LITERATURE CITED

1. Avery, Gene, 1958. "Slotted Clip Board for Viewing Aerial Photos." *Minnesota Forestry Notes*, No. 63, January 15, 2 pp.
2. Heller, R. C., Bean, J. L. & Marsh, J. W., 1952. "Aerial Survey of Spruce Budworm Damage in Maine in 1950." *Journal of Forestry*, Vol. 50(1), 4 pp.
3. Heller, R. C., & Coyne, J. F. & Bean, J. L., 1955. "Airplanes Increase Effectiveness of Southern Pine Beetle Surveys." *Journal of Forestry*, Vol. 53, (7). (483–487).
4. Ivey, Henry F., 1957a. "Electroluminescence." *Westinghouse Engineer*, May, 5. pp.
5. Ivey, Henry F. 1957b. "Electroluminescence." *Scientific American*, August, 8 pp.
6. O'Neill, Hugh T. & Nagel, Wm. J., 1952a, "The O'Neill-Nagel light-table." PHOTOGRAMMETRIC ENGINEERING, 18(1) (134–139).
7. O'Neill, Hugh T. & Nagel, Wm. J., 1952b. "The O'Neill-Nagel non-glare adjustable illumination for stereoscopy." PHOTOGRAMMETRIC ENGINEERING, 18(4) (699–701).
8. O'Neill, Hugh T. & Nagel, Wm. J., 1957a. "The Diachromoscope." PHOTOGRAMMETRIC ENGINEERING, 23, (180–185).
9. O'Neill, Hugh T. & Nagel, Wm. J., 1957b. "The Minythoscope." PHOTOGRAMMETRIC ENGINEERING, 23(3) (533–555).
10. Ottoson, L., 1956. "Comparative tests of the accuracy of panchromatic, infrared and color pictures form the air for photogrammetric purposes." Paper presented to International Congress for Photogrammetry. Stockholm.
11. Simonsson, Gunnar, 1957. "Instrument och tekniska hjälmedel för skoglig användning av flygbilder." *Nämnden Skoglig Fotogrammetri*, Stockholm. Information, No. 3, 16 pp. 5 plates.
12. Waters, R. C. & Bean. J. L., 1958. "Aerial Appraisal of Damage by the Spruce Budworm." *Journal of Forestry*, Vol. 56(4) 8 pp.
13. Wear, J. F. & Dilworth, J. R., 1955. "Color photos aid salvage." *Lumberman*, Dec. (88–89, 132–133).
14. Wear, J. F. & Lauterbach, P. G. 1955. "Color Photographs Useful in Evaluating Mortaliity of Douglas Fir." *Proceedings, Society of American Foresters Meeting*, (169–171).

*Color and Infrared Experimental Photography for Coastal Mapping**

CHARLES THEURER,
Coast and Geodetic Survey, Washington, D.C.

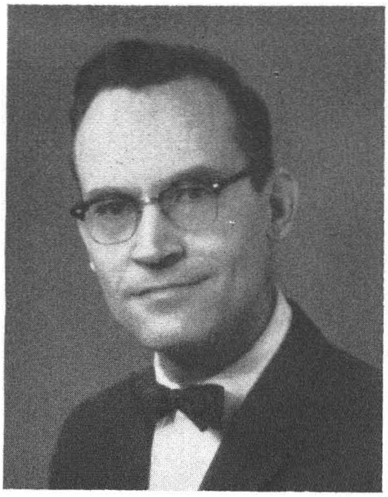
ABSTRACT: *Color, infrared and panchromatic aerial photography of shoal areas have been obtained for comparative studies for applications to coastal mapping. The general idea was originally to continue to use conventional panchromatic photographs for mapping, and also to use the other types in an auxiliary interpretative manner in order to assist the identification of the waterline and significant navigational features. One possible application of color photography is for determining relative depths, not replacing the hydrographic survey, but isolating shallow areas which may require a dense hydrographic study, and assisting in the planning of wire-drag operations. Special devices and techniques are discussed, including the problem of obtaining aerial photographs at a specific stage of the tide, and the possible adaptation of stereoscopic instruments.*

INTRODUCTION

THE nautical chart comprises one of the principal products of the Coast and Geodetic Survey. Published at scales ranging from 1:5,000 to 1:80,000, this chart shows several items which are particularly significant in this discussion, namely: (1) the shoreline; (2) the specific latitude-longitude location of each printed depth or sounding; (3) the depths of the water at each location; and (4) the implication that the bottom has a constant slope between adjacent sounding figures. Mapping topographic features near the shore, although an important item of the chart from the standpoint of photogrammetry, is not included in this discussion.

I will describe briefly how these chart data are ordinarily and currently obtained in order

* Presented at the Society's Annual Meeting, Hotel Shoreham, Washington, D.C. March 8 to 11, 1959.



