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Photointerpretation Guide for Forest Resource Inventories

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16. Abstract

The guide explains the use of small-scale photography for inventorying and assessing resources. The manual introduces high-altitude, color infrared photography to investigators familiar with conventional photointerpretation techniques. Although other film types and scales may be better suited for specific tasks in forest resource inventories, this guide emphasizes the use of 1:60,000-scale color infrared film because of the advantages for forestry investigations. A loose-leaf binder format permits updating the guide as more techniques become available.

In the guide, a brief review of aerial photography and photointerpretation precedes sections on evaluation and applications. The review sections cover the resource requirements, photographic preparation, and mensuration techniques needed to apply the methodology described in the applications sections. The statistical evaluation of aerial mapping is covered to provide the user with a methodology for evaluating accuracy, establishing confidence limits, and determining the required sample size. Applications covered in the guide include land use classification and mapping, landform analysis, timber stand mapping, and erosion detection.

COLOR ILLUSTRATIONS REPRODUCED IN BLACK AND WHITE

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Photointerpretation Guide for Forest Resource Inventories

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In cooperation with
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

PREFACE

Aerial photographs have been used as a tool in forest land management on a regular basis since the end of World War II. Certain techniques of photogrammetry and photo-interpretation have evolved to permit more efficient ways of collecting, storing, and using data related to land management decisions. One of the more recent developments has been the availability of high-quality, small-scale photography taken with true color and color infrared (IR) film from very high-flying jet aircraft. This new addition to remote sensing (a term applied to the collection of data from aircraft and orbiting sensors) has the potential of yielding additional information related to the use of natural resources. However, many of the techniques for using these high-altitude photographs are not being applied in general forest land management.

The Forestry Applications Project (FAP), a cooperative effort between the U.S. Forest Service — Southern Region (USFS/R8) and the National Aeronautics and Space Administration — Lyndon B. Johnson Space Center (NASA/JSC), is developing ways of utilizing data produced by remote sensing.

This manual is intended as a guide for using small-scale photography. The first three chapters review the fundamentals necessary in using aerial photography, and the last chapters give specific examples of the applications of aerial photography. The use of small-scale (1:60,000 to 1:120,000) color IR aerial photography is emphasized.

Forest resource inventories include the principal resources, such as timber, recreation, wildlife, and range.

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As shown in the manual, the studies completed have included primarily timber resources. Studies in progress on other forest resources will be added to the manual later. The looseleaf binding of this manual allows additions to be entered after production by FAP.

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GLOSSARY

AEI: aerial exposure index or average exposure for aerial photography. The AEI is not equivalent to film speed; it is equivalent to the reciprocal of twice the exposure index at the point on the toe of the d log e curve where slope = 0.62 . The AEI is for nominal shutter speed and aperture setting.

AGL: above ground level.

Altitude: the height above a datum level (usually mean sea level).

Attitude, photogrammetric: the angular orientation of a camera, or of the photograph taken with the camera, with respect to some external reference system. Sometimes expressed as roll (q.v.[1]), pitch (q.v.), and yaw (q.v.).

Base, film: a thin, flexible, transparent sheet coated with a light-sensitive emulsion used for photographing. All Eastman Kodak Company aerial films use a polyester base.

Base, photo: the distance between the PP (q.v.) of one photograph and the PP of the adjacent in-flight photograph in the conjugate point position on the first photograph.

Camera calibration: the determination of the calibrated focal length, the location of the PP with respect to the fiducial marks (q.v.), the point of symmetry, the resolution of the lens, the degree of flatness of the focal plane, and the lens distortion effective in the focal plane (q.v.) of the camera and referred to the particular calibrated focal length (q.v.). In a multiple-lens camera, the calibration also includes the determination of the angles between the component perspective units.

Center, photo: the center of a photograph as determined from the fiducial marks; same as the PP in a perfectly calibrated camera.

CFL: commercial forest land – photointerpretation code.

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[1]Definition included in glossary.

CFR: commercial forest research land — photointerpretation code.

Contact print: a print made from a negative or a diapositive (q.v.) in direct contact with sensitized material, either opaque paper print stock or a transparent medium.

Contrast: the difference in light intensity on a photograph between the deepest shadow and brightest highlights.

Control point: a reference point exactly located on a photograph and on the ground, used in assembling photographs for map compilation.

Coverage, photo: the ground area represented on aerial photographs or photomosaics.

CPP: conjugate principal point, the point on a photograph that corresponds to the PP of an adjacent photograph.

Datum: a reference line or plane to which the positions of other lines or planes are referred.

Defense Mapping Agency Topographic Command: formerly the U.S. Army Map Service.

Density, photo: the relative amount of silver deposited by exposure and development in a given area of a photograph.

Diapositive: a positive photographic print on a transparent material such as glass or film base; also called a positive transparency.

dP: differential parallax, the difference in the absolute stereoscopic parallax at the top and base of the object being measured.

Emulsion: a suspension of light-sensitive silver salt (usually silver chloride or silver bromide) in a colloidal medium, used to coat photographic film or paper.

FAP: Forestry Applications Project.

Fiducial marks: index or reference marks on a photograph or the margins. The marks are used to locate the center or PP of the photograph.

Filter, photographic: a selectively transparent material placed over or in the optical path of a camera lens to absorb part of the spectrum and prevent it from affecting the photographic film.

Flight line: see Line, flight.

Flight map: see Map, flight.

Focal length: the distance from the optical center of a camera or other lens to the point where the light rays converge. (Most aerial cameras are focused at infinity. The nominal focal length for aerial cameras is an equivalent focal length representing the distance along the lens axis from the rear nodal point to the plane of best average definition over the entire field used in the aerial camera.)

Focal plane, camera: the plane (perpendicular to the axis of the lens) in which images of points in the object field of the lens are focused.

HATS: Houston Area Test Site.

Hot spot: no shadow point, an elliptical area of high solar reflectivity which appears on vertical aerial photographs at the antisolar point, or 180° from the direction of the Sun.

IMC: image-motion compensator, a device installed with certain aerial cameras to compensate for the forward motion of an aircraft in the process of photographing ground objects. True image motion compensation must be introduced after the camera is oriented to the flight track of the aircraft and fully stabilized.

Index, photo: an index map showing photographic coverage, made by arranging the individual photographs in their relative positions and photographing the montage at a reduced scale, or by plotting photoframe coverage areas on a map or map overlay.

Intervalometer: a timing device that operates a camera shutter at predetermined intervals.

IR: infrared portion of the electromagnetic spectrum with wavelengths longer than light but shorter than radar. The IR wavelengths are 700 to 30,000 nm (q.v.), or 0.7 to 30 micrometers, long. The reflected IR energy of 700 to

900 nm (0.7 to 0.9 picomicrons) can be recorded on IR film. The emitted or thermal portion of the IR spectral range is not recorded on aerial photographic film.

JSC: Lyndon B. Johnson Space Center, NASA (q.v.).

Line, flight: a line drawn on a map to indicate the flight-path of an aircraft. In vertical aerial photography it is the line connecting the PP's of successive frames.

Map, flight: a map that indicates desired or actual aerial photographic flight lines.

Matte print: a photographic print made on paper with a dull finish.

μm: micrometer, a unit of length in the metric system; the thousandth part of a millimeter; previously known as micron (μ).

Mosaic: a montage of overlapping aerial photographs whose edges have been matched to form a continuous photographic image of a part of the Earth's surface.

Mosaic, controlled: a mosaic constructed by using ground control points, in which prints are used that have been rectified and ratioed on the basis of the control points.

Mosaic, semicontrolled: a mosaic constructed by using a basis of orientation other than ground control, using corrected or uncorrected prints.

Mosaic, uncontrolled: a mosaic composed of uncorrected prints assembled without ground control or other orientation.

NASA: National Aeronautics and Space Administration.

NCF: noncommercial forest land – photointerpretation code.

Negative, photo: a photoimage in which tones are reversed and colors appear as their complements.

nm: nanometer, a unit of length in the metric system; the thousandth part of a micrometer; previously known as millimicron.

NOF: nonforest land – photointerpretation code.

Oblique photograph: a photograph taken with the camera axis intentionally directed between the horizontal and the vertical. A high-oblique photograph is an oblique photograph in which the apparent horizon is included within the field of view. A low-oblique photograph is an oblique photograph in which the apparent horizon is not included within the field of view.

Orthophoto: a photographic copy in which image displacements due to tilt and relief have been removed.

Overlap, photographic: amount by which one photograph covers the same area covered by another, usually expressed as a percentage. Endlap is overlap between aerial photographs in the same flight, and sidelap is overlap between photographs in adjacent parallel flights.

Overlay: a sheet of translucent or transparent material on which selected features are traced from a photograph or mosaic.

P: absolute stereoscopic parallax, the sum of the distance measured along the x-axis between an object and its respective nadir on two conjugate photographs set up for stereoscopic viewing.

Parallax: apparent positional displacement with respect to a reference point or system, caused by a shift in the observation point.

Parallax bar: see Stereometer.

Photogrammetry: the science of making reliable measurements from photographs.

Photomap: a single photograph, photocomposite, or mosaic showing coordinates and marginal information, used as a map.

Pitch, air navigation: rotation of an aircraft about the horizontal y-axis normal to its longitudinal axis, to effect a nose-up or nose-down attitude.

Positive, direct: a positive photograph obtained directly without the use of a negative.

Positive photograph: translucent photograph having approximately the same rendition of tones as the original subject, such as light for light and dark for dark.

PP: principal point; the foot of the perpendicular from the interior perspective center of a photograph to its plane; defined by intersection of the fiducial marks in a perfectly oriented vertical photograph.

Print: a photographic copy made by contact printing or projection.

Print, contact: see Contact print.

Print, semimatte: a photographic print made on paper with a semidull finish.

Processing, photographic: the operations by which negatives, diapositives, or prints are made from exposed film or plates.

Rectification: the process of converting a tilted or oblique photograph to the plane of the vertical by projecting it onto a horizontal reference plane, with the angular relationship determined by the use of control points recognizable on the photograph and an accurate map.

Remote sensing: the acquisition of data/imagery (usually using more than one camera or sensor) from a remote platform (for example, aircraft or spacecraft); sometimes used synonymously with aerial photography.

Resolution, film: the minimum distance between two adjacent features, or the minimum size of a feature, which can be detected by a photographic system. This distance is usually expressed in lines per millimeter recorded on a particular film under specified conditions (for example, target contrast ratios).

Resolving power: an expression of lens definition, usually stated as the maximum number of lines per millimeter that can be resolved (that is, seen as separate lines) in the image. The resolving power of a lens, film, or their combination varies with the contrast of the test chart and normally varies also with the orientation and position of the chart within the field of view.

RF: representative fraction; see Scale.

Roll, air navigation: rotation of an aircraft about its longitudinal x-axis to effect a wing-up or wing-down attitude.

Run: a pass by a camera-carrying aircraft over a flight line.

Scale: the relationship between photographic or map distance and ground distance expressed as a fraction or a ratio; for example, 1/250,000 or 1:250,000; 1 cm on photograph = 250,000 cm on ground. Also called RF (q.v.).

Sensitivity, color: the sensitivity of photoemulsion to light of different wavelengths. Different sensitivities may be deliberate (as color IR versus conventional color), or the result of manufacturing process variations and storage temperature conditions.

Stereometer: a measuring device containing a micrometer movement by means of which the separation of two index marks can be changed to measure the parallax difference on a stereoscopic pair of photographs.

Stereoscopic pair: two photographs of the same area taken from different camera stations to afford stereoscopic vision; frequently called a stereopair.

Stereoscopic vision: the particular application of binocular vision which enables the observer to obtain the impression of depth, usually by means of two different perspectives of an object (as two photographs taken from different camera stations).

Stereoscopy: the methods and use of binocular vision for observing a pair of overlapping photographs or other perspective views.

Timber stand: a community of trees having sufficient uniformity of composition and condition to be distinguishable from adjacent communities.

Tip/tilt: the angle between the optical and the vertical axis of a camera.

Transparency: a positive image upon film or glass intended to be viewed by transmitted light, either black and white or in color; also called a diapositive.

USFS: U.S. Forest Service.

USFS/R8: U.S. Forest Service, Southern Region.

Vignetting: a photographic effect in which the image is brightest at its center and fades out toward the edges.

Wavelength (of light): wavelength = velocity ÷ frequency. Each color of light has a characteristic wavelength. The wavelength of light is usually measured in micrometers or nanometers.

Yaw, air navigation: the rotation of an aircraft about its vertical z-axis to cause the aircraft's longitudinal axis to deviate from the flight line; sometimes called crab.

1.0 INTRODUCTION

1.1 Purpose

This manual has been prepared to introduce forest resource planners and managers to the use of small-scale color IR aerial photography in gathering information for forest management. It is assumed that the user knows fundamental photointerpretation techniques and has a working knowledge of forest management practices.

While aerial photography has been used by the USFS for many years, the advent of high-flying aircraft capable of obtaining small-scale photography introduced new methods and techniques. The cost effectiveness and time required in the analysis of ecological management units are primarily important. Color IR photographs are useful in these stages of the analysis:

- Gathering basic environmental data such as soil information, vegetation patterns, and water body distribution
- Collecting and developing a resource use history, including the effects of past mining activities, identification of erosion areas, and location of flood-prone areas
- Preparing land use maps and overlays
- Monitoring management activities generated by land use plan implementation

This manual contains a glossary, introduction in section 1.0, and sections 2.0 through 4.0 to review for the user these principles and applications of aerial photography:

- Photointerpretation and photogrammetry
- Statistical evaluation techniques

Sections 5.0 through 8.0 give detailed procedures for using color IR aerial photography in specific forest resource applications:

- Land use classification and mapping
- Landform analysis
- Stand mapping and canopy density and crown diameter measurements
- *Erosion detection*

The applications primarily cover the use of small-scale color IR aerial photography as related to timber resources in forest planning and management. Later studies will cover other forest resources, such as recreation, wildlife, range, watershed, and mineral services. The results will be included in this manual later.

1.2 Background

Radiant energy, such as light, travels with a wave motion. The wavelength is the distance from the crest of one wave to the crest of the next. The frequency is the number of waves passing a given point in 1 second. The product of wavelength and frequency is the speed of the radiant energy.

The various radiant energies form a continuous series of wavelengths, each differing infinitesimally from its neighbors. This series is the electromagnetic or energy spectrum (fig. 1-1). At one end are the short-wavelength gamma rays emitted by certain radioactive materials. At the other end are the long radio waves, the longest of which are several kilometers. The wavelengths of the visible spectrum range from approximately 400 nm, or 0.4 microns (violet), to approximately 700 nm, or 0.7 microns (red). Beyond the visible spectrum, IR energy has wavelengths somewhat longer than visible energy.[1]

Photographs having scales ranging from 1:60,000 to 1:120,000 are considered as small-scale photographs in this document. Such photography is usually obtained on a 23- by 23-cm (9- by 9-in.) film format with a 15-cm (6-in.) or 30-cm (12-in.) focal length camera flown at an altitude of 9,144 to 18,288 m (30,000 to 60,000 ft).

Color IR film is recommended for small-scale photography taken for general forestry applications. When compared with regular black-and-white or true-color film, color IR film has three advantages that make it the most useful medium for high-altitude photointerpretation:[2]

- Increased haze penetration because the longer wavelength of IR is less subject to scattering than are the shorter wavelengths of the visible spectrum.

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[1]Eastman Kodak Company, Color As Seen and Photographed, publication E-74, Rochester, N.Y., 1972.

[2]R. N. Colwell, ed., Manual of Photographic Interpretation, American Society of Photogrammetry, George Banta Company, Menasha, Wis., 1960.

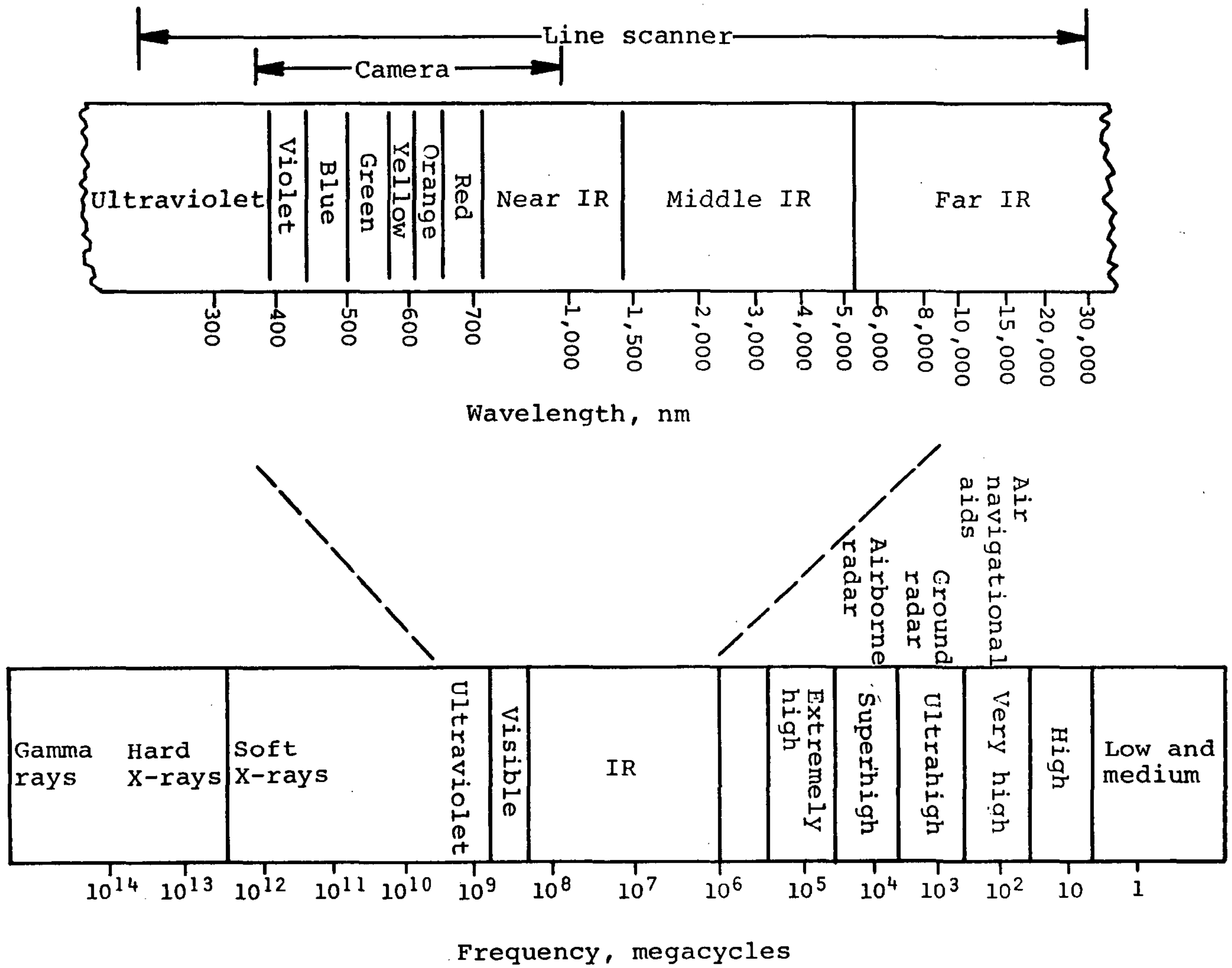

Figure 1-1.— The expanded portion of the electromagnetic spectrum with associated sensors.

- Greater target-to-background contrast caused by the higher total percentage of reflectance of vegetation within the IR range.
- Greater total brightness of vegetation caused by the high IR return from living vegetation.

There are some disadvantages to using color IR film; however, they usually are related to photographic problems and not directly to photointerpretation. The storing of unexposed color IR film, narrower latitudes of exposure, Sun hot-spot sensitivity, and vignetting are problems that must be faced in planning or contracting for photographic missions; however, they should be minimized before the photographs are presented to the user.

Small-scale photography has the advantage of presenting a synoptic, or large-area, view of the forest land. Where usable, it gives a greater cost effectiveness on a per-acre, comparative basis in data acquisition than large-scale photography. Since smaller scale photography permits the aircraft to cover more area in the time available, it offsets the higher operating costs of the high-flying aircraft. This is especially true in regional-scope surveys where thousands of square miles are covered. The approximate costs of acquiring photography at the indicated altitudes, using the same camera, are:[3]

18,288 m (60,000 ft) – $0.004/hectare ($0.002/acre)

9,144 m (30,000 ft) – $0.011/hectare ($0.005/acre)

3,048 m (10,000 ft) – $0.035/hectare ($0.014/acre)

1,524 m (5,000 ft) – $0.067/hectare ($0.027/acre)

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[3]Earth Observations Applications Office, NASA/JSC, Limited Cost Study of Photographic Data Acquisition, LEC-0139, 1973.

Likewise, photodevelopment and printing costs are lower with the high-altitude, smaller scale photography, since a smaller number of prints will be needed to cover a given area. For example, one frame of metric camera, 15-cm (6-in.) focal length photography taken at 9,144 m (30,000 ft) covers an area of approximately 740 sq km (289 sq mi). More than 200 photographs at a scale of 1:12,000 would be required to give stereoscopic coverage of the same area covered by a stereoscopic triplet of 1:60,000 scale photographs.

Photointerpretation costs can be reduced by using small-scale photography because there are fewer frames to analyze. Differences among various applications in the amount or nature of detail to be evaluated make analysis and photointerpretation costs difficult to document quantitatively. The user may wish to document his own comparisons of the cost effectiveness of color IR and other information-gathering techniques for local purposes.

2.0 AERIAL PHOTOGRAPHY

2.1 Remote Sensing and Aerial Photography

Remote sensing refers to the use of various optical and electrical sensing devices mounted on aircraft or spacecraft to detect and measure properties on the surface of the Earth. The physical property sensed is commonly radiation emitted or reflected from the surface of the Earth in wavelengths ranging from the gamma ray through the ultraviolet, visible, IR, and microwave regions of the electromagnetic spectrum.

Aerial photography refers specifically to the use of cameras operated from airborne platforms to sense the near-ultraviolet, visible, and near-IR regions of the electromagnetic spectrum. Since World War I, aircraft have been used to acquire photographs for military and civilian applications. These applications include the areas of forestry, agriculture, geology, oceanography, geomorphology, engineering, municipal planning, and military operations.

2.2 Camera-Carrying Aircraft

Land managers usually have worked with larger scale photographs taken from low-flying, propeller-driven aircraft. Scales ranging from 1:8,000 to 1:30,000 are obtained primarily with a 15-cm (6-in.) or a 21-cm (8-1/4-in.) lens. Jet aircraft are commonly used to acquire the 1:60,000-scale imagery recommended by this manual.

Private companies can be contracted to provide photographic coverage from high-flying jet aircraft. Scales ranging as small as 1:90,000 can be provided by these companies.

2.3 Cameras

There are many types of aerial cameras, but all have characteristic operational features. Basically, an aerial camera consists of a light-free box that supports a lens and shutter at one end, and a light-sensitive film at the opposite end (fig. 2-1). An aerial camera employs a fixed-focus lens because all objects imaged are so distant that they are practically at optical infinity. Aerial cameras have adjustable mechanisms for presetting the rate of film advance and shutter operation. Table 2-I lists the NASA/JSC Earth Resources Program cameras and their use and basic design.

All applications discussed in this manual utilize frame cameras. Most aerial cameras can be classified as frame cameras; that is, cameras in which an entire frame is exposed through a lens that is fixed relative to the focal plane. The film is held fixed in the focal plane during exposure or is moved to compensate for aerial motion. These cameras may be either single-unit, single-lens, or multispectral. The latter are multiunit cameras equipped with different films and filters, designed to provide simultaneous multiple images of a given scene.

In addition to frame cameras, panoramic and strip cameras are used. Panoramic cameras utilize a scanning lens and moving film to obtain wide-swath, high-resolution,

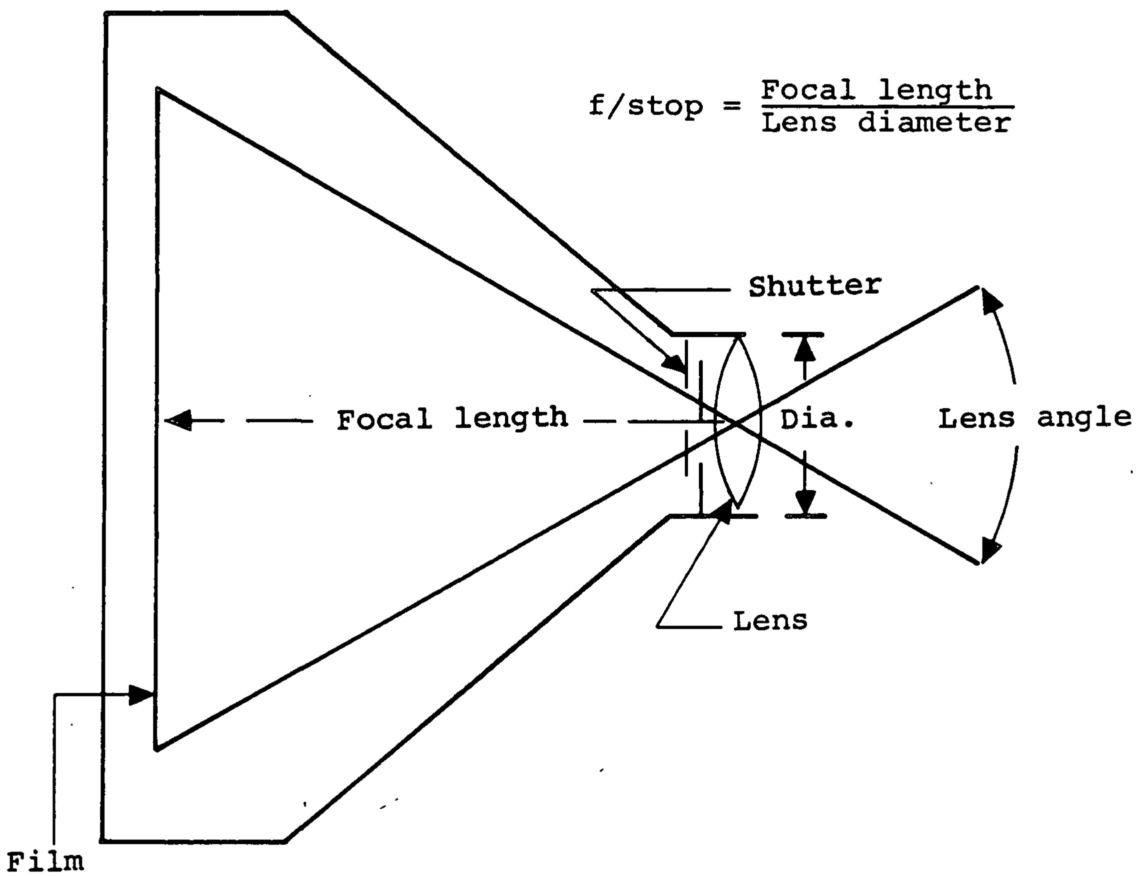


Figure 2-1.— Nomenclature of a simple camera.

TABLE 2-I.— REPRESENTATIVE AERIAL CAMERAS CURRENTLY USED IN NASA/JSC EARTH RESOURCES AIRCRAFT PROGRAM

Camera	Lens		Shutter speeds (sec)	Format (in.)	Film width	Number of exposures	Mount F=fixed S=stabilized	Field of view	Primary use	Imagery scale		
	Focal length	Aperture (f/)								10,000 ft AGL[a]	30,000 ft AGL	60,000 ft AGL
Chicago Aerial Industries KA-62	Paxar 3 in.	4.5	1/60 to 1/500	4.5 × 4.5	5 in.	800	F	73°38'	Mapping and multi-spectral	1:40,000	1:120,000	
Flight Research 207	25 to 150 mm	2.0	to 1/1200	0.97 × 0.72	35 mm	to 19,000	F	53° to 9.4°	Boresighted with non-imaging sensors; up to 3 frames/sec	N/A	N/A	N/A
Hasselblad 500EL	40 mm 50 mm 80 mm 120 mm 150 mm 250 mm 500 mm	4.0 4.0 2.8 5.6 4.0 5.6 8.0	1 to 1/500	2.25 × 2.25	70 mm	23 ft, 80 exp 100 ft, 450 exp	F	71°42' 59°24' 39°12' 26°48' 21°36' 13°2' 6°15'	Multispectral	1:76,200 1:60,960 1:38,100 1:25,400 1:20,320 1:12,192 1:6,096	1:228,600 1:182,880 1:114,300 1:76,200 1:60,960 1:36,576 1:18,288	1:457,200 1:365,760 1:228,600 1:152,400 1:121,920 1:73,142 1:36,576
Hycon HP-307D	80 mm	2.8 .22	1/250	2.25 × 7.20	70 mm	to 300	S	39° × 130°	Wide angle	N/A	N/A	N/A
I^2S	150 mm	2.8	1/150 to 1/350	Four ea. 3.5 × 3.5	9.5 in.	300 sets of four	S	33°	Multispectral	1:20,000	1:60,000	1:120,000
Itek AMPS multiband, 6-stations	6 in.	2.8	1/100 to 1/400	2.25 × 2.25	70 mm	75 ft, 300 exp	F (with IMC)	21°12'	Multispectral	1:20,000	1:60,000	1:120,000
Zeiss RMK A 30/23	Topar 12 in.	5.6	1/100 to 1/1000	9×9	9.5 in.	225	F	41°6'	Precision mapping	1:10,000	1:30,000	1:60,000
Zeiss RMK A 15/23	Topar 6 in.	5.6	1/100 to 1/1000	9×9	9.5 in.	225	F	73°44'	Precision mapping	1:20,000	1:60,000	1:120,000

[a]Above ground level.

panoramic coverage. Strip cameras collect continuous photography of the terrain by passing the film over a stationary slit in the focal plane of the lens at a speed synchronized with the velocity of the ground image across the focal plane.

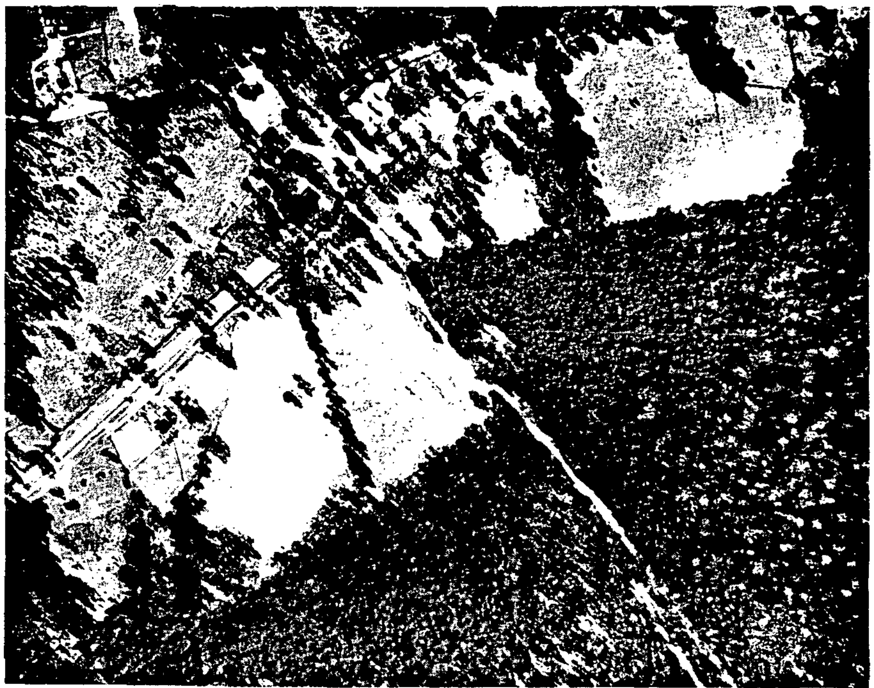
2.4 Films

The four basic film types used in aerial photography are black-and-white panchromatic, black-and-white IR, conventional color, and color IR (fig. 2-2). Table 2-II lists the characteristics and uses of the more common film types.

Black-and-white panchromatic film, which has been used most widely, has approximately the same range of light sensitivity as the human eye (ranging from blue through red). Although panchromatic film is not very sensitive within the green ranges, it is extremely useful in many applications, particularly those requiring maximum spatial resolution and detail.

Black-and-white IR films are sensitive to wavelengths ranging from the visible into the reflected IR region. Healthy angiosperm vegetation has high IR reflectivity, whereas water exhibits extremely low reflectivity. Conifers reflect only a moderate amount of IR energy, thereby affording an opportunity for separation from hardwoods. Hence, this film is often used in applications involving the classification of vegetation and the mapping of surface water.

Conventional color films are composed of three emulsion layers sensitive to the blue, green, and red wavelengths of



(a) Black-and-white panchromatic film.

(b) Black-and-white IR film.

Figure 2-2.— Four photographs of the same area near Richards, Texas (courtesy of NASA/JSC, Mission 192).

(c) Color film.

(d) Color IR film.

Figure 2-2.— Concluded.

TABLE 2-II.— TYPICAL AERIAL FILMS[a,b]

Film type	Film no.	AEI[c]	AFS[c]	Film resolution[d] 1.6:1	Film resolution[d] 1000:1	Film characteristics	Applications
Plus-X	2402	80	250	50	100	Medium speed, high stability.	Mapping, cartography, and multispectral photography.
Plus-X	3401	64	200	40	125		
Plus-X	5401	80		40	100		
Plus-X	8401	80	250	50	100		
Hi def	3404	1.6		200	475	Slow speed, thin base, fine grain high resolution, high altitude.	Very high resolution for high-altitude, reconnaissance-type photography where good ground resolution is required.
Hi def	3414	1.6	8	250	630		
Hi def	SO-243	1.6		205	465		
Hi def	SO-380	1.6		200	475		
Aerial neg.	SO-206	6		112	336		
Pan-X	3400	20	200	40	125	Medium to high speed, high-altitude.	Reconnaissance mapping and cartography.
Double-X	2405	125	320	50	100		
Super-XX	5425	100		30	80		
Tri-X	2403	250	640	22	71	High speed, high stability.	Reconnaissance and mapping.
Tri-X	8403	200		22	71		
Pan	SO-349						Mapping.
Pan	2484					PX backing.	
Pan	SO-267						
IR	2424	100	200	40	80	Black-and-white IR and visual sensitivity.	Special-purpose forestry, agricultural, and hydrological.
IR	5424	125		28	89		
IR	SO-246	125		28	89		
Ekta IR	SO-117	10		36	71	False-color reversal; film slow speed.	Vegetation studies.
Ekta IR	SO-180	10		36	71		
Ekta IR	2443	10	40	32	63		
Ekta Aero color	SO-356	2		100/mm	200/mm	Color reversal; high-speed film; medium to high altitudes.	Mapping; multispectral studies; soil, vegetation, water, geological studies, and inventories.
Ekta EF Aero	SO-397	12		32	63		
Aero neg.	2445	10	100	40	80		
Ekta Aero	SO-242						
Ekta color	SO-276	10		32	50		
GAF	D-500	50				Medium altitude for mapping, color negatives.	
GAF	D-1000	50					

[a]Eastman Kodak Company, Characteristics of Kodak Aerial Films, publication M-57, Rochester, N.Y., Oct. 1973, 4 pages.

[b]Eastman Kodak Company, Kodak Data for Aerial Photography, publication M-29, Rochester, N.Y., 1971, 81 pages.

[c]The use of Aerial Exposure Index (AEI) has been replaced by Aerial Film Speed (AFS). This table lists both AFS and effective AFS in one column.

[d]Target-contrast ratios.

the spectrum, which yield natural color rendition products when properly exposed and processed. Since the human eye can detect many more color variations than gray tones, color film has been found to be extremely useful, especially in applications such as soil mapping.

Color IR (false-color) film (for example, Kodak 2443) differs from conventional color film in that the three emulsion layers are sensitive to blue-green, red, and near-IR wavelengths instead of the blue, green, and red wavelengths (fig. 2-3). When the film is correctly exposed, the resulting color products display false colors for most features. In particular, healthy vegetation shows up as various shades of magenta or red instead of green. Recently, the film has been widely used for agricultural crop analysis, forest timber inventories, pest and disease detection, and forest site quality analysis.

No single film type serves all purposes; each has its particular merits and optimum applications. Where the maximum aerial photographic information is desired, several types of imagery over the area should be acquired and studied simultaneously because the varied tones and patterns produced by differing film types and sensitivity ranges complement each other. However, present research indicates that color IR film is an excellent tool for forestry applications.

2.5 Filters

Photographic filters are used in aerial photography for any of three purposes. One is to filter out the blue-violet part of the light entering the camera to minimize loss of

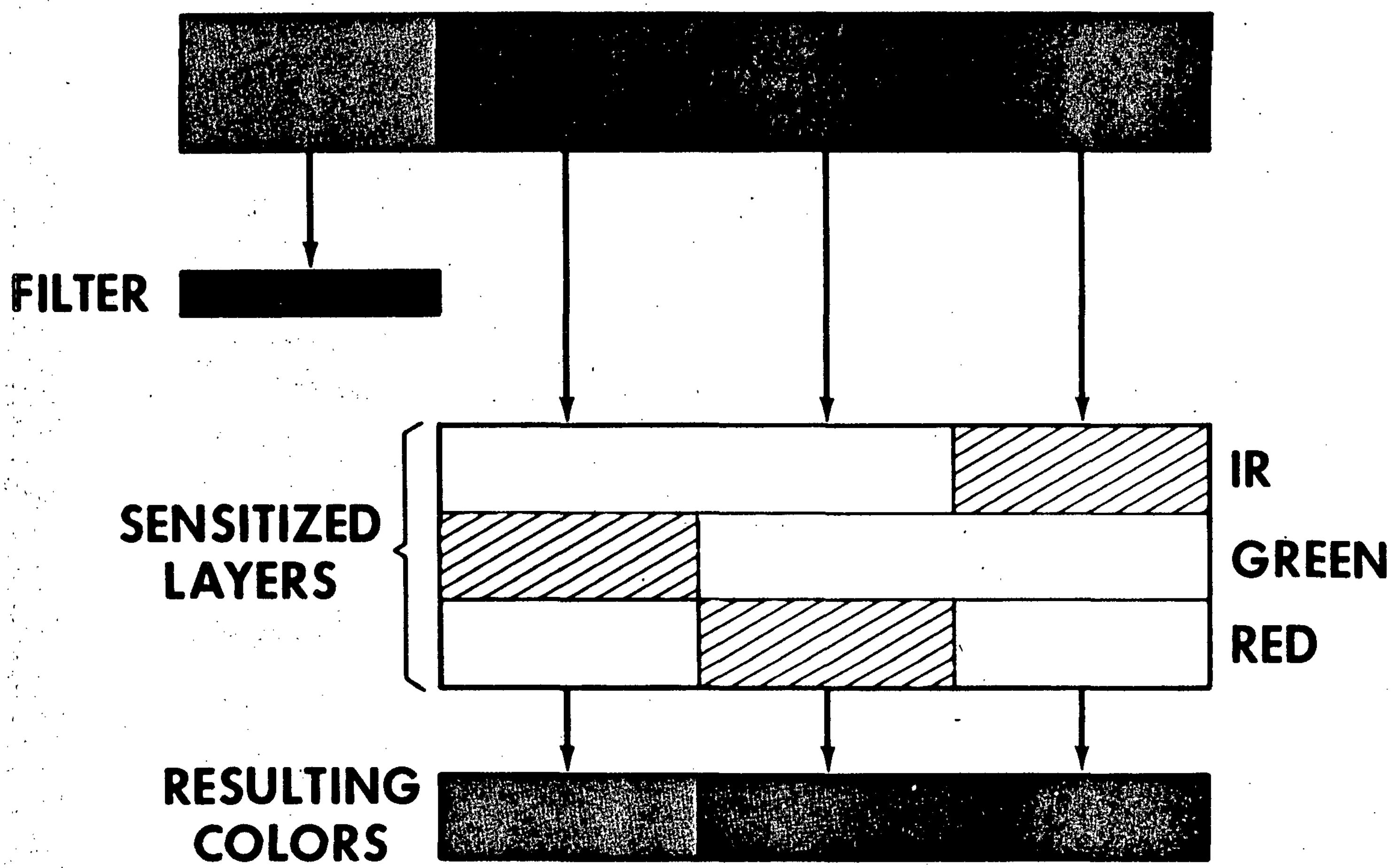


Figure 2-3.– Color IR emulsion layers.

detail and clarity caused by the scattering of light in the wavelengths. Various types of haze filters are used to screen out light in the wavelengths (see table 2-III for a list of commonly used filters and their applications). A second use is as a color-correction filter to compensate for occasional oversensitivity of a given film lot to a certain range of wavelengths. Narrow-band filters, which admit only a selected range of wavelengths, may be used to photograph a scene in only a narrow portion of the photosensitive spectrum by screening out longer or shorter wavelengths. Such selective filtration is used primarily in multispectral photography to simultaneously acquire black-and-white photography in the blue, green, red, or near-IR portions of the spectrum.

2.6 Vertical Versus Oblique Photography

Aerial photographs may be vertical, low oblique, or high oblique (fig. 2-4). Vertical photography, which is acquired with the axis of the aerial camera vertically situated, is the type emphasized in this manual. It produces a series of map views of the Earth, normally overlapping to allow stereoscopic analysis. In practice, the true map view is always slightly distorted by aircraft pitch, roll, and yaw, which cause deviations from true vertical. For precise cartographic work these must be corrected by photogrammetric techniques. Contract specifications should state that no photographs can have more than 3° tilt and, also, the entire mission cannot average more that 1° tilt.

High oblique photographs resemble ground photographs taken from a high peak or other commanding point showing

TABLE 2-III.— AERIAL PHOTOGRAPHY FILTERS[a]

Filter color	Number	Peak transmission range, nm	Application
Light yellow	HF series	Beyond 400	Contrast enhancement, blue absorption, haze penetration
Clear	0	Beyond 300	Compensation filter
Clear	1A	Beyond 380	Blue hue reduction
Yellow	2 series	Beyond 400	Haze reduction absorption
Yellow	12	Beyond 500	Minus blue haze cutter and for use with color IR
Deep yellow	15	Beyond 510	Contrast control
Orange	21	Beyond 540	Blue, blue-green absorption
Tricolor red	25	Beyond 580	Haze cutter and red separation
Violet	32	450 and beyond 600	Minus green
Violet	34	420 and beyond 620	Blue separation
Blue	44A	480 and beyond 710	Minus red
Light blue	47B	400—460 and beyond 750	Color separation
Tricolor green	58	500 to 570	Color separation
Black	89B	Beyond 700	Visible spectrum absorption

[a]Eastman Kodak Company, Kodak Filters for Scientific and Technical Uses, publication B-3, Rochester, N.Y., 1970, 89 pages.

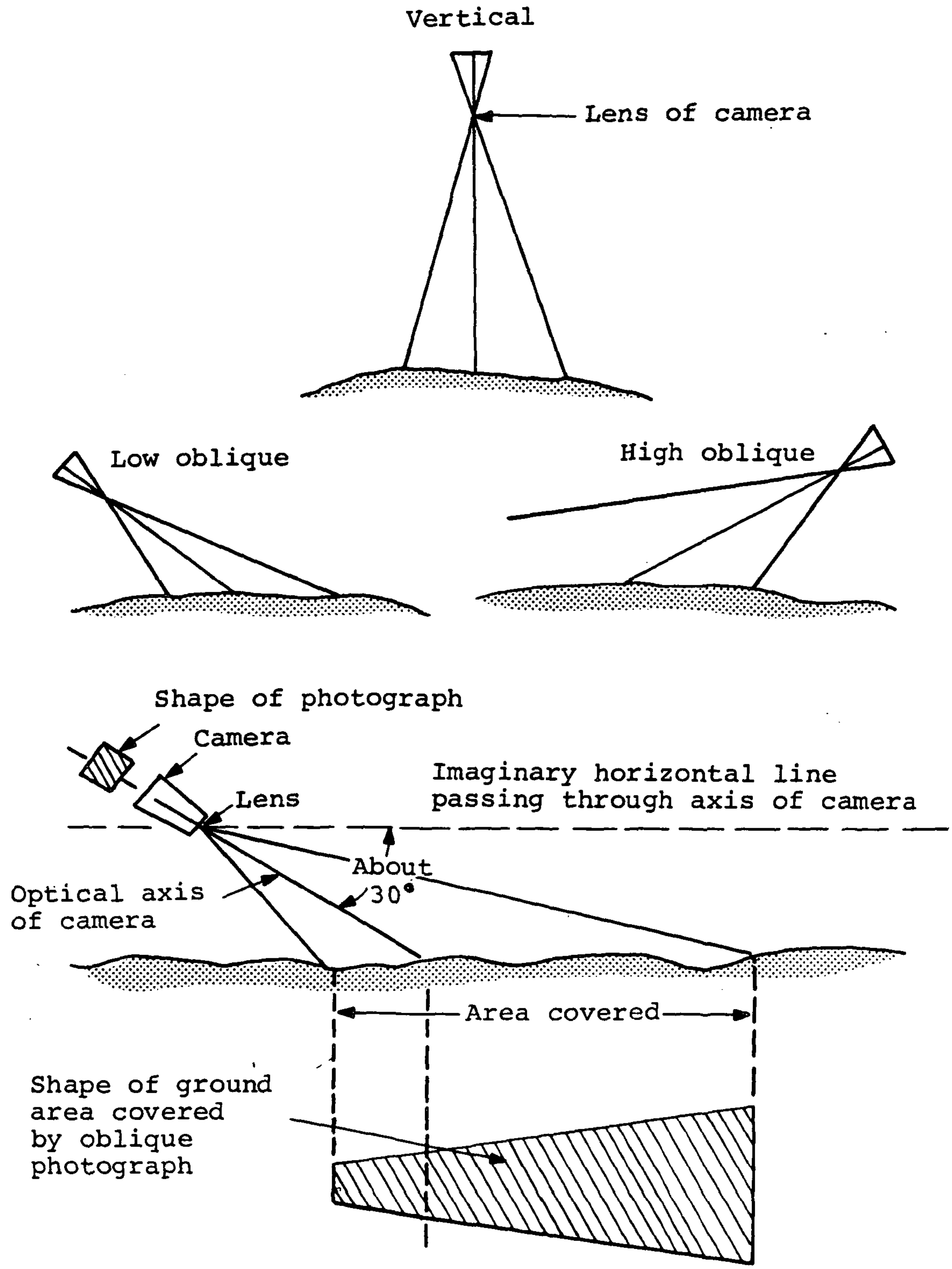


Figure 2-4.— Orientation of aerial camera for vertical and oblique photography.

the horizon. They are particularly effective for pictorial and illustrative purposes and provide a sweeping view in familiar perspective. Low oblique photographs are also taken with the camera inclined from the vertical, showing no horizon.

2.7 Steps in Using Aerial Photography

Any project involving aerial photography can be divided into six steps:

- Data requirements definition
- Major aerial photographic considerations
- Data acquisition (by purchase of existing photographs or by special flights)
- Film processing and finishing
- Photographic preparation
- Photointerpretation

The remainder of this section discusses the first four steps. Section 3.0 covers photographic preparation and interpretation.

2.7.1 Data requirements definition. Certain questions must be answered before aerial photographs are selected from an Earth resources data bank or before an aircraft mission is flown to obtain photographs for a given application. These questions are discussed in the following paragraphs.

2.7.1.1 Geographic area coverage: The area to be covered should be delineated, and the corner coordinates should be listed on the best maps available. The U.S. Geological Survey (USGS) topographic maps at a 1:125,000 scale are good flight maps because they are not too bulky and are easily handled by the flightcrew. Flight lines should be carefully plotted on the flight map with sufficient overhang of the project boundary to ensure complete coverage.

When identifying the high-altitude photographic data of previously covered areas, sources such as the cataloging and indexing reports prepared for the NASA/JSC aircraft program could be of assistance (fig. 2-5). Also, to assist in associating frames with corresponding areas of interest, approximate frame numbers are listed in these reports.

2.7.1.2 Image orientation: Is vertical, low oblique, or high oblique photography required? (Most mapping involves vertical or, occasionally, low oblique photography.)

