Daniel H. Knepper, Jr.
Gary L. Raines
U.S. Geological Survey
Denver, CO 80225

Determining Stretch Parameters for Lithologic Discrimination on Landsat MSS Band-Ratio Images

Histograms of Landsat MSS band-ratio images can be easily obtained without the affects of water and vegetation.

Abstract: *A key factor in preparing band-ratio images of Landsat multispectral scanner (MSS) data for discriminating rock and soil units is the determination of the proper contrast stretches to enhance spectral variations that are related to lithologic differences. In arid regions with little vegetation, histograms of band ratios show the spectral properties mostly of rocks and soils; however, as vegetation and water bodies become more abundant, the histograms no longer reflect the spectral properties of only rocks and soils, and determining appropriate contrast stretches for lithologic discrimination is more difficult. A method has been developed to routinely exclude the effects of vegetation and water from band-ratio histograms that does not require intensive investigator participation. With the exclusion of vegetation and water, the remaining pixels included in the histograms are presumed to represent rocks and soils.*

Introduction

Landsat multispectral scanner (MSS) band-ratio images often enhance the discrimination between lithologically dissimilar rock and soil units as compared to single band images or composites of single band images. Also, the topographic effects on measured radiance are greatly subdued on band-ratio images, allowing the distribution of spectrally different rock and soil units to be better determined. Color composites made from band-ratio images have been used in mapping the regional distribution of spectrally distinct lithologic units, especially limonitic material (Rowan *et al.*, 1974).

The key to preparing high-quality band-ratio and color-ratio composite (CRC) images is stretching the relatively narrow range of band-ratio values for rocks and soils over the entire dynamic range of the display device, usually 0 to 255 in digital value space (Figure 1). This ensures that even subtle differences in ratio values will have sufficiently different data numbers (DN) on the contrast-stretched band-ratio image to be discriminated. Stretch parameters are usually determined by inspection of a histogram which plots the number of picture elements (pixels) against band-ratio value (Rowan *et al.*, 1974, page 6). From this histogram, a range of band-ratio values is selected that includes most of the band-ratio data. A 2 percent linear stretch, which is a stretch that linearly fits the band-ratio values between the 2 percent and 98 percent cumulative frequency points into the entire dynamic range of the display device, produces excellent band-ratio images for data distributions that are symmetrical about the median. However, with skewed data distributions, it is necessary to include an additional stretch parameter that transforms some measure of the center of the data distribution (mean, mode, median) into the middle of the dynamic range of the display device, usually a DN of 127. This type of stretch consists of two linear stretches: (1) a linear stretch from the low band-ratio value (set to 0) to the selected data distribution center (usually set to 127), and (2) a linear stretch between the data distribution center and the high band-ratio value (set to 255).

The above procedures work well when most of the image data represent the spectral characteristics

Photogrammetric Engineering and Remote Sensing,
Vol. 51, No. 1, January 1985, pp. 63-70.
0099-1112/85/5101-0063$02.25/0
© 1985 American Society of Photogrammetry

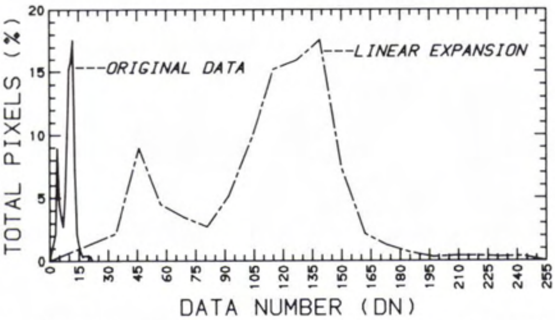

FIG. 1. Example of a contrast stretch that linearly expands the narrow range of DN in the original data to fill the full 0 to 255 dynamic range of a display device.

of rocks and soils, such as in the southwestern deserts of the United States. As the overall abundance of vegetation and water bodies in the scene increases, the procedure becomes less effective because vegetation and water significantly contribute to the band-ratio histograms, and stretches determined from these histograms are no longer based on rock and soil spectral properties alone. Sampling the data for the band-ratio histograms in a geographical window that excludes areas of vegetation and water can solve this problem sometimes, but substantial investigator and computer time is often necessary to determine the digital coordinates of the window and obtain the histograms. Furthermore, it is possible that one or more important rock or soil units may inadvertently occur only in the excluded area and not be considered in the band-ratio histograms.