CHARLES THEURER

to indicate their relative economical importance. Obviously, ships and boats of various sizes and kinds are needed to carry the instruments and men required for measuring the depths and determining the positions. A complete hydrographic survey of an area may include (1):

(a) a systematic coverage of the area with depth measurements to assure that all dangers to navigation have been found;
(b) a development of all underwater features of significance to navigators, such as channels, reefs, banks, shoals, and the determination of the least depths on all dangers to navigation;
(c) the *locations* of the soundings, dangers, and submarine features so that they can be charted correctly; and
(d) contemporary tide observations as reference data for soundings.

Three types of surveys may be utilized in this work: shoreline surveys, depth measurements, and wire-drag operations.

A shoreline survey (2) is needed to map the position of the meandering high-water line, and to locate rocks awash and navigational features near shore. The work is based on aerial photography in addition to walking or sailing the entire shoreline. The photogrammetric work nowadays also determines the positions of the signal locations which are used later for the sextant fixes to determine the position of the sounding launch.

The technique currently used to map the shoreline (say the high-water line) is for the field inspector to draw short lines in a few places on each photograph to denote the shoreline, as he determines it from his observations of the water level, tidal data, and measurements to identifiable objects. Afterwards the compiler connects the various places using a stereoscopic instrument. Usually a faint image of the debris line serves as a subconscious guide to the compiler, especially since electronic printing retains photographic detail in white beach areas.

The geodetic location of the shoreline is, as it has been historically, of basic importance to the services rendered by the Bureau. A chart becomes a dated record for future beach erosion studies, waterfront property litigations, and submerged lands actions. The rapid increase in the land values of waterfront properties for industrial and recreational uses emphasizes the importance of the shoreline survey.

Depth measurements are made from a ship or a launch by means of a continuous, recording echo sounding apparatus while the vessel travels along a designated set of parallel lines. When working close inshore, the position of the vessel is determined by means of three-point fixes obtained frequently from pairs of sextant observations on different pairs of shore signals whose positions are already known, and using a graphic solution which employs a three-arm protractor. Shoran and other electronic distance measuring techniques are ordinarily used as soon as the surveys progress far enough offshore so that the shoran stations established ashore can be used over fairly large areas.

A wire drag consisting of one-eighth-inch cable 3,000 to 24,000 feet long, supported at prescribed depths by buoys and counter weights, is drawn by two ships to supplement depth surveys for the purpose of discovering all obstructions of small extent, such as pinnacle rocks, boulders, sharp ledges, and coral formations. The wire drag method (1) assures that apparently clear water areas are indeed free from obstructions, (2) finds all the obstructions, and (3) develops a maximum safe depth in a channel.

EXPERIMENTATION

Recently the Coast and Geodetic Survey began to experiment with infrared and with color aerial photography for the purpose of assisting still further in hydrographic operations. These efforts comprise the subject of this paper.

Applications of photogrammetric surveys of shoreline and for signal position determination have already been mentioned—they are also discussed by Jones (3). Aerial photographs are commonly used for making revisions on nautical charts as described by

Brooks (4). In 1956 infrared photographs were used productively for the first time in the Bureau to map a *low*-water line, which was also reported by Jones (5). Since then, infrared photography has been procured as a routine action wherever possible to assist in delineating the shoreline.

More recently an investigation of a more elaborate nature was undertaken under the general direction of Captain L. W. Swanson and under the technical surveillance of Mr. William D. Harris. Simultaneous photography was obtained in several areas: Bar Harbor, Maine; Atchafalaya Bay and Mississippi Delta, Louisiana; Key West, Florida; and Puerto Rico. In one instance three cameras were operated simultaneously in the same airplane, using panchromatic, infrared and color films. Three types of color film were exposed in an effort to determine the most appropriate one.

Color and infrared photography were obtained using Wild Aviogon and Infragon cameras, and the panchromatic test was made with the Bureau's super-wide-angle nine-lens camera. The infragon camera contains the red filter, and commercially available infrared aerial film was utilized. For the color photographs, a Kodak A-1 gelatin filter was sandwiched between two pieces of white plate glass—the absence of the Wild variable density neutral filter was noticeable but not particularly damaging. The normal infrared exposure was f/11 at 1/250 second, and the color was f/5.6 at 1/300 second when the panchromatic exposure was f/13 at 1/100 second. The altitude was 6,875 feet for the panchromatic and 5,000 feet for the infrared and color films. All the film was processed in the Bureau's laboratories.

GENERAL REMARKS ABOUT COLOR AND INFRARED

It is significant that infrared and color films are opposite in the sense of water penetration: infrared results in a minimum penetration, whereas the color has a maximum, normally even greater than panchromatic. The infrared, which has a reported penetration of only about 3 inches in clear water, shows a definite line of demarcation between black water areas and the white sand beach. The color film however does not indicate the water-land junction vividly, but instead shows the water to be gradually deeper by means of a darker blue color.

