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Thematic Mapping of Flooded Acreage

The Scene Color Standard technique provides an operational method with which to extract photometric information from aerial photographic imagery.

INTRODUCTION

IN A PREVIOUS publication,[1] hereafter referred to as (1), a technique was introduced for obtaining accurate aerial photographic measurements of terrain spectral reflectance without necessity for preplaced ground control reflectances. This technique—termed the scene color standard or SCS technique—utilizes a natural object, coupled with critical analysis of a scene shadow area, to remove atmospheric and illumination effects and provide for photometric image calibration.

The emphasis on initial application of the SCS technique in (1) was on aerial surveys of water quality. A number of phenomena affect the apparent color of a body of water and make aerial measures of water turbidity difficult. These effects include water surface reflection, atmospheric scattering and absorption, and variations in illumination conditions. The SCS technique applied in (1) utilized natural scene objects and shadow areas to remove these effects, and provide the first aerial photographic measures of water volume spectral reflectance.

ABSTRACT: *Although a considerable amount of scene information can be extracted from an aerial photograph by conventional visual interpretation, a significant amount of information in the photograph remains unresolved. To supplement such standard analyses and to extract further information, the photointerpreter must develop means for accurately measuring, enhancing and interpreting the photometric properties of terrain elements. A practical technique for extracting photometric information by critical analysis of scene shadow images has previously been introduced—that of the scene color standard (SCS) technique. This paper considers further details of the SCS technique, and provides an example of the enhancement and interpretation of photometric image data in thematic mapping of flooded acreage. Mapping is accomplished by noting that vegetation, soil, and water classes can be delineated by a ratio of their reflectances in the infrared and green bands. An approximate map of reflectance ratios which enhances these terrain classes for the interpreter can be easily generated from the photographic image. An example of the use of this technique consists of the successful discrimination of flooding conditions of the Mississippi River near Vicksburg from an Apollo 9 photograph.*

In this paper further details of the SCS technique are presented, with emphasis on use of aerial photometric information for engineering analyses of flood conditions. The flood control engineer is frequently unable to planimeter flooded regions from his visual analyses of an aerial photograph. However,

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by using the photometric information of the photograph in the form of a reflectance ratio of two spectral bands, the engineer-interpreter can obtain an enhanced image which greatly assists his evaluation of flood conditions. Specifically, vegetation, soil, and water can be ordered by reflectance ratios of infrared and green bands. Vegetation has a high infrared-green ratio; soil a ratio of order one; and water a ratio less than one. Approximate reflectance ratios can be easily generated optically, and such ratio displays are surprisingly accurate, as seen in an example of flooding of the Mississippi River.

As the key to such use of photometric information lies in the ability to extract terrain reflectance data from an aerial photographic image, the next section will contain a brief outline of the SCS technique and the results of (1). The third section will discuss the reflectance ratio approach for thematic mapping, and apply photometric ratio information from a satellite photograph to assessment of flooded acreage. The results of this study indicate proper measurement, enhancement and analysis of photometric image data can provide the photointerpreter with a most important addition to his visual analyses.

Preliminary Considerations

This section briefly reviews the results of (1): namely, within each spectral band three parameters (α, α', β) are necessary to calibrate an image photometrically, and these parameters can be obtained by critical analysis of scene shadow areas. It is assumed the photointerpreter has reduced photographic densities to exposure values; i.e., accurate density measurements have been obtained through a densitometer, and density values have been reduced to exposures through a *D-log E* curve.

As shown in (1), the exposure E due to a terrain object can be written to good approximation as:

$$E = \alpha R(\alpha/\alpha') + \beta. \qquad (1)$$

Here α is a parameter proportional to atmospheric transmittance and total (sunlight and skylight) irradiance; α' is proportional to atmospheric transmittance and skylight irradiance; β is proportional to amount of *air light*—light scattered into the camera which has been scattered within the atmosphere; and R is object reflectance dependent on the angular characteristics of the illumination, and hence α/α'.

