.79	3.60	3.81	3.75
TOP SOIL REGRADED	3.49	3.54	3.62	3.63
SPOIL PILES	3.62	3.88	3.75	3.85
SPOIL REGRADED	3.49	3.54	3.51	3.52
RILL EROSION (IDENTIFICATION)	3.23	3.34	3.52	3.58
GULLY EROSION (IDENTIFICATION)	3.74	3.70	3.86	3.84
SHEET EROSION (IDENTIFICATION)	2.32	2.42	2.74	2.76
RILL EROSION (LENGTH)	3.41	3.32	3.52	3.51
GULLY EROSION (LENGTH)	3.49	3.26	3.61	3.42
RILL EROSION (WIDTH)	2.03	1.96	2.24	2.20
GULLY EROSION (WIDTH)	2.58	2.61	3.12	3.11
RILL EROSION (DEPTH)	.71	.63	.92	.75
GULLY EROSION (DEPTH)	.92	.37	1.18	.67
CONIFEROUS TREE IDENTIFICATION	2.26	3.36	3.15	3.65
DECIDUOUS TREE IDENTIFICATION	3.13	3.30	3.00	3.15
RECLAMATION GRASSES IDENTIFICATION	3.18	3.47	3.25	3.62
TREES/ACRE MEASUREMENT	3.18	3.42	3.51	3.52
PERCENT COVER GRASSES	3.28	3.27	3.40	3.35
VEGETATIVE VIGOR	1.82	1.94	1.86	1.85
VEGETATIVE DISTURBANCE	3.17	3.09	3.18	3.12
SLOPE MEASUREMENT	3.60	X	3.72	X
AVERAGE	2.99	3.02	3.16	3.14

The results of this analysis indicates that the interpretation methodologies developed for eastern surface mine reclamation parameters can be directly applied to western surface mining. However, in areas such as vegetation analysis, more detail is required in most western surface mining situations. This is described in the discussion on unique western requirements.

b. Comparison of Interpretability for Pre-mine Planning and Mine Progress Features

The average rating obtained by the interpreters for each pre-mine planning and mine progress monitoring parameter and each film type for the eastern and western sites during the spring season is shown in Table 23.

As the interpretability ratings indicate, slightly higher values were obtained for both color and color infrared aerial photography over the western sites. The ratings were 3.70 and 3.76 respectively, as compared to 3.61 and 3.71 over the eastern sites.

The results of this analysis indicate that the interpretation techniques developed for eastern surface mines can be directly used for the western surface mining sites. However, in several areas such as soils, geology, and vegetation, more detail is required in the western surface mining cycle than was feasible or required in the eastern situation. The fact that a large amount of data is required for pre-mining assessments, for monitoring of mining operations and for making determinations of reclamation success in the western areas makes the interpretation requirements more detailed. This is described in the section on special western requirements.

c. Cost Comparisons for Data Collection

In general, the cost for collecting aerial photography in the West is similar to those costs detailed in Tables 10, 15 and 16 in Section VIII of this report. The cost of interpretation is greater for the western surface mine areas than for the eastern sites, however, the amount of information derived from interpretation is also greater for the

TABLE 23 AVERAGE INTERPRETABILITY RATINGS FOR PREMINE PLANNING AND MINE PROGRESS PARAMETERS-SPRING SEASON 77-71

PARAMETER	AVERAGE EASTERN SITES		AVERAGE WESTERN SITES	
	COLOR	COLOR IR	COLOR	COLOR IR
AGRICULTURE	3.98	3.96	3.99	3.99
PASTURE/GRASSLAND	3.97	3.97	3.99	3.99
RESIDENTIAL	3.90	3.96	3.95	3.97
ABANDONED STRIP PIT	3.84	3.90	3.90	3.92
UTILITY LINES	3.11	3.22	3.56	3.59
TRANSMISSION LINES	3.43	3.58	3.60	3.62
ROADS	3.85	3.87	3.91	3.91
DRAINAGE PATTERNS	3.01	3.11	3.25	3.27
PREPARATION FACILITIES	3.99	3.99	3.99	3.99
STORAGE FACILITIES	3.97	3.97	3.99	3.99
SHIPPING AREAS	3.95	3.97	3.99	3.99
MINING EQUIPMENT	3.23	3.60	3.50	3.60
IMPROVEMENTS	3.80	3.76	3.60	3.76
DRAINAGE DITCHES	3.34	3.50	3.41	3.51
PUDDLES	3.20	3.65	3.25	3.70
LINEAR MEASUREMENTS	3.09	3.19	3.10	3.21
AREA MEASUREMENTS	3.79	3.84	3.80	3.84
HIGHWALL HEIGHT	3.81	X	3.80	X
OVERBURDEN REMOVAL ESTIMATE	3.61	X	3.63	X
AVERAGE	3.61	3.71	3.70	3.76

western sites. This trade-off will probably make aerial photography even more cost-effective than in the East. In addition, the cost on a per ton of coal basis of collecting and interpreting the aerial photography will decrease significantly in the West because of the significantly larger coal production on a per acre basis.

It was not possible to quantify the exact cost benefit of color and/or color infrared photography because of the limited scope of this analysis. It is evident, however, that using color or color infrared aerial photography in conjunction with a ground data collection program would be more cost-effective than a data collection and monitoring program utilizing only ground data collection.

2. Special Uses of Color and Color Infrared Aerial Photography for Western Surface Coal Mining Planning and Monitoring

During the analysis of the compatibility of interpretation methodologies and as a result of previous work on western mining sites, it became obvious that there were several areas where more detailed photographic interpretation techniques were needed for western mining sites. In addition, several unique potential uses of aerial photographic interpretation were determined. This section discusses the special and unique uses and the results of an analysis of techniques related to these uses.

a. Vegetation Analysis

A key element for the pre-mining environmental assessments and for post-mining reclamation activities is vegetation discrimination and mapping. Related to vegetation analysis are such areas as wildlife habitat analysis and range management. Because of the importance of vegetation analysis in the western surface mining cycle, a separate, detailed study of the use of color and color infrared aerial photography for vegetation analysis was undertaken.

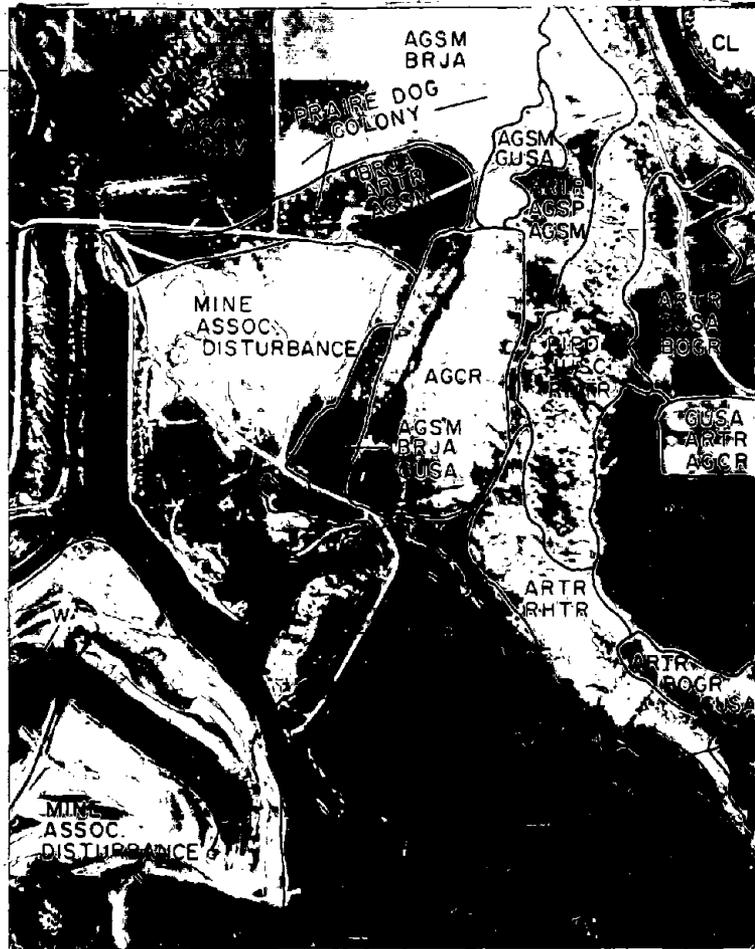
In the previous discussion on the comparison of interpretation ratings, it was found that the interpretation methodologies developed in the East for discriminating coniferous trees, deciduous trees, and grasses

could be used for the western sites. This comparison was accomplished on all of the western test sites.

However, regulations make more detailed vegetation analysis mandatory at the western surface mining sites. One of the most important aspects of vegetation analysis is detailed species discrimination. For this detailed analysis the Big Horn mine site was selected because of the diversity of vegetative cover and the availability of detailed vegetative ground truth provided by Peter Kiewit Sons Company. Several interpreters familiar with western vegetation performed detailed species discrimination on a portion of the Big Horn mine site using 1:12,000 color and color infrared aerial photography. Each interpreter was provided a list of major species present on the site and was required to delineate the results of this discrimination on photo overlays. Species discrimination using color photography was difficult in that differentiation of individual species was difficult. However, color infrared aerial photography proved to be a valuable tool for vegetation species mapping. The only difficulty encountered was in the differentiation of certain herbaceous species, especially native grasses. However, the discrimination of weed invader species on seeded reclamation areas was accomplished quite easily. The two weed species Salsola kali and Kochia scopulorum were extremely visible and indicated vegetative progression in reclaimed areas.

Figure 24 is a color infrared aerial photograph of the study area with an overlay showing the results of species discrimination. This closely matched the ground truth data.