The purpose of this report is to present a method of obtaining band-ratio histograms only for rock and soil units on Landsat MSS data that can be easily incorporated into a routine image-processing scheme requiring no investigator participation. Once this histogram is obtained, standard methods can be used to prepare the band-ratio images for display.

THE METHOD

Detailed procedures used to develop, test, and implement the method are largely dependent on the computing system of the Geophysics Remote Sensing Laboratory at the U.S. Geological Survey in Denver, Colorado. Consequently, the procedure will be described in conceptual terms in order to allow potential users to adapt the technique to their own computing situation.

Any method of automatically preparing band-ratio histograms of only rock and soil units must include a means of readily and uniquely identifying pixels with the spectral properties of rock and soil or, alternatively, those pixels that do *not* represent rock and soil. The Earth, as seen by the Landsat satellites, is composed of water, vegetation, rock, soil, and mixtures of these materials. For practical purposes, it is assumed that clouds, snow, and ice are not represented in the data because images with these features are usually avoided in lithologic studies. Shadows caused by high relief are also presumed to be minimal because high solar-illumination-angle images are usually used in Landsat spectral studies. However, the procedure described below could be expanded to take these features into account.

With precisely calibrated digital Landsat data, band ratios for specfic geographical locations should be reproducible from data set to data set within the limits of atmospheric variation, and characteristic ratio values for materials could be determined and used to map the distribution of specific materials. However, this is not readily feasible for the following reasons.

Although the digital Landsat data obtained from the EROS Data Center have been calibrated according to pre-launch characteristics of the on-board calibration lamp and sensor responses, and although estimates of the degradation of the lamp and sensors through time are available, the six-line striping in the data demonstrates that accurate calibration has not been attained. Therefore, specific band-ratio values or ranges of band-ratio values generated directly from the Landsat DN have not been generally found to be diagnostic of specific materials (Robinove, 1982). Segal (1983) has been successful in identifying limonite using a ratio of band-ratios, but this method is difficult to apply because the resulting ratio intervals specific to limonite are not clearly known. Ranges of band-ratio values representative of rocks and soils might be obtained through detailed analysis of each digital data set processed, coupled with some prior knowledge of the distribution of rocks and soils in the area, but this would be a time-consuming and expensive practice that would not permit rapid image processing. Alternatively, the digital DN could be routinely converted to radiance or reflectance before rationing, as suggested by Robinove (1982). But because the original digital data are so poorly calibrated, the problem of defining specific ranges of band-ratio values for rocks and soils that are applicable from data set to data set remains.

Instead of identifying those pixels dominated by rocks and soils, a simple basis for locating those pixels dominated by vegetation and water is found in the familiar Landsat MSS color-infrared (CIR) composite images formed by compositing band 4 in blue, band 5 in green, and band 7 in red. The CIR composites depict vegetation in shades of red due to the relatively high reflectance of vegetation in the near-infrared (band 7) and water as black or dark blue due to the increasingly high absorption of water with increasing wavelength. A technique suited to identifying pixels by their color on composite images was described by Raines (1977), and the reader should consult his paper for details. Basically, the technique uses the DN of the three data sets used in the color-composited image, which have been linearly expanded to occupy the full dynamic range of the display device (0 to 255), to compute the hue, saturation (chroma), and value (intensity) of each pixel in the Munsell color coordinate system (Figure 2). For a CIR composite, a linear contrast expansion factor that sets the possible DN range in each band (0 to 127 for bands 4 and 5 and 0 to 64 for band 7) to 0 to 255 can be used; this expansion is equivalent to multiplying the DN in bands 4 and 5 by 2 and the DN in band 7 by 4. This type of expansion does not require prior knowledge of the data distribution, which permits automatic processing, and yet is sufficient to produce CIR composites with the familiar color presentation. Munsell hues and values used here to identify vegetation and water are derived from CIR composite data with these contrast stretches; new hue and value ranges must be determined if other stretches are used.

