# FOREST SERVICE USE OF AERIAL PHOTOGRAPHS

*Raymond D. Garver and Karl E. Moessner*[1]

THE Forest Service is an old-line bureau of the U. S. Department of Agriculture. Its work falls logically into three broad classes: National-Forest Administration, Cooperation, and Research.

It is responsible for the administration of 152 national forests, 43 purchase units, 17 experimental ranges, and 11 land-utilization areas, aggregating 180 million acres located in 42 states and territories. It cooperates with 43 states and one territory in fire protection, and with private owners in all states and territories in forest management. It conducts forest and range research nation-wide and in Alaska and Puerto Rico. This widespread sphere of activities indicates the magnitude of the potential need and current use for aerial photographs, which may be considered detailed maps portraying forest conditions and other physical characteristics of the land at a given time and place.

When used as maps, single photographs are relatively free from distortion only when the area pictured is level and they are taken with no appreciable tilt of the camera. In the discussion that follows, the term "aerial photographs" means vertical photographs in black and white taken with a single-lens camera. They are believed to have untold potentialities for saving time and money in forest and range resource management. But it is still necessary to make ground studies and measurements of the timber and other forest resources for wholly satisfactory results, even though concerted effort is made to get all possible information from the photographs.

Practical use of aerial photographs by the Forest Service will be discussed briefly, including some specific examples of use. Aerial photography is relatively new in forestry work. Very probably we do not have the most efficient techniques for getting the largest amount of information by this means. Also, the optimum scales, kinds of films, and filters to use in forestry work are yet to be determined. Actually, it appears that no one kind of film and filter and scale is universally best for all forestry purposes. Consequently, aerial photographs are often used because they are available at moderate or no cost, not because they are the best that could be taken. They may be old—say six years or older—and at too small a scale, or just poor photography. If topographic mapping is the sole purpose, small-scale photographs down to 1:40,000 or smaller are used, but larger scales —1:20,000 to 1:10,000—are considered necessary for best results in forest resource studies, planning fire control improvements, and range and timber management.

A mean scale of 1:15,840, the equivalent of 4 inches to the mile, is believed a good compromise. If funds permitted, the ideal would be new photographs for a specific purpose carefully taken with prescribed scale, film, and filter combination. Even this would be in the nature of guesswork until additional research and tests are carried out. Possibly the answer is dual flights for different scales, one for mapping, the other for resource studies. Nevertheless, we consider aerial photography a valuable quick, and low-cost method of collecting general information about forest resources.

[1] Respectively National Director of Forest Survey and Photogrammetrist, Forest Survey, Central States Forest Experiment Station.

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## NATIONAL-FOREST ADMINISTRATION

Primary items essential to developing and safeguarding the National Forests are adequate improvements, such as roads, trails, telephone lines, fire towers, buildings, etc., a fire-control system, and adequate technical and administrative management.

### IMPROVEMENTS

The use of aerial photographs in the preliminary location of roads, trails, and landing fields is widespread in the Forest Service, and very materially lowers the cost and improves the standard of the final job.

Photographs are used in stereoscopic pairs to select control points and to plot the general location of roads. In addition to the contour of the ground, such pictures indicate the location of rock, timber, and points where soft or hard ground may be encountered. They facilitate selection of a route that avoids timber cover in order to gain good exposure to the sun, or goes through timber for purposes of utilization.

Photographs are often enlarged from 9″×9″ to 20″×20″ to provide more drafting space for plotting the proposed improvement directly on them. This is valuable in relocating existing roads because one can select control points for tangents, and the proper curves may be chosen quite accurately without the usual field work. After the detailed route is selected and drawn on the photographs, a brief examination in the field is generally all that is needed before starting clearing for the center line. Bearings for the proposed tangents may be estimated with sufficient accuracy from section lines, fence lines, or established tangents on existing roads.