To maintain consistency with (1), the phenomena giving rise to α, α', β and calibration technique motivation will be discussed for reflectance interpretation of bodies of water. Similar considerations, of course, hold for other terrain elements. In the case of a body of water, Equation 1 may be specialized to

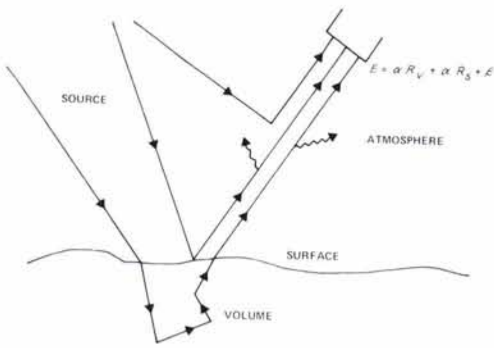

Fig. 1. Schematic diagram of phenomena giving rise to apparent reflectance of a body of water.

$$E = \alpha R_V + \alpha' R_S + \beta \qquad (2)$$

where R_V is volume spectral reflectance (VSR) of the body; and R_S is surface reflectance of the air-water interface as seen from the air.

Motivation for Equation 2 and SCS technique motivation can now be described as follows. The apparent reflectance of a body of water is strongly affected by four phenomena (Figure 1): source effects; atmospheric effects; surface effects; and volume effects. Of these phenomena, only volume effects are normally sensitive to water quality parameters. (We exclude here consideration of surface phenomena such as oil slicks which form a separate class of problems.) Effects of source, atmosphere and surface distort the information of interest, and must be removed from the measurement process to obtain an accurate estimate of VSR.

As reflectance is essentially proportional to the ratio of reflected energy to incident energy, knowledge of source strength for the various spectral regions at the time of measurement is crucial. Additional source effects derive principally from relative distribution of sunglight to skylight. The spectral character of sunlight differs from skylight[2] (Figure 2) as does the angular character of the irradiation. Changes in atmospheric conditions result in variation in sunlight-skylight distribution and yield apparent reflectance changes due to the consequent transformation of the spectral character of the incident radiation.

In addition, specular surface reflections of

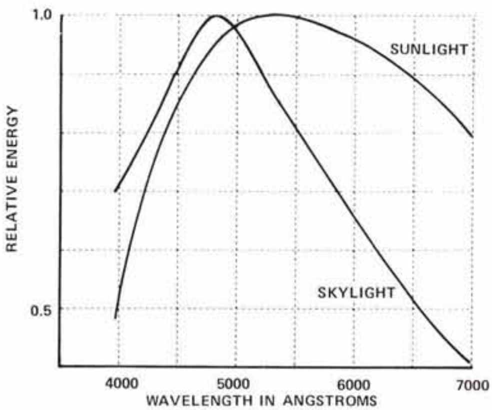

FIG. 2. Typical sunlight-skylight spectral distribution, the maximum value of each curve has been normalized to one. Actual distributions can vary widely from the above example.

skylight exist at every image point of the body of water. The proportion of skylight in the incident irradiance thus determines the magnitude of this surface reflected energy. As this surface reflected skylight contains no water quality information, it must be removed from the data if it is significant compared to the volume reflected energy.

At any image point the ratio of volume reflected energy E_V to energy of surface reflected skylight E_S was shown in (1) to be:

$$E_V/E_S \sim (1 + f) \qquad (3)$$

where f is a parameter equal to the ratio of sunlight irradiance to skylight irradiance.[3] For a very clear day f is about 7; for a day with thin clouds f is approximately 1. Thus even for a clear day of the order of 10 percent of image energy is surface reflected skylight. For a cloudy day, this proportion can rise to the order of 50 percent. Variations of this order can easily mask reflectance effects due to actual water quality characteristics. Meteorological changes from day to day or location to location can cause fluctuations in degree of skylight (and hence E_S) which are potentially interpretable as water quality variations. A reasonable degree of care must be taken to remove these effects.

In the instance of terrain elements other than water, it is still important to establish the proportion of skylight present. This is because the reflectance of soil and vegetation depends on the angle of illumination. Reflectance interpretation thus entails consideration of solar zenith angle *and* amount of diffuse illumination f.

Within the atmosphere, reflected radiance is further modified by attenuation due to atmospheric scattering and absorption, and by the addition of *air light* (light scattered into the camera which has been scattered within the atmosphere). These effects depend strongly on weather conditions and on altitude of measurement.

Taking into account all of these effects, illumination at the camera can be described as in Equation 2. Water quality evaluations can be attempted if exposure values can be reduced to reflectance values R_V. Variation of R_V with wavelength can yield turbidity and hence water quality information (1). As R_S is a well-known function of angle (Figure 3), R_V can be determined from E provided α, α' and β are known. (There is a problem here for observation angles $\gtrsim 40°$ from the vertical, as wave conditions can then make R_S vary by increasing reflection angle to values $\gtrsim 40°$. Useful observation angles for accurate R_V determination are thus restricted to angles $\lesssim 30°$.)