With the data thus transformed, each pixel can be numerically described in terms that relate directly to its color in the CIR composite. As vegetation is visually recognized on CIR composites as shades of red, these pixels can be identified from the Munsell hue computed for each pixel. Red hues are centered around a hue of 240. The boundaries between major hues are largely subjective, but boundaries placed halfway between pure hues appear to adequately mark major hue changes. Thus, hues associated with vegetation are defined by the range from 210 to 270. A binary image mask, which shows all pixels with hues between 210 and 270 as black (DN = 0) and all other pixels as white (DN = 1), depicts the distribution of vegetation-dominated pixels.

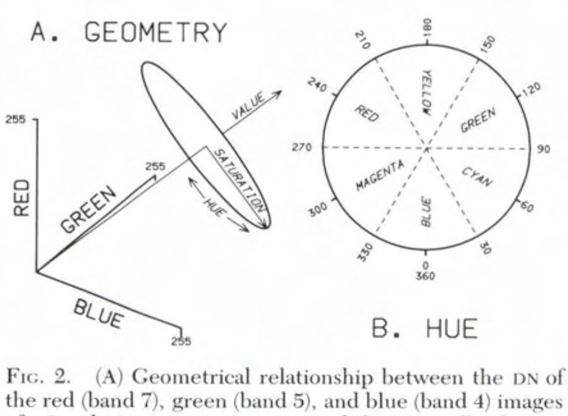

FIG. 2. (A) Geometrical relationship between the DN of the red (band 7), green (band 5), and blue (band 4) images of a Landsat MSS CIR composite and the Munsell color coordinate system. The three single bands of data are represented on the three mutually perpendicular axes. The Munsell value axis is at 45° to the red, green, and blue axes. Saturation is measured perpendicular to the value axis and hue is the azimuth of the saturation vector. (B) Cross section of the Munsell system at a constant value. Saturation is measured outward from the center and hue is the azimuth of the saturation vector. Pure blue is arbitrarily set to 0°. The azimuths of the primary colors and their compliments occur at 60° intervals and the range of a color species occupies a 60°-wide sector. Where the possible values of the red, green, and blue images are the same (0 to 255), the shape of the Munsell solid is a cube with the value axis passing through opposite corners.

Examination of the calculated Munsell hue for numerous water bodies in Landsat scenes of the Canadian Shield, southeastern California, southern New Mexico, eastern Utah, and southeastern Arizona shows a relatively restricted range of hues (10 to 56), corresponding to perceived greenish-blues and cyans with a bluish cast (Figure 2). These hues are not, however, unique to water bodies, and additional Munsell criteria must be used. The most obvious characteristic of the appearance of water bodies on CIR composites is that they are dark, that is, they would be expected to have a very low calculated Munsell value (intensity). Munsell values for the test water bodies mentioned above occur in a narrow range of 8 to 50, lower than any other feature encountered except deep shadows; many shadows have both hues and values similar to water bodies and are identified as water. Therefore, a binary image mask showing all pixels with hues between 18 and 56 and values between 8 and 50 in black (DN = 0) and the remaining pixels in white (DN = 1) depicts the distribution of water-dominated pixels.

Table 1 summarizes the criteria for defining vegetation and water pixels on Landsat MSS CIR composite data. With the pixels dominated by vegetation and water defined and located, the pixels that are white on both the binary vegetation and binary water images are assumed to represent the areas where rocks and soils are exposed. The two classified images can be combined into a single binary image, or digital mask, by multiplying the corresponding pixel DN. The resulting digital mask has only two possible DN values, 0 for pixels that are either vegetation or water and 1 for the remaining pixels (Table 2). All pixels with a DN of 1 are not water or vegetation as defined, and are assumed to represent pixels in which rocks or soils are the dom-

TABLE 1. CRITERIA FOR DEFINING VEGETATION- AND WATER-DOMINATED PIXELS FROM THE MUNSELL HUE AND VALUE OF A LANDSAT MSS COLOR-INFRARED (CIR) COMPOSITE MADE FROM BANDS 4, 5, AND 7 DISPLAYED AS BLUE, GREEN, AND RED, RESPECTIVELY. THE POSSIBLE DATA RANGE IN EACH BAND SHOULD BE LINEARLY EXPANDED TO 0-255 BEFORE CALCULATING THE MUNSELL TRANSFORM

	Vegetation	Water
Hue	210-270	10-56
Value	(Not Needed)	8-50

TABLE 2. RESULTS OF MULTIPLYING THE BINARY VEGETATION AND WATER IMAGES TO PRODUCE A BINARY ROCK/SOIL DIGITAL MASK

	Data Number in Pixel Classes		
Digital Mask	Water	Vegetation	Rocks/ Soils
Binary water image	0	1	1
Binary vegetation image	1	0	1
Rock/Soil digital mask	0	0	1

inant materials. Thus, the digital mask can be used to test whether a pixel in the band-ratio image should be included in the band-ratio histogram.

