GAYLORD A. HELGESON*
Data Corporation
Dayton, Ohio 45432

Water Depth and Distance Penetration

Rather than eliminating the blue-sensitive or yellow dye-forming emulsion layer of the film, a relocation of its peak sensitivity would be more beneficial.

INTRODUCTION

REVIEWING ARTICLES[1,2,3,4,5] written in the past three years on the topic of optical water depth penetration from aerial platforms, the general point of agreement among the authors is that specialized techniques are required to optimize said penetration. Because the specific optimal techniques suggested are often in direct opposition, not all of these techniques can represent effective approaches to the recording of information at any given depth: some may actually provide a decrease in the recorded information.

ABSTRACT: *Reasonable increases in the apparent depth or distance penetration of masses of water may be accomplished by sensing in the proper region of the spectrum and displaying the resulting record so as to make use of the dynamic density range of the presentation material. This procedure yields information concerning the generation of photographic emulsions designed for the specific task of water penetration. Multispectral techniques may be used to demonstrate a special bicolor presentation scheme for water penetration emulsions; however, this technique is not presented as the optimal method but instead is used as a tool to aid in establishment of initial emulsion design criteria.*

The objective of this paper is to review briefly some of the suggested techniques in light of available information concerning absorption and scattering of light by masses of water, and to examine the results of these techniques in practice. The eventual goal is to determine if, by using a judicious application of photographic science, an even more reasonable approach may be found—even to the extent of recommending that a special emulsion be developed for this very use. The approach here is from the standpoint of penetration of a depth of water from an aerial platform, with the understanding that an improvement in depth penetration capabilities in this application will probably provide an increase in underwater distance penetration in the submerged reconnaissance situation.

Because of the varieties of original reconnaissance color (also black-and-white) materials available to the reconnaissance engineer or photogrammetrist, certain problems have arisen in the selection of the proper material to be used in water overflights. Depth penetration has been claimed to be better with one material than another, this judgement having been made on the basis of singular examples of the appearance of imagery on one material compared to imagery on another material taken under dissimilar conditions at different times. Multispectral or spectral zonal reconnaissance is sometimes flown over water, but the utilization and presentation of the processed imagery is difficult because of the design of the camera system. Much of the valuable depth information recorded by multispectral techniques is not apparent and is not used because of a lack of convenient presentation techniques.

Bailey[2] has demonstrated the value of this multispectral technique, especially in a research situation where it is desirable to evaluate the use of different techniques and the combination and display of various sensing bands in presenting water penetration data. We can use multispectral photog-

---

* Submitted under the title "Water Depth and Underwater Distance Penetration."

PLATE 1

Simulation of normal camera original color tripack using multispectral records 1, 4, and 6 printed blue, green, and red, respectively.

PLATE 2

Simulation of Ektachrome Infrared type 8443 using multispectral records 4, 6, and 7 printed blue, green and red, respectively.

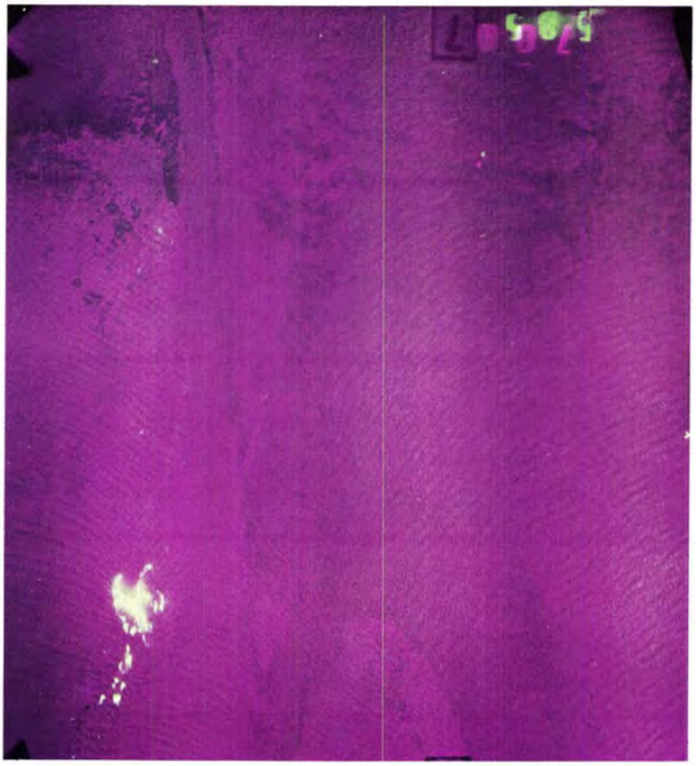
PLATE 3

Simulation of a normal camera original color tripack with a Wratten No. 12 filter over the lens.