The SCS technique determines α, α' and β from a naturally occurring object of known reflectance and a characteristic shadow area. No preplaced control panels are necessary. Effects of variations in α, α' and β from one survey position to another are, as a result, eliminated or reduced by allowing determination of α, α' and β close to, or in, the photographic frame of interest.

The natural object and shadow area con-

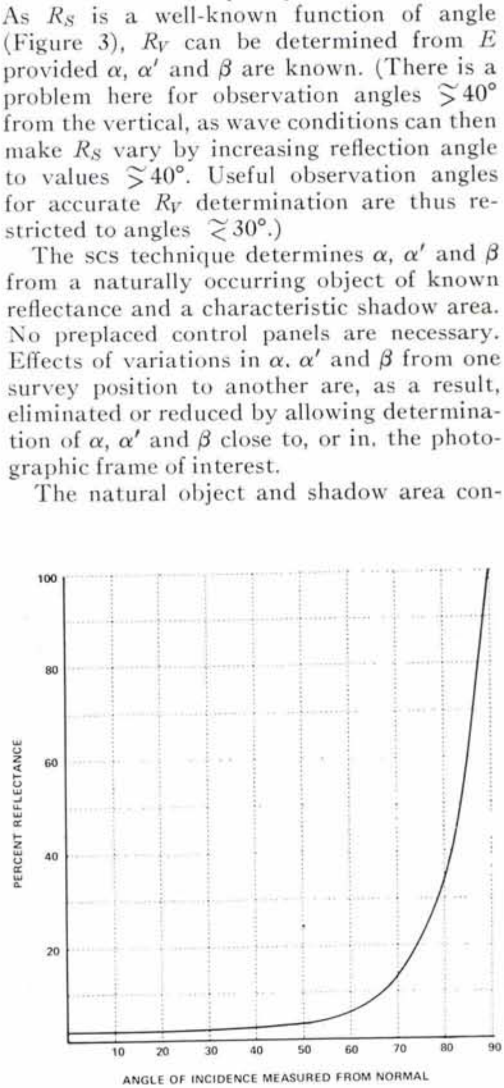

FIG. 3. Percent reflectance of the air-water interface as a function of the angle of incidence (measured from the normal direction). These values are for unpolarized light only.

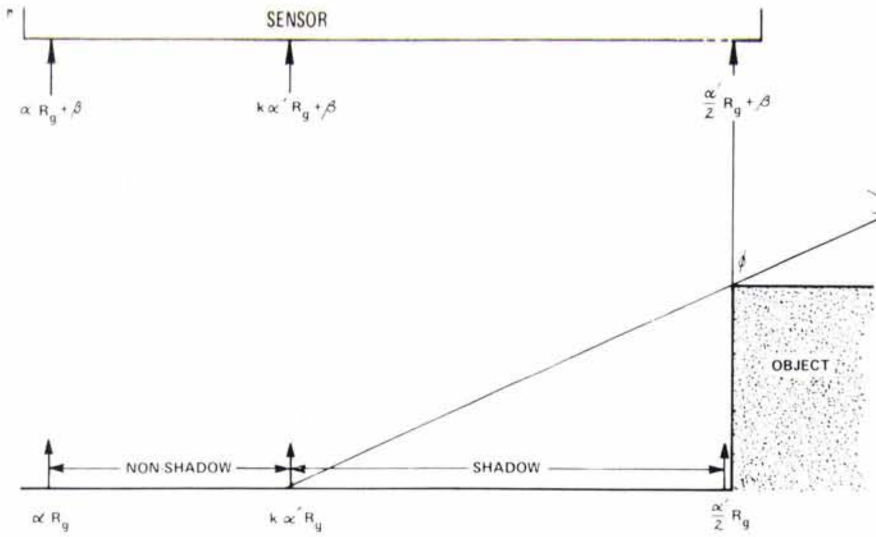

FIG. 4. Geometry of shadow calculation to determine β and α/α'. The term k is a proportionality constant dependent on object width. It is approximately $(1-\psi \cos \phi/2\pi)$ where ψ is the angle subtended by object width at the outer edge of the shadow in radians.

tain sufficient information to determine the three parameters. Figure 4 contains a shadow schematic which yields the following equations:

$$
\begin{aligned}
E_1 &= \tfrac{1}{2}\alpha' R_g + \beta \\
E_2 &= k\alpha' R_g + \beta \\
E_3 &= \alpha R_g + \beta.
\end{aligned} \tag{4}
$$

R_g is local ground reflectance, k is a parameter proportional to shading object angular width and solar zenith angle. The addition of the natural object yields

$$E_4 = \alpha R_0 + \beta \tag{5}$$

where R_0 is the known reflectance of the object. Equations 4 and 5 contain four unknowns (α, α', β, R_g) and are sufficient to determine all of these parameters. Note that in absence of object R_0, Equations 4 are still sufficient to determine β and (α/α').