Band-ratio histograms of the rock/soil pixels can then be inspected to determine the parameters for contrast stretching the band ratios to enhance the discrimination between various rock and soil units. We have found that a 2 percent linear stretch or a 2 percent linear stretch about the mean or median of the rock/soil statistics, as described above, produces images with excellent contrast enhancement.

The underlying assumption for the routine application of this methodology is that vegetation and water will occur in these hue and value intervals for all CIR composites for which bands 4 and 5 have been linearly expanded by a factor of 2 and band 7 by a factor of 4. As mentioned above, these hue and value intervals were tested for various dates and Landsat multispectral scanners for areas in the Canadian Shield, southeastern California, eastern Utah, southern New Mexico, and southeastern Arizona. Vegetation is always red and water is always dark greenish-blues and cyans. Thus, testing indicates that this assumption is robust.

AN EXAMPLE

To illustrate how the method works, we chose a Landsat MSS scene for which it is very difficult to obtain band ratios that are stretched selectively for rock and soil. The scene (Landsat MSS scene E-2587-17170), acquired by the Landsat 2 system on 31 August 1976, covers the area around Wollaston Lake in northeastern Saskatchewan, Canada (Plate 1). The area is a glaciated terrain containing hundreds of lakes of various sizes. Much of the area between the lakes is dominated by vegetation. It is impossible to define a geographical window in the scene that is exclusively rocks and soils.

Using bands 4, 5, and 7 expanded by factors of 2, 2, and 4, respectively, as the corresponding blue, green, and red inputs the Munsell hue and value were computed for the CIR composite image (Figures 3 and 4). Two hue modes exist: blue/cyan and red. Other hues occur on the image, but their percentages are so low that they are not expressed on Figure 3. The red mode includes all the vegetation pixels; water pixels occur in the blue/cyan mode.

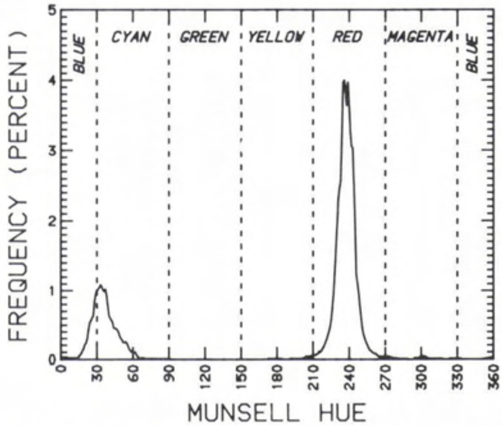

FIG. 3. Histogram of the Munsell hues of the Landsat MSS CIR composite of the Wollaston Lake area, Saskatchewan, Canada, made from bands 4, 5, and 7 displayed as blue, green, and red, respectively. The possible data range in each band was linearly expanded to 0 to 255 before calculating the Munsell transform.

Munsell value also has two modes (Figure 4). The large mode centered around a value of 100 is mostly due to vegetation. The left tail of the smaller mode around 30 includes all the water pixels.

Applying the Munsell criteria described above to define the water and vegetation pixels, binary digital masks were prepared for water and vegetation (Figure 5). On the basis of the number of water and vegetation pixels in the respective masks and the total number of pixels in the Landsat scene, it was calculated that the Wollaston Lake area is composed of 30 percent vegetation, 24 percent water, and 46 percent rock and soil. The masks were combined,