In order to determine if larger scale photography could be utilized for more detailed differentiation of herbaceous species, 1:6,000 scale color and color infrared aerial photography was examined to determine the increased detail present. It was found that there was little increase in accuracy using the color aerial photography at this scale. However, color infrared photography at 1:6,000 allowed the interpreters to discriminate herbaceous species with less difficulty than the 1:12,000 scale color infrared. However, most grasses and all small forbs are not identifiable except through



AGCR
AGSM
ARTR
BRJA
GUSA
AGSP
PIPO
JUSC
RHTR
BOGR
PL
CL
DF
W

CRESTED WHEATGRASS
WESTERN WHEATGRASS
BIG SAGE
ANNUAL BROME
BROOM SNAKEWEED
BLUEBUNCH WHEATGRASS
PONDEROSA PINE
JUNIPER
3-LEAF SUMAC
BLUE GRAMMA
PASTURE LAND
CULTIVATED LAND
DECIDUOUS FOREST
WATER

AGROPYRON CRISTATUM
AGROPYRON SMITHII
ARTEMISIA TRIDENTATA
BROMUS JAPONICUS
GUTTIERREZIA SAROTHRAE
AGROPYRON SPICATUM
PINUS PONDEROSA
JUNIPERUS SCOPULARUM
RHUS TRILOBATA
BOUTELOUA GRACILIS

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FIG. 24 VEGETATION MAP OF STUDY AREA DERIVED FROM 1:12,000 SCALE
COLOR INFRARED AERIAL PHOTOGRAPHY-BIG HORN MINE

inference. An experienced interpreter possessing a thorough knowledge of local ecology and plant associations can provide an educated guess as to the presence of certain grasses and forbs after reviewing the identified species on the photographs.

The need for plant frequency and density statistics during a pre-mining environmental assessment is indicative of the detailed information needed for the western mining situation. At this time, these statistics are generated by permanent ground transects which are field checked on an annual basis. This is a time consuming and expensive procedure. The development of aerial photographic techniques to collect this type of data for shrub and tree species could not be addressed within this limited study; however, the development of these techniques would result in significant ground data collection reduction and cost savings. It should be noted that plant frequency and density statistics for grasses would be difficult to accomplish because of resolution limitations of aerial photography. None of the techniques developed for the eastern study are compatible with this informational need.

The results of this analysis indicate that color infrared photography can be an excellent tool for species discrimination on western surface mine sites. Two factors must be considered, however: first, this type of interpretation can only be accomplished by an experienced interpreter familiar with western vegetation; second, one must determine the amount of detail required versus the cost of various scales of photography. Larger scale photography results in more detailed information, but the costs of data collection of the larger scale photography increase significantly.

It should be noted that this western analysis was limited in scope in that data from only one flight was utilized.

b. Geologic Mapping

Geologic mapping, including coal outcrops, fractures, faults, and linears, is an important aspect of pre-mine planning of any surface mine. A key to successful geologic mapping with aerial photography (photogeology) is the absence of a dense tree canopy. If a tree canopy is present, it often obscures surface geologic features.

Because of the heavy tree canopy in the East, geologic mapping is generally done by ground surveys. The analysis of the eastern sites indicated that it is difficult to utilize aerial photography for detailed geologic mapping of surface mine sites.

In the West, however, it was felt that aerial photography could be utilized as a tool to reduce the amount of ground geologic mapping needed. The general absence of tree cover in the Powder River Basin, and in many parts of the West makes photogeologic interpretation less difficult than in the East.

Two photogeologists utilized the 1:12,000 color aerial photography of the sites to perform geologic interpretation. Figure 25 shows the results of the geologic interpretation over a portion of the Decker mine site. It was found that features such as benchlands, drainages, alluvial deposits, scoria outcrops, faults, fractures, and linears were easily mapped. This indicates that color aerial photography can be a useful tool for geologic mapping. An interesting point brought out by the photogeologists is that smaller scale color aerial photography such as 1:24,000 may provide more useful geologic information, in that larger areas could be interpreted and more subtle regional features may be detected.

Color photography is generally used for photogeologic interpretation rather than color infrared because tonal patterns are a major key in geologic interpretations. Color photography provides true tonal patterns for interpretations. It should be noted that photogeology, much like vegetation analysis, should be performed by a geologist trained in photographic interpretation techniques.



1  ACTIVE MINING

2  BENCHLANDS (FLAT PLATEAUS) SEPARATED BY ESCARPMENTS, BENCHLANDS ARE UNDERLAIN USUALLY BY SANDSTONE OR ANY ROCK MORE RESISTANT TO EROSION. IN SOME AREAS THE CAPROCK OR SANDSTONE LEDGES CAN BE TRACED ON AERIAL PHOTOS OVER DISTANCES THAT ALLOW SOME ESTIMATES OF REGIONAL STRIKE AND DIP.

3  SCORIA OR CLINKER CHARACTERIZED BY AN ORANGE TO RED COLOR AND VERY HUMMOCKY RELIEF

4  DRAINAGE CHANNELS UNDERLAIN BY ALLUVIAL DESPOSITS OR CUT TO BEDROCK

5  FRACTURE TRACES

6  FAULTS

FIG. 25 GEOLOGIC INTERPRETATION OF COLOR PHOTOGRAPHY AT 1:12,000 SCALE - DECKER MINE

In summary, color aerial photography can be utilized for geologic reconnaissance on the western sites. Indications are that smaller scale photography may be useful for this application.

c. Archaeological Reconnaissance

A unique requirement for pre-mining environmental assessments at western surface mine sites is the identification of areas of potential archaeological significance. This requirement was mentioned by several members of the coal community that were contacted, and at least one surface mine operator is actively pursuing the use of color aerial photography for archaeological exploration.

In order to determine the utility of color aerial photography for archaeological reconnaissance, areas of potential archaeological significance on the Decker site were identified from existing ground studies. These studies identified such areas as habitations (teepee rings), lookouts and sites of buffalo kills. The 1:12,000 and 1:6,000 color aerial photography was then studied in detail to determine if such known sites could be identified on the aerial photography. The results of this analysis indicated that these scales were not of sufficient resolution to locate these sites. It is possible, however, that larger scale color photography could be used for archaeological reconnaissance. However, such scales were not included in the scope of this analysis.

It should be noted, however, that color aerial photography of scales of 1:6,000 and 1:12,000 could be used as a preliminary reconnaissance tool for archaeological studies. Possible habitat areas could be identified by topographically high areas, defensible positions, and proximity to water. These areas could be identified and then ground checked for verification.

F. CONCLUSIONS

As a result of the western site analysis the following conclusions were made:

- Most of the interpretation techniques developed for the eastern sites can be utilized for the western surface coal mining sites.

- In the areas of vegetation analysis, geologic reconnaissance and archaeology, more detailed information is required or could be utilized for western surface coal sites.
- The level of expertise in photographic interpretation is higher in western surface mining organizations because of more detailed data requirements.
- This analysis, although limited in scope, indicated that color aerial photography compares favorably with color infrared photography in interpretability except in the area of detailed vegetation analysis, where the infrared photography is better.
- Larger scale photography (less than 1:6,000) are probably more useful for vegetation analysis and archaeological reconnaissance in the West.
- Smaller scale photography (greater than 1:12,000) is useful for regional geologic interpretation.
- Costs of aerial data collection in the West are comparable to the costs developed for the eastern sites.
- Interpretation costs in the West are more variable depending upon the level of detail required.

G. RECOMMENDATIONS

As a result of the analysis and conclusions of the western study the following recommendations are made:

- Seasonal and variable scale color and color infrared aerial photography should be collected over selected test sites to develop detailed interpretive procedures for vegetation analysis, geologic reconnaissance, and archaeological mapping relating to surface coal mining in the West.
- Detailed costs of interpretation should be developed for western site aerial photographic interpretation.
- A manual of photographic interpretation should be developed to address the unique informational requirements associated with western mining. The manual should include newly developed techniques for vegetative, geologic, and archaeological analyses. The manual should also address the standard procedures for land use, soils, and water interpretation, as well as basic photogrammetric methods useful in the mining situation.
- Consideration should be given to short-course training for western operators and regulatory personnel.

XI. RECOMMENDATIONS

At approximately the mid-point of this study it became apparent from preliminary results that color and color infrared aerial photography could be effective tools for meeting certain informational needs of operators and possibly regulatory personnel. At this time discussions with operators and regulatory personnel indicated a lack of experience and knowledge concerning aerial photography. Based on the results of this study and discussions with the mining community the following recommendations are made.

1. Because of the general lack of knowledge within the mining community the manual was written at the beginner level. Although the manual was designed to introduce the use of aerial photography to the mining community there is no substitute for personal contact with an instructor. In light of expressed interest which we have noted, it is recommended that a short course be developed to present the material covered in the manual.

2. It is suggested that the manual be distributed in a manner that provides optimum visibility and availability to the mining community, especially surface mine operators.

3. The study task concerned with the western surface mining situation brought to light certain needs for further investigations. Western surface operators could use aerial photography for detailed vegetative mapping, geologic mapping, and archaeological investigations. Informational needs in these three areas are very great especially for preliminary environmental analysis and impact statements. It is recommended that an additional study be conducted to determine the utility of utilizing aerial photography for collecting information concerning pre-mine vegetation, both quantity and quality; geology; archaeology; and post-mining reclamation vegetation, quantity and quality.

XII. USER RECOMMENDATIONS

The following paragraphs contain recommendations concerning the time of day, scale, film type, camera, and season for using aerial photography for pre-mine planning, mine monitoring and reclamation monitoring.

Pre-mine Planning - Low sun angles are not useful for monitoring most pre-mine planning features. Aerial photography should be collected between 10:00 a.m. and 2 p.m. If only one flight can be afforded for pre-mine planning color film should be collected with a 6 inch focal length mapping camera just after leaf drop in the fall. The photography can be used to effectively map all land use features and cultural features (cemeteries, transmission lines, etc.) which could affect the mining plan. Water bodies and drainage patterns can be mapped for pre-mine water testing on the ground. Yellowboy is still visible at this time and the photography can be used to document its presence. Photo-geologic interpretations can be made from this photography; however, black and white photogrpahy at a scale of 1:24,000 would be more useful and could be collected during the same fall flight. Some vegetation interpretations could be made on the fall color photography; however, vegetation type and cover is best determined on late spring photography. Pre-mine vegetation typing will be important because the new federal strip mine regulations require the establishment of vegetative reference areas before mining can begin. The vegetative quality on the reference areas will be used as a standard to judge revegetation reclamation quality. Preliminary selection and characterization could be accomplished on aerial photography.

