SECTION 110

COASTAL AND ESTUARINE APPLICATIONS
OF MULTISPECTRAL PHOTOGRAPHY

by

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ABSTRACT

An evaluation of multispectral photographic techniques for optical penetration of water in northeastern United States and Gulf of Mexico coastal waters is made. Spectral bands to maximize the detectability of underwater objects is a function of the type of particulant matter in suspension, as well as the size and quantity of the particles. The spectral band (493-543 nm), when exposed to place the water mass at about unity density on the photographic emulsion, was found to give the best water penetration independent of altitude or time of day as long as solar glitter from the surface of the water was avoided.

When optimally exposed, the images of surface and underwater objects showed greater chromatic enhancement in multispectral color renditions than on conventional aerial Ektachrome color films. Multispectral negative color renditions were found to be equally as good as positive color images for achieving color differences between the water mass and submerged objects.

An isoluminous color technique has been perfected. This photographic process eliminates the dimension of brightness from a multispectral color presentation. By this method, objects exhibiting subtle spectral differences which are normally obscured by the comparatively large brightness present in coastal waters can be detected. Colorimetric measurements of isoluminous images showed that they provided vivid color differences of underwater targets. The isoluminous technique should be quite useful in detecting subtle color differences in coastal waters which result from phytoplankton concentrations, suspended particulant matter, oil and pollutants, as well as for the identification of sub-surface objects.

INTRODUCTION

The results of a two-part experiment to evaluate multispectral photographic techniques for remote sensing of coastal environments are discussed herein. The research was conducted during the last half of 1967 and during 1968, with analysis extending through 1969.

The Long Island University four-lens multispectral camera was used to obtain spectral photography of both a northeastern coastal site at Montauk Point, Long Island, New York and the Gulf of Mexico coastal site off Santa Rosa Island (Pensacola), Florida. Photo interpretation, densitometric and colorimetric analyses of the imagery obtained were performed using the multispectral additive color viewer and auxiliary equipment. Simultaneous aerial Ektachrome photography was also taken during both parts of the experiment. Five different spectral bands were used to obtain spectral photography. At the northeastern coastal side, the spectral bands were chosen to match the bands of the spectrum to which the color film was sensitive. At the Gulf Coast site, filters especially designed for coastal water penetration were used.

Throughout the experiment extensive environmental measurements were made. These environmental "controls" included: (1) surface and submerged gray scale and color targets, (2) measurements of the intensity and spectral distribution of solar radiation incident upon the water surface and "downwelling" at various depths, (3) spectroradiometric measurement of solar energy reflected by surface and underwater targets, as well as the "natural" upwelling irradiance of the water; (4) colorimetric measurements of the surface targets, and (5) biological-physical analysis of the samples of the water in which the targets were embedded.

FUNDAMENTAL PROBLEMS

Prior to performance of the experiment, two fundamental problems were distinguished as being of critical importance in obtaining precision multispectral photography of coastal waters. These problems are not unique to photographic sensors and, in fact, generally apply to any remote sensing technique in the .26 to 3 micron part of the electromagnetic spectrum where reflection rather than emission phenomenon is encountered.

The first problem relates to the lack of accuracy and precision in the structure of the image due to instrumentation errors. These arise from three sources: (1) sensor errors in formation of the spectral image, (2) photographic errors in transforming the image energy to density in the photograph subsequently used in data reduction, (3) errors in the viewing apparatus which constructs the color image for qualitative viewing by the interpreter and for quantitative colorimetric analysis.

Psycho-physiological variables in viewing color images are not treated in this report, although such considerations are critical in the qualitative interpretation of aerial photography. All the data presented herein are in terms of analytical color measurement and thus psychological variables such as simultaneous contrast enhancement do not appear in this analysis.

The second problem centers on the environment. In this case, three variables are distinguished: (1) the intensity and spectral distribution of the solar illuminant (a fractional part of which is reflected into the camera and thus forms the image) changes as a function of the solar angle, atmospheric conditions, secondary reflectance, and the relative composition of direct sunlight and diffuse skylight, (2) the in situ spectral reflectance of surface objects is known to vary dynamically at least as a function of the non-lambertian (directional) spectral reflectance of such objects (due to their orientation with respect to both the angle of incidence and angle of reflection), as well as due to temporal changes in the absorption and transmission of the object itself, and (3) the atmosphere and water media between the object and the sensor which scatters and absorbs the radiation reflected by the object.

OBJECTIVES

The primary objectives of the research were as follows:

-- To establish the factors which affect the detection and identification of man-made objects embedded in coastal waters using multispectral techniques.

-- To evaluate to what degree subtle differences between underwater objects and the water in which they are embedded can be used for detection and identification without special knowledge of their spectral reflectance characteristics.

-- To compare the characteristics of images formed by multispectral additive color photography with conventional subtractive color film.

-- To measure the environmental variables which affect the multispectral technique of remote sensing and to correlate these environmental variables with the imagery.

-- To obtain upwelling and downwelling irradiance measurements of coastal waters in order to indicate the optimum spectral bands for optical penetration.

-- To improve techniques for imaging and analysis of subtle surface and sub-surface phenomena peculiar to coastal waters.