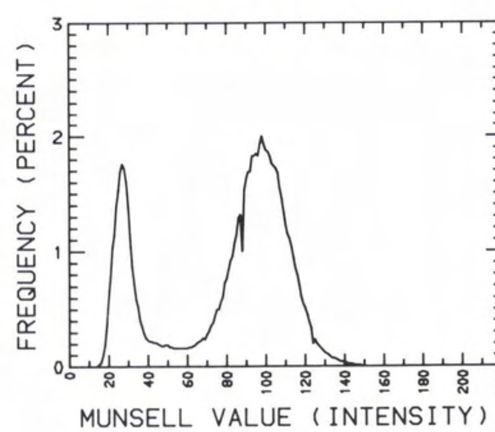

FIG. 4. Histogram of the Munsell values (intensity) of the Landsat MSS CIR composite of the Wollaston Lake area, Saskatchewan, Canada, made from bands 4, 5, 7 displayed as blue, green, and red, respectively. The possible data range in each band was linearly expanded to 0 to 255 before calculating the Munsell transform.

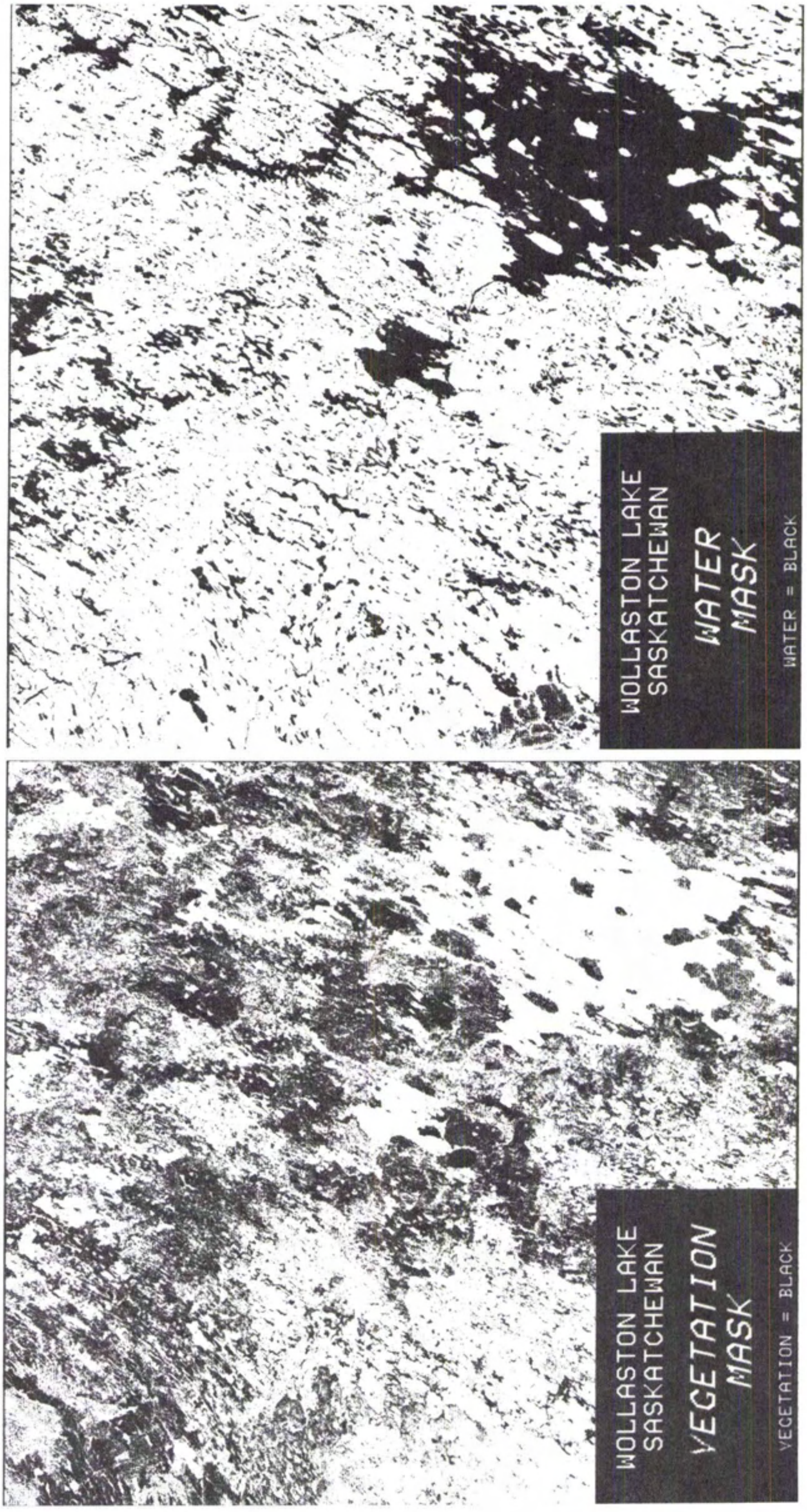

FIG. 5. Binary image masks for vegetation (left) and water (right) (shown in black) in the Wollaston Lake area, Saskatchewan, Canada, defined by Munsell hue and value characteristics of the Landsat MSS CIR composite.

and the resulting digital mask was used to test whether pixels should be included or excluded in the histograms of band ratios commonly used in color-ratio composite (CRC) images employed in mapping the distribution of limonitic rocks and soils (Rowan *et al.*, 1974). Band-ratio histograms were also prepared for the vegetation pixels, the water pixels, and all of the pixels in the scene. Figure 6 summarizes these band-ratio histograms. Note that the rock/soil histograms are consistently more symmetrical than the histograms for the whole scene, indicating that the rock/soil pixels represent a more spectrally homogeneous sample. The band-ratio DN for water are generally higher than those of rock/soil and vegetation; many of the water band-ratio DN occur beyond the range of the histogram plots.

From the rock/soil band-ratio histograms, contrast stretches can be determined that will selectively enhance the discrimination between the rock and soil units present in the area. Plate 2 is a color-ratio composite image of the Wollaston Lake area made from the 4/5 (red), 6/7 (green), and 4/6 (blue ratios. Each of the composited ratios has a 2 percent linear stretch about the median band-ratio DN value determined from the rock/soil band-ratio DN histograms. The image has good overall scene brightness, and the colors of the vegetation (shades of red) and water (white) on the image indicate that the stretches are appropriate.

Discussion

The technique just described was designed to allow most water- and vegetation-dominated pixels to be excluded from band-ratio histograms used to determine stretch parameters specifically for lithologic discrimination. We are routinely using the method during the preparation of CRC images used for mapping the distribution of limonitic materials (Rowan *et al.*, 1974) in various geographic terranes and climates. The ranges of Munsell hue and value used to identify water and vegetation pixels were derived by inspecting the Munsell transforms of numerous Landsat scenes; these ranges do a good job of isolating the obvious water and vegetation occurrences. Consequently, the technique can be routinely applied during image processing without

