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AUTOMATED DELINEATION OF WETLANDS IN PHOTOGRAPHIC REMOTE SENSING

June 1971

RESEARCH DEPARTMENT

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BETHPAGE NEW YORK

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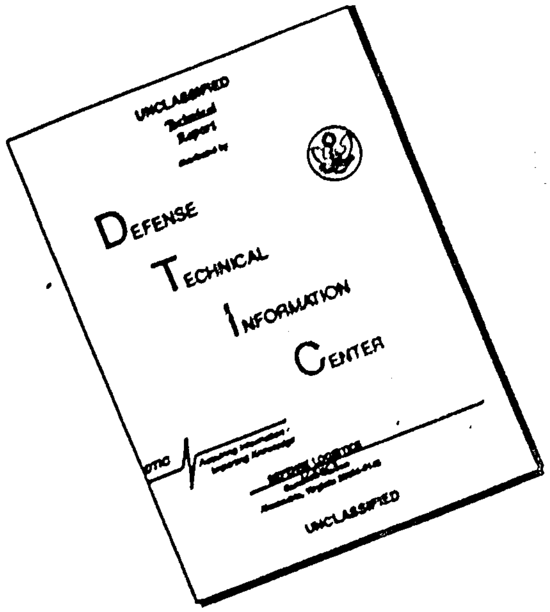

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AUTOMATED DELINEATION OF WETLANDS IN PHOTOGRAPHIC REMOTE SENSING[†]

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ABSTRACT

Precision automated photometric mapping of wetlands in Calvert County, Maryland has been achieved in an operational system as the result of a program including aerial color film (both true color and false color infrared) calibration and control. Although the system was operated over this area, it may be adapted to other areas. The recognition appears to be most accurately achieved by microdensitometric analysis of the true color transparency in a narrow band centered in the red (0.633 μm), on 3000-foot altitude imagery. A computer generated map is obtained.

INTRODUCTION

Wetlands are land-water edge areas that exist in every state of the United States as well as all areas of the world. These areas are characterized by unique plant communities as a result of temporary, cyclic, or permanent submersion by rain, tides, or storms. Wetlands may be known locally as a salt marsh, tidal marsh, marshland, tideland, submerged land, swamp, swampland, gut, slough, pothole, bog, mud flats, wet meadow, overflow land or flood plain. Such areas have evolved over a period of many years, and once disturbed or destroyed cannot be replaced by engineering. They are of supreme importance for aquatic flora and fauna, in that many essential nutrients have their origin in wetlands. Further, many aquatic fauna, during certain stages of their life cycles, spend time in wetland areas for reproduction purposes.

Due to their worldwide distribution and ecological importance, a current need exists for the detailed mapping of wetlands. This need has been further emphasized by studies (see, for instance, Refs. 1, 2), and by wetland preservation laws enacted by various states, notably Maryland and New Jersey. The true impact of alterations of these areas by dredging and fill, bulkheading, and establishment of recreational sites cannot be adequately assessed without a basic inventory as regards spatial distribution, primary production, and their role in the marine food webs.

Physical mapping by ground surveys is slow, expensive, and at times practically impossible because of the physical topography of wetlands. Thus, a very practical solution to the problem of the mapping of wetlands is the use of remote sensing. Aerial photography, as a remote sensing technique, allows large scale, rapid mapping, provides a baseline for comparison with future development, and, since several surveys can be completed in one year, allows time-dependent phenomena to be assessed.

In response to the widespread need for wetland mapping, and with a desire to standardize techniques in such a way that the analysis of the remote sensing data may be automated, the Research Department of the Grumman Aerospace Corporation and the Adelphi Institute of Marine Sciences (AIMS) have initiated an optical remote sensing program on selected wetland areas on Long Island (Ref. 3). Also, in collaboration with Grumman Ēcosystems Corporation and the State of Maryland, a test site in Calvert County (Md.) has been the object of a detailed multi-altitude operational aerial photographic survey, with simultaneous acquisition of ground truth, followed by a computer-oriented data analysis.

In contrast to present photographic remote sensing, whereby visually observed color contrasts on transparencies or prints are cues to physiological stress or disease, our approach involves detailed color calibration and control procedures on the imagery obtained with true color and false color Ektachrome films, with evaluation by microdensitometry. We have described our calibration procedures previously (Ref. 4) and have applied the techniques to the aerial photography of the Long Island (Ref. 3) and Maryland wetlands. Both programs involved the use of true color and false color infrared imagery.

The preliminary results of the use of calibrated high speed Ektachrome and type 8443 false color infrared Ektachrome on a wetland island in Great South Bay, Long Island were presented in Ref. 3. The original aerial imagery for that paper was obtained at an altitude of 8000 feet using synchronized Rolleiflex cameras with 75 mm focal length lenses; subsequently, imagery of the same island was obtained at 3000 and 1000 foot altitudes to compare information content in the color representation.

The lower altitude imagery contains much more information, but covers a correspondingly smaller ground area. In essence, a trade off is involved between information requirements for wetland mapping versus the higher cost of low altitude imagery. It appeared, from the preliminary analyses, that automated delineation of ground cover species was possible when carefully calibrated positive transparencies are used (Ref. 3).

SURVEY AREA

The area covered by aerial photography for this paper was along the Patuxent River in Maryland, between Hunting Creek on the south and Chew Creek on the north (Fig. 1). The Patuxent River is an estuary area that is amenable to remote sensing from aircraft and satellites (Ref. 5). The area is undeveloped industrially and is mainly farmland, interspersed with wetlands and forested areas. The Chalk Point power plant is located south of the survey area, with the condenser outfall near the south boundary of the survey area.

APPROACH

Imagery of the area (Fig. 1) was obtained by a Grumman Ēcosystems Corporation Gulfstream I aircraft on 25 September 1970. The entire area was covered at 3000, 6000, 9000, and 12000 feet using Wild RC-8 cameras and Kodak Aero Neg Type 2445 and Kodak false color infrared Ektachrome, Type 2443 film. All imagery was obtained with 60 percent forward overlap for stereo pairs. The camera lenses were 6-inch f/5.6 Universal Aviogons with +1.4 anti-vignetting filters, combined with a minus blue filter for the camera containing the Type 2443 film.