PLATE 4

Simulation of a normal camera original color tripack without a blue sensitive, yellow dye forming layer.

PLATE 5



Bicolor presentation of record 1 (400-460 nm) printed blue and red with record 7 (685-900 nm) printed green. Sea state and surface detail recorded with very little depth information.

PLATE 6

Bicolor presentation of record 2 (430-530 nm) printed red and green, record 4 (540-620 nm) printed blue. These bands selected from area of maximum transmission of pure water.

PLATE 7

Same presentation scheme and records as plate 6 only with a 2.5 times increase in gamma.

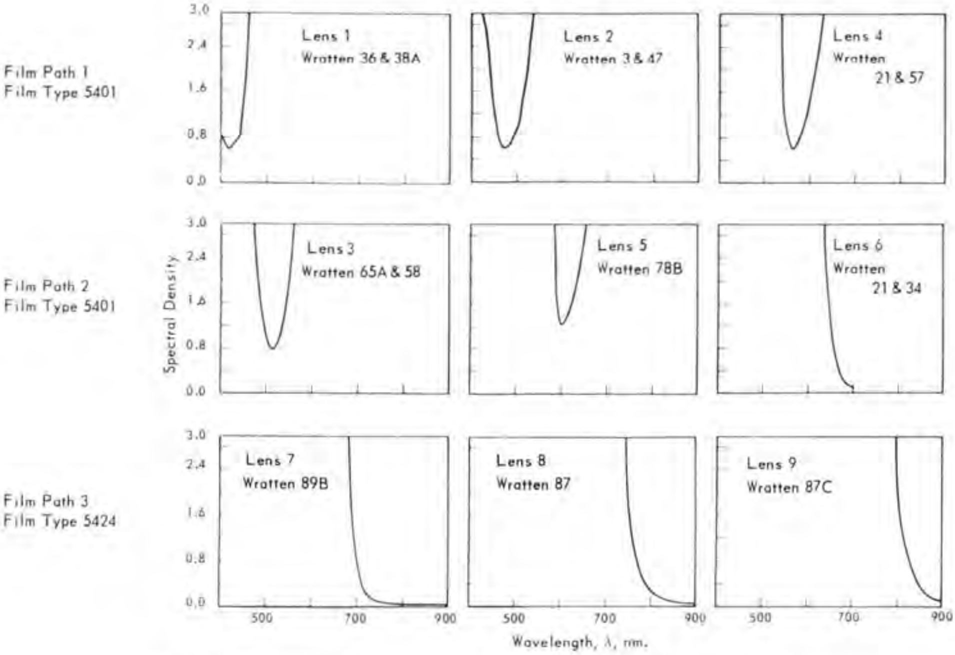


FIG. 1. Filter and film path configuration of the Itek Nine-Lens Multispectral Camera used in this application.

raphy to aid in the decision of where, in the electromagnetic spectrum, reconnaissance materials should respond to increase the apparent depth penetration through water. The black-and-white record produced in the usual multispectral technique also allows investigation of the presentation scheme that can best be used. However, it must be emphasized that the multispectral reconnaissance technique is not being offered as a solution to the water depth penetration problem; it is being used only as a convenient demonstration tool.

In this instance, records produced by an Itek nine-lens multispectral camera are used to demonstrate current color capabilities and techniques, as well as other approaches to the problem. The spectral bands sensed, or the filters used in this situation, are shown in Figure 1. The simulation of original color, false color, and special color techniques were created by registering the black-and-white negative records generated by this camera and using various combinations of the registered negatives, one at a time, to make tricolor prints on Ektacolor paper.

METHODS

An example frame showing a considerable amount of bottom detail is used to demonstrate the techniques mentioned. This shot, taken over the western edge of the Great Bahama Banks in the vicinity of Beach Cay, shows some surface features and sea state information. Ground truth concerning the water depth in the area is not available, but it is estimated that we are looking through one to four fathoms of exceedingly clear water with the six-inch focal-length lenses found on the nine-lens multispectral camera; the altitude is 14,850 feet.

