Remote Sensing for Reclamation Applications [1]

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Abstract. This paper presents an overview of remote sensing technology applicable for reclamation specialists. Historically, remote sensing has been a technology that has presented great promise but relatively few useful applications, a technology waiting for a purpose. With the development of remote sensing data capture techniques (satellite and aerial photography) and the development of micro-computer technology, remotely sensed data exists that can be rapidly evaluated and analyzed. Multivariate statistics has allowed remotely sensed data to sometimes generate useful spatial information that was computationally impossible to generate in the past. There are a variety of platforms suitable for conducting remote sensing projects that operate with MACINTOSH, DOS and UNIX operating systems and are often affordable to small firms and operators. Data input into remote sensing software is generally easy, with a tape drive or an optical digitizer. Aerial photography is relatively inexpensive and often consists of a fine spatial resolution suitable for small surface mines, but geophysically distorted requiring rectification. In contrast, satellite data is geo-referenced but often much more expensive and is often at a very coarse resolution unsuitable for small surface mine site projects. However, satellite data is available for a variety of seasons, dates, and years; while, existing aerial photography may be limited to a particular season and may not contain the appropriate electromagnetic data. In addition, knowledge about the appropriate type of electromagnetic data to capture is still in the formative stages, requiring extensive comparative investigations before remote sensing standards are available for project applications. Also, the variability of electromagnetic data from aerial photograph to aerial photograph or from satellite scan to satellite scan often means that electromagnetic classification techniques are difficult to control, and interpretable and meaningful results are difficult to obtain. Nevertheless, remotely sensed data can be helpful in identifying physical features of the landscape for post-mining land-use planning and design applications. Once a landscape has been classified, geographical information modeling techniques can then be applied to the remotely sensed and classified data.

Land classification appears to be the most current useful application of remotely sensed data, helpful to reclamation and surface mine specialists who have rugged or inaccessible terrain and complex landscapes to evaluate. This paper documents the types of output that can be generated through remote sensing and the utility of this technology in surface mining and reclamation applications.

Key Words: Landscape planning, landscape classification, aerial photography, satellite data, electro-magnetic data, computer applications.

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Table 1. This table illustrates the type of electromagnetic waves in the spectrum and denotes the position of current Landsat-Thematic Mapper data available to investigators.

Electromagnetic Region	Wavelengths		Thematic Mapper Bands
Gamma Rays	3 x 10-6 um	3 x 10-5 um	
X-rays	3 x 10-5um	0.01 um	
Ultra-violet Rays	0.01 um	0.4 um	
Visible Light	0.4 um	0.7 um	
Violet			
Blue			1
Green			2
Yellow			
Orange			
Red			3
Reflected Infrared (Near Infrared)	0.7 um	3.0 um	4,5,7
Medium and Far Infrared	3.0 um	1.0 mm	
Thermal Infrared	3.0 um	15.0 mm	6
Microwave	1.0 mm	0.8 m	
Radiowaves	0.8 m	3 x 10+6 m	

where: um=microns, mm=millimeters, m=meters

Introduction

Reclamation specialists and mine operation engineers are interested in obtaining spatial information efficiently and effectively. Remote sensing is one technological tool that has been presented with great prospects in surface mine applications. This paper presents an overview of remote sensing technology applicable for reclamation specialists.

Remote sensing is the act of obtaining spatial information without actually visiting/occupying the site. Aerial photographs and satellite information are the two most common methods of acquiring remotely sensed information; other approaches include: booms, helicopters, and balloons. Because one does not actually visit the site, the type of information is limited to physical properties associated with a site that can be recorded away from the site. The primary physical property that can be remotely sensed is electromagnetic radiation. Lindgren (1985:3) states, "All materials at temperatures above absolute zero (0 K) produce electromagnetic energy. This energy is caused by the motions of the various charged particles that make up the atoms. Thus, in principle, any substance made up of atoms can produce electromagnetic energy; in practice, however, it is not that simple. The emission of energy depends primarily on the temperature of an object; the hotter the object, the greater the emission of energy. However, it is also influenced by what is termed its emissivity. The emissivity of any object is a function of the chemical composition and physical state of that object."