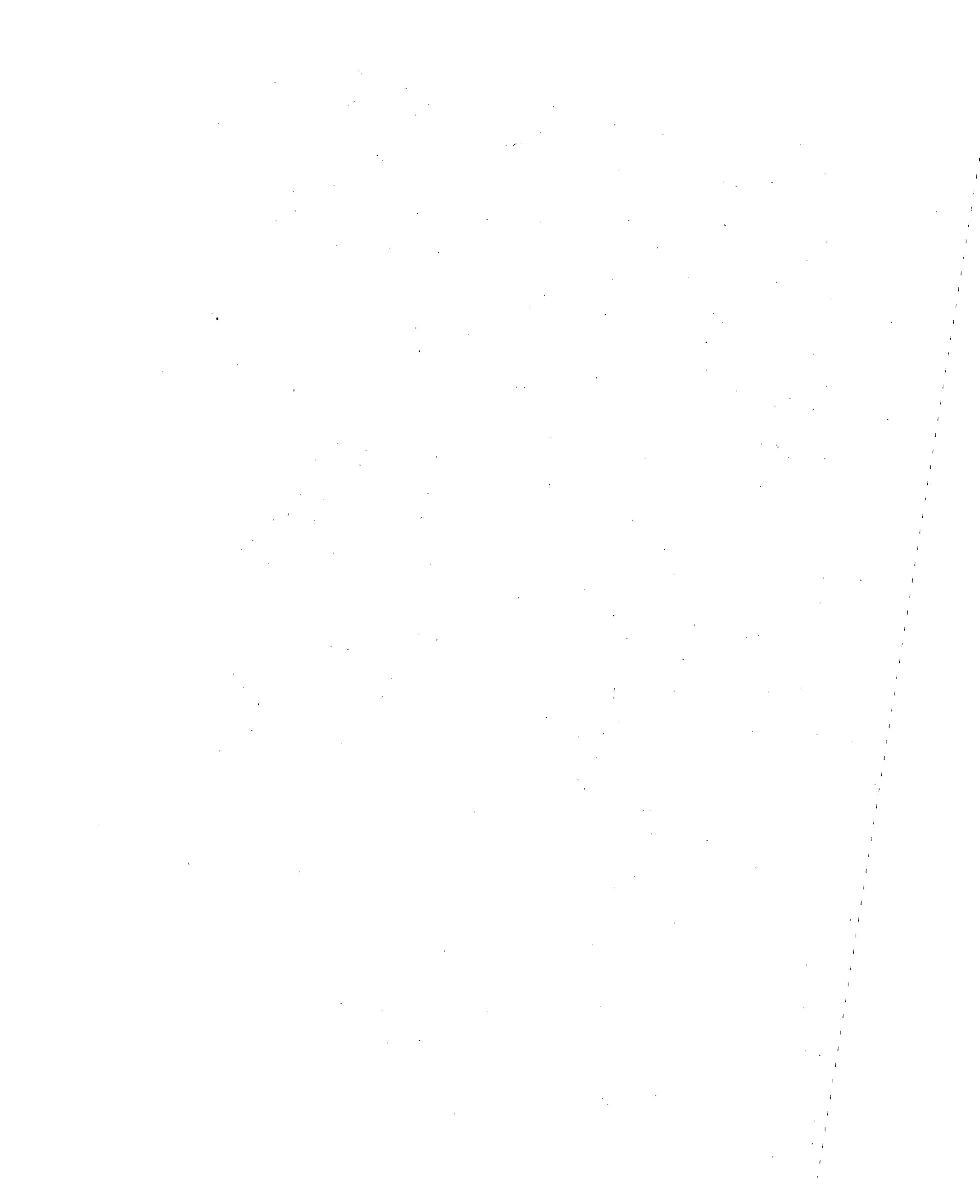
Mine Monitoring - Photography should be collected between 10:00 a.m. and 2:00 p.m. because low sun angles will not enhance interpretation of mine monitoring features. Color photography collected during spring, summer or fall at 1:12,000 scale with a 6 inch focal length mapping camera is recommended for mine monitoring purposes. Color is recommended over black and white because soil and spoil differentiations are more accurate on color photography and because yellowboy water quality problems that may arise from mining can be seen on the color

photography. If the photography is only being used for mine progress monitoring of parameters such as overburden removed, regraded area measurements, spoil area measurements, etc. then black and white photography at a scale of 1:12,000 is sufficient to accomplish these measurements.

Reclamation Monitoring - Photography should be collected between 10:00 a.m. and 2:00 p.m. to avoid low sun angles. Color photography at 1:12,000 scale collected in late spring with a 6 inch focal length mapping camera is recommended for reclamation monitoring.

Film Types - Color infrared photography has not been recommended even though interpretability ratings were slightly higher for most features when color infrared was used, and the costs of collecting and processing color infrared photography are lower than the costs for color photography. We have not recommended the use of color infrared photography for the following reasons: 1) Color infrared photography is cheaper than color if the format is a transparency. Light tables are necessary to interpret color infrared transparencies. This negates any effective use of color infrared transparencies in the field. 2) Some water quality features are not visible on color infrared photography. Water reflects very little infrared light and therefore, the bottoms of water bodies are not very visible on color infrared photographs. 3) The interpretation accuracies shown in Table 10 for color infrared can not be attained by neophyte interpreters. A total understanding of the color formation process on color infrared film is necessary before interpreters can begin to attain good interpretation accuracies.

Stereo coverage is desired for pre-mine planning, mine monitoring, and reclamation monitoring.



APPENDIX A REMOTE SENSING BIBLIOGRAPHY

REMOTE SENSING BIBLIOGRAPHY

VEGETATION REFERENCES

- Aldred, A. H. and Kippen, F. W., 1967.
Plot volumes from large scale 70mm air photographs.
Forest Science 13: 419-426.
- Avery, E. T., 1968
Interpretation of Aerial Photographs
Burgess Publishing Co., Minneapolis, MN, 324 pp.
- Bailey, W. F., 1973
Beetle Damage in the Black Hills National Forest
Proceedings: Fourth Biennial Workshop: Color Aerial Photography
in Plant Sciences, University of Maine, Orono, Maine, pp. 227-232.
- Benson, M. L. and Sims, W. G., 1967.
False color film fails in practice.
Journal of Forestry 65: 904.
- Carnegie, D. M., 1968
Remote sensing applications for the inventory of range resources.
First Annual Earth Resources Program Review, NASA Manned
Spacecraft Center, Houston, Texas, pp. 39-1 to 39-27.
- Ciesla, W. M.; Drake, L. E.; and Wilmore, D. H., 1971.
Color photos, aerial sprays, and the forest tent caterpillar.
Photogramm Eng. 37: 867-873.
- Ciesla, W. M., 1974.
Forest insect damage from high altitude color IR photos.
Photogramm Eng. 40: 683-689.
- Colwell, J. E., 1974.
Vegetation canopy reflectance.
Remote Sensing of Environment 3: 175-183.
- Colwell, R. M., 1956.
Determining the prevalence of certain cereal crop diseases by means
of aerial photography.
Hilgardia 26(5).
- Driscoll, R. S., 1970.
Identification and measurement of shrub-type vegetation on large
scale aerial photographs.
Third Annual Earth Resources Program Review NASA Manned Space-
craft Center, Houston, Texas, p. 32-1 to 32-15.

- Driscoll, R. S., 1971.
Color aerial photography - a new view for range management.
U.S. Forest Service Research Paper RF-67, p. 11, Rocky Mt.
Forest and Range Exp. Station, Ft. Collins, Colorado.
- Driscoll, R. S.; Currie, O.; and Morris, M. J., 1972.
Estimates of herbaceous standing crop by microdensitometry.
Proceedings: 38th Annual Meeting, American Society of Photo-
grammetry, p. 358-364.
- Driscoll, R. S. and Coleman, M. D., 1974.
Color for shrubs.
Photogramm Eng. 40: 451-459.
- Edwards, G. J.; Schell, T.; and Ducharme, E. P., 1975.
Multispectral Sensing of citrus young tree decline.
Photogramm Eng. 41: 653-657.
- Fritz, E. L. and Pennpacker, S. P., 1974.
Satellite detection of vegetative damage and alteration caused by
pollutants.
Annual Meeting, American Phytopathological Society, Vancouver,
British Columbia (Abstract).
- Fritz, N. L., 1967.
Optimum methods for using infrared-sensitive color films.
Photogramm. Eng. 33: 1128-1138.
- Fox, L., 1973.
Remote sensing of Fomes Annosus in pine plantations and of pine
canopies in general.
Proceedings: Fourth Biennial Workshop, Color Aerial Photography
in Plant Sciences, University of Maine, Orono, Maine, p. 77-93.
- Garofalo, D. and Wobber, F. J., 1973.
Remote Sensing for Environmental studies in mined areas.
Photographic Applications 8(5): 32-48.
- Gausman, H. W.; Allen, W. A.; Myers, U. T.; and Cardenas, R., 1969.
Reflectance and internal structure of cotton leaves Gossypium
hirsutum L.
Agronomy Journal, Vol. 61: 374-376.
- Gausman, H. W., 1974.
Leaf reflectance of near-infrared.
Photogramm Eng. 40: 183-191.
- Heath, G. R., 1974.
ERTS data tested for forestry applications.
Photogramm Eng. 40: 1087-1091.

