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Water Depth Penetration Film Test*

Evaluation of recording efficiency of nine film-filter combinations over a typical water body.

ABSTRACT: *As part of the National Aeronautics and Space Administration Earth Resources Program, a comparative and controlled evaluation of nine film-filter combinations was completed to establish the relative effectiveness in recording water subsurface detail if exposed from an aerial platform over a typical water body. The films tested, with one exception, were those which prior was suggested had potential. These included an experimental 2-layer positive color film, a 2-layer (minus blue layer) film, a normal 3-layer color film, a panchromatic black-and-white film, and a black-and-white infrared film. Selective filtration was used with all films.*

INTRODUCTION

INVESTIGATORS in the fields of hydrology, oceanography, limnology, underwater geology, archeology, and related areas use aerial photography over water as a basic investigative tool. Differentiation of detail at and below the water surface is essential to these investigators for acquiring data on phenomena such as industrial effluents, plant life, silt movement, and tidal effects. Recording the water-covered areas of the United States and its surrounding oceans on photographic film is a routine activity of NASA's Earth Resources program.

Efficiency of photographic penetration of the water surface to record this detail depends on a match of the subject's spectral and brightness character with the photographic system spectral sensitivity and sensitometric character.

As a part of a continuing program to optimize photographic recording systems, the Photographic Science Office of the NASA Photographic Technology Division at the Johnson Space Center completed a comprehensive evaluation of nine film-filter combinations (Table 1) for water-depth penetration. A basic ingredient in this evaluation was the concurrent exposure of all films to a completely common set of target conditions, thus yielding an increased accuracy in determining their relative effectiveness. A principal film in the evaluation was an Eastman Kodak experimental two-layer color film. This film was proposed[1] and introduced[2] in *Photogrammetric Engineering. ing.*

Imagery was obtained with a six-camera 70-mm Hasselblad system during December 1972, on a NASA C-130 flight at an altitude of 1.45 km over a well-documented area adjacent to the Scripps Institution of Oceanography. The mapped water depth in this area varied from zero on the beach to 50 meters within 1 kilometer of the shoreline.

DISCUSSION

Three of the film-filter combinations produced imagery which demonstrated similar

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TABLE 1. EXPERIMENT FILMS AND FILTERS

Film	*Wratten Filters*
2-Layer Experimental	3 (light yellow)
SO-397 (4-mil base Ektachrome EF)	64 + 2E (blue-green)
SO-426 (minus blue layer color film)	none
SO-397	12 (Yellow)
SO-397	3 (light yellow)
2402 (Kodak Plus-X Aerographic)	64 + 2E (blue-green)
2402	3 + 47 (blue
2402	21 + 57 (green)
2424 (Kodak Infrared Aerographic)	89B (Infrared)

superior water depth penetration in this water at 10 to 15 meters:

- Experimental 2-layer color with Wratten 3,
- SO-397 with Wratten 12,
- SO-397 with Wratten 3.

Density or color brightness changes were visually discriminated in these map-correlated deep water areas.

Imagery obtained with SO-397 film and a Wratten 3 filter was used to determine the spectral character of the subject water body. This was done by correlating the film spectral sensitivity data shown in Plate 6 with the colors displayed in the SO-397 image. The result was the curve of approximate subject character drawn in Figure 6.

The typical water attenuation characteristics of this type water body are shown in Figure 1. Although maximum relative transmittance of water is centered between 500 mm and 550 nm, the spectral character of water bodies does vary. This experiment was designed to study photographic recording efficiency of films and filter with peak sensitivities covering the maximum water transmission region, as well as blue and near infrared. The film-filter spectral responses are shown in Figure 2.

Information obtained from this experiment

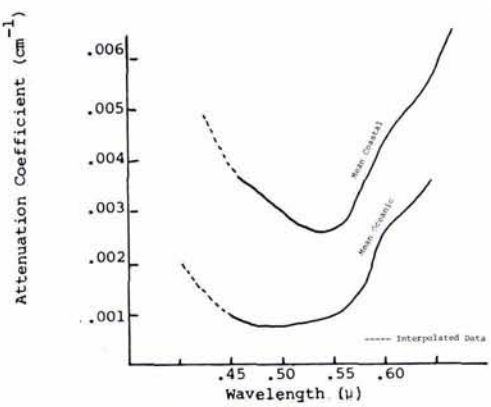

FIG. 1. Water attenuation coefficient.