2.7.1.3 Flight altitude and image scale: What is the indicated flight altitude; what scale of photograph is required for analysis? This will be determined by the degree of ground resolution desired and the information content for the particular application. Color IR aerial photographs can be enlarged up to approximately 8× to yield a desired scale and still maintain a usable resolution.

2.7.1.4 Film considerations: What type of photography, what film or films (table 2-II), and what filter or filters (table 2-III) are required? Color IR aerial photography is

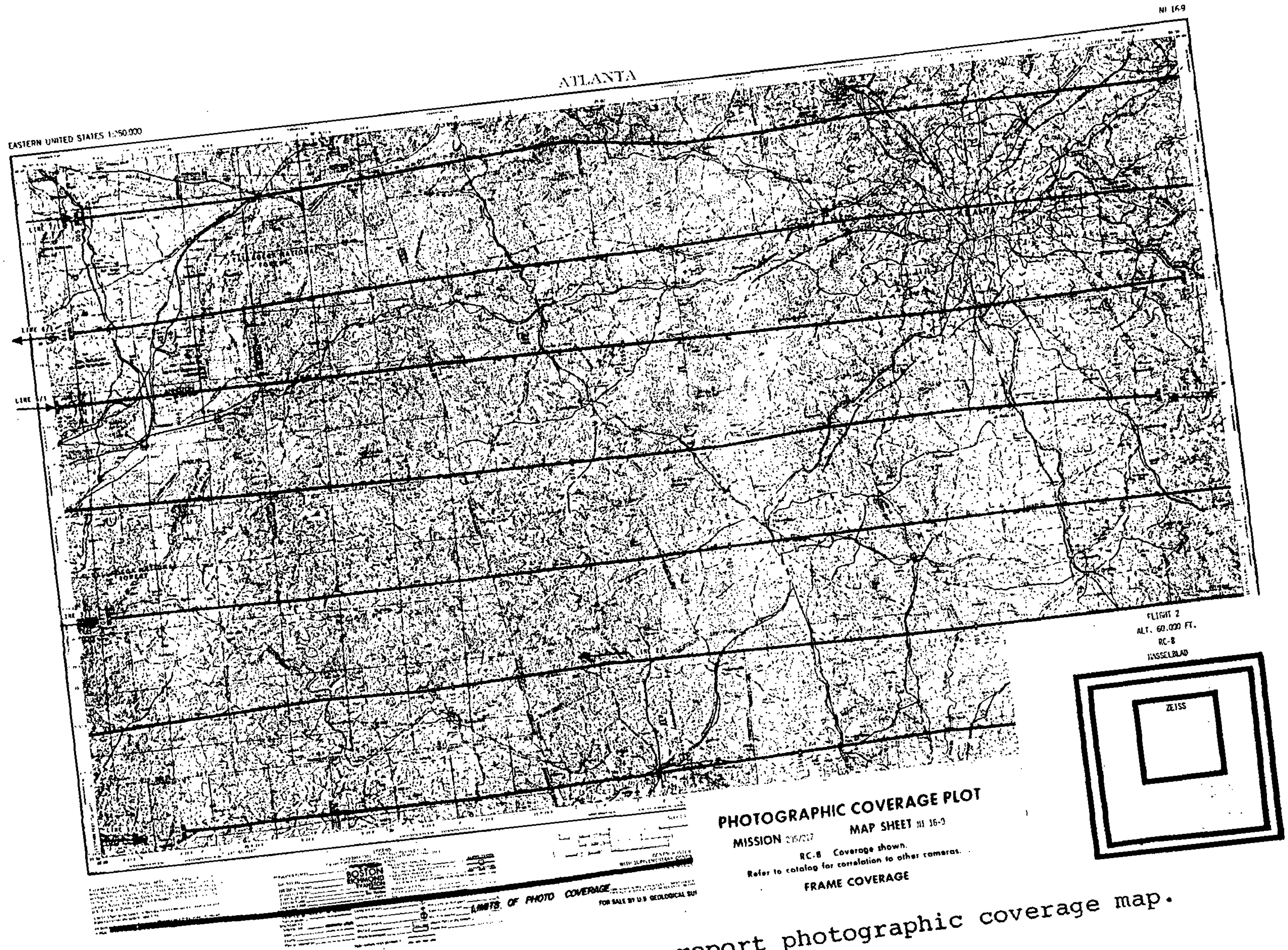


Figure 2-5.- A typical mission report photographic coverage map.

particularly useful for forestry applications because of the information it provides about vegetation. The specific applications discussed in sections 5.0 through 8.0 emphasize the use of color IR photography. Research has indicated that color IR film can produce better results than true color when film types only are compared.[1]

2.7.1.5 Seasonal considerations: In what season should the photography be acquired? This will depend on the study objectives as related to vegetation growth stages. Imagery acquired during times of vegetative dormancy is best for source studies such as conifer/hardwood separation and landform analysis, where the ground surface is of paramount interest during periods of optimum terrain and stream visibility. Studies of vegetation type would require photography acquired during the season of maximum foliage growth.

2.7.1.6 Historical considerations: In what year should the photography be or have been taken? Historical studies of land use change and the progress of management activities or other considerations might require earlier photographs for comparison.

2.7.1.7 Shadow considerations: How critical are terrain and cloud shadows? Ordinarily, data with minimum shadows should be acquired.

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[1]R. W. Douglass and M. P. Meyer, Forest Vegetation Classification and Mapping, Applications of Aerial Photography and ERTS Data to Agricultural, Forest and Water Resources Management, Institute of Remote Sensing, College of Forestry, University of Minnesota, 1973.

Terrain shadows can be minimized by scheduling flights during the season and at the times of the day when Sun angle can be the highest. The optimum season varies with latitude but generally corresponds to the time that the Sun is farthest north of the Equator. Consideration must also be given to the effects of "hot-spotting." The "hot spot" or "no shadow point"[2] in a photograph, which is particularly noticeable over forested areas, appears as a bright area lacking in detail immediately surrounding the antisolar point (180° from the direction of the Sun). Thus, it is advisable to avoid its occurrence within the area of the photograph. (See reference for a more complete discussion of Sun angle problems.[3]) At times it may be necessary to balance terrain shadow constraints against those imposed by the growing season considerations discussed in section 2.7.1.5.

In the final event, results will depend on the actual weather at the time of overflight. To assist in the general planning of an aircraft overflight, figures 2-6 through 2-17 show aerial photography clear-day maps of the United States for each month of the year.[4] These maps indicate the average number of clear days expected from sunrise to sunset that meet the minimum 30° solar altitude criterion usually required

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[2]J. T. Smith, ed., Manual of Color Aerial Photography, first ed., American Society of Photogrammetry, Falls Church, Va., 1968.

[3]G. Heath, The Determination of Hot-Spot-Free Periods for Aerial Photography of Forest Areas, Lockheed Electronics Company, Inc., LEC/HASD no. 640-TR-127, Houston, Tex., 1972.

[4]Reference footnote 2. The aerial photographer's clear-day maps came from the Environmental Data Service of the U.S. Department of Commerce.

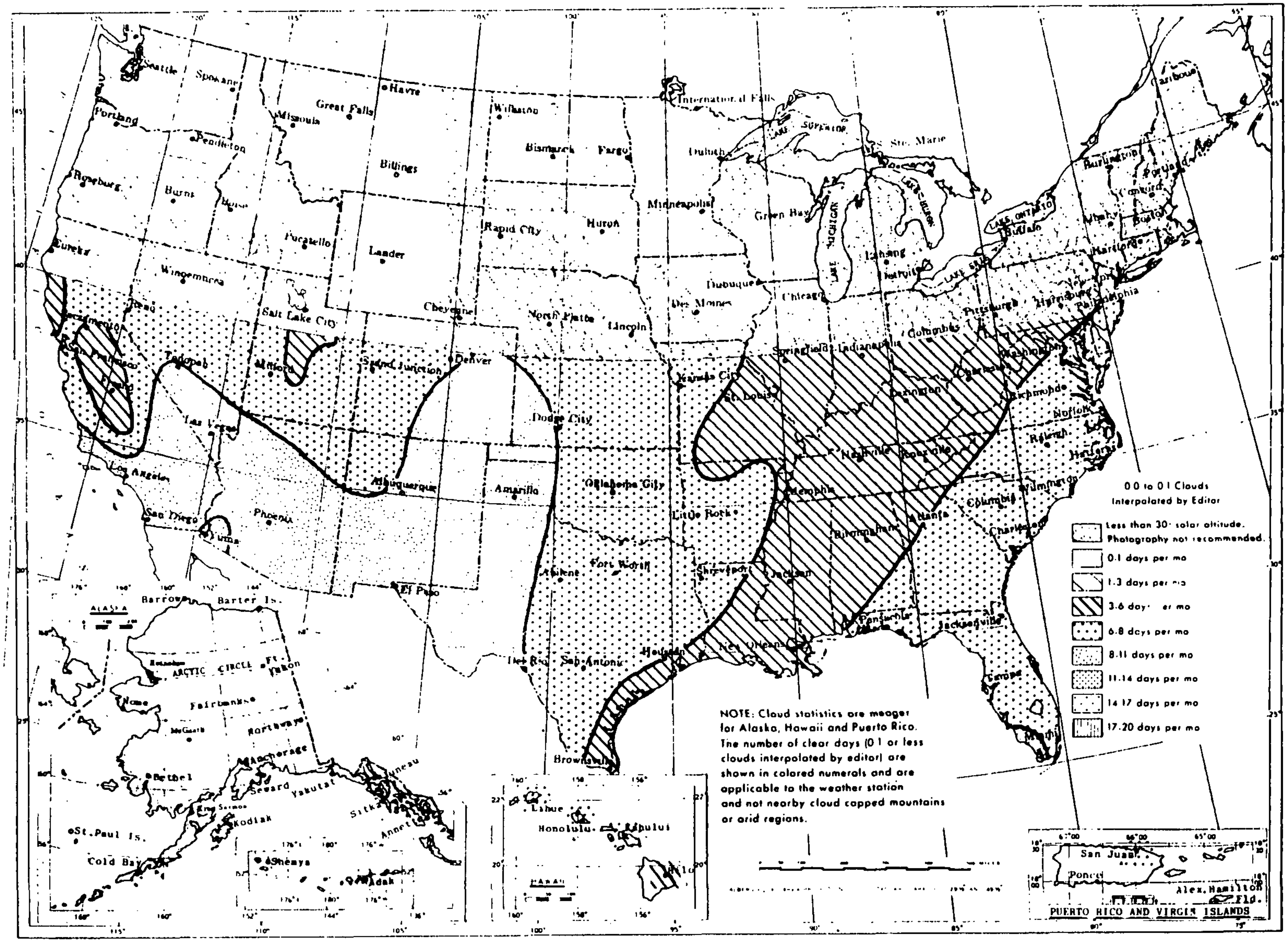

Figure 2-6.– January clear-day map for the United States and Puerto Rico.

NOT REPRODUCIBLE

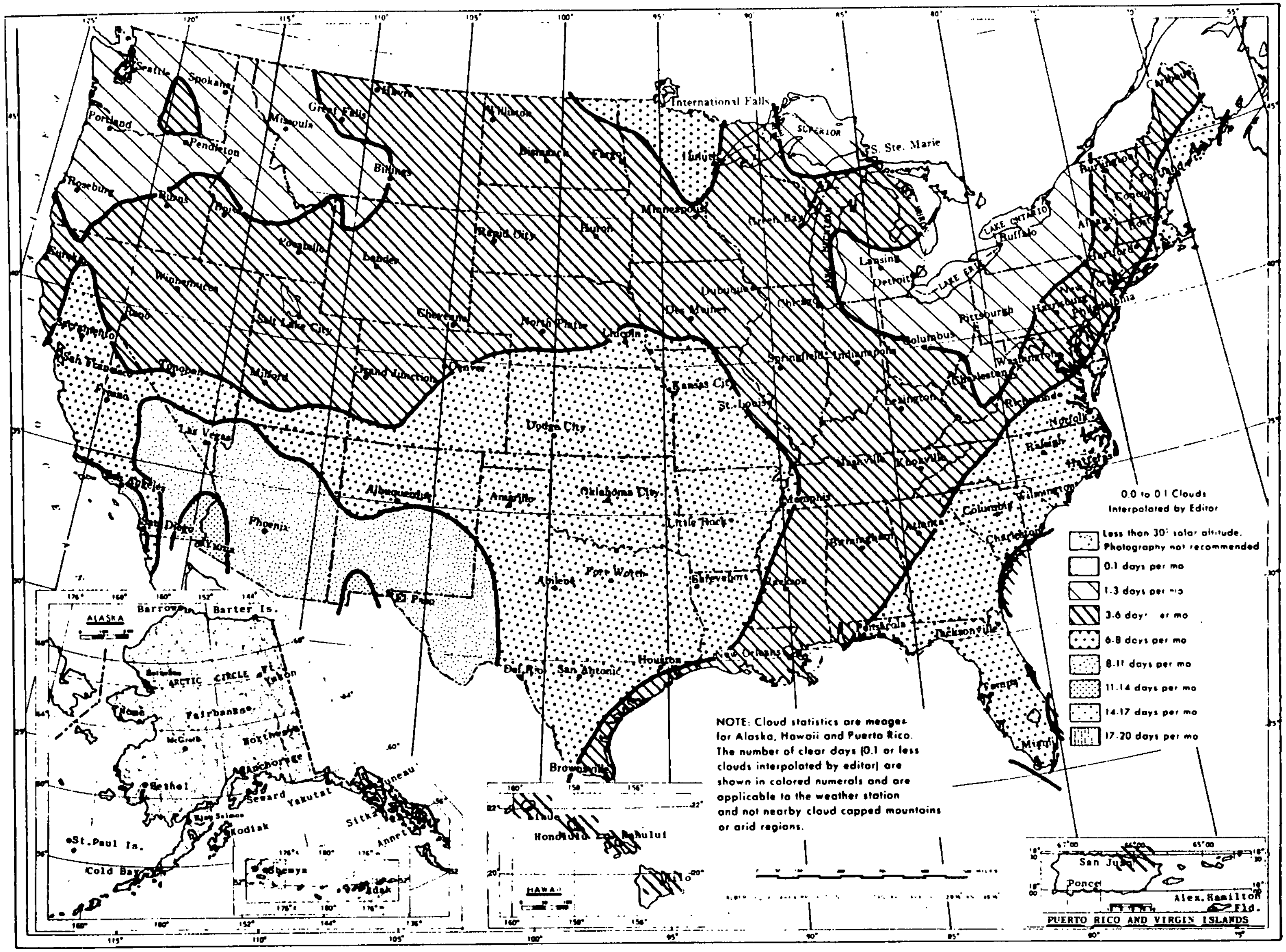

Figure 2-7.– February clear-day map for the United States and Puerto Rico.

Figure 2-8.– March clear-day map for the United States and Puerto Rico.

NOT REPRODUCIBLE

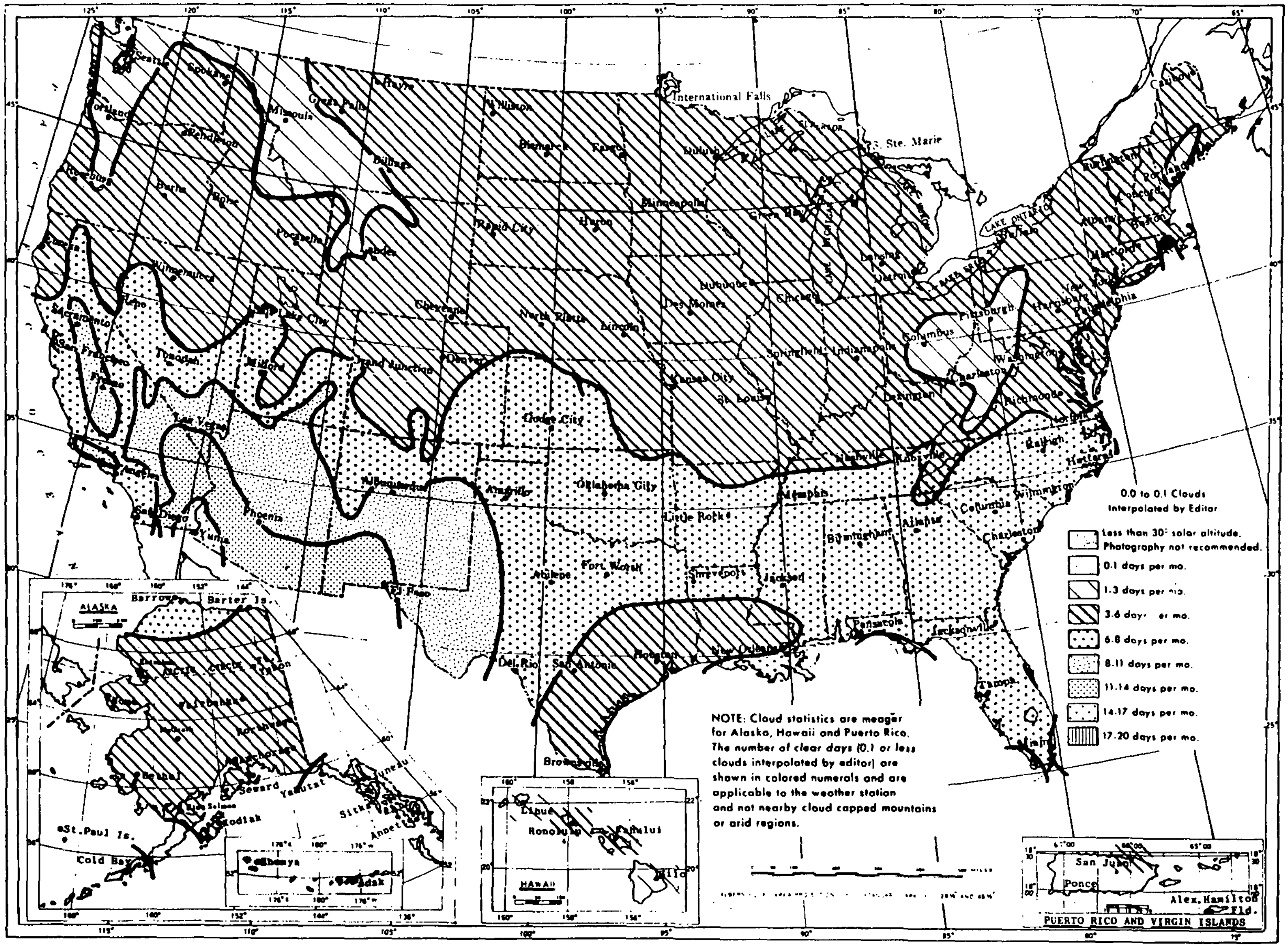

Figure 2-9.— April clear-day map for the United States and Puerto Rico.

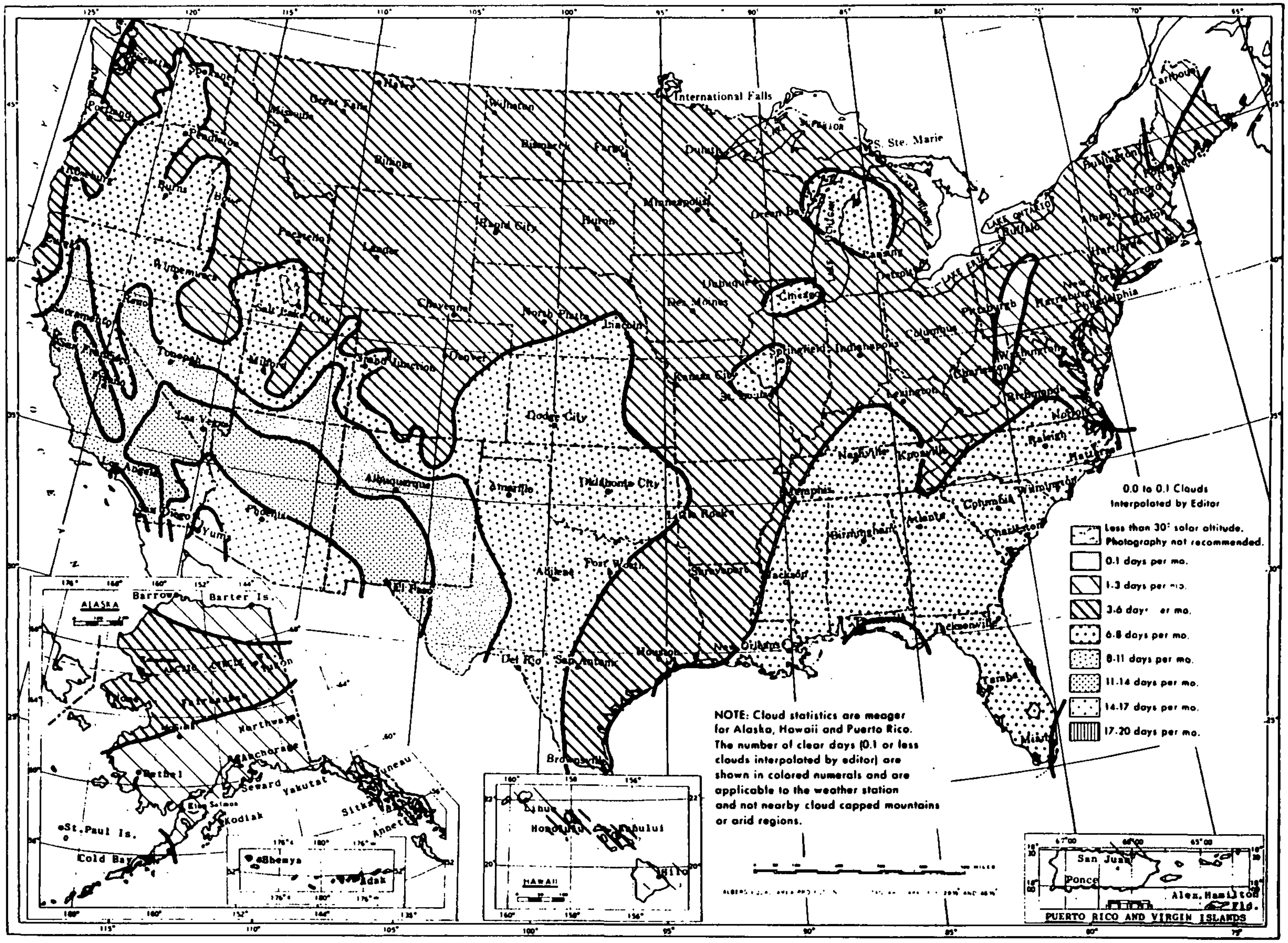

Figure 2-10.– May clear-day map for the United States and Puerto Rico.

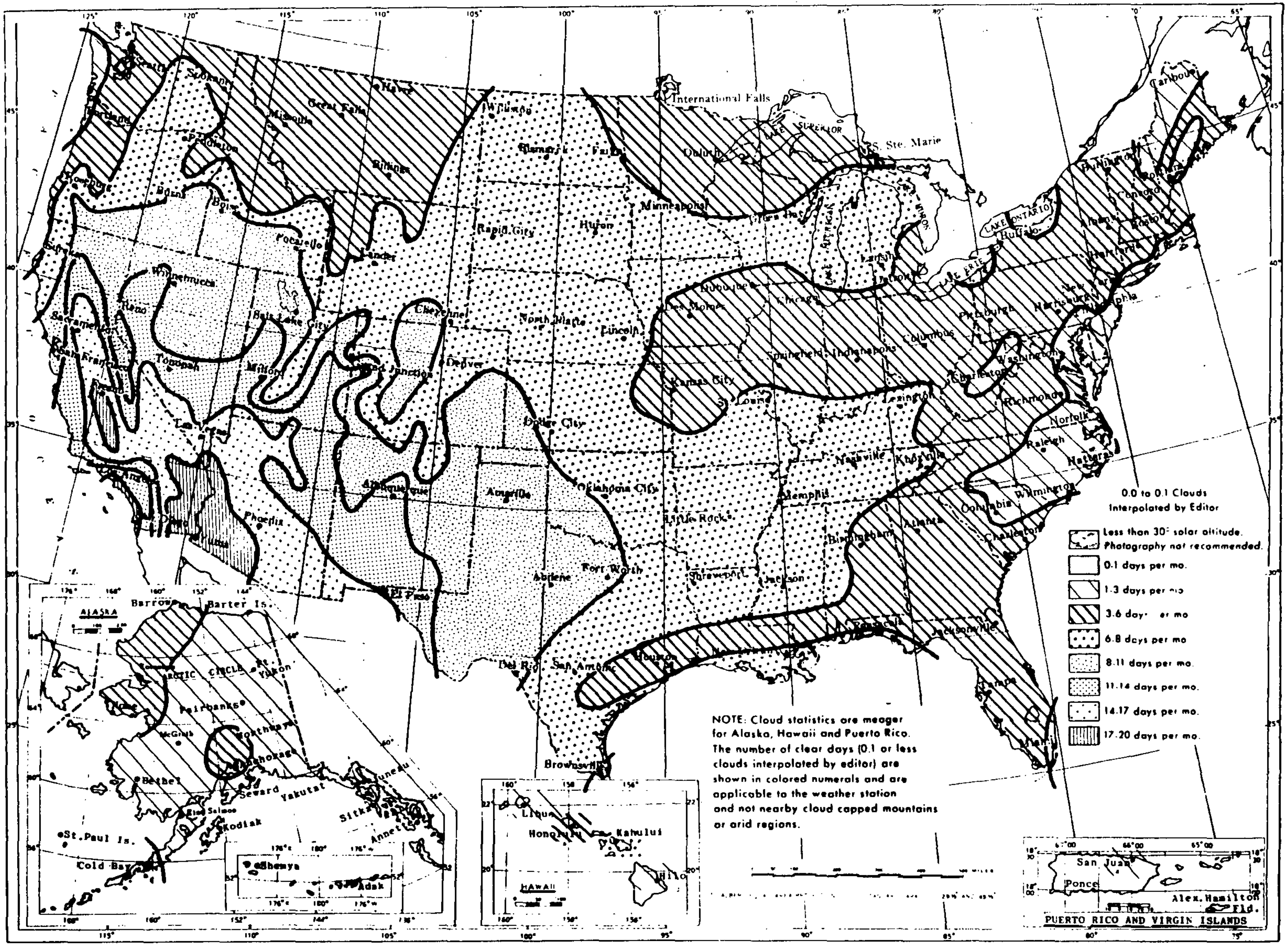

Figure 2-11.– June clear-day map for the United States and Puerto Rico.

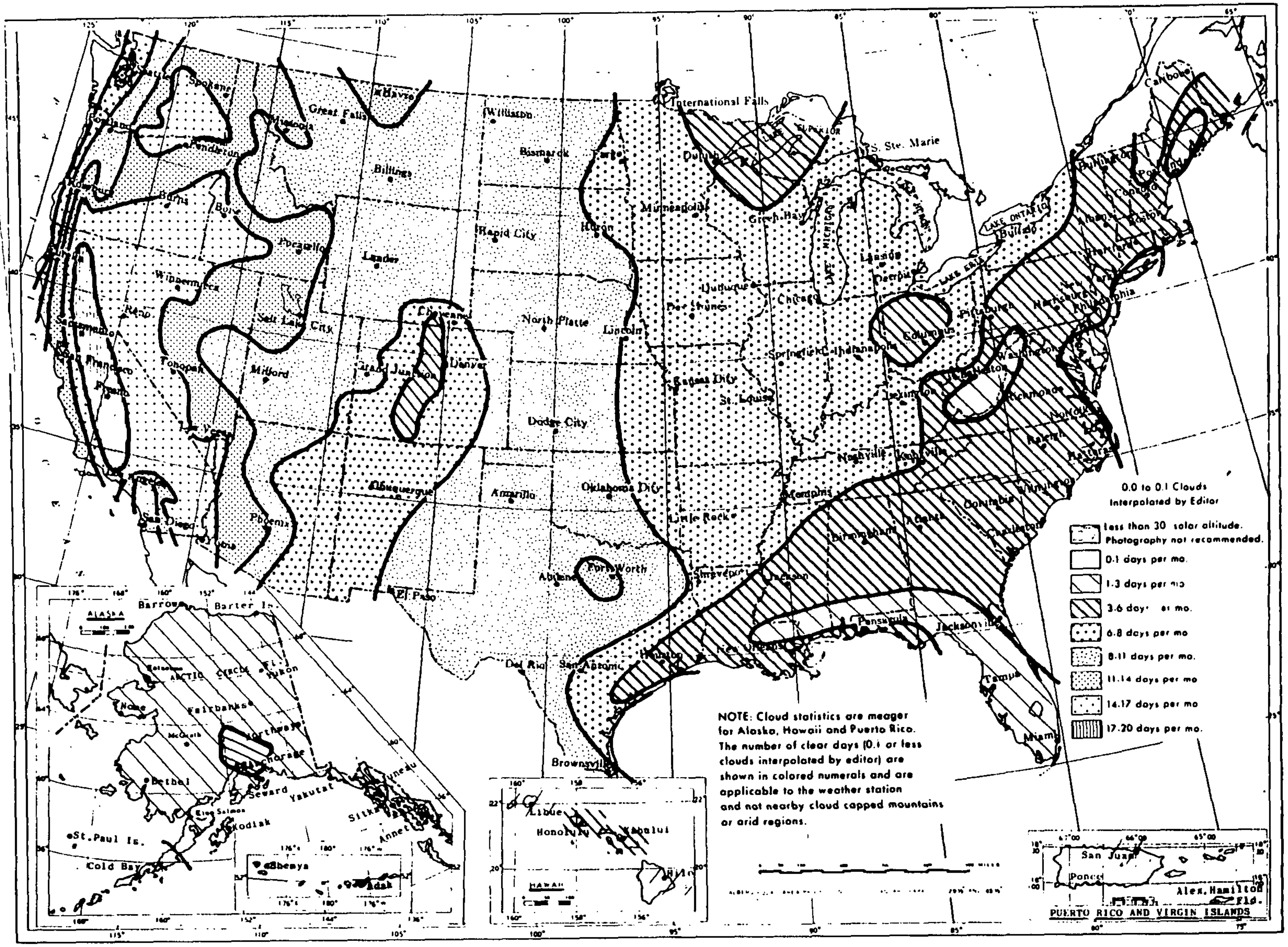

Figure 2-12.– July clear-day map for the United States and Puerto Rico.

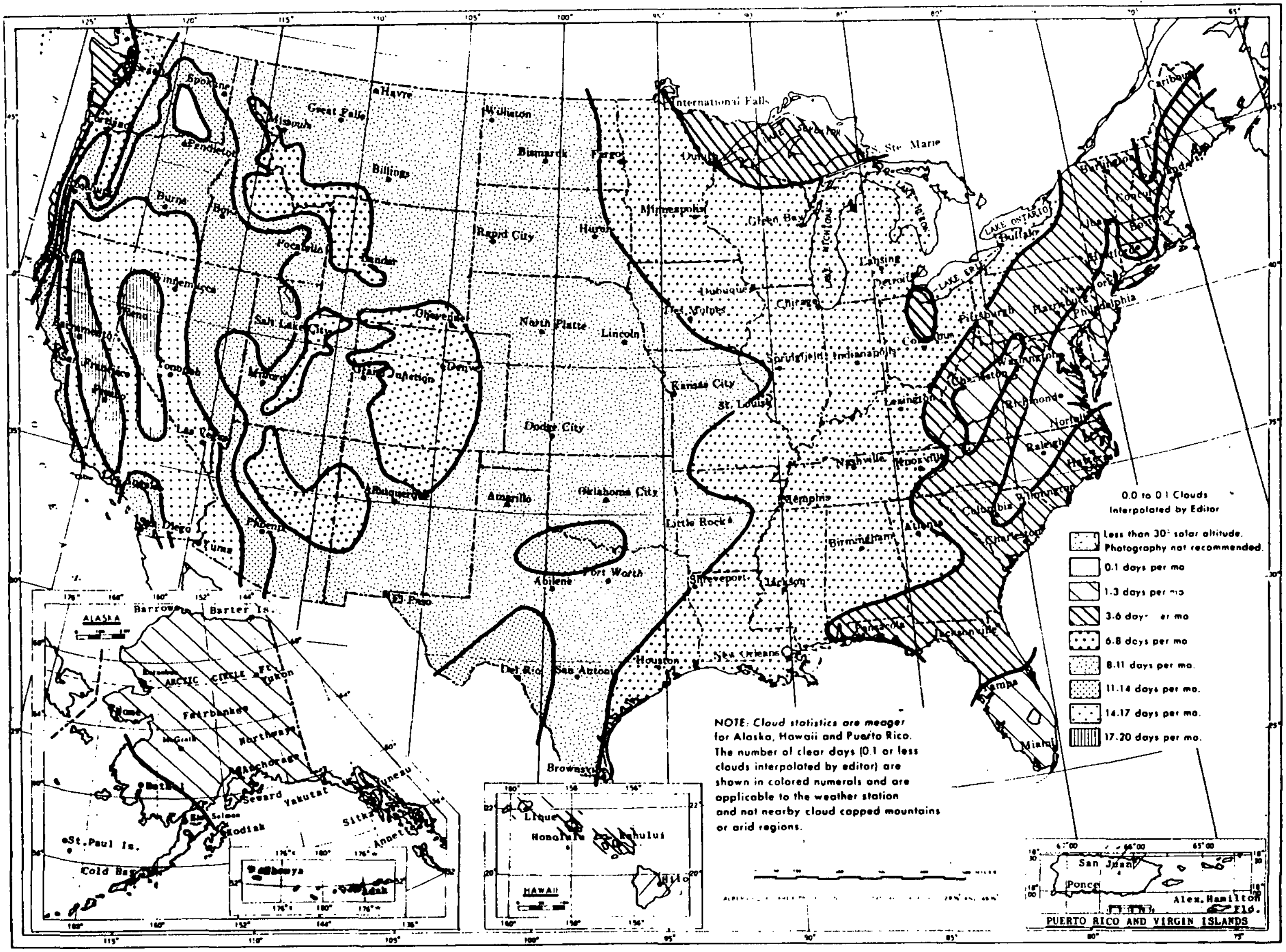

Figure 2-13.- August clear-day map for the United States and Puerto Rico.

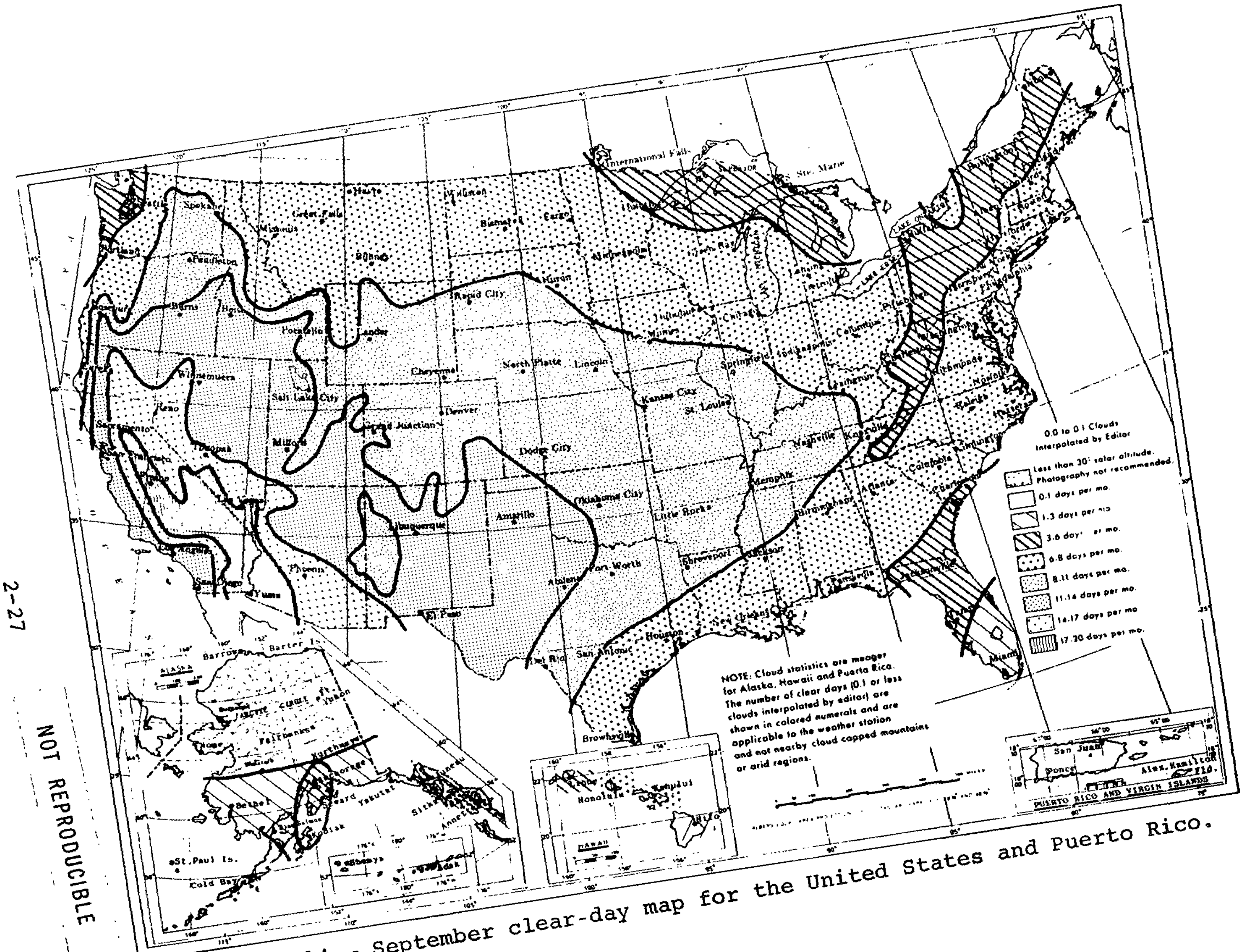

Figure 2-14.– September clear-day map for the United States and Puerto Rico.

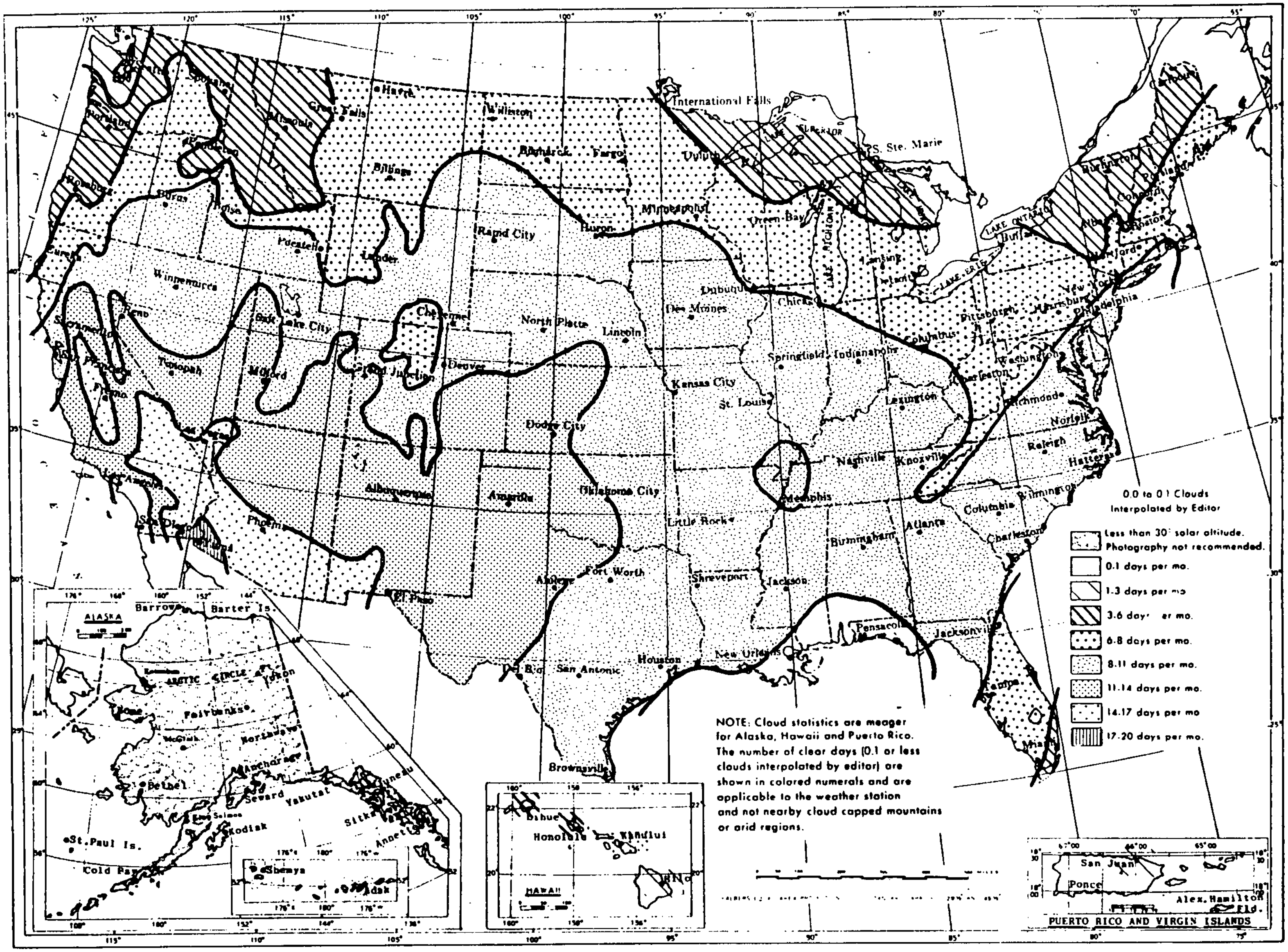

Figure 2-15.– October clear-day map for the United States and Puerto Rico.

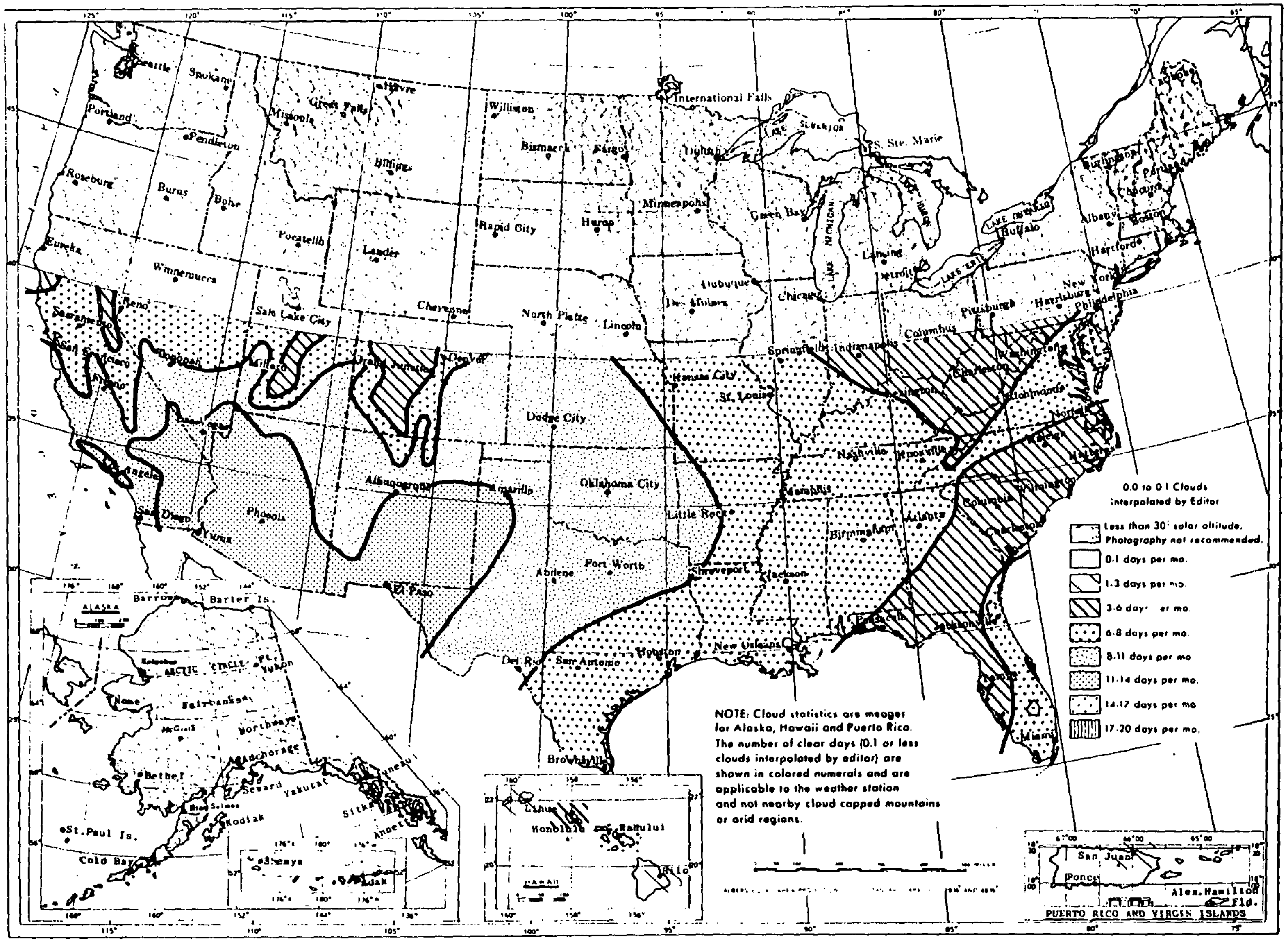

Figure 2-16.– November clear-day map for the United States and Puerto Rico.

Figure 2-17.— December clear-day map for the United States and Puerto Rico.

for color aerial photography. The climatological data, based on many years of U.S. Weather Bureau observations, have been interpolated to reflect 10 percent or less cloudiness at any location in the United States. Thus, if high solar altitudes are required, areas within the northern latitudes should not be overflown during November through January.

2.7.1.8 Weather considerations: How critical is the appearance of recent weather, such as snow cover or localized flooding, on the imagery? In most cases these effects should not be present in the data, but they may be tolerated where they only partially cover the area and offer no interference with the features of interest.

However, even if the area to be photographed is within a highly probable clear area, consideration still must be given to how much cloud cover and/or haze can be tolerated before the imagery is degraded beyond use. High-altitude aircraft (40,000 ft or 12,200 m and above) are more affected by clouds and haze than the low- and medium-altitude aircraft. The low- and medium-altitude aircraft sometimes can fly under cloud cover or overcast skies, depending on the intended uses of the photography. Also, because of the smaller area covered on each frame of low- and medium-altitude photography and because of the thin atmospheric layer between the camera and the target, the aircraft are less hampered by haze. Therefore, to assist in alleviating the above problems, consideration should be given to the general expected weather conditions. If morning haze or fog is a potential problem, late morning or afternoon flights should be planned; conversely, if afternoon cloud-cover buildup is anticipated, morning flights should be planned.

2.7.1.9 Photoproduct considerations: What photoproducts will be used in the analysis: paper prints? positive transparencies? negatives? Transparencies designed for light-table viewing show maximum detail and better color rendition, but prints are less expensive, less easily scratched, and more suitable for field use. Transparencies are recommended for use in the office and paper prints for fieldwork. Occasionally, existing negative transparencies can be interpreted in lieu of paper prints, and negatives can be used to highlight certain subjects.

2.7.2 Major aerial photographic considerations. The reliability of measurements and maps derived from aerial photography depends on the geometric principles that relate the photographic image positions to the corresponding ground positions. Three general sources of error can disrupt this geometric relationship:

- Conditions for obtaining and preserving the original negatives
- Accuracy of the information transfer from the original negatives to the compilation product
- The lack of a level, flat, or smooth ground surface

2.7.2.1 Acquiring and preserving the original negatives: If the user intends to use his data for photogrammetric purposes, such as either analog or analytical mapping, he should be aware of some of the inherent problems that have come about during data acquisition. Theoretically, to obtain good usable photographs and to prepare the analysis products in the most economical way, the following conditions should be met:

- Each exposure must be made at the prescribed predetermined position and altitude, along the planned flight line.
- The optical axis of the lens should be as close to vertical as possible at the instant of exposure.
- The camera should have stable and known metrical characteristics and should be in calibrated adjustment, prior to data acquisition.
- The emulsion-bearing surface of the photographic film or plate should be flat and properly oriented with respect to the lens at the instant of exposure.
- The emulsion should have uniform thickness and give infinite resolution.
- The dimensional stability of the film base should be the best obtainable.
- Atmospheric conditions during photography acquisition should be the best possible.