Electromagnetic Properties

Electromagnetic radiation is often characterized as being waves containing a wavelength and frequency. Electromagnetic waves include: gamma rays, x-rays, ultraviolet rays, visible light, infrared rays, and radio waves (Table 1).

Visible light is often employed in remote sensing applications for two reasons. First, this type of electromagnetic radiation travels through the earth's atmospheric gases relatively easily, meaning that it can be recorded remotely. Other types of electromagnetic radiation such as gamma rays, x-rays, and most ultra-violet radiation cannot penetrate atmospheric gases, reducing their usefulness for some remote sensing applications. In addition, visible light is a type of electromagnetic radiation that is probably the simplest type of information to interpret, because humans process visible light radiation as a part of their natural biological daily capabilities, meaning that humans have an extensive range of experience associated with interpreting visible light radiation. For example, visible light is a relatively simple set of electromagnetic information to separate needle-leafed conifers from deciduous broad-leafed vegetation.

Near infrared radiation (reflected infrared) has also been extensively employed in remote sensing. Some infrared radiation wavelengths are blocked by atmospheric gases, but there are wavelength "atmospheric windows" that allow infrared radiation to pass through the atmosphere. Infrared radiation is affected by water content, meaning that infrared information is often helpful in assessing the health of vegetation by interacting with the water content properties of an object (plant, soil). While a plant in poor health may radiate relatively equal amounts of green visible light, an unhealthy plant lacking much water will reflect/emit more infrared radiation than a healthy plant containing more water. Consequently, artificial turf may appear similar to vegetation in the visible light zones, but artificial turf will reflect a greater amount of near infrared radiation.

The infrared and visible light regions comprise the electromagnetic regions most often employed in remote sensing. Therefore, remote sensing applications are embedded in the concept that electromagnetic properties are useful to record. This concept may be one of the shortcomings of remote sensing. Historically, remote sensing, especially satellite gathered information has been a technology that has presented great promise but relatively few useful applications. In contrast, aerial photography (the other standard remote sensing technique) is a common application tool employed by surface mine planners and reclamation specialists. Meanwhile, some individuals have privately stated that satellite technology is a technology still waiting for a purpose.

Presently, with the development of remote sensing data capture techniques (satellite and aerial photography) and the development of micro-computer technology, remotely sensed data exists that can be rapidly evaluated and analyzed. This relatively inexpensive technology has stimulated the interest of numerous reclamation specialists and mine operation planners. However, individuals interested in employing remotely sensed information for their projects should have an understanding concerning what type of remotely sensed information would be useful for them. Often remotely sensed information may add very little to increasing personnel efficiency or productivity. For further reading, Sabins (1986), Lillesand and Keifer (1979), and Howard (1991) provide adequate introductions concerning the fundamentals of remote sensing.

Remotely Sensed Products

Electromagnetic information is gathered and presented to the user in several general formats. First, the information can be presented photographically in a panchromatic format (black and white reading from all light colors) containing lumped readings of the red, green and blue (RGB) electromagnetic bands or the information can be infrared black and white, containing red, green, and infrared bands (RG&IR). Second, there are also true color (RGB) and false color (RG&IR) remotely sensed information, also presented in photographic formats. In the United States and Canada, there are many sources of photographic information ranging from private sources, to state/provincial sources to federal sources. In the United States, one can obtain unclassified Federal aerial photographs by contacting:

National Cartographic Information
Center
U.S. Geological Survey
507 National Center
Reston, Virginia 22092

Lindgren (1985:57-66) describes in greater detail the sources of aerial photographs and how to obtain this information.

Aerial photographic information can be interpreted hueristically by humans (meaning humans visually inspect the photograph, draw lines around homogeneous areas, and calculate areas), or the photograph can be interpreted digitally by scanning the photograph into a computer.