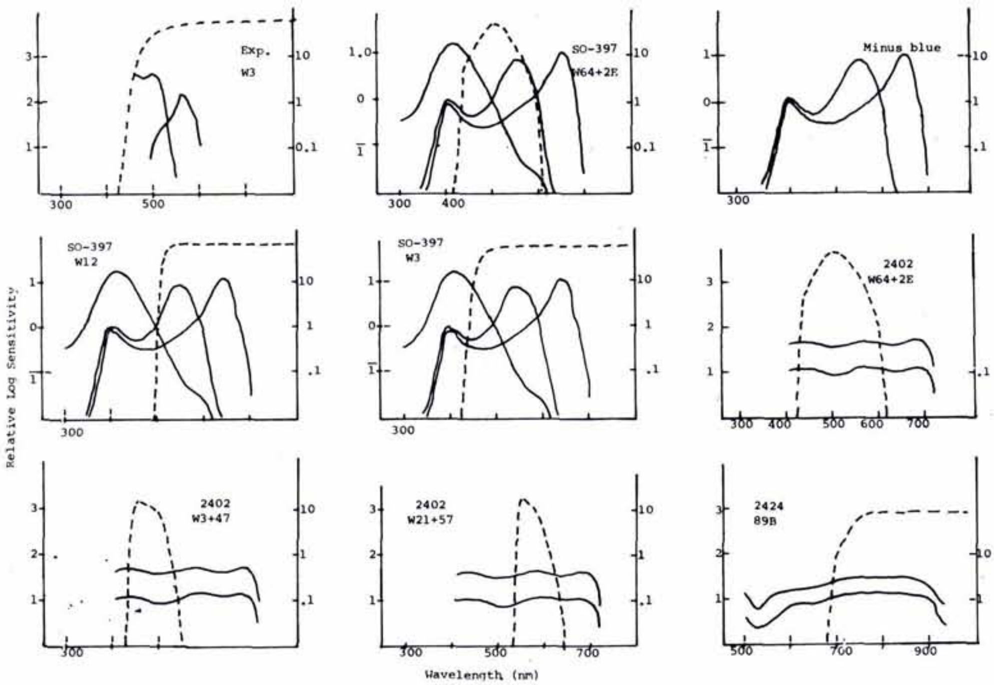

FIG. 2. Film-filter spectral sensitivities.

will significantly improve the process for determining films and filters to be employed in future photographic missions over bodies of water.

Subjective evaluation criteria were emphasized in this evaluation because visual analysis is the most common technique used by investigators. Where data did warrant other types of special analyses, it is interesting to note that the results were consistent with those achieved visually.

Evaluation Procedures

Six records (the color films plus 2402 film with Wratten 64 and 2E filters) were exposed in the Hasselblad system simultaneously on two flights along the California coastline. The remaining records were obtained minutes later in a single flight along the same coast line such that identical subject matter appears in all nine sets of imagery. The imagery was processed and duplicated by the Photographic Technology Division at the Johnson Space Center.

Mapped water depths and reference points were correlated with the imagery for depth determinations. Images were analyzed subjectively on a standard viewing table using the evaluation criteria listed. Experimental results are shown in Table 2.

Results were correlated with spectral sensitometric data to estimate subject spectral character and to study effects of spectral sensitivity variations.

Some image enhancement techniques were evaluated for their usefulness in improving imagery and presenting the subsurface data in an easier-to-interpret format.

Results

A tabulated subjective analysis of the nine film records is presented in Table 2, Experimental Results. The criteria key for analysis was as follows:

Shallow color contrast. Visual color or density differences in water at map positions indicating 1.5 meters or less.

Medium color contrast. Visual color or density differences in water at map positions indicating 1.5 meters to 3.5 meters depth.

Deep color contrast. Visual color or density differences in water at map positions indicating depths of 3.5 meters or more.

Water penetration. Definite density or color differences visually discriminated at depths indicated on map referenced points. This does not necessarily mean that the ocean bottom is visible.

Color. Spectral range observed in the imagery.