It is impossible to satisfy all of these conditions concurrently. Therefore, the data user should know what to look for and how to overcome unavoidable shortcomings in the data products. A discussion of these seven subjects and their respective effects on the data user follows.

Even with modern high-speed aircraft, the effects of buffeting winds, headwinds, tailwinds, thermals, and crosswinds will cause even the most expert pilot/photographer team to miss the exact planned position for exposure. This can cause coverage gaps (holiday areas), improper scales, or scale variations.

Wind effects and the pilot's attempts to correct for them can cause the aircraft to oscillate about its pitch, roll, and yaw axes. The results of such deviations are shown in figure 2-18. Some of the aircraft's deviations can be accommodated by a modern gimbaled automatic compensating camera (stabilized) mount. Such a mount seeks to maintain the camera's optical axis in a vertical position at all times.

The extent of these deviations may be ascertained and appropriate corrections or rectification undertaken. The instant-of-exposure position and orientation may be recovered by mathematical, optical, or mechanical photogrammetric techniques. Figures 2-19 and 2-20 show the effect that various degrees of tip or tilt will have on distance and area measurement on uncorrected photography.

Forward movement of the camera during film exposure will cause the image to be smeared on the photographic emulsion. An aircraft traveling at 965 kph (600 mph), taking a photograph with an exposure time of 1/200th second, will move 1.34 m (4.4 ft) during the time the shutter remains open. Generally, this is no great problem for 1:60,000-scale imagery. The resulting image smear on the emulsion would be 0.00034 cm (0.00088 in.) in the instance cited. This can be

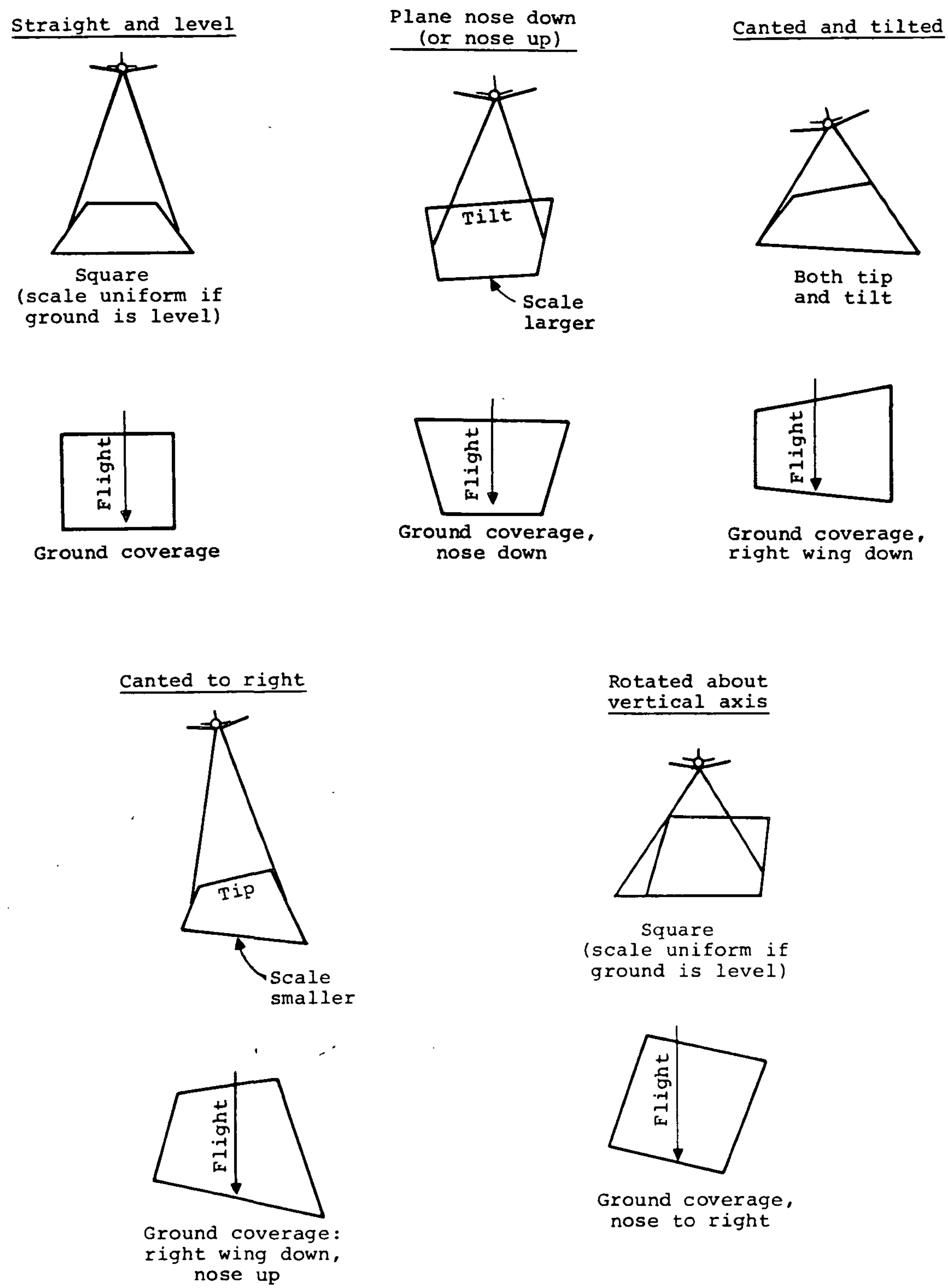

Figure 2-18.– Effective scale and ground coverage variations resulting from not flying straight and level.

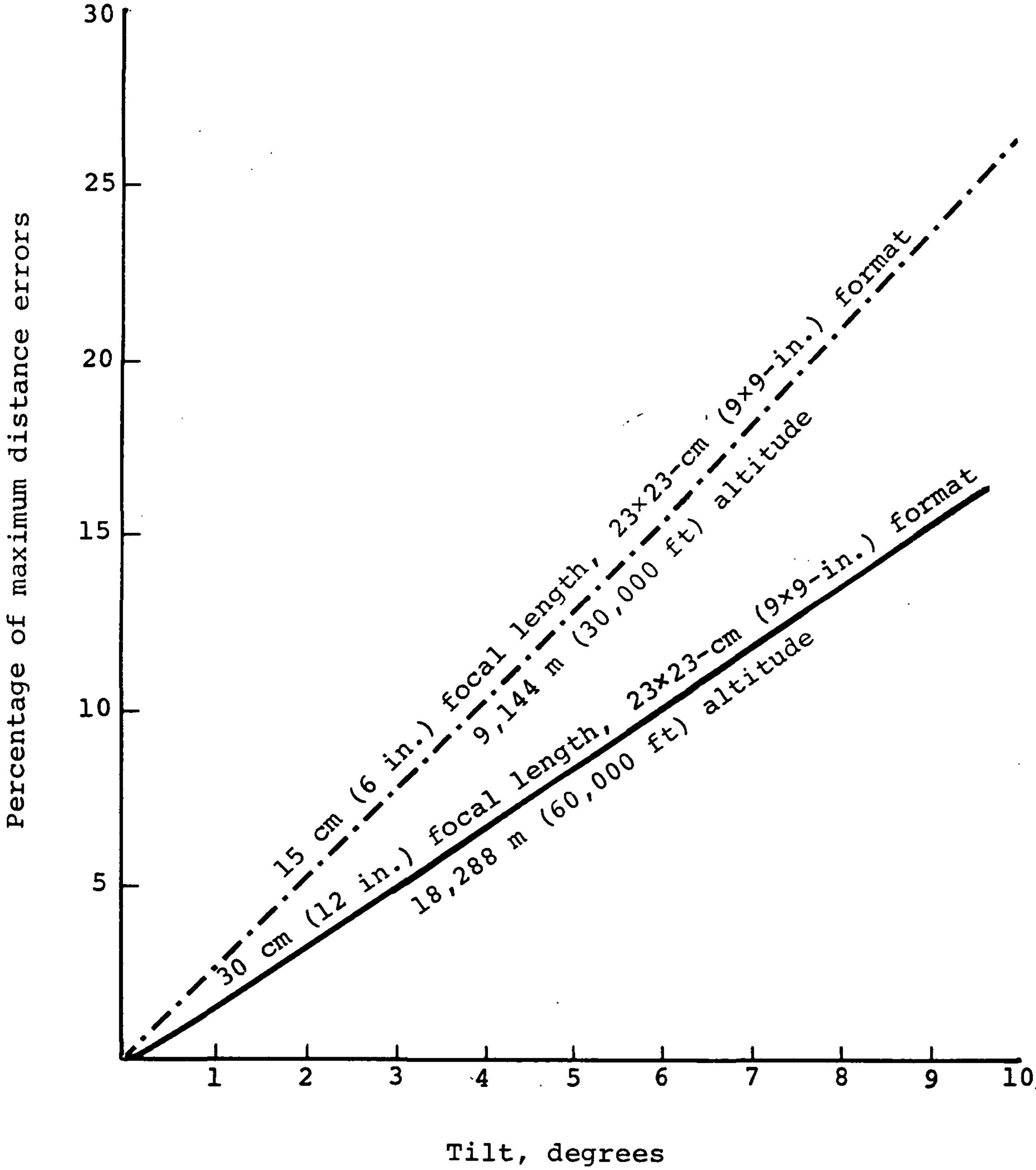

Figure 2-19.— Maximum errors in distance derived from tilted-frame photography (expressed as a percentage of the true distance), assuming flat terrain.

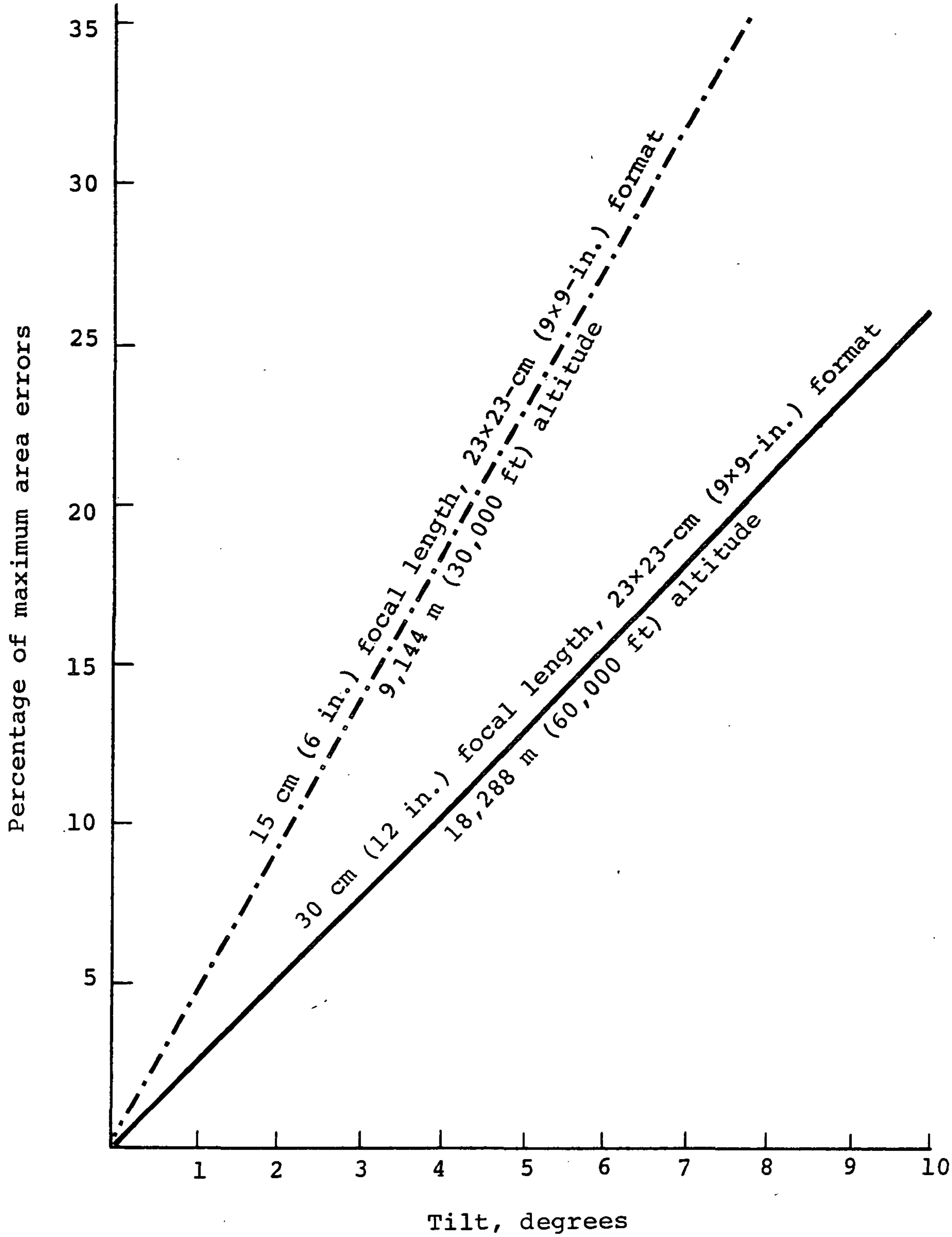

Figure 2-20.— Maximum errors in areas derived from tilted-frame photography (expressed as a percentage of the true distance), assuming flat terrain.

remedied for larger scale photography by reducing the aircraft speed, using faster film emulsions and faster camera lenses, or using a camera that moves the film during exposure at a rate that compensates for relative camera-to-ground movement (called image motion compensation or IMC).

Most modern aerial cameras have a vacuum system which holds the film perfectly flat against the film platen during exposure. After exposure the vacuum releases, the film advances, and the vacuum is restored. The film platen contains numerous tiny holes to facilitate operation of the vacuum. Occasionally, some of these become clogged, causing the film to flatten only in certain areas. This causes a distorted image in the areas that are improperly flattened. Out-of-focus imagery over an entire frame usually indicates a complete vacuum failure, which can cause totally useless data, and necessitates a reflight.

Modern emulsions on stable base film are usually adequate for most forestry applications regarding spatial distortions caused by emulsion creep or film base stretch. Only for the most exacting measurements does this cause serious concern.

Distortion of the ground image by refraction can usually be disregarded except where very critical measurements are being made. The most serious atmospheric considerations are clouds, haze, and smoke. These can seriously hamper the interpretation of ground detail.

2.7.2.2 Accuracy of the information transfer: Because of the risk of mistreatment, the original film is rarely used for analysis. A duplicate film product is usually generated for analysis purposes. The most dimensionally stable copies are those made on glass plates, usually called diapositives; these are followed by film transparencies and the least stable of all, paper prints. Some stable mylar bases produce excellent prints.

Extreme care and great skill in processing the original film and printing the duplicates are necessary to prevent the introduction of intolerable spatial errors. Improper temperature or chemical treatment can cause expansion, shrinkage, stretching, warping, curling, or tearing of the film emulsion or base. Spectral distortions can also be introduced by improper lighting, filtration, copy film, or temperature, or by chemical mishandling.

2.7.3 Data acquisition. Aerial photography may be acquired either by purchase from existing stocks or through new photocoverage for particular project requirements. In either case the data requirements in section 2.7.1 can serve as a guide.

2.7.3.1 Purchase of existing aerial photography: Existing aerial photography can be purchased from both government and private sources. Two principal sources of available data are identified below.

The "Status of Aerial Photography in the U.S." in map index form is available from

Map Information Service
Geological Survey
U.S. Department of the Interior
Washington, D.C. 20242

This map index (fig. 2-21) shows, by county, all areas of the United States that have been photographed by or for the U.S. Agricultural Stabilization and Conservation Service, Soil Conservation Service, Forest Service, USGS, Corps of Engineers, Air Force, National Oceanic and Atmospheric Administration, and various commercial firms. Names and addresses of agencies holding the photonegatives are printed on the back of the map, and inquiries should be sent directly to the appropriate organization.

In addition, users may obtain information on the availability of NASA Earth Resources Survey Program aircraft photography and certain other data from the Earth Resources Observations System (EROS) Data Center at

EROS Data Center
Sioux Falls, South Dakota 57198

Figures 2-22 through 2-24 comprise the index maps of NASA/JSC Earth Resources Aircraft Program coverage. The available aerial photography products and costs appear in figure 2-25.

2.7.3.2 Acquiring new photocoverage: Several government agencies and many private contractors fly aerial photographic missions. The Forest Service regularly does aerial mapping

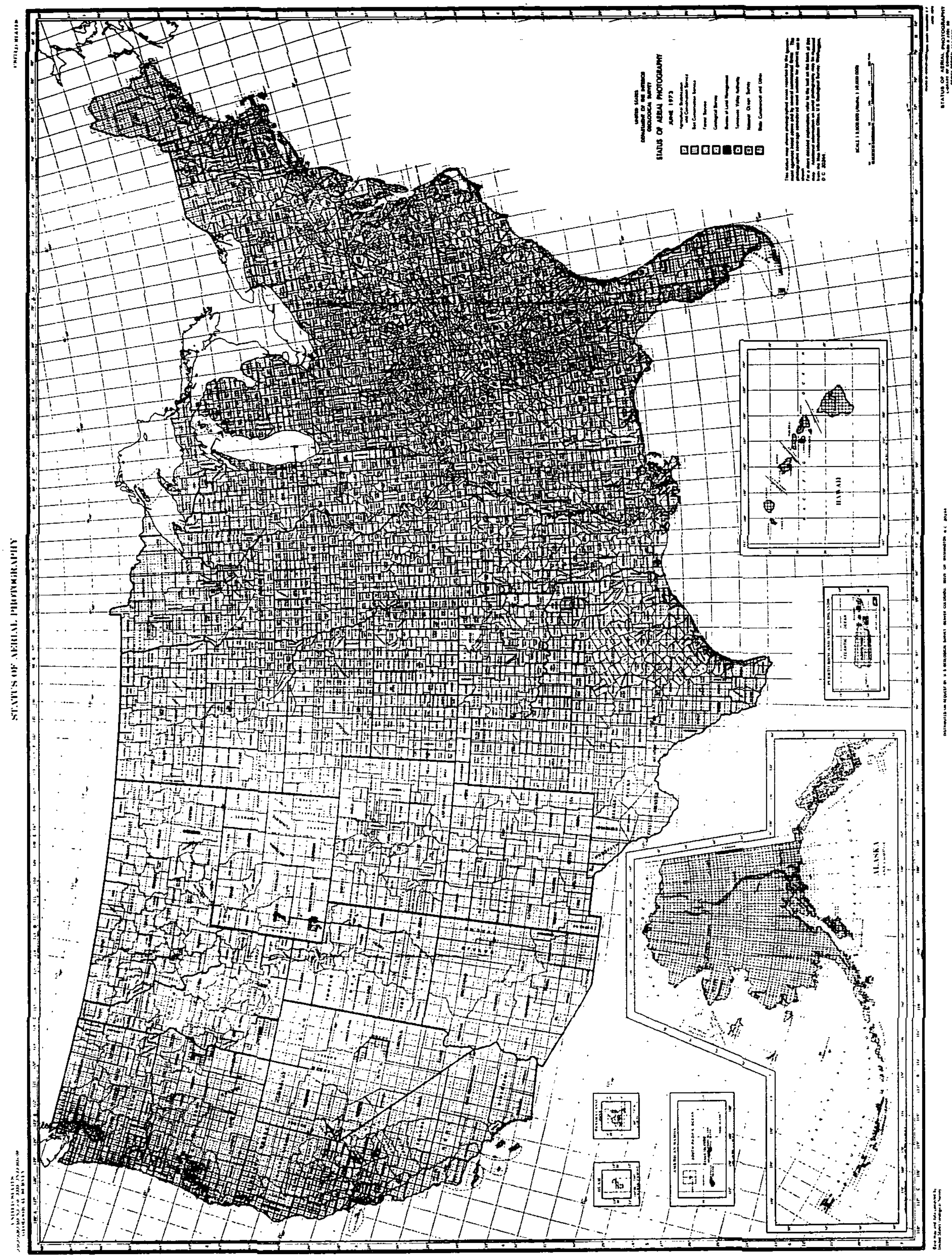

Figure 2-21. - Status of aerial photography in the United States.

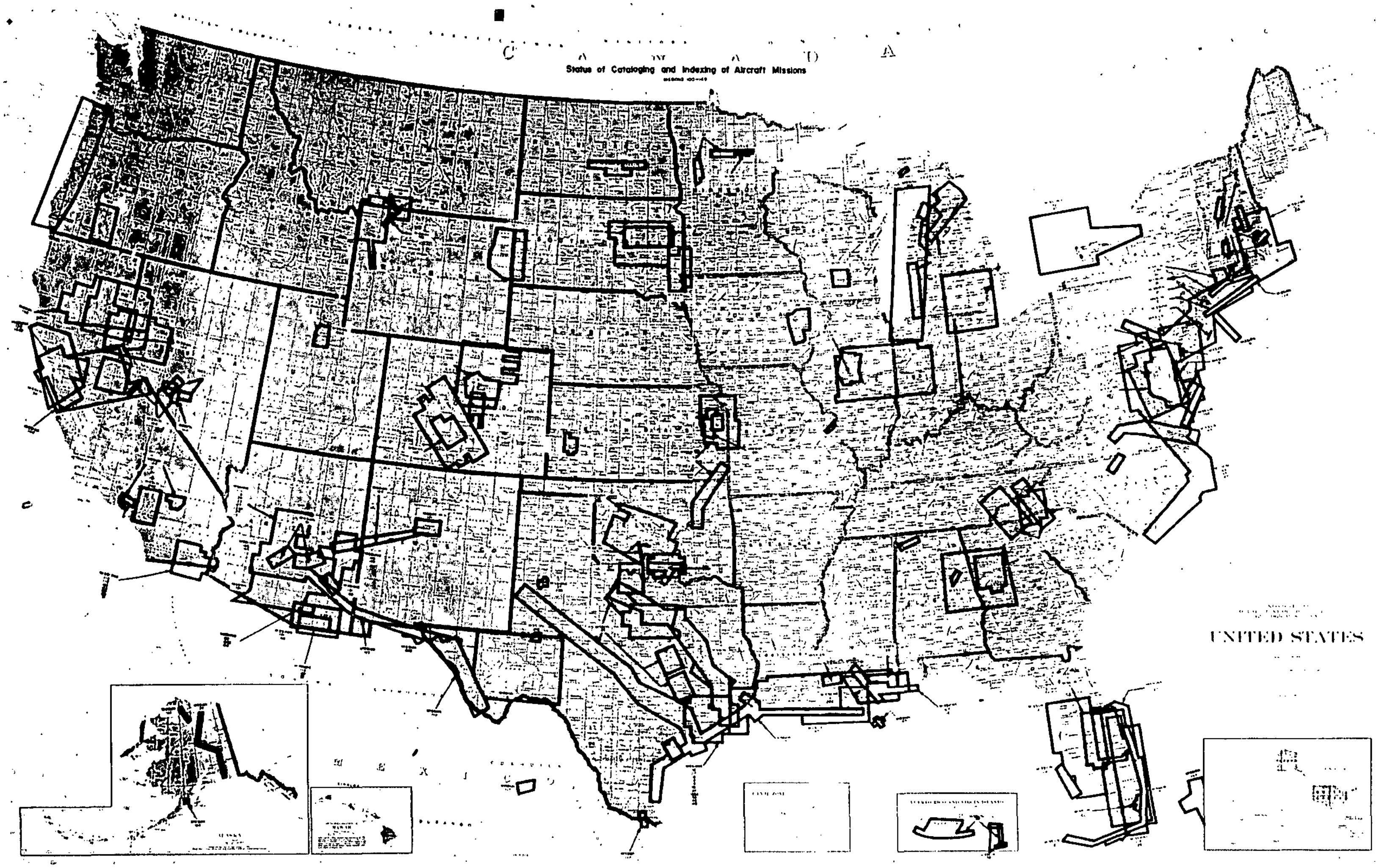

Figure 2-22.– NASA/JSC aircraft program remote sensor data coverage map, Missions 100 through 149.

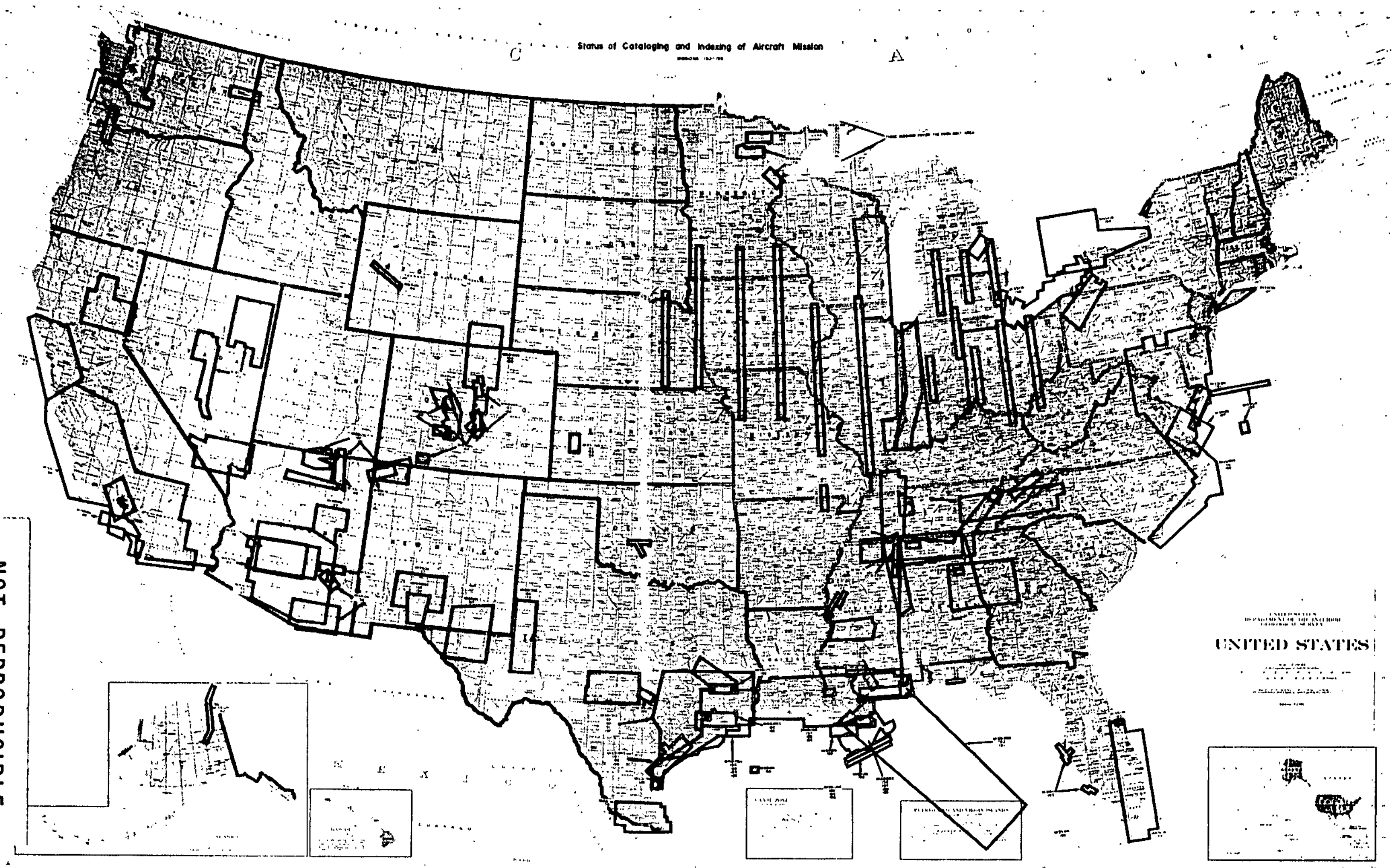

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Figure 2-23.– NASA/JSC aircraft program remote sensor data coverage map, Missions 150 through 199.

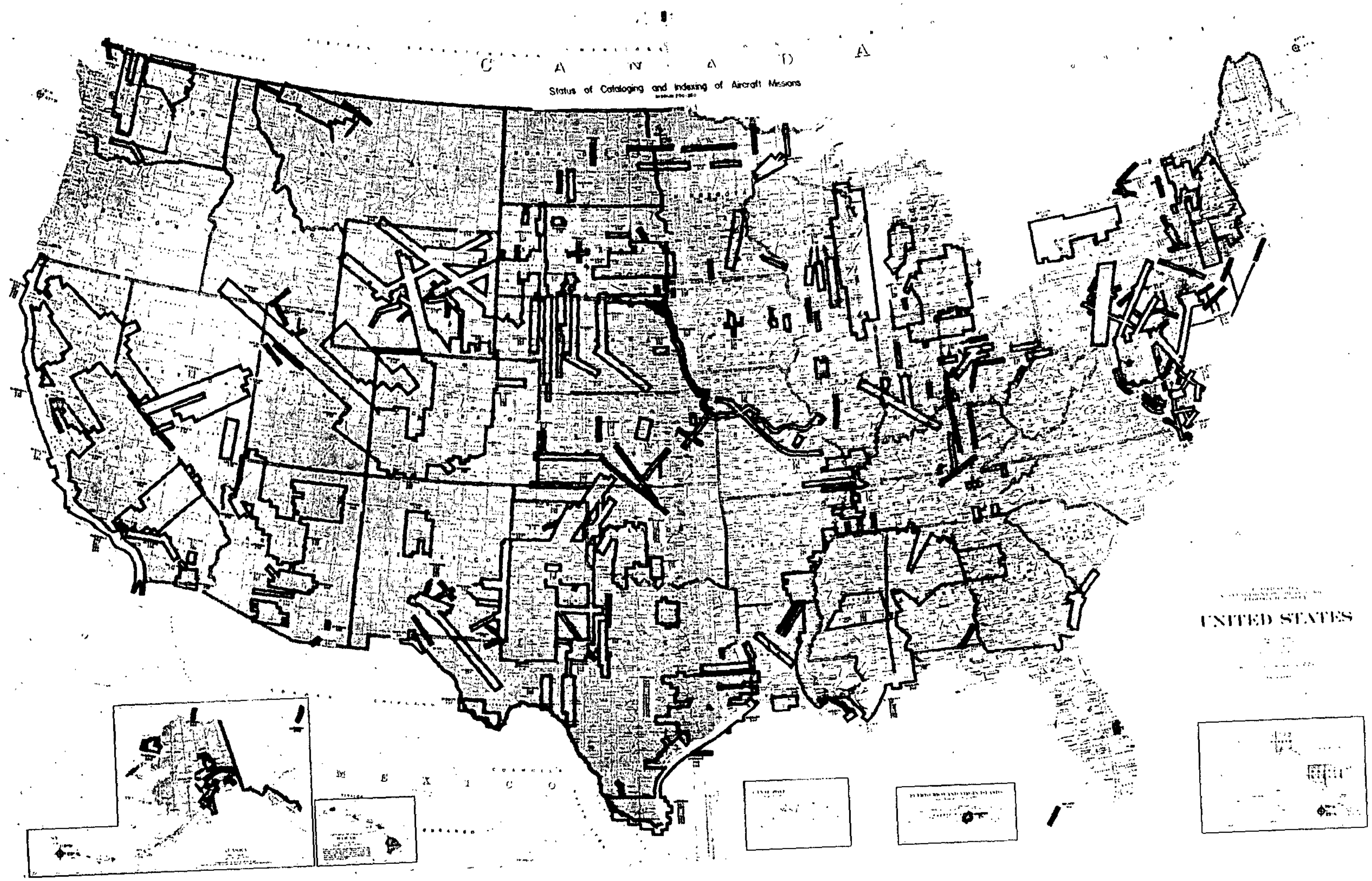

Figure 2-24.– NASA/JSC aircraft program remote sensor data coverage map, Missions 200 through 250.

EROS DATA CENTER STANDARD PRODUCTS

SATELLITE PRODUCTS

Sept. 1, 1974

ERTS DATA

Image Size	Scale	Format	Black & White Unit Price	Color Composite Unit Price
2.2 inch.	1:3369000	Film Positive	$ 2.00	N.A.
2.2 inch.	1:3369000	Film Negative	2.00	N.A.
7.3 inch.	1:1000000	Film Positive	3.00	12.00
7.3 inch.	1:1000000	Film Negative	3.00	N.A.
7.3 inch.	1:1000000	Paper	2.00	7.00
14.6 inch.	1:500000	Paper	5.00	15.00
29.2 inch.	1:250000	Paper	12.00	30.00

COLOR COMPOSITE GENERATION *(When not already available)

Image Size	Scale	Format	Unit Price
7.3 inch.	1:1000000	Printing Master **	$ 50.00

* Color composites are portrayed in false color (infrared) and not true color.
** Cost of product from this composite must be added to total cost.

COMPUTER COMPATIBLE TAPES

Tracks	b.p.i.	Format	Set Price
7	800	4-tape set	$200.00
9	800	4-tape set	200.00
9	1600	4-tape set	200.00

NASA ERTS CATALOGS

Title	Cost Per Volume
U.S. Standard Catalog - Monthly	$ 1.25 each
Non - U.S. Standard Catalog - Monthly	1.25 each
Cumulative U.S. Standard Catalog - 1972/1973 Volume 1 Observation ID Listing Volume 2, Coordinate Listing	1.25 each
Cumulative Non - U.S. Standard Catalog - 1972/1973 Volume 1 Observation ID Listing Volume 2 Observation ID Listing Volume 3 Coordinate Listing	1.25 each

SKYLAB PHOTOGRAPHY

S190A

Image Size	Scale	Format	Black & White Unit Price	Color Unit Price
2.2 inch.	1:2850000	Film Positive	$ 2.00	$ 5.00
2.2 inch.	1:2850000	Film Negative	4.00	N.A.
6.4 inch.	1:1000000	Paper	2.00	7.00
12.8 inch.	1:500000	Paper	5.00	15.00
25.6 inch.	1:250000	Paper	12.00	30.00

S190B

Image Size	Scale	Format	Black & White Unit Price	Color Unit Price
4.5 inch.	1:950000	Film Positive	$ 2.00	$ 6.00
4.5 inch.	1:950000	Film Negative	4.00	N.A.
4.5 inch.	1:950000	Paper	2.00	6.00
8.6 inch.	1:500000	Paper	2.00	7.00
17.2 inch.	1:250000	Paper	5.00	15.00
34.4 inch.	1:125000	Paper	12.00	30.00

See Reverse

Figure 2-25.– Listing of EROS Data Center standard products and prices.

EROS DATA CENTER STANDARD PRODUCTS*

AIRCRAFT PRODUCTS

Sept. 1, 1974

AERIAL MAPPING PHOTOGRAPHY

Image Size	Format	Black & White Unit Price
9 inch.	Film Positive	$ 3.00
9 inch.	Film Negative	6.00
9 inch.	Paper	2.00
18 inch.	Paper	5.00
27 inch.	Paper	6.00
36 inch.	Paper	12.00
Photo Index	Paper	3.00

NASA RESEARCH AIRCRAFT PHOTOGRAPHY

Image Size	Format	Black & White Unit Price	Color Unit Price
2.2 inch.	Film Positive	$ 2.00	$ 5.00
2.2 inch.	Film Negative	4.00	N.A.
4.5 inch.	Film Positive	2.00	6.00
4.5 inch.	Film Negative	4.00	N.A.
4.5 inch.	Paper	2.00	6.00
9.0 inch.	Film Positive	3.00	12.00
9.0 inch.	Film Negative	6.00	N.A.
9.0 inch.	Paper	2.00	7.00
9X18 inch.	Film Positive	6.00	24.00
9X18 inch.	Film Negative	12.00	N.A.
9X18 inch.	Paper	4.00	14.00
18.0 inch.	Paper	5.00	15.00
27.0 inch.	Paper	6.00	20.00
36.0 inch.	Paper	12.00	30.00

MISCELLANEOUS

MICROFILM

	Black & White Roll Price	Color Roll Price
16mm (100 foot roll)	$15.00	$35.00
35mm (100 foot roll)	20.00	40.00

KELSH PLATES

	Black & White
Contact Prints on Glass Specify thickness (0.25 or 0.06 inch) and method of printing (emulsion to emulsion or through film base).	$10.00

TRANSFORMED PRINTS

	Black & White
From convergent or transverse low oblique photographs.	$ 7.00

35mm MOUNTED SLIDE

35mm mounted duplicate slide where available	$ .60

ROLL TO ROLL

Roll to Roll reproductions delivered in roll carries a 50% reduction in price.

See Reverse

Figure 2-25.— Concluded.

of its areas of responsibility, and special flights can be arranged. The names and addresses of other government and private organizations through which flights may be arranged are available through the offices listed on the back of the map index sheet "Status of Aerial Photography in the U.S." (section 2.7.3.1). There are a few private contractors that currently can acquire aerial photography at a scale of 1:60,000.[5,6,7]

Addresses and activities of major aerial survey companies are described annually in the yearbook issue of "Photogrammetric Engineering and Remote Sensing," the journal of the American Society of Photogrammetry. Addresses are also available on request from Department 926, Eastman Kodak Company, Rochester, New York 14650.

When requesting a photographic flight or participating in flight planning, the following information should be furnished, based on evaluation of the factors discussed under Data Requirements Definition (section 2.7.1):

- Location of flight lines to be flown, shown on an aeronautical chart or other map, with latitude and longitude of the beginnings and ends of noted flight lines

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[5]Geosurvey International LTD, 117 Hook Road, Surbiton, Surrey KT6 5AR, England (50,000-ft, or 15,240-m, ceiling, RC10 camera).

[6]Mark Hurd Aerial Surveys, Inc., 345 Pennsylvania Avenue South, Minneapolis, Minn. 55426 (45,000-ft, or 13,716-m, ceiling).

[7]Gates Lear Jet, International Marketing, P.O. Box 1280, Wichita, Kan. 67201 (45,000-ft, or 13,716-m, ceiling, dual cameras).

- Cameras and lenses desired
- Films desired
- Filters
- Flight altitudes and/or scales
- Desired time of data acquisition (preferably a 4- to 6-week span to allow flexibility in scheduling)
- Weather constraints, such as cloud cover or recent flooding
- Time of day limits (see section 2.7.1.7, Shadow considerations)

For some applications it is desirable to coordinate ground observations, measurements, or sample-taking with the overflight. In these cases, the field-checking activities and the flight schedule should be closely coordinated.

2.7.4 Photographic or film processing and finishing. The most common types of copies used for photoanalysis and interpretation are duplicate positive transparencies and positive prints. Double-weight paper is commonly used for prints; and, although gloss finish is best for showing fine detail, a semimatte finish is preferable in map work for ink or pencil annotation.

As an example of aerial photoproduct costs, figure 2-25 lists EROS Data Center products and prices. Commercial prices may differ from those shown.

The next section of this guide covers fundamental principles of photointerpretation using products such as those discussed above.

3.0 PHOTOINTERPRETATION

3.1 Definition

The American Society of Photogrammetry states:

> "Photointerpretation using aerial photographs consists of the art and science of recognizing natural and cultural features, subtle as well as obvious, on the earth's surface and concluding therefrom valuable information."[1]

This section of the manual covers the following aspects of photointerpretation:

- Resource requirements (data, equipment, facilities, and skills)
- Preparation of photoindexes
- Preparation of photographs for stereoviewing
- Delineation of the effective area
- Photointerpretation criteria and guides

3.2 Resource Requirements

3.2.1 Data. The type of photography acquired for a given investigation will depend on the pertinent data requirements as outlined in section 2.7.1. Material required for most photoanalysis projects includes the following:

- Photocopies for analysis (positive transparencies, positive contact prints, and/or enlargements)

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[1]American Society of Photogrammetry, The Manual of Photographic Interpretation, George Banta Company, Menasha, Wis., 1960.

- Photocopies for preparation of index mosaics, usually unrectified positive paper prints
- Base maps of the study area for making photo-coverage index maps and for transfer of interpretation results (scale depends on factors such as the nature of the study, the scale of imagery, and organizational practices and standards)
- Map indexes for ordering and cataloging maps
- Ancillary data, that is, existing resource maps, contour maps, etc.

3.2.2 Equipment and facilities. The materials listed in table 3-I are recommended for a sustained program of photo-interpretation, including stereoscopic analysis.

3.2.3 Skills and resources. A sustained photo-interpretation effort will require the following skills and resources:

- Map reading and simple mosaicking
- Photointerpretation experience
- General familiarity with natural and cultural feature associations and activities in the area being studied
- Maintained files of photographs, maps, and investigation products
- Method for reproducing, enlarging, and reducing output products

TABLE 3-I.— PHOTOINTERPRETATION EQUIPMENT AND SUPPLIES

Item	Description
[a]01	Light table with multiple film viewing and stereoscope mounting capability.
02	Light table with an illuminated viewing area of suitable size to accommodate the stereoscope and provide working area (figs. 3-1 and 3-2).
03	Lamp of a nonglare, desk-top, swivel-base, fluorescent type.
04	Reducing/enlarging projector for transferring film overlay information to base maps: A Kail reflecting projector or its equivalent is satisfactory where no rectification is necessary; where rectification is necessary and it is advisable to rectify mechanically, a rectifying enlarging projector with a table for hand drafting, such as the Kargl type, is required.
05	Stabilene drafting films with clean ink surface, base thickness 0.008 cm (0.003 in.), and size approximately 22 by 28 cm (8-1/2 by 11 in.), for making photo-overlays.
06	Frosted acetate, 5 mil, for making base map overlays.
07	Rapidograph pens with 1, 0, 00, and 000 points.
08	Lens stereoscope, or mirror stereoscope with binoculars (figs. 3-3, 3-4, and 3-5).
[a]09	Bausch & Lomb Zoom 70 and model 240 stereoscopes with × 10 and × 20 eyepieces (fig. 3-6).
10	Parallax bar or stereometer for measuring heights of objects in photographs.
11	Engineer's scale, 30 cm (12 in.) with 50 gradations to the inch.
12	Scale gradated in millimeters.
13	Polar planimeter for measuring areas on photographs.

[a]Optional.

TABLE 3-I.– Concluded.

Item	Description
14	Dot grid for measuring areas on photographs.
15	Drafting instruments: triangles, T-square, protractor (360° azimuth).
16	Tube magnifier with millimeter reticle.
17	Cotton gloves for handling film.
18	Rubber cement.
19	Camel-hair lens brush.
20	Drafting tape.
21	Metal eraser shield.
22	Offset eraser.
23	Thin lead automatic pencils with red, green, brown, and blue leads.
24	Felt-tip pens.
25	Poster board.
26	Scissors.
27	Map measure.
28	File and map cabinets for storing photographic and map products.
29	Needles for point-picking on photographs.
30	China-marking pencils or water-soluble ink pens.
31	Tracing paper and lens cleaning tissue.
32	Cotton swabs and liquid solvent cleaner for photographs.

NASA S-74-23811

Figure 3-1.— Light table (Richards model GFL-3040).

NASA S-74-23812

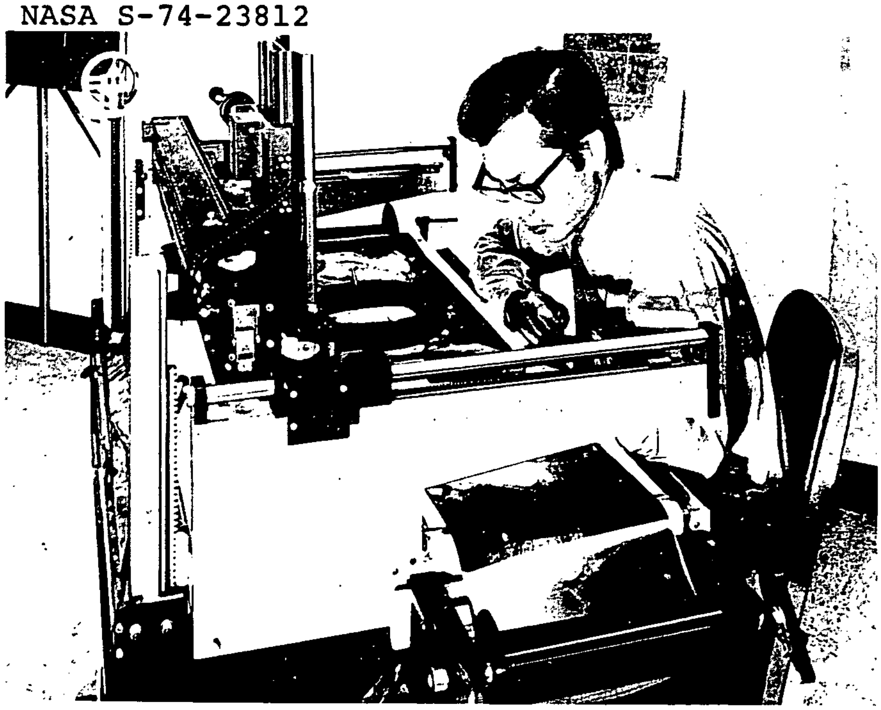

Figure 3-2.— Light table (Richards model MIM-11100).

NASA S-74-23806

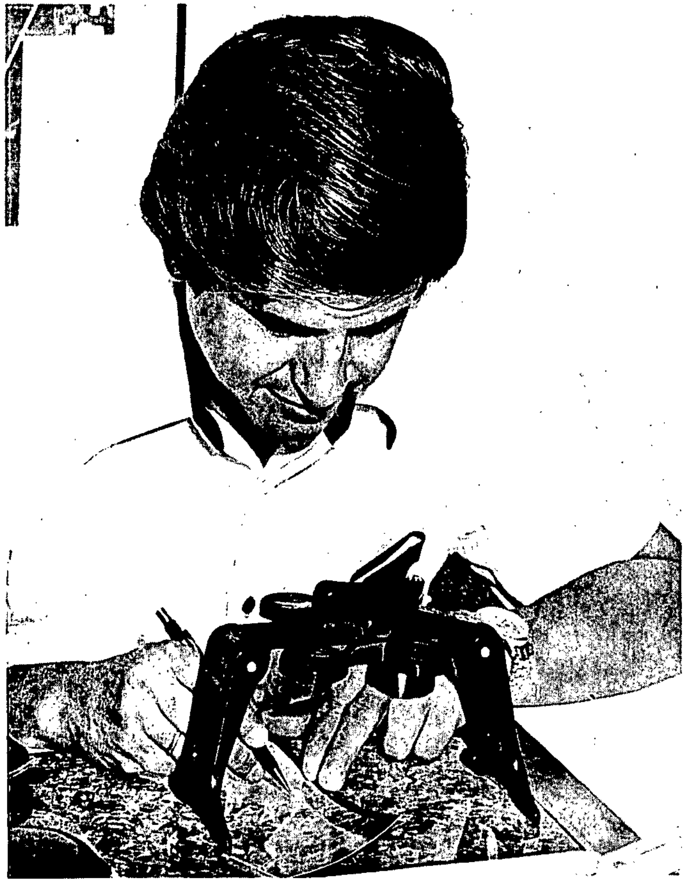

Figure 3-3.— Abrams folding-type lens stereoscope, model CB-1.

NASA S-74-23808

Figure 3-4.— Old Delft scanning stereoscope.

NASA S-74-23809

Figure 3-5.— Fairchild F-71 stereoscope with binoculars.