A ground survey team visited the test site from 24 September to 27 September 1970. This team, consisting of an ecologist, a botanist, an aquatic microbiologist, and an engineer with forestry and photo interpretation experience, visited each marsh area along the eastern shore of the river. Specific areas for study were initially located using standard USGS quadrant maps: Benedict, Md. SW/4 Prince Frederick 15' Quadrangle, and Lower Marlboro, Md. NW/4 Prince Frederick 15' Quadrangle. Each site was visited by land and notes were made of the general utilization and development of the wetlands and surrounding areas. Due to inaccessibility of some areas, and land-owner restrictions, these areas were also visited by boat, and each creek followed to its farthest upstream navigable point.

In each marsh area, field notes were made of the dominant marsh vegetation and a photographic record kept of each representative habitat type. Representative examples of each dominant species were taken for later checks on identification (Ref. 6). In addition to vegetative analysis, temperature and salinity records were kept for intervals along the creeks and for the river proper.

Where topography allowed, white plastic strips (18 inches wide) were stretched across certain areas showing marked vegetative zonation or relatively homogeneous stands of a dominant species. These plastic strips were also used to denote the mean high water line along the shore at Deep Landing at the time the imagery was obtained.

Of all areas visited, only Chew Creek, Cocktown Creek, Deep Landing, Little Lyons Creek, and Hunting Creek showed significant marsh development. All areas were within the range of tidal influence as shown by their salinity values. Anderson, et al. (Ref. 7) showed the salt front to extend at least 13 miles north of Benedict.

Dominant marsh vegetation in all areas consisted of *Spartina alterniflora* as a narrow band along the intertidal shore; *Spartina cynosuroides* on the dryer areas bordering creek beds; *Typha angustifolia* as a band in the center of the marsh proper; *Peltandra virginica* and *Pontederia cordata* as narrow bands along the upper fresher reaches of creek borders. Mosaics of these species occurred in each area depending on local topography and distance from the main creek channels. *Scirpus americanus* and *Iva frutescens* were also found as mixtures with *Sp. cynosuroides* and *Typha sp*. Ground surveys of the marsh proper are almost impossible in all cases, owing to the unconsolidated hummocks and soft muck subsurface.

The river border is characterized by sharply sloping bluffs dominated by *Quercus* species (*Quercus ilicifolia*, *Quercus rubra*, *Quercus velutina*, and *Quercus stellata*) in almost all areas except where creeks empty into the river.

Calibration was accomplished with seven 6-foot-square panel arrays located at Deep Landing. For ease of transport, each 6-foot-square array was made up of four anodized aluminum panels painted with 3-M Company "Nextel" Brand Velvet Coating 110 Series. The gray shades were obtained by combining appropriate parts of white 110-A-10 with black 110-C-10. Red 110-D-4, green 110-G-10, and blue 110-H-10 were used undiluted.

The spectral reflectances of the paints, on the anodized aluminum surfaces, were measured on a large scale laboratory photometer in the wavelength range between 0.400 μm and 1.0 μm (Ref. 8). The geometry was that for an incident sun angle 50 degrees above the horizon (that existed during the aerial survey), at a phase angle of 3 degrees, and the results are plotted in Fig. 2 (the phase angle is the angle between the incident and scattered rays). The red is more saturated than the blue and green, and all three colors have appreciable infrared reflectance, with the red being the strongest. The white and three gray shades vary somewhat in constancy of reflectance as a function of wavelength.

The flatness (nonspecularity) of the paints was also measured for the seven painted panels at 0.433, 0.533, 0.633, and 0.8 μm (corresponding to emulsion sensitivity peaks), and a typical set of photometric curves for the white panel are shown in Fig. 3. As the phase angle becomes smaller, there is a distinct increase in backscatter.

These spectral reflectance and photometric curves are used to calculate the relative brightness of the test panels when placed on the ground and photographed in the course of the aerial survey

IMAGERY ANALYSIS

The aerial photography produced 350 9- x 9-inch photographs, half being true color and the other half being false color Ektachrome. Of these, 188 were at 3000-foot altitude. At the onset of the program, it was not clearly evident that recognition of wetlands could be accomplished with a computer-oriented approach. To check the validity of an automated delineation of wetlands from photographic imagery, a manual photographic analysis was made concurrently (Ref. 9).

Photo interpretation was performed on 9- x 9-inch prints of stereo pairs of both color and color IR imagery. Sets of prints from each altitude were examined for gross topographic and vegetative features. To prevent duplication, acetate overlays were made only on those frames covering the east shore of the river from the mouth of Hunting Creek to the northern-end of the Chew Creek marsh, and by eliminating stereo coverage. However, each area was examined in stereo.

Changes in the degree and frequency of submergence either by stream flow or tides are characterized by variations in the dominant species composition within these areas. Vegetative patterns were delineated on each overlay and correlated with "ground truth" observations and measurements of temperature and salinity. A dark line was used to delineate the maximum upland border of the designated marsh areas. Where no marsh vegetation was apparent, this line was drawn along the shore to indicate that there is an intertidal zone present but its extent is not visible in the imagery.

In each marsh area, certain features were noted for each frame and altitude. The upland-marsh border was delineated mainly on the existence of terrestrial tree species. In most cases, this was rather simple due to the abrupt rise in topography along the river and the resulting sharply defined tree line. However, in those areas where the topography showed only slight slopes toward the upland, pioneer tree species could often be found invading the marsh. In these cases, this area was included as part of the marsh but shown as "PIONEER" on the overlays.

Each overlay included the river-marsh shore, the upland forest border, farm or field, watercourse delineation, and gross vegetative patterns of marsh species. Letters were used on the overlays to denote certain recurring features. Gross vegetative patterns were delineated based on variations in color contrast and height as determined by stereo inspection.

Not all features were marked in each area, to avoid needless duplication. Gross vegetative patterns, marsh, upland, and river borders were marked on all 3000-foot imagery.

The imagery at 3000 feet was analyzed and overlaid first, and this may be a cause for subjective bias as to presence or absence of some feature in the later six, nine, and twelve thousand foot imagery. However, since this altitude gave the most complete coverage and best resolution, it was thought that it would be better to start with 3000 feet first for identification and correlation purposes.