Neither the color nor the infrared photography seem to comprise an independent form of mapping photography: both depend on aerotriangulation using panchromatic film (or ground surveys) for position determination. The infrared photography lacks contrast in the terrain areas which interferes with the identification of control, pass-points, the interpretation of terrain features needed for topographic mapping. Color photography cannot be used well in a quantitative way at the present state of development, because of instrumentation problems, illumination of the transparencies, and the preparation of diapositives.

Direct color transparencies have a considerably greater density-difference range on the same photograph than is ordinarily used in panchromatic diapositives prepared for such instruments as the Kelsh plotter. The log-density range is about 2 for color and about 0.8 for diapositives, which corresponds to a linear ratio of about 15:1. The exposure and development characteristics of the direct color process do not allow this characteristic to be adjusted very much (although the negative color process does have considerably greater latitude). We believe, however, that we may prefer this large density range because it seems to benefit the water-depth penetration characteristic. But this large density difference places an illumination problem on any device used to study or measure these photographs, mainly because the devices were not designed for this kind of use. (It might be mentioned in this connection that some stereoscopic plotters using the usual black-and-white photography also might well benefit from a more powerful source of illumination.)

Lest some are unaware of the fact, I will mention here that ordinarily no water-surface image is created in a stereoscopic model from aerial photographs. The reason is that white caps or foam, the only features which are visible on the surface of the water, are not sufficiently stationary to appear in two successive aerial photographs.

INFRARED PHOTOGRAPHY

The primary reason for our use of infrared photography is for shoreline demarcation. Consequently, the aerial photographs need to be taken at the time when the tide is at the wanted level, presenting a three-parameter problem—weather, sunlight, and tide. As an unusual example, extreme high tides occur during photographic hours only about three days each month in the Cobscook Bay, Maine, area. The photographs should be taken within a few minutes of the specified time, the flexibility depending on the range of the tide and the accuracy specified. Moreover, it may be necessary to have someone on the ground to observe the tide and to advise the photographer, rather than depend on predicted values which may be influenced by local winds. In the Cobscook Bay area (5) the flight strips were planned in a way which coordinated the photography with the inward advance of the stage of the tide whence all of the nine strips were photographed within 10 minutes of their specified times.

Calm water is ideal for infrared whereas turbulent water along rocky shores is not a good photographic subject for any kind of film. Infrared may be only of limited assistance on precipitous shoreline whereas it may be invaluable for gentle beach areas such as the Gulf Coast.

COLOR PHOTOGRAPHY

We are pleasantly surprised by the maximum measurable depth penetration of 60 feet obtained in coral formations by color photography in Puerto Rico. The depths and bottom contours are verified by both older hydrographic surveys and several photogrammetric instruments, utilizing corrections for the effects of water refraction. Stereoscopic instrument operators can draw contour lines of bottom terrain with no difficulty, but obviously not as accurately as on land. Bottom relief is vivid in the stereoscopic model, and the features may be mapped with considerably greater detail than is possible from echo sounding techniques.

The original color transparency film seems to be the only type appropriate for the present applications. Negative color film was also tested, but the inconvenience of the printing operation offset any advantages which might have been gained through its flexibility, especially as no color prints were needed and the exposure of the original color positive film was not difficult to control. Also, faithful color rendition is not important in this sort of work. If, however, color prints are required, the negative color system seems to have definite advantages.

Our experience with sun spots may be interesting. Ordinarily they have no significance in topographic mapping although they have been mentioned from time to time, but in taking photographs over water, a reflection of the sun must be expected in every photograph. The bright spot obliterates nearly all detail in a relatively large area whose size is influenced by the roughness or glassiness of the water surface. On the recent color test photography the sun spot varied from $1\frac{1}{2}$ inches in diameter to essentially one-fourth of the photograph. The time of photography was near noon, the latitude was 18°N, and the date was November 1. Naturally no stereoscopic model is possible in the area of the sun spot, although the area may be clear in the adjacent photograph. More study is needed to determine whether taking the photographs at a different time of day will reduce the sun-spot area without seriously decreasing the depth penetration feature.

INSTRUMENTATION

A few comments are perhaps appropriate concerning plotting apparatus useful for infrared and color photography. Several ideas were tried.

Infrared photography was used for aerotriangulation with the *C*-8 stereoplanigraph. The operators objected to the inherent lack of contrast between terrain images and the resultant questionable identification of land features. Unquestionably the infrared was more difficult to work with, and accuracy suffered as a consequence of identification difficulties.