PROCEDURES

The general procedures used throughout the experiment are discussed below with reference to the objectives of the experiment and the fundamental problems to be overcome when using the multispectral photographic technique for remote sensing.

The multispectral camera was equipped with filters which passed radiation in the desired bands of the spectrum (Yost and Wenderoth, 1967). The film used was both black-and-white Plus-X (8401) or Tri-X (8403). An auxiliary K-24 camera, with a lens identical to those used in the multispectral camera, was loaded with Aero Ektachrome (8442) color film. The two cameras were aligned in a common mount such that the optical axes were parallel. All cameras were activated by a common intervalometer so that exposures were taken at the same time (within the shutter tolerances of the two cameras). A range of exposures was used in both the multispectral camera and color camera to insure the best possible exposure of the scene on the film.

The negative film was processed in a continuous Versamat processor using D-19 developer. Sensitometric control was maintained throughout the processing. In general, a medium-to-high contrast was obtained on the negative although this varied depending on the conditions encountered at a particular test site. Positive transparencies were obtained by duplicating on Kodak Aerial duplicating film (5427) using a Niagara printer and processed in a Versamat using MX 641-1 developer. Sensitometric control was, of course, maintained. Color films were processed using the rewind method, control strips being used to insure the best possible development within the state of the technology.

Densitometric measurements were made of water, the surface, and underwater target images on the black-and-white spectral negatives. The positive images were placed in the additive color viewer. Numerous color spaces were experimentally formed in order to establish those which gave the greatest color differentiation of the images from each other and from the water. These additive color renditions on the viewer screen were photographed using color film. The surface and underwater target images and the images of the coastal waters were measured on the color reproduction using a color densitometer. An analytical chromaticity coordinate determination was made from the color densities using a special computer program. This data was compared with surface measurements of the target colors and spectra made close to the time the photography was taken. A similar analysis was performed on the subtractive color film (aerial Ektachrome)

Environmental measurements of the indident and reflected solar radiation were made. Analyses were performed comparing the percent directional reflectance of surface and underwater targets and the spectral irradiance of the water in which the targets were embedded.

DISCUSSION

An experimental methodology was developed for measuring the performance of various exposures and film/filter combinations for multispectral remote sensing of coastal waters. This quantitative process involved computing the underwater exposure latitude of standard gray scale targets in relation to the exposure latitude of surface targets. At the same time the incident solar radiation and "downwelling" radiation impinging on the sub-surface target array was measured. The methodology included densitometric and colorimetric measurements of the spectral images formed on the multispectral additive color viewer and on aerial Ektachrome film.

A 120-foot by 15-foot hydrodynamically stable structure was designed and oonstructed to submerge the target array below the surface to any desired depth up to 100 feet (see Figure 1). This structure held the targets parallel to the surface and taut without ripples in the cloth (which would cast shadows on the targets, thereby reducing their brightness). The target array was recovered and used repeatedly. The spectral reflectance and colorimetric characteristics of the subsurface and an identical surface gray scale and color target array were calibrated (see Figure 2). In situ measurements of spectral reflectance were made when imagery was obtained (see Figure 3).

Techniques for colorimetric analysis of color imagery were perfected and methods for processing to compensate for the effects of the radiation passed by the filters established. The effects of gamma and the density of the images were also determined as shown in Figure 4.

Spectral measurements of the optical properties of water obtained both independently and jointly with the spectral photography showed the existence of great variation in both the percent of incident light which is downwelling at various depths and the percent upwelling to the surface (see Figure 5). The clearest coastal waters (in which objects can be photographed at depths of 150 feet) were measured to have a peak percent downwelling light at 480 nm, 97 percent reaching a depth of 10 feet and 70 percent reaching a depth of 42 feet. At lower depths radiation at wavelengths greater than 625 nm was absorbed (see Figure 6). High backscatter was measured to exist in the clearest coastal waters at 450 nm. In "dirty" inshore coastal waters, both in the Gulf of Mexico and in the northeast, the peak percent upwelling light was at 560 nm, demonstrating the absorption of both blue and red light (see Figure 7). Off-shore measurements showed peak upwelling light at 525 nm.

The exposure latitude of targets submerged in northeastern coastal waters recorded by spectral photography using blue (397-512 nm), green (491-585 nm), and red (597-715 nm) filters was determined (see Figure 8). These waters contain large quantities of suspended particulant matter. Quantitative measurement of the comparative penetration capability of the filtration demonstrated that the log exposure latitude of the green spectral band was twice that of the red and three times that of the blue band (see Figure 9). The optimum exposure of underwater objects for all spectral bands was found to occur when the surface was overexposed to place that ambient water illumination at unity density on the recording emulsion.

A series of experiments to reduce solar glitter from the water surface by using polarizing filters was conducted. Various orientations of the plane of polarization were used with respect to the angle of the incident solar radiation impinging on the water surface. No improvement in water penetration capability was found. In fact, the reduction in exposure produced by these filters made them of dubious value.