The automated analysis of the imagery is accomplished by the procedure indicated in Fig. 4. The 9- x 9-inch positive transparencies, either true color or false color infrared, are density scanned automatically at three wavelengths (0.433, 0.533, and 0.633 μm), corresponding to peaks in the transmissions of the three emulsions. The parameters of the scan, such as lines per film frame, scanning aperture size, scanning speed, and optimum wavelength must be determined for the particular image under analysis. The output of the density scans are fed to a mini-computer programmed with appropriate recognition criteria. The recognition criteria are based on the film sensitometry and the spectrophotometric functions of the surfaces being photographed. If the recognition criteria are simple, and one color densitometry is adequate, a map overlay printout is obtained from the mini-computer directly. If correlation between colors and/or thermal data are necessary for recognition, the facilities of a larger computer, such as a time-shared IBM 360/67, are necessary. The time-sharing feature is essential because of the variability of the spectrophotometric properties of a biological environment and the necessity of making minor program corrections during a computer run.

A refinement of the recognition technique may be included, whereby optical data processing can be used in certain instances for recognition of regularly recurring features, such as crop furrows.

RESULTS

To illustrate the application of an automated delineation of wetlands, a representative 3000-foot altitude frame (Fig. 5, Frame No. 5592) will be used to illustrate both manual and automated analysis. The manual analysis was made on a true color print obtained from the Aero Neg Type 2445 format, and the automated analysis performed on a true color transparency.

The manually produced overlay of Fig. 6 delineates the wetlands at the area of Little Lyons Creek and Hunting Creek. The code for the notations in the figure is listed in Table 1.

TABLE I. LETTER CODES FOR OVERLAYS

BW	Back wash patter in river
CB	Creek bed in uplands
D	Discontinuity in river of stream flow patterns
DP	Drainage pattern in marsh or upland
F	Farm or field
GY	Gray area on marsh
G	Green area on marsh
GB	Green-brown area on marsh
LB	Light-brown area on marsh
OF	Old field
OSB	Old stream bed
PA	Path
P	Pond
S1 through S11	Station number for ground site
SG	Sun glitter
UF	Upland forest

To produce an equivalent computer overlay, the red emulsion on the true color transparency was selected. This selection was based on the calibration curve for the true color transparencies resulting from the photometric properties of the test panels (Fig. 7). It is to be noted that the test panel reflectances must be corrected for their location in the field of view of the camera; the over-all transfer function of the camera is a strong function of the location in the plane of the negative and not completely compensated by the anti-vignetting filter (Ref. 10).

By referring to Fig. 7, it is observed that the blue ($\lambda = 0.433$ μm) emulsion density does not increase as the standard panels decrease in reflectance because atmospheric scattering produces a residual brightness level. The red emulsion is unaffected by atmospheric scattering and shows a high contrast for green tree foliage. This is also verified by measurements of the density ranges obtained on the true color transparencies.

The false color infrared transparencies were not used because the infrared emulsion was less differentiated between wetlands and forest areas surrounding the wetlands. The infrared emulsion normally would have had the highest contrast of the three emulsions on false color infrared film (see Fig. 8, and include atmospheric scattering effects).

A typical microdensitometer scan, based on a 200 line raster for the 9-inch format, is shown in Fig. 9. The size and shape of the scanning aperture crucially affects the scan results. A 1-mm-square effective aperture size was optimum for the present analysis, but circular or rectangular apertures with dimensions on the order of microns can be more suitable for data analysis in other instances. The smaller apertures concurrently produce more information. The scan raster starts with line number 1 at the lower left (southwest) corner of Fig. 5, and ends with line number 200 at the upper right (northeast) corner of Fig. 5. Farmlands, trees, wetlands, and the Patuxent River are designated in the margin. It is seen that tree regions are darker as a result of the reflectance properties of oak leaves (Ref. 8) and shadowing effects. The reflectance of black oak leaves is known to vary with phase angle (Ref. 8), and also the angle relative to the plane of incidence (plane including the normal to the ground surface and the incident sun rays). There will be some differences in scattering between oak leaf varieties, but the general properties of a shiny leaf, as exhibited by the black oak leaves, will be followed. The computer program must include these effects (Figs. 10 and 11). The minimum photometric threshold of the trees varies from the south to north of the transparency (as a function of raster scan line number) (Fig. 10), and very greatly across the raster for a particular raster scan line number (Fig. 11) because of shadowing effects and camera lens vignetting. The tree minimum photometric threshold (Fig. 10) indexes the left edge of the convergence of the tree photometric calibration lines of Fig. 11. This variable index serves as the discrimination threshold to delineate the trees, and the photometric function (Fig. 11) varies with raster trace number. The wetlands, however, because of the diverse nature of the vegetation, do not have a well defined photometric range. Because of the lack of shadowing, there is a negligible east-west variation. This can be seen by referring to photographs made of the wetland areas. Figure 12 in the Hunting Creek area is a typical overview of the marsh showing the sharp delineation between the *Typha spartina* communities and the upland oak forest. Note the almost uniform height of the marsh vegetation. The only shadow effects apparent are immediately adjacent to open water areas. Figure 13 illustrates the typical shoreline development along the streams in the study area. Note the almost fence-like structure of the *Spartina cynosuroides* and the uniform height of the vegetation. Figure 14 demonstrates the use of plastic strips to delineate differences in dominant species types for better photo interpretation. This strip was placed in an east-west direction in Little Lyons marsh. The sharp change in height between the *Typha sp*. on the north of the strip and *Spartina patens* and *Scirpus* on the south is easily seen.

By applying the decision criteria, a computer printed map is obtained delineating the wetlands in terms of the forest areas bounding them (Fig. 15). The areas delineated by Fig. 15 agree with those manually deduced (Fig. 6). The accuracy of location of the automated delineation is of the order of a few feet when a sharp line of demarcation exists between trees and wetland. If there is a pioneer tree area, the edge of the wetland area is less well defined.