- Heller, R. C., 1969.
Large scale photo assessment of smog-damaged pines.
New Horizons in color aerial photography. Published jointly by:
The American Society of Photogrammetry and The Society of
Photographic Scientists and Engineers.
- Heller, R. C., 1970.
Remote detection of insect epidemics in Conifers.
Third Annual Earth Resources Program Review, NASA Manned
Spacecraft Center, Houston, Texas, p. 34-1 to 34-36.
- Heller, R. C., 1971.
Color and false color photography: its growing use in forestry.
INT Union Forest Research Organization, Section 15, Freidburg,
Germany, Druckhaus and Romback and Co., pp. 37-56.
- Klein, W. H., 1973.
Beetle killed pine estimates.
Photogramm Eng. 39: 385-388.
- Knipling, E. B., 1970.
Physical and physiological basis for the reflectance of visible and
near infrared radiation from vegetation.
Remote Sensing of Environment 1: 155-159.
- Krumpe, P. R., 1971.
An ecological analysis of forest landscape parameters by multiband
remote sensing.
Seventh Int. Symp. Remote Sensing of Envir., Ann Arbor, Michigan,
p. 715-730.
- Latham, R. P., 1972.
Competition estimators for forest trees.
Photogramm Eng. 38: 48-50.
- Meyer, M. P. and Franch, D. W., 1967.
Detection of diseased trees.
Photogramm Eng. 33: 1035-1040.
- Murtha, P. A. 1971.
A guide to Air Photo Interpretation of Forest Damage in Canada.
Canadian Forest Service Publication No. 1292.
Canadian Forestry Service, Ottawa, Ontario.
- Norman, G. G. and Fritz, N. L., 1965.
Infrared photography as an indicator of disease and decline in citrus
trees.
Proc. Florida State Horticultural Society
78: 59-63.

- Parry, J. T.; Cowan, W. R.; and Heginbottom, J. A., 1969.
Color for coniferous forest species.
Photogramm Eng. 35: 669-678.
- Payne, J. A.; Hart, W. G.; Davis, M. R.; Jones, L. S.; Weaver, D. J.; and
Horton, B. D., 1971.
Detection of peach and pecan pests and diseases with color infrared
aerial photography.
Proceedings: Third Biennial Workshop, Color Aerial Photography in the
Plant Sciences, University of Florida, Gainesville, Florida,
p. 215-229.
- Pearson, R. L., 1972.
Remote mapping of standing crop biomass for estimation of the pro-
ductivity of the shortgrass prairie.
Eighth Int. Symp. Remote Sensing of Envir., Ann Arbor, Michigan,
p. 1355-1379.
- Rhode, G. W. and Olson, C. E., 1970.
Detecting tree moisture stress.
Photogramm Eng. 36(6): 561-566.
- Rhode, W. G. and Olson, C. E., 1972
Multispectral sensing of forest tree species.
Photogramm Eng. 38: 1290-1212.
- Sayn-Wittgenstein, L., 1960.
Recognition of tree species on air photographs by crown characteristics.
Canadian Department of Forestry Technical Note No. 95, pp. 56.
- Sayn-Wittgenstein, L., 1961.
Phenological aids to species identification on air photographs.
Canadian Department of Forestry Technical Note No. 104, pp. 26.
- Sayne-Wittgenstein, L. and Aldred, A. H., 1972.
Tree size from large scale photos.
Photogramm Eng. 38: 971-973.
- Turner, R. M., 1970.
Measurement of plant community cover from aerial photographs using
ektrackrome infrared aero film.
Third Annual Earth Resources Program Review NASA Manned Spacecraft
Center, Houston, Texas, p. 50-1 to 50-8.
- Van Arsdel, E. P.; Bush, D. L.; and Jares, T. W., 1974.
Previsual detection of oak decline and rust diseases in Texas with
infrared photography.
Annual Meeting, American Phytopathological Society, Vancouver,
British Columbia (Abstract).

Weber, F. P. and Polcyn, F. C., 1972.

Remote Sensing to detect stress in forests.
Photogramm Eng. 38(2): 163-175.

Wobber, F. J. and Garofalo, D., 1971.

Remote Sensing for Mined Area Reclamation: Applications Inventory.
USDI, Bureau of Mines., pp. 40.

Wobber, F. J. and Amato, R. V., 1974.

Photography and the environment Part II: Aerial photography for
surveying surface mining and reclamation.
Photographic Applications 9(5): 22.

REMOTE SENSING BIBLIOGRAPHY

WATER REFERENCES

- Ambionics, Inc., Washington, D.C.
Remote Sensing of Coal Mine Pollution in the Upper Potomac River Basin, 1974, p. 70, NASA - CR 132529.
- Blanchard, Bruce J. and Leamer, Ross W., 1973.
Special Reflectance of Water Containing Suspended Sediment.
Remote Sensing and Water Resources Management, edited by Keith P. B. Thomson, Robert K. Lane and Sandor C. Sallany.
American Water Resources, Urbana, Illinois, pp. 339-347.
- Brown, W. L., F. C. Polcyn, A. N. Sellman and S. R. Stewart, 1971.
Water Depth Measurement by Wave Refraction and Multispectral Techniques.
Report No. 31650-31-T, Willow Run Labs., Ann Arbor.
- Brown, W. L., Polcyn, F. C., McKinney, J. R. and Polwett, O. E., 1972.
Calculating Water Quality Parameters Using Remotely Sensed Scanner Data.
Proceedings of the Eighth International Symposium on Remote Sensing of Environment.
Ann Arbor, Michigan, pp. 563-567.
- Burnett, E. S. and White, P. G., June-July, 1970.
Water Pollution: The Role of Remote Sensing.
Journal of Remote Sensing.
Vol. 1, No. 3, pp. 8-14.
- Chandler, P. B., Dowdy, W. L., and Hodder, D. T., Sept., 1970.
Study to Evaluate the Utility of Aerial Surveillance Methods in Water Quality Monitoring.
Prepared for State Water Resources Control Board, the Resources Agency, State of California, Pub. No. 41, p. 98.
- Chase, Phillip E., 5 August 1972.
Ecological Effects of Strip Mining in Ohio.
Progress Report.
Principal Investigator, Bendix Corp., Ann Arbor, Mich.
- Cooper, R. A. McGuinness, R., Mintzer, O. W. Ricca, V. T., Shumante, K. F., Wilson, R. A., Jr., June 1969.
Applications of Color Aerial Photography in Water Pollution Studies.
New Horizons in Color Aerial Photography.
American Society of Photogrammetry.

- Davis, Ernst M., Fosbury, W. J., Dec. 1972.
Application of Selected Methods of Remote Sensing for Detecting
Carbonaceous Water Pollution.
Texas Univ., Houston, Inst. of Environmental Health.
- Deely, Daniel J., Russell, Orville R. and Wobber, Frank J., 1973.
Applications of Aerial and Orbital Remote Sensing to the Study of
Mined Lands.
Papers Presented Before the Research and Applied Technology Symposium
on Mined-Land Reclamation.
Pittsburgh, Pa.
- Garofalo, Donald and Wobber, Frank J., Sept. 1973.
Remote Sensing for Environmental Studies in Mined Areas.
Photographic Applications in Science, Technology and Medicine, pp 32.
- Hodder, D. T., 1973.
Evaluation of Water Penetration Photography for Bottom Sediment
Mapping in Little Harbor, Catalina Island.
Presented at American Society of Photogrammetry and American Society
of Surveying and Mapping Fall National Convention Symposium on Remote
Sensing in Oceanography.
- Hom, Leonard W., October 1968.
Remote Sensing of Water Pollution.
Journal of Water Pollution Control Federation.
Vol. 40, pp. 1928-1938.
- Hoskins, E. R. Hainmerquist, D. W., Rahn, P. H., 1969.
A Preliminary Investigation of Terrestrial and Low Altitude Aerial
Infrared Photography as an Aid in Determining Water Table Depths and
Buried Geologic Structures in the Pierre Shale in western South Dakota.
Final Report of the South Dakota School of Mines and Technology.
The South Dakota Highway Dept. and the Federal Highway Administration.
- Johnson, Gene O. and Willson, Robert D., 1969.
A Color and Color Infrared Study of Mine Acid Drainage in Rich Run
of Jackson County, Ohio.
- Kiefer, Ralph W. and James P. Scherz, Jan. 1971.
Aerial Photography for Water Resources Studies.
Presented at ASCE National Water Resources Engineering Meeting.
Wisconsin Univ., Madison; Dept. of Civil Eng., Phoenix, Arizona.
- Link, Lewis Edwin, Jr., August, 1973.
The Use of Remote Sensing Techniques for Detection and Identification
of Pollutant Discharges.
A Thesis submitted to the Faculty of Mississippi State University.

- McCauley, James R., Yarger, Harold W., James, Gerald W., Magnuson, Larry M. and Marzolf, G. Richard, 1973.
ERTS-1 Reservoir Monitoring Studies in Kansas.
Remote Sensing and Water Resource Management, edited by Keith P. B. Thomson, Robert K. Lane and Sandor C. Csallany.
American Water Resources Association, Urbana, Illinois, pp. 112-119.
- McCauley, James R., June-August 1974.
Skylab Study of Water Quality.
Progress Report.
Kansas University, Lawrence.
- Mitsch, William J., May 1973.
Remote Sensing of Water Quality: A State of the Art Report.
Florida University, Gainesville.
- Neumaier, Gerhard and Silvestro, Frank, 1969.
Measurement of Pollution Using Multiband and Color Photography.
New Horizons in Aerial Photography.
American Society of Photogrammetry, Falls Church, Va., pp. 47-58.
- Oswald, William J., 1969.
Remote Sensing Data and Evaluation of Water Quality.
Proceedings: First Annual International Remote Sensing Institute Symposium.
Sacramento, California, Vol. 2, pp. 142-153.
- Petrus, Carolyn A., 1975.
Investigation of Exit Areas of Groundwater Related to Anthracite Deep Mines.
Proceedings from the International Conference on Environmental Sensing and Assessment.
Las Vegas, Nevada.
- Pionke, H. B. and Blanchard, B. J., March 1975.
Water, Air and Soil Pollution.
Vol. 4, No. 1, pp. 19-32.
- Polcyn, Fabian C. and Lyzena, David R., 1973.
Multispectral Sensing of Water Parameters.
Remote Sensing and Water Resources Management, edited by Keith P. B. Thomson, Robert K. Lane and Sandor C. Csallany.
American Water Resources Association, Urbana, Illinois, pp. 394-403.
- Prewett, O. E. Lyzena, D. R. and Polcyn, F. C., 1973.
Techniques for Measuring Light Absorption Scattering, and Particle Concentrations in Water.
Environmental Research Institute of Michigan, Ann Arbor.