Figure 5 contains reflectances of typical scene objects as determined by the SCS technique and compared to expected values from laboratory and field analyses. Figure 6 contains typical effects of α, α' and β on VSR of Chautauqua Lake as determined on August 5, 1970. Further experimental results are contained in (1). The accuracy of the data is quite impressive, in view of the fact that no ground controls were utilized in the analyses.

PHOTOMETRIC INTERPRETATION FOR ENGINEERING DATA

This section provides an example of potential application of the SCS technique and detailed photometric data to engineering imagery analyses. The particular example chosen is that of determination of flooded acreage, in this instance from a March 9, 1969 Apollo 9 photograph of a section of the Mississippi River near Vicksburg, Mississippi,

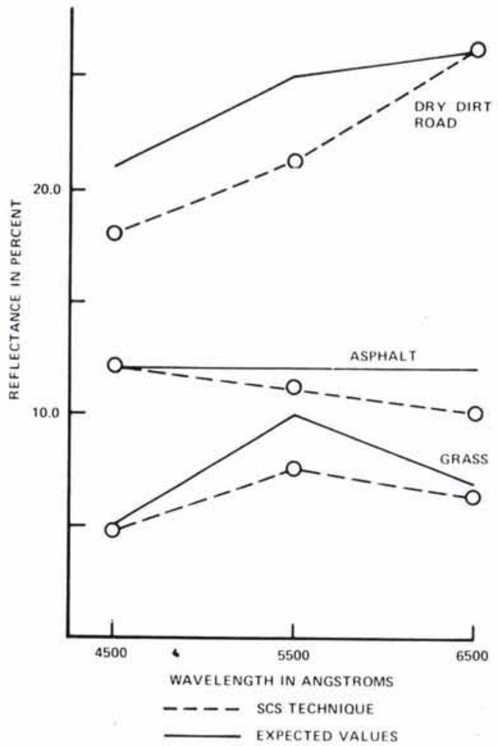

FIG. 5. Scene reflectances as determined by the SCS technique compared to expected values.

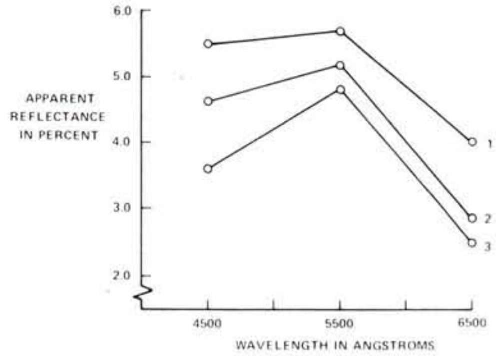

FIG. 6. Apparent reflectance of Lake Chautauqua on August 5 with (1) atmospheric transmittance correction only, (2) atmospheric transmittance and air light corrections, and (3) atmospheric transmittance, air light, and surface reflection corrections.

as shown in Figure 7A. Determination of such acreage is difficult, either visually, or by various single band processing techniques. A method for displaying or computing flooded acreage from the image would be of great utility. Accurate photometric data, coupled with a study of the reflectance ratio between two spectral bands holds, great promise for such interpretation problems. In many instances, vegetation, soil, and water can be distinguished by comparison of these reflectance ratios. Use of such ratio techniques depends crucially on the ability to obtain accurate reflectance values in each band, in order to compute such a ratio for interpretation purposes. The SCS technique thus provides the photometric calibration procedure enabling such an analysis. The details of this ratio procedure are as follows.