TABLE 2. REVERSE COLOR SCALE TO SCALE COLOR

FILM / FILTER	COLOR CONTRAST: Shallow/ Color Scale	Medium/ Color Scale	Deep/ Color Scale	Water Penetration (meters)	COLOR	Surface Vegetation	Surface Reflections	Visual Compatibility
Experimental 2-Layer Wratten 3	3 / Magenta	2 / M to N	1 / Neutral	10 to 14	Magenta to Near Neutral	4	4	2
SO-397 (Ektachrome EF) Wratten 64 + 2E	5 / Green	5 / Green	6 / Green	3 to 5	Green	10	2	5
SO-426 (minus blue) None	4 / M to C	3 / C to B	3 / Blue	6 to 8	Lt. Mag. to Blue	3	3	4
SO-397 Wratten 12	2 / Yellow	2 / Lt.G	3 / Dk. G	10 to 14	Yellow to Green	1	4	3
SO-397 Wratten 3	1 / Lt. Y	1 / Y to G	1 / Green	10 to 14	Y/G to Green	2	4	1
2402 Wratten 64 + 2E	3 / B&W	3 / B&W	4 / B&W	3 to 5	B & W	10	3	2
2402 (PlusX Aerographic Wratten 3 + 47	4 / B&W	4 / B&W	2 / B&W	5 to 8	B & W	10	n/a	2
2402 Wratten 21 + 57	4 / B&W	4 / B&W	1 / B&W	10 to 14	B & W	10	n/a	2
2424 (Infrared Wratten 89B	10 / B&W	10 / B&W	10 / B&W	0	B & W	4	n/a	3

Surface vegetation. The ability to see plant life contrasted against the water body background.
Surface Reflections. Specular reflections observed on the water surface.
Visual compatibility. The effect of scene color and color differences in making visual density and color difference determinations.

The films were graded on a relative basis: *1* signifies excellent and *10* poor in any category. Samples of the imagery are included in Figures 3 through 5, and Plates 1 through 5.

Maximum brightness near the shoreline (yellow in the SO-397/W3 filter image) relates to the 550 nm (nanometers) in the spectral sensitometric exposure or the peak water transmittance for shallow water. Minimum brightness (green in the image) correlates to a deep water peak transmittance of 500 nm. There is little spectral change beyond a depth of 5.0 meters. The advantage of a film with wide spectral sensitivity range is demonstrated by the range of image color.

Water bodies represent a subject of extensive brightness range, from bright shallow water to dark deep water, with minimum brightness range in deep water making detail discrimination a problem. Color contrast and film-process characteristic curve shape as well as spectral sensitivity are key factors in effective recording over water bodies. This is particularly true in deep water.

Water depth penetration depends highly on spectral sensitivity, as well as image contrast. The problem is complex because a high brightness, wide spectral range subject (shallow water) is combined with a low brightness, low brightness range subject (deep water). To record all of the subject properly, high film gamma is desirable to separate brightness differences in the low exposure area and a wide exposure range is needed to record the shoreline and deep water in the same image.

The visual contrast increase inherent with color film-filter combinations like the experimental two-layer film or SO-397 with either a Wratten 12 or a Wratten 3 filter is a significant aid when making visual analyses.

IMAGERY DISCUSSION

The two-layer experimental color positive water penetration film with a Wratten 3 filter resulted in magenta to nearly neutral imagery. Magenta is predominant in shallow

