(NASA-TM-X-73533) UTILITY OF A SCANNING DENSITOMETER IN ANALYZING REMOTELY SENSED IMAGERY (NASA) 21 p HC A02/MF A01 CSCL 05B

N77-16415

Unclas
G3/43 11538

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NASA TM X-73533

NASA TM X-73533

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December 1976

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-73533		

4. Title and Subtitle	5. Report Date
UTILITY OF A SCANNING DENSITOMETER IN ANALYZING REMOTELY SENSED IMAGERY	December 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Joyce T. Dooley	E-8955
	10. Work Unit No.
9. Performing Organization Name and Address	176-30
Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D. C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Screening; Terrain analysis; Water quality; Strip mining; Energy conservation; Thermal mapping; Aerial photography; Satellite-borne photography; Scanners; Imagery	Unclassified - unlimited STAR Category 43

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	20	$3.50

* For sale by the National Technical Information Service, Springfield, Virginia 22161

UTILITY OF A SCANNING DENSITOMETER IN ANALYZING REMOTELY SENSED IMAGERY

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Lewis Research Center

ABSTRACT

The utility of a scanning densitometer for analyzing imagery in the NASA Lewis Research Center's regional remote sensing program is evaluated. Uses studied include (1) quick-look screening of imagery by means of density slicing, magnification, color coding, and edge enhancement; (2) preliminary category classification of both low- and high-resolution data bases; and (3) quantitative measurement of the extent of features within selected areas.

The densitometer was capable of providing fast, convenient, and relatively inexpensive preliminary analysis of aerial and satellite photography and scanner imagery involving land cover, water quality, strip mining, and energy conservation.

INTRODUCTION

Remotely sensed environmental data are now being used regularly with success by many large users and potential future applications are numerous, especially when the variety of small users and their many requirements are considered. However, widespread use of remote imagery is hampered for two reasons: (1) Many potential users are unfamiliar with the advantages of remote sensing; and (2) an inexpensive, but expedient, method of analyzing the data to meet many of the users' basic requirements has not been demonstrated.

The Lewis Research Center is using remote sensing for studying regional problems dealing with land cover, water quality, strip mining, and energy conservation. All of these applications require preliminary data analysis. Thus, Lewis also needs an expedient method for preliminary screening and interpreting of remotely sensed data. The work reported herein was done to determine the usefulness of a scanning densitometer to meet this need for photographic and multispectral scanner imagery.

The approach used in this study was (1) to analyze the characteristics of the densitometer system, and (2) to apply and evaluate its capabilities for typical Lewis regional applications, which are representative of the needs of most users.

BACKGROUND

In general, remotely sensed data are recorded photographically (in pictorial form) or digitally (on magnetic tapes). Photographic data (imagery) are usually easier to obtain and less expensive to analyze than digital data, which often require the use of sophisticated computers for analysis.

The analysis of imagery, however, can be performed by man and/or machine. When performed by human photointerpreters, it is a subjective process, which can become costly, due to the skilled man-hours required. Speed and objectivity can be gained by using computers, but here, again, the cost may be beyond the financial means of many potential users (i.e., private industries, academic institutions, and state and local governmental agencies).

In analyzing remotely sensed imagery, the primary objective is to derive information from the image that will lead to the identification of objects and/or phenomena and to the possible assessment of their significance. Along with this identification, the need exists for sorting objects and/or phenomena into groups or classes and for measuring their areas.

The optical properties of materials determine such image characteristics as film tone and texture. Shape and size determine shadow, boundaries, and pattern, all of which serve as identifying elements. The significance of each of these image characteristics varies with the scale and resolution of the imagery used and with the information to be interpreted. Many terrain features can be distinguished on the basis of gray-level differences in the imagery, regardless of the type of sensor used or the wavelength measured. The brightness and hue of an object recorded on a remotely sensed image are especially helpful in image analysis. The intensity of light that is reflected or emitted by an object as a function of wavelength constitutes the spectral signature of that object and often provides positive identification.

DESCRIPTION OF SCANNING DENSITOMETER

Many researchers in remote sensing (e.g., refs. 1 to 3) have used scanning densitometers in their work. Densitometry has a number of capabilities that are worth evaluating for research purposes. These capabilities are (1) magnification; (2) edge enhancement; (3) density slicing; (4) color enhancement (color addition, subtraction, and combination); (5) unbiased quantitative measurement of the extent of features in terms of the percentage of the total area of the scene; and (6) display on a cathode ray tube (CRT) for visual study and analysis, which can be photographed for a permanent record.

The spectral characteristics of materials and the spatial characteristics of size, shape, and geometry of features in imagery as displayed in an enhanced form by a scanning densitometer more clearly reveal the informational content of images. As a result, the ability to accurately identify objects and/or phenomena is often improved.

The scanning densitometer used in this study (refs. 4 to 6) is shown in figure 1. It is an inexpensive (approx $18 000), commercially available system consisting of a light box, a precision television camera, camera optics, a black-and-white CRT monitor, an electronic color analyzer, a color television monitor, an electronic planimeter, and an edge enhancer, as shown in block diagram form in figure 2.

The light box illuminates remotely sensed imagery with a relatively constant (±5 percent variation over the entire screen), high-intensity cold light source of over 10 764 lumens per square meter (1000 footcandles), so that the transmitted light through the transparency is a true indication of the density. The light box has a maximum useful area of 30.5 centimeters by 35.5 centimeters (12 in. by 14 in.) that is movable in any direction.