A set of filters specially designed for coastal water penetration were used in the second phase of the experiment conducted in the Gulf of Mexico. The detectability of underwater objects was found to be best in the 493-543 nm band and almost as good in the 491-595 nm band. The detection of underwater objects was found to be considerably reduced in the 552-604 nm band and unuseable in the 593-658 nm band. It was found that the time of day produced no measurable change in underwater detectability of objects as long as solar angles which cause surface glitter are avoided. However, the relative exposure in each spectral band was measurably affected by time of day. The lens apertures of each spectral band must be adjusted to compensate for this effect in the manner discussed in the text. A decrease in aperture opening of 1 f/stop is necessary when increasing altitude from 1000 feet to 10,000 feet above sea level. In addition, it was found that objects darker than the water in which they were embedded were often as detectable as brighter objects, a condition which persisted to the extinction depth. The overriding consideration in detection of sub-surface objects was found to be the amount of organic and non-organic particulant in suspension in the water. This is the major factor which affects the detection of underwater objects next to wave deformation of the water surface.

CONCLUSIONS

Colorimetric analyses of surface and underwater target images in various multispectral additive color renditions and in aerial Ektachrome photographs were performed on the images obtained at the northeastern test site near Montauk Point, Long Island, New York. These results are summarized as follows:

-- Color of surface images can be greatly enhanced in multispectral color photography by increasing the saturation of these images. To achieve this enhanced color effect the multispectral photographs must be optimally exposed for surface detail which obscures most underwater objects. However, the colorimetric measurements made indicate that improved identification of surface objects by their color is undoubtedly possible.

-- The detection and identification of underwater targets by image color differences is superior on multispectral color renditions compared to color film (aerial Ektachrome) when both are optimally exposed for underwater detail. However, surface detail is lost in the multispectral image due to over-exposure.

-- By using multispectral negative black-and-white transparencies for additive color projection, it is possible to get equally as good color enhancement of underwater targets without incurring the added time and expense in making positive transparencies.

-- Bright underwater detail was detectable in conventional color film (aerial Ektachrome), but all color differences were lost with the exception of the yellow and white targets which were visible although greatly desaturated.

A multispectral photographic technique previously developed by the authors and used in detecting subtle surface differences in coastal waters (Life magazine, 1966) has been brought along to a point where it can be used as a precision tool for detecting subtle color (spectral) differences in water masses. A color image of surface and underwater targets using this isoluminous technique is shown in Figure 10.

This photographic technique eliminates all brightness differences from the scene and shows as a color image only those objects which have a spectral difference. In this manner, both very bright detail such as color targets and objects of low brightness (underwater color targets) are both well imaged as vivid colors. The color differences between identical color surface and underwater targets is due solely to the water between them unaffected by their relative brightness.

All chromatic (colorless) objects such as the surface and underwater gray scale targets are shown as images of equal brightness. The reader should notice that variations in brightness do not offset isoluminous image characteristics. The shadow of a building over the yellow target does not affect the image color. The reader should compare this to conventional color film image (Figure 10) where the target can only be seen in the shadow area. It is anticipated that this technique will be quite useful for detecting very subtle differences in water color such as are cuased by chlorophyll. Such small changes in color are often masked by large brightness differences from the water surface.

REFERENCES

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Figure 1. Underwater target array showing buoy arrangement with target submerged.

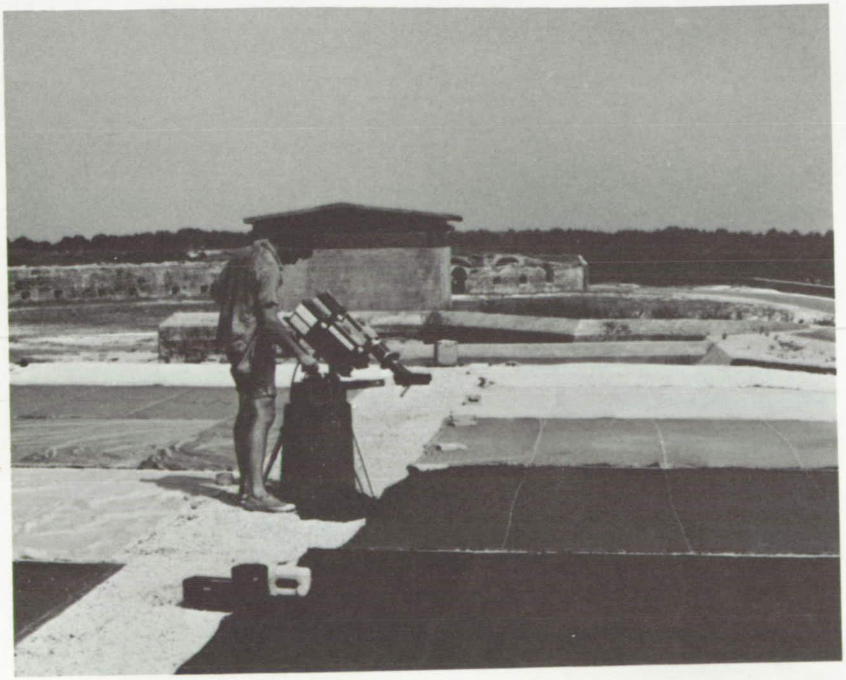

Figure 2. Measurement of the reflectance spectra of surface targets.