Aerial photographs are used in the same manner for locating trails, but since grades are less important here, the main use is in selecting routes to avoid heavy rock or clearing work.

In locating landing fields, the photographs are used in preliminary exploration to select a bearing for the landing strip that will give the best approaches to the field and the maximum use of a limited area. When the line is selected and the bearing established, it is a simple matter to select the corresponding points on the ground. These are sufficient to guide the brushing out of a center line, preparatory to proceeding with the detailed survey.

In addition to the usual small-scale photographs, "low-level" large-scale photos are sometimes taken for special road jobs. These give more detail, and are valuable in determining such things as the proper side of a stream for road location and points for strategic bridge crossings. Care is necessary, however, not to fly so low that blurred photographs result from lack of synchronization of plane and camera-shutter speeds.

### FIRE CONTROL

Aerial photographs are an invaluable adjunct in fire-control planning because they show not only the kind of vegetation but, under stereoscope, the topography of the area also. They assist in delineating high and low-hazard areas, and in anticipating the rate and direction of spread of a fire. Once a fire occurs and is located by land description or otherwise, photographs may be the first-line reference for fire-fighting strategy, both on the ground and in the dispatcher's office. At a glance, they place the fire geographically, indicate its accessibility by roads, trails, or water, disclose the type of fuel burning and that ahead, whether topography permits the operation of power equipment or requires the use of hand tools, the most vulnerable point of attack, and the most strategic location for fire lines. Such photographs are also used, smoke permitting, in mapping a fire from the air as a basis for progress reports, strategy discussions between the fire boss and plans chief, and decisions on the sequence and kind of attack best adapted to controlling the fire. Where photographs are not available, going fires are sometimes photographed from the air to get a quick size-up of the situation, as was done in one disastrous fire in eastern Montana this past summer. On the whole, aerial photographs are a generally useful and, in back-country areas, an essential tool in efficient and effective fire control.

### TIMBER MANAGEMENT

Timber management is another major phase of National-Forest administration. It is composed of two steps. One is an inventory of the area to determine location of timber, acreage, volume, stand-size, species, types, condition, growth, accessibility, and desirable cutting practices, as a basis for management plans designed to use and improve the forest. Both forest type or cover maps and planimetric maps are essential to such plans, and in certain forest regions such as the Pacific Northwest, topographic maps are desired. The second step is the application of the plans to sales of timber and cutting and logging operations.

In each step aerial photographs are fast becoming a necessity. They are at best, however, complementary to ground techniques in timber inventory work, though very much less so in planimetric mapping. However, they enable the forester or engineer to do a better job at a lower cost.

How are the photographs used? In cases where a planimetric map is lacking, one can be made from them by engineering methods. Forest types and stand-size classes are delineated on contact prints, usually after stereoscopic examination. After cursory field checking, this information is transferred to the planimetric base map by use of some device, such as a reflecting projector, camera lucida, duoscope, Radial Planimetric Plotter, or Multiscope, depending on whether single or overlapping pairs of photographs are used. Areas of the different forest types and stand-size classes are determined from the base map by planimeter, dot or square count, or other methods. Total timber volumes are computed by applying the results from sample plot measurements to the areas in the various types and stand-size classes. These sample plots are from a 0.2 to 0.25 of an acre in size. The number needed to meet a prescribed sampling accuracy for volume, such as $\pm 5$ per cent at one standard error, is statistically computed. These plots are randomly placed on the aerial photographs within the various types and stand-size classes, in accordance with the number required to meet the inventory sampling design. Taken to the field by inventory crews, the photographs are used in locating the plots, and in checking photo-interpretation results against ground conditions.

Working circles, management units, and often individual timber-sale areas are plotted on the base map. Aerial photographs in conjunction with the corresponding base map are especially useful in discussing timbered areas with prospective purchasers. If topographic maps are lacking, they are valuable in appraising felling and logging conditions, and later in mapping the progress of cutting. Such photographs are also useful in developing forest planting programs for cut-over and burned areas. Among the many other uses for aerial photographs are blocking out broken ownerships by plotting section corners on them, and tentatively locating camp or airplane-landing sites and logging roads. To the forester responsible for technical management of the forest, they are close to being indispensable.