In addition to aerial photographs, there is also information that has been gathered in various combinations of red, green, blue, reflective infrared, and thermal infrared bands (see Table 1) from satellite sources. Questions concerning satellite information can be obtained from:

NOAA Landsat Customer Service
Mundt Federal Building
Soiux Falls, South Dakota 57198

Lindgren (1885:67-86) describes in greater detail issues associated with ordering satellite data. Satellite information allows the user to generate images by combining electromagnetic bands of information to create RGB, RG&IR, or other types of visual output. For example, Thematic Mapper information (a current satellite data type) contains Blue, Green, Red, three reflected infrared bands, and one thermal infrared band. This information is stored and presented digitally. Each data value represents the electromagnetic information from a spatial location, ranging from numerical values "0" to "255." The larger the number, the greater the recorded radiation for a particular band of electromagnetic information. Suppose a Thematic Mapper satellite captured the following readings for a particular spatial position: Band 1=21, Band 2=44, Band 3=55, Band 4=117, Band 5=119, Band 6=99, Band 7=120. The visible color region is relatively dark and the infrared region is moderate, similar to readings from a dark colored soil. Numerical clusters of statistically similar band readings can be classified into a particular land cover type, such as wet soil. This information and resulting classifcations are stored digitally.

This digital data allows computers to readily read a stream of numbers and produce geo-referenced electromagnetic information. The problem faced by the reclamation specialist is "do any of these bands mean anything important to reclamation activities?" There have been relatively few scholarly works conducted to answer this question.

Remote Sensing Applications: Landscape Classification

Suppose that remotely sensed bands do mean something for reclamation specialists and mine operation planners, then one is faced with analyzing up to seven bands of remotely sensed data into practical applications. If one employs the seven bands, one is faced with assessing electromagnetic information in a multivariate space of seven dimensions. Statistical techniques developed in this century and made readily accessible by micro-computer technology now allow remotely sensed data to generate useful spatial information that was computationally impossible to generate in the past (see Pielou 1984 for a general discussion of this technique, primarily plant ecology examples but applicable to remote sensing). In other words the bands can be interpreted in multivariate space for analysis. The most common form of multivariate analysis in remote sensing is spatial classification based upon concepts found in matrix algebra, principal component analysis, and

.irst pixel of this map is original pixel 401, MAP PROCESSED BY TM 1234567 CLASSIFICATION--TRAINING AREA--BURLEY

COVER TYPE	SYMBOL 1	SYMBOL 2	
1 WATER	M	$	■
2 CONIFER	+	^	‡
3 BOAOLEAVED FOREST	+	•	♦
4 AGRICULTURE	#		#
5 RANGELAND	/		/
6 BARE SOIL/GRAVEL	.		.
7 URBAN AND BUILT-UP	ø		ø

<< 111 LINES WERE PROCESSED >>

1 - 5793 POINTS HAVE BEEN IDENTIFIED AS WATER
2 - 2312 POINTS HAVE BEEN IDENTIFIED AS CONIFER
3 - 2921 POINTS HAVE BEEN IDENTIFIED AS BOAOLEAVEO FOREST
4 - 796 POINTS HAVE BEEN IDENTIFIED AS AGRICULTURE
5 - 893 POINTS HAVE BEEN IDENTIFIED AS RANGELAND
6 - 218 POINTS HAVE BEEN IDENTIFIED AS BARE SOIL/GRAVEL
7 - 48 POINTS HAVE BEEN IDENTIFIED AS URBAN AND BUILT UP

450 POINTS WERE NOT CLASSIFIED

Figure 1. This map (line printer output from LIG-3, a classification program written at the University of Michigan) is a cover-type classification image from Thematic Mapper remotely sensed data. The site is located in Michigan and contains sand and gravel mines. The mining operations may be difficult to seperate from sandy beach and dirt road electromagnetic data.

discriminant functions. The landscape can be classified into relatively homogeneous types according to selected electromagnetic signatures (training sets). For example, one can select geo-referenced positions containing a landscape type of interest, such as a conifer woodland. The electromagnetic signature of this stand can be employed to search for areas with similar signatures. Figure 1 illustrates the results of classifying the landscape with this approach, called a supervised classification method. This approach may lead to 80-85% of the landscape being accurately classified (see Lindgren 1985:115). However, this classification approach may be no more accurate than traditional landscape field methods and traditional aerial photograph interpretation methods employed by the United States Forest Service for remote mountainous regions.