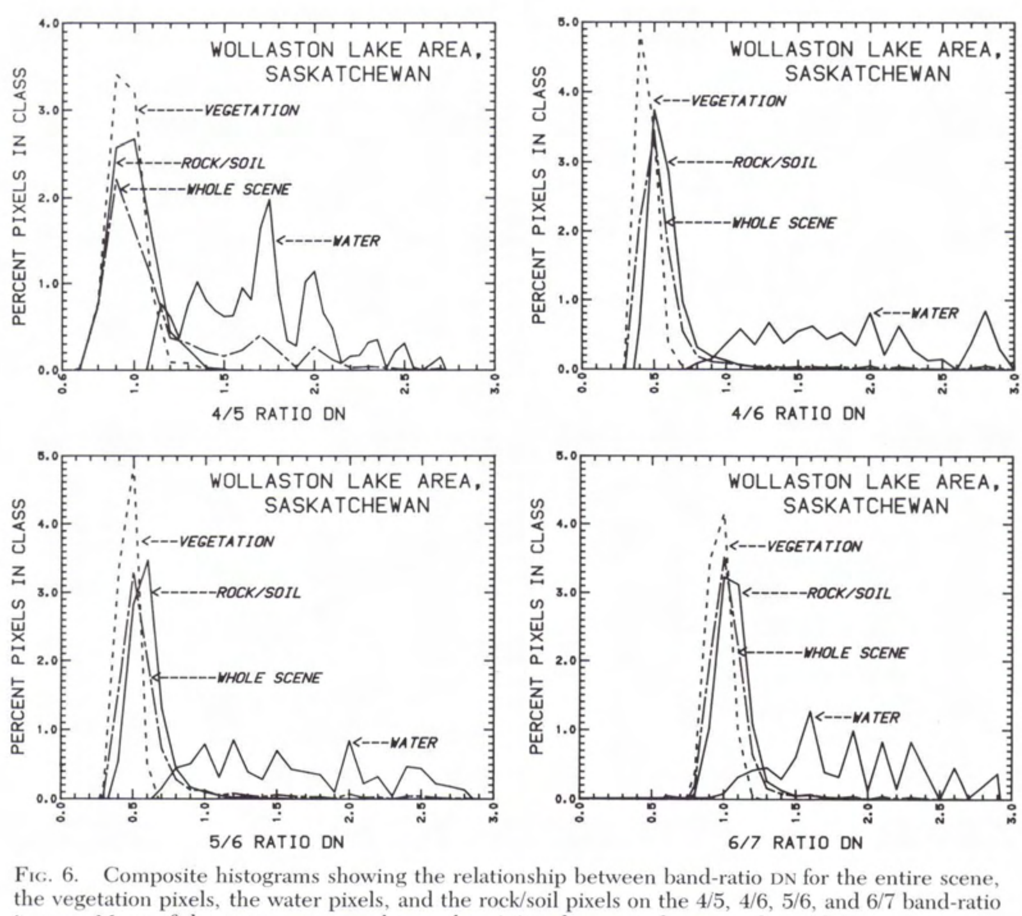

FIG. 6. Composite histograms showing the relationship between band-ratio DN for the entire scene, the vegetation pixels, the water pixels, and the rock/soil pixels on the 4/5, 4/6, 5/6, and 6/7 band-ratio images. Many of the water ratios are larger than 3.0 and are not shown on these plots.

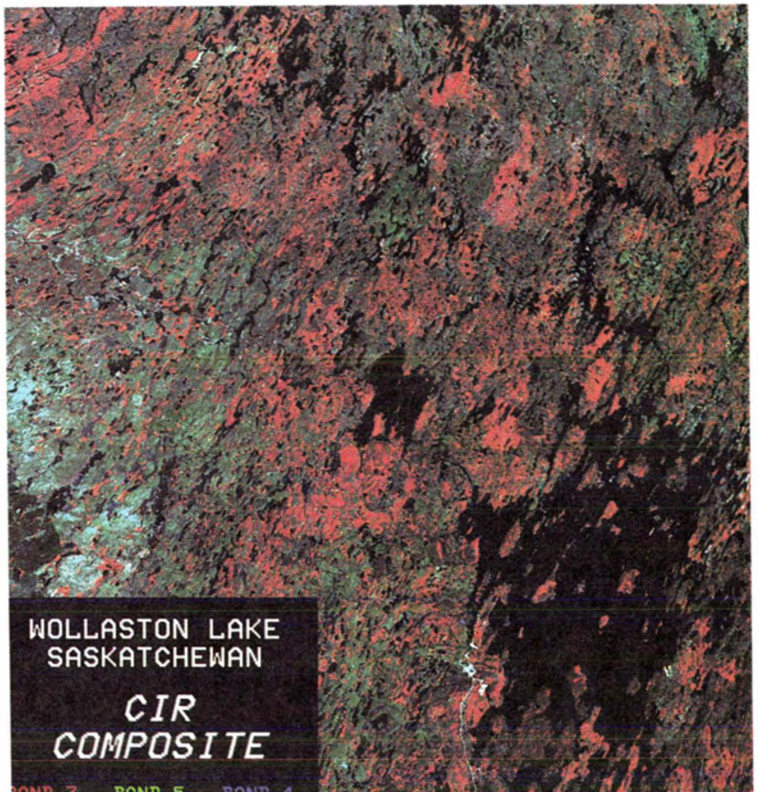

Plate 1. Color-infrared composite (CIR) image of Landsat MSS scene E-2587-17170 (31 August 1976) covering a portion of northeastern Saskatchewan, Canada. Wollaston Lake is the large lake in the lower right. Distance across the top of the title block is 56 kilometers.