The precision, high-quality, closed-circuit television camera converts the transmitted light to an electrical video signal. The camera is mounted on a vertical column above the light box, so that it can be raised or lowered to permit the viewing of both large (24.1 cm by 26.7 cm (9.5 in. by 10.5 in.)) and small (3.8 cm by 5.1 cm (1.5 in. by 2 in.)) transparencies with the 25-millimeter lens. In addition, with the 75-millimeter telephoto lens and bellows attachment, areas smaller than 3.8 centimeters by 5.1 centimeters (1.5 in. by 2 in.) can be viewed and magnified. The imagery can be displayed at magnifications as great as 30×. By using a standard resolution test pattern, it was determined that the scanning densitometer can resolve 60 line-pairs per millimeter at a magnification of 30×. Generally, images were magnified to 25× to avoid geometrical distortion. The imaging resolution spot size is 1/500th of the height of the viewed area, which is limited by the camera vidicon of standard television scan rates. The resolution element (minimum resolution spot size) is 25 micrometers. The camera lenses have adjustable apertures to accommodate transparencies of various densities. The camera's vidicon tube and precision electronics provide uniform response to the light intensity across the image. Coarse and fine mechanical focus controls are also provided.

The 30.5-centimeter (12-in.) black-and-white CRT monitor and 48.3-centimeter (19-in.) color television monitor can be used for simultaneous viewing.

The electronic color analyzer separates the camera signal into as many as 12 equal-density intervals, with a preselected color being designated for each interval, and displays the density values in color on the color television screen. The minimum density level is 0.03 density units (D), and the maximum level is 2D (i.e., the density range is 1.97 density units, or 0.164 density units per color level). Each color represents an equal increment of film densities. The film density D is related to the transmittance T (0 to 1) of the film by

$$D = \log_{10} \frac{1}{T}$$

Thus, a transmittance of 1/100th corresponds to a density of 2D, and a transmittance of 0.93 (i.e., the film is transmitting 93 percent of the light) corresponds to a density of 0.03 D. The light intensity that is transmitted to the vidicon imagery and displayed on the television monitor is converted to density by means of a logarithmic amplifier in the color analyzer. An analog-digital converter then digitizes the density signal into 12 discrete intervals. Each value is presented to a digital-analog converter that produces analog signals for the red, green, and blue electron guns in the color television tube. The three colors are mixed on the screen of the color television monitor to produce the desired color analysis.

The 12 colors are in a fixed order, starting with white, which represents the lowest density area of the transparency, and proceeding through dark blue, light blue, light green, medium green, dark green, yellow, brown, light red, dark red, magenta, and violet. Saturation occurs on both ends (white and violet). Those transparency densities that are less than the density corresponding to white are automatically shown as white, and those densities that are greater than the density corresponding to violet are automatically shown as black. The lower and upper limits of the density range are preset by the operator.

The color television monitor permits display of all or any portion of the transparency in color (per the color analysis) or in black-and-white density levels. Any one or more of the 12 color-coded density levels can be (1) replaced with its original black-and-white density level or (2) masked out by making it black. This is extremely useful for emphasizing features of particular interest. All options are available to the operator through control switches.

The electronic planimeter associated with the densitometer measures the percentage of area on the color television monitor display represented by each color in the analysis. It also provides a digital readout of the area of each colored part in terms of the percentage of the total image area. This is accomplished by measuring the percentage of time that each of the 12 density levels from the analog-digital converter is activated. Since the television scan is linear, the time is directly proportional to the area of the displayed colors. The accuracy of the planimeter measurements is ±1 percent of full scale.

Edge enhancement is available to emphasize edges of features for easier recognition of boundaries, lines, and fine structures. Edge enhancement is accomplished by displaying the variation in the derivative of the film density. The camera converts the density values in the imagery to video signals that are then processed by analog computer circuits to produce a new signal proportional to the rate of change of density (i.e., the density slope) across the original imagery in the horizontal direction. The image is displayed on the 31-centimeter (12-in.) black-and-white CRT monitor and/or on the 48-centimeter (19-in.) color television monitor, with lines and edges greatly enhanced. Since the unit does not respond to density changes in the vertical direction, horizontal lines on the original imagery are not reproduced. Interfering line structures may be filtered out by positioning them horizontally, leaving other lines greatly enhanced over the original. In addition, controls are available for adjusting the enhanced brightness and contrast and for selecting the edge width and mode of enhancement (i.e., positive or negative edge enhancement).

TYPICAL REMOTE-SENSING APPLICATIONS

Quick-Look Screening of Imagery

In many studies where remotely sensed imagery is to be used, one must select, from all available imagery, that which is most appropriate for detailed study of the specific phenomenon of interest. The densitometer can aid in making this selection by providing fast screening of all available imagery with magnification, color, and edge enhancement options. Less than 5 minutes is usually sufficient to isolate the area to be screened, to calibrate the equipment, and to switch on the options to be used. Then the display capability instantaneously puts the photographic data in a more convenient format that permits greater discrimination by the observer. Factors that affect the usefulness of imagery, such as cloud cover, haze, noise, vignetting, sun angle, and rate of change in contrast, can be more readily detected from the enlarged and enhanced displays obtained with the scanning densitometer.