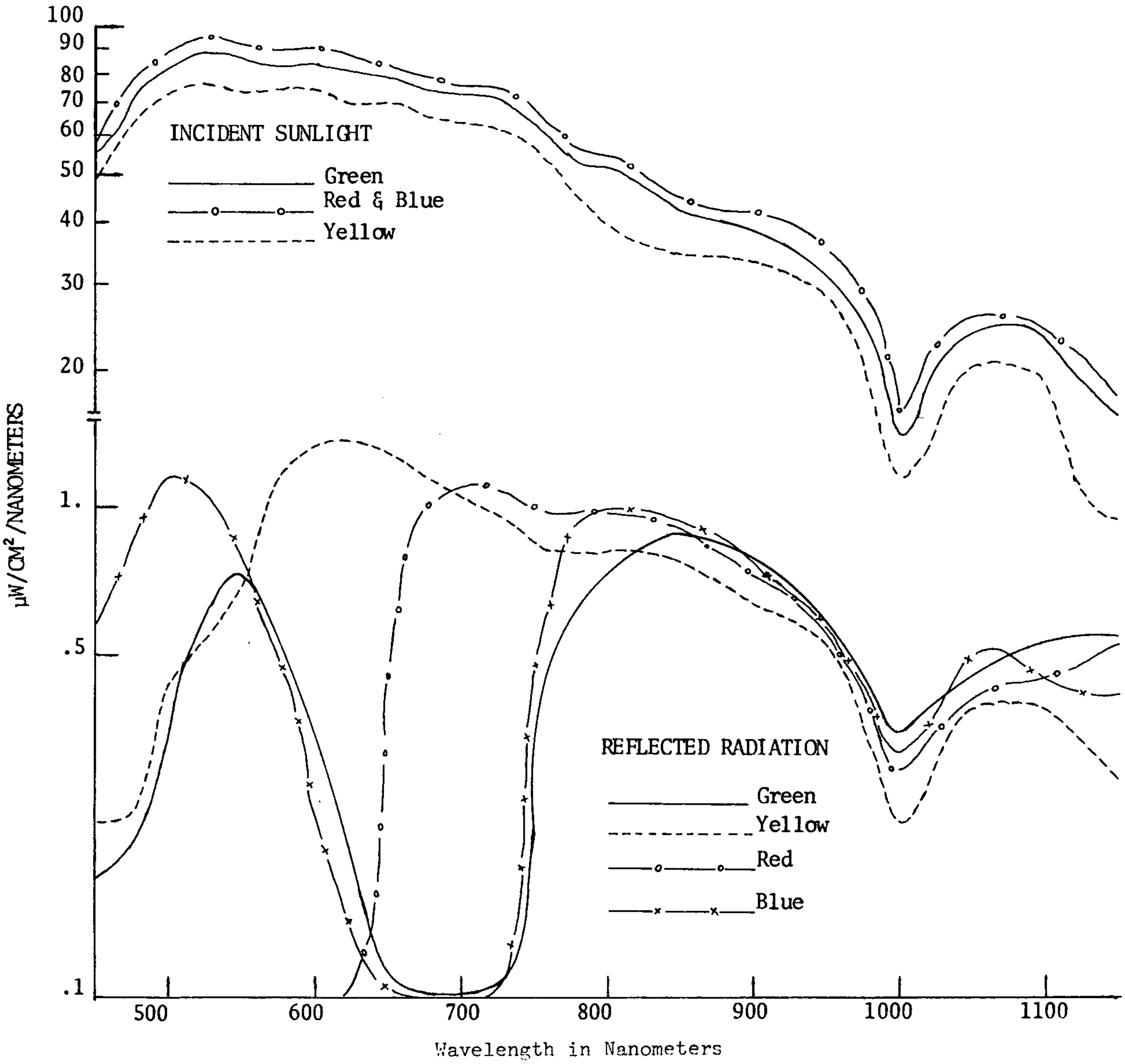

Figure 3. Incident solar radiation and radiation reflected from dacron targets used in second phase of experiment.