As an alternative, the wetland density criteria may be used to obtain a printout that requires further analysis. This is accomplished through optical data processing, whereby farmlands, which may have the same reflectance range as the wetlands, are eliminated. The farmlands, which are generally plowed, then have a characteristic spatial frequency. This permits them, as well as river areas where waves exist, to be discerned automatically. Thus, the areas marked F (farm) and R (river) would be deleted from the final printout by optical data processing (Fig. 16).

An example of optical data processing is shown in Fig. 17. A rectangular aperture was used with a He-Ne laser operating at a wavelength of 0.6328 μm. The amplitude diffraction patterns (a two dimensional Fourier transform of the original transparency) are of a forested area adjoining the wetlands at Little Lyons Creek. The pattern (a) has two intersecting lines resulting from the square aperture, but also a wedge shaped decreased density area resulting from the shadowing by the trees. This coherent shadow pattern produces the wedge shaped diffraction pattern. There is a weak radial symmetry, seen better in diffraction pattern (b), which is the result of the diffraction of the images of the tree crowns.

A further benefit of the calibration program is the possibility of prediction of true ground cover color (based on three spectral bands) using the imagery and the calibration curves. This technique may be applied to color transparencies or color prints.

As an example, calibration curves are presented in Figs. 18 and 19. These curves are obtained by reflectance measurements on sets of true color and infrared color prints made from the 3000-foot-altitude imagery. These curves are valid only for the set of prints produced from the imagery taken on 25 September 1970, for the existing sun angle, atmospheric scattering present, and film processing techniques. A set of curves such as these would result from a specific aerial survey when calibration panels are used.

The curves of Figs. 18 and 19 are applied by measuring the diffuse print reflectance (either true color or false color infrared) for a particular ground object of interest at wavelengths of 0.433, 0.533, and 0.633 μm. The values measured correspond to an equivalent narrow band reflectance of an equivalent test panel on the ground, being the same wavelengths for true color imagery (Fig. 18) or shifted in wavelength for false color imagery (Fig. 19). The equivalent narrow band reflectances are read from the appropriate curves for the wavelength of interest and film used.

As a result of the analysis of imagery produced at 6000, 9000, and 12000 feet in comparison to the 3000-foot imagery, it is found that the system color degradation measured on the ground test panels increased with altitude, and was minimal to 6000 feet on true color prints and to 9000 feet on false color infrared transparencies. Color consistency across the frame was generally within 0.1 D for the true color negatives and within 0.4 D for the false color infrared transparencies, and differed for each emulsion. With altitude increase, the false color infrared transparencies become greener, apparently the result of atmospheric scattered light.

CONCLUSION

Objective information may be obtained from automated computer analysis to delimit the boundaries of wetlands. Using information so obtained, monitoring and enforcement may be implemented rapidly and currently, estimates of primary biological production may be made, and their role in the marine ecosystem may be assessed. Accuracies of the order of a few feet in delineation are possible in surveys made at an altitude of 3000 feet.

In the future, we expect to improve the quality of automated delineation using correlation techniques and optical data processing, resulting in recognition of species within a wetland area.

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FIGURE 1. SURVEY SITE, SHOWING GROUND TRUTHING AREAS AND FLIGHT COVERAGE

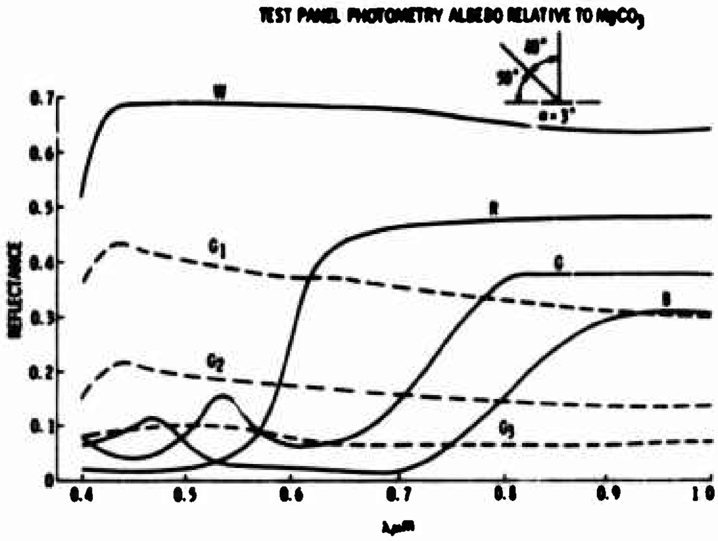


FIGURE 2. SPECTRAL REFLECTANCE (RELATIVE TO $MgCO_3$) OF TEST PANELS AT AN INCIDENT ILLUMINATION ANGLE OF 40°, AND A PHASE ANGLE OF 3° (W - WHITE, G_1, G_2, G_3 - GRAY SHADES, R - RED, G - GREEN, B - BLUE)

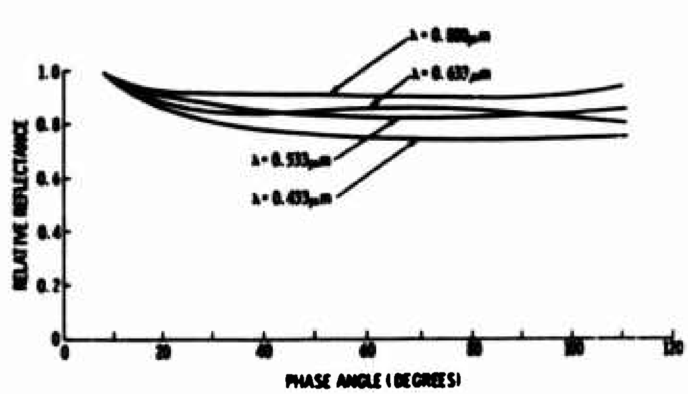


FIGURE 3. SPECTROPHOTOMETRIC PROPERTIES OF WHITE 110-A-10 AS A FUNCTION OF PHASE ANGLE AND WAVELENGTH FOR AN INCIDENT ILLUMINATION ANGLE OF 40°