To expand on this feature of the densitometer, consider, for example, the need to periodically update land-cover maps by using black-and-white Landsat imagery. Here, one is interested in (1) choosing the most current imagery that also has the best (noticeably clearer and sharper) coverage of the area in question and (2) quickly spotting changes, which are often embedded in a large amount of ground detail. Changes that involve very high environmental contrasts, such as major road and airport construction, can be visually detected. The magnitude of the change and the gray-scale variation involved are so great that ambiguities are kept to a minimum. However, less obvious changes require considerably more time for analysis. With the densitometer, all available imagery can be quickly and easily screened on the color television monitor in a magnified, color-coded, or edge-enhanced form. As a result, the pertinent imagery is narrowed down, and the most appropriate imagery can be quickly selected. Finally, those features of special interest can then be singled out for detailed study and analysis. Lengthy and detailed study periods with such equipment need not represent a cost problem since it is both uncomplicated and inexpensive to operate.

Quick-look screening is also an invaluable aid for determining the number of density levels present in a particular area of interest. This step was illustrated by using remotely sensed imagery from the Lewis Research Center's water-quality investigation. The densitometer's screening technique was applied to determine the degree of nonuniformity in density of a small body of water. Such water-density profiles are important in determining water depth, water pollution, thermal pollution, and aquatic plant life. Of course, in order to correlate the measured density profile with an actual physical phenomenon, the interested user would have to acquire ground-based data. However, for this study, it is sufficient to demonstrate that varying density values can be revealed in what otherwise appears to the eye to be constant-density portions of the imagery.

The imagery used in this demonstration was Skylab satellite photography from the Earth Resources Experimental Package (EREP), specifically the September 15, 1973, coverage of Ohio's Buckeye Lake. This Skylab imagery was taken with the Earth terrain camera (S-190B), which provided ground coverage of approximately 109 kilometers (59 n mi) on each side. The particular frame used was SL3-87-054, infrared color imagery (bandpass, 0.5 to 0.88 μm), having an estimated ground resolution, at low contrast, of 30 meters (100 ft) at a nominal scale of 1:500 000 and viewed from a nominal altitude of 435 kilometers (235 n mi) (ref. 7).

The Buckeye Lake portion of this frame of imagery (i.e., the smallest rectangular area in which the entire lake could be contained) was enlarged approximately 12× with the densitometer. The resulting scene is shown in figure 3, as displayed on the densitometer's color television screen. All nonwater features were then masked out of the scene (i.e., set to black), and only the water (Buckeye Lake) portion was subjected to a nine-level density slice, as shown in figure 4.

It is noteworthy that the lake area associated with each of the nine density levels, isolated in color by using the densitometer's quick-look screening process, may also be quantitatively measured by using the densitometer's planimeter option. In this fashion the total area associated with a given physical phenomenon can be conveniently determined.

Preliminary Land-Cover Classification Using Satellite and Aircraft Imagery

The densitometer was used to provide preliminary land-cover classification of portions of Ohio, West Virginia, Pennsylvania, and the Ohio River by using Landsat I, October 1974 imagery. An inventory of the percentage of water (including wet lands, water impoundments, and rivers) within the area was obtained from the satellite's multispectral scanner (MSS) imagery. This high-altitude (920 km (496 n mi), low-resolution (0.079 km (259 ft)) imagery covers approximately 185 square kilometers (100 sq n mi) of the Earth's surface in each frame (ref. 8). Landsat I, black-and-white, MSS band 7 imagery covering the reflective infrared (IR) portion of the electromagnetic spectrum (0.8 to 1.1 μm) was used for this analysis. This band was chosen because water bodies are delineated very clearly in this wavelength range. A 12-color density slice of the positive transparency resulted in the areas given in table I and in the color-enhanced monitor display shown in figure 5. Although the accuracy of the areas given in table I was not determined, the overall accuracy of the planimeter measurements is quoted as ±1 percent of full scale (100.0 percent). The land-water categorization shown in table I was determined and assigned by using readily available topographical maps of the area. Thus, 34 225 square kilometers (10 000 sq n mi) of the tristate area were quickly inventoried for water cover. There are approximately 1232 square kilometers (360 sq n mi) of water cover in this particular area.

The scanning densitometer was also evaluated for classifying land cover within the middle third of a small strip-mine test site (approx 15.5 km^2 (5 sq mi)) located in Noble County, Ohio. This test site is an Ohio orphaned strip mine where the Eastern Ohio Resource Development Center (EORDC) is conducting research on effective reclamation techniques. High-resolution aircraft imagery was used in this demonstration. Specifically, a positive, black-and-white transparency of an aerial photograph (obtained in September 1974 over the EORDC test site at an altitude of 1.8 km (6000 ft) with a 23-cm (9-in.) format mapping camera) was used. The resulting eight-level density slice of the imagery is shown in figure 6. Correlating this density slice with ground truth supplied to Lewis by on-site EORDC research personnel yielded table II. In figure 6, medium green is shown as black for additional contrast between shades of green.

An additional application of the densitometer, in the area of strip mine reclamation, is as an aid in determining highwall boundaries, which are sometimes difficult to see on the remotely sensed imagery. Highwalls are the near-vertical slopes left in hilly or mountainous terrain after contour strip mining has occurred. This alternation in the shape of the land affects the surface drainage patterns and often leads to the impoundment of water. The area between the highwall and the steeply inclined spoil bank is where water quite frequently becomes trapped. The highwall is therefore a significant feature to be considered in strip-mined areas in terms of reclamation.