Table 2. This table illustrates the computational methods associated with specificity and sensitivity.

Multivariate Classification	True Condition: Conifer Woodland	True Condition: Not Conifer Woodland	Total
Conifer Woodland	3,677 cells	431 cells	4,108 cells
Not Conifer Woodland	1,508 cells	11,015 cells	12,523 cells
Total	5,185 cells	11,446 cells	16,631 cells

Sensitivity = 3677/5185 = 0.70916 or 70.916%

Specificity = 11015/11446 = 0.96234 or 96.234%

Predictive Power of Sensitivity = 3677/4108 = 0.89508 or 89.508%

Predictive Power of Specificity = 11015/12523 = 0.87958 or 87.958%

In contrast, the unsupervised classification method utilizes "clustering algorithms to automatically sort data into spectrally similar classes (clusters)" (Lindgren 1985:83). "This method is utilized most frequently when little ground truth is available and the mix of surface features is great" (Lindgren 1985:83).

One remote sensing issue that is of great concern is associated with the variance in electromagnetic radiation from the same landscape cover type based upon the position of the recording device, the source/position of radiation (such as the sun), aspect orientation of the landscape, and yearly season changes of the cover type, meaning that the electromagnetic signature of the landscape cell may be constantly changing and not necessarily consistent. If landscape signatures are constantly changing, the identification of landscape types may be more difficult than sometimes imagined. To adjust for this change, 'image ratioing' has been employed as a technique to compensate for differences in sun angle, sunlight intensity, and shadows that may exist between data sets of different dates. Instead of employing direct electromagnetic readings, a ratio between bands may be employed. In addition 'image differencing' is also employed, where the difference between two bands attempts to compensate for electromagnetic spatial changes. While ratioing and differencing may prove to be valuable techniques, much work needs to be accomplished before these approaches can be applied reliably in standard equations for remote sensing applications.

Multivariate remote sensing methods (as with any method) may lead to sensitivity classification problems (known as omission errors) and specificity classification problems errors (known as co-mission errors), (see Hennekens, and Buring 1987 for detailed discussion of these concepts, primarily epidemiology examples but applicable to remote sensing). Sensitivity is defined as the number of true landscape cells (a landscape cell is a unit area of land, in Thematic Mapper data, this unit is a 30 meter by 30 meter cell) for a given type of homogeneous landscape (such as conifer woodland) divided by the number of landscape cells identified by the classification method as being that particular type. In other words, sensitivity is the ability of a classification attempt to give a positive finding when the landscape truly is that landscape type. In contrast, specificity is defined as the number of true cells not identified as being associated with a particular landscape type divided by the number of landscape cells identified by the classification methods as not being that particular type. Thus specificity is the ability of the classification to give a negative finding when the landscape is truly not the type sought. Both sensitivity and specificity computations can also be examined for their predictive power. For example, suppose an investigator was searching for a conifer woodlands and then carefully matched the remote sensing classification results with actual field surveyed results and developed a sensitivity/specificity table (Table 2). This type of work should be conducted to develop an understanding of the predictive power of classifications, especially under conditions not typically studied.

To illustrate the classification problem further, Figure 2 is an aerial Thematic Mapper image from a particular band of a site in Michigan, where several sand and gravel operations are located in the image. However, is the spectral image any different that the information being captured from the sandy beach or even the gravel road? While computational methods in landscape classification have been rapidly advancing in technological ability, there are still many important issues to be addressed and carefully examined. Presently, there is no substitute for an investigator who carefully examines the information and results of a particular technique and knows the limitations of the technology.