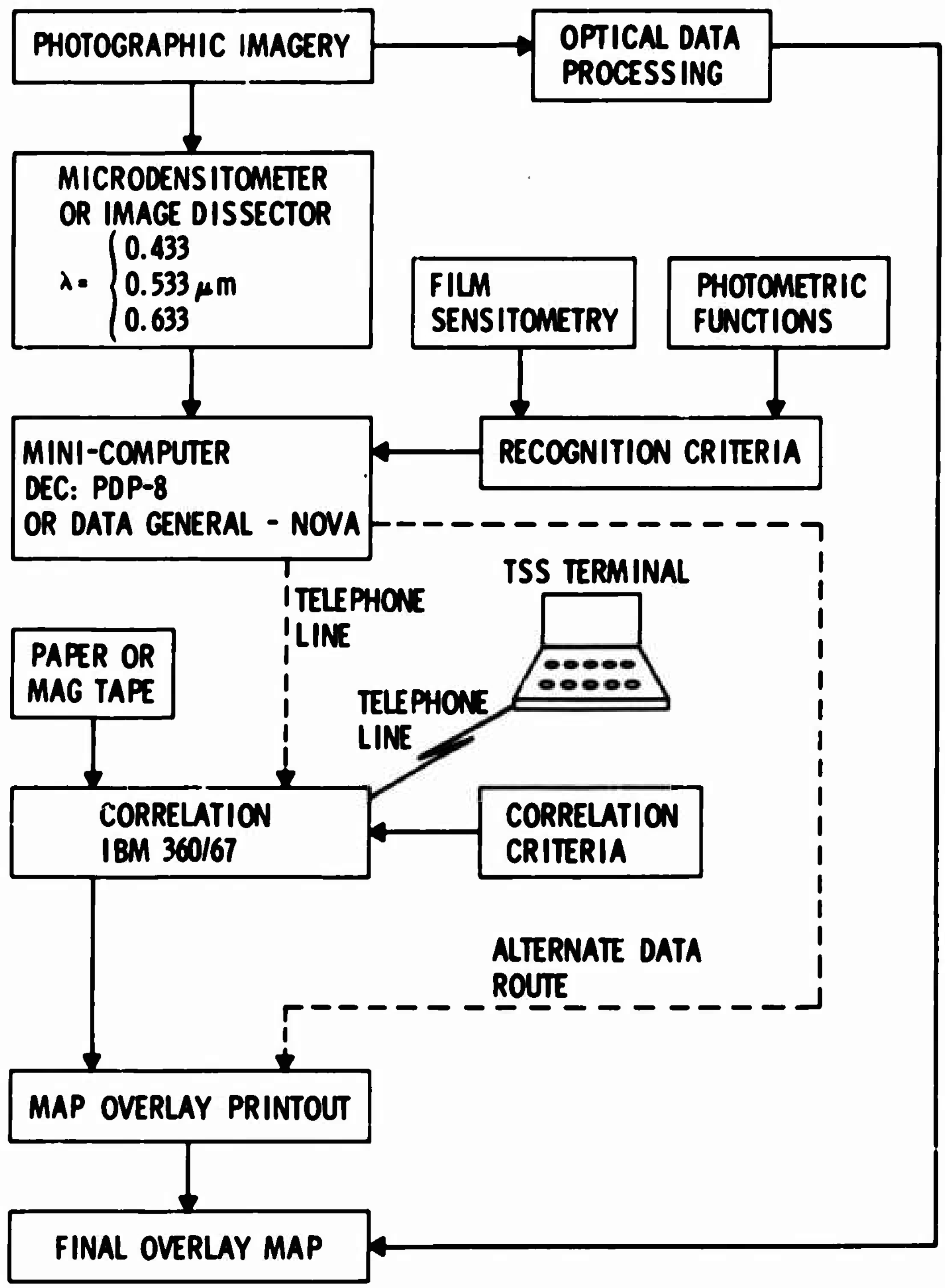


FIGURE 4. COMPUTER DATA ANALYSIS FLOW CHART

FIGURE 5. BLACK AND WHITE RENDITION OF TRUE COLOR TRANSPARENCY (FRAME No. 5592); LITTLE LYONS CREEK-HUNTING CREEK AREA, PATUXENT RIVER, MARYLAND