NASA S-74-23810

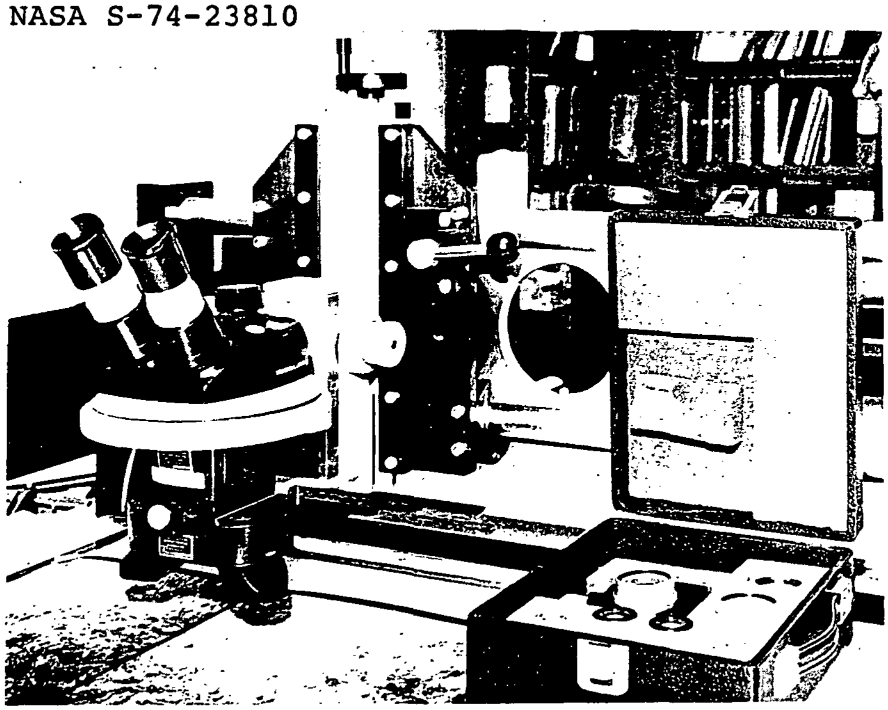

Figure 3-6.— Bausch & Lomb Zoom 70 stereoscope with scanning stage.

3.3 Photographic Preparation

In photographic preparation, the imagery is reviewed for quality, and a photoindex for planning the work to be accomplished is constructed. The photographs should be checked to ensure that no gaps exist between flight lines and that the forward and side overlaps are consistent with the specifications. If any deviation from the specifications is discovered, the flight lines concerned should be reflown.

All imagery to be used should be reviewed to spot any coverage problems and to evaluate the quality of the reproduction products acquired. Problems include clouds, snow cover, terrain or cloud shadows, hot spots, smoke, haze, or other features hampering the analysis. Image quality factors include color, tone, and contrast. Color and color IR film sometimes present tonal differences because the films are sensitive to lighting intensities and because variations may occur between film lots.

3.4 Preparation of Photoindexes

Photoindexes are used to document and illustrate flight-line coverage, plan the analysis, and provide a reference display. Two types of indexes are commonly used: the map overlay index and the composite photoindex.

3.4.1 <u>Map overlay index</u>. The steps below should be followed when preparing a map overlay index.

- Step 1 — Acquire suitable maps. The scale used should be adequate to clearly delineate and differentiate individual photoframes and adjacent flight-line coverage. This in turn depends on the altitude of data acquisition and camera focal length, which determine the area of ground covered by each photoframe. For high-altitude, small-scale imagery, a USGS 1:250,000 topographic map or a 1/2 in. = 1 mi (1.27 cm = 1.61 km) Class A Forest Service Administrative Map is acceptable. For lower altitudes, larger scale imagery, a larger scale map, such as 1:24,000, 1:31,680, or 1:62,500, might be preferable.

- Step 2 – Place a clear or frosted overlay material on the map. Register or match the overlay to the map by tick marks or match lines.
- Step 3 – Determine the boundaries of each photoframe with regard to the map by recognizing and correlating topographic and cultural features.
- Step 4 – Plot the boundaries of the photoframe on the overlay. For practicality, plot every other frame or some other multiple. The choice is usually determined by the relationship of photographic scale to the index map scale; that is, when every frame is plotted, if the frame density makes the map difficult to follow, an interval of two, three, or more frames should be used.
- Step 5 – Annotate frame numbers or other identifying information on the overlay (fig. 3-7).

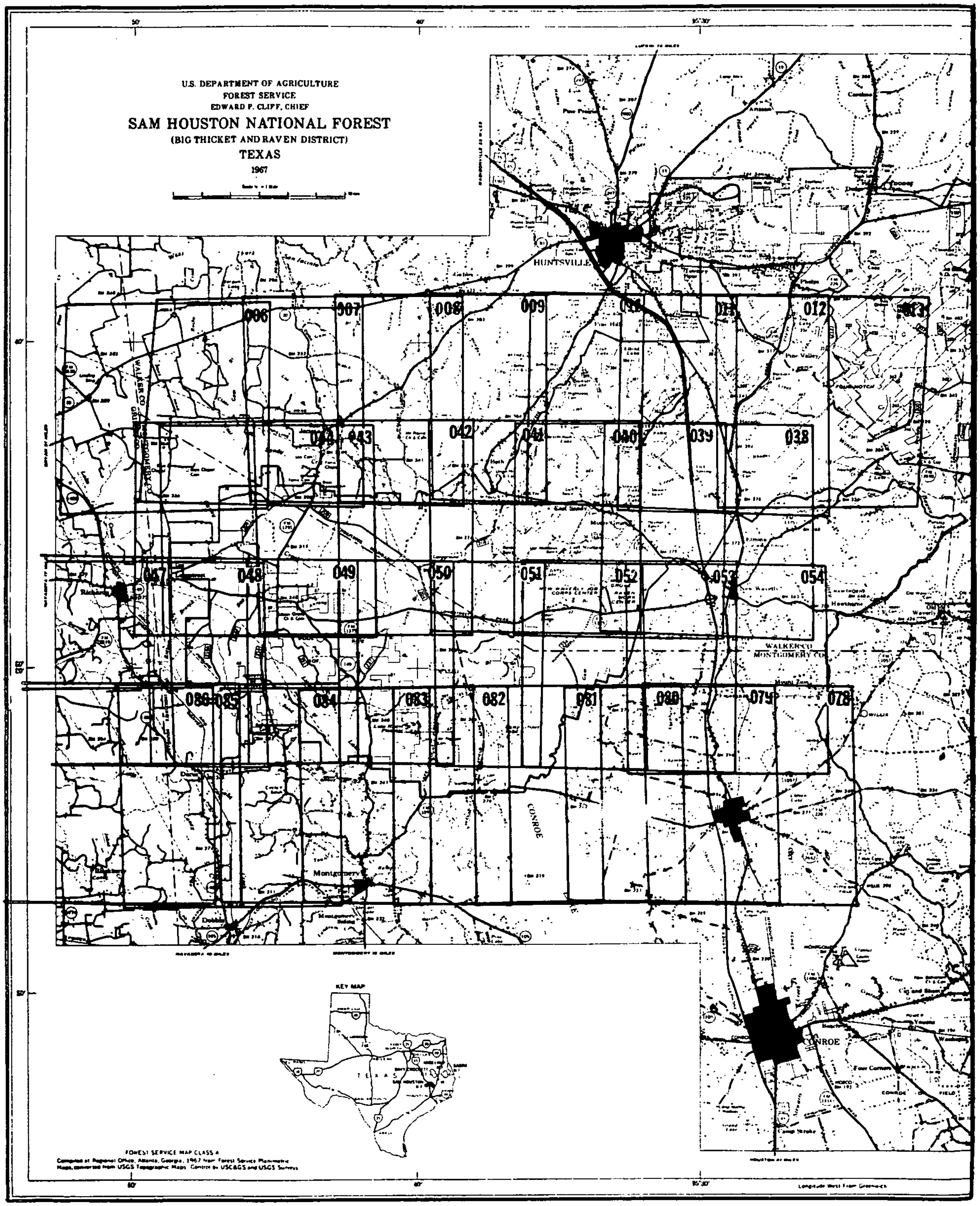

Figure 3-7.— Construction of photoindex map overlay.

NOT REPRODUCIBLE

3.4.2 Composite photoindex. The composite photoindex is an uncontrolled mosaic of the aerial photographs to be used and is constructed as follows:

- Step 1 — Assemble prints of the photographs to be mosaicked. Trim the borders or margins, leaving only the image area; write any identifying marginal information on the back of the print.
- Step 2 — Orient and match up adjacent prints. Because of slight vertical deviations during photography, the match will seldom be perfect.
- Step 3 — Tape, cement, or staple the properly matched photographs to a suitable base. Attachment to plywood or other type of semipermanent base is preferred for a photoindex that will be used for extended periods (fig. 3-8).

The composite (mosaicked) photoindex can be reduced with a copy camera and used as a reference tool, project planning aid, or catalog for ordering additional copies prior to project completion.

Either kind of photoindex will reveal total photocoverage area, existence and location of gaps, effects of camera malfunctions, relationships among major terrain features, geographic coordinates, study area boundary relationships, and frame identifications for forward lap and sidelap photocoverage. In addition, the composite photoindex shows exposure problems, cloud or snow cover, and will serve as a guide for field checks.

Figure 3-8.— A portion of the Houston Area Test Site high-altitude photoindex prepared by matching and stapling down photoframes.

3.5 Use of Stereoscopic Instruments

This section provides information on stereoscopy and the various types of stereoviewing instruments used in photointerpretation and photogrammetry.

Aerial photography suitable for stereoscopic analysis is obtained by setting the aerial camera intervalometer so that the shutter operates at speeds sufficient to obtain successive overlapping exposures along the flight line. The degree of overlap between adjacent frames is generally about 60 percent. Overlap parallel to the flight line is called "forward lap"; overlap between photographs on adjacent flight lines is called "sidelap." Two overlapping photographs are called a "stereopair." The three-dimensional view of the area to be analyzed is obtained by viewing the same scene in overlapping photographs with a stereoscope.

The simple lens stereoscope is the most widely used and generally the least expensive ($10 to $40). It has the advantages of relative simplicity and portability, with certain disadvantages in its limited magnification range and narrow field of view. Examples are the Abrams CF-8, Abrams CB-1 (fig. 3-3), and Ryker D-10. They may be used with prints on a sturdy work table or desk, but an illuminated viewing table is required for studying transparencies.

Mirror stereoscopes are exemplified by the Old Delft type and the Fairchild F-71 (figs. 3-4 and 3-5). They can be used with prints or transparencies on any stable working surface. They permit full physical and visual separation of the stereopair and provide full view of the entire stereoscene when used with no magnification. However, they are more costly ($200 to $3,500) and less portable. They require more maintenance than the lens type.

Binocular microscopes use a combination of lenses and prisms or mirrors to achieve stereoscopic effects. Many different types afford such features as continuously variable magnification, image rotation, optical light dimming, and film transport. They may be used to examine photography recorded as transparencies, prints, glass plates, and roll or cut film of different widths. The capabilities and specifications of binocular microscopes vary. Examples are the Bausch & Lomb Zoom 70 and model 240 (fig. 3-6). The price for basic models is in the range of $1,000 to $1,500 with optional attachments adding $1,000 to $1,500 to the cost.

3.6 Preparation of Photographs for Stereoviewing

The steps for preparing photographs for stereoviewing with a mirror stereoscope appear in the following paragraphs.

3.6.1 Orientation of the stereoscope. The orientation of the stereoscope for proper viewing is important in obtaining optimum three-dimensional study conditions and in avoiding undue eyestrain.[2]

Place the photographs on top of each other so that the detail within the 60-percent overlap area matches. Place the

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[2]American Society of Photogrammetry, Manual of Photogrammetry, George Banta Company, Menasha, Wis., 1966.

stereoscope over the photographs with the axis of the eye base parallel to the line of flight.

Slowly move each photograph outward in amounts sufficient to place them under the corresponding lens (or mirror) of the stereoscope.

To ensure that the photographs are separated by the proper distance and rotated in azimuth with respect to each other, take these preliminary steps.

Locate the principal point (PP) or center of the photograph (fig. 3-9) by drawing a pencil line from opposite fiducial marks located on the four sides or four corners of the photograph. The intersection of these lines is the PP.

Since the adjacent photographs overlap by about 60 percent, the image detail of the PP of one photograph appears on the adjacent photograph. This image detail is the conjugate principal point (CPP). Four definite points along the flight line axis, two points on each photograph, will exist in the stereoscopic overlap area of the two photographs.

Put the left photograph on a board or table using a fine needle placed through the PP. Position the right photograph carefully because the correct distance between the photographs is important.

Measure the distance from one PP to the same image point on the adjacent photograph (CPP). Separation distances

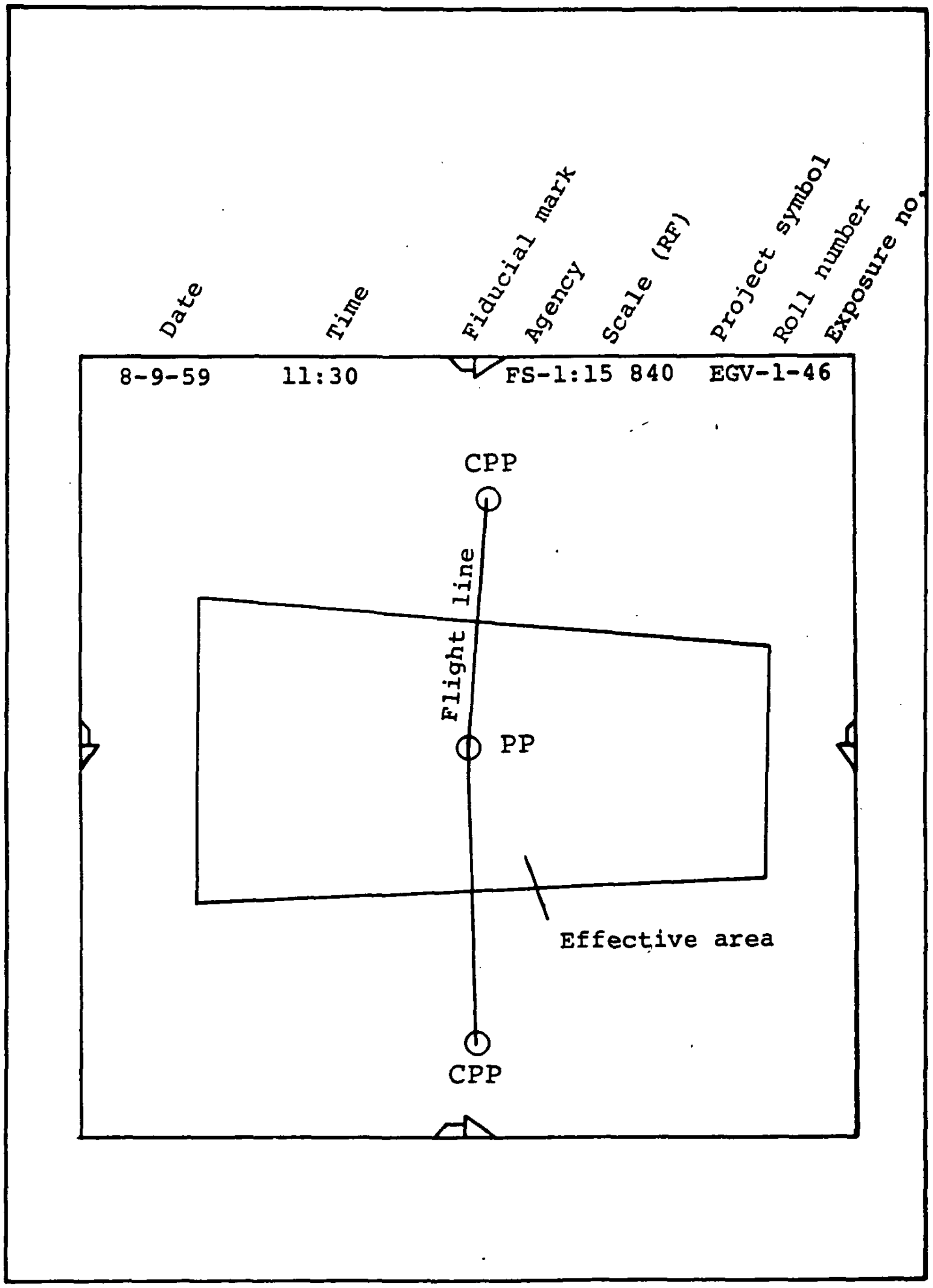

Figure 3-9.— Features for an aerial photograph.

may vary from about 5.08 cm (2 in.) for a lens stereoscope to 25.4 cm (10 in.) or more for the mirror stereoscopes.

After the right photograph is fastened to the table at the correct separation distance with a needle through the PP, lay a straightedge across both photographs against the two needles. Rotate the two photographs so that the PP's and CPP's are aligned with the straightedge. Fasten the photographs securely and remove the needles.

Place the stereoscope over the photographs parallel to the straightedge. Rotate the stereoscope until the straightedge appears continuous through the entire field of view. The photographs and the stereoscope are now oriented properly for viewing.

With experience, the photointerpreter may orient the photographs properly without performing all the steps. However, when high accuracy measurements are to be made with a parallax bar or other instruments, follow the full procedure.

3.6.2 <u>Alignment of flight lines</u>. The flight lines of both photographs always should be aligned when looking with both eyes through the stereoscope. The eye base, instrument base, and photobase must be parallel to permit studying the stereomodel without eyestrain. All parts of the stereomodel can now be observed by moving the stereoscope as desired, keeping the instrument base parallel with the flight line. With the stereopair properly oriented under the stereoscope, the two fields of view should cover the same parts of the terrain.

After the preparations are completed, the interpreter will study and analyze the images, annotate the photographs, and construct overlay manuscripts or transfer information to base maps as appropriate.

3.7 Delineation of the Effective Area

The effective area of a vertical photograph is the area closer to its PP than to the PP of any other photograph. The shape of the camera lens and variations of topography make only a portion of the aerial photograph suitable for mapping within reasonable accuracy limits. The true effective area is circular as is the camera lens; but to simplify the procedure, a rectangular area is generally used. The procedures for mountainous country, where elevation differences exceed 152 m (500 ft), are given in the following steps:

- Step 1 — Select from the indexed photographs the flight strip on the east edge of photocoverage.
- Step 2 — Starting from the south end of this flight strip, begin with the first two photographs that give stereocoverage of a given ownership.
- Step 3 — By inspection, place the south boundary of the area on photograph 1 or the southernmost photograph (line A→B on fig. 3-10).
- Step 4 — Since it is easier for a right-handed person to transfer a line from the north to the south, move to photograph 2 or the next photograph north. To delineate the south boundary of the effective area on this photograph, construct a line approximately bisecting the overlap. Extend this line to both edges of the photograph (line C→D on fig. 3-10).

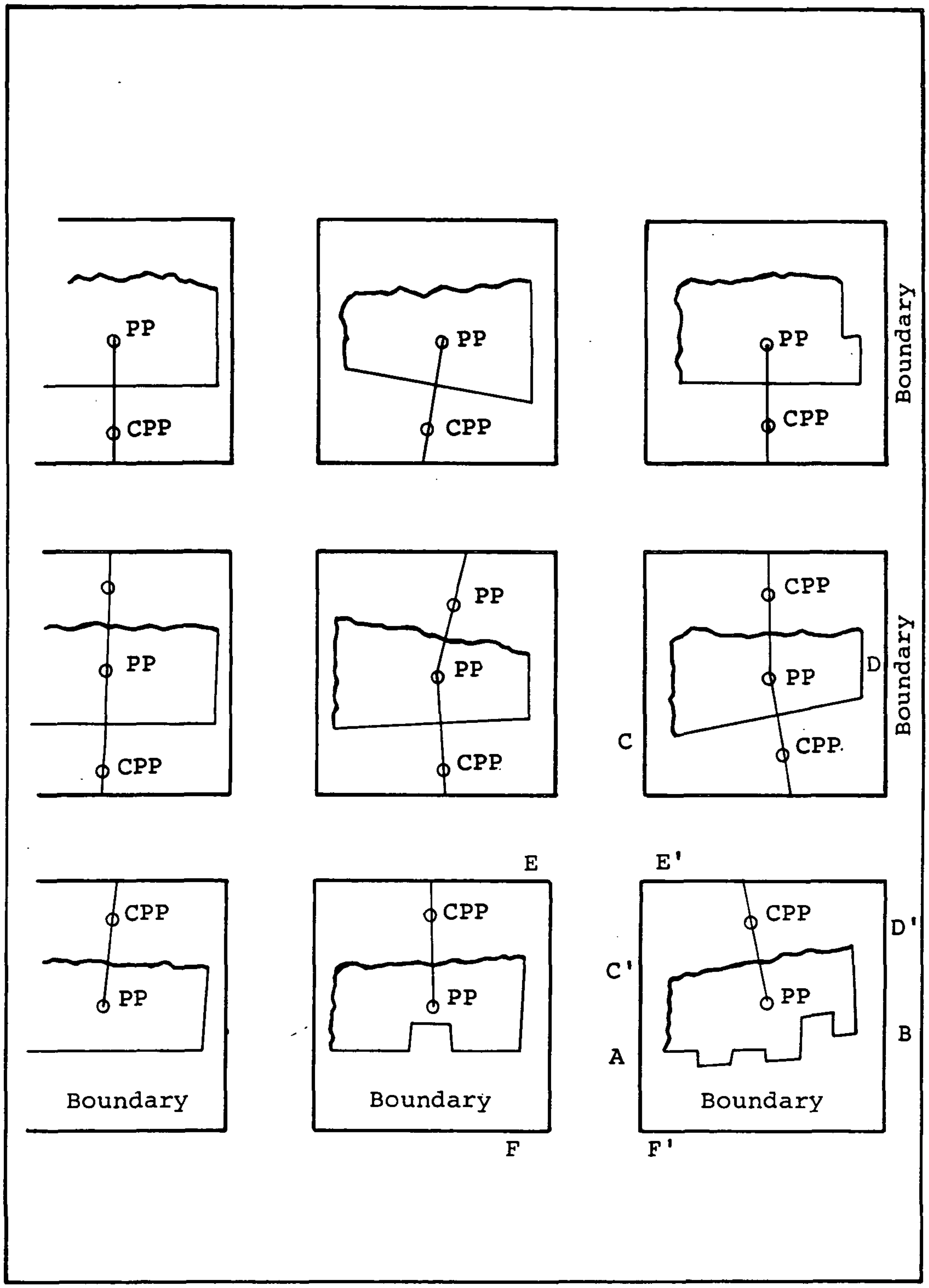

Figure 3-10.— Effective area delineation for mountainous areas.

- Step 5 — Place photographs 1 and 2 in stereoposition and transfer the line drawn on photograph 2 to photograph 1. This is most easily done by drawing dashes where the line appears to cross ridges and valleys and then connecting them under stereovision. Depending on the variation in topography, this line may be undulating rather than straight (line C'→D' on fig. 3-10).

- Step 6 — The northern and southern effective area boundaries are now on photograph 1. Follow this same procedure northward up the flight strip until it is completed. The northern effective area boundary on the northernmost photograph will be the area boundary.

- Step 7 — After working two adjoining flight strips as above, begin delineating the east and west boundaries of the effective area.

- Step 8 — Beginning at the south end again, select adjacent photographs from the two easternmost flights and place them in stereoposition to view the sidelap. (The stereocoverage may be poorly defined because of the interval between photoexposures in these two flights and the aggravated distortion on the edges of the photographs.) Draw the matching line under the stereoscope whenever possible, using the same procedure as used for endlap match lines. In some situations, stereomodels will be impossible to achieve between flight lines. When this situation occurs, dot the corresponding images in the center area of the sidelap and connect them with straight lines. In many cases one picture covers only a portion of the sidelap match line; therefore, the picture immediately above or below must be used to complete the boundary (line E→F on fig. 3-10).

- Step 9 – Transfer the line drawn on the left-hand photograph to the right-hand photograph, completing the outlining of the effective area (lines E' and F' on fig. 3-10).

- Step 10 – Continue in this manner until all photographs are completed. The result is an effective area in the center of each, which covers all areas in the project without duplication. Figure 3-10 shows the appearance of the completed photographs.

For areas of low topographic relief (elevation differences less than 152 m or 500 ft), the procedure can be changed slightly.

The effective areas can be delineated on alternate photographs. In step 4 above, using photographs 1 and 3, instead of bisecting the flight line, the line should be drawn near the CCP (approximately one-half the overlap) and perpendicular to the flight line. Sidelap should be divided in the same manner as for mountainous areas. Figure 3-11 shows the appearance of the completed photographs.

3.8 Photointerpretation Procedures and Criteria

Comprehensive photointerpretation usually involves two phases. The first is a general overview of the area of study. Prior to any specific analysis the interpreter should familiarize himself with the general landscape of

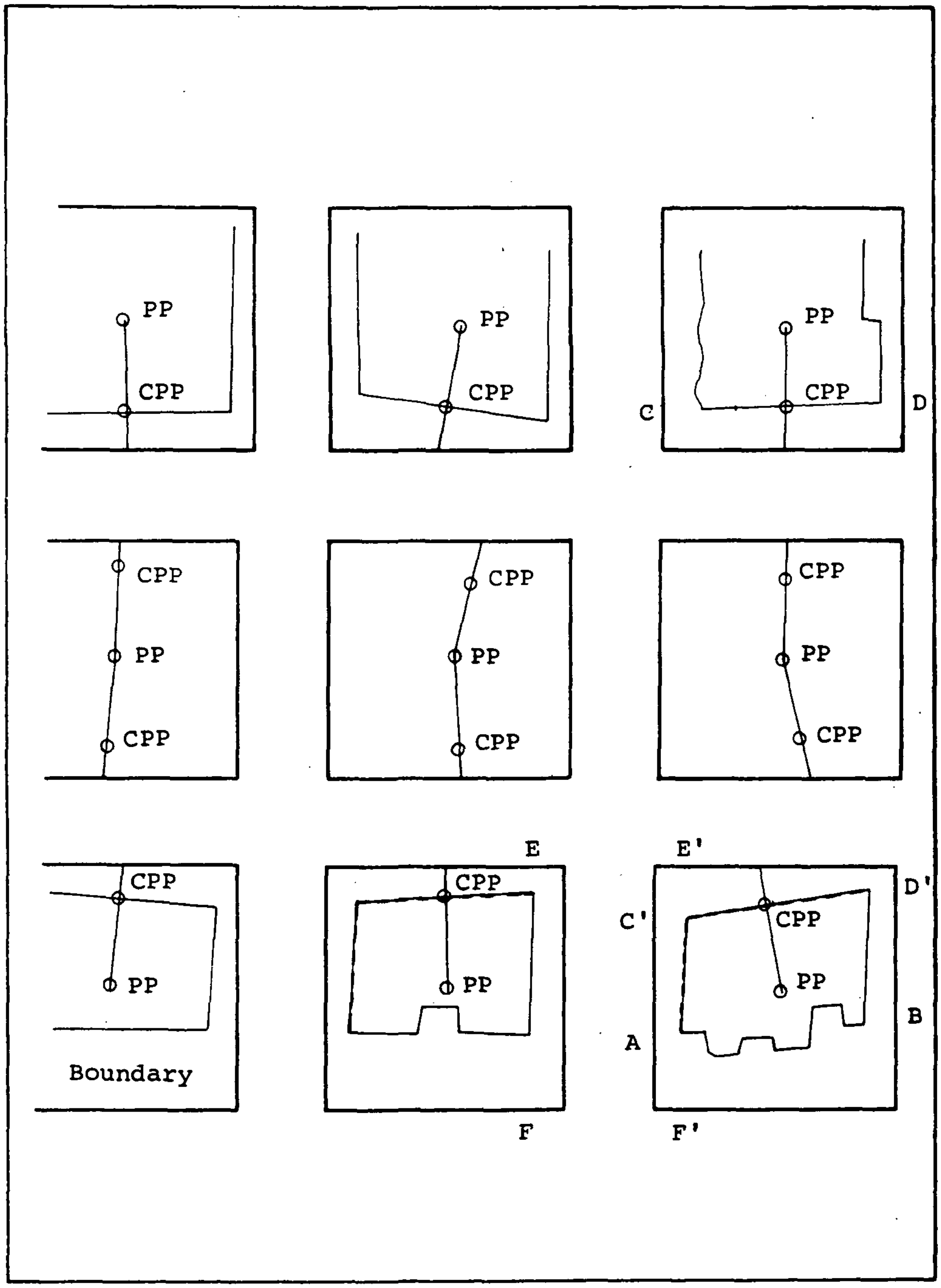

Figure 3-11.— Photopreparation for flatwoods.

the study area. This can be accomplished by scanning the photographs stereoscopically or individually and noting both cultural and natural features. The second phase is translating the image into information relating to some particular field of inquiry, such as landform study, land use practices, regional planning, or disease and blight detection.

Whatever the scope of the project, proficiency in photointerpretation is largely a matter of experience and common sense. Usually, photographs of typical nature and cultural features are studied together with training sets of photography showing assemblages of such features, and the results are extended to unknown areas. It is important also to have or to acquire some knowledge of the ground features encountered (for example, typical tree harvesting techniques, logging, and milling practices.)

Photointerpretation involves associating features, one with the other, to properly identify them. It is helpful to train the photointerpreter by making a field trip to the study area. He should first identify all features which he does not recognize in the imagery. When in the area of study, the photointerpreter can compare the photofeature with the same feature on the ground. Using these ground features which have been correlated to the photograph as training sets, the interpreter then locates other similar features and classifies them. By associating ground features and photofeatures, the photointerpreter increases his ability to identify or interpret specific forest features which are to be inventoried. The following is a sample procedure for accomplishing the above for classifying pine sawtimber:

- Step 1 — Taking the photographs with you, go to the study area and locate a stand of pine sawtimber (as homogeneous as possible).
- Step 2 — Using the photograph, locate and delineate the boundary for that stand.
- Step 3 — Study the delineated stand on the photograph, noting the shape, size, color or tone, and site.
- Step 4 — Train yourself to locate the stand by the above characteristics.
- Step 5 — Scan the photograph for a second area which appears similar in tone (color), size, texture, and possibly shape. Locate the second area on the ground to check your identification.
- Step 6 — If the above identification was correct, repeat step 5 again for further familiarization. If the identification was incorrect, repeat steps 1 through 5 until a correct identification is made.
- Step 7 — Repeat this procedure for pine pulp timber, landforms, and all other features to be inventoried.
- Step 8 — Return to the office and identify and delineate all pine sawtimber stands in the photography.
- Step 9 — At random, check several stands in the field again to ensure the accuracy of your interpretation.
- Step 10 — As seasons change and new photography is acquired, compare it to original delineations. Note any changes in the stand.

The above steps become instinctive as proficiency increases but require conscious application for obscure or uncertain features. Certain basic criteria and photorecognition guides are involved, including:[3,4]

- Color or tone: This depends on the spectral reflectance and absorption and the smoothness or roughness of the surface materials. Although the colors and tones are false with color IR films, the colors are often diagnostic. (For example, magenta or red indicates healthy deciduous trees; reddish to bluish-purple, healthy conifers; and yellow, green, or brown, blighted foliage).
- Shape and size: This is an extremely important key to many natural and cultural features such as stream patterns, logged-out areas, logging roads, and large buildings.
- Shadows: Terrain shadows are occasionally a hindrance in photointerpretation, particularly when they hamper identification of vegetation on slopes, or when they conceal roads or other features. However, they are often useful in landform analysis. Shadows are sometimes useful in identifying ground objects such as lumber mill smokestacks and tree crown shape and can assist in ascertaining tree height; however, this is true mainly for low-altitude photography.

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[3]Reference footnote 1.

[4]T. E. Avery, Forester's Guide to Aerial Photo Interpretation, U.S. Department of Agriculture Handbook 308, USFS Oct. 1966, revised Dec. 1969.

- Texture: The aggregate appearance of unit features too small to be individually distinct, texture is a product of the tone, size, shadow effects, and arrangements. It is described as coarse or fine, smooth or rough, speckled, linear, or otherwise. For example, the texture of forest land varies somewhat according to the density, crown size, and type of timber growth.

- Pattern: This refers to a more or less orderly spatial arrangement of photoelements. Examples include rectangular, checkerboard, radial, or random. Agricultural fields, city street systems, and treefarm areas are typical features with distinctive patterns.

- Stereoscopic relief: A basic photointerpretive aid and the most essential for mapping such categories as landforms and drainage, stereoscopic relief also provides valuable information for inventories in visual resources, erosion detection, and transportation system mapping and planning. Relief displacement or object displacement provides the basis for height determination.

- Relation of associated features: One of the photointerpreter's best tools is his ability to identify features by association. It has been mentioned that tone, shape, and texture size are the basic characteristics for feature identification. The ability to associate an unidentifiable object to one that can be identified increases the photointerpreter's recognition capabilities. For instance, a 3-year-old regeneration area cannot be identified by the seedlings at 1:60,000; however, visible windrows and other site preparation characteristics give the photointerpreter a good indication of the land use.

Application of these criteria and guides in a given situation will depend on factors such as the camera system resolution capability, scale of imagery, sharpness of definition, and photographic contrast.

3.9 Photogrammetry

Photogrammetry is defined as

> "...the art, science and technology of obtaining reliable information about physical objects and environment through processes of recording, measuring and interpreting photographic images and patterns of electromagnetic and accoustical radiant energy and magnetic phenomena."[5]

This section deals with that portion of photogrammetry concerned with obtaining reliable measurements from photography.

Photogrammetry is categorized according to the kind of photography employed. Terrestrial photogrammetry deals with photographs taken from points on the ground. Aerial photogrammetry utilizes either vertical or oblique photography taken from an airborne vehicle. Stereophotogrammetry deals with overlapping pairs or sets of photographs that are viewed, interpreted, and measured with a stereoscopic viewing instrument which re-creates a three-dimensional view and creates

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[5] American Society of Photogrammetry, What Photogrammetry Is, Photogrammetric Engineering and Remote Sensing, vol. XLI, no. 1, Jan. 1975.

the illusion of viewing a relief model of the terrain. Analytical photogrammetry involves taking measurements on photographs and deriving the image position by mathematical computations.

The forester needs to understand the photogrammetric relationships to interpret the ground features of interest from photography and to map them with reasonable reliability and positional accuracy. Once the level of accuracy for the final analysis product is defined, certain photogrammetric techniques can be applied to attain these accuracies. Knowledge of photogrammetric techniques can also indicate whether these accuracies are attainable from intended photographic source data. This question should be resolved in the project planning stage. If the desired accuracies are unattainable, alternate methods (possibly a larger scale or a different camera) must be used, or the accuracy requirements must be compromised.

Various photoplotting instruments may be used to transfer interpreted data to a map base. Their use requires specially skilled operators and a good ground control network. Most forestry applications discussed in this guide require no such accuracy; the methods of interpretation and information transfer discussed in sections 5.0 through 8.0 are usually sufficient.

The forest resource planner or manager will probably escape involvement in the more exotic aspects of photogrammetry when he uses small-scale color IR photography to derive planning information. Exact area and distance measurements are not in themselves objects of such activities. Nevertheless, the user should keep these factors in mind when analyzing photography.

3.10 Mensuration

This section covers obtaining reliable measurements using aerial photographs. The examples refer to vertical photographs where the PP is assumed to be the nadir because of photomission specifications.

Since all relief is displaced radially away from the nadir, or PP in vertical photographs, certain geometric allowances must be made to obtain correct horizontal distances on photographs with mountainous terrain relief. For true photographic scale in mountainous terrain, the elevation of the terrain must be subtracted from the flying height above mean sea level to obtain aircraft altitude above the ground, as shown in equation (3-1).

If the original photograph is to be used for measurement, follow these precautions.

- Make distance measurements between points lying at the same approximate elevation.
- Use a scale for the average elevation of the two points if the points lie at different elevations.
- Compute an appropriate scale for the elevation above or below the datum plane for measurements along ridgetops or any elevation different from the datum plane of the photograph.

3.10.1 Representative fraction (RF) determination (photographic scale).[6] The vertical aerial photograph presents a true record of angles, but measures of horizontal distances vary widely with changes in ground elevations and flight altitudes. The nominal scale (1:60,000) is representative only of the datum, an imaginary plane passing through a specified ground elevation above sea level. Calculation of the average photographic scale will increase the accuracy of subsequent photograph measurements. However, specific scales calculated for each land elevation will give an even better photographic measurement.

Common aerial cameras have focal lengths of 6, 8.25, or 12 in. (0.5, 0.6875, or 1.0 ft) or 15, 21, or 30 cm. This information, with the altitude of the aircraft above ground datum, makes it possible to determine the RF or natural scale:

$$\text{Scale (RF)} = \frac{\text{Focal length in feet}}{\text{Flying height above ground in feet}} \tag{3-1}$$

That is,

$$\text{RF} = \frac{0.5 \text{ ft}}{30{,}000 \text{ ft}} = \frac{1}{60{,}000}$$

The height of the aircraft is sometimes not known to the interpreter, and the photographic scale should be checked

[6]Reference footnote 4.

against map or ground measurements. This is done by the equation

$$\text{Scale (RF)} = \frac{\text{Photographic distance between two points}}{\text{Ground or scaled map distance between same points}} \qquad (3\text{-}2)$$

That is,

$$\text{Scale (RF)} = \frac{0.25\ \text{ft}}{15{,}000\ \text{ft}} = \frac{1}{60{,}000}$$

3.10.2 Determining scale from ground measurements.[7] Two pairs of points should be selected so that a line connecting a pair passes near the PP and at approximate right angles to the other line. The points within the pair should be at the same approximate elevation, equidistant from the PP, and at least 500 ft apart. The points must be easily identifiable on the photograph and the base map so that the distance between them can be measured precisely. This is the photographic distance that is used in formula 3-2. It is not necessary to calculate the scale of every photograph in a flight strip. In hilly terrain, every 3rd or 5th print may be used; in flat topography, every 10th or 20th. Scales of intervening photographs can be obtained by interpolation.

3.10.3 Office checks of photographic scale.[8] Scale determination from ground measurements is laborious and expensive; hence, other methods should be used wherever possible. If a USGS quadrangle sheet is available, the map

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[7]Reference footnote 4.

[8]Reference footnote 5.

distance can be measured and used in formula 3-2, provided the same distance can be measured on the photograph.

Another alternative is presented in areas of flat terrain where General Land Office subdivisions of sections, quarter sections and forties (40-acre tracts), are visible on the photographs. Since the lengths of these subdivisions will be known, they can also be used as ground distances. A given section may rarely be exactly 1,609 m (5,280 ft) on a side, but determining scale by this method is more accurate than accepting the nominal scale.

3.10.4 Determining north orientation. Although flight lines are normally flown north-south or east-west, few photographs are oriented exactly with the cardinal directions. A reference line must be located before bearings can be determined. A USGS quadrangle sheet or any other accurate map of the area can be used. The following is one method of establishing north on the photographs:

- Step 1 — Select two readily identifiable features on the photograph that are at approximately the same elevation and draw a connecting line between them.
- Step 2 — Locate the same two points on the map and draw a connecting line between them.
- Step 3 — On the map, construct a line parallel to the indicated north arrow that will intersect the line drawn between the identifiable features.
- Step 4 — Using a protractor, measure the angle between the two lines.

* Step 5 – The protractor can then be used to duplicate the angle on the photograph to north. Care should be taken to place the north arrow, and any other similar data on the overlay, outside of the area of interest.

3.10.5 Compass bearings and distance measurements.[9] The USFS field teams use the following procedure to locate a reference line for determining compass bearings and distance measurements:

* Step 1 – Use the north direction line as a reference line. If a true north line has not been established as described above, a direct compass reading between two intervisible points that are apparent on the photograph and at the approximate same elevation will serve as the reference line.
* Step 2 – Locate the line to be measured on the photograph and transfer that line to the overlay. Extend the line and/or the reference line until they intersect.
* Step 3 – Use a protractor to obtain bearing of the line.
* Step 4 – Scale off the distance along that line from the starting point to the area of interest.

3.11 Area Measurement

3.11.1 General. Inventories of forest resources require relatively accurate area measurements. Photographs offer an inexpensive means of making such determinations.

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[9] Reference footnote 5.

In locations where photographic scales are not appreciably altered by topographic changes, areas can be measured directly on contact prints. Greater accuracy is possible if delineated boundaries are transferred to controlled base maps before an area is determined. This procedure is essential for mountainous terrain. On the other hand, if only relative proportions of the area are needed and measurements are limited to the effective areas of contact prints in areas of low topographic relief, little bias results from using photographs. This conclusion is based on the assumption that the PP is located on a representative elevation and errors in measurement of areas below the datum plane are compensated by errors of a similar magnitude above the datum plane. Small tracts in rough topography should be measured on controlled maps. Measurement techniques are similar in both cases, so the procedures outlined for measuring an area on photographs generally apply to map determinations. See tables 3-II and 3-III.

3.11.2 Devices for area measurement.[10] The principal devices for area measurement are polar planimeters, dot grids, electronic planimeters, and weighing scales. The polar planimeter is relatively inexpensive, and its use is somewhat tedious. The pointer is carefully run clockwise around the boundaries of an area two or more times (for an average reading). From the vernier scale, the area is read in square inches and then converted to the desired units on the basis of photographic or map scale.

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[10] Reference footnote 5.

TABLE 3-II.— SCALE CONVERSIONS FOR VERTICAL AERIAL PHOTOGRAPHS[a]

Representative fraction (scale) (1)	Feet per inch (2)	Chains per inch (3)	Inches per mile (4)	Acres per square inch (5)	Square miles per square inch (6)
1:10,000	833.33	12.63	6.34	15.94	.0249
1:12,000	1000.00	15.15	5.28	22.96	.0359
1:15,840	1320.00	20.00	4.00	40.00	.0625
1:20,000	1666.67	25.25	3.17	63.77	.0996
1:24,000	2000.00	30.30	2.64	91.83	.1435
1:31,680	2640.00	40.00	2.00	160.00	.2500
1:50,000	4166.67	63.13	1.27	398.56	.6228
1:60,000	5000.00	75.76	1.06	573.92	.8968
1:62,500	5208.33	78.91	1.01	622.74	.9730
1:120,000	10,000.00	151.52	0.53	2295.68	3.5870
1:125,000	10,416.67	157.83	0.51	2490.98	3.8922
1:250,000	20,833.33	315.66	0.25	9963.91	15.5700
Method of calculation	$\frac{\text{RFD}}{12}$	$\frac{\text{RFD}}{792}$	$\frac{63{,}360}{\text{RFD}}$	$\frac{(\text{RFD})^2}{6{,}272{,}640}$	$\frac{\text{Acres/sq in.}}{640}$

[a]Conversions for scales not shown can be made from the relationships listed at the bottom of each column. With the scale of 1:60,000 as an example (column 1, line 8), the number of feet per inch is computed by dividing the representative fraction denominator (RFD) by 12 (number of inches per foot). Thus, 60,000÷12 = 5,000 feet per inch (column 2). By dividing the RFD by 792 (inches per chain), the number of chains per inch is derived (column 3). Other calculations can be made similarly. Under column 4, the figure 63,360 represents the number of inches in 1 mile; in column 5, the figure 6,272,640 is the number of square inches in one acre; and in column 6, the number 640 is acres per square mile.

TABLE 3-III.— METRIC SCALE CONVERSIONS

1 inch	= 2.54 centimeters	1 centimeter	= 0.393701 inches
1 foot	= 0.3048 meters	1 meter	= 3.2808 feet
1 yard	= 0.9144 meters	1 meter	= 1.0936 yards
1 statute mile	= 1.6093 kilometers	1 kilometer	= 0.62137 statute miles
1 acre	= 0.40468 hectare	1 hectare	= 2.471 acres

A dot grid is one of the more widely used methods for determining area on aerial photographs. A dot grid is a transparent overlay with dots systematically arranged on a grid pattern (fig. 3-12).[11] In use, the grid is aligned with a straight-line feature to avoid positioning bias, and then dots are counted for each area. Areas can be calculated by proportions. The number of dots on a given area divided by the total number of dots counted yields a percentage value that is multiplied by the total area to obtain the acreage of the type. If total acreage is not known, the number of acres per square inch is determined. This figure is then divided by the number of dots per square inch to find the acreage represented by each dot.

Several manufacturers now produce electronic measuring devices which enable the analyst to measure areas automatically. Most models have the capability of not only a digital display of area, but also a multiplier for volume measurement.

Electronic planimeters are fast, simple, and in most instances within the budget of most field units. They are operated by setting a scale factor into the display and moving the cursor around the area of interest. The area is recorded automatically. Straight line distances can also be computed and/or accumulated on some models. Some models even have tape printout capability.

In cases where many categories can be confusing, a weighing process provides the proportions to be translated

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[11] Reference footnote 5.

Figure 3-12.— Dot grid positioned over part of an enlarged print for acreage determination.

into area. Since quality control provides paper or mylar weight, the total weight of all effective areas of the photographs can represent the total acres in the area of interest. Each mapping unit can be cut out of the overlay and placed in the appropriate pile. The percentage of the total weight for each pile is related to the percentage of land in that mapping unit. This simple, effective method determines area when many mapping units occur. Repetition or omission is likely with other counting methods.

3.12 Height Determination

This section deals with the use of the mirror stereoscope and parallax bar for object height determinations. Object heights are commonly determined on aerial photographs by measuring either stereoscopic parallax or shadow lengths. The parallax method is faster, requires fewer calculations, and is more adaptable to a variety of conditions. For height determinations the stereopair should be set up in the manner described in section 3.6. Once the photographs have been properly oriented, the following measurements are made using the engineer's scale:

- Step 1 – Measure the distance between the two PP's to the nearest 0.5 mm (0.01 in.). Subtract the distance between the like images from the distance between PP's to get the absolute stereoscopic parallax (P). "This is the algebraic difference, parallel to the air base, of the distances of the two images from their respective principal points."[12]

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[12] S. H. Spurr, Photogrammetry and Photo-interpretation, second ed., The Ronald Press Co., N.Y., 1960.

- Step 2 — Determine the altitude (H) of the aircraft above ground datum (see section 3.10.1 for scale/altitude determinations).

- Step 3 — Place the parallax bar[13] over the stereoscopic image parallel to the line of flight. The parallax bar has two glass plates attached to a metal frame that houses a vernier and a gradated metric scale. The left lens contains a fixed reference dot; the dot on the right lens can be moved laterally by means of the vernier. Place the bar over the stereoscopic image parallel to the line of flight. Move the vernier clockwise until the right-hand dot fuses with the reference dot and rests on the ground at the base of the object. Record the vernier reading to the nearest 0.01 mm (0.004 in.). (See instructions shipped with the parallax bar for more detail.)

- Step 4 — Turn the vernier counterclockwise until the fused dot appears to "float" next to the top of the object, and record a second reading. Do not place dots on tree tops.

- Step 5 — Subtract the two readings. The difference between them is the parallax difference (dP) in millimeters.

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[13]A transparent plastic parallax wedge is often used for height determination. It produces the same level of results as does the more expensive parallax bar described here (J. A. Howard, Aerial Photo-Ecology, American Elsevier Publishing Co., Inc., New York, 1970).

- Step 6 — Determine the object height. The formula for converting parallax measurements to object heights on aerial photographs is:

$$h = \frac{H \times dP}{P + dP} \tag{3-3}$$

where h = height of object in feet or meters

H = altitude of aircraft above ground datum in feet or meters

P = absolute stereoscopic parallax at base of object being measured in inches or millimeters

dP = differential parallax in inches or millimeters

All values for height will be in feet or meters, as required by the formula.

3.13 Mosaics

A mosaic is an assembly of individual photographs fitted together systematically to form a composite view. Utility and accuracy depend on the quality of imagery of the parts and the construction techniques used. To increase accuracy, photorectification may be necessary. Photorectification is the art of removing the effects of in-flight tip and tilt. The image is projected so that orientation of the control points coincides with the same points on a controlled surface such as an accurate map.

Mosaics are either uncontrolled or controlled. The term semicontrolled is just a reference to the degree of control used.[14]

- Uncontrolled mosaics are constructed by fitting photographs together in the best apparent manner by cutting off the edges and forming a continuous photographic representation.
- Controlled mosaics are scaled and fitted to horizontal ground control points. Rectified photographs are generally used.

3.14 Photorectification

Because of the combined effects of photographic acquisition and topographic relief, the relative horizontal positions of surface features on an uncorrected aerial photograph are displaced and shifted from their true positions.

A special technique called rectification permits the removal of geometric distortions caused by camera tilt. Rectification involves the selection of a network of geographic control points composed of distinctive features on the photographs, on a map, or on other ancillary control sources. Using projection techniques, the photograph is tilted and reoriented until the relative positions of the control points coincide on both the photographs and the control surface. The rectified image is then photographed. The geometric effects of rectification cause the image area

[14]Reference footnote 2.

in a rectified photograph to be somewhat trapezoidal instead of square.

Photorectification removes the effects of in-flight tip and tilt but does not correct for the radial displacement caused by topographic relief.

In flat terrain, using small-scale imagery (1:60,000 to 1:120,000 scale), rectification generally is not necessary for relatively accurate mosaics. If adequate overlap is obtained, map and control points can be used with contact prints to produce excellent mosaics (fig. 3-13). Normally, the higher the platform, the less radial displacement is evident in the effective area of the photograph.