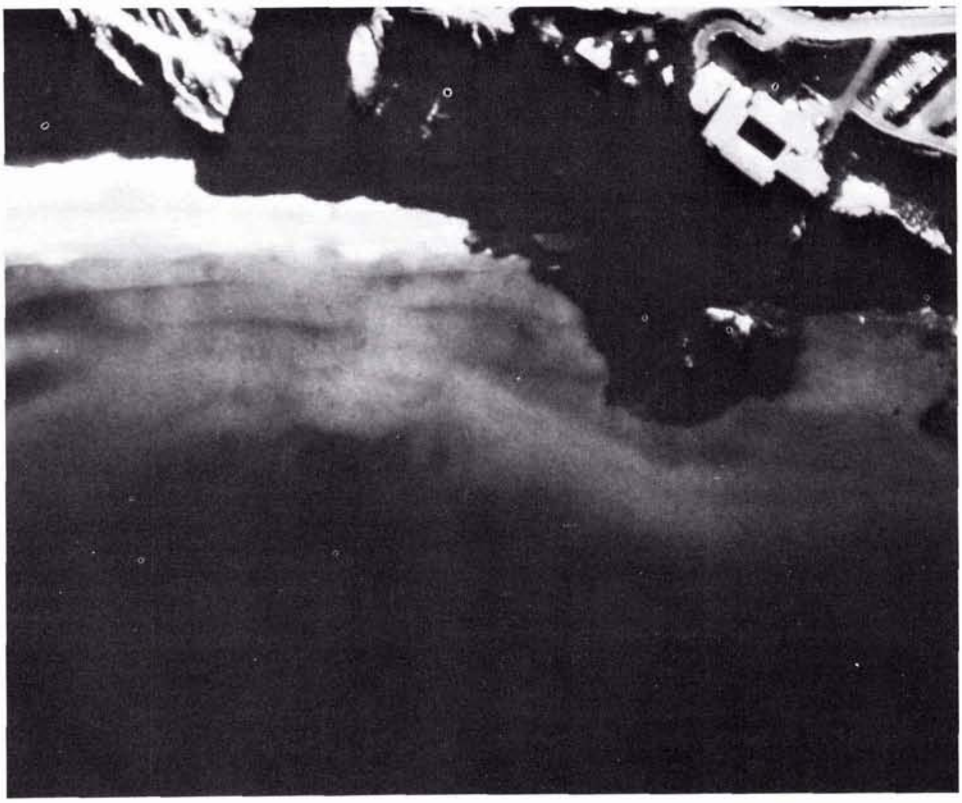

FIG. 3. 2402 film/Wratten 64 + 2E filter image.

PLATE 1. Two-layer film/Wratten 3 filter image.

PLATE 2. SO-397 film/Wratten 64 + 2E filter image.

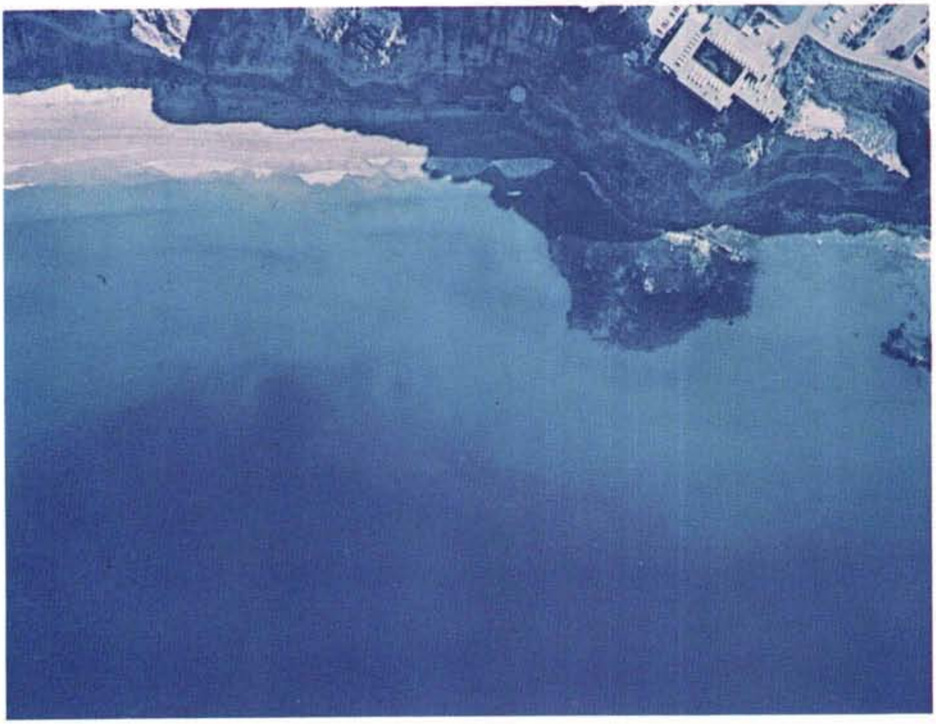

PLATE 3. SO-426 film image.

PLATE 4. SO-397 film/Wratten 12 filter image.