Nevertheless, in surface mining/remote sensing applications, landscape classification can be a useful task, especially in remote regions where rugged terrain prohibits access. Remote sensing landscape classification can be useful in determining pre-mining cover types and computing the physical areas of these pre-mining cover types. Determining the area of land cover types can also be helpful for "office-bound" reclamation specialists in the United States who must restore the post-mining landscape to the same cover-type extent as in the pre-mining landscape. Remote sensing and classification become a landscape accounting tool. For example, Repic et al (1991) describe the use of three video bands (yellow-green, red, and near infrared) to predict the iron ion concentration and pH of two water bodies in Clay County, Indiana. The water bodies were unreclaimed abandoned mines capable of producing acid mine drainage and high ferrous ion levels. Repic et al (1991) determined that the yellow-green band was most sensitive to iron content and pH, implying that this band could possibly be employed to monitor water quality.

Other investigators have described the potential use of remote sensing in reclamation/surface mining operations. Lindgren (1985:154-156) (providing one can excuse his sometimes demeaning tone concerning surface mining operations) notes,

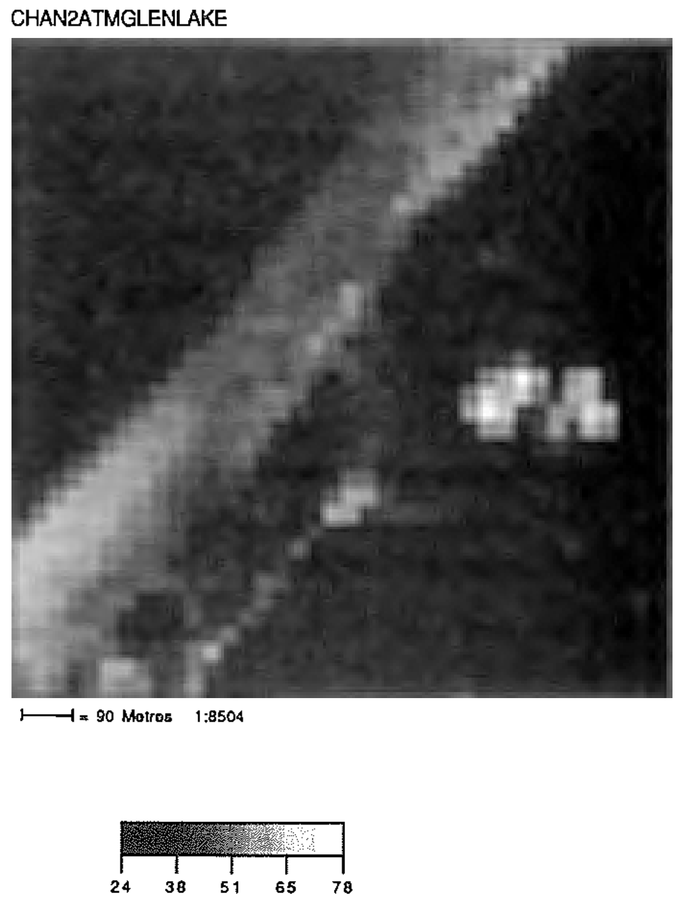

Figure 2. This map illustrates Thematic Mapper information from Band 2. A lake is in the upper left-hand corner, a sandy beach cuts across the map in a diagonal manner, the remaining portion in the image is primarily wooded, with execpetion of roads, sand and gravel operations, and grasslands.

"Another area where increasing use is being made of aerial photographs is in the monitoring of stripmining activities. Coal, in particular, has been stripmined since the 1890s and over the years thousands of hectares of land have been devastated by this practice. Ground scarring, erosion, spoil banks, landslides, and polluted streams are typical features of unreclaimed stripmining sites. Historically, coal companies have been able to 'scrape and run' because their considerable political influence has made it difficult for state legislatures to enact laws requiring those companies to reclaim stripped land. At least in theory this situation has changed with passage of the Surface Mining Control and Reclamation Act (1977) which establishes minimum national standards governing the surface mining of coal. Enforcement is left to the individual states who may deny mining permits to companies violating stripmining statutes.