In rugged terrain, the images still may not have the required accuracy because of image displacement caused by relief. This displacement can be eliminated through orthographic projection, in which stereoscopic imagery is averaged and plotted on photographic film with an image line scanner. The product is a photograph with horizontal accuracy within mapping standards. Orthophotographs are available if the need for their use arises.

The forest manager should be aware of the more involved details of each of these products so that cost, accuracy, and time requirements can be estimated against ultimate needs. The rest of this section includes descriptive data to assist in making these decisions.

NASA S-70-34860

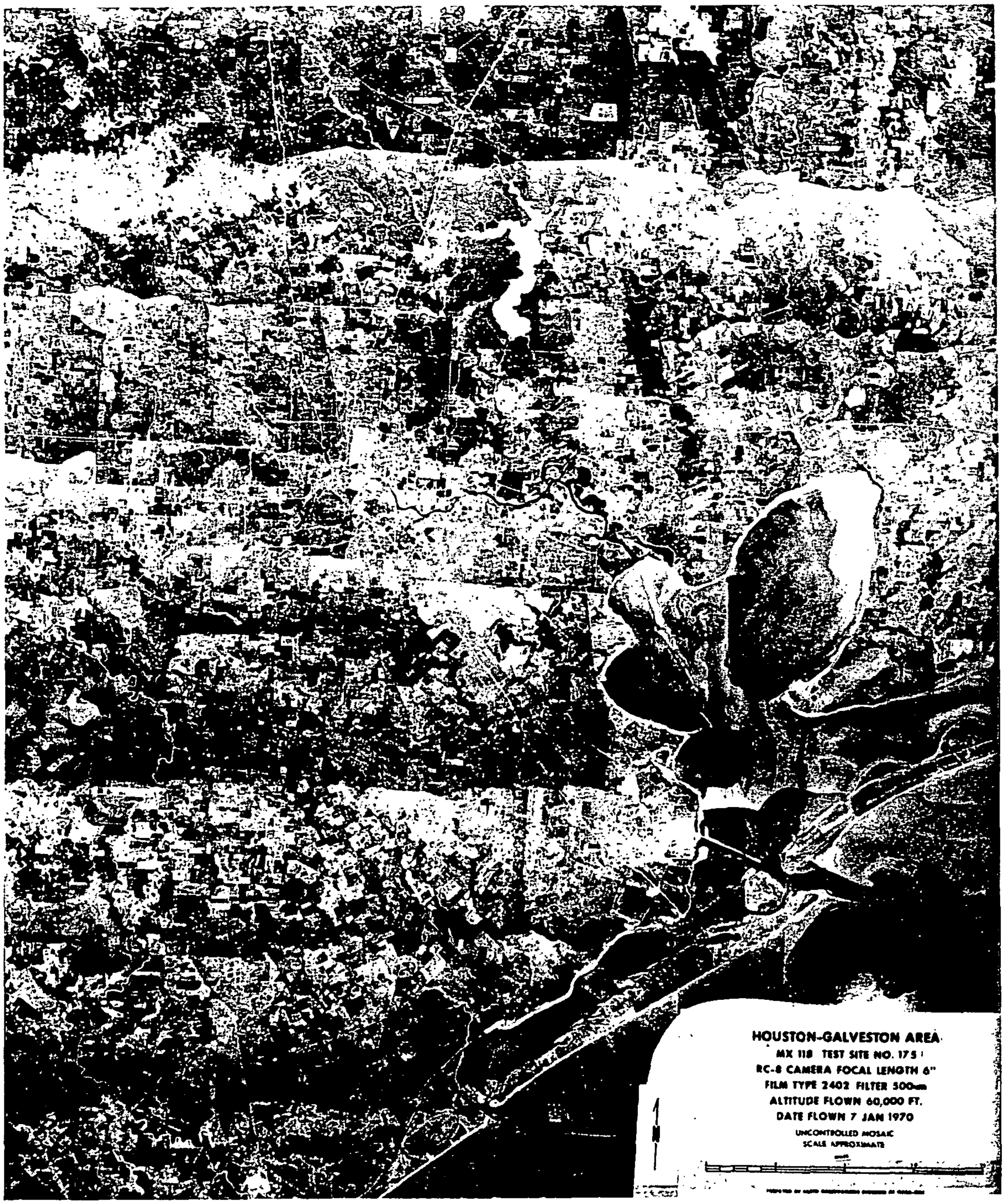

Figure 3-13.– Uncontrolled mosaic made from high-altitude aerial photographs of the Houston, Texas, area.

3.15 Preparation of Photomosaics

The preparation of the two types of photomosaics, uncontrolled and controlled, are described briefly.

3.15.1 Uncontrolled mosaics.

- First, photographic prints at the desired scale are acquired and prepared for mosaicking by trimming or tearing off the outside areas until little more than the effective area remains.

- Adjacent photographs are matched using photofeatures as guides. The central areas of the photographs are used as a basis for matching because of radial distortions at the edges. Because the fit of unrectified photographs is imperfect, it is necessary to shift, stretch, and compromise for a best fit. Successive photographs are laid out on a fiberboard panel or other mounting medium and glued down. The process and product are essentially the same as for making a composite photoindex during the photopreparation phase of photointerpretation (section 3.4, fig. 3-7).

  Where time and resources permit, a better product can be made by trimming the photographs within the area of overlap along the curvilinear lines corresponding to breaks within the photographs. These might be, for instance, a river, a road, a prominent vegetation-change line, the edge of a forest, or similar feature. The photographs are joined at these curvilinear lines to minimize the visually distracting effects of differences in color shade between adjacent photographs caused by lighting variations or other irregularities during the flights.

The photographs may then be matched for best fit and glued down as described above. Optional supplementary operations include sanding the back edges of the overlapping photoprint to get a better feather-edge mapping effect and applying toner solutions to minimize the contrast between adjacent photographs. However, such elaborate techniques are seldom indicated in uncontrolled mosaics constructed at the land use planning level.

- The finished mosaic may then be annotated, marked on directly, or, more often, covered with transparent overlays to mark selected items of interest. It may also be photographed at the same, a larger, or a smaller scale for use in the office or field.

The uncontrolled mosaic may be used to good advantage for field checks and in analysis where geometric relationships and accuracy are not critical. Controlled or semi-controlled mosaics should be used in applications where distance and a high level of accuracy are important.

3.15.2 Controlled mosaics. These involve the use of rectified aerial photographs. The controlled mosaic is composed of rectified prints which have been laid to ground control utilizing at least two ground control points per print and may be supplemented by radial-line triangulation. The basic assembly is the same as described in section 3.15.1. The forest manager will seldom be involved with the photogrammetric process of making controlled mosaics.

3.16 Uses of Photomosaics

Photomosaics are extremely useful in the generation, compilation, maintenance, and display of various types of information used in the land use planning process and in various operational phases of forest management. The information may be derived from the mosaic itself, from aerial photointerpretation, from other data in map format, or from nonmap data posted on the mosaic. Controlled mosaics are a useful medium because of their geometric accuracy; however, uncontrolled mosaics and photoindex sheets are used more often because of the ease and speed in preparing them. The sections below give some specific uses.

3.16.1 Compilation of land use planning and resource data. A photomosaic can be used as a base map for compiling and displaying information derived by photointerpretation or other techniques. This may be done by using copies of the mosaic itself, or by using separate translucent or transparent overlays on the mosaic. Specific displays that might be generated would include:

- Topography
- Soil types
- Land use
- Timber types
- Crown density
- Transportation
- Water and streams
- Recreation areas

- Special uses
- Field data inventories

3.16.2 <u>Land use plan approval, implementation, and monitoring</u>.

3.16.2.1 Display: Public involvement is an integral part of land use planning. A mosaic can be used at public hearings to display the concerned land unit and its relationship to other land areas and their uses within a forest. It may also be used to show the various management activities within the district to visitors to the district ranger office.

3.16.2.2 Monitoring and updating: Mosaics may be used to monitor the resource activities set forth in the land use plan. By depicting planned work and plotting progress on the mosaics or overlays, a visual record of plan implementation would be available. This would be helpful in updating the plan and in pinpointing discrepancy areas requiring more or less work than planned, more or less funds than budgeted, or possible changes.

3.16.3 <u>Other uses</u>.

3.16.3.1 Insect and disease infestation: Reconnaissance flights require the accurate plotting of infestations. The mosaic should be helpful in this, since it depicts the actual ground scene for plotting and location.

3.16.3.2 Fire control: Since the mosaic displays the actual ground scene, it is possible to locate a fire accurately in relation to roads, drainage, timber type, and access to a more knowledgeable plan of attack on the fire.

3.16.3.3 Conference displays: At meetings of forest users, such as timber purchasers, range permittees, and others, mosaics would pictorially display forest plans, help illustrate acceptable implementation methods, and identify potential problem areas.

4.0 PHOTOINTERPRETATION MAPPING ACCURACY: STATISTICAL EVALUATION TECHNIQUES

This section presents statistical procedures for evaluating the quality of a photointerpreted product or the performance of a photointerpreter. The evaluation uses the parameter of classification accuracy (p), or mapping accuracy. In general, two approaches exist to evaluate the results of the photointerpretation. One approach is to compare areas to an accepted standard and the other is to check statistically on points.

The statistical method discussed here is better than the widely practiced method of areal measurement because the statistical method evaluates the correctness of each spot sampled rather than comparing areal totals. Using the areal method, mapped features usually are planimetered for their areal extent which is then compared to ground-truth acreages. Ground truth is a term used in remote sensing for known information. An error using the areal method can be demonstrated with an image containing one-half forest and one-half nonforest. The interpreter could wrongly classify forest as nonforest and nonforest as forest. This interpreted map would be completely erroneous but have 100 percent accuracy using the areal measurement method because the map would have the same areal measurement of forest and nonforest as did the ground truth. This extreme case example indicates the need for the evaluation method employing mapping accuracy instead of areal measurement.

In this section, the procedures will be presented for two-class and multiclass images. The statistical concept of confidence intervals and the requirement for adequate sample sizes (n's) are introduced. Formulas for calculating confidence intervals and n's are derived for the two-class case. The same formula for n also applies to the multiclass case. However, simple formulas for confidence intervals of the multiclass p are not derived in this guide. Detailed expositions of these statistical aspects can be found elsewhere.[1,2,3,4]

4.1 Evaluation Procedures

Procedure A for the two-class case and procedure B for the multiclass case are outlined in this section. The sample two-class image is a photointerpreted map of forest and nonforest while the sample multiclass image is a map of the features of softwoods, hardwoods, range, and "other."

4.1.1 Procedure A for two-class images. The procedure includes seven steps.

- Step 1 — Establish a grid cell system overlaid on the image (section 4.3).
- Step 2 — Determine the n (section 4.6).

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[1]T. E. Avery, Forest Measurements, McGraw-Hill, New York, 1967.

[2]F. Freeze, Elementary Statistical Methods for Foresters, USFS, U.S. Department of Agriculture Handbook 317, Jan. 1967.

[3]S. S. Wilks, Mathematical Statistics, John Wiley & Sons, Inc., New York, 1962.

[4]E. C. Pielou, An Introduction to Mathematical Ecology, Wiley-Interscience, New York, 1969.

- Step 3 – Locate n samples on the image (section 4.3).
- Step 4 – Check the classification of the n samples against ground truth. Let m be the number of samples correctly classified.
- Step 5 – Compute the p using equation 4-6 (section 4.4).
- Step 6 – Determine the confidence interval of p using equation 4-7 (section 4.5).
- Step 7 – If the confidence on the estimated p is not satisfactory, repeat steps 2 through 6. If necessary, change the grid cell system.

4.1.2 Procedure B for multiclass images. The procedure includes three steps.

- Step 1 – Establish a grid cell system overlaid on the image (section 4.3).
- Step 2 – Perform steps 2 through 7 of procedure A for each class of images versus the rest. For example, consider the four-class case of softwoods, hardwoods, range, and "other." The first iteration of step 2 of procedure B is the evaluation of the image for softwoods versus the conglomerate class of hardwoods, range, and "other." The second iteration evaluates hardwoods versus the conglomeration of softwoods, range, and "other." The third and fourth iterations similarly evaluate range and "other."
- Step 3 – Calculate the overall p using equation 4-10 (section 4.7).

4.2 Examples

4.2.1 Example 1 – Computation of the confidence intervals of two-class images.

In an image of forest and nonforest features, if $n = 200$ and if 171 cells are correctly classified,

$$p = \frac{171}{200} \times 100\% = 85.5\% \qquad (4\text{-}1)$$

The confidence interval half-range E at a confidence level L of 0.95 then can be computed.

$$E = 1.96 \sqrt{\frac{85.5(100 - 85.5)}{200}}\ \% = 4.9\% \qquad (4\text{-}2)$$

That is, for 95 out of 100 times, the true statistical accuracy will fall in the interval (85.5 - 4.9, 85.5 + 4.9) percent or (82%, 91%). Similarly, the confidence interval at $L = 0.99$ can be computed using the t-value of 2.58 instead of 1.96. In this example, the confidence interval at $L = 0.99$ would be (80%, 90%). The t is a numerical value which depends on the L value and is required in the calculation of confidence intervals or n's.

4.2.2 Example 2 – Sample size determination of the two-class images.

Again, consider the image of forest versus nonforest features. If the required E is within ±5 percent of the estimated accuracy 95 percent of the time (that is, at $L = 0.95$):

- Case A: If prior knowledge of the approximate value of the accuracy is not available, the following equation can be used to calculate an upper bound on n :

$$n = 2500 \times \left(\frac{1.96}{5}\right)^2 = 384 \tag{4-3}$$

- Case B: If the accuracy is known to be around 85 percent, the n can be computed by:

$$n = 85(100 - 85)\left(\frac{1.96}{5}\right)^2 = 196 \tag{4-4}$$

4.2.3 <u>Example 3 – Evaluation of multiclass images</u>. Consider a four-class image consisting of softwoods, hardwoods, range, and "other." Through proper calculations of n's, p's, and confidence intervals, let the following result:

p_1 = p of softwoods versus the other three classes
= 95 percent with confidence interval (91%, 99%) at an L of 0.95

p_2 = p of hardwoods versus the other three classes
= 85 percent with confidence interval (79%, 91%) at an L of 0.95

p_3 = p of range versus the other three classes
= 78 percent with confidence interval (71%, 85%) at an L of 0.95

p_4 = p of "other" versus the other three classes
= 91 percent with confidence interval (86%, 96%) at an L of 0.95

Using equation 4-10, the overall p of the four-class image is:

$$\text{Overall } p \text{ percentage} = \frac{1}{2}(p_1 + p_2 + p_3 + p_4 - (4 - 2)100)$$

$$= \frac{1}{2}(95 + 85 + 78 + 91 - 200)$$

$$= \frac{1}{2}(149)$$

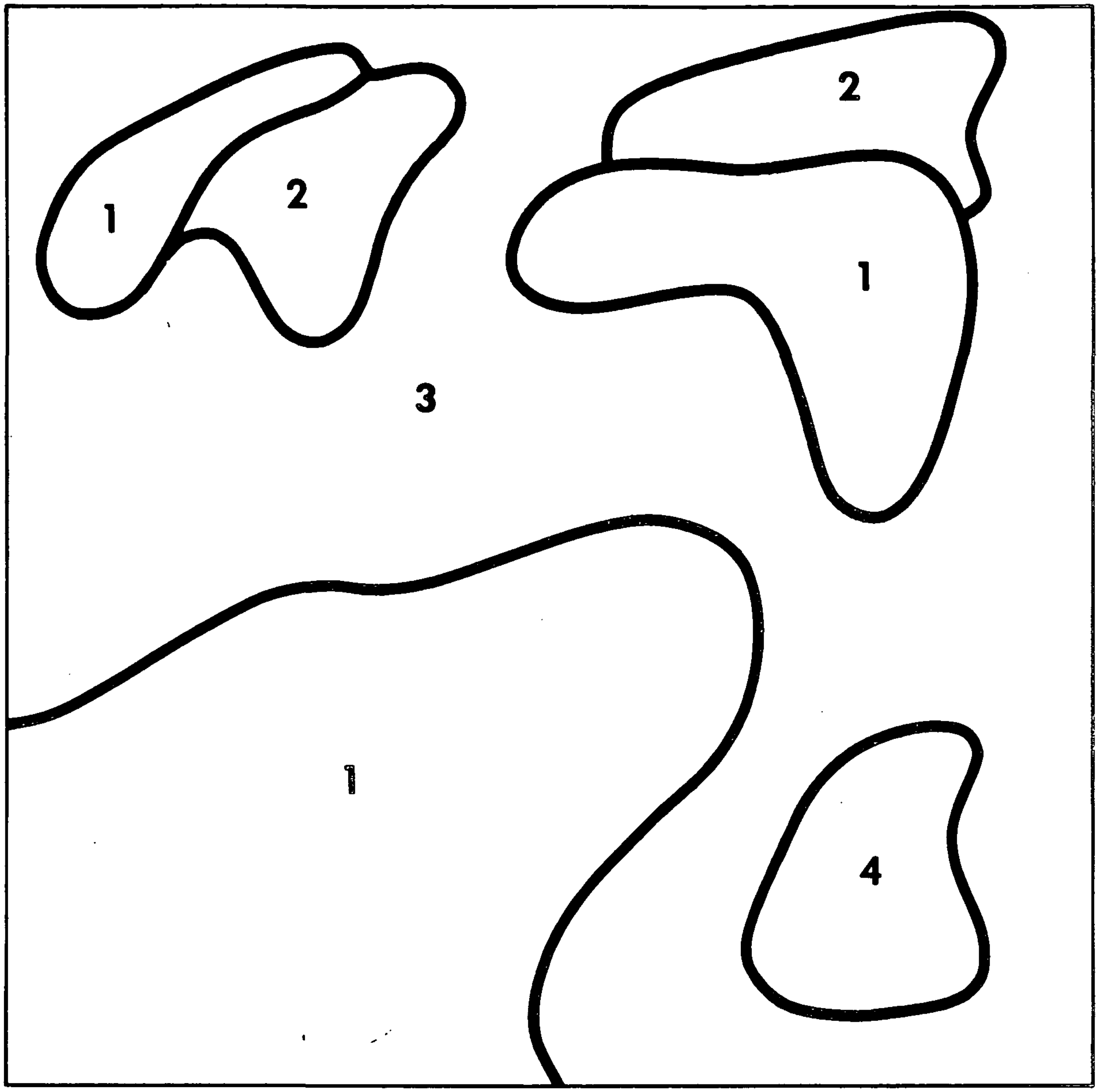
$$= 74.5 \tag{4-5}$$

However, no simple formula exists to establish confidence statements on the accuracy figure.

4.3 Grid Cell System

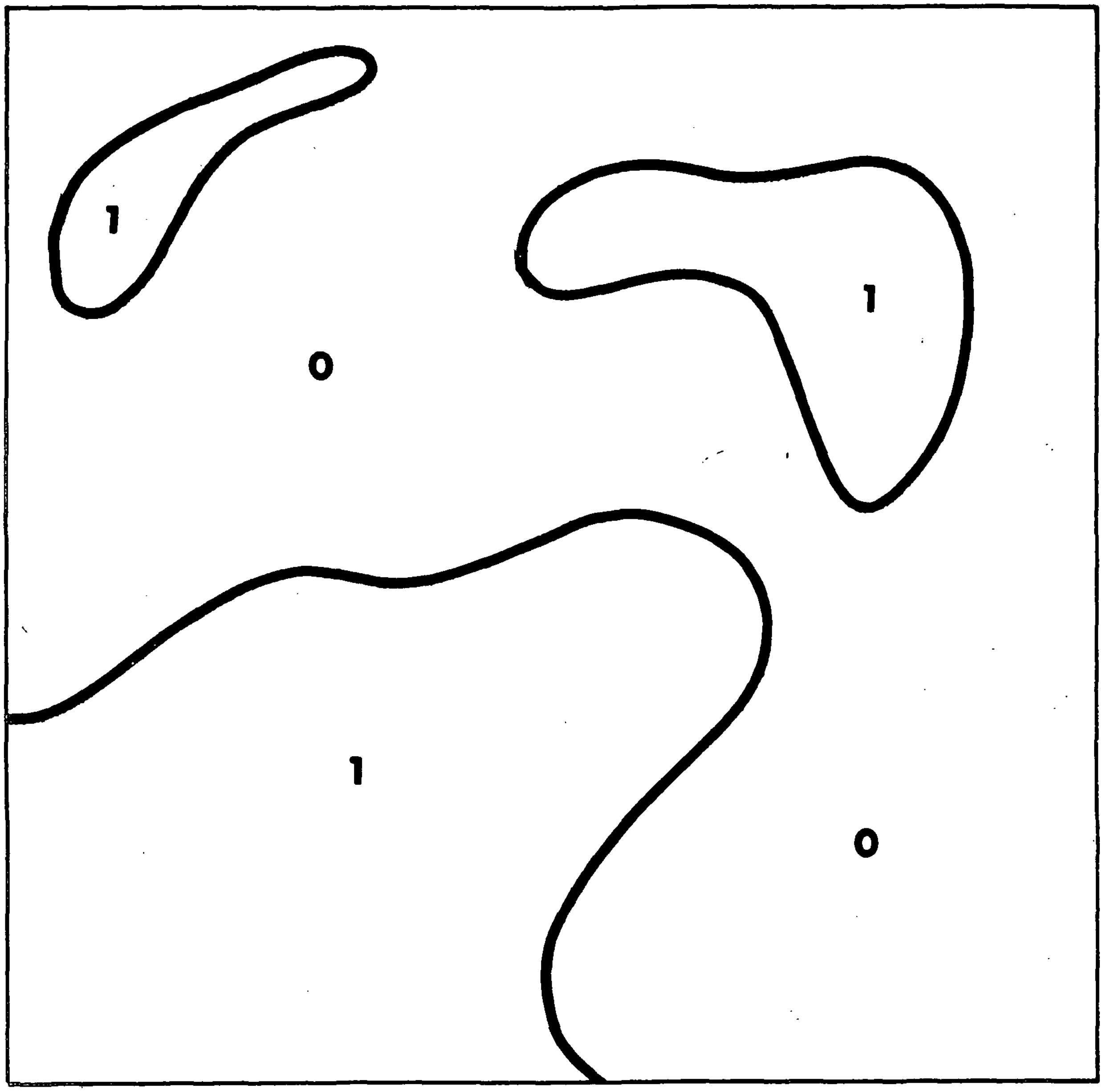
Consider the interpreted image of figure 4-1 which contains the four classes of softwoods, hardwoods, range, and "other." When one feature is considered at a time, this four-class image becomes a two-class image. For example, the two-class derived image containing softwoods and nonsoftwoods is shown in figure 4-2. In fact, only images such as figure 4-3 need to be examined because procedures A and B are designed for two-class images, or derived two-class images.

To evaluate the classification image, a cell system will be utilized. A dot grid system could be employed, but the grid cell system will be used in this section. Figure 4-3 shows the grid cell system overlaid onto the classification image of figure 4-2. When placed over the image, the dimension of each cell should be approximately the size of the



1 = softwoods
2 = hardwoods
3 = range
4 = other

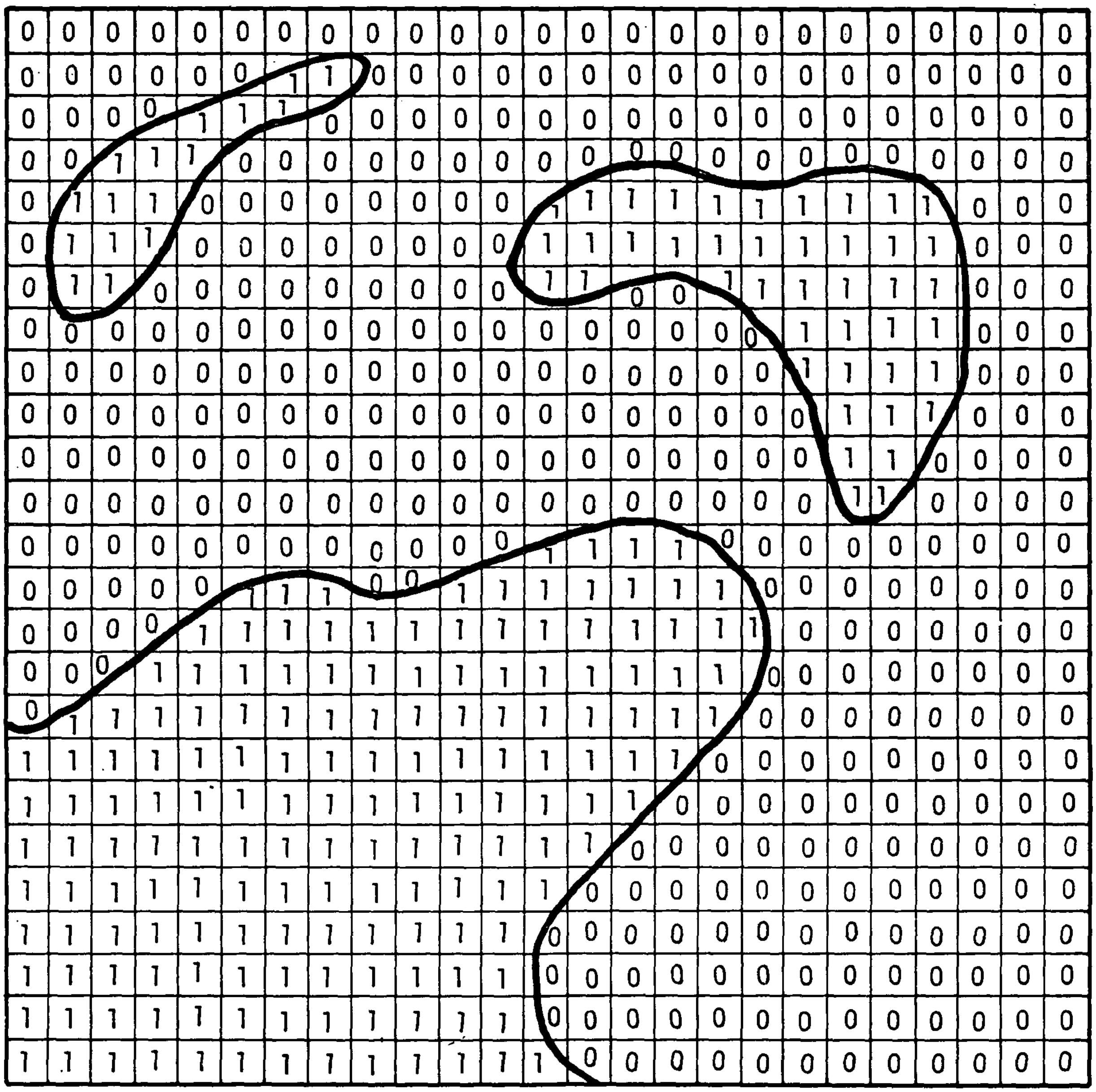
Figure 4-1.— An interpreted four-class image.



1 = feature of interest: softwoods

0 = remainder of features: hardwoods, range, and "other"

Figure 4-2.— Two-class classification image, derived from the four-class classification image of figure 4-1.



1 = feature of interest

0 = remainder of features

Figure 4-3.– Grid cell system overlaid on the classification image (fig. 4-2). The type into which the largest portion of each cell falls determines whether the cell received a 1 or a 0 classification.

smallest width of the feature of interest. The intent is that the size of the cell be as large as possible without causing ambiguous associations between cells of type 1 and type 0. An example of this is the strip of feature type 1 in the upper left-hand corner of figure 4-2, where narrow features are encountered. As a rule, a grid system smaller than 50 by 50 cells should not be used.

When the grid cell system is established, the classification image becomes a conglomerate of cells, each of which will be labeled 0 or 1. The type into which the largest portion of each cell falls is the basis for determining whether the particular cell receives a type 1 or type 0 classification. In the case of a dot grid system, the type under the dot determines the classification.

The location of any one cell is given by its row and column number. During the random sampling of a cell, two random numbers are generated. The first random number determines the row number, and the second random number determines the column number of the cell to be sampled. The random numbers can be obtained from a random number generator or a random number table,[5] with values normalized to the maximum number of columns or rows in the image.

4.4 Evaluation of Accuracy

The evaluation of p includes checking the selected samples from the classification image against ground truth.

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[5]Reference footnote 1.

Let n denote the number of samples chosen for evaluation, out of which m is classified correctly. Then the

$$p = \frac{m}{n} \times 100\% \qquad (4\text{-}6)$$

4.5 Confidence Interval of Computed Accuracy

Two complementary parameters, L and confidence interval, are necessary for a thorough evaluation with a sense of reliability and repeatability. An example of the notions of L and confidence interval can be described as follows:

> *The accuracy of 95 percent has a confidence interval of (92%, 98%), read as the interval of 92 to 98 percent, at an* L *of 0.99.*

This description implies that

> *for 99 out of 100 times, the true statistical accuracy is between 92 and 98 percent, while the* p *of 95 percent is an estimate of the true statistical accuracy.*

In the above instance, the confidence interval range is 6 percent (98 to 92 percent); equivalently, E is 3 percent.

To determine the confidence interval on p, the L must be specified. The L's of 0.95 and 0.99 are commonly used. The following formula can be used to compute confidence intervals and the equivalent E's at the prescribed L's.

For a specified L, the E (considered as an allowable error in this case) will be

$$E = t\sqrt{\frac{p(100 - p)}{n}}\ \% \qquad (4\text{-}7)$$

That is, the confidence interval will be (p - E, p + E), where

p = accuracy computed by m, divided by n, times 100 percent, as in equation 4-6

n = sample size

t = a numerical value taken from the table of t-distribution with (n - 1) degrees of freedom[6]

Good approximate values of t at specified L's can be selected from the following table:

L	0.999	0.99	0.98	0.95	0.90	0.80	0.70	0.60	0.50
t	3.29	2.58	2.33	1.96	1.65	1.28	1.04	0.84	0.67

4.6 Sample Size Determination

Sometimes, n is prescribed by management decisions governed by the limitation of resources to be expended on the evaluation. But frequently, n is determined at the onset of the evaluation so that the evaluated accuracy has a prescribed L and a prescribed E (allowable error). An upper bound on the necessary n can be calculated by the following formula:

$$n = 2500\left(\frac{t}{E}\right)^2 \qquad (4\text{-}8)$$

where t is taken from the table of t-distribution and

[6] Reference footnote 2.

E is the confidence interval half-range acceptable in the evaluation. The E's of 2 or 5 percent are generally used as an allowable error of 2 or 5 percent would be used in volume estimation. Also, popular L's are 0.95 and 0.99.

In the event that prior knowledge of the approximate value of p is available, a better estimate of n can be calculated as:

$$n = p(100 - p)\left(\frac{t}{E}\right)^2 \tag{4-9}$$

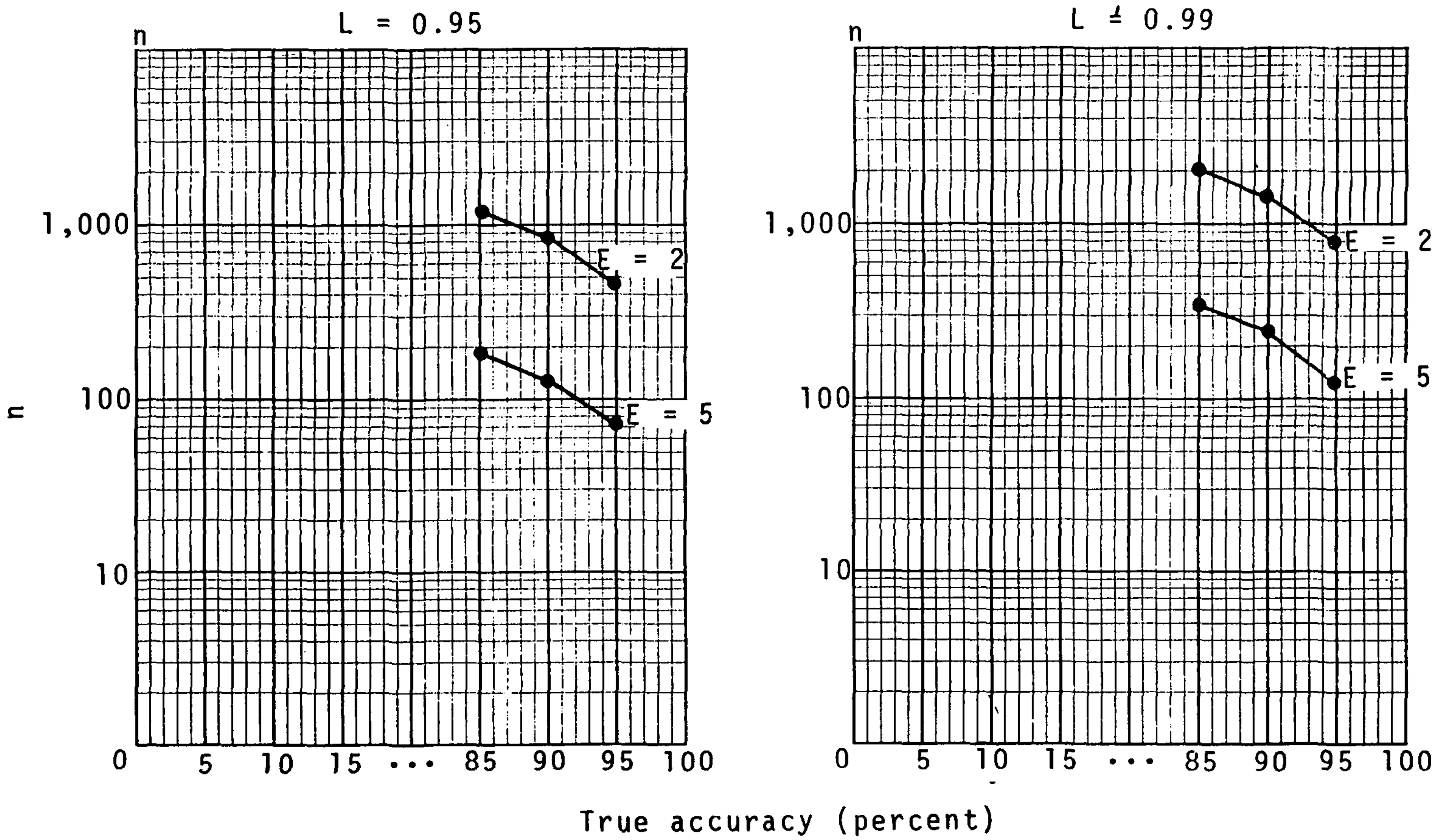
The value of n calculated from equation 4-9 is always smaller than that from equation 4-8.

Note: Whether the n (calculated from equation 4-8, equation 4-9, or chosen arbitrarily) is used in the actual sampling and computation of p as described in section 4.4, a final evaluation of the confidence interval still needs to be performed as described in section 4.5. This is because the confidence interval depends on p, which is obtainable only through the procedures in section 4.4.

Variations of n for different E's at different L's are plotted in figure 4-4.

4.7 Relationship Between Two-Class and Multiclass Accuracies

Procedure B of section 4.1 for multiclass (M classes) image evaluation requires that each class be evaluated at a time as if the image were a two-class image composed of that



L = confidence level

E = confidence interval half-range
(allowable error)

Figure 4-4.– Charts plotting n's required to achieve L's and E's plotted against true accuracy.

class and the conglomerate class of the rest (M - 1) of the classes. Let p_1 be the classification accuracy of class 1 versus the conglomerate of classes 2, 3, ···, M. Let p_2 be the classification accuracy of class 2 versus the conglomerate of classes 1, 3, 4, ···, M. The p_3 through p_M are evaluated similarly.

The overall p of the multiclass image can be shown[7] to be:

$$\text{Overall multiclass } p = \frac{1}{2}(p_1 + p_2 + \cdots p_M - (M - 2)100)\% \tag{4-10}$$

4.8 Final Remarks

This section presents a statistical technique for evaluating the performance of photointerpreters in terms of p's, confidence intervals of the computed accuracies, and n's necessary to achieve prescribed confidences. The formulas are believed to be the simplest practical results of very rigorous formulations. In this connection, the following remarks should be noted:

- The formulas stated in the chapter are not exact, but they will suffice for all practical purposes.

[7]E. P. Kan, Relationship Between Two-Class and Multiclass Accuracies, Lockheed Electronics Company, Inc., Houston, Texas, Tech. Memo., Dec. 1975.

- The exact results are complicated but are available.[8,9,10]

- If all the n specified samples cannot be verified by ground truth, the stated calculations will be biased. Confidence statements cannot be made on the calculations that include unverified samples. This situation could occur if field trips are needed for verification when some samples are geographically inaccessible and substitution is impossible.

- In the above case, equation 4-2 has been used in common practice to compute confidence intervals by using the reduced n (original n less the missing samples). Theoretically these statements are not correct, but in practice they can be used with caution.

- A remedy for the above case is to select the random samples once again and repeat the procedures in section 4.2.

- Confidence statements can be made for accuracies computed of two-class images, using simple formulas.

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[8] E. S. Pearson and C. J. Clopper, The Use of Confidence or Fiducial Limits Illustrated in the Case of the Binomial, Biometrica, vol. 26, 1934, p. 404.

[9] H. Cramer, Mathematical Methods of Statistics, Princeton University Press, Princeton, N.J., 1946.

[10] J. P. Basu and E. P. Kan, Confidential Intervals for Probability of Correct Classification, Lockheed Electronics Co., Inc., Houston, Texas, Tech. Memo. LEC-5003, Dec. 1974.

- No simple formulas exist for expressing confidence statements for the overall p of multiclass images. However, if the confidence intervals of the accuracies of all derived two-class images are narrow (for example, 10 percent at $L = 0.90$), the user can assume similar confidence on the estimated overall p.

5.0 LAND USE CLASSIFICATION AND MAPPING

5.1 General

This section discusses the steps involved in producing regional land use maps by visual interpretation of high-altitude color IR aerial photography. Accurate land use maps will assist the forest manager in determining the nature and potential productivity of the land and, consequently, in achieving optimum forest resource management. Information on land use activities in nearby areas may influence management decisions in areas under the USFS jurisdiction. Land use changes affect land use decisions in neighboring National Forests.

The use of aerial photointerpretation to recognize and map land use patterns has been an accepted practice since the 1940's. However, many of the procedures and criteria are based on the use of panchromatic black-and-white photography acquired at relatively low altitudes (less than 3,048 m, or 10,000 ft) and rely heavily on recognition of detailed features, such as shadow, size, and shape. High-altitude, small-scale, color IR photography shows less detail, but its spectral characteristics make it useful in land use mapping. The first two levels of land use (table 5-I) may be inferred from aerial photographs by the interpretation of land cover. Any further breakdown probably will require input of other data sources.

The study area on which these procedures are based is the NASA/JSC Houston Area Test Site (HATS) in southeast Texas, but the principles and procedures followed are

TABLE 5-I.— A LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA

[USGS Circular 671]

Level I	Level II
01. Urban and built-up land	01. Residential
	02. Commercial and services
	03. Industrial
	04. Extractive
	05. Transportation, communications, and utilities
	06. Institutional
	07. Strip and clustered settlement
	08. Mixed
	09. Open and other
02. Agricultural land	01. Cropland and pasture
	02. Orchards, groves, bush fruits, vineyards, and horticultural areas
	03. Feeding operations
	04. Other
03. Rangeland	01. Grass
	02. Savannas (palmetto prairies)
	03. Chaparral
	04. Desert shrub
04. Forest land	01. Deciduous
	02. Evergreen (coniferous and other)
	03. Mixed
05. Water	01. Streams and waterways
	02. Lakes
	03. Reservoirs
	04. Bays and estuaries
	05. Other
06. Nonforested wetland	01. Vegetated
	02. Bare
07. Barren land	01. Salt flats
	02. Beaches
	03. Sand other than beaches
	04. Bare exposed rock
	05. Other
08. Tundra	01. Tundra
09. Permanent snow and icefields	01. Permanent snow and icefields

generally applicable. The HATS includes 18 counties, covering some 4,000,000 hectares (16,000 sq miles) (fig. 5-1). It lies in the western part of the gulf coastal plain. The east Texas timberlands cover the northeast part of HATS. The forests give way to coastal prairies and rolling plains in the western part of HATS. Along the south and east side of the area lie the coastal marshlands, estuaries, bays, and barrier islands of the Texas coast. The area is drained by numerous parallel southeast-flowing streams, many of which have been dammed for recreation and water supply.

Superimposed on the above is a cultural landscape reflecting a wide range of human activities. The Houston, Galveston-Texas City, and Bryan-College Station Standard Metropolitan Statistical Areas are the main urban areas, but smaller cities and towns abound. While the HATS contains a variety of economic activities, the regional economy is dominated by the petrochemical industry, oil and gas production, agriculture, livestock raising, and transportation (including the Port of Houston and the Intercoastal Waterway). Additional major industries located within the region include timber production, sand and gravel extraction, sulfur extraction, commercial fishing, aerospace, and tourism.

The HATS land use pattern reflects the above economic structure and the corollary commercial, residential, and recreational land use activities.

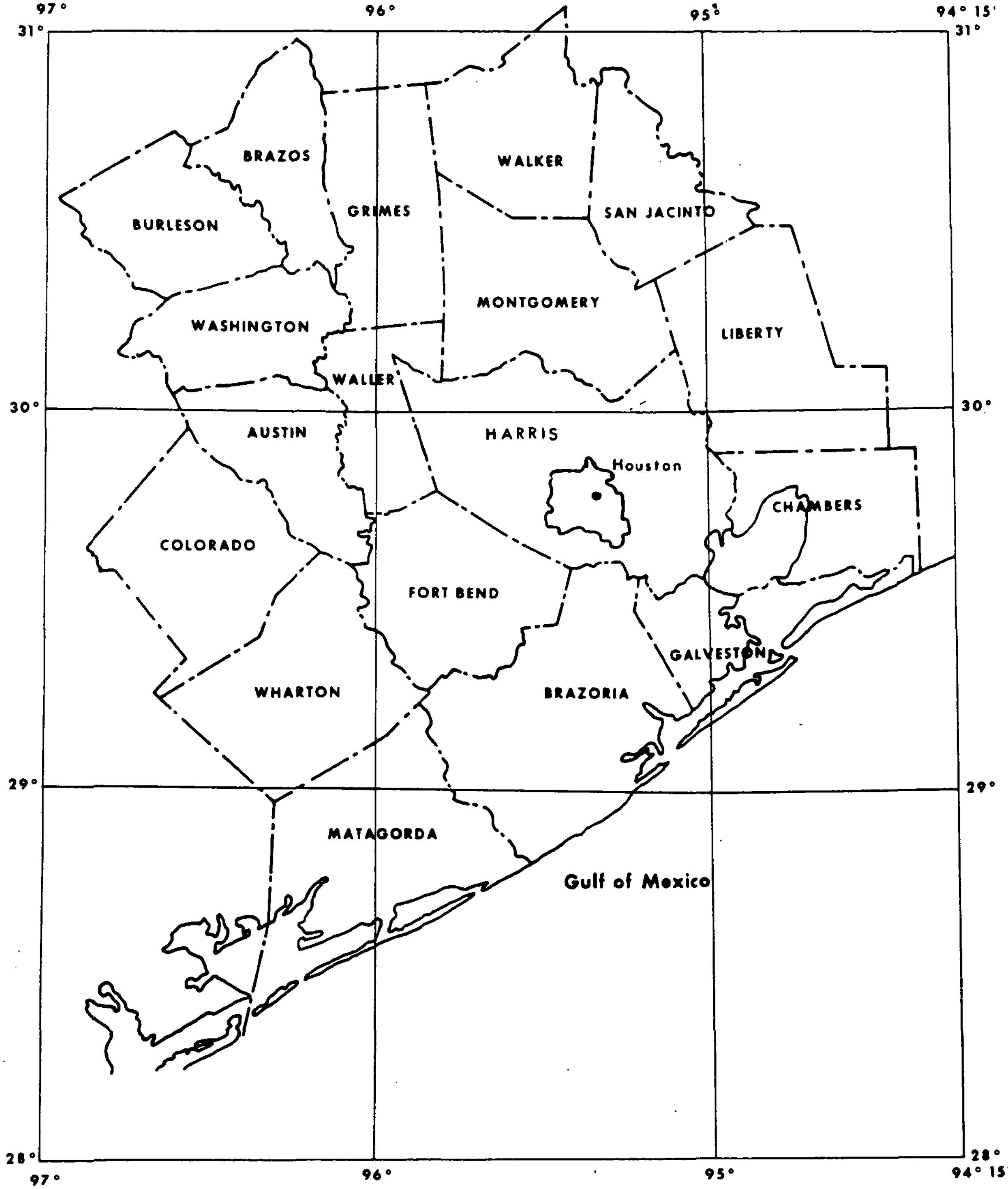

Figure 5-1.– Houston Area Test Site (HATS).

The USGS Circular 671[1] (table 5-I) was used as an example classification scheme in this section. Other classification schemes can be employed. This section presents a method of using small-scale color IR photography in classifying and mapping. Therefore, the user may prefer to use a land use classification scheme better fitting his needs.

The classification scheme used here was developed by the Interagency Steering Committee on Land Use Information and Classification. It is designed for use with high-altitude aircraft and spacecraft imagery but has additional levels of detail adapted to low-altitude or ground-level data acquisition. The system is suitable for use in a wide range of geographic and economic settings, and its flexibility allows modification to suit specific land use studies.

In applying this or any other land use classification, aerial photography usually must be supplemented by other data, such as maps and politico-economic information, to obtain a complete land use picture. Land use classification is derived from three questions, only one of which can be answered with reasonable certainty from aerial photography. These are:

- What is the surface cover? This can be determined from aerial photography using the color/tone and shape criteria.
- What functions or activities occur there? By analogy to known areas, or by deduction from shape, associations, and related criteria in aerial photography,

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[1] A Land-Use Classification System for Use With Remote-Sensor Data, USGS Circular 671, Washington, D.C., 1972.

it is possible to differentiate residential, industrial, transportation, and other such activities, as well as the more obvious agriculture, forestry, and mineral extraction. However, some areas are very difficult to differentiate. For example, a modern office center, medical center, and government complex will appear quite similar.

- What is the private industrial/government status of the area? This information is necessary to positively identify such uses as government buildings and installations, prison farms, and parks, but it is seldom evident from aerial photographs. It is in this area that ancillary information is most needed.

Land use classification schemes can be used with high-altitude color IR photography, supplemented by the necessary ancillary information, to produce a useful land use inventory at a fraction of the time and cost of ground-based or low-altitude photography methods.

Table 5-I lists Levels I and II of the USGS classification. Section 5.6 of this manual describes the criteria used for recognizing the various land use categories. The USGS scheme for land use and land cover type has been revised since it was used in this study. Because the USGS scheme is used as an example only, no changes were made in this document.

The land use map preparation procedure recommended is basically the following:

- Photointerpreters identify the various land use classes visible on each frame of aerial photography and delineate their boundaries on transparent film overlays.
- Technicians then transfer the information on the photo-overlays to a map base. The photo-overlay information is traced onto base map overlays with the aid of a reflecting and reducing/enlarging projector.
- Drafting personnel prepare final copies of the land use base map overlays for coloring and preparing printing masters.

5.2 Data Resource Requirements

Photographic and other ancillary data types needed are

- 23- by 23-cm (9- by 9-in.) duplicate positive color IR transparencies for analysis. Recommended scale is 1:60,000 or smaller.
- Positive paper prints for making field checks and composite (mosaicked) photoindexes.
- USGS and Defense Mapping Agency Topographic Command 1:250,000 topographic maps or 1/2 in. = 1 mile (1 cm = 1.27 km) USFS administrative map for photo-index preparations.
- USGS 1:24,000 or 1:62,500 topographic maps for additional information on land uses, such as administrative boundary definition and identification of institutional complexes.

- Roadmaps for field trips.
- Copies of the base maps to which the photo-overlays are to be transferred, their type and scale depending on the user. In the HATS project a 21-sheet series of 1:125,000 semicontrolled photomosaic maps was used as the base, and the photo-overlay information (at 1:120,000 scale) was transferred to it.