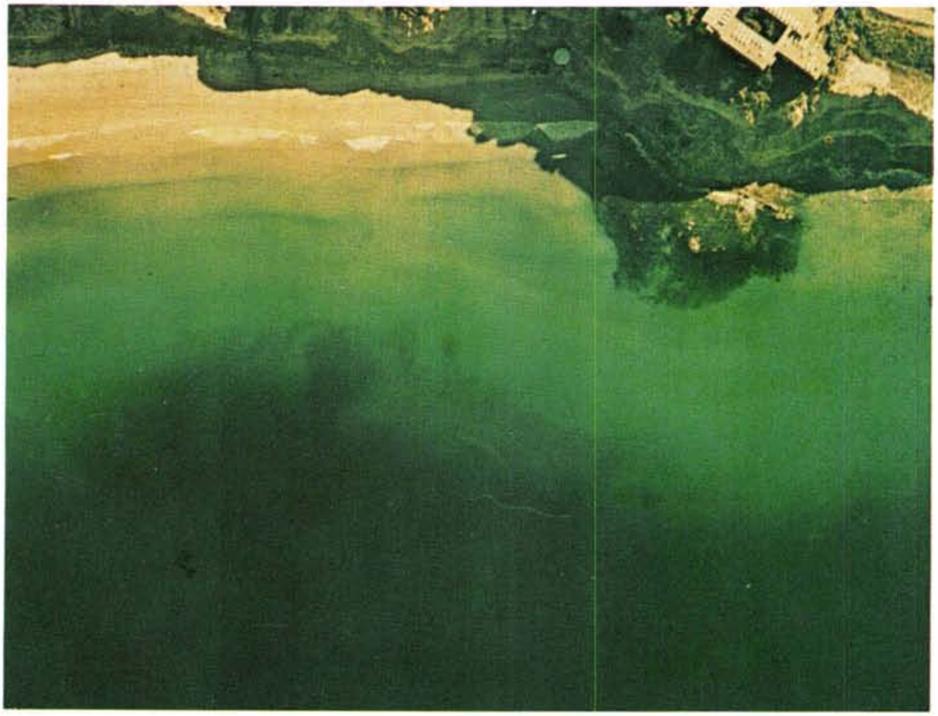

PLATE 5. SO-397 film/Wratten 3 filter image.

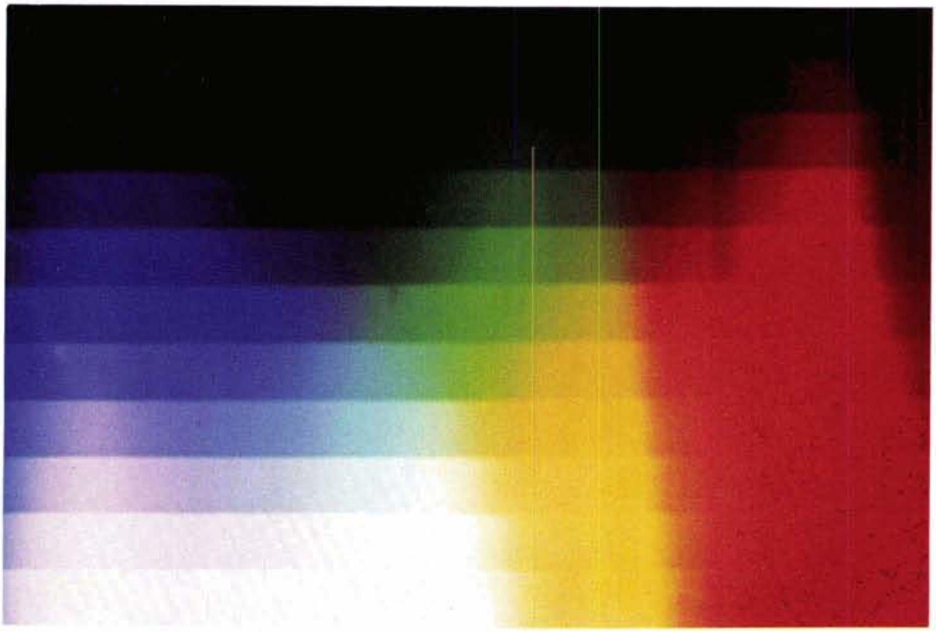

PLATE 6. SO-397 spectral sensitivity data.

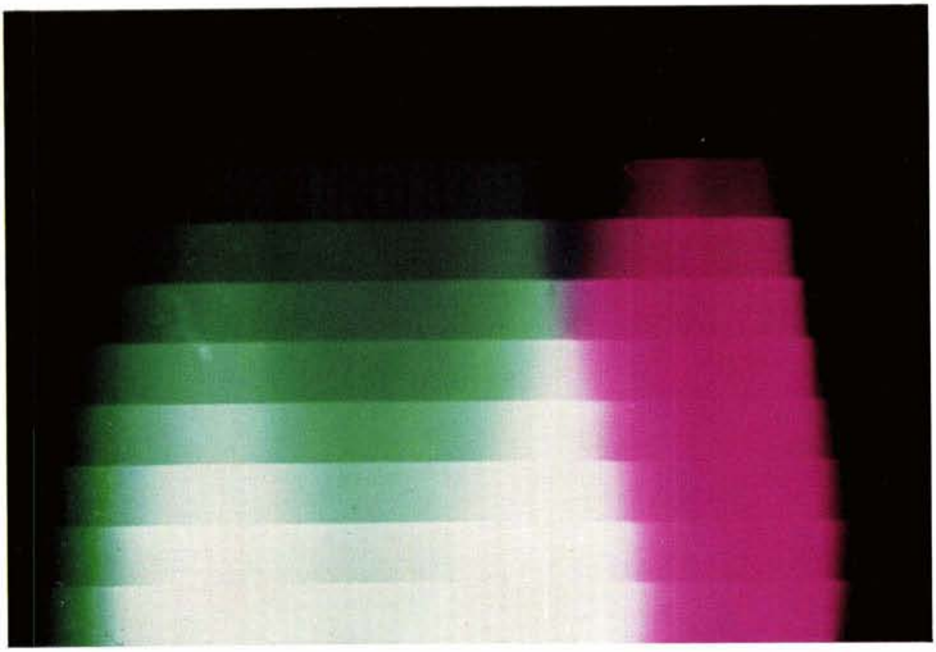

PLATE 7. Two-layer film spectral sensitivity data.