- Ruff, J. F., Feb. 1973.
A Feasibility Study of Using Remotely Sensed Data for Water Resource Models.
Colo. State Univ., Fort Collins.
- Scherz, J. P., October 2-6, 1972, (Wisconsin, University, Madison, Wis.)
Development of a Practical Remote Sensing Water Quality Monitoring System.
Proceedings from the International Symposium on Remote Sensing of Environment, 8th.
Ann Arbor, Mich., Proceedings, Vol. 1.
- Scherz, James P. and Van Domelen, John F., 1973.
Lake Superior Water Quality near Duluth from Analysis of Aerial Photos and ERTS Imagery.
Remote Sensing and Water Resources Management, edited by Keith P. B. Thomson, Robert K. Lane and Sandor C. Csallany.
American Water Resources Association, Urbana, Illinois, pp.147-160.
- Schneider, William J. and Kolipinski, Milton C., 1969.
Applications of Color Aerial Photography to Water Resources Studies.
American Society of Photogrammetry.
Falls Church, Va. pp. 257-262.
- Schubert, J. S. and Machead, N. H., 1973.
Digital Analysis of Potomac River Basin ERTS Imagery: Sedimentation Levels at the Potomac-Anacostia Confluence and Strip Mining in Allegheny Co., Md.
NASA Goddard Space Flight Center Symposium on Significant Results obtained from the ERTS-1.
Vol. 1, Section A and B, p. 659-664.
- Silvestro, Frank B., April 20-24, 1969.
Quantitative Remote Sensing of Water Pollution.
Proceedings of the 15th Annual Technical Meeting: Man and His Environment.
Institute of Environmental Science, Anaheim, Calif., pp. 611-618.
- Strandberg, C. H. 1966.
Water Quality Analysis.
Photogrammetric Engineering.
Volume 32, pp. 235-248.
- Strandberg, C. H., 1968.
Water Pollution Analysis.
Manual of Color Aerial Photography.
American Society of Photogrammetry, Chapter 10.20.

- Ward, Robert C., May 1973.
Data Acquisition Systems in Water Quality Management.
- Welch, Robin I., 1969.
Remote Sensing Systems in Water Quality Control Programs.
Proceedings, First Annual Symposium of the International Remote
Sensing Institute
Sacramento, Calif., Vol. 2, pp. 46-65.
- Wezernak, Chester T. and Polcyn, Fabian C., Nov. - Dec. 1970.
Pollution Surveillance and Data Acquisition Using Multispectral
Remote Sensing.
Water Resources Bulletin, Vol. 6, No. 6.
pp. 920-934.
- White, P. G., May 1971.
Remote Sensing of Water Pollution.
International Workshop on Earth Resources Survey Systems.
U.S. Government Printing Office, Wash., D.C.
- Wobber, Frank J. and Amato, Roger V., Sept. 1974.
Aerial Photography for Surveying Surface Mining and Reclamation.
Photographic Applications in Science, Technology and Medicine.
p. 22.
- Wobber, Frank J., Weir, Charles E., Leshendok, Thomas, Beeman,
William, Oct. 22, 23, 24, 1974.
Survey of Coal Refuse Banks and Slurry Ponds for the Indiana State
Legislature Using Aerial and Orbital Inventory Techniques.
First Symposium on Mine and Preparation Plant Refuse Disposal.
Sponsored by the National Coal Association, Louisville, Kentucky.
- Wood, C. R., 1972.
Ground Water Flow.
Photogrammetric Engineering.
Vol. 38, pp. 347-352.

REMOTE SENSING BIBLIOGRAPHY

SOILS REFERENCES

- Avery, T. E., 1968
Interpretation of Aerial Photographs.
Burgess Publishing Company
Minneapolis, Minnesota, p. 324.
- Cihlar, J. and Protz, R., 1972
Color film densities for soil Part I.
Photogramm. Eng. 38: 1091-1098
- Fezer, F., 1971
Photo interpretation applied to geomorphology - a review.
Photogrammetria 27: 7-53.
- Hunter, G. T. and Bird, S. J., 1970
Critical terrain analysis.
Photogramm. Eng. 36: 939-952.
- Kihlblom, V., 1972
The reliability of the interpretation of soils from aerial photographs
in highway planning practice.
Eighth Int. Symp. Remote Sensing of Environment
Ann Arbor, Michigan, p. 755-764.
- Kristof, S. J. and Zachary, A. L., 1974
Mapping soil features from multispectral scanner data.
Photogramm. Eng. 40: 1427-1434.
- Kuhl, A. D. 1970
Color and color IR photos for soils.
Photogramm. Eng. 36: 475-482.
- Matthews, H. L., Cunningham, R. L., and Petersen, G. W., 1973
Spectral reflectance of selected Pennsylvania soils.
Soil Science Society of America Proc. 37: 421-424.
- Mintzer, O. W., 1966
Terrain investigation techniques - airphoto interpretation.
Final Engineering Report 196B, Engineering Experiment Station
Ohio State University, Columbus, Ohio.
- Mintzer, O. W., 1968
Soils
In Manual of Color Aerial Photography, American Society of Photo-
grammetry, Falls Church, Virginia, p. 550.

- Moessner, K. E. and Choate, G. A., 1964.
Estimating slope percent for land management from aerial photos.
Intermountain Forest and Range Exp. Station, Research Note, INT-26.
- Moessner, K. E. and Choate, G. A., 1966
Terrain slope estimation.
Photogramm. Eng. 32: 67-75.
- Parry, J. T., Cowan, W. R., and Heginbottom, J. A., 1969
Soil studies using color photos.
Photogramm. Eng. 35: 44-56.
- Parry, J. T. and Turner, H., 1971
Infrared photos for drainage analysis.
Photogramm. Eng. 37: 1031-1038.
- Piech, K. R. and Walker, J. E., 1974
Interpretation of soils.
Photogramm. Eng. 40L 87-94.
- Poole, D. H. 1969
Slope failure forms: Their identification, characteristics, and distribution as depicted by selected remote sensor returns.
Sixth Int. Symp. Remote Sensing of Environment.
Ann Arbor, Michigan, p. 927-965.
- Schmer, F. A., Werner, H. D., and Walt, F. A., 1970
Remote sensing soil moisture research.
Third Annual Earth Resources Program Review, NASA Manned
Spacecraft Center
Houston, Texas, pages 49-1 to 49-9.
- Schmugge, T., Gloersen, P., Wilheit, T., and Geiger, F., 1974
Remote sensing of soil moisture with microwave radiometers.
Journal of Geophysical Research 79: 317-323.
- Valentine, K. W. G., Lord, T. M., Watt, W., and Bedwany, A. L., 1971
Soil mapping accuracy from black and white, color, and infrared
aerial photography.
Canadian Journal of Soil Science 51: 461-469.
- van der Bent, E. T., 1969
Dip estimation for photogeology.
Photogramm. Eng. 35: 1225-1227.

Waelti, H., 1970

Forest road planning.

Photogramm, Eng. 36: 246-252

Werner, H., Schmer, F., Horton, M., and Waltz, F., 1971

Application of remote sensing techniques to monitoring soil moisture.

Seventh Int. Symp. Remote Sensing Environment

Ann Arbor, Michigan, p. 1245-1258.

REMOTE SENSING BIBLIOGRAPHY

GEOLOGY REFERENCES

- Avery, T. E., 1968.
Interpretation of Aerial Photographs.
Burgess Publishing Company
Minneapolis, Minnesota, p. 324.
- Gay, S. P., 1973.
Pervasive Orthogonal Fracturing in Earth's Continental Crust.
American Stored Map Co., Tech. Pub. No. 2, p. 122.
- Gold, D. P., Parizek, R. R., and Alexander, S. A., 1973.
Analysis and application of ERTS-1 data for regional geologic mapping.
Symp. on significant results obtained from ERTS-1.
Sponsored by NASA/Goddard Spaceflight Center, Greenbelt, Maryland
Vol. I, Section A, p. 231-245.
- Lattman, L. H., 1958
Technique for mapping geologic fracture traces and lineaments on
aerial photographs.
Photogramm. Eng. 23: 568-576.
- Lattman, L. H., and Matzke, R. H., 1961.
Geologic significance of fracture traces.
Photogramm. Eng. 27: 435-438.
- Lattman, L. H. and Ray, R. G., 1965.
Aerial Photographs in Field Geology.
Holt, Rinehart, and Winston, Inc., New York, New York, p. 221.
- Miller, U. C., 1961.
Photogeology
McGraw-Hill Book Company, New York, New York, p. 248.
- Ray, R. G., 1960.
Aerial photographs in geologic interpretation and mapping
Geological Survey Professional Paper 373
U. S. Dept. of the Interior, U. S. Government Printing Office,
Washington, D. C.
- Trainer, F. W. and Ellison, R. L., 1967.
Fracture traces in Shenandoah Valley, Virginia.
Photogramm. Eng. 33: 190-199.
- van der Bent, E. T., 1969.
Dip estimation for photogeology.
Photogramm. Eng. 35: 1225-1227.

Wier, C. W., Wobber, F. J., Russel, O. R., and Amato, R. V., 1973A.
Fracture mapping and strip mine inventory in the midwest by using
ERTS-1 imagery.
Symp. on Significant Results Obtained from ERTS-1.
Sponsored by NSAS/Goddard Spaceflight Center, Greenbelt, Maryland
Vol. I, Section A, p. 553-560.

Wier, C. E., Wobber, F. J., Russel, O. R., Amato, R. V. and Leshendok, T. V.,
1973B.
Relationship of roof falls in underground coal mines to fractures
mapped on ERTS-1 imagery.
Third Earth Resources Technology satellite - 1 Symposium Goddard
Spaceflight Center, Washington, D.C., Vol. 1, Section A, p. 825-843.