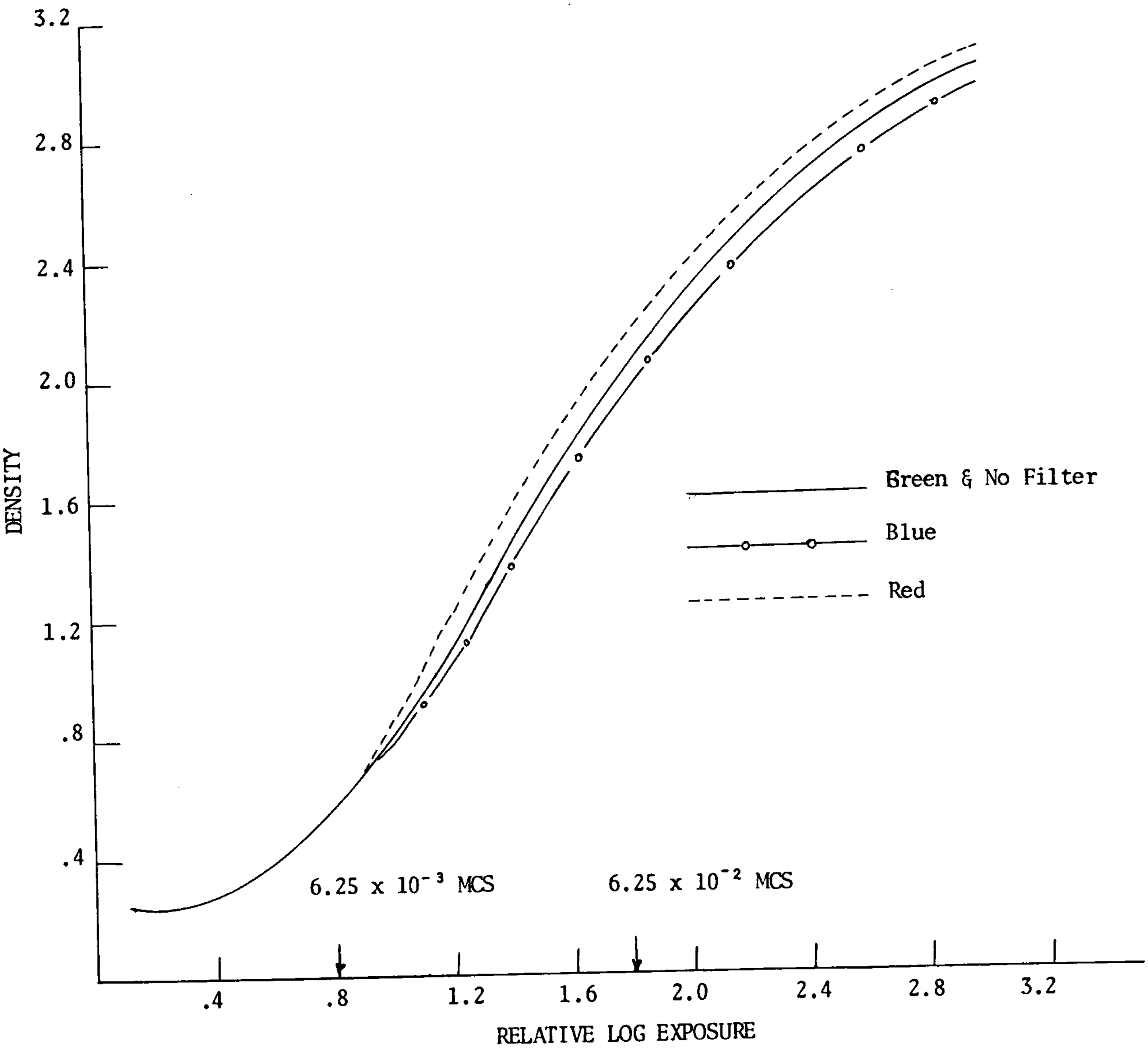

Figure 4. Characteristic curves of multispectral imagery. Ektachrome film (8401), MX 641 developer, five minutes at 80°F.

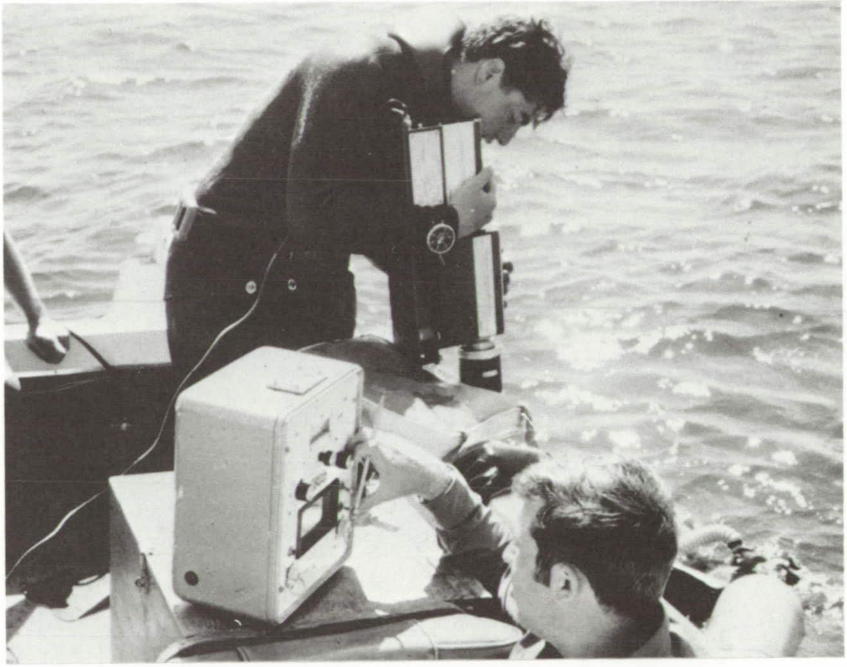

Figure 5. Surface measurements of incident sunlight and upwelling irradiance.