5.3 Data Requirements Definition

For a typical land use mapping project, the following considerations and requirements apply to either data purchase or special overflight data acquisition:

- Geographic coverage: This will be dictated by the size and shape of the area. It should allow for overlap into areas containing features influencing land use in the area of prime interest.
- Camera orientation: Vertical photography with less than 3° tilt is required for constructing land use photo-overlays suitable for transfer to a base map (see section 2.0).
- Type of photography: Color IR film is recommended because of the flying heights involved.
- Year: as current as possible.
- Terrain and cloud shadows: Zero cloud cover is preferable; terrain shadows should be minimized by acquiring photographs during midmorning or midafternoon.
- Snow or water cover: minimal except for lakes and permanent snow fields.

- Scale of imagery: 1:60,000 to 1:120,000 (23- by 23-cm or 9- by 9-in. film format) is preferable.
- Products: Transparencies are preferable for analysis because of their greater detail and better color rendition; prints are useful for field checks and composite (mosaic) photoindex preparation.

5.4 Photointerpretation

The photointerpretation phase of the project involves:

- Training
- Land use delineation on photo-overlays
- Quality checks
- Interim data disposition
- Field checks

5.4.1 Training.

- Step 1 — Become familiar with the classification system.
- Step 2 — Using one photograph, familiarize yourself with how the different land uses appear.
- Step 3 — Make a field trip to the area of the training photography to become familiar with the ground-based and high-altitude appearance of various land use classes. This step is optional according to time, cost, and location factors; but it is strongly recommended for inexperienced photointerpreters.

5.4.2 <u>Delineating land use on photo-overlays</u>.

- Step 1 — Orient the photography being analyzed under the stereoscope. If the equipment used does not allow the film to be viewed on continuous rolls, cut the individual frames apart for viewing.
- Step 2 — Cut and tape a 23- by 23-cm (9- by 9-in.) piece of 2-mil acetate to the frame of photography being analyzed. Put the photograph corner marks and frame identification numbers on the overlay with a Rapidograph pen.
- Step 3 — Select 8 to 10 points on the photograph and mark them on the acetate overlay with a Rapidograph pen (for later use in orienting the photo-overlays to transfer the information to a base map). Suggested features include road junctions, isolated buildings, small dams, and stream junctions. Locate points along the edges as well as in the center of the photograph.
- Step 4 — Delineate roads and railroads in red pencil and annotate with the proper code.
- Step 5 — Recognize and delineate streams and other water bodies in blue pencil. Annotate with the proper code. Section 5.6 describes and discusses the land use interpretation criteria and codes used in this phase.
- Step 6 — Examine the film under a stereoscope, identify land use types and delineate land use boundaries using a 4H pencil. Annotate the identifying code within the boundary. See section 5.6 for land use recognition criteria and codes.

Although only the first two levels of land use appear in this classification system, the interpreter can make further breakdowns and modifications. An example appears in figure 5-2 on the left of the photograph where a clear-cut and prepared site is classified as 04-02-01-02 and a clear-cut but unprepared site as 04-02-01-01. Level I of table 5-I shows that 04 is forest land.

In Level II of table 5-I, forest land is divided into three categories. The second set of digits in the example is 02, representing evergreen (coniferous and other). The third and fourth sets of digits were developed by the interpreter for this particular study. The third set, 01, represents a clear-cut site; and the fourth set, 02, represents a prepared site. The 01 in the fourth set represents an unprepared site.

5.4.3 <u>Quality checks</u>. At this stage of the analysis it is advisable to have another interpreter check each photo-overlay for gross errors.

5.4.4 <u>Interim data disposition</u>. After each photo-overlay is completed, a machine copy should be made. The originals and copies should be filed separately pending use of the originals in transferring the film overlay data to the base maps.

5.4.5 <u>Field checks</u>. As time, cost, location, and project objectives permit, continual field checks of the photographs being interpreted are advisable. The purpose is to maintain uniform criteria among the interpreters and minimize discrepancies among them. Field checks should

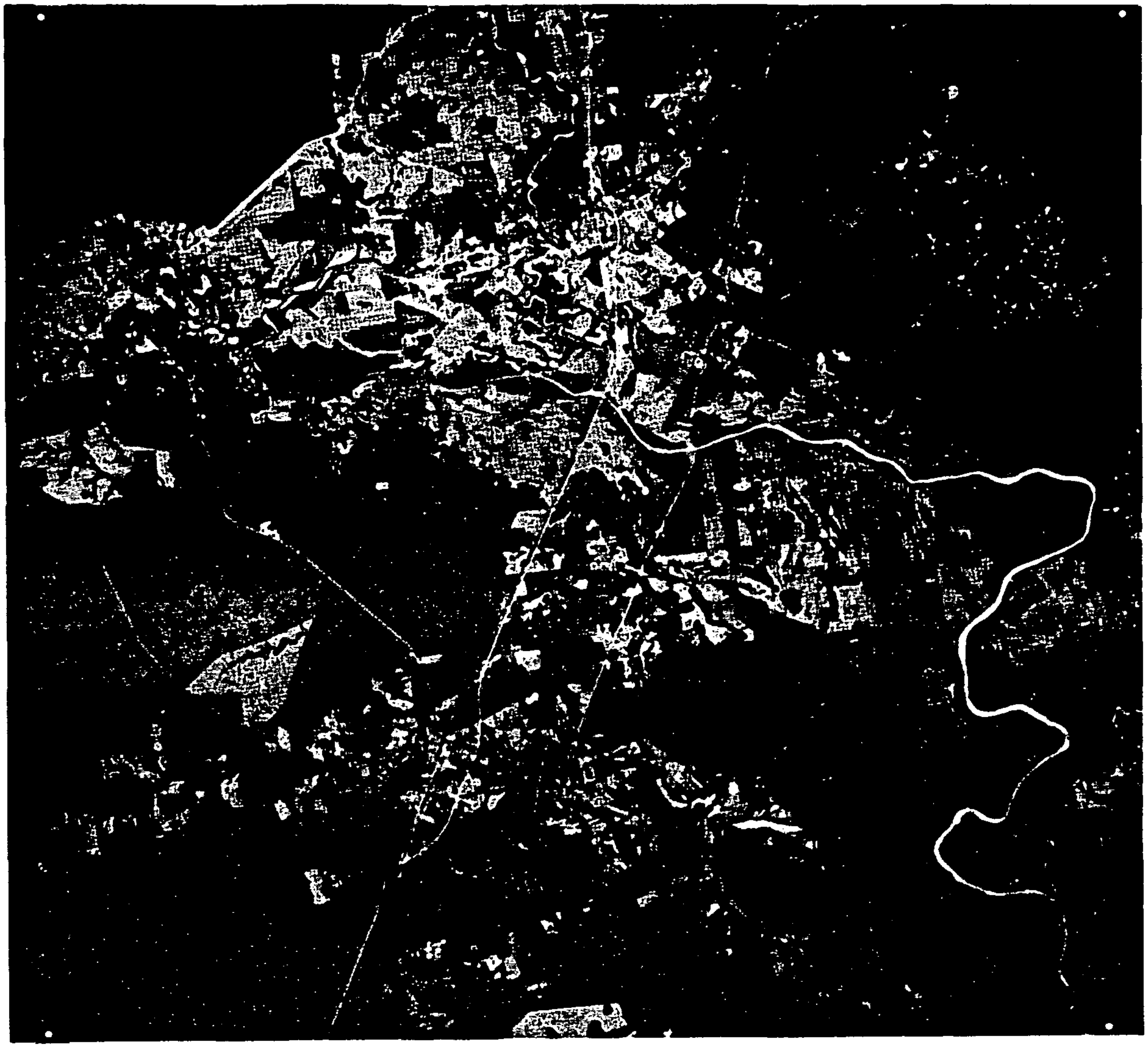
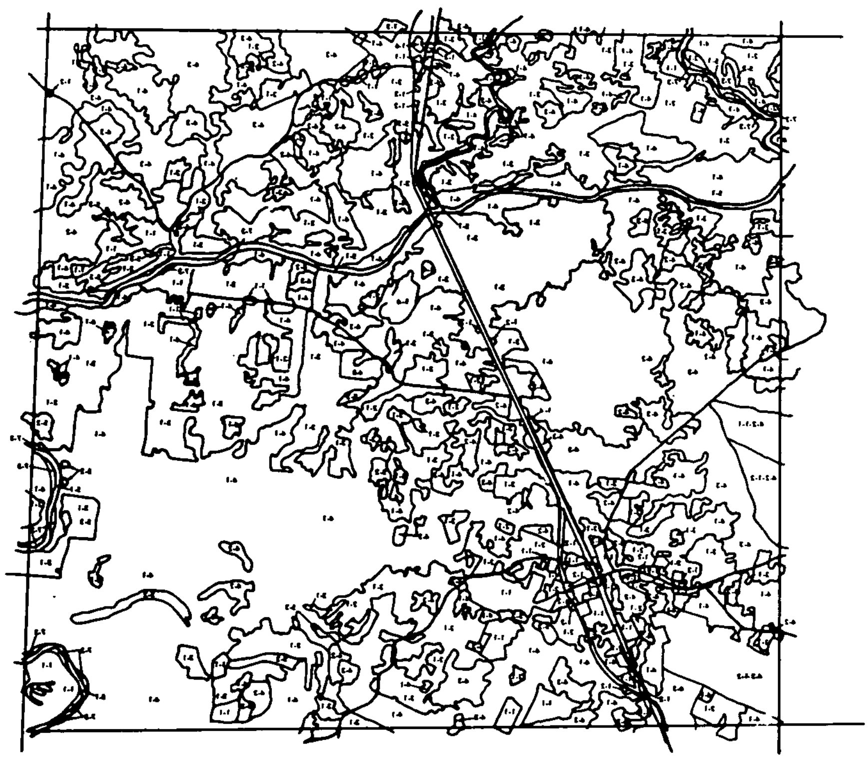


Figure 5-2.– Photograph with the land use overlay for training.



follow soon after each frame is delineated. This will provide continual feedback to the photointerpretation process.

Field checks should employ contact prints of the area to be checked, the interpreted photo-overlay, and a 1.3-cm (1/2-in.) grid overlay on 5-mil frosted acetate (fig. 5-3). The route should be planned in advance, and the areas to be checked should be marked and numbered on the grid overlay to avoid marks on or damage to the photographs or photo-overlays.

During the field checks each mapped land use category should be checked. Attention should be given to the checking of Level II land use categories in problem land use areas, such as those involved in natural plant succession after the cessation of intensive agriculture, recently clear-cut forest stands, and residential areas in early planning stages. It is advisable to take ground photographs of the various checkpoints.

5.5 Information Transfer

This section covers the procedures for transferring land use mapping information on the individual photo-overlays to a base map. The HATS project used a Kail reflecting projector to project a reduced scale (1:125,000) image of the 1:120,000 land use photo-overlays and then traced the land use boundaries and other features onto base map overlay sheets. The exact scale of the photo-overlays and base map overlays and the amount of enlargement or reduction required will differ among various applications. The steps to be followed are:

- Step 1 — Assemble the base map sheets to which the photo-overlay data are to be transferred.

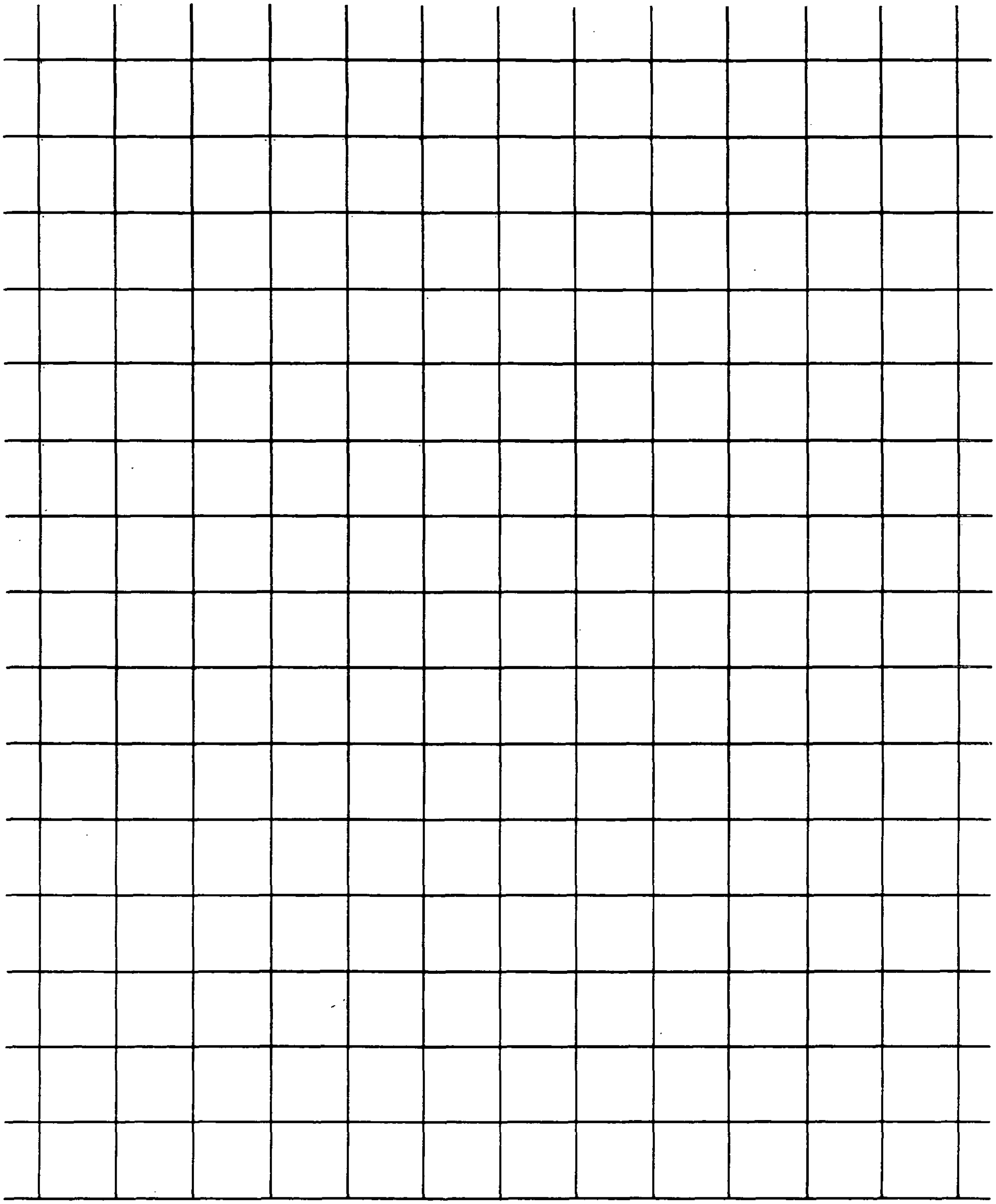


Figure 5-3.— Photointerpreter 1.3-cm (1/2-in.) grid overlay used for locating field check plots.

- Step 2 — Cut overlays of 2-mil acetate film (one side matte) for each base map sheet, allowing a 1.3-cm (1/2-in.) margin around the actual map area. Mark the corners of the map area on each overlay and mark the map identification number or name in the margin of each overlay. Tape the overlays to the base maps.
- Step 3 — Select a base map sheet for information transfer and retrieve corresponding photo-overlays using the map overlay index prepared earlier as a guide.
- Step 4 — Select one of the photo-overlays, preferably corresponding to an area in the middle of the base map sheet. On the base map sheet, identify the features corresponding to the previously marked orientation points on the photo-overlays. Mark these features on the base map overlay sheet on the matte side.
- Step 5 — Use the Kail reflecting projector (or equivalent) to project an image of the photo-overlay sheet on a sturdy, flat, working surface. Adjust the magnification and focus until the geographic control points on the photo-overlays coincide as closely as possible with those on the base map sheet overlay. The scale of the reflected overlay of the photo-overlay should be identical to that of the base map sheet overlay.
- Step 6 — Trace land use map detail from the reflected, reduced, or enlarged photo-overlay image onto the acetate base map sheet overlay. Use 4H pencil for land use class boundaries, red pencil for roads, and

blue pencil for streams. Cotton gloves should be worn to prevent smudging. Erasures should be made with the offset eraser, using a metal eraser shield.

- Step 7 – After transferring information from one photo-overlay to the base map overlay, select another adjoining photo-overlay sheet. Repeat steps 4 through 6 until all photo-overlays for that base map sheet have been transferred.

- Step 8 – Select another base map sheet and overlay and repeat steps 3 through 7 until all base map sheet overlays have been processed.

- Step 9 – Make continual quality control checks during the information transfer phase. As each base map sheet overlay is completed, the person who did the work should check it carefully for errors or omissions. The more common errors are: omitting a land use area outlined on the original photo-overlay; omitting Level I and II land use category codes from the base map sheet overlay; indicating incorrect identification or marking of land use categories, thus causing frame boundary discrepancies; and hanging land use boundaries, indicating incomplete photointerpretation or a discrepancy between photo-overlays. Errors and omissions are reconciled with the use of the original photo-overlays by reinterpreting areas where necessary.

  In addition to the indicated quality control operations, it is advisable to obtain an independent check by another photointerpreter or a supervisor.

- Step 10 – After errors and omissions on the base map sheet overlays have been corrected, make ozalid copies and file them separately from the originals.

The colored elements on the originals should be filled in on the ozalid copies (red for roads, blue for streams). These copies provide a backup against loss or destruction of the originals.

- Step 11 – Coordinate with drafting and graphics personnel. For practical and effective dissemination of the land use mappers' results, the base map sheet overlays must be drafted in final form and prepared for reproduction, using distinctive colors or patterns to distinguish the various land use categories. The originals of the base map sheet overlays should be furnished to the drafting and graphics personnel for their use. The photointerpretation and information transfer personnel normally should check the accuracy of the draftsmen's work, resolve discrepancies, and answer questions to ensure product quality commensurate with the professional resources expended. This is the final stage of the information transfer process as far as the photo-interpretation personnel are concerned.

5.6 Land Use Interpretation Criteria

This section discusses criteria for recognizing the various land use categories defined in USGS Circular 671, based on the experience of the HATS study. The classification scheme is designed for general applicability; however, appearance of a given land use class may vary among geographic, economic, and cultural settings. Consequently, the analysis of a training photograph showing a wide range of land use types is advisable before starting a large-scale project.

Figure 5-2 contains an example of a photograph used for training in the HATS study. The colors and hues indicated are those shown on false-color IR photography. An overlay for the frame 34-0099 serves as an example of photo-interpreted land use. Table 5-II is a description of those types of land use features found in the photograph. An example of a completed land use interpretation using a modified classification scheme appears in figure 5-4.

TABLE 5-II.— GENERAL DESCRIPTION OF USGS LAND USE CATEGORIES USED AS AN EXAMPLE IN THE HATS STUDY

Code	Name and Description
1-1	Residential. Single-family residential areas contain numerous relatively small, highly reflective rectangular buildings, spaced somewhat uniformly and of uniform size and appearance from high altitudes. A closely spaced checkerboard street pattern is characteristic of older neighborhoods, while curvilinear patterns are more common in newer suburbs. Houses occur in a matrix of trees, grass, or bare ground, depending on the geographic setting, age, and income level. Apartment buildings are commonly indicated by a rectangular arrangement of buildings around a courtyard, which often contains a swimming pool. Trailer parks show a herringbone pattern. Relatively undeveloped residential areas appear as a network of roads with some evidence of new housing starts. The key is the presence of homes. An area that has roads but no evidence of homes, even though excavation may be evident, would not be considered residential.
1-2	Commercial and Services. Buildings of this type are usually longer and larger than residential buildings. They are usually taller than residential buildings, when height can be discerned. There is little or no uniformity among the buildings in terms of size, parking space, and vegetation. They are commonly

TABLE 5-II.— Continued.

Code	Name and Description
	located in the city centers, on major transportation routes, or at the intersections of major transportation routes. Commercial and services buildings commonly have more adjacent parking space (particularly away from city cores). This is evident as concrete of a whitish or bluish-gray hue. Shopping centers are commonly apparent as one large building or several linked buildings surrounded by parking areas. Motels usually appear as relatively long buildings with one to four 90° corners and a courtyard with a swimming pool, usually located on the outer edges of an urban area.
1-3	Industrial. Buildings are generally large and rectangular, often in groups covering a large area. They may appear similar to commercial structures but are often recognizable by associated features and settings. Features such as oil storage tanks, smokestacks, storage yards, and reservoirs are often present. They are almost always located near major transportation (especially railways) and shipping facilities. They are highly reflective due to large areas of bare ground. They are usually located away from residential areas.
1-4	Extractive. In HATS these were usually oilfields, gravel pits, or sulfur mines.

TABLE 5-II.— Continued.

Code	Name and Description
	Oilfields are characterized by a dense network of white roads, each of which dead-ends at a rectangular pad where the wellhead is located. Some storage tanks and lease separators are sometimes visible. Oilfields may be located in forest, farmland, pasture, marshland, or other land use areas, sometimes causing difficulty in designating the actual land use.
	Gravel pits are recognizable as large open pits appearing as bare soil, sometimes partially filled with water, sometimes as vegetated fingers of land extending out into the water.
	Sulfur mines also appear in the Houston area. They are located on top of subsurface salt domes and are small areas (usually less than 500 hectares, or 2 sq mi), with numerous highly reflective bright disposal pits, waste pits, and white-to-chartreuse sulfur piles. Oilfields are commonly associated.
	Open pit mines and quarries are common in the Houston area but would be recognizable as excavations of various shapes and depths, often with reflective piles of waste materials from the mining or benefaction processes. In the case of underground (shaft) mines the mine opening is inconspicuous, but the operation is usually detected by associated waste piles and structures used for hoists and processing facilities.

TABLE 5-II.— Continued.

Code	Name and Description
1-5	Transportation. Highways, paved streets, and roads have a thin linear appearance and are highly reflective. Railroads have a linear appearance and are reflective due to the roadbed material, but are usually straighter than vehicular roads. Small airports appear as crisscross patterns of runways about the width of a four-lane highway, usually with an adjacent large building. Large airports are visible as large runways with peripheral taxi strips, several large buildings, and control towers. Port and waterfront areas are found on rivers, estuaries, and bay shores and are evidenced by their gray color and piers extending into the water.
1-6	Institutional. This category is often difficult to detect from aerial photography alone because of its similarity to other land use categories. High schools and universities are often recognizable as complexes of large buildings surrounded by well-kept lawns (bright red), circular or curving drives, and football stadiums. Elementary schools, sometimes difficult to detect because they have no athletic fields, can be detected by the presence of grouped buildings, well-kept lawns, and circular drives to the main entrance. Churches have a similar appearance. Schools and churches are most easily recognized when located in residential and suburban areas; inner-city examples are more difficult to identify.

TABLE 5-II.— Continued.

Code	Name and Description
	Post offices and other government buildings are almost impossible to separate from commercial buildings. Most prisons and associated farms require auxiliary information for positive identification.
1-7	Strip and Cluster Settlements. This category was not used in the HATS project. In most cases it consists of an assortment of commercial and service buildings concentrated at or along the intersections of transportation routes.
1-8	Mixed. This category was not used in the HATS mapping project. See USGS Circular 671 (table 5-I) for details.
1-9	Open and Other. This category includes several vacant (undeveloped) land use types within urban areas. Parks are islands of forest or grass cover. Golf courses have a pinkish or reddish hue; the fairways have a links-of-sausage appearance. Cemeteries are pink in appearance with uniform texture and rectangular road network similar to city blocks, but with smaller and often uniformly spaced trees.
2-1	Cropland and Pasture. Cropland has a uniforn texture and is red in color, especially when the crops are fully developed and healthy. Field crops

TABLE 5-II.– Continued.

Code	Name and Description
	(for example, wheat and rye) are fairly uniform in texture, while row crops (corn and potatoes) have a linear texture. In some cases irrigated cropland (for example, rice) has visible contours and is usually blue green with canals. Pasture varies in color from red to green with a salt-and-pepper texture, indicating a mixture of vegetation. Boundaries are often irregular, weaving in and out of forest land, in contrast to cropland, which is more often rectangular.
2-2	<u>Orchards, Groves, Vineyards, Bush Fruits, and Horticultural Areas</u>. These appear as distinctive evenly spaced patterns of small red points against a lighter red-to-green background. They are usually rural, but sometimes urban.
2-3	<u>Feeding Operations</u>. ● Livestock: Feedlots may appear as small rectangles with no vegetation, adjacent to one or more large buildings such as tin barns. ● Fishponds: These resemble reservoirs but usually show no connection to streams and are usually distant from industrial complexes. Usually they are divided into smaller ponds.

TABLE 5-II.— Continued.

Code	Name and Description
	• Chickenhouses: These are locally important in the Houston area. Each is about 91 m (300 ft) long and as wide as a residential house. They are usually situated parallel to each other.
2-4	Agricultural, Other. This may be described as dry rural land with vegetation ranging from timber to agricultural crops. It is typified by old agricultural land in an early stage of succession to timber. It has a speckled red and green appearance indicating vegetative ground cover of diverse species and heights. (In the Houston area project this was used instead of rangeland.)
3-1 through 3-4	Rangeland. In the USGS Circular 671 classification this includes grass, savannas (palmetto prairies), chaparral, and desert shrub. This classification was not used in the Houston area study because vegetative cover areas were more closely related to agricultural land or forest land. This reflects the history of agricultural and pastoral practices in the southeast Texas areas, where most natural grassland and other rangeland have been planted, grazed down, put into pasture, or built over since large-scale settlement by European immigrants began in the 1820's.

TABLE 5-II.– Continued.

Code	Name and Description
4-1	Forest Land, Deciduous. Deciduous or broad-leafed forest is easily recognized by a bright red appearance. The red will be the only cover appearing in dense homogeneous hardwoods. One way to find waterways hidden by the forest canopy is to locate the winding stream of rich red hardwood, which favors the stream bottoms.
4-2	Forest, Evergreen. Evergreen forest cover in homogeneous stands appears a rust-reddish color on color IR film, although there can be a more reddish hue when trees are smaller or of certain species. Pure pine plantations will be rust red with corduroy texture. Reforestation (young plantations) may be confused with categories 2-1 or 2-4, but can often be distinguished by circumstantial evidence. If a cutting operation (clearcut) is accompanied by windrowing of slash, this site preparation usually means that the area being reforested contains young saplings.
4-3	Forest Land, Mixed. A forest stand is considered mixed when neither the deciduous nor evergreen component is more than 75 percent of the vegetative cover of the area. Mixed forest types can be simply detected by the presence and relative proportions of red (deciduous) and rust-red (evergreen) hues.

TABLE 5-II.— Continued.

Code	Name and Description
5-1	Streams and Waterways. When not obscured by vegetation these usually appear somewhat blue, depending on the water's clearness or reflectivity at the time of photography (due to Sun angle, lighting, and surface motion). Sun effects sometimes cause a more white than blue appearance. Some waterways are detected by circumstantial evidence, like the winding strip of rich red bottomland hardwood that distinguishes streamways in an evergreen or mixed forest.
5-2	Lakes. Natural lakes are relatively uncommon in HATS, occurring usually as oxbows or sloughs along a larger waterway, or lakes within coastal marshlands. Oxbows are usually crescent shaped. Unlike dammed reservoirs, natural lakes have no straight edge or side.
5-3	Reservoirs. These include all artificially dammed impoundments. Those resulting from damming rivers and creeks are recognizable by a straight edge at the downstream end; they taper in width until the upstream end shows the entrance of a small stream. In contrast, industrial reservoirs usually appear as straight-sided geometric figures (commonly square, trapezoidal, or rectangular). In some cases these may be confused with large irrigated fields, but

TABLE 5-II.— Continued.

Code	Name and Description
	industrial reservoirs always have associated industrial structures and features (code 1-3).
5-4	Bays and Estuaries. These are marine water areas that occur as indentations into the landmass. Estuaries are drowned river valleys, enlarged due to marine flooding. Along the Texas coast these are saline-to-brackish bodies lying between the mainland and the landward side of the barrier islands, such as Galveston Island, which fringe the coast. Care must be taken to separate estuaries from simple marshland, since much of the coastal marshland is intermittently estuarine as a consequence of tides or rainfall. The boundaries between estuaries and rivers, on the one hand, and bays and the gulf are based on geomorphic criteria, not the remote sensor response of the water area per se.
5-5	Other Water. The Gulf of Mexico was assigned to this category in the current study.
6-1	Nonforested Wetland, Vegetated. These are low-lying areas with irregular boundaries along the coast. They usually appear as a mottled, streaked, or blotched combination of blue, black, and red colors.
6-2	Nonforested Wetland, Bare. This land appears light blue green and usually has white mottling due to

TABLE 5-I1.— Concluded.

Code	Name and Description
	dry, bare mineral soil. It is relatively uncommon in the Houston area, occurring mostly in the coastal area and in dried reservoirs.
7-1	Salt Flats. These occur as white, highly reflective areas, varying from a uniform to mottled appearance depending on the circumstances of formation. In the Houston area these are present only as artificial salt flats resulting from brine disposal near oilfields or salt domes.
7-2	Beaches. In the Houston area these appear as highly reflective, white strands along the shores of the Gulf of Mexico and some of the bays.
7-3	Sand Other Than Beaches. This most frequently occurs along the outward side of bends in major rivers. It appears as highly reflective, white surfaces.
7-4, 7-5, 8-1, and 9-1	Bare Exposed Rock, Other, Tundra, Permanent Snow and Icefields. None of these categories were found in the Houston area.

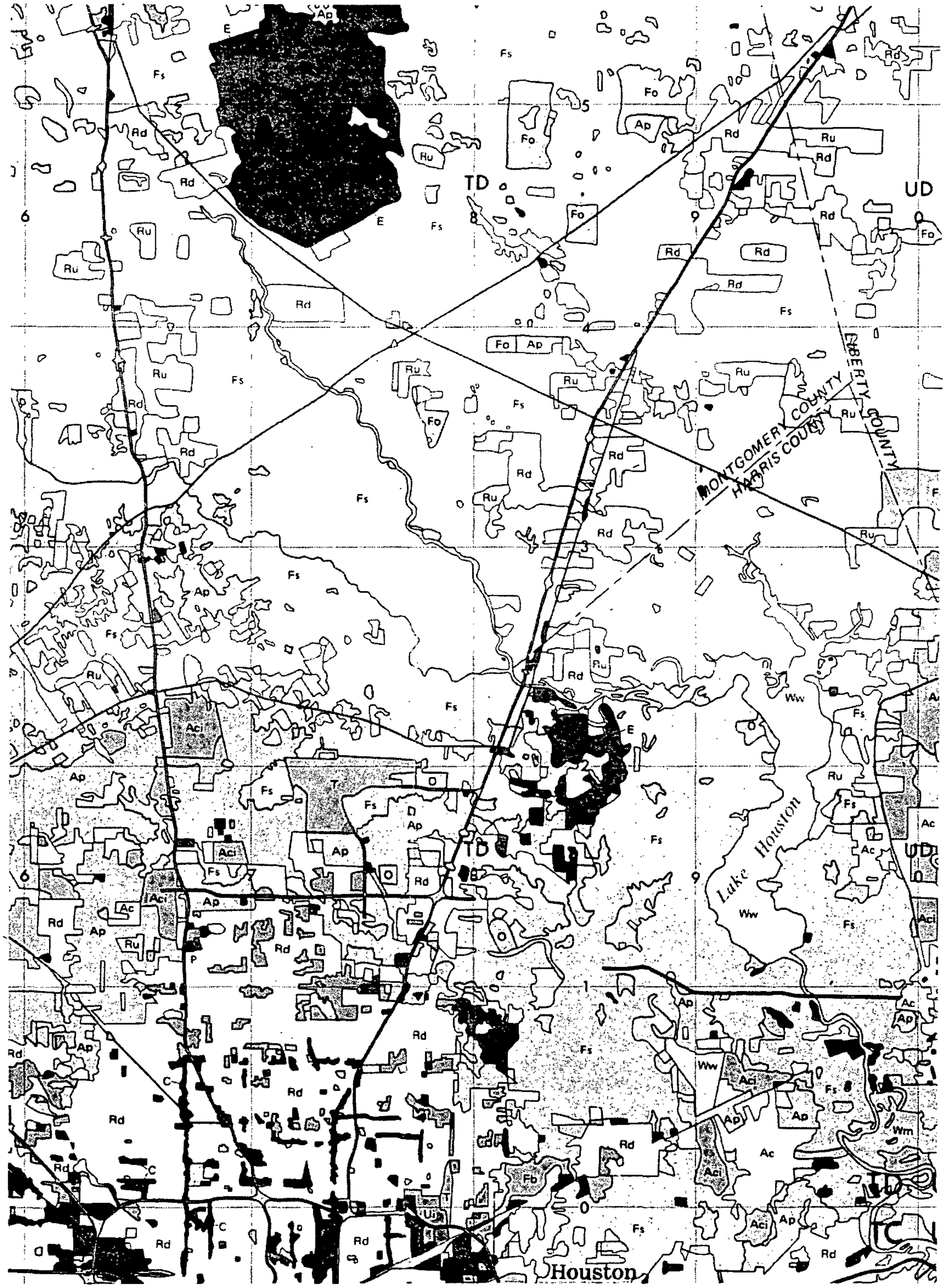


Figure 5-4.—Completed land use interpretation map of North Houston, Texas. The classification scheme was modified from USGS Circular 671 and uses letter codes instead of numbers.

6.0 LANDFORM ANALYSIS

6.1 General

According to the physical division classification, Region 8 of the USFS contains eight different physiographic provinces. These provinces are often grouped into three general subregions: the coastal plain, piedmont, and mountains (fig. 6-1). The procedures for mapping landforms from each of these general regions using high-altitude color IR photography will be discussed.

The term "landform" is used by physiographers to mean features taken together that make up the surface of the Earth. Landforms include broad features, such as plains, plateaus, and mountains, and minor features, such as hills, valleys, slopes, canyons, arroyos, and alluvial fans. Most of these features are the products of erosion, but landforms include all features formed by sedimentation and movements within the crust of the Earth.[1] Landforms also include easily recognizable natural terrain segments characterizing different ecosystems (figs. 6-2, 6-3, and 6-4).[2] Soil characteristics or components such as those in tables 6-I, 6-II, and 6-III are a function of landforms. Landforms and their components can be the basis for compiling a soils resource inventory.

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[1]National Academy of Sciences for the American Geological Institute, Dictionary of Geological Terms, second ed., Dolphin Reference Books, Garden City, N.Y., 1962.

[2]USFS/R8, Soils Resource Guide, 1972. This publication is recommended as a supplemental information source.

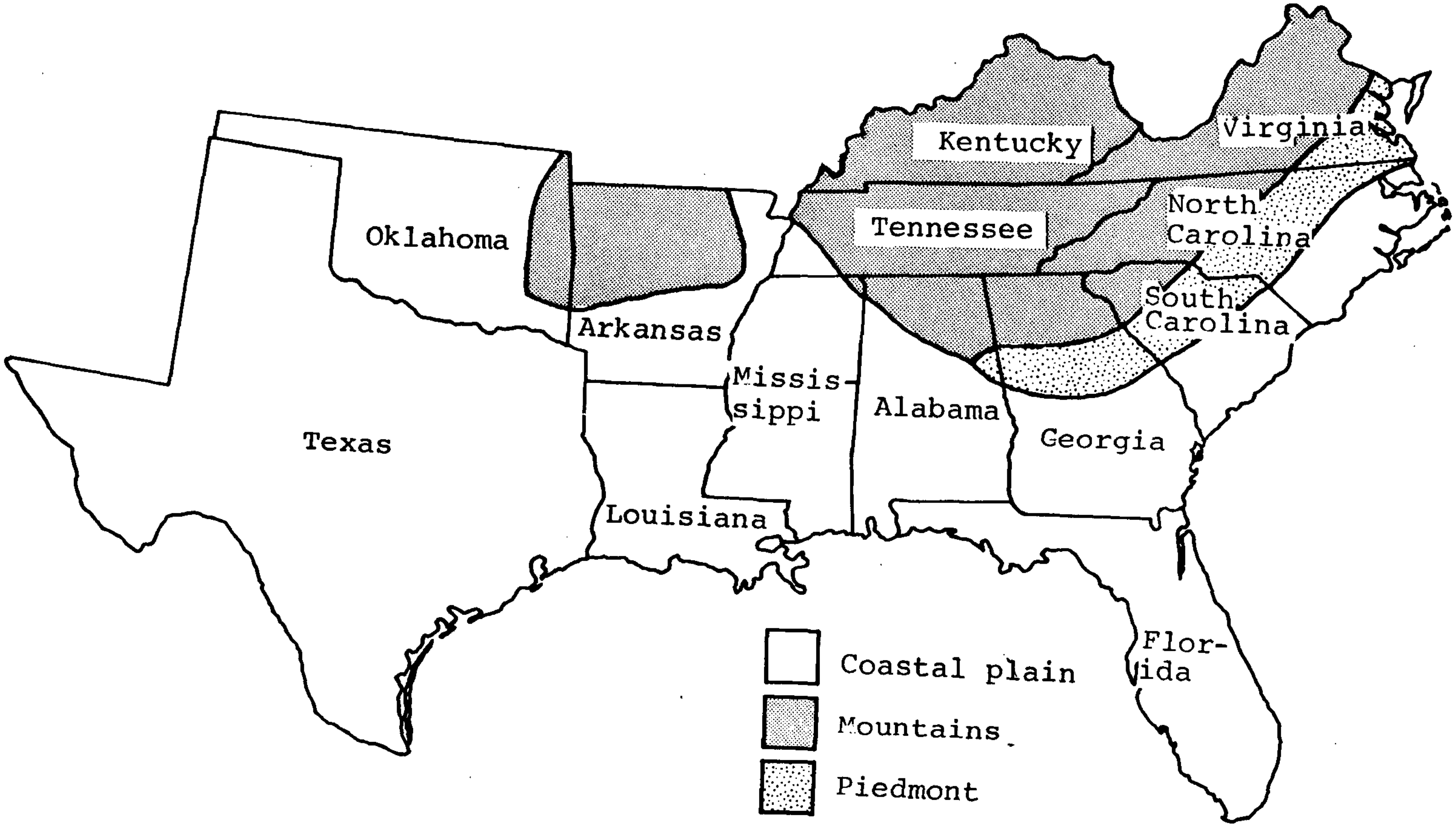


Figure 6-1.— Subregions of the USFS Southern Region. From USFS/R8, Soils Resource Guide, 1972.

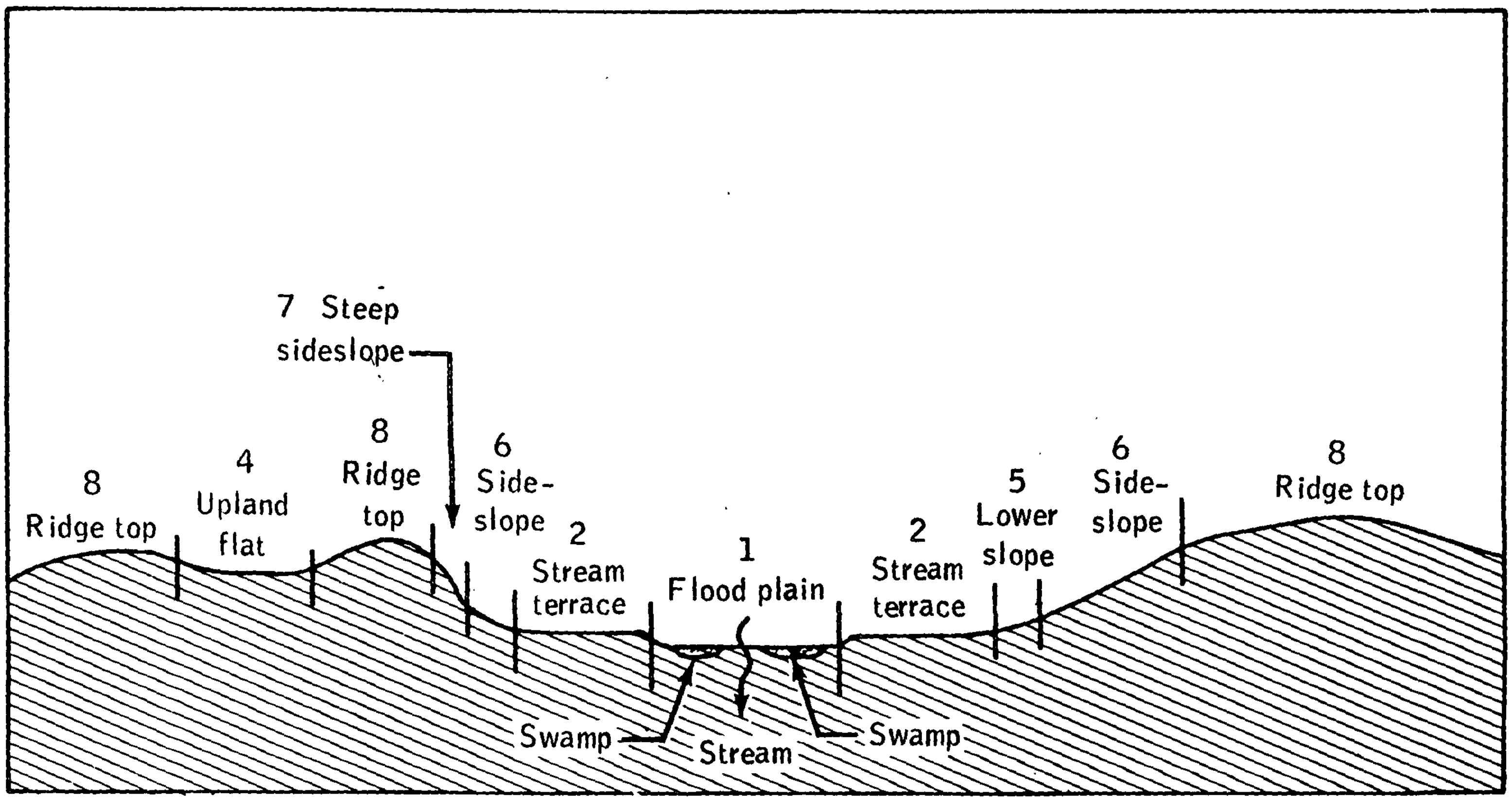


Figure 6-2.– Coastal plain landforms.

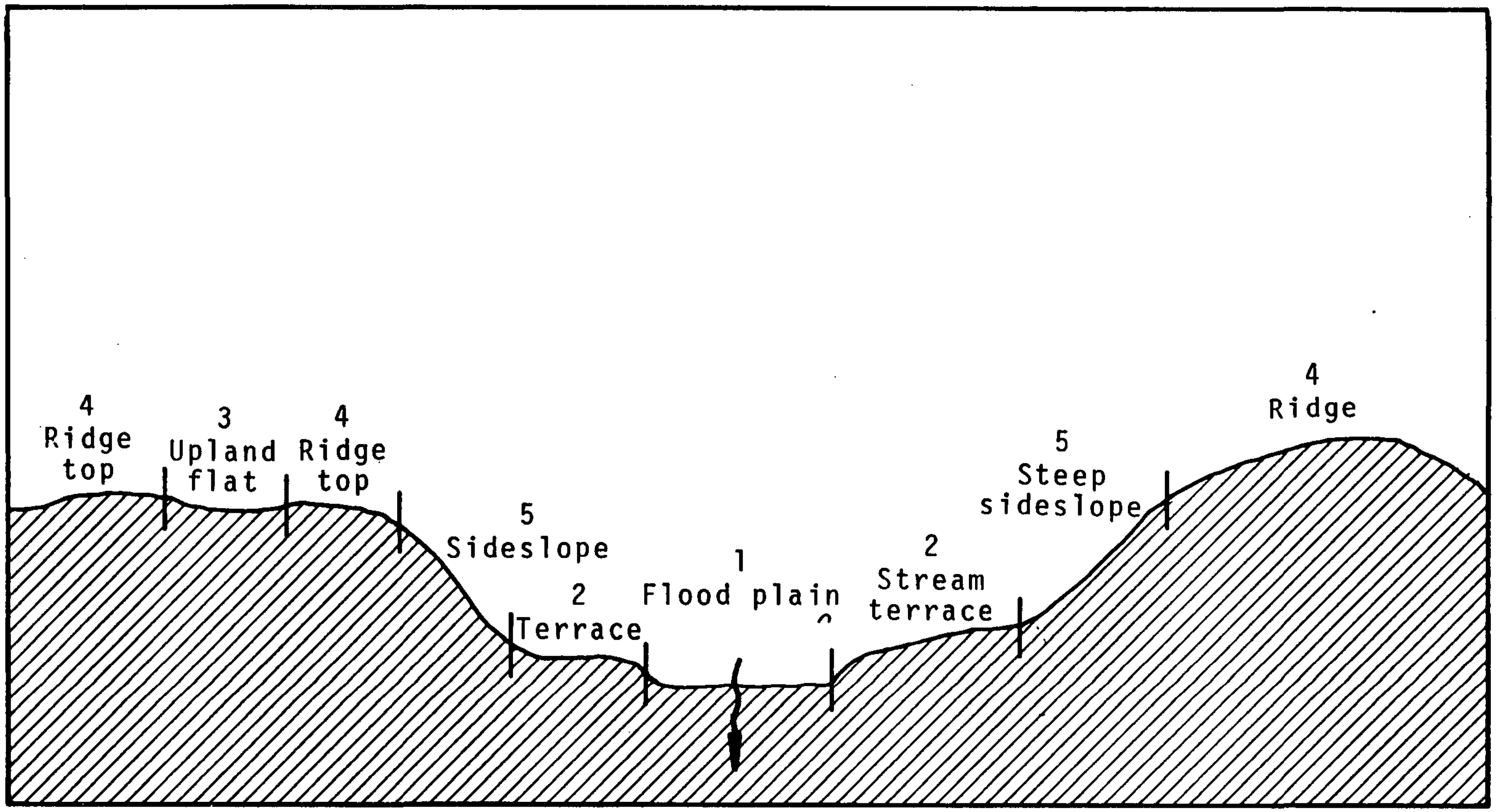


Figure 6-3.— Piedmont landforms. From USFS/R8, Soils Resource Guide, 1972.

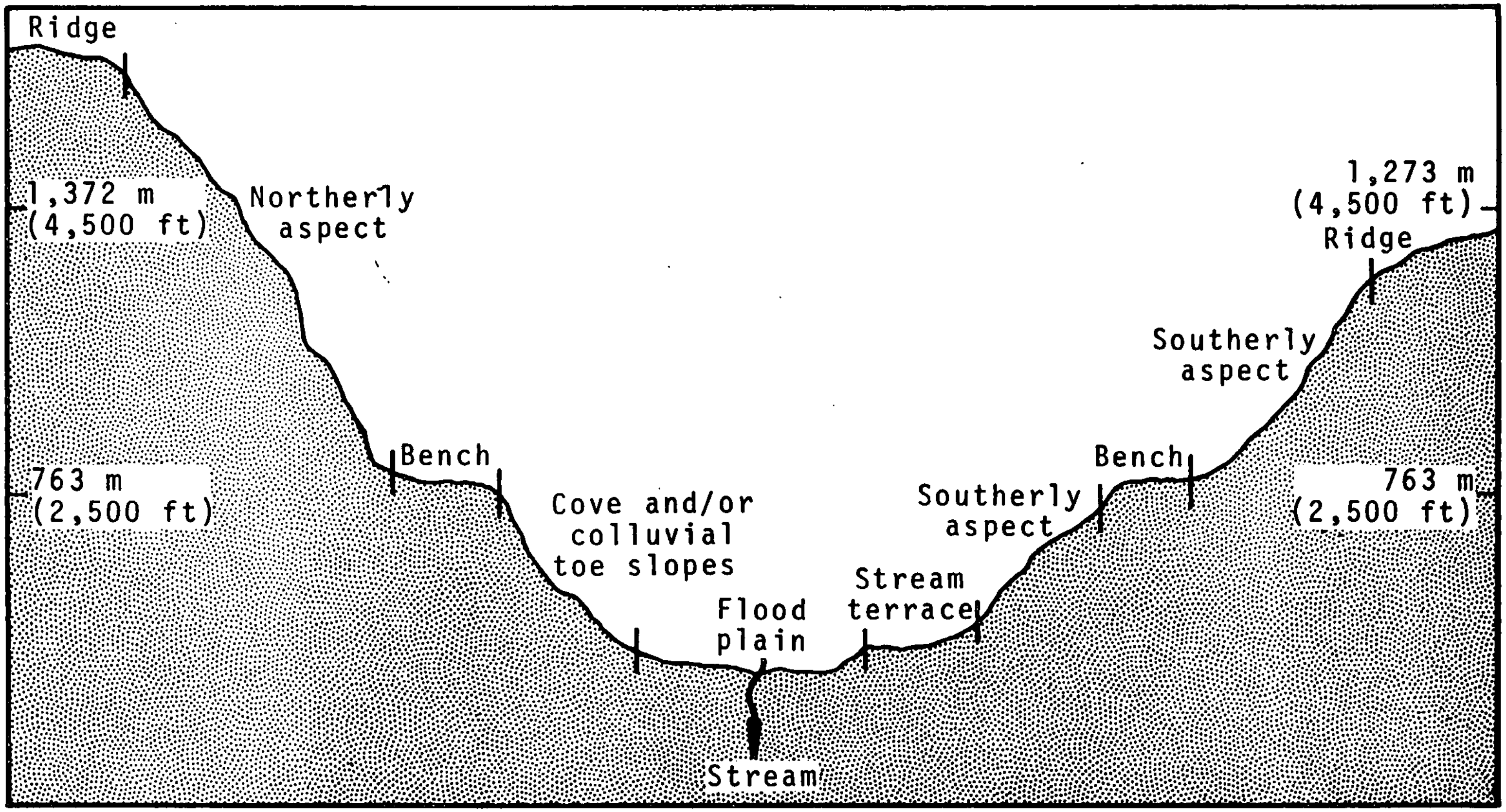


Figure 6-4.— Mountain landforms.