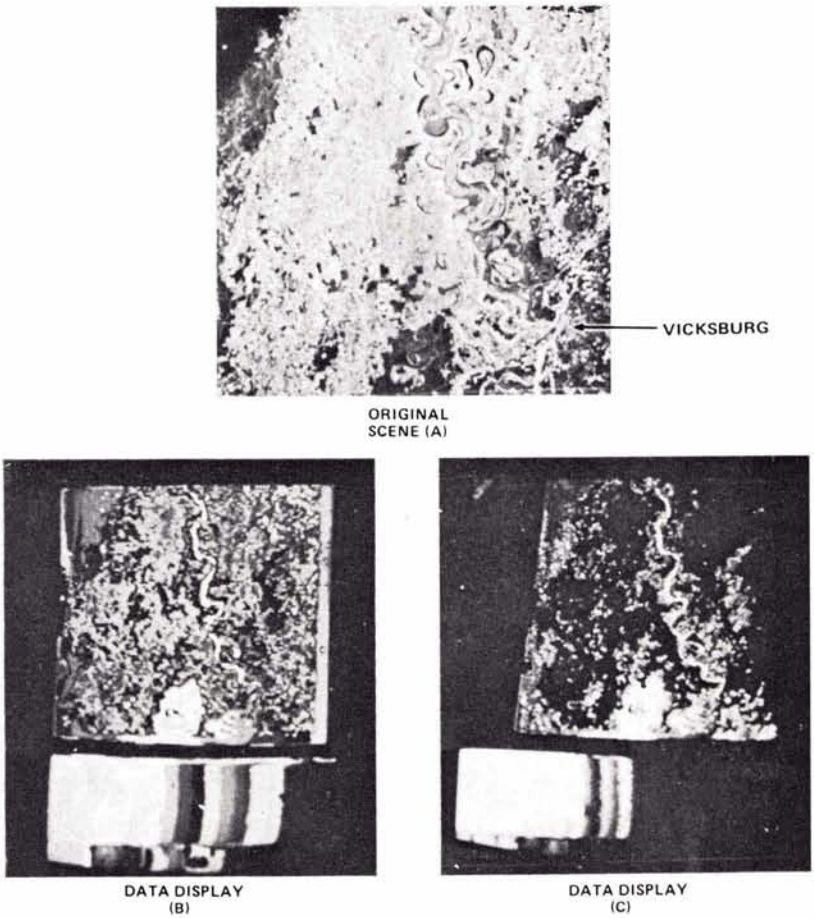

FIG. 7. Conventional infrared ektachrome photograph and two displays of preprocessed information from two spectral bands. The gray tones in the wedges under *B* and *C* represent the following colors on the original scenes: white, dark blue, light green, dark green, olive, gold, brown, red, magenta, violet, and black, respectively, left to right.

A photointerpreter is skilled at discriminating ground objects from qualitative image properties such as shape, pattern, texture, and relative brightness or color. His analysis process is easily confused by variations in photometric properties of images, i.e., contrast, absolute transmission and color shifts. Determining acreage under flooding from a photograph as Figure 7A is a difficult task because water color is not uniform over the scene. It varies from almost white through various hues of blue and red to black. Attempts at using methods such as chromaticity coordinates and density slicing in a particular band will thus not achieve the desired result of enhancing the flooded acreage, so that it can be easily planimetered in some manner by the flood control engineer.

A process converting photometric image information in selected pairs of spectral bands to ratio information for redisplay and interpretation by a photointerpreter holds promise for such a problem, and has been under development at Cornell Aeronautical Laboratory since 1967.[4] A complete description of this process will be the subject of another paper of this series.

Very briefly the process is based on the somewhat unique reflectance characteristics of various classes of objects. In Figure 8 the general reflectance properties of water, soil and vegetation are illustrated. Reflectance ratios between the infrared and green bands, for example, differ widely for the three classes of objects. Vegetation appears to have a ratio on the order of six. Soil, whether a high reflecting gray (white) or a low reflecting gray (black), has a ratio slightly greater than one. The ratio for water is much smaller than one, but approaches one as turbidity increases.

Thus, if aerial image data can be reduced to accurate reflectance information (as with the SCS technique), the scene can be processed to display image regions which are potentially water covered on the basis of such photometric properties. The word *potentially* has been deliberately utilized, because some scene objects are combinations of these