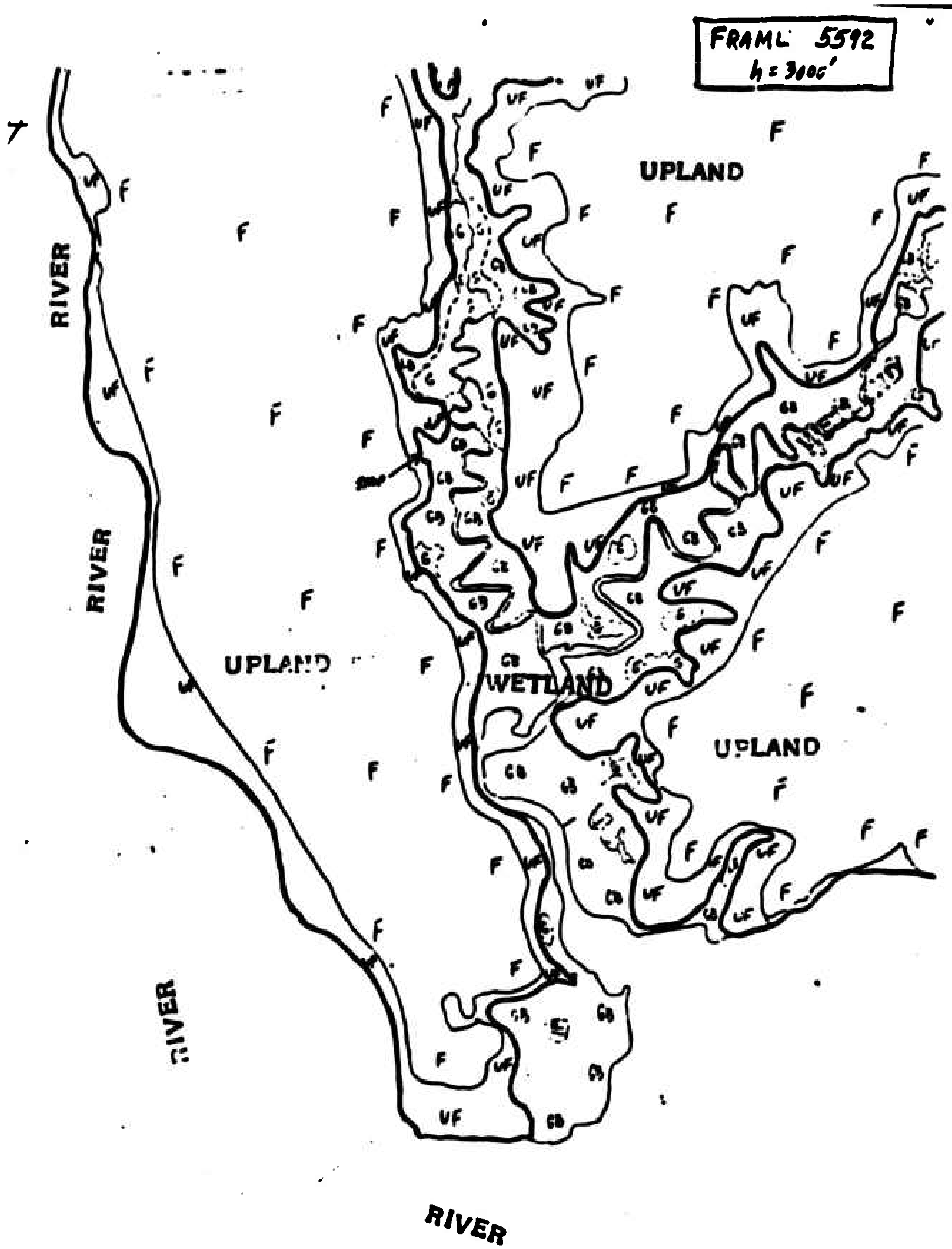


FIGURE 6. REPRODUCTION OF MANUALLY PRODUCED DELINEATION OF WETLAND AREAS FOR FRAME NO. 5592 (FIG. 5); SEE TABLE 1 FOR CODING OF OVERLAY

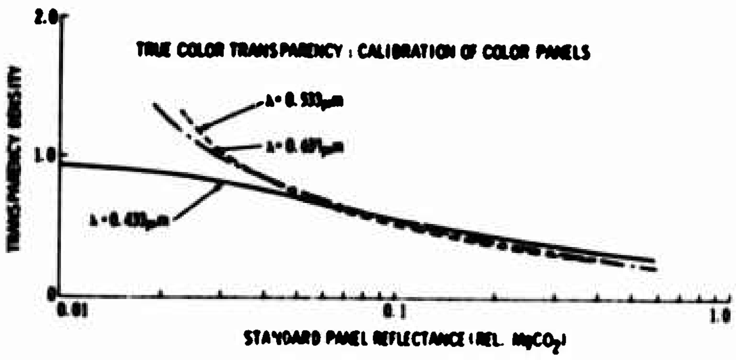


FIGURE 7. COLOR TEST PANEL CALIBRATION ON TRUE COLOR TRANSPARENCIES

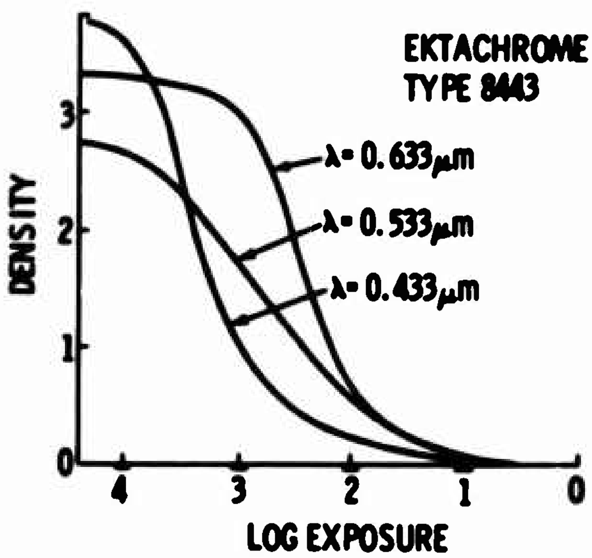


FIGURE 8. INTEGRAL DENSITY CURVES FOR TYPE 8443 INFRARED EKTACHROME FILM OBTAINED ON JOYCE LOEBL MICRODENSITOMETER (FROM REF. 4)