Plate 1 is a simulation of a normal color tricolor material made by printing multispectral records 1, 4, and 6 blue, green, and red, respectively. The inherent residual magnification differentials between the lenses and the finite errors in registration presently limit the true utility of this procedure of presenting multispectral data to an investigative tool. This observation admits the conclusion that, if particular spectral bands are to be used in water depth or distance penetration, then the photographic sensor will need to be a multiple-coated emulsion to provide the metric stability and resolution with ease of processing and display.

In a simulation of Kodak Ektachrome Infrared type 8443, Plate 2 was created by printing multispectral records 4, 6, and 7 blue, green, and red, respectively. An increase in

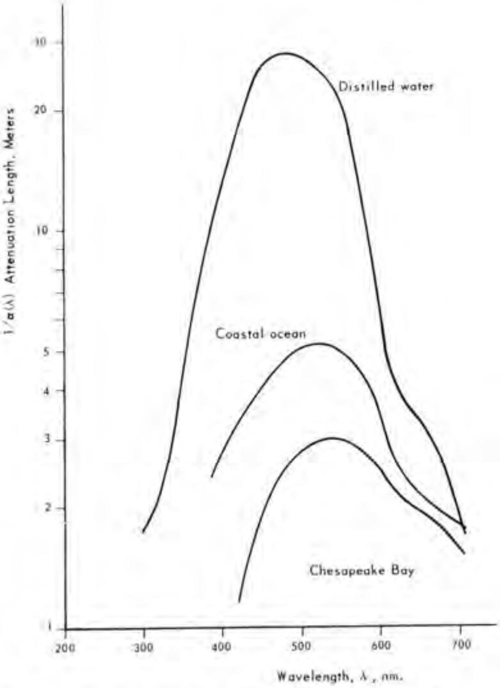


FIG. 2. Duntley's plot of attenuation length as a function of wavelength and water.

sea state information and a greater detectability of surface features are immediately apparent. No great improvement of bottom detail is observed.

Now, there are two approaches that are presently being followed in efforts to develop special techniques for achieving the water penetration objective. One is the use of a yellow filter (Wratten No. 12) with a normal color tripack,[4] yielding a result similar to Plate 3. The other method is to coat the usual color tripack without the blue-sensitive, yellow dye-forming layer.[5] Plate 4 is a simulation of the results obtained when this approach is used. Observation of the spectral absorption function of bodies of water explains why neither of these methods is accomplishing the objectives for which it was designed.

The processes of absorption and scattering of electromagnetic energy together generate the volume attenuation coefficient of water. This volume attenuation coefficient α is a function of the incident wavelength; i.e., $\alpha(\lambda)$. The attenuation process, as a function of distance, follows the simple exponential relationship[7,8]:

$$E(\lambda, l) = E(\lambda, 0) \exp [-\alpha(\lambda) l]$$

where $E(\lambda, 0)$ is the initial energy of the beam at wavelength λ, and $E(\lambda, l)$ is the energy at distance l.

The usual method of displaying the volume attenuation of water as a function of distance is to plot the reciprocal attenuation coefficient $[1/\alpha(\lambda)]$ as a function of wavelength. As the unit of $\alpha(\lambda)$ is reciprocal distance, then the unit of $1/\alpha(\lambda)$ is distance and is referred to as the attenuation length. Duntley's plot[6,7] of attenuation length, as a function of wavelength for water from various regions, is shown in Figure 2. The percent transmission of pure water at various depths, as reported by Bailey,[2] is given in Figure 3.

From Figures 2 and 3, it can be seen that eliminating the blue record from the standard color tripack, either by filtration or manufacture, is an incorrect procedure. The attenuation loss in water is as severe in the red region of the visible spectrum as in the deep blue end; of course, absorption is very large in the infrared. Comparing the spectral absorption minimum (greatest attenuation length)

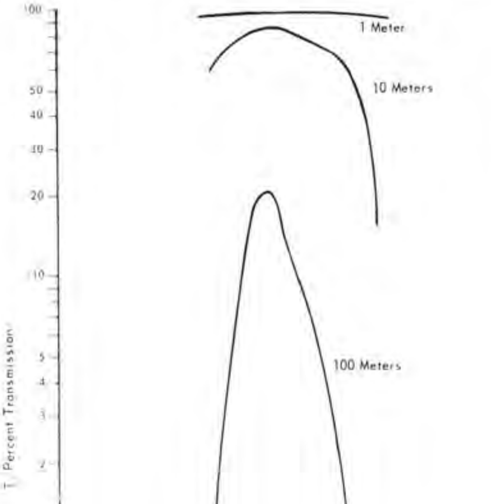


FIG. 3. Percent transmission of pure water at various depths.