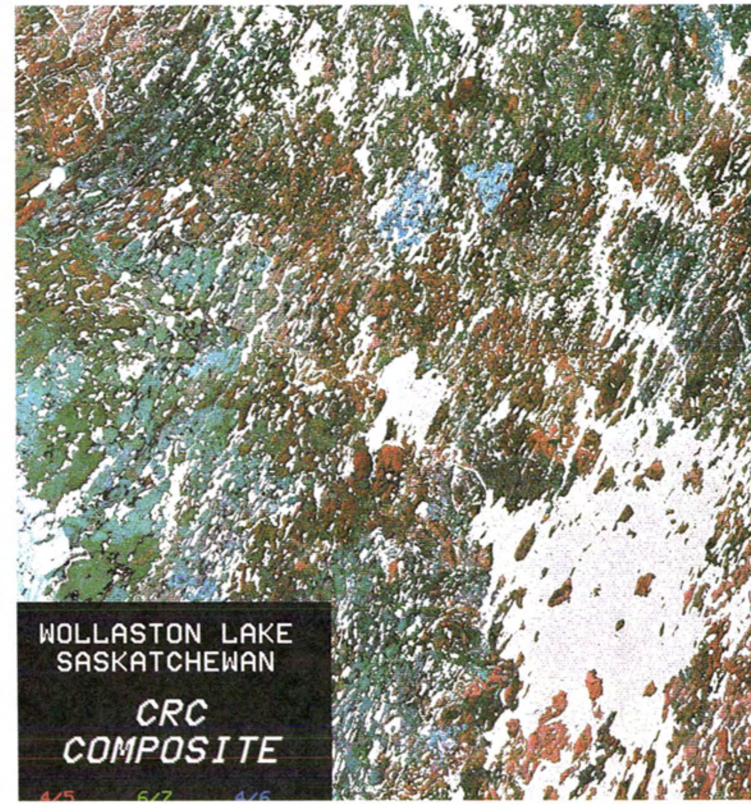

Plate 2. Landsat color-ratio composite image of the Wollaston Lake area, Saskatchewan, Canada. A 2 percent linear stretch about the median ratio DN, based on the rock/soil histograms, was applied to each of the band ratios. Distance across the top of the title block is 56 kilometers.

prior knowledge of the area covered by the image and with minimal investigator participation, as long as the data ranges of the single-band data are linearly expanded to 0 to 255 before the Munsell transforms are calculated.

Several possible sources of error exist in using the technique, but they did not appear to cause serious problems in the Landsat scenes tested. For example, the problem of pixels containing mixtures of vegetation, water, rock, and soil in various proportions has not been addressed. Also, water bodies containing suspended sediment or abundant vegetation will probably be misidentified. Similarly, shallow water bodies in which the bottom material makes a significant contribution to the reflectance will not be excluded from the band-ratio histograms.

References

Raines, G. L., 1977. Digital color analysis of color-ratio composite Landsat scenes: *Proceedings, Eleventh International Symposium on Remote Sensing of Environment*, pp. 1463-1472.

Robinove, C. J., 1982. Computation with physical values from Landsat digital data: *Photogrammetric Engineering and Remote Sensing*, vol. 48, no. 5, pp. 781-784.

Rowan, L. C., P. H. Wetlaufer, A. F. H. Goets, F. C. Billingsley, and J. H. Stewart, 1974. *Discrimination of rock types and detection of hydrothermally altered areas in south-central Nevada by use of computer-enhanced ERTS images:* U.S. Geological Survey Prof. Paper 883, 35p.

Segal, D. B., 1983. Use of Landsat multispectral scanner data for definition of limonitic exposures in heavily vegetated areas: *Economic Geology*, vol. 78, pp. 711-722.

(Received 18 February 1983; accepted 4 March 1984; revised 28 August 1984)

Aerial Photography/Aerial Photo Interpretation Workshop

University of Idaho, Moscow, Idaho
11-15 February 1985

This course—sponsored by the College of Forestry, Wildlife and Range Sciences and the Office of Continuing Education, University of Idaho, and the SAF Remote Sensing Working Group—is for those land resource managers who have not had or who need a refresher on such topics as obtaining aerial photography, small format camera systems, preparing and viewing aerial photos stereoscopically, determining scale, distances, heights, slopes, and area, making simple maps, and interpreting vegetation and landforms. The cost is $295.

For further information please contact

Dr. Joseph J. Ulliman
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, ID 83843
Tele. (208) 885-7209