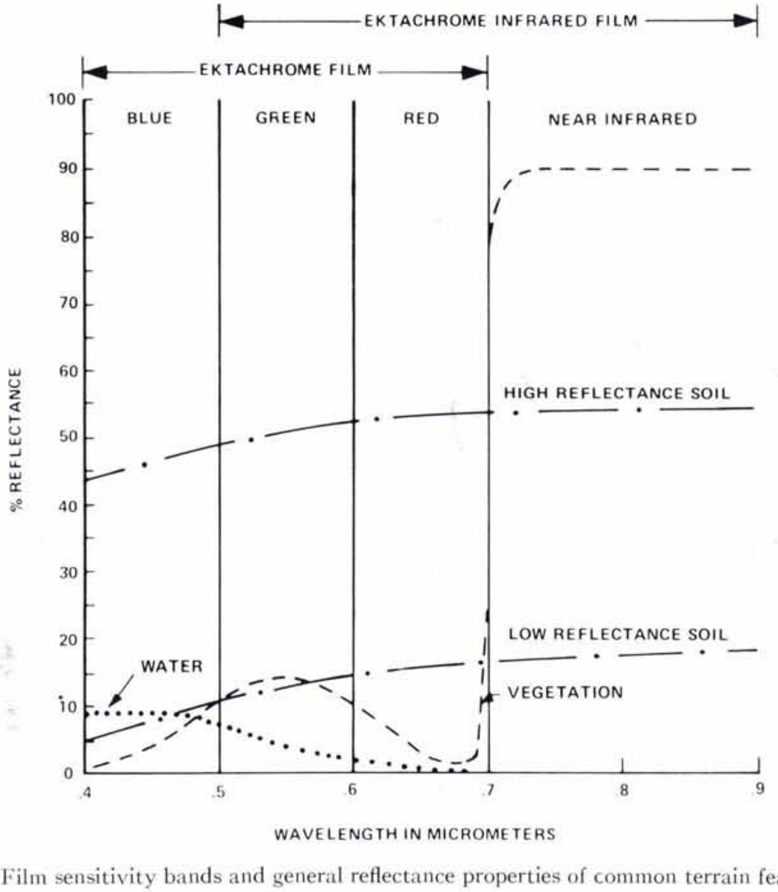

FIG. 8. Film sensitivity bands and general reflectance properties of common terrain features.

classes, e.g., shallow water over soil or vegetation, and soil covered with sparse vegetation. In this instance, the ratio technique will not yield a definite output, and as a result the photointerpreter must utilize other information at his disposal to complete the analysis.

To indicate the basic features of this ratio technique, it will be applied to the unprocessed photometric information of Figure 7A. Use of the SCS technique to remove atmospheric and source phenomena would improve the sensitivity of the results, and actual applications of the SCS technique to ratio display will appear elsewhere.

From the photometric information recorded in the near infrared and green radiance regions on the original photograph, an image whose density is proportional to ratio of exposure in the infrared band to that of the green band was generated in the color encoded picture shown in Figure 7B. This was accomplished by first making a unit gamma positive of the infrared layer of the original image, and a unit gamma negative copy of the green layer. A third unit gamma negative copy was then made of the superimposed infrared and green copies. The density of the resulting image is then proportional to the logarithm of the ratio of infrared to green exposures. The density variations of the third copy were then encoded in color as depicted in Figure 7B. Each color represents an approximate density slice of 0.06 over a density range of 0.04 to 1.00. As this film was processed to unit gamma, the ratio of copy exposure creating the violet images to that causing the dark blue images is of the order of a factor of 4, with violet representing the highest ratio in the scene.

By comparing violet and magenta images to the original scene, one notes that these colors relate primarily to red images on the original scene which are large fields containing healthy vegetation. Upon comparing the light and dark blue areas to the original scene, one notes these are primarily water images. The yellow areas in general appear to relate to images of high and low reflectance coil areas in the original scene which are devoid of large areas of healthy vegetation or water.

Figure 7C shows a display generated by slicing the scene at the maximum ratio obtained from images in the original scene which could be identified positively by the interpreter as water. All values below its maximum ratio appear on the display as water. It is interesting to note how many other areas also have spectral ratio for water even though they do not look like water on the original photograph. Laboratory experiments with a large variety of soils with varying degrees of saturation (from dry to saturated) show that the infrared to green ratio remains greater than one (i.e., characteristic of soil) until a depth of water is reached over the soil which balances the effect of radiance return from the underlying soil.[5] Because of the large differences in the reflectance properties of water in the infrared and green bands, only a small depth of water is necessary to reach this radiance balance point.

Direct visual observation of such a condition by the eye (which is insensitive to near infrared radiance) would not detect much change between the dry soil color and the color of the soil under the water, except for an overall brightness change. The color which the image of such a condition on Ektachrome infrared fim appears would depend highly on the relative spectral sensitivity of an individual's eye and the illumination level of his light table. For example, if water were over a high reflecting surface, the condition would generate an image appearing white (clear) to the eye. If over a low reflectance surface, the image would tend toward black. Similar considerations hold for vegetation under water where, even though the ratio of exposures could be less than one, the Ektachrome infrared image can look red because of the relative sensitivity of the eye to blue and red.