PLATE 8. Contrast enhanced imagery.

water changing to neutral in greater indicated water depths (minimal exposure areas). Surface vegetation appears magenta against a nearly neutral water background. Figure 3 shows the water penetration at depths of 10 to 14 meters.

The magenta imagery near the shoreline correlates well with spectral sensitivity at 550 nm (Plate 7). At 500 nm the imagery is not correlated as easily because of the low subject brightness. The imagery is nearly neutral (red density is 1.29, green is 1.36, blue is 1.11), but definitely not green as might be suggested by spectral sensitometric data. This situation results in minimal color contrast and color brightness variation in deeper water.

Type 2402 film with Wratten 3 and 47 filters provides imagery with minimal density differences at indicated depths below 3.5 meters and good density differences beyond 3.5 meters. Surface vegetation is not easily visually discerned. Figure 4 shows the water penetration at indicated depths of 5 to 8 meters.

Type 2402 film with Wratten 21 and 57 filters shows minimal density differences at depths under 3.5 meters, but excellent gradation at depths greater than 3.5 meters. For deeper water this record compares very favorably with SO-397 with a Wratten 3 filter and may show greater density differences. Penetration is possible at the 10 to 14 meter depths (Figure 5). Surface vegetation is not easily discernable.

Black-and-white infrared aerographic film, 2424, with an 89B filter provides no water penetration. Surface vegetation may be visually discriminated and the shoreline is easily noted.

Infrared sensitive film with an 89B filter would be excellent for detecting vegetation against a water background if it is exposed properly. Water is opaque in the near-infrared making the contrast easy to achieve.

These are obviously not the only films which have a use for recording over water. One worthy of note is type 2443, color-infrared. Its sensitivity, color contrast and gamma produce excellent results over shallow water. Type 2443 may be applied to silting studies, water-current evaluations and oil-spill searches. Results in deep water are not as promising because a combination of the spectral cut-off at 510 nm of the yellow filter required, the low film sensitivity and

FIG. 4. 2402 film/Wratten 3 + 47 filter image.