TABLE 6-I.— COASTAL PLAIN KEY FOR PROVIDING FIVE-DIGIT CODES TO MAPPING UNITS

(a) Landforms

Characteristic	Code
Swamp	0
Flood plain	1
Stream terrace	2
Bay	3
Upland flat	4
Lower slope	5
Sideslope	6
Steep sideslope	7
Ridge	8

(b) Textures

Characteristic	Code
Coarse	0
Sandy	1
Loamy	2
Silty	3
Medium	4
Fine	5
Very fine	6
Organic (<51 cm or 20 in.)	7
Clay to surface	8

TABLE 6-I.— Continued.

(c) Water regimes

Characteristic	Code
Waterlogged	0
Wet	1
Moist	2
Dry	3
Droughty	4
Very droughty	5

(d) Accessories

Characteristic	Code
None	0
Rhodic	1
Organic (6 to 12 m or 2 to 4 ft)	2
Organic (>12 m)	3
Pan (fragipan)	4
Pan (plinthite)	5
Organic pan (<51 cm deep)	6
Pan (other)	7
Sand cap (51 to 102 cm or 20 to 40 in. deep)	8
Sand cap (102 to 153 cm or 40 to 60 in. deep)	9

TABLE 6-I.— Concluded.

(e) Modifiers

Characteristic	Code
None	0
Extremely acid	1
Extremely alkaline	2
Shallow soils (<51 cm to restrictive layer)	3
Sodium	4
Water	5
High shrink-swell clays	6
Gravel	7

(f) Special symbols[a]

Characteristic	Code
Critical erosion	E
Stoniness	
Sand spots	
Gravel	
Active gully	
Wet spots	

[a]Add other standard symbols needed.

TABLE 6-II.— PIEDMONT KEY FOR PROVIDING FIVE-DIGIT CODES TO MAPPING UNITS

(a) Landforms

Characteristic	Code
Flood plain	1
Stream terrace	2
Upland flat	3
Ridge	4
Steep sideslope	5

(b) Sources of material

Characteristic	Code
Dominantly acid rocks	1
Dominantly basic rocks	2
Mixed acid and basic rocks	3
Recent alluvium	4
Old alluvium	5
Mica schist	6
Feldspar	7
Carolina slate	8

TABLE 6-II.— Continued.

(c) Water regimes

Characteristic	Code
Waterlogged	1
Wet	2
Moist	3
Dry	4
Droughty	5

(d) Modifiers

Characteristic	Code
None	0
Erosion	1
Critical erosion	2
Critical soil depth	3
Critical stones	4
Excess water	5

TABLE 6-II.— Concluded.

(e) Special symbols[a]

Characteristic	Code
Critical erosion	E
Bedrock outcrop	R
Critical stones	
Critical soil depth	D
Wet spots	W
Active gully	
Stony and/or cobbly	

[a]Add and define other special symbols needed.

TABLE 6-III.— MOUNTAIN KEY FOR PROVIDING FIVE-DIGIT CODES TO MAPPING UNITS

(a) Landforms[a]

Characteristic	Code
Flood plain	00
Stream terrace	01
Bench	02
Cove and/or colluvial toe slopes	03
Northerly aspect slopes <763 m (2,500 ft) in elevation	04
Northerly aspect slopes 763 to 1,373 m (2,500 to 4,500 ft) in elevation	05
Northerly aspect slopes >1,373 m in elevation	06
Southerly aspect slopes <763 m in elevation	07
Southerly aspect slopes 763 to 1,373 m in elevation	08
Southerly aspect slopes >1,373 m in elevation	09
Ridge and upper slope <763 m in elevation	10
Ridge and upper slope 763 to 1,373 m in elevation	11
Ridge and upper slope >1,373 m in elevation	12

[a]Manageable elements of the landscape.

TABLE 6-III.– Continued.

(b) Sources of material

Characteristic	Code
Transported	0
Dominantly sandstone	1
Dominantly shale	2
Mixed sandstone-shales	3
Phyllites	4
Dominantly gneiss	5
Micas	6
Novaculites	7
Mafics	8
Calcareous	9

TABLE 6-III.— Continued.

(c) Textures

Characteristic	Code
Lithic	0
Skeletal	1
Coarse	2
Sandy	3
Loamy	4
Silty	5
Medium	6
Fine	7
Very fine	8
Organic	9

(d) Water regimes

Characteristic	Code
Waterlogged	0
Wet	1
Moist	2
Dry	3
Droughty	4
Very droughty	5

TABLE 6-III.– Continued.

(e) Modifiers

Characteristic	Code
None	0
Critical erosion	1
Critical steepness	2
Critical stoniness	3
Critical bedrock	4
Critical depth to restrictive layer	5
Cherty	6
Extremely alkaline	7
Extremely acid	8
Steep, stony, uneven slopes	9

TABLE 6-III.— Concluded.

(f) Special symbols

Characteristic	Code	Color
Borrow pit and/or quarry		Black
Wet spot		Blue
Swamp or marsh		Blue
Bedrock escarpment		Black
Mountain peak		Black
Mine dump		Black
Rock outcrop		Black
Stoniness		Black
Chert		Black
Critical erosion		Red

The ecological management units used by the USFS for planning are determined by the soils resource inventory. Therefore, landforms play an important part in USFS planning. With the aid of high-altitude color IR photography, a fast, inexpensive landform survey can be made while maintaining the required accuracy.

Aerial photography has been used in landform analysis and other geomorphological applications since the 1920's. Most of this work has been done with panchromatic black-and-white photography acquired at relatively low altitudes. Now, small-scale, high-altitude, color IR photography has been found very useful in landform analysis. It provides more information on vegetation patterns, which are often closely related to landforms. For example, some streams in the coastal plain can be detected by the change in color tone of the riparian vegetation but not by topographic relief. In leaf-on seasons, the lush growth along streams shows up as a brighter red than the adjacent vegetation. This is especially true when the adjacent vegetation is coniferous.

6.2 Resource Requirements

6.2.1 Data. The photographic and ancillary data needed are:

- Duplicate positive color IR transparencies of size 23 by 23 cm (9 by 9 in.). Transparencies are preferable to prints because they exhibit better color rendition, sharper detail, and greater contrast; and they avoid the glare problem encountered when studying paper prints. Rectified images, if obtainable, might be preferred for analysis purposes.

- Positive paper prints 23 by 23 cm (9 by 9 in.) for making a composite (mosaicked) photoindex and for field checks.
- Copies of the base map to which the photo-overlays are to be transferred.

6.2.2 Skills. The on-the-job photointerpretation training required for this application should include work in geomorphology, geology, or terrain analysis.

6.3 Data Requirements Definition

The following considerations should be weighed in connection with purchasing or arranging for aerial photography for a landform analysis.

6.3.1 Geographic area coverage. Coverage should extend outside the area of interest to provide an adequate landform picture. This might include extending the coverage to a critical stream divide, the headwaters of an important stream, or other geomorphic features.

6.3.2 Image orientation. Vertical photography is required.

6.3.3 Type of photography. Color IR is used because it distinguishes differences in vegetation by color tone and gives better penetration of atmospheric haze.

6.3.4 Season. Spring photographs are recommended because they display the extremes in tonal differences of vegetation.

6.3.5 Year. This is not critical because landforms change very slowly.

6.3.6 Terrain and cloud shadows. Cloud cover of less than 5 percent is preferable. Terrain shadows are not critical in that the lower Sun angles may facilitate landform analysis by accentuating ridge lines and escarpments (section 2.7.1.7).

6.3.7 Snow/water cover. This should be minimal; temporary flooding can make it more difficult to distinguish some bottom land features.

6.3.8 Scale of imagery. A 1:60,000-scale is recommended because it gives a larger area per photograph and reduces the photographic cost per acre and the number of photographs needed.

6.4 Indexing

After receipt of data the user should review the photographs for quality, with regard to the criteria in section 3.4.

Next, the user should prepare an index plot of imagery frames on a base map (see section 3.4). While the index is being prepared, the user should observe the general characteristics of the topography by comparing the photographic detail with the map detail.

6.5 Photointerpretation

A landform analysis should be performed in the following manner.

6.5.1 Site familiarization. The analyst should visit the site to become familiar with the landforms to be mapped. (See section 3.8 for site familiarization procedures.) Additional field trips might be necessary at a later time if questions arise that can be answered only in the field.

6.5.2 Preparation for stereoanalysis.

- Step 1 — Separate or, if necessary, cut from the film roll each of the frames that are to be interpreted.
- Step 2 — Attach to each frame a sheet of clear, ink-surface drafting film with drafting tape.
- Step 3 — Label each overlay with the frame number and a north arrow.
- Step 4 — Outline the effective area of each frame to be interpreted.
- Step 5 — Bring overlapping stereopairs into stereoscopic view for photointerpretation of the landforms. A more exaggerated relief may be helpful in mapping some areas. If so, two methods are applicable. One is to use sidelap, or a stereopair of adjacent flight lines. The other is to use overlap of alternate frames within the same flight line.

Study the photopairs under the stereoscope and identify and delineate the landforms by reference to the identification keys in tables 6-I, 6-II, and 6-III and the landform descriptions in table 6-IV. Table 6-IV gives an easy method for the photointerpreter to learn to identify landforms. For each landform, the table gives the soils resource inventory guide description, code, photointerpretation key, IR reflectance,

TABLE 6-IV.– MOUNTAIN LANDFORMS OF THE CHATTAHOOCHEE NATIONAL FOREST, GEORGIA, CONTROL SITE IN 1:60,000-SCALE COLOR IR AERIAL PHOTOGRAPHS

[Frame 8552 obtained April 29, 1974*]

Landform	Soils resource inventory description	Code	Photointerpretation description	IR reflectance description	Example grid code	Example description of feature	Remarks
Flood plain	Plain or nearly level area along permanent or intermittent stream courses subject to overflow or flooding	00	Flat, narrow, gently sloping expanse located between the steep sideslopes of the mountains and hills with the stream readily discernible	Cultivated fields, magenta to pink; barren fields, white to brown; streams and ponds, blue; tree species, red; winter-cultivated fields, white to brown	C-2 C-3	Flood plain oriented east-west with the stream flowing east; cultivated crops and some barren or fallow fields visible	-
Stream terrace	Flat or undulating plain bordering a flood plain, normally occurring at higher elevations and usually flood-free	01	Not visible, probably minor and localized	Under cultivation, showing the IR characteristics of this land use		-	Steep mountain sideslopes precluding terracing
Bench	Gentle step-like interruption in a sideslope mostly of colluvial soils	02	Flat to gently sloping areas on a mountain slope, some of which have been cleared, are under cultivation, or are in other use	Barren fields, white to blue; emerging growth, pink; dirt road, white, denoting high reflectance	H-6	Bench oriented north-south in the northwest corner of the square with the dirt road bisecting the bench	Bench in the colluvium
Cove and/or colluvial toe slope	Colluvial soils associated with drainage ways, lower slopes, and drain heads	03	Mass wasting or mantle of loose debris slowly creeping down hillsides, visible as the break between the steep slope to the less steep attitude of the colluvium and prominent in drains and toe slopes	IR reflectance of the cover vegetation; deciduous in the drains, magenta red; conifers, dark violet; cultivated areas, pink to red; barren fields, white to brown	D-5	South of highway extending halfway up the north slope of the hill with healthy red vegetation, denoting good soil; visible break in the slope and some cultivated bottom land	-
Northerly aspect slopes <763 m (<2,500 ft) in elevation†	Position generally facing north, northwest, or northeast	04	Slopes with more water with deciduous species dominating the mixed deciduous and coniferous forests; higher quality tree species and better soil because of weathering in wetter slopes	Distinctive red color of deciduous trees predominating	F-3	Lower slope of a northerly aspect facing the north directly up from the furrowed, white valley floor in the lower half of the grid square	Higher quality tree species in hardwood timber types and a more brilliant red visible
Northerly aspect slopes 763 to 1,373 m (2,500 to 4,500 ft) in elevation†	Sideslope between the ridge and toe slope or drainage way	‡05	Same as northerly aspect slopes <763 m in elevation	Wetter north aspects with dominating deciduous trees. Above 763 m, unleaved trees appearing blue green or red	C-5	Upper northerly aspect in grid C-5 on Screamer Mountain, which has several small white roads	Topographic sheet used to determine the 763-m line
Southerly aspect slopes <763 m in elevation†	Position generally facing south of northwest or northeast	07	With less moisture than the northerly aspect, not an optimum growing site; dominating pines and plentiful hardwoods	Pine forest, dark violet; hardwood, red	C-2	Dark violet, south-facing lower pine slope in t'e top of the grid squa' down to the flood pl	Rabun, Dillard, Tiger, and Rainy Mountain topographic sheets used
Southerly aspect slopes 763 to 1,373 m in elevation†	Same as southerly aspect slopes <763 m in elevation	‡08	Same as southerly aspect slopes <763 m in elevation	Pine forest, dark violet; unleaved hardwoods, blue green; other hardwoods, red	A-2	Southerly aspect above 763 m covered with blue-green hardwoods and dark violet pine in the lower half of the grid square	-
Ridge and upper slope <763 m in elevation†	Elongate crest and upper slope of a hill or mountain	10	Narrow elevation prominent because of the steep rising angle	Same as southerly aspect slopes 763 to 1,373 m in elevation	G-6	Lower ridge running parallel to the road on the left side of the grid square. Red hardwoods on the north side and dark violet pine on the south	-
Ridge and upper slope 763 to 1,373 m in elevation†	Same as ridge and upper slope <763 m in elevation	‡11	Same as ridge and upper slope <763 m in elevation	Same as southerly aspect slopes 763 to 1,373 m in elevation	A-3	Elongate crest with a white road through the upper left of the grid square, showing an upper ridge covered with blue-green hardwoods	-

*North aspect code 06, south aspect code 09, and ridge code 12 do not apply to this frame. No elevations appear above 1,373 m (4,500 ft).

†Elevations determined from USGS topographic sheets.

‡Delineated only on the 1:24,000-scale landform map.

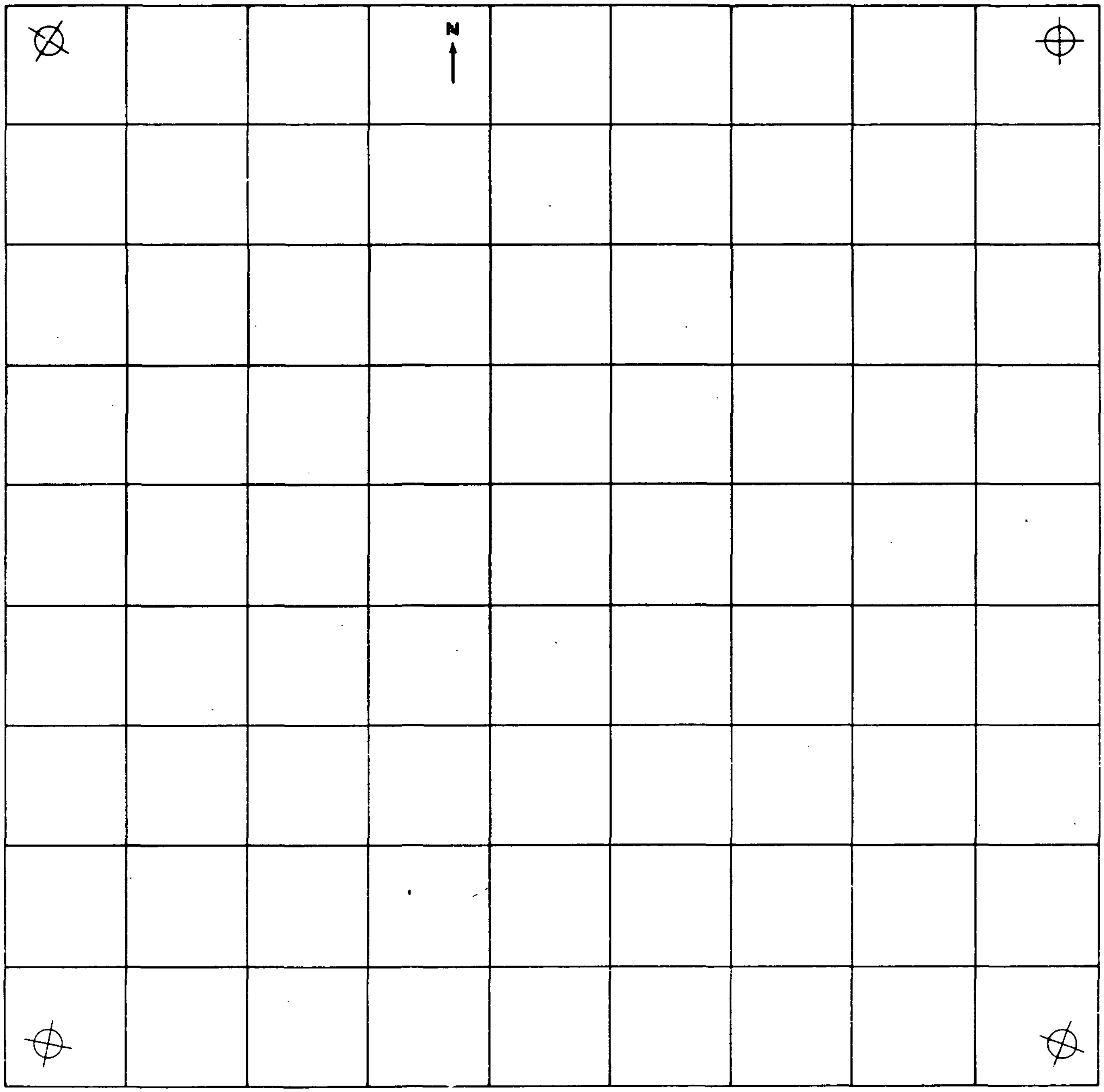
example grid code, example description, and other remarks. The photograph, landform overlay, and grid in figure 6-5 are an example of how the different landforms appear on the photograph. The numbers in this figure are keyed to the landforms in table 6-IV.

6.5.3 Landform analysis. In preparation for actual landform delineation, an order of landforms from the first to the last mapped is helpful. In the mountains, the order of landforms is:

- Streams
- Flood plains
- Ridges
- Stream terraces
- Cove and/or colluvial toe slopes
- Benches
- Aspects

Collect stereocoverage of the area to be analyzed. The mountain subregion is used as an example. Referring to the base map, first mark on the film overlay 8 to 10 reference points, such as road intersections and other distinct, permanent features common to the photograph and the base map. These points will be used later in orienting the photo-overlays for information transfer to a base map.

A landform chart such as the one above exists for the coastal plain (fig. 6-6) and piedmont regions (fig. 6-7). This chart should be made early for any new physiographic region which a photointerpreter may encounter.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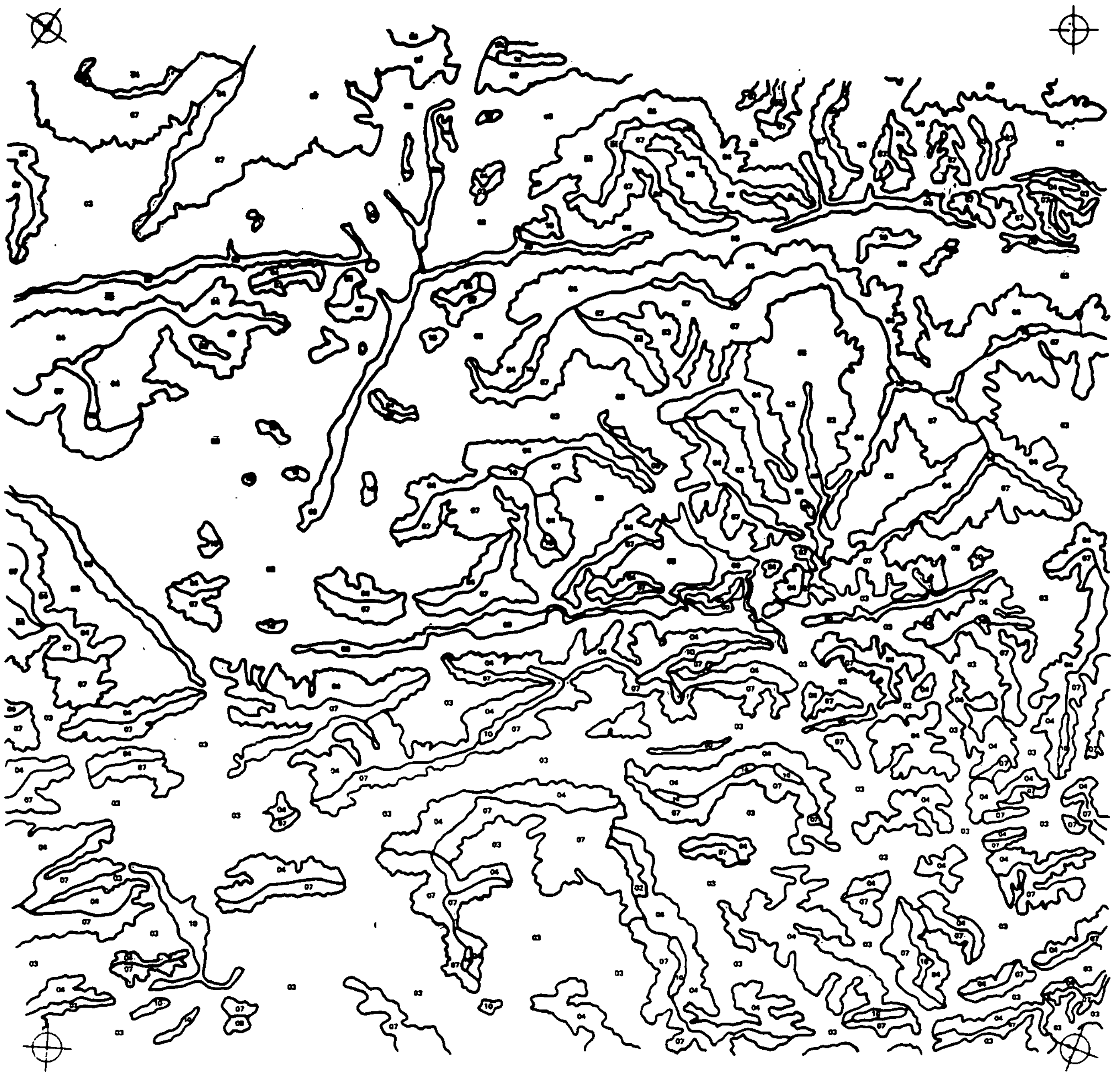

6-22(b)

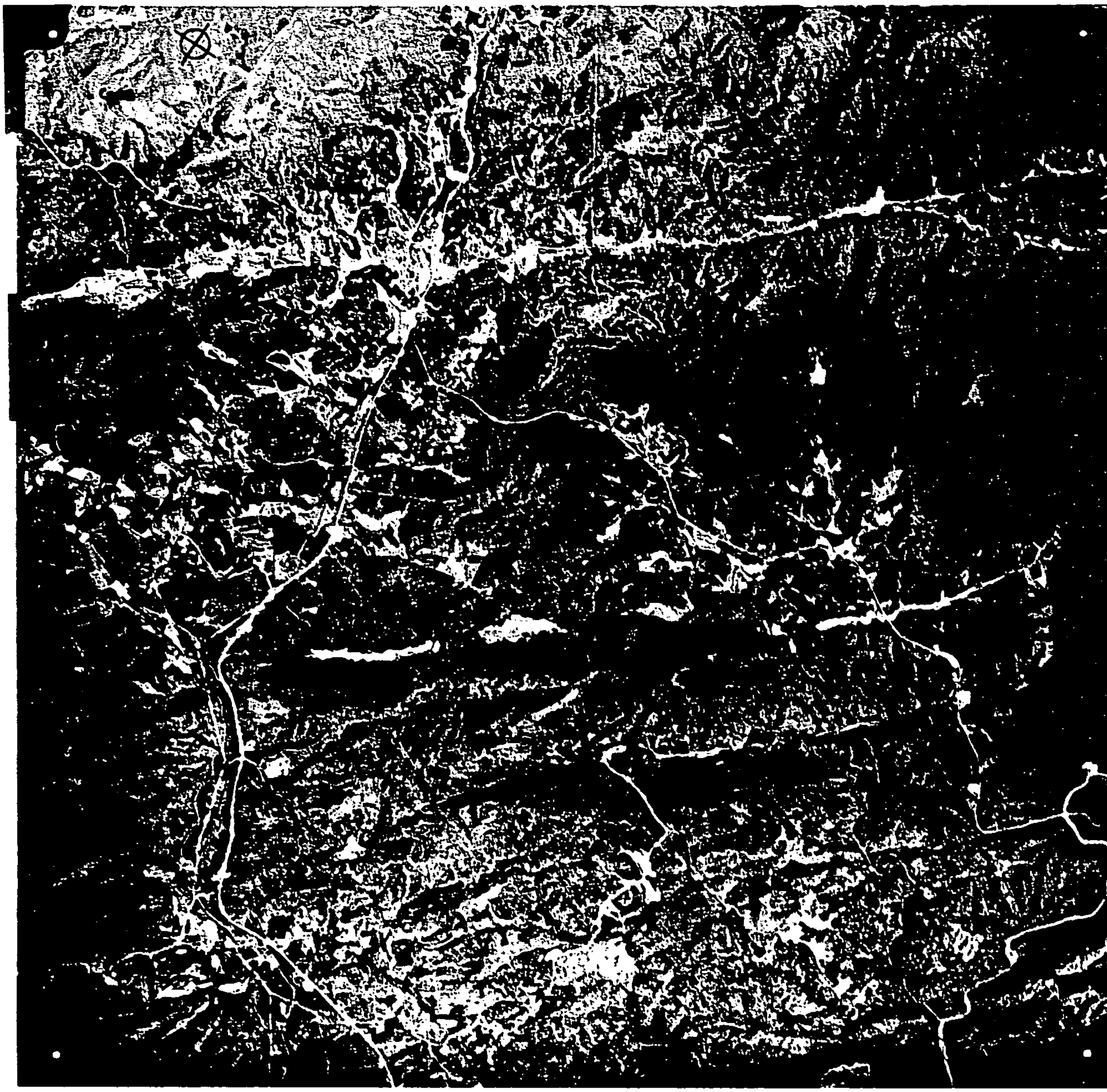

Figure 6-5.– Mountain landform overlay with photograph.

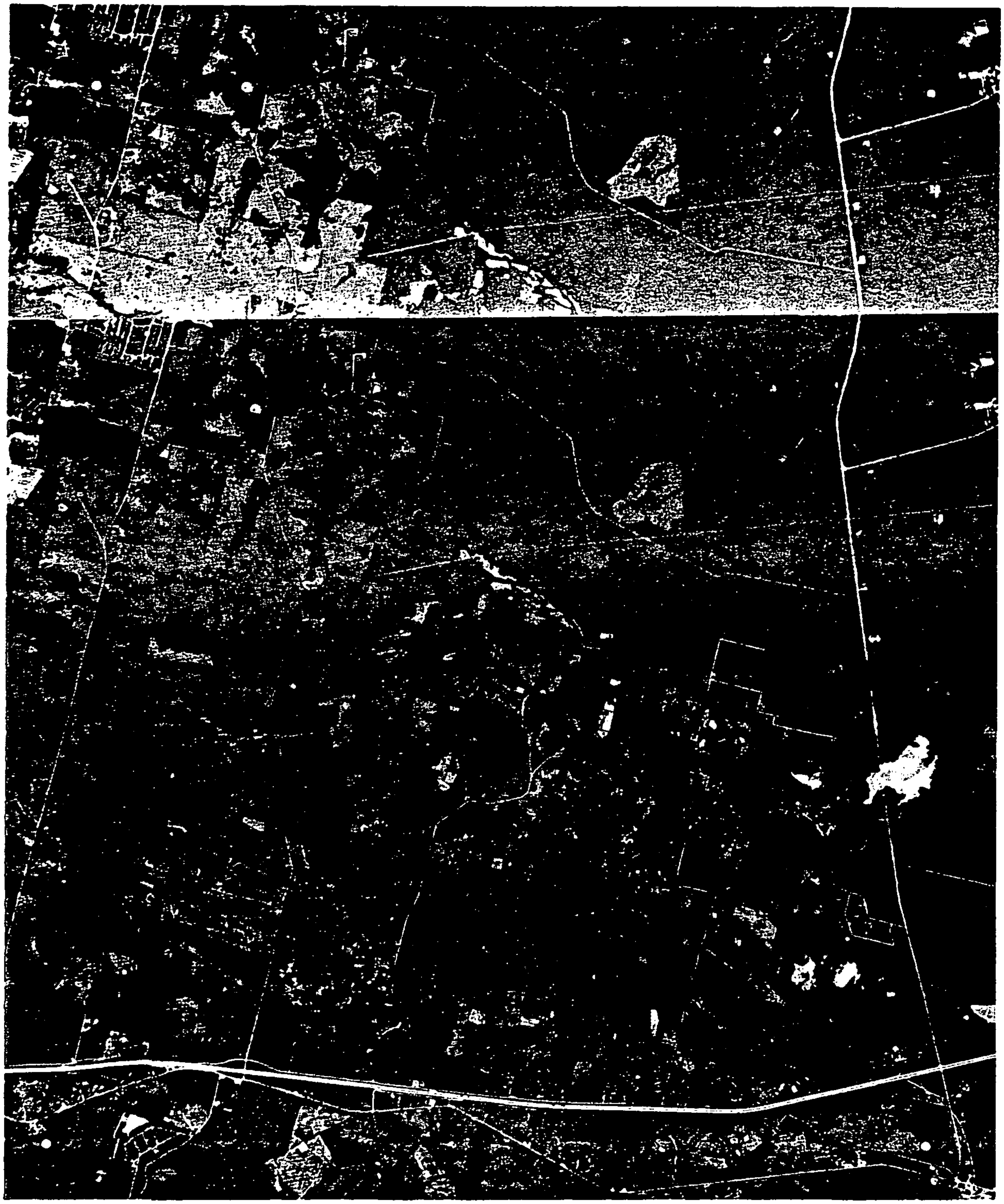

Figure 6-6.— Coastal plain landform overlay with photograph.

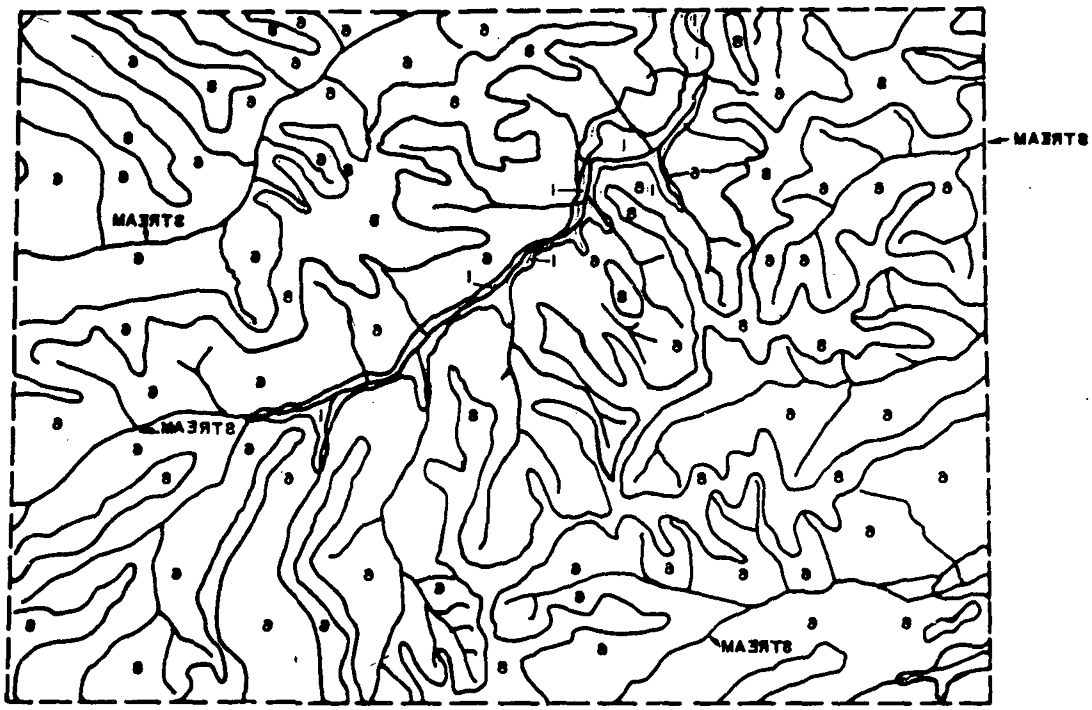
STREAM
STREAM
STREAM

Figure 6-7.— Piedmont landform overlay with photograph.

In making and using a landform analysis, the investigator should be aware of the accuracy attainable by this method. Accuracy depends on the interpreter's experience and knowledge of the site, quality of photography, and complexity of the site analyzed. The greater the relief on a site, the easier and more accurate is the landform interpretation.

To acquire the end product, an ecological management unit, for which landforms are needed, further work is required. Relationships exist between landforms and one or more of the complementing components, such as source of material, texture, water regime, modifiers, and vegetation. These relationships appear in figures 6-8, 6-9, and 6-10. From these figures a correlation can be made between landforms and components. This correlation generally remains consistent throughout the photoframe. Once the correlation between landforms and components is determined, much information needed for compiling a soils resource map may be taken directly from the landform overlay.

For example, after a flood plain landform has been delineated on a stereopair, a correlation can be made to obtain the following information. As found in the soils resource inventory mountain control site, a flood plain has transported material, loamy texture, wet or moist water regime, no modifiers, and cove or bottom land hardwoods.

6.6 Adjustment of Delineated Film Overlays

When all frames have been interpreted, line adjustments of the delineated detail should be made so that each frame

LANDFORM	SOURCE OF MATERIAL	TEXTURE	WATER REGIME	MODIFIERS	VEGETATION
	Transported	Lithic	Waterlogged	None	Upland hardwoods
	Dominantly sandstone	Skeletal	Wet	Critical erosion	Cove hardwoods
	Dominantly shale	Coarse	Moist	Critical steepness	Conifers
	Mixed sandstone and shale	Sandy	Dry	Critical stoniness	Mixed hardwoods and conifers
Flood plain	Phyllites	Loamy	Droughty	Critical bedrock	Nonforest
	Dominantly gneiss	Silty	Very droughty	Critical depth to restrictive layer	Cutover
	Micas	Medium		Cherty	
	Novaculites	Fine		Extremely alkaline	
	Mafics	Very fine		Extremely acid	
	Calcareous	Organic		Steep, stony, uneven slopes	

Figure 6-8.— Mountain area showing flood plain and associated components.

LANDFORM	SOURCE OF MATERIAL	TEXTURE	WATER REGIME	MODIFIERS	VEGETATION
	Transported	*Lithic*	*Waterlogged*	*None*	*Upland hardwoods*
	Dominantly sandstone	Skeletal	Wet	Critical erosion	Cove hardwoods
	Dominantly shale	Coarse	Moist	Critical steepness	Conifers
	Mixed sandstone and shale	Sandy	Dry	Critical stoniness	Mixed hardwoods and conifers
Cove or colluvial toe slope	Phyllites	Loamy	Droughty	Critical bedrock	Nonforest
	Dominantly gneiss	Silty	Very droughty	Critical depth to restrictive layer	Cutover
	Micas	Medium		Cherty	
	Novaculites	Fine		Extremely alkaline	
	Mafics	Very fine		Extremely acid	
	Calcareous	Organic		Steep, stony, uneven slopes	

Figure 6-9.— Mountain area showing cove or colluvial toe slope and associated components.

LANDFORM	SOURCE OF MATERIAL	TEXTURE	WATER REGIME	MODIFIERS	VEGETATION
	Transported	Lithic	Waterlogged	None	Upland hardwoods
	Dominantly sandstone	Skeletal	Wet	Critical erosion	Cove hardwoods
	Dominantly shale	Coarse	Moist	Critical steepness	Conifers
	Mixed sandstone and shale	Sandy	Dry	Critical stoniness	Mixed hardwoods and conifers
Southerly aspect slope	Phyllites	Loamy	Droughty	Critical bedrock	Nonforest
	Dominantly gneiss	Silty	Very droughty	Critical depth to restrictive layer	Cutover
	Micas	Medium		Cherty	
	Novaculites	Fine		Extremely alkaline	
	Mafics	Very fine		Extremely acid	
	Calcareous	Organic		Steep, stony, uneven slopes	

Figure 6-10.— Mountain area showing southerly aspect slope and associated components.

overlay is compatible with its adjacent frame overlay. That is, if the overlays are mosaicked, the line details of each overlay should join or match adjoining details precisely. If they fail to match, adjust them so that they do. This step would be the same as performed in match line checking on effective areas.

6.7 Information Transfer

Before transferring the photo-overlay information to a base map overlay, check for tip, tilt, and scale discrepancies. The scale of the photographs may need rectification or adjustment.

The purpose of the information transfer is to fit the interpreted information from the photographs to an overlay for the previously chosen base map, using rectification and scale adjustment. Using this method, the landform overlay map be combined with cultural or other detail from the base map.

Although other rectifying equipment may be used, the procedure set forth below is based on the use of a Kargl rectifying enlarging projector to transfer photo-overlay information to base map sheet overlays.

- Step 1 — Assemble the base map sheets to which the photo-overlay data are to be transferred.
- Step 2 — Cut 2-mil Herculene overlay for each base map sheet with a 1-cm (1/2-in.) margin around map area. Mark the corners of the map area and print the map identification name or number on the overlay.

- Step 3 – Select a base map sheet and the corresponding photo-overlays for information transfer.
- Step 4 – Select one of the photo-overlays for transfer. On the base map sheet, identify the features corresponding to the distinctive geographic control points previously placed on the photo-overlays. Mark these features on the matte side of the base map overlay sheet.
- Step 5 – Project an enlarged and rectified image of the photo-overlay onto the corresponding base map sheet overlay. Using the projector, tilt, magnification, and focus controls, adjust the projected image until the geographic control points on the projected overlay image match the base map sheet overlay (fig. 6-11).
- Step 6 – Trace landform patterns from the projected photo-overlay image onto the base map sheet overlay.
- Step 7 – After transferring information from one photo-overlay onto the base map overlay, select another (adjoining) photo-overlay sheet. Repeat steps 4 through 6 above until all photo-overlays from the base map sheet have been processed.
- Step 8 – After all the photo-overlay information has been transferred to a given base map overlay, select another base map sheet and repeat steps 3 through 6 until all base map sheet overlays have been completed.

NASA S-68-24560

Figure 6-11.— The projector and apparatus used in rectifying the frame overlay. Both the projector and table can be tilted to simulate the tip and tilt of the aircraft when the picture was taken.

6.8 Conclusions

To aid the USFS in locating and planning the use of ecological management units, landform identification is important. Small-scale (1:60,000) photographs are a useful tool in mapping or updating maps. This scale provides a greater coverage per photograph, reducing the photographic cost per acre and the number of photographs needed while maintaining the required accuracy. Color IR film is recommended because of its haze-penetrating capabilities at high altitudes and the color tone differences shown among vegetation types.

7.0 SMALL-SCALE COLOR IR PHOTOGRAPHY IN TIMBER STAND MAPPING AND CANOPY DENSITY AND CROWN CLOSURE DETERMINATION

7.1 Timber Stand Mapping

7.1.1 General. This section covers the steps in the visual interpretation for the stand delineation portion of timber stand[1] mapping using high-altitude, small-scale, color IR photography.[2]

Aerial photographs have been used in stand mapping for years. However, the procedures and criteria are based largely on the use of panchromatic or black-and-white IR large- and medium-scale photography. Black-and-white photo-interpretation relies on recognizable features, such as tree crowns and canopy density, and on film characteristics, such as texture, pattern, and gray tone levels.

The color photographs recently available over many national forests provide more information than the panchromatic photographs. Medium-scale color photographs proved to be excellent for forest management interpretation. However, color film may be less effective than color IR when exposed at the high altitudes of small-scale photography.

Moving from a large scale (1:20,000) to a small scale (1:60,000) causes a loss in identifiable ground detail, resulting in the inability to measure individual trees. Discriminating between species within hardwoods or conifers

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[1]See Glossary for definition of timber stand.

[2]USFS/R8, Compartment Prescription Handbook, FSH-2409.21d R, Amendment 3, Atlanta, Ga., Sept. 1970.

becomes very difficult. The small-scale photography also makes separation of stand condition difficult. High-altitude photographs give the interpreter a relatively good estimate of acreage but should not be used for a high-level survey without rectifying or transferring the details to a planimetric map.

7.1.2 Resource requirements.

7.1.2.1 Data:

- The 1:60,000-scale color IR positive transparencies (23 by 23 cm or 9 by 9 in.) for analysis. Transparencies are better than prints because of the more visible detail.
- Positive prints for field checking.
- Copies of the base map to which the photo-overlays are to be transferred. The recommended 1:24,000-scale is large enough for the detail needed, fits USGS maps, and is a USFS standard.

7.1.2.2 Skills: The remarks about photointerpretation in section 3.0 apply to this section as well. If possible, the photointerpreter should use field trips and any ancillary data to learn about the area and facilitate recognition of stand types from high-altitude photography.

7.1.3 Photointerpretation. The use of an adequate stereoscope, such as a Fairchild mirror, Old Delft, Bausch & Lomb Zoom 70, is recommended. Use the procedure outlined in section 3.6 to train for the identification of stand features, covering as many different stands as possible. This training enables the interpreter to learn enough about the area to recognize the small-scale appearance of stand features (fig. 7-1). For area delineation, orient the phototransparencies on the light table in the correct position for stereoviewing. Delineate the effective area on the phototransparencies (section 3.7). Cover the transparency with 2-mil overlay material and secure it in place with tape. Transfer the fiducial marks to the overlay. This transfer will register the overlay to the photograph. Transfer the lines depicting the effective area to the overlay.

The false color presented by IR film may at first confuse the interpreter. However, after a short orientation, an intrinsic color relationship will be determined. Most conifers appear purple, and most hardwoods appear bright red.

The finer the texture appears, the younger the stand is. Hardwoods generally have a coarser textural pattern than pines. Healthy hardwood trees growing on a high-quality site will reflect a more brilliant red. Variations of color appear from one film roll to another even though the film type may be the same. Elevation, time of year, and time of day also affect the color. For example, on spring photographs the upland hardwoods in the Georgia mountains appear blue green while the cove hardwoods appear normal red. The upland hardwoods do not have full leaf development, but the lower cove species do.

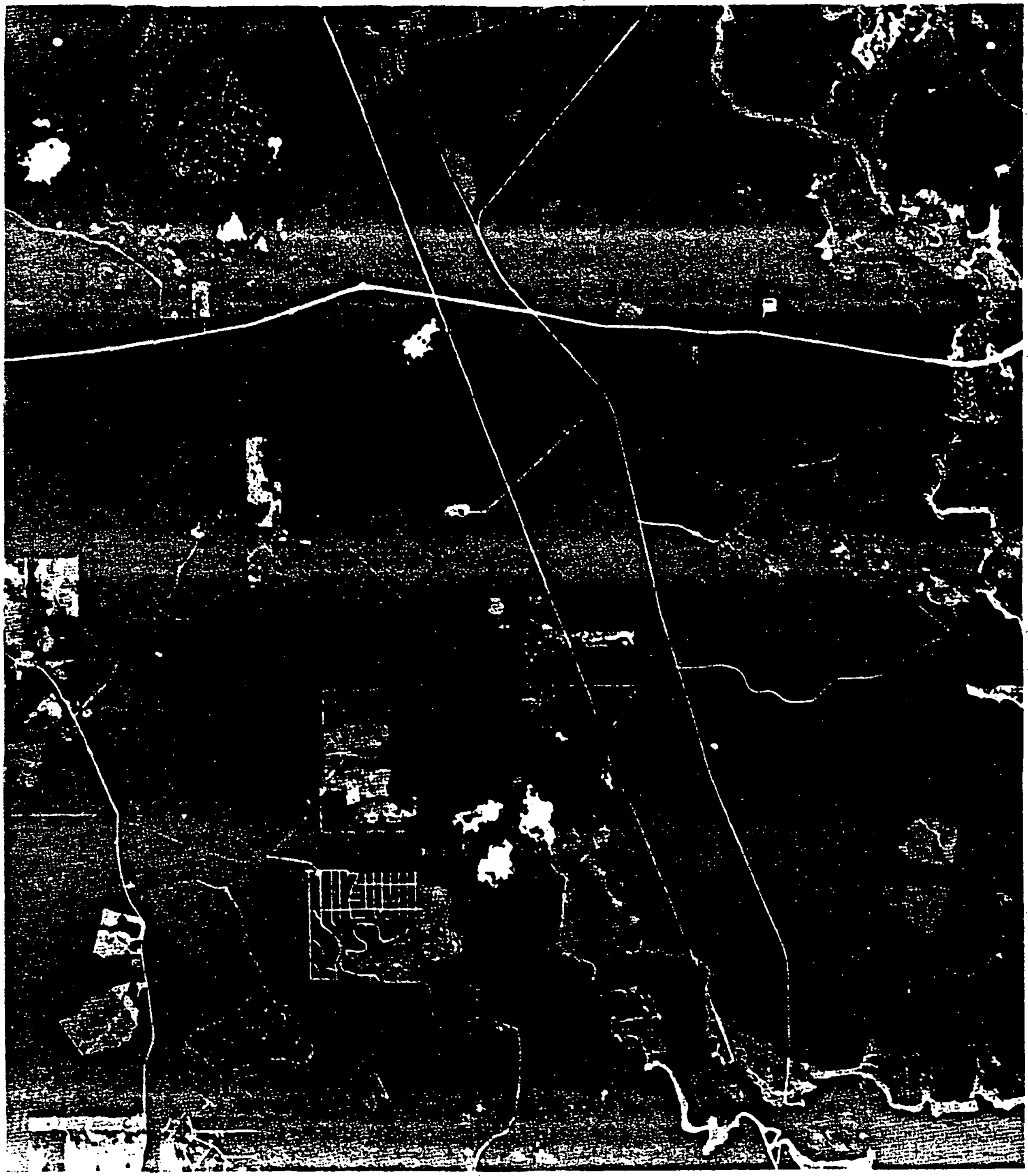
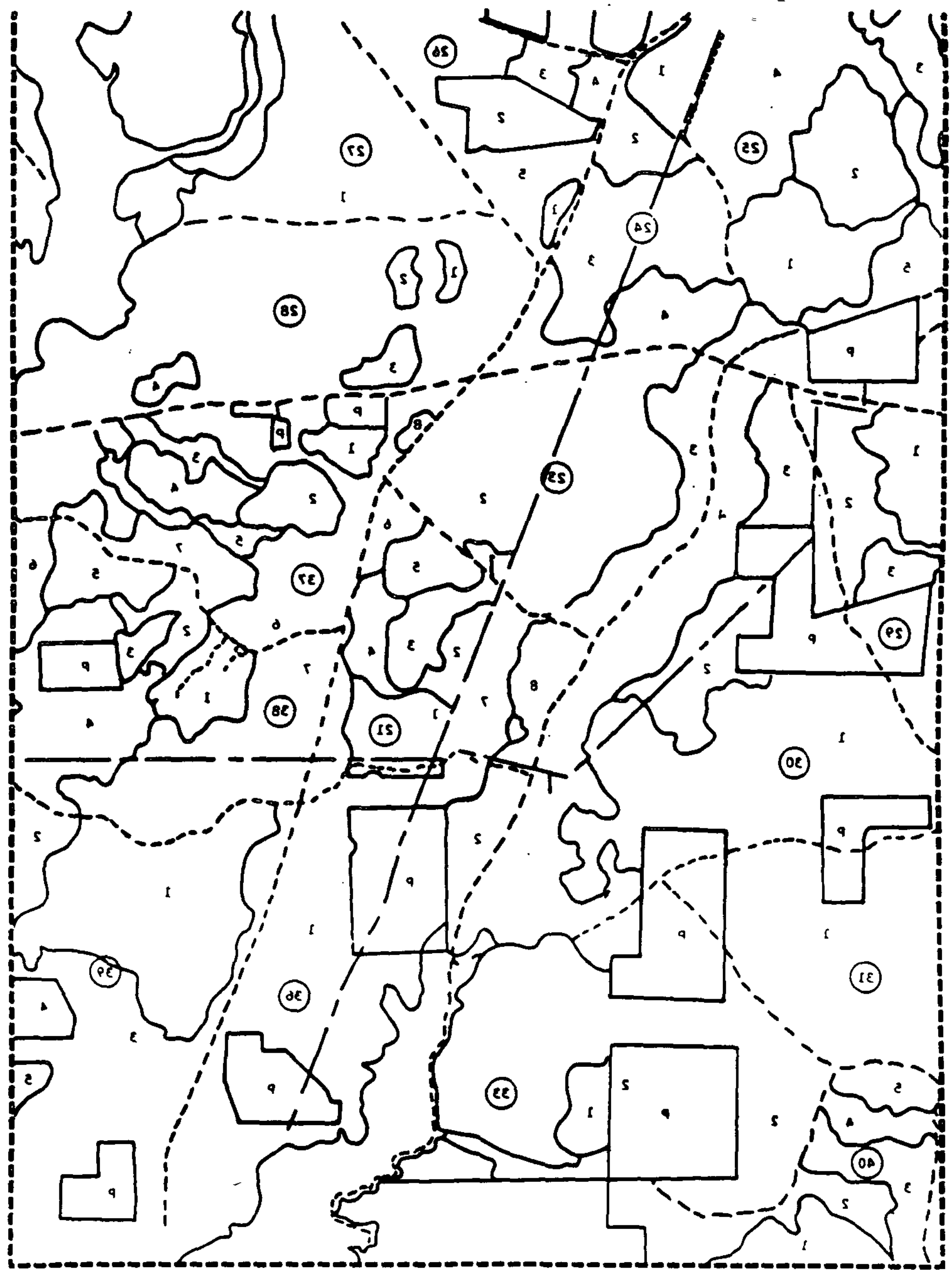


Figure 7-1.— Example of completed stand map overlay and photograph. Areas marked "P" are private lands. The circled numbers are USFS compartment designations, and the uncircled numbers are USFS stand designations.