Successful measurements were obtained using color photography with a *C*-8 stereoplanigraph; however this instrument is regarded as too costly for this type of work inasmuch as the device is fully occupied by aerotriangulation problems. Moreover, its illumination system needs to be brightened four to ten times to be completely satisfactory.

The Kelsh plotter was tried. It requires considerable adaptation to be fully successful. The usual red and green anaglyphic system cannot be used. Polaroid was tried: its limitations with regard to illumination and "blind" viewing angles are considered to eliminate it from further consideration. The flicker system seems to be appropriate, but many design and manufacturing details need to be developed before it is practical, in addition to increasing the illumination.

The most satisfactory device for the color photography to date has been an adapted Zeiss stereotope. The original instrument was altered by raising the stereoscope and adding false plattens sufficiently high to admit small-tube lamps beneath the color transparencies. Problems still remain with regard to leveling the models on an insufficient number of poorly distributed control points. Nevertheless the apparatus works well and experimental contour maps of shallow ocean bottoms are continuing to be made.

For simply viewing color transparencies, any good mirror (or mirror-binocular) stereoscope set on a light table works very well.

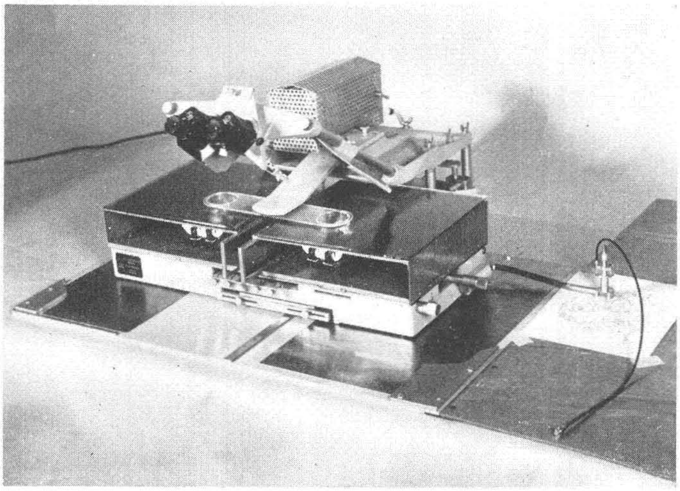


FIG. 1. Zeiss stereotope converted to accommodate transparencies.

To protect the film from damage from handling, the transparencies are often mounted between two sheets of plastic.

I wish to emphasize, however, that our investigation of appropriate instruments is far from being exhaustive, and undoubtedly some know of more and better ways for a quantitative utilization of color photography.

In all these tests, it was recognized that stereoscopic depth readings require an adjustment because of the refraction bending which the light rays undergo upon passing from water into air. The instrument readings must be multiplied by a factor which varies throughout the model area from about 1.35 to about 1.60.

CONCLUSIONS

It is evident that auxiliary color and infrared photography can be used to considerable advantage for coastline mapping and for supporting hydrographic surveys. The use of this auxiliary photography will not only reduce costs but will insure more complete and more accurate surveys.

The Cobscook Bay and other projects have shown that infrared photography applies particularly well to problems associated with the line of demarcation between land and water. It has been found practical to coordinate flight line photography with tidal data over fairly large areas.

Although we are just beginning to experiment with color photography, we are encouraged and enthusiastic about its possibilities for supporting inshore hydrography in areas of uneven bottom. Where the bottom details appear in the color photography, preliminary contours, or form lines, can be drawn to outline channels and shoals before the hydrography is started. This information will then give the hydrographer, or wire-drag party, a valuable guide as to the location of the places that need special development. This will not only save time but also tend to insure adequate development in channels and on shoals.

The possibilities are intriguing when one remembers that ordinarily the hydrographer must develop the bottom topography without ever being able to see the topography. With color photography we hope to provide him with at least a reconnaissance map of the inshore areas that he must develop. The advantages will be particularly important on rocky or coral bottoms where wire-drag operations are required. If approximate contours and depths on shoals can be furnished, the drag party will have an indication of practicable dragging depths, reducing the number of drag groundings which make this operation ordinarily very tedious and costly.

REFERENCES

1. Adams, K. T., Hydrographic Manual, Special Publication No. 143, U. S. Government Printing Office, p. 191, 1942.
2. Swanson, L. W., Topographic Manual, Special Publication No. 249, U. S. Government Printing Office, p. 519, 1949.
3. Jones, Bennett G., "Photogrammetric Surveys for Nautical Charts," PHOTOGRAMMETRIC ENGINEERING, 23: 2, 291, 1957.
4. Brooks, H. R., "Chart Revisions," PHOTOGRAMMETRIC ENGINEERING, 23: 2, 303, 1957.
5. Jones, Bennett G., "Low-Water in Cobscook Bay, Maine," PHOTOGRAMMETRIC ENGINEERING, 23: 2, 338, 1957.