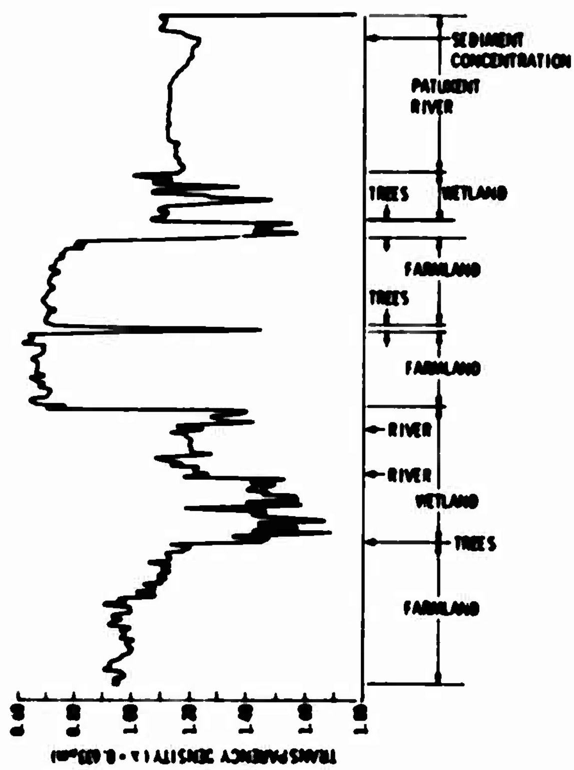


FIGURE 9. MICRODENSITOMETER SCAN OF RASTER LINE NO. 80 SHOWING GROUND TRUTH RESULTS

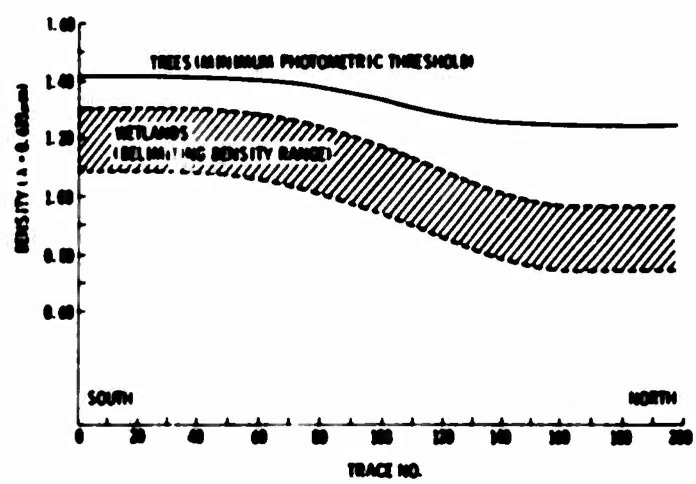


FIGURE 10. NORTH-SOUTH PHOTOMETRIC FUNCTION OF TREE AND WETLAND AREAS

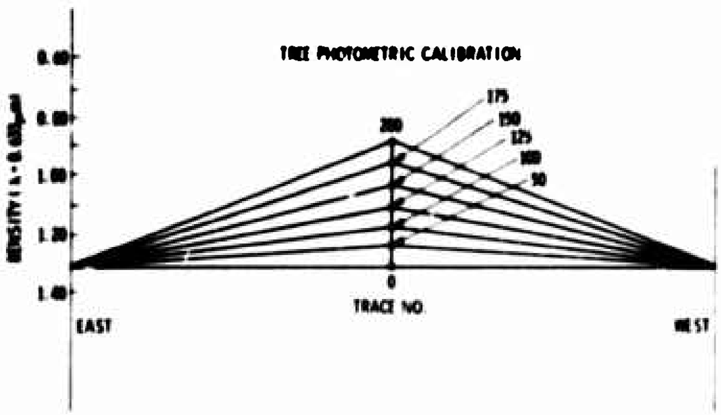


FIGURE 11. EAST-WEST PHOTOMETRIC FUNCTION OF TREE AREAS

FIGURE 12. HUNTING CREEK MARSH: TYPICAL OVERVIEW OF MARSH AND UPLAND

FIGURE 13. TYPICAL SHORELINE DEVELOPMENT ALONG TIDAL CREEKS

FIGURE 14. PLASTIC GROUND STRIP USED TO DELINEATE DIFFERENCES IN DOMINANT FLORAL COMMUNITIES

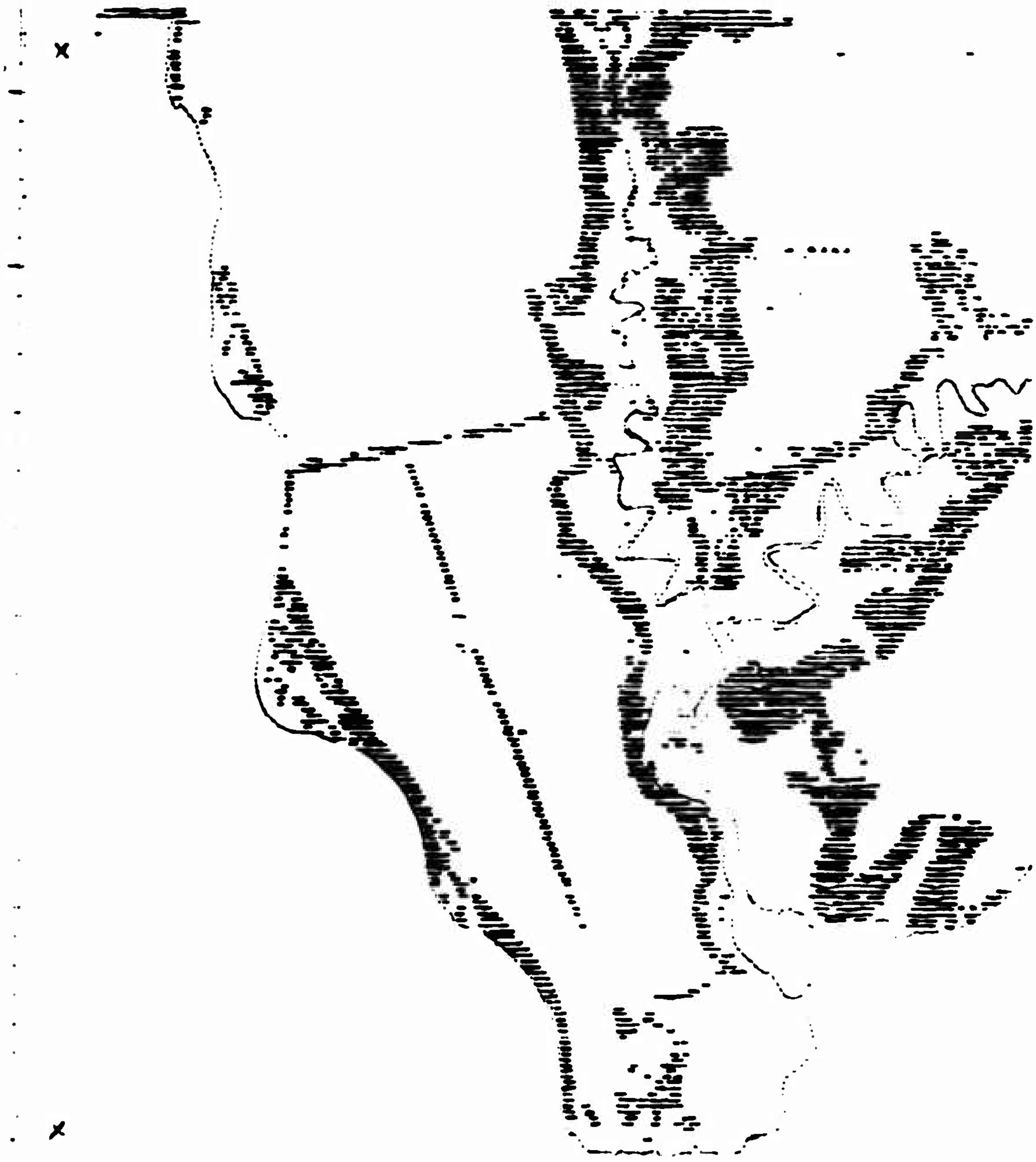
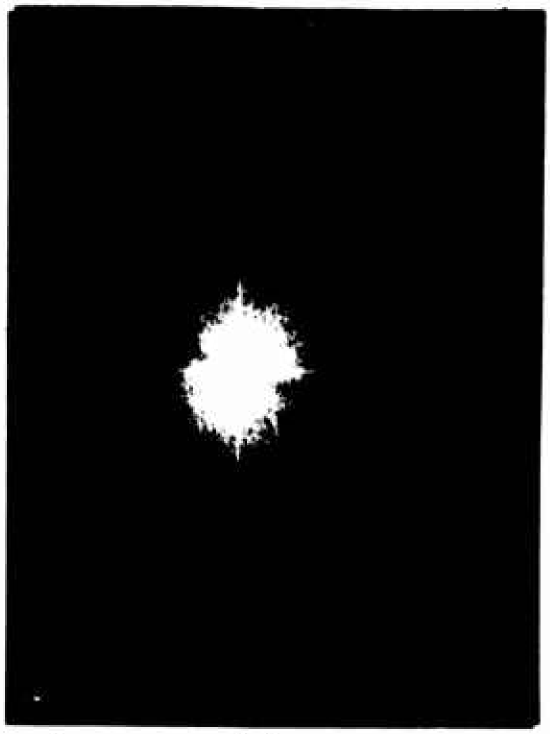
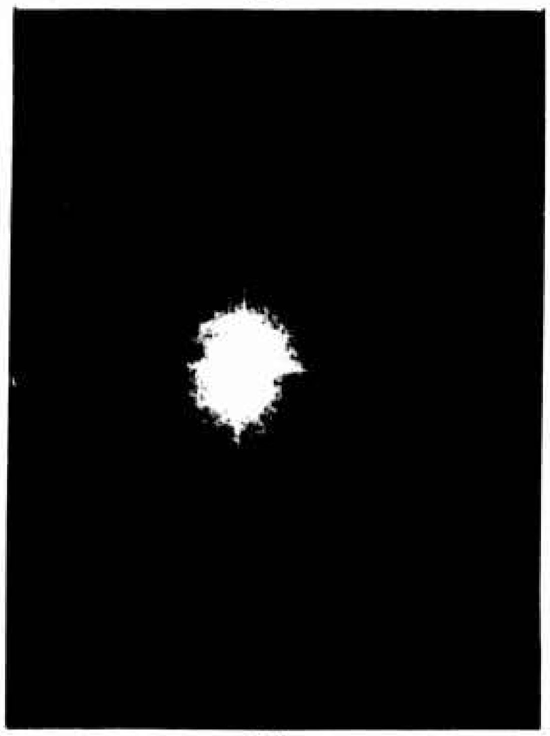