of water with the nominal sensitivity function of normal color tripack materials (Figure 4), certainly the yellow-forming blue-sensitive layer does not peak in a band where pure water readily transmits. However, the long wavelength sensitivity of the blue-sensitive layer does extend into the water transmission band, as does the short wavelength sensitivity of the green-sensitive layer. Rather than an elimination of the blue-sensitive or yellow dye-forming layer, it seems evident that a relocation of its peak sensitivity would be more beneficial. Also, the high absorption by water of the red and infrared implies that it is senseless to monitor these bands, except for detection of sea state and surface information. Plate 5 shows that the bands from 400–460 nanometers (nm) and 685–900 nm add relatively little to the detection of detail at the sea bottom. Here, frames 1 and 7 from the multispectral camera have been printed so that information from frame 1 forms a green record (i.e., frame 1 was printed through both blue and red filters) and frame 7 forms the magenta record (frame 7 was printed through the green filter).

Such experiments in bicolor presentation schemes have shown that display of one record as an additive primary and the second record as the complement result in a composite image which visually is quite satisfactory. What constitutes an optimum primary-complement pair for interpretation of bicolor presentations has not been determined.

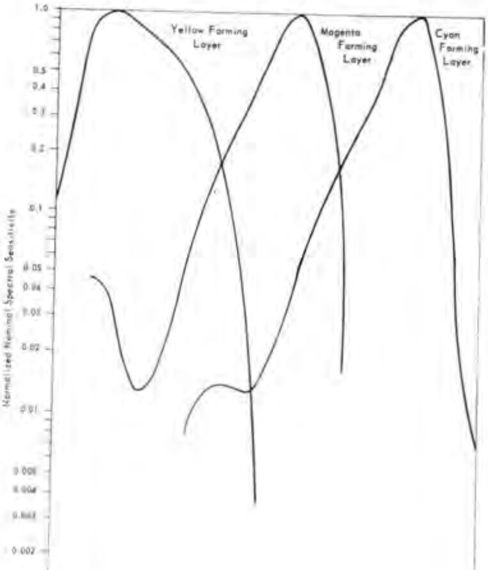


FIG. 4. Nominal spectral sensitivity function of a normal color tripack.

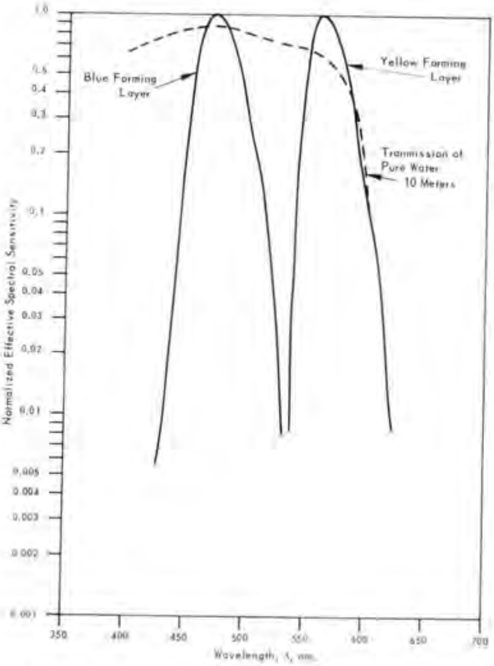


FIG. 5. Effective normalized spectral sensitivity function of bicolor presentation showing improved depth penetration.

In terms of providing the most efficient use of the energy that is likely to be present in a water-depth or distance-penetration problem, the most reasonable approach is to use a sensor that responds in the area in which the media will most probably transmit, and to record as little of the scattered light as possible. The transmittance of pure water represents the upper constraint on this specular transmittance function.

By taking two or more bands within the domain of the transmittance band of pure water and properly displaying them, some improvement may be made in apparent bottom detail. Plate 6 is a bicolor presentation of a band 430–530 nanometers (lens 2) and a band 540–620 nm (lens 4). The former band printed to form cyan and magneta dyes, and the latter band printed to form the yellow dye. Figure 5 is the effective normalized spectral sensitivity resulting from this approach. Since the shortcoming of this presentation is the low contrast, this was corrected in Plate 7, where a 2.5 times gamma increase over Plate 6 was accomplished.