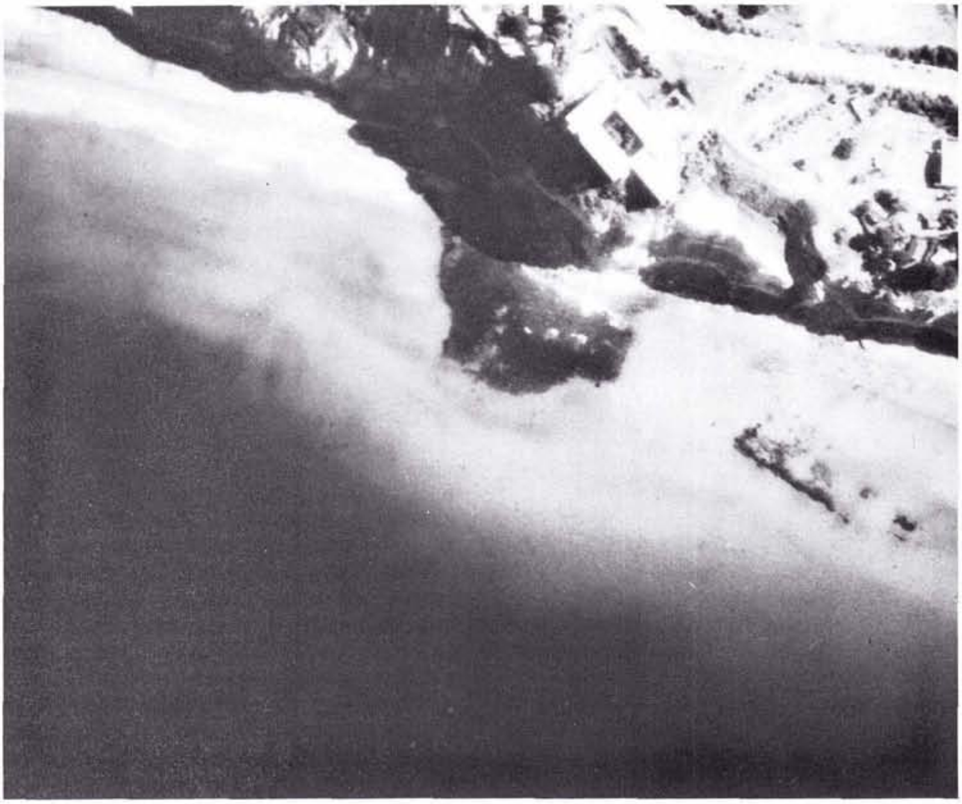

FIG. 5. 2402 film/Wratten 21 + 57 filter image.

the deep water transmittance do not permit enough exposure of the film.

Film type SO-397, Ektachrome EF Aerographic, (4-mil base) with Wratten 64 and 2E filters (green) provides light-green imagery. Color contrast at all indicated water depths is poor, the overall light-green color making visual determinations difficult. Surface vegetation discrimination is not possible because of poor color contrast. Plate 2 shows the water penetration at 3 to 5 meter depths.

Type SO-426, a two-layer color positive film (sensitivity similar to SO-397 red and green sensitive layers only), with no filter resulted in light blue to blue imagery. Color contrast and saturation are inferior. Plate 3 shows the water penetration at indicated depths of 6 to 8 meters.

The two-layer (minus blue) film imagery correlates well with subject transmittance and spectral sensitivity. With the removal of the blue sensitive-yellow dye-forming layer, the yellow filter used to control residual blue sensitivity in the lower layers apparently loses some of its efficiency. In shallow water at 500 nm where green is expected, the added blue produces a cyan image. At 500 nm, low exposure areas, the blue imagery correlates well with spectral sensitivity data. The addition of a Wratten 3 filter might be advisable to correct this problem.

Film type SO-397 with a Wratten 3 filter provides an excellent record for water depth penetration. Light yellow predominates at shallow (under 1.5 meters) depths, changing to a yellow-green contrast at 1.5 to 3.5 meters and green at depths in excess of 3.5 meters. Color contrast is excellent at all depths, definitely superior to other films. Water penetration is possible at indicated depths of 10 to 14 meters (Plate 5) and surface vegetation is identified with ease. Visual compatibility is excellent for this film-filter combination.

Type SO-397 film with a Wratten 3 filter (Plate 5) produced excellent imagery, not only because of water depth penetration, but also because of the spectral range (color contrast) in the image. The changes are observable in the spectral sensitometric image. The colors are also saturated and brightness variations are observed easily. The presence of a wider range of colors in the imagery offers a better chance for color contrast to be displayed if subject brightness level as well as peak spectral transmittance are factors. The same film with a Wratten 12 filter introduced excessive yellow into the imagery.

Type SO-397 film with a Wratten 12 gives a yellow to green record. Saturated, bright yellow predominates at depths under 1.5 meters changing through green at 1.5 to 3.5 meters to green at depths greater than 3.5 meters. Color contrast is good at all depths with water depth penetration indicated at map positions of 10 to 14 meters, Figure 6. Vegetation above water surface is imaged best by this record, bright yellow against green water.

Poor image contrast was exhibited by all of the black-and-white films in shallow water where a wider subject spectral transmittance range was present. In deeper water, 2402 with 64 +2E filters is more sensitive than the same film with 21 + 57 filters which have negligible sensitivity at 500 nm. The latter required 10× more exposure to provide good imagery.

Type 2402 film with Wratten 64 and 2E filters results in density differences at depths of 3.5 meters or less that are better than other black-and-white records. Detail discrimination is relatively poor at greater depths. Surface vegetation is very difficult to discriminate and water penetration is possible at 3 to 5 meters, Figure 8.

IMAGE ENHANCEMENT

The photographic recording problem posed by sub-water surface subjects frequently results in imagery that is difficult to analyze. Speed of the films combined with camera shutter-aperture limitations and the low-contrast, low-brightness deep water subject may result in underexposure and low image contrast. In many instances this underexposure is easily corrected in the photographic laboratory in the printing step by exposing for and reducing positive image densities.

A second technique, less used especially with color imagery, is contrast enhancement. Deep-water brightness differences are normally so small that, if combined with the overall dense imagery, they result in little or no observable density differences. A combination of a reduction in average subject density and an increase in density differences in the imagery by factors of 2× to 8× can result in greatly improved data. Contrast enhancement can achieve this.