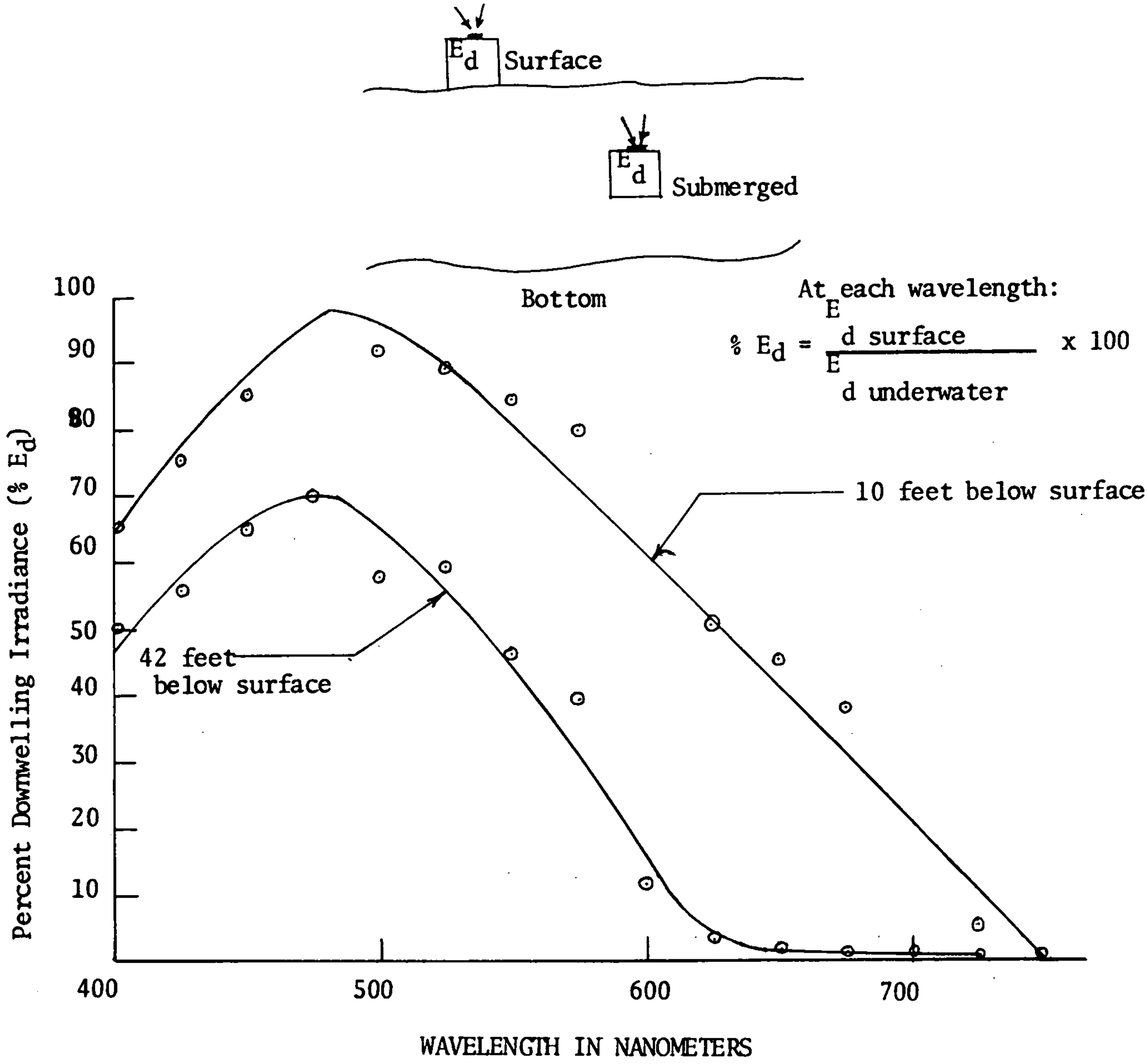

Figure 6. Downwelling reference: Percent downwelling irradiance at 10 and 42 feet below the surface, Tongue of the Ocean, Andros Island, Bahamas.