The magnification and edge enhancement features of the densitometer were used to provide a more detailed view of a highwall in the EORDC test site. The imagery used in this example was a positive transparency of the 23-centimeter (9-in.) square black-and-white photograph taken from a C-47 aircraft at 3000 meters (10 000 ft). The entire approximately 5-kilometer-long and 3-kilometer-wide (3-mi-long and 2-mi-wide) general test site area was shown in the transparency (fig. 7(a)). From this imagery, as displayed on the densitometer's black-and-white CRT monitor, it is difficult to locate and evaluate the highwalls. (Highwalls have a direct bearing on the type and amount of reclamation required to restore orphaned lands and are key features for monitoring restoration progress.) The highwall (pointed out in fig. 7(a) with the arrow) and the adjacent area were enlarged with the densitometer, by approximately 16× (fig. 7(b)) and then edge enhanced, both positively (fig. 7(c)) and negatively (fig. 7(d)). The edge enhancements (figs. 7(c) and (d)) provide greater insight as to the general slope and smoothness of the terrain. From these densitometer displays, the boundaries of the highwall can be more easily identified, which permits more accurate determination of the acreage involved. Thus, densitometer display of imagery, in an edge-enhanced format, can aid in better locating and assessing the extent of pertinent features in strip mine reclamation studies. Potential highwalls and other features of interest can be pin-pointed for gathering ground truth, thereby reducing the extent of field trip efforts. The densitometer's edge enhancement feature, combined with color enhancement and magnification of 30×, resulted in the television monitor display (fig. 7(e)) of the small portion of the highwall that is outlined in figure 7(b). Here the total range of densitometer enhancement is demonstrated, which provides even greater detail of specific areas of interest.

Examination of Energy-Loss Scans

Another application of the scanning densitometer centers around a Federal energy conservation program. The efficient use of energy has become a critical issue with large Federal installations such as NASA. As a result, Lewis has made thermal scans of all NASA facilities as part of the Federal energy conservation program. The 11-micrometer thermal band of the Lewis Research Center's modular multiband scanner (M^2S) provided the remote thermal digital data, which were converted to photographic data (imagery) by means of computer processing techniques. Using the resulting remotely sensed thermal imagery, the densitometer quickly detected some of the energy losses. An example of this is the September 10, 1975, 8:00 a.m. overflight of the National Space Technology Laboratory (NSTL) in Bay St. Louis, Mississippi, at an altitude of 460 meters (1500 ft). The middle third of a black-and-white, 70-millimeter transparency obtained by processing the original M^2S digital data tape on computers was used (fig. 8). The area of interest in this analysis is the NSTL central heating plant. It has 20- and 25-centimeter-diameter (8- and 10-in.-diam), high-temperature hot water (HTHW) distribution pipes (both supply and return lines) buried 1.5 to 2.0 meters (5 to 7 ft) underground. As shown in the black-and-white imagery, the buried lines stand out clearly and can be traced without difficulty because they are losing heat. This is much clearer in the 12-color enhanced form of the black-and-white imagery (fig. 9). Figure 9 is the result of a 12-color density slice, where the higher density (hotter) areas of the black-and-white negative transparency are shown in ascending order, as yellow, brown, light red, dark red, magenta, and violet. The areas of heat loss can be readily detected by using the densitometer's rapid screening technique. The density levels of this thermal imagery represent the specific temperatures shown in figure 9. If a rough estimate of the wasted energy from the indicated hot spots is desired, the areas associated with each of the high-temperature colors can be found. With these areas, the measured temperatures, and the handbook values for heat-transfer coefficients and surface emittance, the heat loss can be calculated. A preliminary discussion of the NASA thermal scans and of the approach to quantifying the thermal imagery may be found in reference 9.

SUMMARY OF RESULTS

The utility of a scanning densitometer for a number of remote-sensing research purposes was studied. It is useful for certain applications. The densitometer's versatile, instantaneous display and quantitative area-measurement capabilities proved to be valuable tools in the preliminary analysis of particular remotely sensed imagery pertaining to land cover, water quality, strip mining, and energy conservation programs. Specifically, the densitometer provides (1) quick-look screening of imagery with magnification and color and/or edge enhancement, (2) measurement of the area or extent of features, (3) broad category classification of selected areas using low-resolution imagery, and (4) less broad classification of selected areas using high-resolution imagery.

In conclusion, the equipment described in this report is a fast, convenient, and relatively inexpensive means of analyzing remotely sensed imagery for certain regional applications where gross but quick answers and/or colorful displays are desired. The equipment is not recommended for detailed analysis of remotely sensed imagery, which requires a high degree of accuracy.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 22, 1976,
176-30.

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TABLE I. - PERCENTAGE OF TOTAL AREA FOR EACH PRELIMINARY LAND-COVER TYPE IN TRISTATE AREA - LANDSAT I IMAGERY

Preliminary land-cover category	Color	Land-cover area, percent of total area
Land type		
1	White	1.4
2	Dark blue	3.0
3	Light blue	9.9
4	Light green	24.1
5	Medium green	24.5
6	Dark green	21.1
7	Yellow	6.7
8	Brown	3.5
9	Light red	2.2
Water type		
1	Dark red	1.5
2	Magenta	1.2
3	Violet and black	.9
		100.0

TABLE II. - PERCENTAGE OF TOTAL AREA FOR EORDC TERRAIN TYPES - AERIAL IMAGERY

Terrain type	Color	Terrain-type area, percent of total area
Bare soil (including strip mine)	Light blue	5.0
	Light green	10.5
Light vegetation (e.g., grass)	Medium green	16.5
	Dark green	22.0
	Yellow	18.5
Heavy vegetation (e.g., trees or forest)	Brown	16.5
Water impoundments	Dark red	9.0
	Violet	2.0
		100.0