FIGURE 15. COMPUTER PRINTOUT OF TREE BOUNDARIES OF WETLANDS (SIMULATED)

FIGURE 16. COMPUTER PRINTOUT OF WETLAND AREAS; ERRONEOUSLY DESIGNATED AREAS (R - RIVER, F - FARMLAND) ARE INDICATED, AND WOULD BE DELETED BY OPTICAL IMAGE PROCESSING (SIMULATED)



(a)



(b)

FIGURE 17. TWO DIMENSIONAL FOURIER TRANSFORMS OF FORESTED AREA ADJOINING WETLANDS AT LYONS CREEK:
(a) TREE SHADOW EFFECTS (b) TREE CROWN SYMMETRY EFFECTS

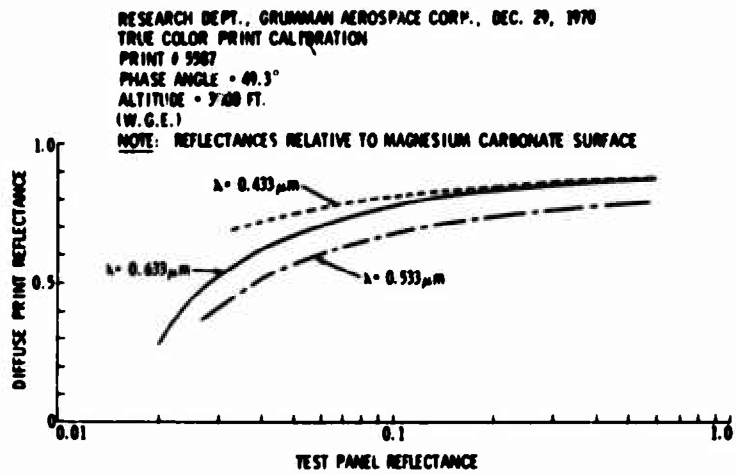


FIGURE 18. TRUE COLOR PRINT CALIBRATION

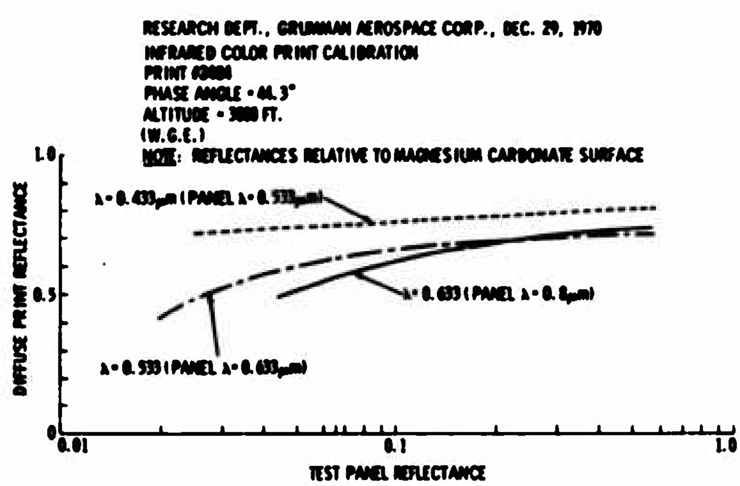


FIGURE 19. INFRARED COLOR PRINT CALIBRATION