Title IV of the Act has established a national program to reclaim lands mined prior to August 1977. Administered by the Department of Interior's Office of Surface Mining, the program would cover unreclaimed lands and those partially reclaimed but still endangering the health and safety of the public. As a part of this program the State of Pennsylvania undertook an Abandoned Mine Land Inventory the purpose of which was to accurately identify and map all surface features and disturbances from mining sites [125] {Clemens and Warnick 1982}. One portion of the inventory was conducted from 1:80,000 black-and-white photos. Nearly all surface expressions of mining activities abandoned prior to 1977 were detected and accurately delineated on the photos. quality control was maintained by field-checking. The authors of the report concluded that had the inventory been conducted entirely by field survey methods the final cost would have been at least eight times higher.

In a similar study Mroczynski and Weismiller found color-infrared photos to also be effective for identifying abandoned mine land [126] {1982}. In this instance 1:120,000-scale images enlarged to 1:30,000-scale prints were employed to identify several categories of non-reclaimed land including barren soil, gob, and slurry ponds. Identification from color-infrared proved highly successful as 98 percent of the sites were correctly classified by category.

For lands in the process of being mined a more continuous monitoring system is required. Research suggests that Landsat may be capable not only of monitoring the progress of the surface mine operations but of the reclamation process as well. Spisz and Dooley [127] {1979} use Landsat digital data to classify a surface mining area in eastern Kentucky into six land cover classes representative of various stages in surface coal mining operations -- two classes of undisturbed forest, two classes of barren land, and two classes of revegetated land (greater than 50 percent vegetation cover and less that 50 percent vegetation). Classification was done on Landsat data of three dates (July 1973, August 1976, and April 1978). Comparison of results revealed the gradual enlargement of newly mined areas and the reclamation of older mined areas. Forested and barren areas were identified only 60 percent of the time. The computer had difficulty discerning areas in the early stages of reclamation from spoil banks sprouting a sparse cover of natural vegetation.

Davis et al. have suggested further that Landsat digital data can be used to provide information on reclamation effectiveness [128] {1982}. Under present mining laws companies are encouraged to revegetate stripped areas as rapidly as possible. If proper soil fertilization and stabilization measures are not taken first, however, many species may die within a year or two. To test this theory Landsat digital data for several dates between 1973 and 1981 were separated into six classes using an unsupervised classification algorithm: water, water (with heavy sedimentation), vegetation, reclaimed, barren, and mixed pixels. Reclaimed areas were easily separated though over the eight-year period some reclaimed areas moved into the vegetation category. Significantly, the analysis of the several data sets revealed areas which experienced a vegetation breakdown, that is, barren areas previously classified as reclaimed. Although such areas were small the authors contended they represented a good illustration of the effectiveness of Landsat in providing data on mining reclamation activities."

According to Lindgren, remote sensing applications seem to have some potential in reclamation and surface mining operations. If an investigator pursues a remote sensing application for reclamation or surface mining operations, the investigator will have to contend with errors.

To reduce error, two methods of statistical sampling have been commonly employed: multiphase sampling and multistage sampling (see Howard 1991:347-350 for further elaboration). In multiphase sampling, samples of aerial photographs from a study area are compared with field plots that cover the same area as the aerial photographs. In multistage sampling, field plots are smaller than aerial photographs or satellite imagery. Essentially in both methods, field data allows the investigator to check and corroborate or refute remotely sensed information. In studies that demonstrate a fair degree of correlation between field and remotely sensed information, the remaining aerial photographs or satellite imagery (not employed in the correlation subsample study) can then be classified with a known level of classification confidence.