7-4 (a)

7.1.4 <u>Analysis procedure</u>.

7.1.4.1 Stand mapping: The stand mapping procedure described herein consists basically of the following:

- Identifying USFS land by delineating boundaries on transparent film overlays
- Delineating stands within the forest on the transparent overlays
- Field checking those delineations and transferring them to the base map

7.1.4.2 Stand delineation:

- Step 1 – Delineate stands on National Forest land within the effective area of each photograph.
- Step 2 – Using red lines delineate the areas that appear to be different from adjoining areas. Start with the most obvious areas; then bound the remaining areas.

The smallest area to delineate as a stand is 4 hectares (10 acres). Smaller areas occasionally appearing distinctly different from all adjoining areas and unsuitable for inclusion with any stand should be delineated. The stand with which the small areas can best be identified should be determined by field check. Long, narrow stands should be avoided except when necessary to maintain continuity. Stands should not average less than 100 m (5 chains) wide. However, the local policy on stand description will be used to decide the size and shape limitations. For example, some areas smaller than 4 hectares (10 acres) have inherently different species suitability and should be delineated as separate stands.

7.1.4.3 Travel route: Before field examinations are conducted, plan travel routes to prevent unproductive deadheading and to eliminate conscious or unconscious bias in stand sampling. Place a distinctive colored line on an overlay to depict the route to be followed.

7.2 Canopy Density and Crown Diameter Determination Using Photography

7.2.1 General. This section discusses the steps involved in producing a canopy density map and determining crown diameters of trees on specific areas by subjective visual interpretation of aerial photography. This will help forest managers and experienced field workers to make proper management decisions for a particular land area.

Crown diameter is usually determined in conjunction with canopy density determination. These two measurements are generally determined on a per-stand basis and are critical factors needed for entering an aerial stand volume table.

In some cases, average tree crown diameter is related to age, stand density and, with some species, to stem diameter.[3] Thus, crown diameter can be a useful photographic measurement to use when estimating individual tree volumes, even though the individual tree approach is of limited value when the interpreter is restricted to photoscales smaller than 1:12,000. In such instances, these images are generally too small to permit accurate assessment of individual

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[3] S. H. Spurr, Photogrammetry and Photo-interpretation, second ed., The Ronald Press Co., N.Y., 1960.

trees using traditional equipment.[4] Work is presently being done using large-scale imagery (1:1,000) to determine individual tree volumes in a multistage sampling procedure to be used in conjunction with small-scale photography and Land Satellite (Landsat) data.[5]

7.2.2 Resource requirements.

7.2.2.1 Data: Photographic and cartographic data types required are:

- Positive paper prints for constructing mosaics and working copies
- Duplicate positive color IR transparencies in 23- by 23-cm (9- by 9-in.) format for analysis
- National Forest map, 1/2 in. to a mile (scale 1:126,720)

7.2.2.2 Equipment:

- Forest survey crown density scale (fig. 7-2)
- Forest survey crown diameter scale (fig. 7-3)

7.2.3 Data requirements definition. Requirements for (1) purchasing photographic data or (2) flying or contracting

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[4] T. E. Avery, Interpretation of Aerial Photographs, Burgess Publishing Company, Minneapolis, Minn., 1969.

[5] J. Nichols, *et al.*, ERTS Applications in Timber Inventory: A Summary of Two Case Studies, University of California at Berkeley, 1975.

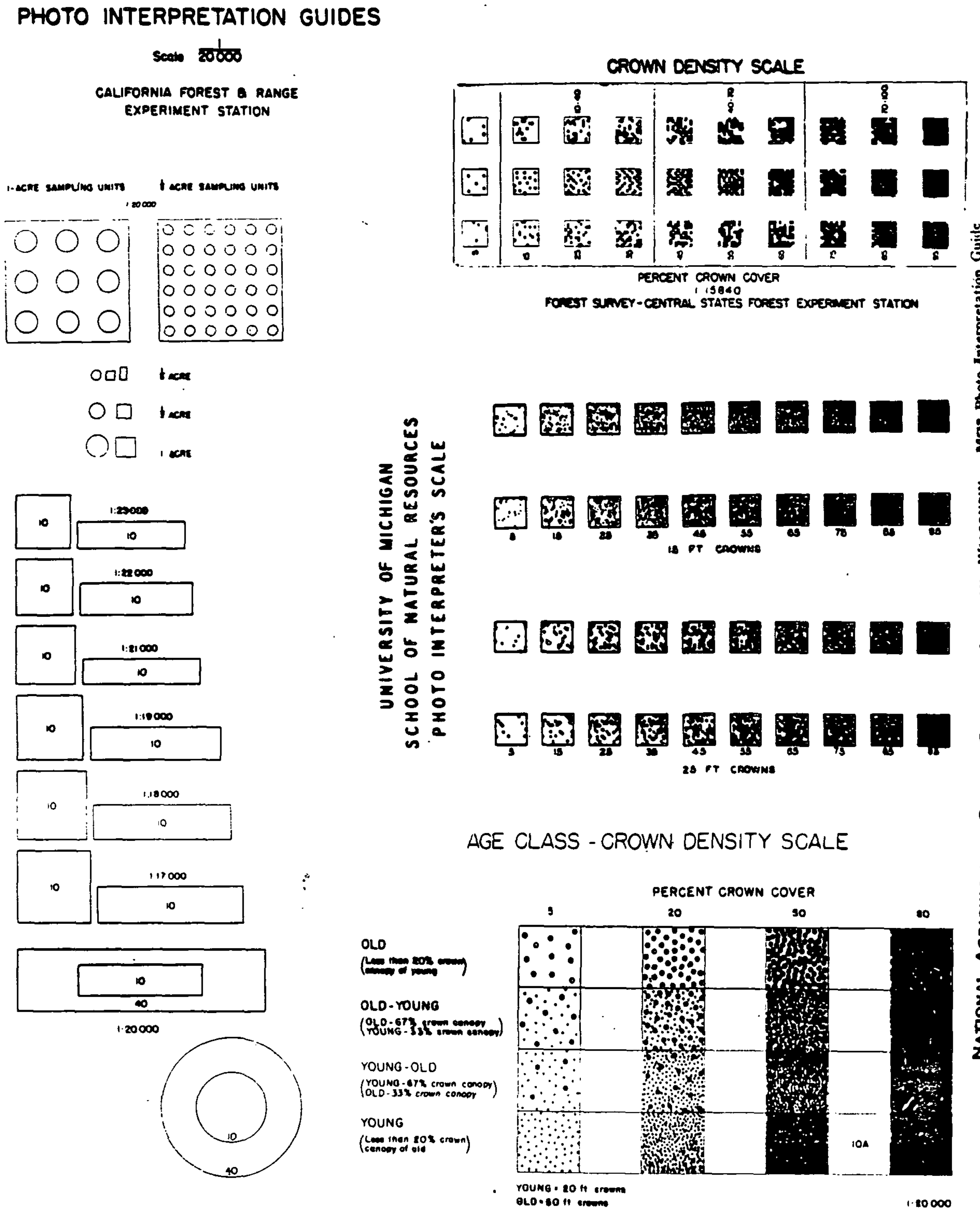

Figure 7-2.— Forest survey crown density scale.

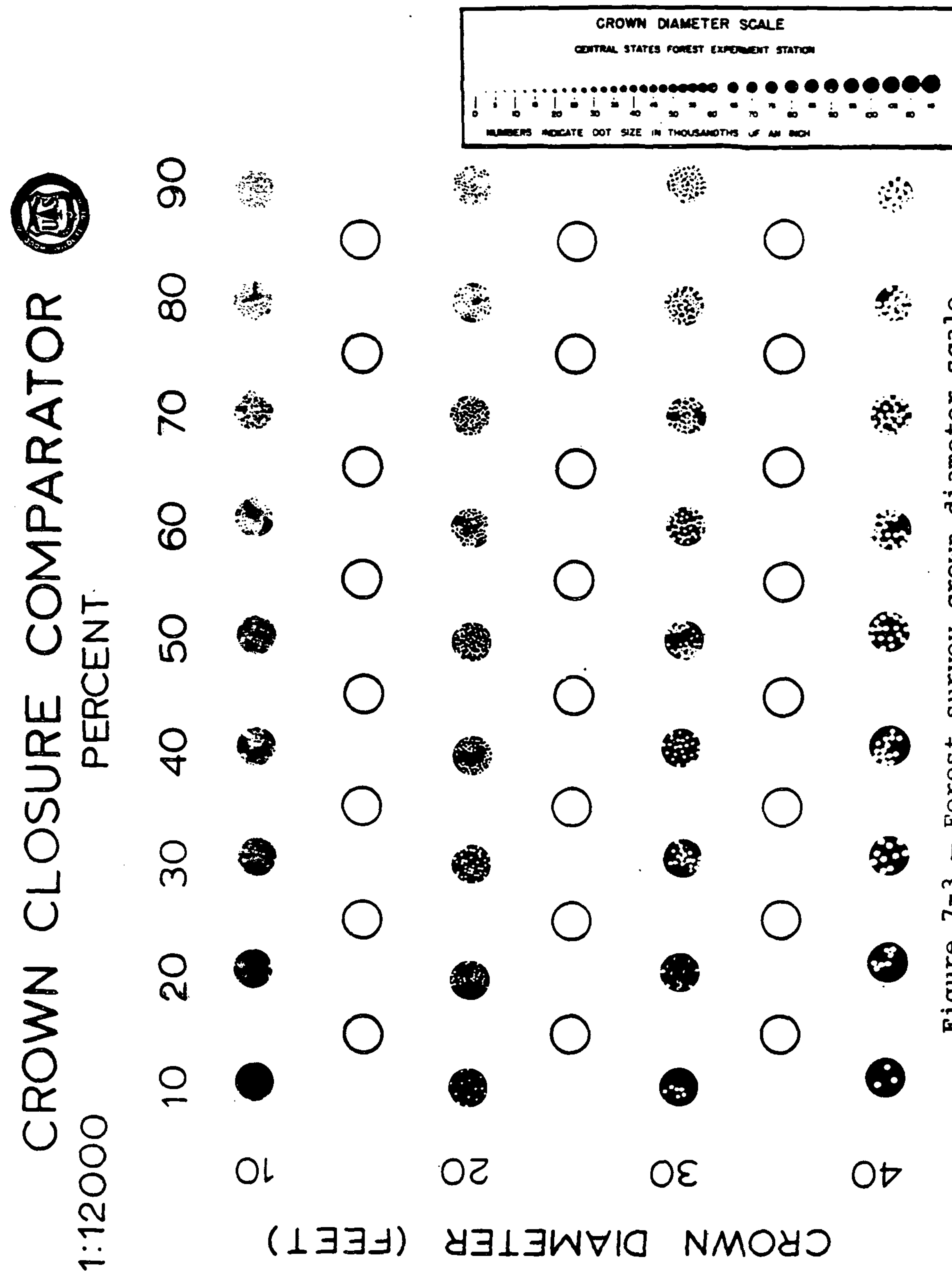

Figure 7-3.— Forest survey crown diameter scale.

for a data acquisition aircraft mission to delineate canopy density on predetermined sites are as follows:

- Geographic coverage: will be governed by size and shape of the area of interest. Flight lines should be flown following long dimension of tract; should allow for 30-percent sidelap and 60-percent overlap for stereocoverage. Number of lines will depend on flight altitude.
- Image orientation: Vertical photography is required for this analysis.
- Type of photography: Color IR film is recommended for the small-scale photography. Other film types could be used for the large-scale photography.
- Season: preferably the late spring or early summer, to take maximum advantage of the vegetative growth cycle.
- Year: current or recent.
- Terrain and cloud shadow: Zero cloud cover is required. Data should be acquired from midmorning or midafternoon to minimize terrain shadow. Photographs should not be taken between 11 a.m. and 1 p.m. to avoid sunspot degradation.
- Scale of imagery: 1:1,000 to 1:60,000.
- Products: transparencies and prints.
- Snow/water cover: minimal.

7.2.4 Photointerpretation. The photointerpretation phase includes the following:

- Training

- Delineation of crown diameter and canopy densities on overlays. Figure 7-4 shows a wildlife habitat analysis based upon crown density levels
- Quality checks and field checks

7.2.4.1 Training: The personnel factors that determine the training required for this type of analysis are (1) familiarity with the area being studied and (2) experience in this type of analysis.

- Personnel should refer to the training handbook published by the Intermountain Forest and Range Experiment Station, USFS.[6]
- Crown density estimation should be done on a stereomodel because the displacement of tree height tends to cover small openings when viewed monoscopically.
- Trainees should delineate a sample photograph into the various 20-percent density classes.
- The trainees' results should be checked by a skilled interpreter.

7.2.4.2 Delineation of crown diameter and canopy densities on photo-overlays: The procedures are:

- Step 1 – Separate or, if necessary, cut from the film roll each of the frames that are to be interpreted. Orient the conjugate pair for proper stereoviewing if the work is to be done in the stereomodel. Stereoviewing is recommended.

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[6]K. E. Moessner, Basic Techniques in Forest Photointerpretation, U.S. Department of Agriculture, USFS, Intermountain Forest and Range Experiment Station, Ogden, Utah, 1960.

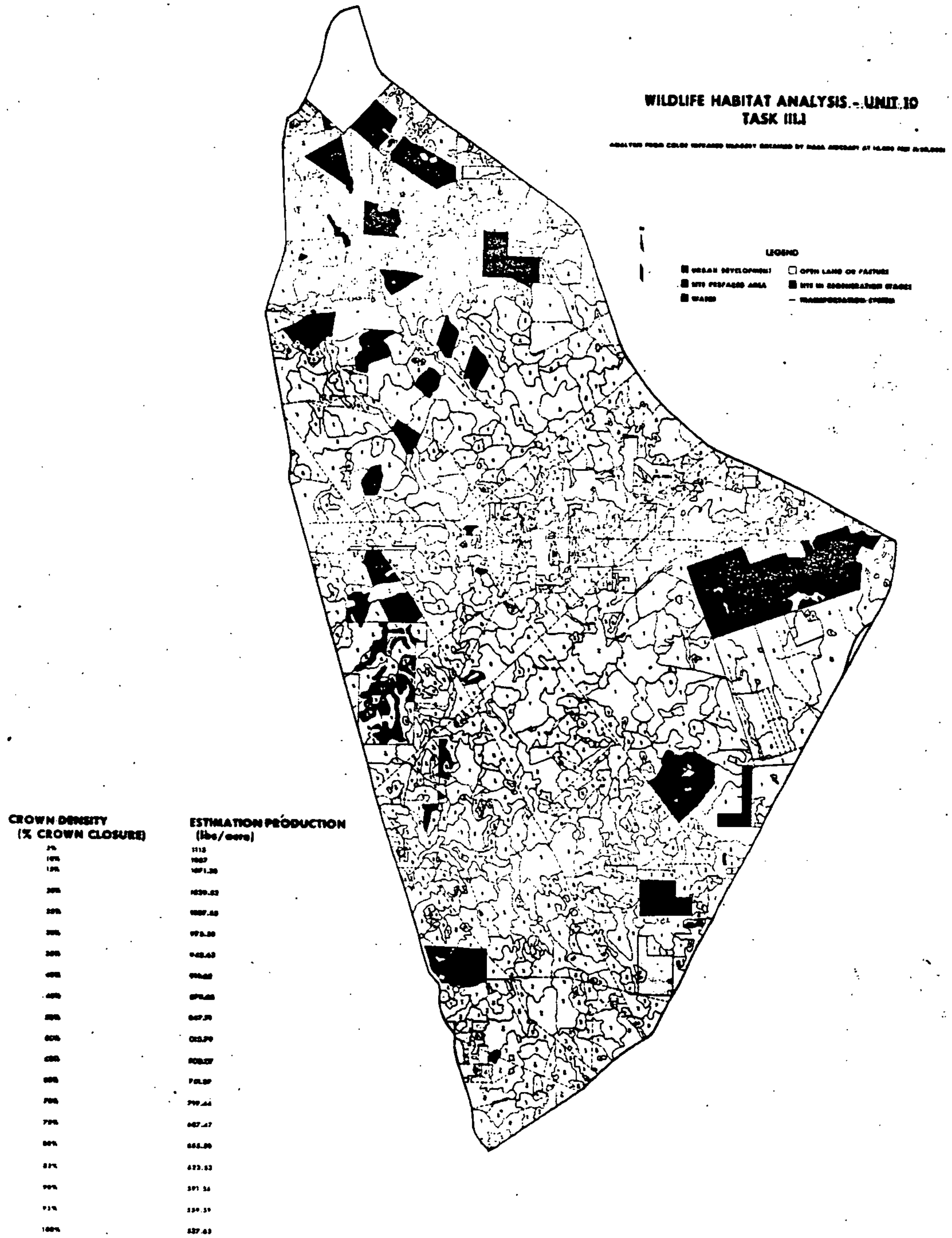


Figure 7-4.— Wildlife habitat analysis based on crown density levels.

- Step 2 — Attach to each frame with drafting tape a sheet of clear, ink-surface drafting film.
- Step 3 — Label each overlay with the frame number and a north arrow.
- Step 4 — Mark and cut a 10- by 10-cm (4- by 4-in.) window in the poster board.
- Step 5 — Overlay the window template on the imagery on the light table.
- Step 6 — Orient the photography being analyzed under the magnifying instrument.
- Step 7 — Place a printed density scale and crown diameter space alongside the photography.
- Step 8 — Select a landmark for reference and starting point.
- Step 9 — Outline land uses such as roads, cutovers, pastures, and agricultural fields.
- Step 10 — Delineate canopy density differences that can be determined on the Stabilene film by the unaided eye.
- Step 11 — Delineate the more subtle variations in canopy density on the Stabilene film using the magnification source.
- Step 12 — Select the trees or stands on which the crown diameter should be determined.
- Step 13 — Overlay the scale and determine the crown diameter. Record this figure inside the delineated stand.

- Step 14 – After all frames have been processed, compile the individual frames into a rough mosaic (use no glue) to determine amount of coverage. Check line junctions and erase those that are needless or misleading.

7.2.4.3 Quality checks: After several (usually three) frames of imagery have been delineated, it is advisable to have a skilled interpreter make a cursory check of each overlay and relate each to the imagery to detect gross anomalies.

7.2.4.4 Field checks: The evaluation of canopy density is more subjective than the determination of tree height or crown diameter. True measurement is virtually impossible on most photographs; thus, accuracy is dependent on the interpreter's judgment. Inexperienced interpreters tend to overestimate closure by ignoring small stand openings or including portions of crown shadows. Devices for checking closure on the ground fail to provide estimates truly comparable to those made on vertical photographs. Thus, to develop proficiency, the novice must rely on practice with the results checked by skilled interpreters.

7.2.5 Information transfer. This portion of the analysis involves the transfer of the delineated canopy grouping onto a base map at the desired scale; in this case a 1:24,000 base map was used. The technique employed a Kail reflecting projector, or its equivalent, to project a reduced or enlarged image of the overlay on a flat work area – usually frosted acetate. Specific steps to be followed are:

- Step 1 – Assemble the base map sheets to which the overlays are to be adjusted.

- Step 2 — Select a base map sheet for information transfer and secure corresponding overlays.
- Step 3 — Select one of the overlays, usually the one having the greatest number of landmarks (cultural development such as roads, lakes, and pipelines).
- Step 4 — Transfer these features onto the base map work surface (frosted acetate), using a 0 or 1 Rapidograph pen.
- Step 5 — Repeat the above steps until transfer is completed.
- Step 6 — Check periodically during the transfer stage to determine the quality of the data. Check specifically for the omission of density values and incomplete line junctures.

8.0 EROSION DETECTION USING SMALL-SCALE COLOR IR PHOTOGRAPHY

8.1 General

The following procedures are designed to familiarize the forest manager with photointerpretation techniques usable for detecting soil erosion caused by certain management practices. These procedures are designed to point out possible soil erosion problems caused by logging.

Erosion is the process by which earth or rock is loosened or dissolved and removed from the surface of the Earth and transported elsewhere. This wearing away is caused by running water, wind, ice, or waves.

Factors influencing erosion include soil type, slope, structure, aspect, annual rainfall amount, and type and density of the vegetative cover.

Drainage patterns should be delineated in detail by tracing the stream tributaries as far upslope as detectable. The drainage detail and texture show the geologic structure and, to some extent, soil types. The regional drainage system is controlled by the surface slope, lithology, and climatic conditions. Slope profile is an important factor in soil erosion. See figure 8-1.

> "On convex slopes, erosion increases as the distance from the divide increases. The total runoff becomes greater, and the steeper inclinations cause a faster flow. Temporary sediment deposits scarcely occur. The more severe forms of erosion are expected to occur in the lower parts of the slope.

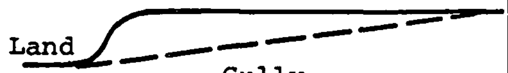
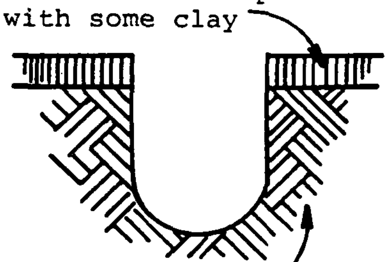
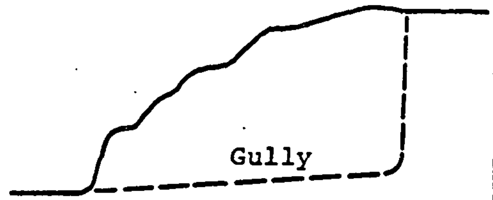
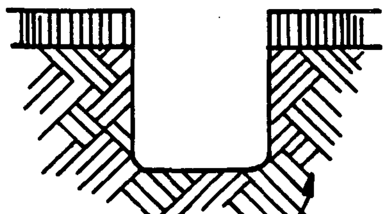
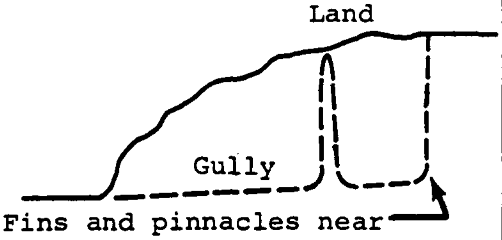
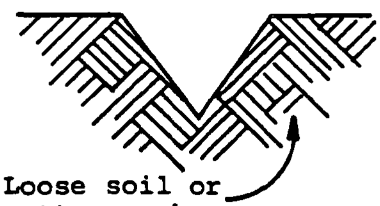
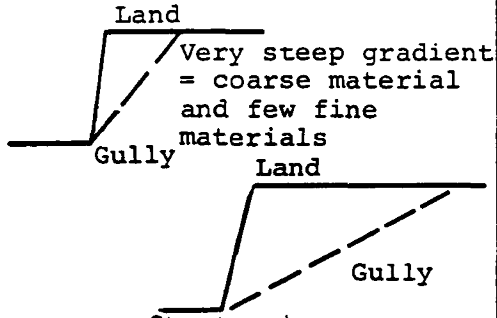
Soil	Cross section	Land surface and gully profile
Cohesive: clays and silty clays usually in lake beds, marine terraces, and clay shale areas		 Land; Gully; Low, uniform gradient
Moderately cohesive: weakly cemented sand clays in coastal plains and many bedrocks	Weathered soil profile with some clay  Loose soil or rotten rock	 Land; Gully; Compound gradient
Moderately cohesive: silt, primarily loess, alluvial deposits, and fine volcanic ash falls	 Loose soil or rotten rock	 Land; Gully; Fins and pinnacles near head end; Compound gradient
Noncohesive: granular materials often in terraces and outwash plains	 Loose soil or rotten rock	 Land; Very steep gradient = coarse material and few fine materials; Gully; Land; Gully; Short, steep, uniform gradient = well-graded mixtures

Figure 8-1.– Gully forms. From P. J. Belcher, Airphoto Analysis General Landforms, Cornell University, U.S. Navy contract NR-257001, 1951.

"On concave slopes, the most severe erosion occurs in the upper part. After a short distance on which the runoff gradually increases, erosion is active. Gullies can develop, often easily attacking the upper slope by headward erosion. Their occurrence depends on the profile and slopes of the lateral and summit areas. In the lower places sheet erosion becomes less, but gully erosion can continue or even increase, since the total runoff becomes greater downslope. Sometimes temporary sediment deposits occur. More permanent deposits, like colluvium, can occur at the lower slope.

"On straight slopes, factors other than shape often play a dominant role, especially surface roughness. Temporary deposits are common, with gullies developing below at some distance from the divide. Soils of straight slopes are often of medium depth, because a loss of material is generally compensated by gain from above. The most severe erosion takes place at the very upper part, which is often slightly convex, and in the lower part, where the volume of runoff has become greater. This causes a short concave footslope."[1]

"When the average slope is less than 60 degrees, a change of one or two degrees can noticeably effect the depth of the soil profile. This is because the runoff rate changes with a change in slope and sedimentation is changed accordingly. When the average slope is greater than 60 degrees, gravity and mass movement become very important."[2]

Logging trails create breaks in slope profile as logs are dragged along skid trails. In the past, logs were dragged

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[1]E. Bergsma, Aerial Photo Interpretation for Soil Erosion and Conservation Surveys, Vol. I, Erosion Features, ITC-Enschede, Sept. 1971, p. 23.

[2]Reference footnote 1, p. 25.

upslope and more or less perpendicular with the contours (fig. 8-2). The skid trails created from this logging technique made small furrows that became natural channels for runoff, thus creating erosion problems. A new technique of skidding is to work one major upslope skid with cross-slope skids parallel to the contours. These act as slope breaks (fig. 8-3).

Erosion in clear-cut areas is influenced by the size and shape of the cut, soil type, slope, and degree of revegetation. Less stable or impermeable soils tend to erode more readily. Slope breaks (terraces, roads, and horizontal skid trails) slow runoff and decrease downslope erosion. Slope steepness directly influences the rate of erosion. As ground cover increases during the revegetation process, gullying will decrease. Selectively cut areas must be field checked for gullying since it is difficult to detect erosion features through ground cover from aerial photography (fig. 8-1).

It has been feasible for many years to use low-altitude, conventional, black-and-white, aerial photography to map erosion patterns caused by logging operations. This application is essentially a specialized aspect of landform analysis. Low-altitude photography has the natural advantage of being suited to the very detailed mapping required to detect erosion areas related to highly localized logging operations. High-altitude color IR photography has been proven valuable in identifying and locating National Forest areas in the northwest where logging activities have caused serious erosion problems in the past. Evident at both scales of 1:60,000 and 1:120,000 are the clear-cut areas,

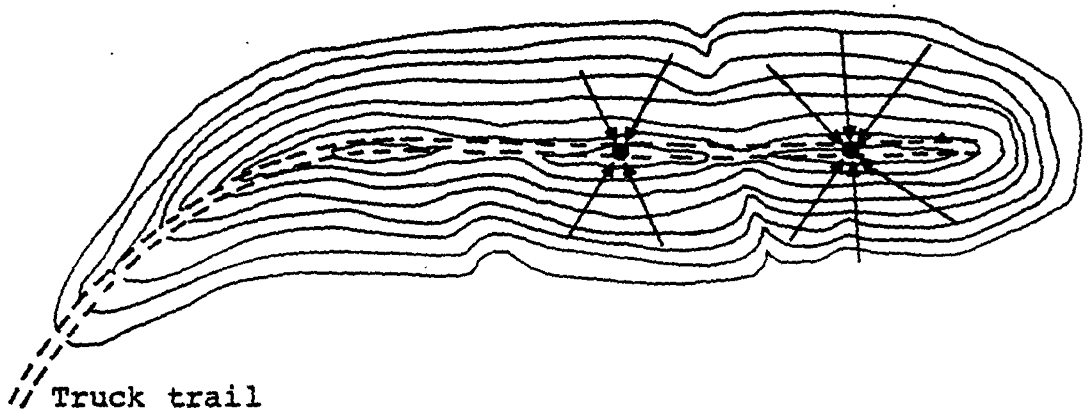
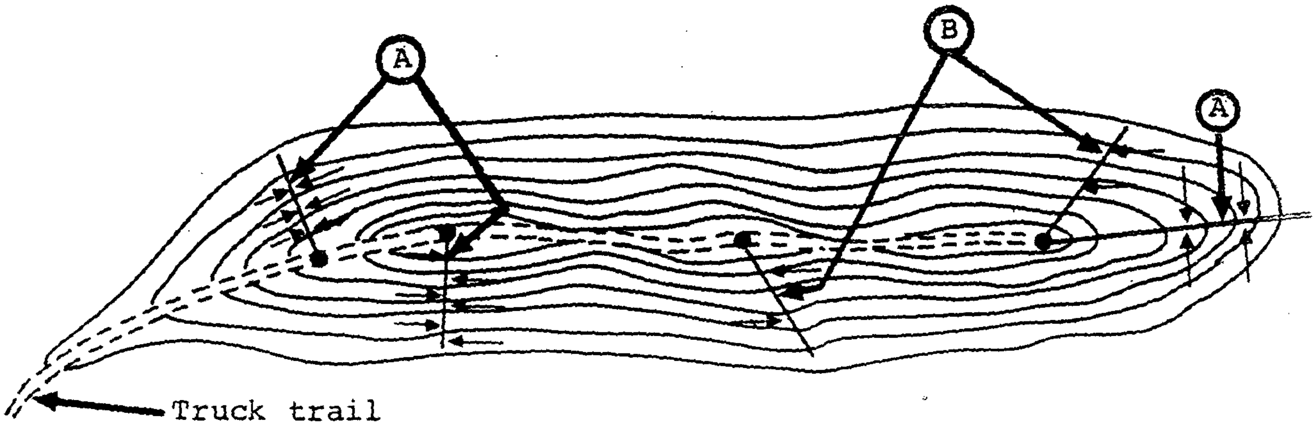


Figure 8-2.— Old method of skidding logs.



(A) Trees are skidded parallel to the contours and then upslope. These skid trails intersect the upslope trail at right angles.

(B) Trees are skidded parallel to the contours and then upslope. In this case, however, the skid trails do not intersect the upslope trail at right angles.

Figure 8-3.— New method of skidding logs.

logging trails, log loading stations, and natural drainage patterns. Approximate slope angle also can be estimated at these areas.

8.2 Resource Requirements

8.2.1 Data. Color IR photography is recommended because of the valuable information its spectral (false-color) effect yields on vegetation patterns and land surface characteristics, as well as its superior atmospheric haze penetration. Specific photographic and ancillary data are

- Positive transparencies of the photoframes that cover the study area, in 23- by 23-cm (9- by 9-in.) format. This is most convenient to work with when using a mirror stereoscope. Positive transparencies are preferred over paper prints because of their superior resolution. If paper prints are to be used for analysis, a matte finish is advisable to avoid surface glare and reflection.
- Paper prints of the frames that cover the detail study area, for field checks of the results. Color prints are preferred, but black-and-white prints should be satisfactory for this purpose.
- Medium-scale maps of the coverage area, for photo-index preparation. The USGS and Defense Mapping Agency Topographic Command 1:250,000 topographic maps are recommended.

8.2.2 Skills. The prime skill requirement for this application is formal or on-the-job photointerpretation training, preferably including some training in geomorphology and forest management practices. The analyst also should be familiar with logging and other forest industry practices in the area of study.

8.3 Data Requirements Definition

The following should be considered in acquiring aerial photography for an erosion detection study:

- Geographic coverage: should completely cover the area of interest with sufficient overlap (60 percent) and sidelap (30 percent).
- Image orientation: Vertical photography is required, preferably with a tilt of 3° or less. However, the tilt factor is less critical than in other applications discussed in this manual.
- Type of photography: color IR photography.
- Season of year: during a time of vegetation dormancy when deciduous species are in leaf-off condition. This condition applies only to those areas which are snow-free or to snow-prone areas during the late spring after the snows have disappeared.
- Year: current or as recent as possible; ideally, should be updated semiannually for maximum operational values.
- Cloud cover, snow, or flood conditions: minimal except for specific requirements.
- Scale of imagery: approximately 1:120,000 or 1:60,000.
- Products: 23- by 23-cm (9- by 9-in.), duplicate, positive, color IR transparencies; color or black-and-white 23- by 23-cm (9- by 9-in.) prints for field checks.

8.4 Photointerpretation Procedures

8.4.1 Checking for film quality. On receipt of the imagery, the film quality should be checked for overexposure or underexposure, heavy cloud cover or shadows. An excess of any of these conditions will make the imagery useless.

8.4.2 Selection of frames. Frames should be selected in the study area and their coverage indexed on a medium-scale map. The exact planimetric limits covered by each frame should be outlined on the map. Frames that have stereo-coverage over specific study sites should then be selected.

8.4.3 Preparation of overlays. The photointerpretation approach used in this application will prepare three separate clear acetate overlays for each aerial photograph, showing (1) drainage patterns and water bodies, (2) clear-cut and selectively cut areas, and (3) logging trails and loading stations. Sample overlays and their composition with the base photograph are shown in figures 8-4 through 8-7. These overlays can be analyzed, singly or collectively, to deduce the relationships among gullying and other erosion phenomena and lumbering operations.

First, three 23- by 23-cm (9- by 9-in.) sheets of clear acetate should be cut for each photoframe to be interpreted. Then, the three overlays should be delineated using a fine point drawing pen. Tick marks or other orientation points (preferably the four corner fiducial marks if they are in the form of an X , on the corners of the frame) should be placed on the overlays to facilitate precise registration for analysis. Then, the following steps should be taken.

Figure 8-4.- Drawing of drainage pattern and water body overlay.

Figure 8-5.— Drawing of clear-cut and selectively cut areas overlay.

Figure 8-6.– Drawing of logging trails and loading stations overlay.

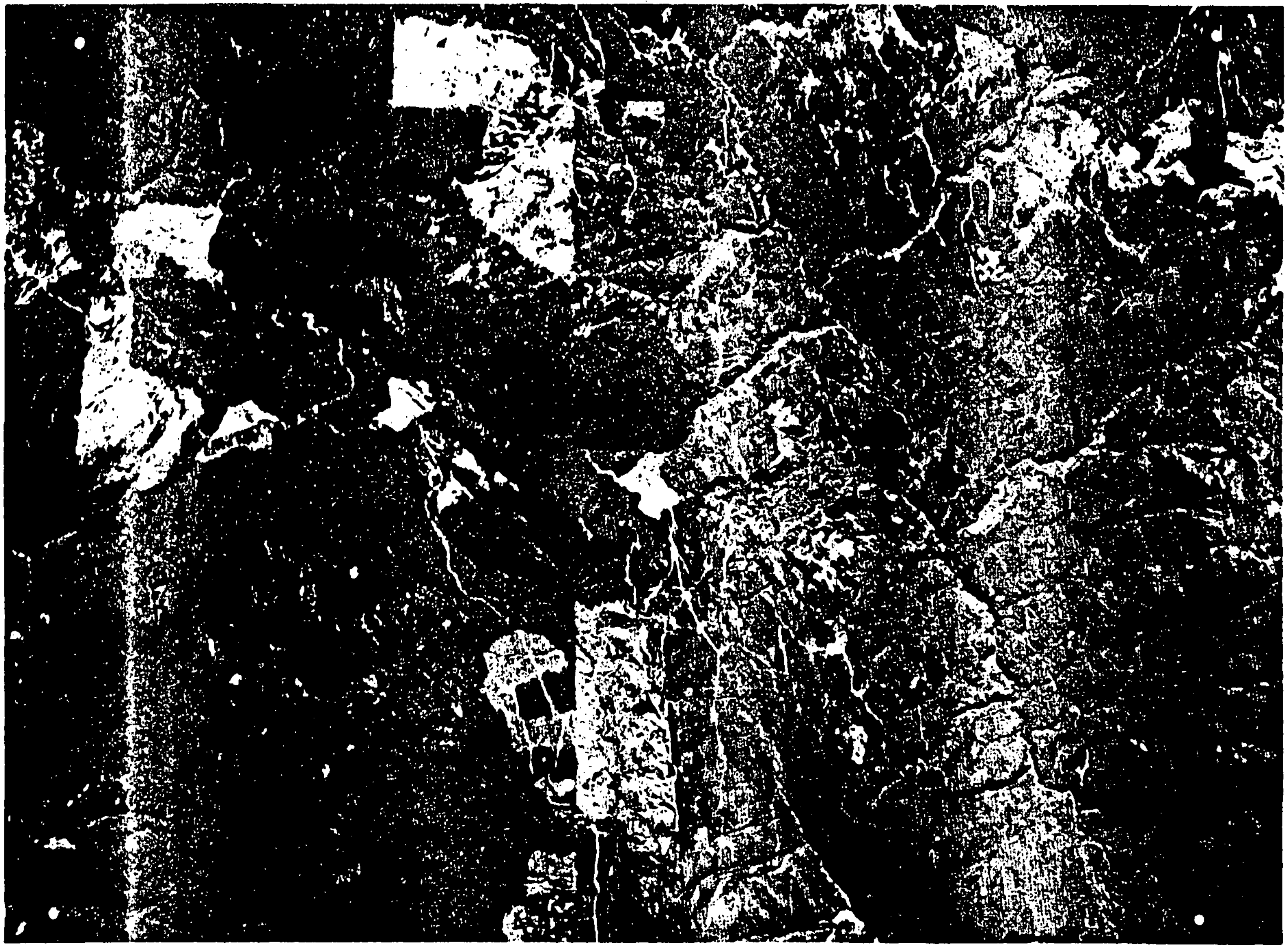


Figure 8-7.— Color IR photograph with overlays of Mt. Baker National Forest area, Washington, for erosion detection (NASA Mission 189, roll 23, frame 119).

8-12(a)

8-12(b)

8-12(c)

- Make the drainage pattern and water body overlay (fig. 8-4) to include streams, creeks, and gullies. These may appear as discrete thin lines for all features, regardless of their size.
- Prepare the clear-cut and selectively cut areas overlay (fig. 8-5). Normally these appear on the photograph as large rectangular openings in the forest canopy, but they may be irregular with well-defined boundaries. If the cut was recent, little or no vegetation cover will be apparent, and a strong, bare, soil appearance will be seen (that is, light, bright reflectance). Windrows of slash may be evident if the area has been site-prepared. The clear-cut areas near the loading stations should be examined closely. Erosion is most likely to occur here because of the depressions left in the disturbed ground.
- Prepare the overlay of logging trails and loading stations (fig. 8-6). Bright or light-colored linear features characterize the trails. The loading stations are recognized as bright spots along these lines.

8.5 Interpretation and Application of Results

The results of the photointerpretation can be put to immediate practical use in forest management. The three overlays may be studied and analyzed singly or collectively and superimposed on the phototransparency or on a paper print.

The logging trails overlay and the clear-cut overlay both show areas of human alteration, whereas the drainage overlay shows natural alteration of the land. When the three overlays are combined with the photograph (fig. 8-7), it is possible to identify areas of excessive erosion or probable areas where gullying will occur.

The interpretation procedure identifies areas of erosion or areas with a tendency toward erosion, to which field personnel then can go directly. They can determine whether the area is undergoing erosion, the degree and rate of erosion, and what measures should be taken to prevent further degradation.

Unfortunately, the beginning stages of erosion are invisible on aerial photography of any scale. Mensuration and profiling are impracticable with the scales of imagery used in this study. If lower altitude, temporal, stereoscopic imagery is used, cross-sectional profiles of the erosion can be developed, and the erosion condition can be monitored. The acceleration of erosion probably could be determined if the number of gullies increased significantly. In addition, temporal photography might show changes in gully lengths, which would indicate the intensity of the erosion activity in the area.

The soil-erosion-detection, photo-overlay data can be transferred to base maps at a larger scale for displays and presentations. An enlarging, rectifying projector can make properly scaled copies of the original overlays, which can then be transferred to selected base maps.

8.6 Conclusions

High-altitude color IR photography has been found to be an aid in erosion detection. It may be used to find both natural drainage and erosion caused by man's activities.

Three overlays have been prepared. One shows logging roads and loading stations; another indicates the location of clearcuts and selective cuts; and the last shows natural drainage, gullies, and gully erosion possibly caused by logging. When the three overlays are combined with the photograph, the locations of areas of excessive erosion and their probable causes may be identified.

From these overlays and the information provided by them it may be assumed that high-altitude IR photography (scales of 1:60,000 and 1:120,000) is a means to erosion detection.

9.0 BIBLIOGRAPHY

A Land-Use Classification System for Use With Remote-Sensor Data. USGS Circular 671, Washington, D.C., 1972.

American Society of Photogrammetry: Manual of Photogrammetry. George Banta Company, Menasha, Wis., 1966.

American Society of Photogrammetry: The Manual of Photographic Interpretation. George Banta Company, Menasha, Wis., 1960.

American Society of Photogrammetry: What Photogrammetry Is. Photographic Engineering and Remote Sensing, vol. XLI, no. 1, Jan. 1975.

Avery, T. E.: Forest Measurements. McGraw-Hill, N.Y., 1967.

Avery, T. E.: Forester's Guide to Aerial Photo Interpretation. U.S. Department of Agriculture Handbook 308, USFS, Oct. 1966, revised Dec. 1969.

Avery, T. E.: Interpretation of Aerial Photographs. Burgess Publishing Co., Minneapolis, Minn., 1969.

Basu, J. P.; and Kan, E. P.: Confidence Intervals for Probability of Correct Classification. Lockheed Electronics Co., Inc., Houston, Tex., Tech. Memo. LEC-5003, Dec. 1974.

Belcher, P. J.: Airphoto Analysis General Landforms. (Cornell University; U.S. Navy Contract NR-257001.) 1951.

Bergsma, E.: Aerial Photo Interpretation for Soil Erosion and Conservation Surveys. Vol. I, Erosion Features. ITC-Enschede, Sept. 1971.

Colwell, R. N., ed.: Manual of Photographic Interpretation, American Society of Photogrammetry, George Banta Company, Menasha, Wis., 1960.

Cramer, H.: Mathematical Methods of Statistics. Princeton University Press, Princeton, N.J., 1946.

Douglass, R. W.; and Meyer, M. P.: Forest Vegetation Classification and Mapping. Applications of Aerial Photography and ERTS Data to Agricultural, Forest and Water Resources Management. Institute of Remote Sensing, College of Forestry, University of Minnesota, 1973.

Earth Observations Applications Office, NASA/JSC: Limited Cost Study of Photographic Data Acquisition. LEC-0139, 1973.

Eastman Kodak Company: Characteristics of Kodak Aerial Films. Publication M-57, Rochester, N.Y., Oct. 1973.

Eastman Kodak Company: Color As Seen and Photographed. Publication E-74, Rochester, N.Y., 1972.

Eastman Kodak Company: Kodak Data for Aerial Photography. Publication M-29, Rochester, N.Y., 1971.

Eastman Kodak Company: Kodak Filters for Scientific and Technical Uses. Publication B-3, Rochester, N.Y., 1970.

Freeze, F.: Elementary Statistical Methods for Foresters. U.S. Department of Agriculture Handbook 317, Jan. 1967.

Heath, G.: The Determination of Hot-Spot-Free Periods for Aerial Photography of Forested Areas. Lockheed Electronics Company, Inc., LEC/HASD no. 640-TR-127, Houston, Tex., 1972.

Howard, J. A.: Aerial Photo-Ecology. American Elsevier Publishing Co., Inc., N.Y., 1970.

Kan, E. P.: Relationship Between Two-Class and Multiclass Accuracies. Lockheed Electronics Company, Inc., Houston, Tex., Tech. Memo., Dec. 1975.

Moessner, K. E.: Basic Techniques in Forest Photointerpretation. U.S. Department of Agriculture, USFS, Intermountain Forest and Range Experiment Station, Ogden, Utah, 1960.

National Academy of Sciences for the American Geological Institute: Dictionary of Geological Terms. Second ed. Dolphin Reference Books, Garden City, N.Y., 1962.

Nichols, J., et al.: ERTS Applications in Timber Inventory: A Summary of Two Case Studies. University of California at Berkeley, 1975.

Pearson, E. S.; and Clopper, C. J.: The Use of Confidence or Fiducial Limits Illustrated in the Case of the Binomial. Biometrica, vol. 26, 1934, p. 404.

Pielou, E. C.: An Introduction to Mathematical Ecology. Wiley-Interscience, N.Y., 1969.

Smith, J. T., ed.: Manual of Color Aerial Photography. First ed. American Society of Photogrammetry, Falls Church, Va., 1968.

Spurr, S. H.: Photogrammetry and Photo-interpretation. Second ed. The Ronald Press Co., N.Y., 1960.

USFS/R8: Compartment Prescription Handbook. FSH-2409.21d R, Amendment 3, Atlanta, Ga., Sept. 1970.

USFS/R8: Soils Resource Guide, 1972.

Wilks, S. S.: Mathematical Statistics. John Wiley & Sons, Inc., N.Y., 1962.

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