REMOTE SENSING BIBLIOGRAPHY

SATELLITE MONITORING REFERENCES

- Ahmad, M. U., Kantner, D. A., and Antalovich, J. W., 1973.
Mapping of spoil banks using ERTS-1 pictures.
Symposium on significant results obtained from Earth Resources
Technology Satellite-1.
Goddard Spaceflight Center, Washington, D.C., p. 1575-1582.
- Alexander, S. S., Dein, J., and Gold, D. P., 1973.
The use of ERTS-1 MSS data for mapping strip mines and acid mine
drainage in Pennsylvania.
Symposium on Significant Results obtained from Earth Resources
Technology Satellite-1.
Goddard Spaceflight Center, Washington, D.C., p. 569-575.
- Ambionics, Inc., 1974.
Remote sensing of coal mine pollution in the upper Potomac River Basin.
Ambionics, Incorporated, Washington, D.C., pp. 66.
- Chase, P. E. and Pettyjohn, W., 1973.
ERTS-1 investigation of ecological effects of strip mining in eastern
Ohio.
Symposium on Significant Results obtained from Earth Resources
Technology Satellite-1.
Goddard Spaceflight Center, Washington, D.C., p. 561-568.
- Deely, D. J. 1976.
Application of Landsat-2 Data to the Implementation and Enforcement of
Pennsylvania Surface Mining Conservation and Reclamation Act.
Earth Satellite Corporation, Washington, D.C., pp. 58.
- Henkes, W. C., 1971.
Satellite monitoring of open pit mining operations.
U.S. Bureau of Mines Information Circular No. 8530.
- Pettyjohn, W. A., Rogers, R. H., and Reed, L. E., 1973.
Automated Strip Mine and Reclamation Mapping from ERTS.
Third Earth Resources Technology Satellite Symposium.
Goddard Spaceflight Center, Washington, D.C., Vol II., p., 87-101.
- Schubert, J. S. and MacLeod, N. H., 1973.
Digital Analysis of Potomac River Basin ERTS imagery: Sedimentation
levels at the Potomac-Anacostia confluence and strip mining in
Allegheny County, Maryland.
Symposium on Significant Results obtained from Earth Resources
Technology Satellite-1.
Goddard Spaceflight Center, Washington, D.C., p. 659-664.

Thompson, D. N. and Borden, F. Y., 1973.

Mapping of anthracite refuse.

Annual report, Office for Remote Sensing of Earth Resources.

The Pennsylvania State University, University Park, Pa., p. 144-160.

Wier, C. E., Wobber, F. J., Russel, O. R., Amato, R. U., and Leshendok, T. V., 1973.

Relationship of roof falls in underground coal mines to fractures mapped on ERTS-1 imagery.

Third Earth Resources Technology Satellite-1 Symposium.

Goddard Spaceflight Center, Washington, D.C., Vol I, p. 825-843.

REMOTE SENSING BIBLIOGRAPHY

GENERAL REMOTE SENSING, PHOTOGRAMMETRY, AND INTERPRETATION TEXTS

- American Society of Photogrammetry, 1960, Manual of Photographic Interpretation. George Banta Co., Inc., Menosha, Wis. 868 p.
- American Society of Photogrammetry, 1968. Manual of Color Aerial Photography. George Banta Co., Inc., Menosha, Wis. 550 p.
- American Society of Photogrammetry 1975. Manual of Remote Sensing. American Society of Photogrammetry. Falls Church, Va., 2144 p.
- Avery, T. E. 1969. Foresters Guide to Aerial Photo Interpretation. USDA, Forest Service, Agricultural Handbook No. 308, 40 p.
- Bird and Hale Ltd. 1977. Surveillance of the Environmental Effects of a Highway Facility by Remote Sensing A State of the Art. Ministry of Transportation and Communications, Ontario, Canada, Publication No. RR 209, 76 p.
- Eardley, A. J. 1941, Aerial Photographs - Their Use and Interpretation. Harper & Brothers. 203 p.
- Lintz, J. and Simonett, D. S. 1976. Remote Sensing of Environment. Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 694 p.
- Lueder, D. R. 1959. Aerial Photographic Interpretation - Principles and Applications. McGraw-Hill Book Co., Inc., New York, N.Y., 462 p.
- National Academy of Sciences. 1970. Remote Sensing. National Academy of Sciences, Washington, D.C., 423 p.
- Simakova, M. S. 1964. Soil Mapping by Color Aerial Photography. Daniel Davey and Company, Inc., New York, N.Y., 81 p.
- Smith, H.T.U. 1943. Aerial Photographs and Their Applications. Appleton Century Crafts, New York, N.Y.
- Spurr, S. H. 1960. Photogrammetry and Photo Interpretation. Ronald Press Co., New York, N.Y. 472 p.
- Strandberg, C. H. 1967. Aerial Discovery Manual. John Wiley and Sons, Inc., New York, N.Y., 249 p.
- Talley, B. B. 1938. Engineering Applications of Aerial and Terrestrial Photogrammetry. Pitman Publishing Co., New York, N.Y., 612 p.
- Wanless, H. R. 1966. Aerial Stereo Photographs. Dept. of Geology, University of Illinois, Hubbard Scientific Co., Northbrook, Ill., 92 p.

APPENDIX B DETAILED LIST OF FEATURES AND PARAMETERS
BY CATEGORIES WITH OPTIMAL SEASONS AND
FILM TYPES

TABLE B-1 LIST OF MAPPED LAND USE FEATURES USED IN THIS STUDY

FEATURE	CAN BE BEST MAPPED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
AGRICULTURE	-	X	-	SPRING/SUMMER/FALL	COLOR OR COLOR IR
FOREST	-	X	-	ALL SEASONS	COLOR OR COLOR IR
GRASS LAND/FALLOW LAND	-	X	-	SPRING/SUMMER/FALL	COLOR OR COLOR IR
RESIDENTIAL	-	X	-	ALL SEASONS	COLOR OR COLOR IR
ACTIVE STRIP PIT	-	-	X	ALL SEASONS	COLOR OR COLOR IR
INACTIVE STRIP PIT	-	-	X	ALL SEASONS	COLOR OR COLOR IR
ABANDONED STRIP PIT	-	-	X	ALL SEASONS	COLOR OR COLOR IR
TREATMENT FACILITIES	-	-	X	FALL/WINTER	COLOR IR
PREPARATION FACILITIES	-	-	X	ALL SEASONS	COLOR OR COLOR IR
STORAGE FACILITIES	-	-	X	ALL SEASONS	COLOR OR COLOR IR
SHAFT OPENINGS	X	-	-	DIFFICULT TO MAP FROM AERIAL PHOTOS	N/A
SLOPE OPENINGS	X	-	-	DIFFICULT TO MAP FROM AERIAL PHOTOS	N/A
DRIFT OPENINGS	X	-	-	DIFFICULT TO MAP FROM AERIAL PHOTOS	N/A
BOREHOLES	X	-	-	DIFFICULT TO MAP FROM AERIAL PHOTOS	N/A
SHIPPING AREAS	-	-	X	ALL SEASONS	COLOR OR COLOR IR
SPOIL BANKS	-	-	X	SPRING/SUMMER/FALL	COLOR IR
TOPSOIL PILES	-	-	X	SPRING/SUMMER/FALL	COLOR
ACTIVE RECLAMATION	-	-	X	ALL SEASONS	COLOR OR COLOR IR
COMPLETED RECLAMATION	-	-	X	SPRING	COLOR OR COLOR IR
MINING EQUIPMENT	-	-	X	SPRING/SUMMER/FALL	COLOR IR
BUILDINGS	-	X	-	FALL/WINTER	COLOR OR COLOR IR
CEMETERIES	-	X	-	ALL SEASONS	COLOR OR COLOR IR
ROADS	-	X	-	ALL SEASONS	COLOR OR COLOR IR
RAILROADS	-	X	-	ALL SEASONS	COLOR OR COLOR IR
UTILITY LINES	X	-	-		N/A
TRANSMISSION LINES	-	X	-	ALL SEASONS	COLOR OR COLOR IR
PIPE LINES	X	-	-		N/A

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

TABLE B-2 LIST OF MEASURED LAND USE PARAMETERS USED IN THIS STUDY

PARAMETER	CAN BE BEST MEASURED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL 1 PHOTOGRAPHY	BOTH		
AGRICULTURE (AREA)		X		ALL SEASONS	COLOR/COLOR IR
FOREST (AREA)		X		ALL SEASONS	COLOR/COLOR IR
RESIDENTIAL (AREA)		X		ALL SEASONS	COLOR/COLOR IR
ACTIVE STRIP PIT (AREA)		X		ALL SEASONS	COLOR/COLOR IR
ABANDONED STRIP PIT (AREA)		X		ALL SEASONS	COLOR/COLOR IR
RECLAMATION (AREA)		X		ALL SEASONS	COLOR/COLOR IR
ROAD (WIDTH)			X	ALL SEASONS	COLOR IR
ROAD (DISTANCE FROM MINE)			X	ALL SEASONS	COLOR/COLOR IR
SPOIL BANK (AREA)		X		ALL SEASONS	COLOR/COLOR IR
TOP SOIL PILE (AREA)		X		ALL SEASONS	COLOR/COLOR IR
SPOIL BANK (PEAK WIDTH)		X		ALL SEASONS	COLOR/COLOR IR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

APPENDIX B-3 LIST OF MAPPED VEGETATION FEATURES USED IN THIS STUDY

FEATURE	CAN BE BEST MAPPED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL 1 PHOTOGRAPHY	BOTH		
CROPLAND		X		SUMMER/FALL	COLOR OR COLOR IR
PASTURE		X		SPRING/SUMMER/FALL	COLOR OR COLOR IR
ORCHARD		X		FALL/WINTER	COLOR OR COLOR IR
IDLE FIELDS		X		SPRING/SUMMER/FALL	COLOR OR COLOR IR
DECIDUOUS FOREST		X		FALL/WINTER	COLOR IR
CONIFEROUS FOREST		X		FALL/WINTER	COLOR IR
MIXED FOREST		X		FALL/WINTER	COLOR IR
CATTAILS AND SEDGE	X			DIFFICULT TO MAP FROM AERIAL PHOTOS	N/A
LAWNS & GARDENS		X		FALL	COLOR OR COLOR IR
RESIDENTIAL TREES		X		FALL	COLOR OR COLOR IR
GRASSES AND LEGUMES		X		LATE SUMMER/FALL	COLOR IR
GRASSES, LEGUMES & TREES (MIXED)		X		LATE SUMMER/FALL	COLOR IR
INDIVIDUAL CONIFEROUS TREES			X	FALL	COLOR IR
INDIVIDUAL DECIDUOUS TREES			X	FALL	COLOR IR
ANNUALS ON STORED TOPSOIL			X	SUMMER/FALL	COLOR OR COLOR IR
AREAS OF DYING GRASSES & LEGUMES			X	SUMMER	COLOR IR
VEGETATIVE STRESS			X	SUMMER	COLOR IR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER