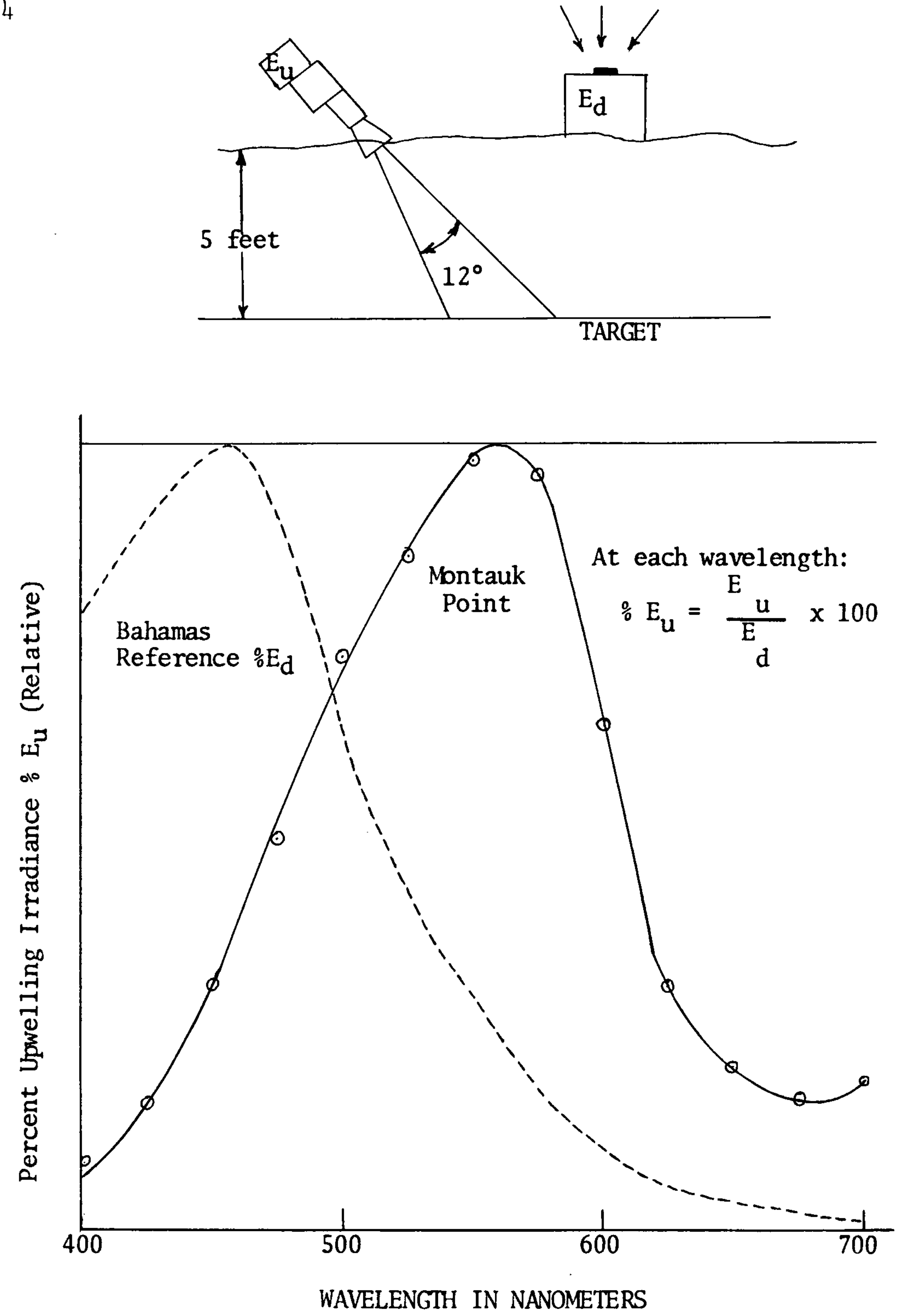

Figure 7. Percent upwelling irradiance of water mass with white target five feet below the surface, Fort Pond Bay, Montauk Point, Long Island, New York. Average of four readings 1722 to 1747 GMT, October 7, 1967.