Unfortunately, standard photographic laboratory practices and films used for duplication do not provide much contrast enhancement although exposure compensations are possible. Perhaps the best solution to this problem would be the use of a camera film stock; Ektachrome EF, for example, can be processed to a gamma of nearly 2.0, doubling whatever density differences were inherent in the imagery.

This capability lies within most laboratories. The expense should be approximately that of making a duplicate transparency and the technique may be applied to entire rolls of films. The results in Plate 8 are typical of a 2× contrast enhancement of deep water imagery.

Further, where a close relationship exists with the processing laboratory, properly selected filters in the printing of color imagery can also increase image density differences.

Digitizing and computer manipulation of imagery, color reconstruction of black-and-white imagery, dissection of color imagery and isodensity contouring of imagery are additional enhancement techniques worthy of investigation. Unfortunately, these tools have inherent limitations of cost, time required or equipment availability which may limit their usefulness to a few frames. At the same time, application of laboratory contrast enhancement, print exposure and filtration may yield the best results.

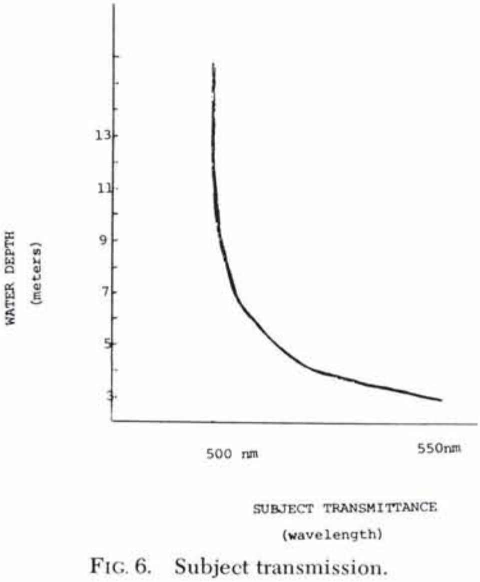

FIG. 6. Subject transmission.

CONCLUSIONS

The following are concluded from this evaluation of nine films for water depth penetrating ability over a typical subject area.

* SO-397 (Ektachrome EF Aerographic Film on a 4-mil base) with a Wratten 3 filter for atmospheric haze reduction produced the best overall imagery for water depth penetration at all depths. The wide spectral sensitivity (450 nm

to 650 nm) of this combination make it an excellent choice for recording over bodies of water at this altitude.

* Water depth penetration ability of the Kodak experimental color film with a Wratten 3 filter was comparable to SO-397 with a Wratten 3 filter, but its color contrast (magenta and near neutral) was not as good.
* SO-397 film with a Wratten 12 filter was best for differentiating surface and subsurface vegetation. Imagery produced yellow surface vegetation contrasted against a green water background.
* Color film imagery was superior to black-and-white imagery where a wide subject spectral range was present; e.g., shallow *vs.* deep water, and surface *vs.* subsurface vegetation.
* Type 2402 (Kodak Plus-X Aerographic film) with Wratten 21 and 57 filters was the most effective black-and-white film. Its ability to discriminate deep water subsurface detail was equal to SO-397 with a Wratten 3 filter.
* Type 2424 (Kodak Infrared Aerographic Film) with a 89B filter defines shoreline well. Water is a poor transmitter of infrared and produces no exposure on infrared film producing a clear discrimination between it and the beach or shoreline.
* Color film should be included in water body studies. Color contrast is a definite aid in visual analysis of water surface and subsurface detail. It also provides a much better image of shallow water areas.
* Imagery shows that deep water subsurface detail discrimination depends on photographic exposure and contrast. Subject spectral range is small and subject brightness and brightness ranges are low, requiring higher contrast and film speed.
* Serious consideration should be given high-contrast printing and exposure compensation as image enhancement tools for deep water penetration.
* As additional films or film-filter combinations with potential for aerial recording are available, they should be evaluated and reported on.

References

1. A two-layer color positive film as proposed by Gaylord A. Helgeson in February 1970, *Photogrammetric Engineering*, "Water Depth and Distance Penetration" (and produced by Eastman Kodak Company), 36(2):164-172.
2. The 2-layer color positive film was described in an April 1973, *Photogrammetric Engineering* paper, "New Color Film for Water Penetration," by M. R. Specht, D. Needles, N. T. Fritz, 39(4):359-369.

Change in Name of Magazine

The board of Direction of the American Society of Photogrammetry voted on September 11, 1974 to change the name of its journal to *Photogrammetric Engineering and Remote Sensing* to become effective with the January 1975 issue.