The spatial resolution associated with the remote sensing technology is also an important issue to address. For example, Thematic Mapper information is available at a resolution of 30 meters by 30 meters for bands 1,2,3,4,5,7 and 120 meters by 120 meters for band 6. The reclamation specialist must assess this resolution for its applicability. A 30 meter by 30 meter cell can be a very coarse depiction of a site for small sand and gravel operations (a 40 acre mine would contain about 175 to 185 cells) but be a relatively fine grained depiction of an extensive surface coal mining operation (a 50,000 acre mine could contain 222,150 to 222,200 cells). "How many cells?" and "At what resolution?" are issues that have not been sufficiently addressed by the scientific community. Often the resolution is related to the available technology, not the application. A 30 meter by 30 meter cell contains electromagnetic information averaged from a wide variety of sources within the cell. Exposed small patches of soil, isolated eastern red cedar trees (Juniperus virginiana), or a truck moving along a dirt road can alter the electromagnetic signature, making classification difficult. Even though some scholars state that remote sensing may have applications in surface mine and reclamation applications, there are presently few, if any precedents to readily incorporate this technology into practical/everyday operations.

Remote Sensing Platforms

There are variety of platforms suitable for conducting remote sensing projects that operate with MACINTOSH, DOS and UNIX operating systems and are often affordable to small firms and operators. Data input into remote sensing software is generally easy, with a tape drive or an optical digitizer. Sometimes, remote sensing users are more interested in the "bangs" and "whistles" or "greased lightning" effects of the latest hardware and software; however, one should not be fooled by the latest toys in technology. Often less expensive hardware and software adequately perform a remote sensing task. In addition, remote sensing software is not always "user friendly," meaning that unless one invests considerable time in training to become familiar with a specific hardware/software package, one may find that one cannot quickly perform a remote sensing task during a time period when efficiency is important.

Summary

This paper documents the types of output that can be generated through remote sensing and the utility of this technology in surface mining and reclamation applications. However, the actual use of this technology in surface mining situations has been limited. Future applications require extensive documentation and scientific investigation before practical remote sensing applications may become common.

Bibliography

Davis, A.L., H.L. Bleomer, and J.O. Brumfield. 1982. A temporal approach to monitor surface mine reclamation progress via Landsat. Proceedings: National Conference on Energy Resource Management, Volume II, NASA Conference Publications 2261.

Clemens, E., and L Warnick. 1982. Remote sensing applications to the Pennsylvania abandoned mine reclamation program. Proceedings: National Conference on Energy Resource Management, Volume II, NASA Conference Publications 2261.

Hennekens, C.H., and J.E. Buring. 1987. Epidemiology in Medicine. Little, Brown and Company.

Howard, J.A. 1991. Remote Sensing of Forest Resources: Theory and Application. Chapman and Hall.

Lillesand, T.M., and R.W. Keifer. 1979. Remote Sensing and Image Interpretation. John Wiley and Sons.

Lindgren, D.T. 1985. Land Use Planning and Remote Sensing. Martinus Nijhoff Publishers.

Mroczynski, R.P. and R.A. Weismiller. 1982. Aerial photography : a tool for strip mine reclamation. Johannsen, C.J., and J.L. Sanders (eds) in: Remote Sensing for Resource Management. Soil Conservation Society of America, Ankeny, Iowa.

Pielou, E.C. 1984. The Interpretation of Ecological Data. John Wiley and Sons.

Repic, R.L., J.K. Lee, and P.W. Mausel. 1991. An analysis of selected water parameters in surface coal mines using multispectral videography. Photogrammetric Engineering and Remote Sensing, 57(12):1589-1596.

Sabins, F.F. Jr. 1986. Remote Sensing: Principles and Interpretation. W.H. Freeman and Company.

Spisz, E.W., and J.T. Dooley. 1979. Assessment of Satellite and Aircraft Multispectral Scanner Data for Strip-Mine Monitoring. Lewis Research Center, NASA TM-79268.