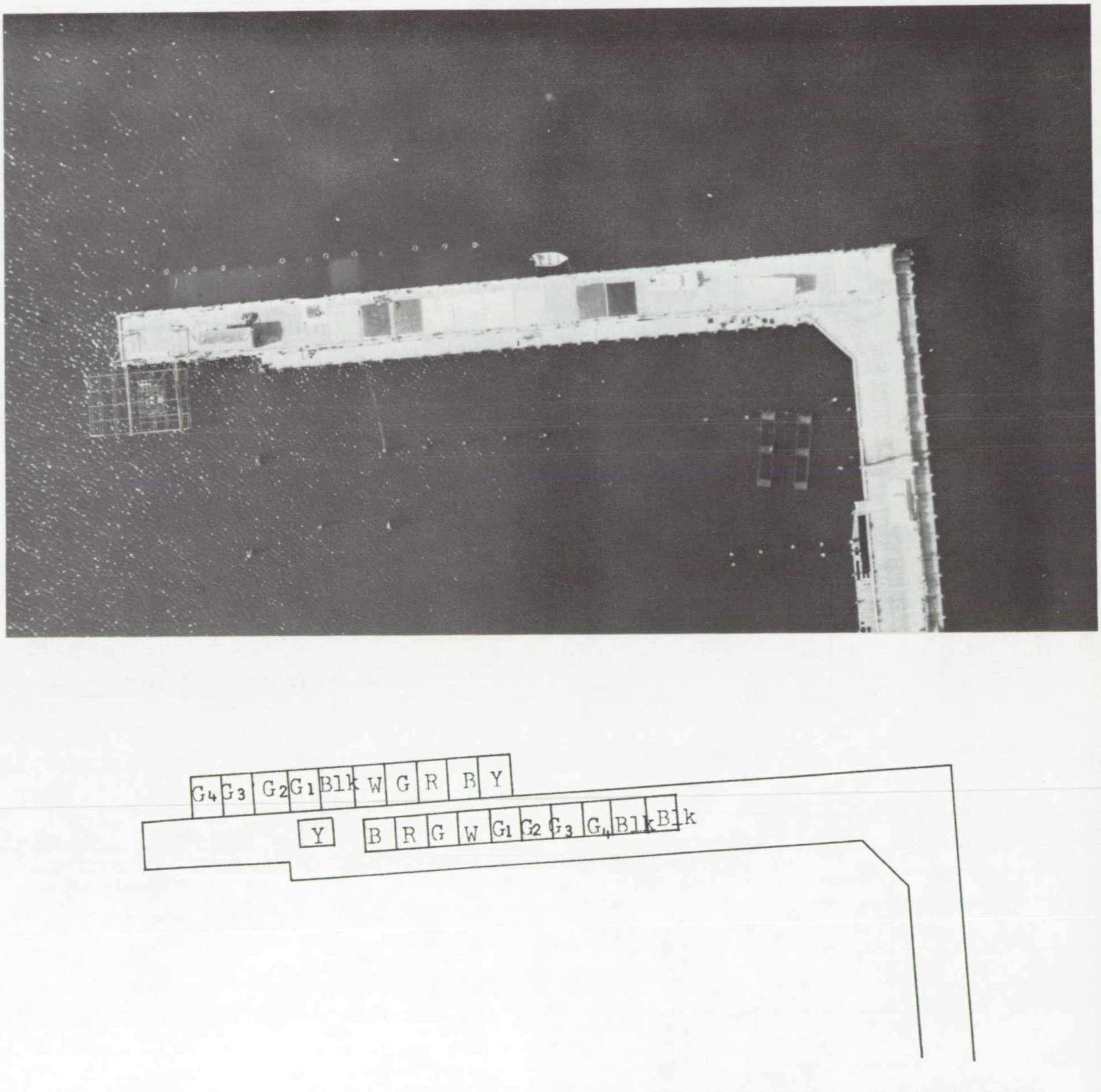

Figure 8. Details of the target area, Fort Pond Bay, Montauk Point, Long Island, New York.

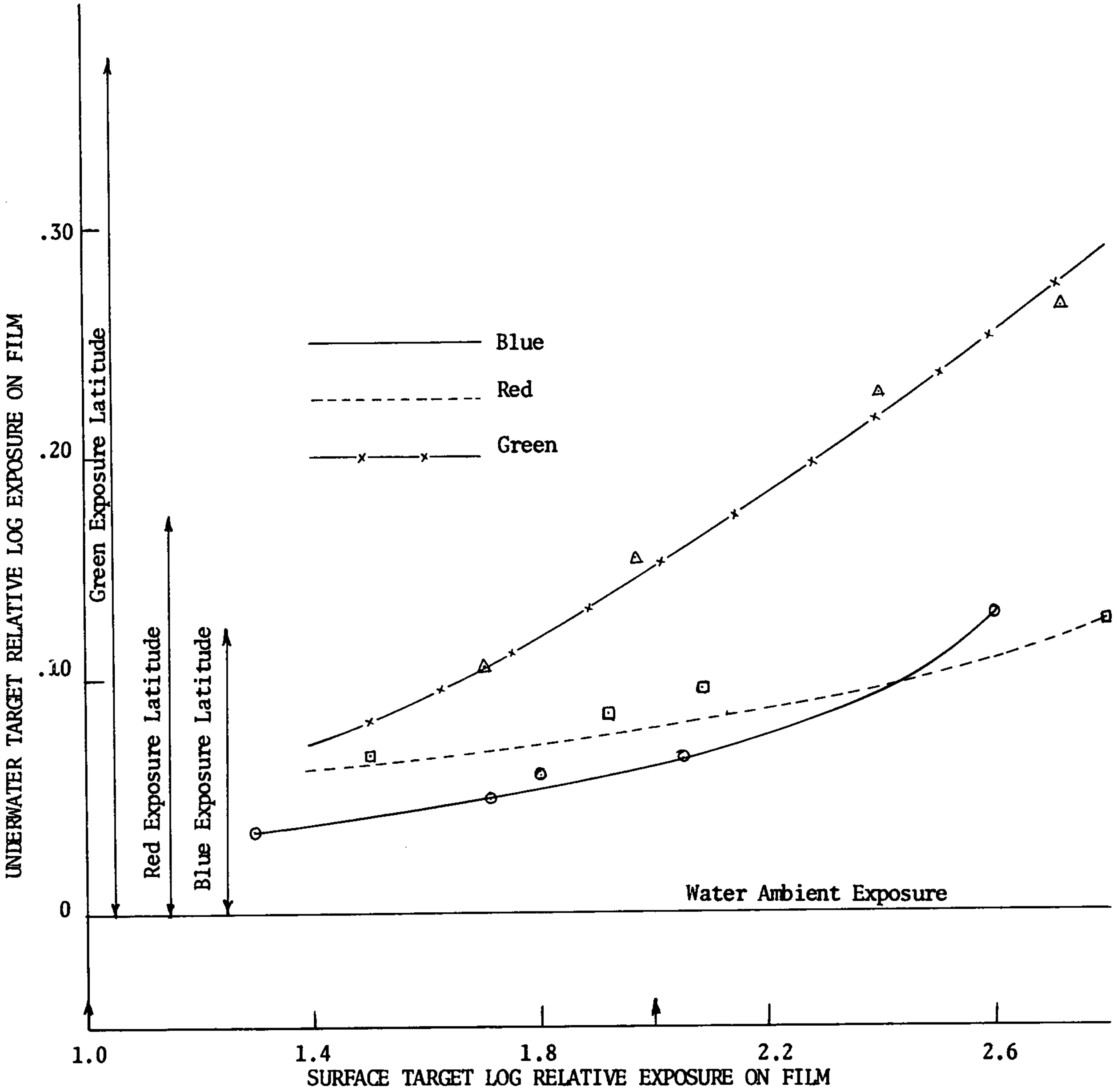

Figure 9. Underwater target relative log exposure in green spectral band, Montauk Point, October 1967.

Figure 10. Photographic reproductions of surface underwater target arrays on isoluminous and conventional color multispectral renditions, as well as on aerial Ektachrome color film. Underwater target array submerged 12 feet in murky northeastern coastal waters.