Water-level data supplied by the Waterways Experiment Station at Vicksburg have been used with topographic maps of the area in an attempt to verify the predictions of Figure 7C. The verification is difficult, as the topographic maps of the region are somewhat dated, and because accurate contour levels are difficult to extrapolate due to smoothness of the terrain. In addition, water-level data for only a limited number of water level gauges are available.

It must also be emphasized that the purpose of the photographic thematic analysis presented here is *not* accurate mapping of flooded acreage in the photogrammetric sense. Rather, the purpose is to describe a technique that enables the interpreter to assess flooding conditions in an area. Comparison of topographic and ratio map data here provides an indication of the correlation between the two techniques for assessing flooding conditions, and hence an evaluation of the ratio map approach. As will be seen below, the correlation is quite good. Other evaluations of results, such as flooding near terrain features such as levees, can also be used. These analyses corroborate the conclusions presented below generated from comparison with topographic data.

Using water-level data and topographic maps, the principal flooded areas were determined to be as shown in Figure 9, with an extent of about 750 sq. miles. Reduction of the major areas of Figure 7C to an equivalent map is contained in Figure 10. Here approximately 1150 sq. miles are flooded. Of the 750 sq. miles determined to be flooded from the topographic map, 600 sq. miles, or about 80 percent, are designated as flooded by the ratio determination. This agreement is, of course, very encouraging. All major flooded areas determined from the topographic maps are designated as flooded in the ratio map in Figure 10. The actual flooded acreage is probably well in excess of 1150 sq. miles as the smaller regions of Figure 7C have not been mapped or planimetered in Figure 10. The 150 sq. miles discrepancy between topographic and ratio mapping is probably due to: a combination of the failure to remove α and β effects (recall from the above that exposure ratios have been used here, as opposed to reflectance ratios); the fact that some of this acreage may be of a combination class such as those described above (e.g., water mixed with dense vegetation); and inaccuracy in determining flooded area in topographic mapping from water level data due to the difficulties described. It is our contention that all of these effects can be further minimized, and flood mapping evaluation further improved.

Several areas are incorrectly mapped, most notably the upper left-hand corner of the photograph, and the region to the southeast of Vicksburg. These regions are designated *A* and *B*, respectively, in Figure 10. Region *A* occurs due to vignetting, whereas region *B* probably occurs due to a combination of lens transmission effects and the failure to remove α and β effects from the ratio computation. Nevertheless, the accuracy of the predictions is quite good.

Conclusion

The scene color standard technique in-

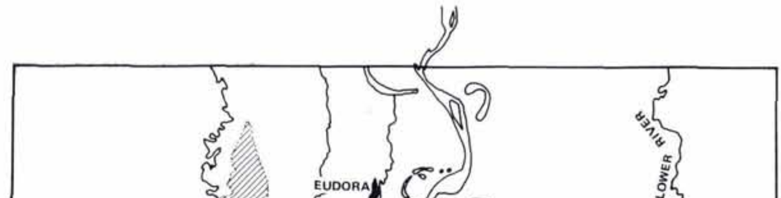

FIG. 9. Flooding conditions determined from topographic maps and water-level data.