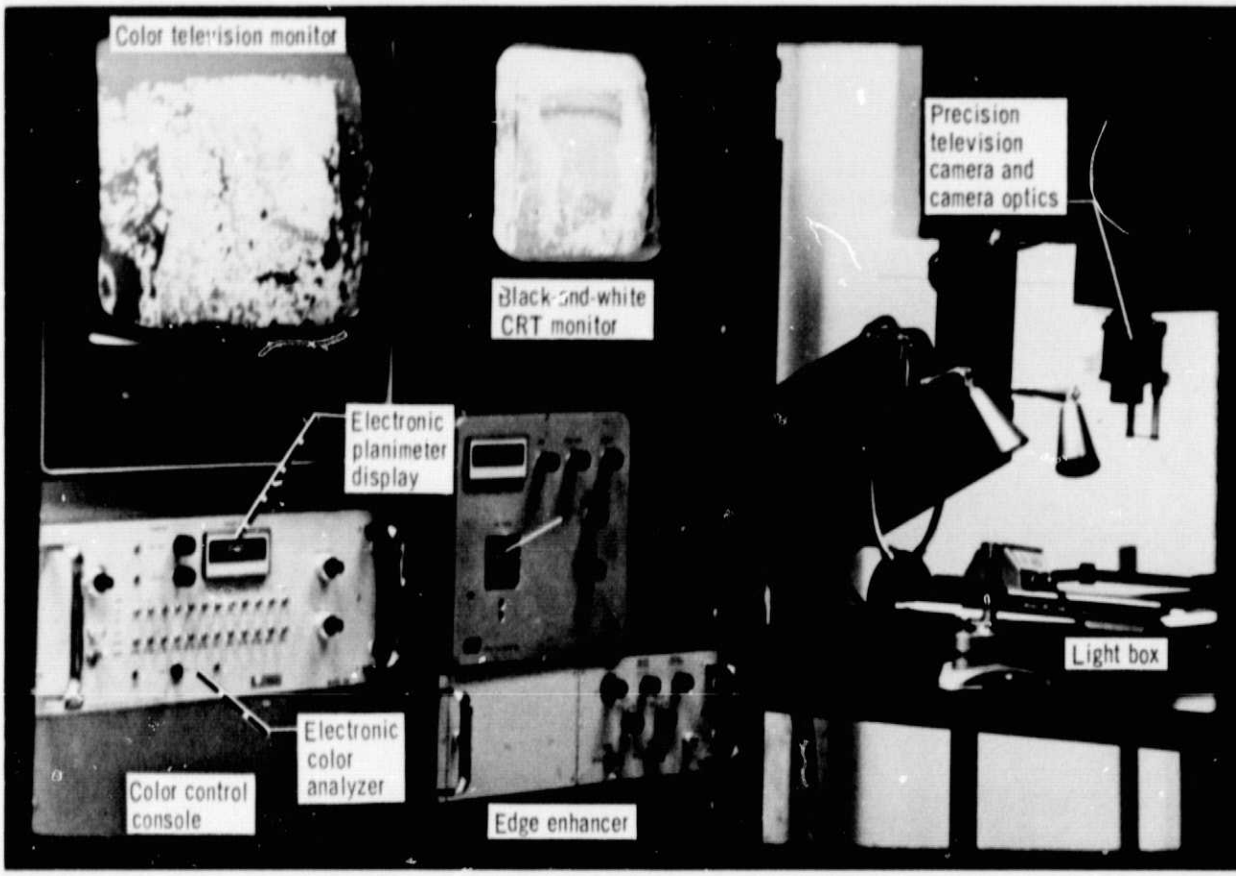

Figure 1. - Scanning densitometer system.

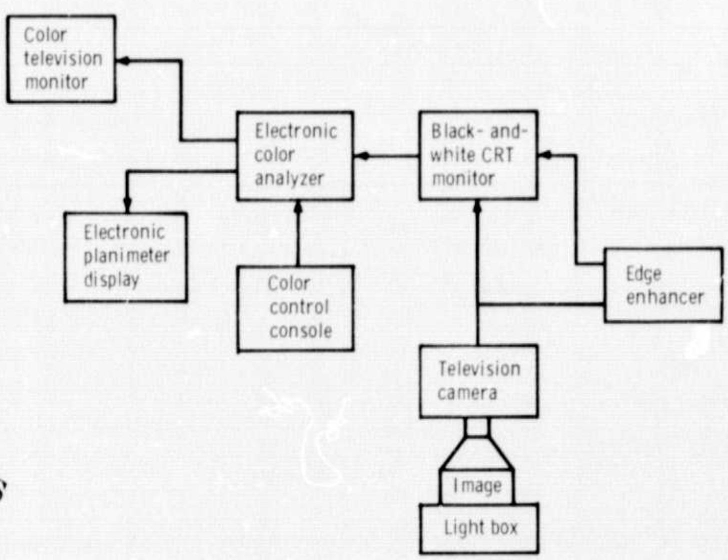

Figure 2. - Block diagram of scanning densitometer system.