The presentation of these results is not a statement that this represents an optimal solution to the water depth or distance penetration problem. It merely demonstrates that, by the proper choice of the bands in which sensing is accomplished and by using some elementary thoughts in tone reproduction and presentation, a reasonable improvement in the apparent penetration may be produced.

CONCLUSIONS

Reasonable increases in the apparent depth or distance penetration of masses of water may be accomplished by sensing in the proper region of the spectrum and displaying the resulting record so as to make use of the dynamic density range of the presentation material. This procedure yields information concerning the generation of photographic emulsions designed for the specific task of water penetration. Multispectral techniques are not applicable where large quantities of film are to be utilized, as the effort involved in presentation preparation is large and the probability of resolution loss through misregistration is high.

Where multispectral sensing is useful from the research standpoint, a more reasonable approach from the large volume operational standpoint is to construct a multilayer package. Bicolor or tricolor tripacks may be used, provided the proper bands are selected based on the constraints of the spectral absorption and scattering of water. The choice of whether a tripack of bicolor construction scheme should be used should be based on the spectral differentiation required for the bottom detail to be properly detected. In either case, the optimal presentation scheme should be determined through consideration of the use to which the final imagery is to be put.

Because of the flare introduced by scattering, the dynamic range of the input luminance is low; thus, a total system gamma of approximately three to five is necessary. To desire a film speed of ASA 1000 is not unreasonable, due to the large energy losses incurred in water, although trade-offs in speed with the system gamma are likely. High resolution does not seem necessary; the initial resolution requirement should be met by 20 to 45 lines per millimeter.

This simple analysis demonstrates a procedure whereby an increase in apparent depth or distance penetration of water may be accomplished, and establishes a very basic criterion for the design of a special emulsion to meet this requirement.

ACKNOWLEDGEMENT

The multispectral imagery was made available through the courtesy of NASA, Earth Resource Mission 23, flown May 9, 1966.

REFERENCES

1. Swann, William F., "Films for Underwater Photography," *Photogrammetric Engineering*, Vol. 33, No. 8, August 1967, pp. 912, 924.
2. Bailey, E. A., *Oceanographic Spectral Photography; Part I—Basic Investigations*, VIDYA Report No. 219, AD 634 748, August 1966.
3. Schneider, William J., "Color Photographs for Water Resource Studies," *Photogrammetric Engineering*, Vol. 34, No. 3, March 1968, pp. 257–262.
4. Lepley, L. K., "Coastal Water Clarity from Space Photographs," *Photogrammetric Engineering*, Vol. 34, No. 7, July 1968, pp. 667–674.
5. Current, Ira B., "A Blue-Insensitive Anscochrome Aerial Film," *Papers from the 35th Annual Meeting of the American Society of Photogrammetry*, March 1969, pp. 43–54.
6. Hulbert, E. O., "Optics of Distilled and Natural Water," *Journal of the Optical Society of America*, Vol. 35, No. 11, November 1945, pp. 698–705.
7. Duntley, Seibert Q., "Light in the Sea," *Journal of the Optical Society of America*, Vol. 53, No. 2, February 1963, pp. 214–233.
8. Duntley, Seibert Q., "Visibility in the Oceans," *Optical Spectra*, 4th Qtr., 1967, pp. 64–69.

New Publication

La Photogrammetrie des Plans Topographiques et Parcellaires (Photogrammetry in Topographic and Cadastral Mapping), Bernard Dubuisson: Paris, Editions Eyrolles, 61, boulevard Saint-Germain, 1969. 312 pages, paper bound, 77 francs plus 4.02 francs postage to U.S.

This new French-language textbook was written for civil engineers, and specifically for cadastral and topographic engineers who are well grounded in geodesy, topography, and mensuration. The book covers the principles of taking and using photographs for work in these fields. Separate chapters are devoted to (1) the aerial photographic mission, including discussions of flight planning, cameras, and navigation aids; (2) the use of single metric photographs, with sections on camera and photograph geometry and on the principles of radial single-photo triangulation; and (3) stereophotogrammetry, including sections on mathematical principles, stereoplotting and stereotriangulation equipment, and stereotriangulation methods.