APPENDIX B-4 LIST OF MEASURED VEGETATIVE PARAMETERS USED IN THIS STUDY

PARAMETER	CAN BE BEST MEASURED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
TREES PER ACRE (NUMBER)	--	--	X	SPRING/SUMMER/FALL	COLOR OR COLOR IR
SPACING OF TREES (FEET)	X	--	--	SPRING/SUMMER/FALL	COLOR OR COLOR IR
ROWS PER TREE SPECIES (NO)	--	--	X	SPRING/SUMMER/FALL	COLOR OR COLOR IR
SIZE OF BLOCK PLANTING (ACRE)	--	X	--	SPRING/FALL	COLOR OR COLOR IR
TIME OF PLANTING GRASSES AND LEGUMES (SEASON/AGE)	X	--	--	SPRING/SUMMER/FALL	COLOR OR COLOR IR
DEAD OR DYING GRASSES OR LEGUMES (AREA)	X	--	--	SUMMER	COLOR IR
COVER OF GRASSES AND LEGUMES (%)	X	--	--	SPRING/SUMMER/FALL	COLOR OR COLOR IR
GROUND COVER - TREE PLANTINGS (%)	--	X	--	SUMMER	COLOR OR COLOR IR
VEGETATIVE STRESS - ACIDITY (AREA)	--	--	X	SUMMER	COLOR IR
VEGETATIVE STRESS - SOLID DISTURBANCE (AREA)	--	--	X	SUMMER	COLOR IR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

APPENDIX B-5 LIST OF MAPPED WATER FEATURES USED IN THIS STUDY

FEATURE	CAN BE BEST MAPPED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
PONDS			X	SUMMER/FALL	COLOR/COLOR IR
STREAMS			X	FALL/WINTER	COLOR/COLOR IR
SEEPS	X				
DRAINAGE DITCH			X	SPRING	COLOR IR
IMPOUNDMENTS			X	SPRING/SUMMER/FALL	COLOR IR
PUDDLES			X	SPRING	COLOR IR
SWAMPS			X	SPRING	COLOR IR
HOLDING PONDS			X	SUMMER/FALL	COLOR/COLOR IR
YELLOWBOY			X	SPRING/SUMMER/FALL	COLOR
HIGH TURBIDITY			X	ALL SEASONS	COLOR
MODERATE TURBIDITY			X	ALL SEASONS	COLOR
SLIGHT TURBIDITY			X	ALL SEASONS	COLOR
TRANLUCENCE			X	ALL SEASONS	COLOR
SEDIMENT ON LAND			X	SPRING	COLOR IR
SUBAQUEOUS SEDIMENT		X		SUMMER	COLOR
COLOR OF WATER			X	ALL SEASONS	COLOR
SHEET EROSION	X				
RILL EROSION			X	ALL SEASONS	COLOR/COLOR IR
GULLY EROSION			X	ALL SEASONS	COLOR/COLOR IR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

APPENDIX B-6 LIST OF MEASURED WATER PARAMETERS USED IN THIS STUDY

PARAMETER	CAN BE BEST MEASURED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
POND (AREA)			X	FALL	COLOR IR
STREAMS (WIDTH)			X	FALL/WINTER	COLOR IR
SEEPS (AREA)	X				N/A
DRAINAGE DITCH (WIDTH)	X				N/A
IMPOUNDMENTS (AREA)			X	SUMMER/FALL/WINTER	COLOR/COLOR IR
IMPOUNDMENT (DIST TO DWELLING)			X	FALL/WINTER	COLOR OR COLOR IR
IMPOUNDMENT (DIST TO WELL)	X				N/A
IMPOUNDMENT DAM (WIDTH)			X	SUMMER/FALL	COLOR IR
IMPOUNDMENT DAM (LENGTH)			X	SUMMER/FALL	COLOR IR
DRAINAGE DITCH (LENGTH)			X	SPRING	COLOR/COLOR IR
RILL EROSION (WIDTH)	X			NOT EASILY OR ACCURATELY DETERMINED	N/A
RILL EROSION (DEPTH)	X			NOT EASILY OR ACCURATELY DETERMINED	N/A
GULLY EROSION (WIDTH)	X			MARGINAL IN SUMMER	COLOR OR COLOR IR
GULLY EROSION (DEPTH)	X			NOT EASILY OR ACCURATELY DETERMINED	N/A
RILL EROSION (LENGTH)			X	ALL SEASONS	COLOR/COLOR IR
GULLY EROSION (LENGTH)			X	ALL SEASONS	COLOR/COLOR IR
SWAMP (AREA)			X	SPRING	COLOR/COLOR IR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

APPENDIX B-7 LIST OF MAPPED GEOLOGICAL FEATURES USED IN THIS STUDY

FEATURE	CAN BE BEST MAPPED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR, COLOR IR, OR BW)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
ROCK UNITS			X	FALL/WINTER	COLOR, COLOR IR, B&W
COAL OUTCROPS			X	FALL/WINTER	COLOR, COLOR IR, B&W
FRACTURE TRACES		X		SPRING	COLOR, COLOR IR, B&W

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER

B-8 LIST OF MAPPED SOILS FEATURES USED IN THIS STUDY					
FEATURE	CAN BE BEST MAPPED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
SOIL TYPE			X	SUMMER	COLOR
SPOIL BANKS			X	SPRING/SUMMER/FALL	COLOR IR
TOPSOIL PILES			X	SPRING/SUMMER/FALL	COLOR
TOPSOIL REGRADED			X	SPRING/SUMMER/FALL	COLOR/COLOR IR
SHEET EROSION	X				N/A
RILL EROSION			X	ALL SEASONS	COLOR/COLOR IR
GULLY EROSION			X	ALL SEASONS	COLOR/COLOR IR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

B-9 LIST OF MEASURED SOILS PARAMETERS USED IN THIS STUDY					
PARAMETER	CAN BE BEST MEASURED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
SPOIL BANK (AREA)		X		ALL SEASONS	COLOR/COLOR IR
TOPSOIL PILE (AREA)		X		ALL SEASONS	COLOR/COLOR IR
RILL EROSION (WIDTH)	X				N/A
RILL EROSION (DEPTH)	X				N/A
GULLY EROSION (WIDTH)	X				N/A
GULLY EROSION (DEPTH)	X				N/A
RILL EROSION (LENGTH)			X	ALL SEASONS	COLOR/COLOR IR
GULLY EROSION (LENGTH)			X	ALL SEASONS	COLOR/COLOR IR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FILM FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

B-10 LIST OF MEASURED PARAMETERS REQUIRING HEIGHT MEASUREMENTS					
PARAMETER	CAN BE BEST MEASURED BY			BEST SEASON OR SEASONS FOR COLLECTION OF AERIAL PHOTOGRAPHY	BEST FILM TYPE (COLOR OR COLOR IR)
	FIELD WORK	AERIAL PHOTOGRAPHY	BOTH		
HIGHWALL HEIGHT			X	SPRING/SUMMER/FALL	COLOR/COLOR IR
SLOPE			X	ALL SEASONS	COLOR/COLOR IR
OVERBURDEN REMOVED		X		ALL SEASONS	COLOR/COLOR IR
DIP OF COAL BEDS			X	WINTER	COLOR

¹ BASED ON USING 1:12000 SCALE COLOR AND COLOR INFRARED AERIAL PHOTOGRAPHY, 9" FORMAT, STEREO COVERAGE, AND <10% CLOUD COVER.

APPENDIX C COST ESTIMATES FOR THE OPERATIONAL USE OF COLOR
AND COLOR IR FILMS BY LANDSCAPE PARAMETER
CATEGORIES FOR 1, 10, 100, 1000 SQUARE MILE USING
1:12,000 SCALE, BY SEASONS

TABLE C-1 AVERAGE TIME SPENT FOR PHOTOINTERPRETATION PER SQUARE MILE (IN HOURS) BY FILM TYPE BY LANDSCAPE CATEGORY BY SEASONS USING 1:12,000 SCALE.

77-71

INTERPRETATION PARAMETER CATEGORY	SUMMER		FALL		WINTER		SPRING	
	COLOR	COLOR IR	COLOR	COLOR IR	COLOR	BLACK & WHITE	COLOR	COLOR IR
(A) LAND USE	4.16	3.60	2.81	2.47	2.98	2.82	2.88	2.90
(B) WATER	1.75	2.28	1.54	1.66	2.60	2.62	2.63	2.70
(C) VEGETATION	1.76	1.87	1.96	1.94	1.94	2.10	2.00	2.11
TOTAL (A) & (B) & (C)	7.67	7.75	6.31	6.01	7.52	7.52	7.51	7.11

THE AVERAGE WAS CALCULATED BASED ON THE DATA COMPILED FOR SIX INTERPRETERS AND 6 SITES OF 3/4 SQ. MILES EACH.