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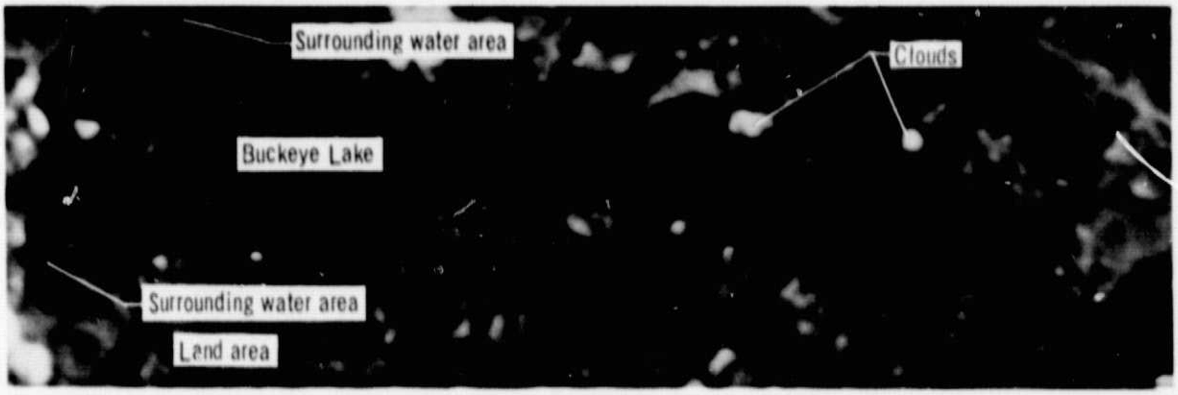


Figure 3. - Skylab imagery of Ohio's Buckeye Lake as displayed on the densitometer's 48-centimeter (19-in.) television screen at a magnification of 12X.

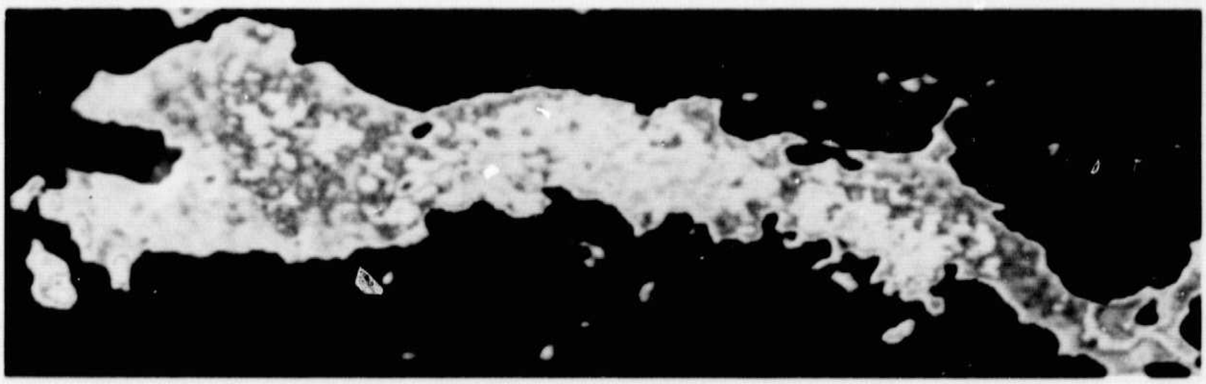


Figure 4. - Nine-level density slice of Buckeye Lake and surrounding water and wetland areas.

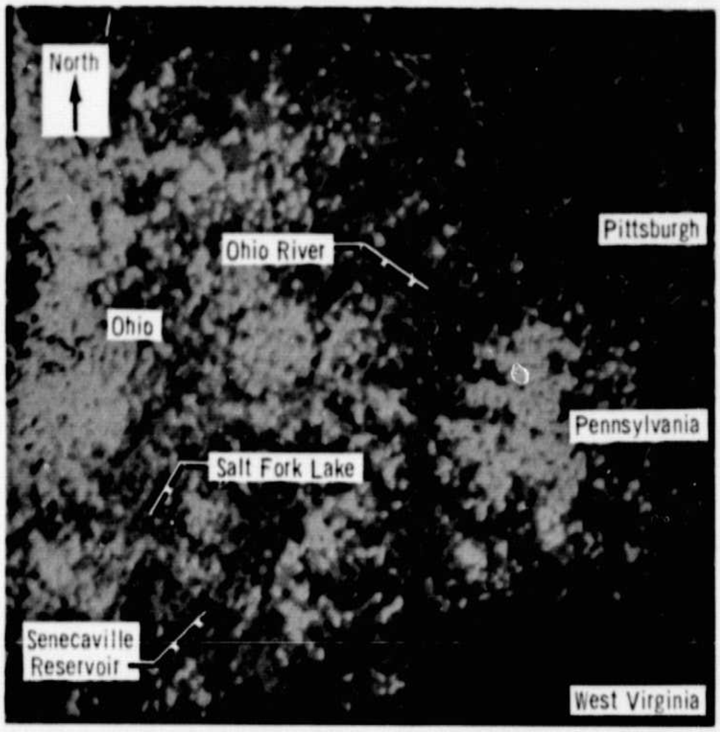
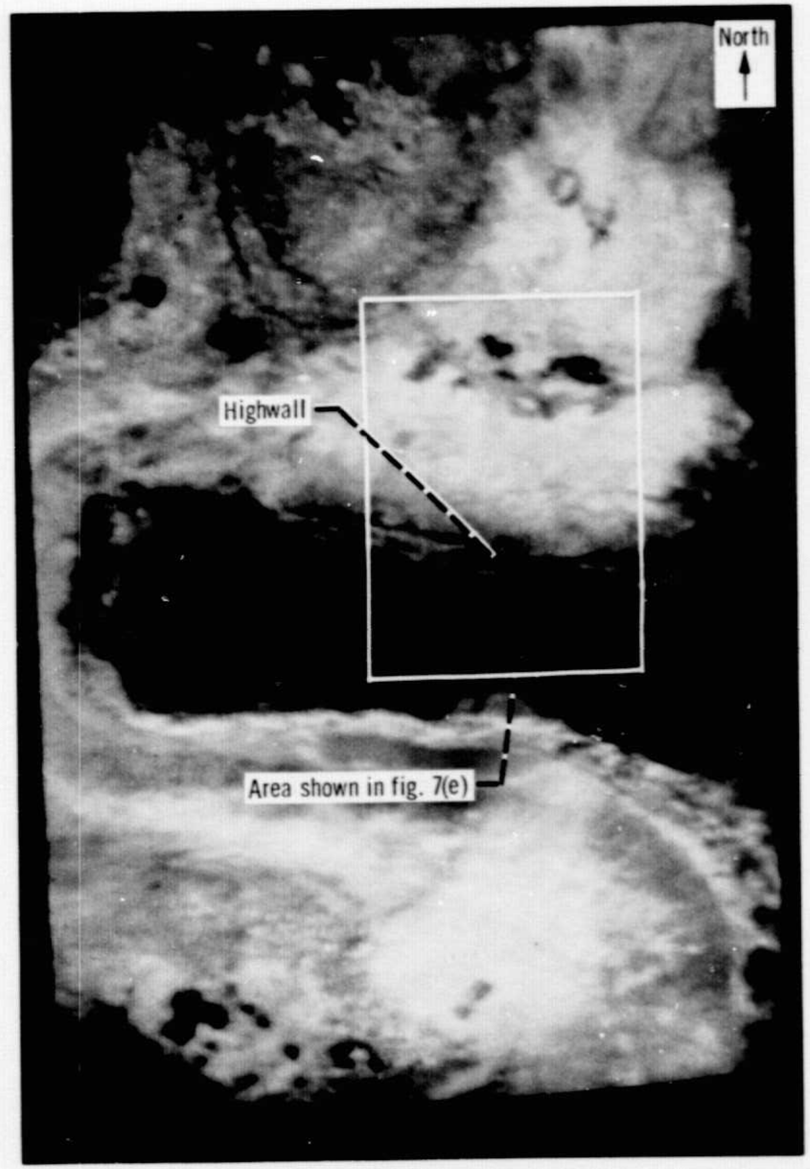