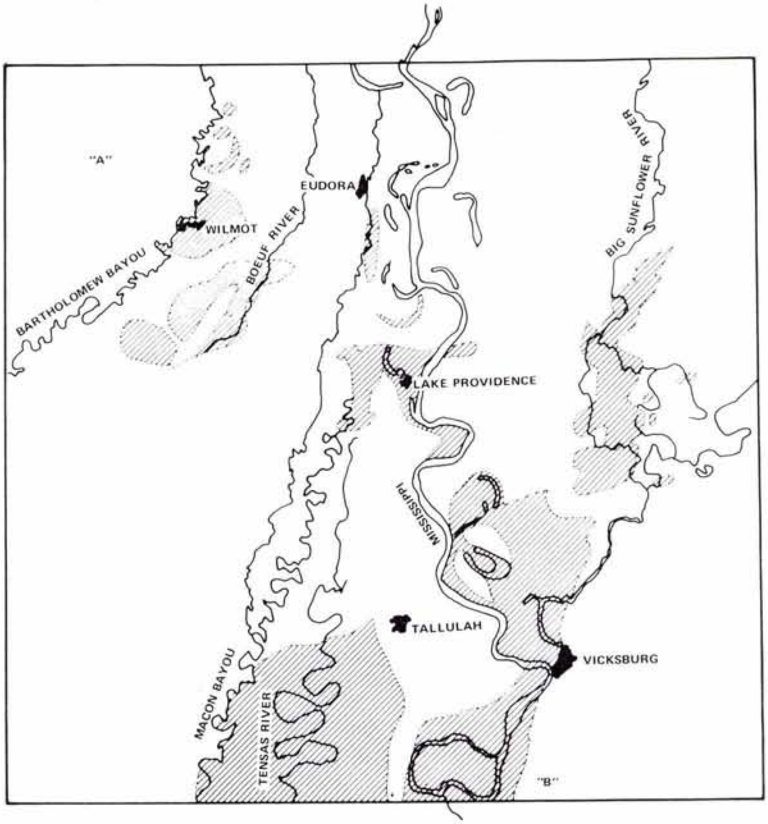

FIG. 10. Flooding conditions determined from the ratio of infrared to green bands.

troduced in the first paper of this series provides an operational method with which to extract photometric information from aerial photographic imagery. This technique precludes the necessity for preplacement of ground control reflectances in the photometric calibration process. The technique contains the additional feature that it yields a measure of the angular character of irradiation, i.e., ratio of sunlight-skylight distribution. Knowledge of this distribution is of importance in removing surface skylight reflection effects in water quality surveys, and in other terrain problems where reflectance values are a function of angular nature of irradiance.

An example of the utility of photometric information in determination of flooded acreage from an Apollo 9 photograph was given herein. Reflectance information utilized in a ratio manner was of use in aiding the interpreter in obtaining such estimates. The results indicate accurate measurement, enhancement and interpretation of image photometric properties promise to provide a new dimension for extending the usefullness of aerial color photography in environmental engineering problems.

In summary, a means now exists for quantifying the spectral radiance received at an aerial camera from ground objects, taking into account atmospheric and collection system perturbations, A technique has also been developed utilizing sets of spectral radiance data to generate new scenes which contain spatial and photometric image properties *that differ* from the original scene in the important respect that they provide keys to the information of interest. We believe the combination of these two techniques provides a crucial step toward obtaining more useful and accurate engineering data from color aerial photography.

NOTE ADDED IN PROOF

A determination of β and α/α' more convenient than that described above can frequently be obtained by comparing *two* shadows over *different* terrain reflectances.

The equations for exposure in sunlight just outside of one shadow E_3 and the exposure in skylight just inside the same shadow E_2 can be put into the form

$$k \frac{E_3 - \beta}{E_2 - \beta} = \frac{\alpha}{\alpha'} \quad (6)$$

The parameter α/α' is constant for the frame or frame area being studied. Hence, the expressions for α/α' for two different shadows can be equated to yield β if the measured shadow exposures are utilized. The parameter α/α' is then immediately determined.

ACKNOWLEDGMENT

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March 1974* Chase-Park Plaza, St. Louis, Mo.

March 7–12, 1975* Washington Hilton, Washington, D. C.

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1973* (open), Disneyland East, Orlando, Florida; Jon S. Beazley, Florida Dept. of Transportation, H. Burns Bldg., Tallahassee, Florida 32304.

Sept. 8–13, 1974,† Washington Hilton, Washington, D. C.

1975,* (open), Phoenix, Arizona.

Sept. 28–Oct. 1, 1976,* Olympic Hotel, Seattle, Wash.; C. E. Buckner, 803 Seattle Municipal Bldg., Seattle, Wash. 98104.

* Jointly with the American Congress of Surveying and Mapping.
† To be held as part of the International Congress of FIG.

Oct. 18–21, 1977, Little Rock, Arkansas.

SEMINARS AND SYMPOSIUMS

Jan. 18–20, 1973, San Jose, Calif.

July 1973, Univ. of Maine, Orono, Maine. Fourth Biennial Workshop—Color Aerial Photography in the Plant Sciences.

October 1973, Sioux Falls, S. Dak. Management & Utilization of Remote Sensing Data. Convention Center and USGS EROS Data Center. Cosponsored by AIAA, IEEE and AGI. Dr. Harold T. Rib, 10129 Glenmere Road, Fairfax, Va. 22030.

INTERNATIONAL MEETINGS

July 1973, Mexico City, Mexico. Joint Technical Meeting with the Mexican Society of Photogrammetry.

Sept. 9–16, 1974, Washington Hilton, Washington, D. C., *14th Congress of the International Federation of Surveyors*, (FIG); Jeter P. Battley, Jr., P.O. Box 14262, Washington, D. C. 20044.