TABLE C-2 COST OF DATA COLLECTION AND DATA INTERPRETATION FOR 1, 10, 100 AND 1000, SQUARE MILES (IN DOLLARS) BY FILM TYPES, LANDSCAPE CATEGORY, AND SEASON USING 1:12,000 SCALE²

COST ITEMS INTERPRETATION PARAMETER CATEGORY	SUMMER		FALL		WINTER		SPRING	
	COLOR	COLOR IR	COLOR	COLOR IR	COLOR	BLACK & WHITE	COLOR	COLOR IR
COST ESTIMATE FOR ONE SQUARE MILE								
(A) LAND USE	33.28	28.80	22.48	19.76	23.84	22.56	23.04	23.20
(B) WATER	14.00	18.24	12.32	13.28	20.80	20.96	21.04	21.60
(C) VEGETATION	14.08	14.96	15.68	15.52	15.76	16.80	16.00	16.96
TOTAL INTERPRETATION (1)	61.36	62.00	50.48	48.56	60.40	60.32	60.08	61.68
DATA COLLECTION (2)	18.00	12.00	18.00	12.00	18.00	6.00	18.00	12.00
SUBTOTAL (1) & (2)	79.36	74.00	68.48	60.56	78.40	66.32	78.11	73.68
MOBILIZATION (3)	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
GRAND TOTAL (1) & (2) & (3)	779.36	774.00	768.48	760.56	778.40	766.00	778.11	773.68
COST ESTIMATE FOR TEN SQUARE MILES (DOLLARS)								
LAND USE	332.80	288.00	224.80	197.60	238.40	225.60	230.40	232.00
WATER	140.00	182.40	123.20	132.80	208.00	209.60	210.40	216.00
VEGETATION	140.80	149.60	156.80	155.20	157.60	168.00	160.00	168.96
TOTAL INTERPRETATION (1)	613.60	620.00	504.80	485.60	604.00	603.20	600.80	616.80
DATA COLLECTION (2)	180.00	120.00	180.00	120.00	180.00	60.00	180.00	120.00
SUBTOTAL (1) & (2)	793.60	740.00	684.80	605.60	784.00	663.20	780.80	736.80
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
GRAND TOTAL	1493.60	1440.00	1384.80	1305.60	1484.00	1363.20	1480.80	1436.80
PER SQUARE MILE ESTIMATE (DOLLARS)								
COST ESTIMATE	149.36	144.00	138.48	130.56	148.40	136.32	148.08	143.68
COST ESTIMATE FOR 100 SQUARE MILES (DOLLARS)								
LAND USE	3328.00	2880.00	2248.00	1976.00	2384.00	2256.00	2304.00	2320.00
WATER	1400.00	1824.00	1232.00	1328.00	2080.00	2096.00	2104.00	2160.00
VEGETATION	1408.00	1496.00	1568.00	1552.00	1576.00	1680.00	1600.00	1689.60
TOTAL INTERPRETATION	6136.00	6200.00	5048.00	4856.00	6040.00	6032.00	6008.00	6168.00
DATA COLLECTION	1800.00	1200.00	1800.00	1200.00	1800.00	600.00	1800.00	1200.00
SUBTOTAL	7936.00	7400.00	6848.00	6056.00	7840.00	6632.00	7808.00	7368.00
MOBILIZATION	700.00	700.00	700.00	700.00	700.00	700.00	700.00	700.00
GRAND TOTAL	8636.00	8100.00	7548.00	6756.00	8540.00	7332.00	8508.00	8068.00
PER SQUARE MILE ESTIMATE								
COST ESTIMATE	86.36	81.00	75.48	67.56	85.40	73.32	85.08	80.68
COST ESTIMATE FOR 1000 SQUARE MILES (DOLLARS)								
LAND USE	33280.00	28800.00	22480.00	19760.00	23840.00	22560.00	23040.00	23200.00
WATER	14000.00	18240.00	12320.00	13280.00	20800.00	20960.00	21040.00	21600.00
VEGETATION	14080.00	14960.00	15680.00	15520.00	15760.00	16800.00	16000.00	16896.00
TOTAL INTERPRETATION	61360.00	62000.00	50480.00	48560.00	60400.00	60320.00	60080.00	61680.00
DATA COLLECTION	18000.00	12000.00	18000.00	12000.00	18000.00	6000.00	18000.00	12000.00
SUBTOTAL	79360.00	74000.00	68480.00	60560.00	78400.00	66320.00	78080.00	73680.00
MOBILIZATION	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00
GRAND TOTAL	80760.00	75400.00	69880.00	61960.00	79800.00	67720.00	79480.00	75080.00
PER SQUARE MILE ESTIMATE (DOLLARS)								
	80.76	75.40	69.88	61.96	79.80	67.72	79.48	75.08

2) THE COST OF DATA COLLECTION WAS BASED FROM THE QUOTES FROM SIX AERIAL SURVEY FIRMS AND ACTUAL COSTS FROM DATA COLLECTION. COST OF INTERPRETATION WAS BASED ON THE ASSUMPTION OF \$8.00 PER HOUR LABOR RATE FOR AN INTERPRETER.

APPENDIX D MEAN VALUES OF PERFORMANCE ACCURACY (in percent) AND RELATIVE
ERROR VARIANCE (in percent) BY FILM TYPE AND LANDSCAPE
CATEGORIES, BY SEASONS

TABLE D-1 SUMMARY TABLES OF LAND USE, VEGETATION, AND WATER INTERPRETATION STATISTICS BY SEASON FOR COLOR AND COLOR IR FILM TYPES									
77-71									
		VARIABLE	AVERAGE VALUE	STANDARD DEVIATION SQUARED	STANDARD DEVIATION	EFFICIENCY	EFFICIENCY	EFFICIENCY	
LAND USE	NUMBER					N=1	N=10	N=6	
	COLOR	FALL	1	80.714127	287.432617	16.953827	21.004776	6.642294	8.575164
		SPRING	2	88.080231	173.550919	13.173872	14.956671	4.729714	6.106035
		SUMMER	3	88.214096	76.091232	8.723028	9.888470	3.127008	4.036951
	COLOR IR	SPRING	4	91.517700	117.749603	10.851249	11.856991	3.749510	4.840596
		SUMMER	5	94.330231	64.407684	8.025439	8.507812	2.690406	3.473299
		FALL	6	90.580154	55.379781	7.441759	8.215659	2.598020	3.354029
VEGETATION	NUMBER					N=1	N=10	N=6	
	COLOR	FALL	1	83.749854	798.281863	28.253525	44.319275	14.014987	18.093262
		SPRING	2	78.078827	526.186523	22.938751	29.007446	9.172960	11.842240
		SUMMER	3	76.776123	280.610107	16.751419	21.818512	6.869820	8.907371
	COLOR IR	SPRING	4	78.618347	815.084473	28.548683	36.314270	11.483582	14.825239
		SUMMER	5	86.315720	349.734375	18.701172	21.666000	6.851392	8.845108
		FALL	6	81.184021	304.421875	17.447678	21.491501	6.798209	8.773869
WATER	NUMBER					N=1	N=10	N=6	
	COLOR	FALL	1	52.783077	1181.869873	34.378326	65.156021	20.604141	26.599823
		SPRING	2	72.980419	567.048096	23.812759	32.637909	10.321014	13.324371
		SUMMER	3	73.881424	391.300048	19.781296	26.774368	8.466800	10.930591
	COLOR IR	SPRING	4	57.887266	1109.592529	33.310532	57.733276	18.256866	23.569504
		SUMMER	5	80.986725	608.085936	24.659393	30.448669	9.628718	12.430617
		FALL	6	83.026154	144.151855	12.006328	14.480891	4.572935	5.903634

TABLE D-2 SUMMARY TABLES OF LAND USE, VEGETATION, AND WATER INTERPRETATION STATISTICS FOR WINTER FOR COLOR AND BLACK AND WHITE FILM TYPES									
77-71									
		VARIABLE	AVERAGE VALUE	STANDARD DEVIATION SQUARED	STANDARD DEVIATION	EFFICIENCY	EFFICIENCY	EFFICIENCY	
LAND USE	NUMBER					N=1	N=10	N=6	
	COLOR		1	85.446289	227.568863	15.085385	17.654800	5.582938	7.207542
	BLACK & WHITE		2	76.740906	235.107346	15.333210	19.980484	6.318384	8.156999
VEGETATION	NUMBER					N=1	N=10	N=6	
	COLOR		1	59.523666	657.260742	25.637085	43.070404	13.620059	17.593420
	BLACK & WHITE		2	48.228074	654.760498	25.588287	53.059021	16.778732	21.661255
WATER	NUMBER					N=1	N=10	N=6	
	COLOR		1	76.381409	342.689697	18.511871	24.236084	7.664124	9.894340
	BLACK & WHITE		2	61.032490	537.718750	23.188751	37.981659	12.010857	15.505948

APPENDIX E ANALYSIS OF VARIANCE BY FILM TYPE BY LANDSCAPE
CATEGORIES, BY SEASONS

TABLE E-1 ANALYSIS OF VARIANCE FOR LAND USE FEATURES

77-71

LEVELS OF FACTORS	A	3	SEASON WITHIN SENSOR OR FILM TYPE
	B	2	SENSOR OR FILM TYPE (COLOR VS COLOR IR)
	C	28	SAMPLE FEATURES FOR LAND USE INTERPRETATIONS
GRAND MEAN	88.90625		
SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
A	745.47974	2	372.73975
B	1759.90503	1	1759.90503
AB	499.38599	2	249.69299
C	14758.09766	27	546.59619
AC	4289.89844	54	79.44255
BC	1143.99976	27	42.37036
ABC	722.47729	54	13.37921
TOTAL	23919.23828	167	

TABLE E-2 ANALYSIS OF VARIANCE FOR VEGETATION FEATURES

77-71

LEVELS OF FACTORS	A	3	SEASON WITHIN SENSOR OR FILM TYPE
	B	2	SENSOR OR FILM TYPE
	C	19	SAMPLE FEATURES FOR VEGETATION INTERPRETATIONS
GRAND MEAN	77.62061		
SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
A	2623.87598	2	1311.93799
B	2226.00049	1	2226.00049
AB	556.27734	2	278.13867
C	43858.96875	18	2436.60938
AC	9738.04688	36	270.50122
BC	650.29980	18	36.12776
ABC	1090.07520	36	30.27886
TOTAL	60743.53906	113	

TABLE E-3 ANALYSIS OF VARIANCE FOR WATER FEATURES

77-71

LEVELS OF FACTORS	A	3	SEASON WITHIN SENSOR OR FILM TYPE
	B	2	SENSOR OR FILM TYPE
	C	19	SAMPLE FEATURES FOR WATER INTERPRETATIONS
GRAND MEAN	70.21928		
SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
A	12847.88281	2	6423.94141
B	1547.36841	1	1547.36841
AB	90.37828	2	45.18913
C	42857.48438	18	2380.97119
AC	23370.28516	36	649.17456
BC	2284.40186	18	126.91121
ABC	3524.72021	36	97.90889
TOTAL	86522.43750	113	

A-SPRING, SUMMER, FALL UNDER COLOR AND COLOR IR
 AB-INTERACTION OF A WITH B
 AC-INTERACTION OF A WITH C
 ABC-INTERACTION OF A WITH B AND C