Figure 5. - Twelve-level density slice of tristate area taken by Landsat I.

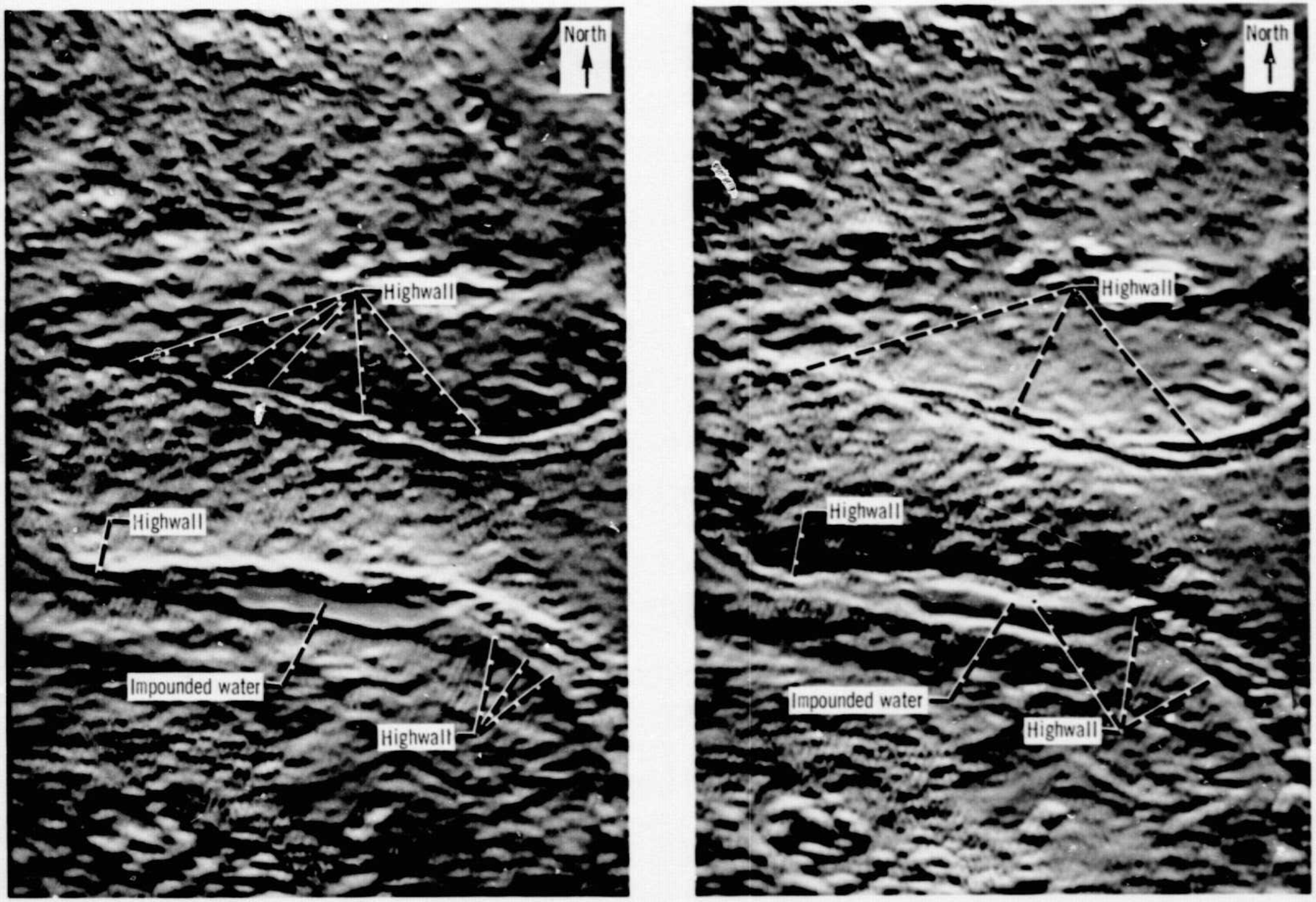
Figure 6. - Eight-level density slice of aerial photograph taken from 1830 meters (6000 ft) showing middle third of EORDC strip mine test site.

(a) Aerial photograph taken at 3000 meters (10 000 ft).



(b) Highwall area magnified 16X.

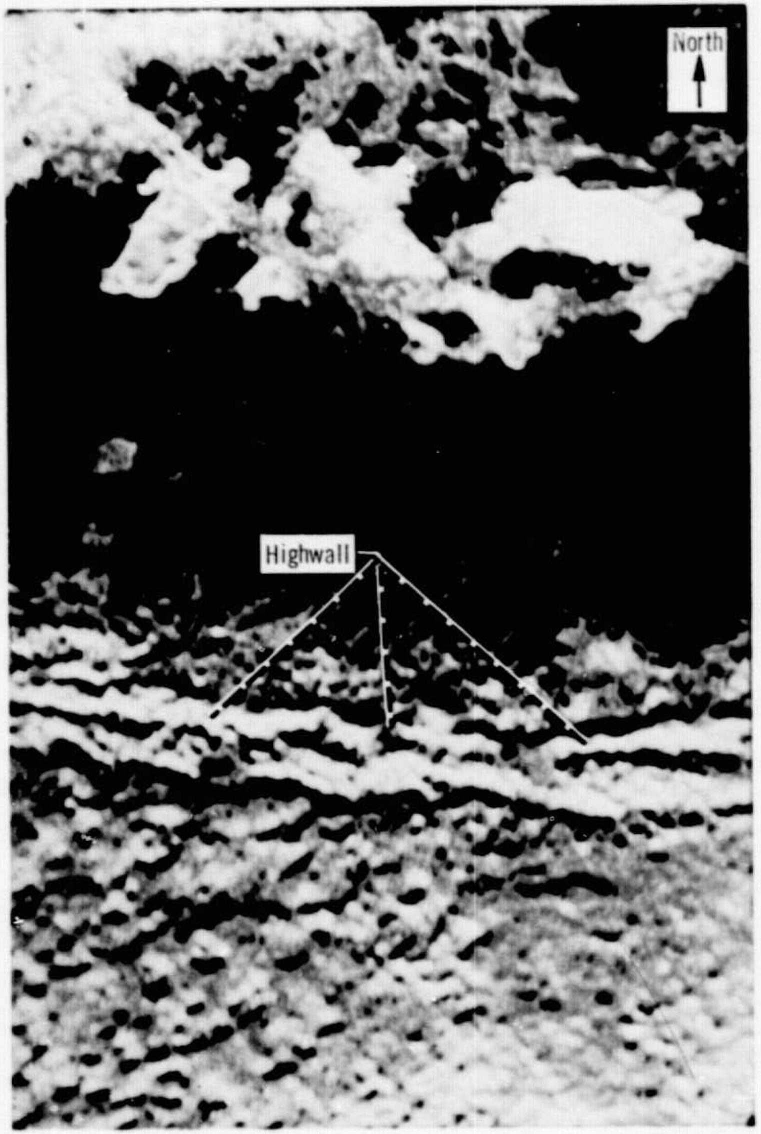
Figure 7. - Various imagery of strip mine reclamation.



(c) Positive edge enhancement.

(d) Negative edge enhancement.

Figure 7. - Continued.



(e) Area outlined in figure 7(b) magnified (30X) and color and edge enhanced.

Figure 7. Concluded.

Figure 8. - Thermal-channel, modular-multiband-scanner imagery from thermal scan of National Space Technology Laboratory as part of Federal energy management program. (Middle third of black-and-white, 70-millimeter transparency; digital data from M^2S magnetic tape converted to imagery by computer processing. Flyover altitude, 460 meters (1500 ft).) Scale, 1 cm = 305m (1 in. = 2500 ft).

Scanning densitometer colors	Thermal-channel temperature °C (°F)	
1. White	≤ 20.8	(≤ 69.4)
2. Dark blue	21.0 - 21.7	(69.7 - 71.0)
3. Light blue	21.9 - 22.6	(71.3 - 72.6)
4. Light green	22.7 - 23.5	(72.9 - 74.2)
5. Medium green	23.6 - 24.4	(74.5 - 75.8)
6. Dark green	24.5 - 25.2	(76.1 - 77.4)
7. Yellow	25.4 - 26.1	(77.7 - 79.0)
8. Brown	26.3 - 27.0	(79.3 - 80.6)
9. Light red	27.2 - 27.9	(80.9 - 82.2)
10. Dark red	28 1 - 28.8	(82.5 - 83.8)
11. Magenta	29.0 - 29.7	(84.1 - 85.4)
12. Violet	≥ 29.9	(≥ 85.7)

Figure 9. - Densitometer analysis of the thermal-channel, modular-multiband-scanner imagery for detection of heat losses. (Twelve-level density slice, magnified 10X and color enhanced, of 48-centimeter (19-in.) color television monitor display of specific area shown in fig. 8.)