### RANGE MANAGEMENT

Range or grazing-resource management also ranks high among the primary responsibilities in National-Forest administration. Like the timber manager, the range manager needs an inventory of the resource, in this case the forage. He needs a range type map in order intelligently to fix proper grazing seasons, allot stock in correct numbers and class to given areas, program range improvements, and coordinate grazing use in the multiple-use plan of the National Forest in question. The first thing needed is a good planimetric base map. The second, a range inventory map superimposed on the base map. These usually show the forage cover types, sometimes the soil types, and an estimate of the carrying capacity in forage acres as a basis for allotting the correct numbers of cattle, sheep, goats, or horses to a given area. How can this information be obtained?

The planimetric map is a work of engineering, usually accomplished with limited primary ground control and aerial photographs. With such a map available the range inventory crew takes over. Guided by previously prepared field and office instructions, including specially designed forms, qualified men begin work. Generally, aerial photographs are studied in overlapping pairs for the purpose of identifying and delineating major range types on them. These photos are then taken to the field where major types are checked and revised as needed, detailed types added, and primary forage species identified. If soils are being classified, this will be done ordinarily on map overlay. The number of range types recognized varies, but 18 is a good average. Other range information includes estimates of forage density, forage-acre factor, current utilization, range condition, presence of noxious forage plants, erosion, improvements, reseeding sites, etc.

These data are compiled and shown in part on the base map for use of the range administrator. From them and compilation sheets, it is possible to compute the approximate number of stock that should be run in a given watershed or other range allotment, having in mind the needs of the area in question. Like timberland, range land has a normal yield capacity which must be recognized when deciding whether an area is below par and in need of improvement, or is in top condition and requires only maintenance of the current yield.

Aerial photographs are especially useful in discussions of ranges with permittees. A glance at them, with or without lines outlining the types, strikingly shows the timbered areas, open grassland, streams, lakes, and (under stereoscope) whether the land is rough, rolling, or flat, and many details of the forage itself. As in timber management, aerial photographs are a "must" item in range management. They are expected to increase in value as more ways to use them are discovered, and films, filters, and cameras are improved.

### OTHER WORK

Other phases of National-Forest administration, such as recreation, game and watershed management, forest-land acquisition, and informing the public about forestry matters, also require maps and photographic illustrations. Aerial photographs are basic reference material in all these activities. Previous discussions illustrate in a general way how they are used.

## COOPERATION

Cooperative Federal fiscal assistance in the prevention and suppression of forest fires on state and privately owned land is authorized under the Clarke-McNary Act. Actually the states administer the fire-control activities under plans approved by the Federal Government.

In this work aerial photographs are used in a number of ways. One major use is in determining the acreage of forest land in protection units. This is often accomplished by placing a clear acetate dot grid over the photograph, for the purpose of counting the number of dots that fall on and off forest land. The percentage of forest land is computed from this count. This factor, applied to the total land area, gives the forest area. Another use is in the preparation of fire plans and maps, including the location and need of fire towers, firebreaks, strategic roads, and routes for air-plane patrol. High and low-hazard areas based on fuel types and topography are often discovered by examining aerial photographs. In fire suppression, they indicate effective locations for fire lines, type of fuel being burned and in the path of the fire, and the most effective travel routes in deploying the fire-fighting force.

A second kind of Federal cooperation deals with forest-management assistance to timberland owners and naval stores operators, and to farmers, including the distribution of trees for woodland planting. All these lines of cooperation are concerned with forest land, either currently sustaining trees or in need of planting, and in one form or another extend to most States and Territories. Inevitably, the need for maps comes up and with it the potentialities of aerial photographs. Many forest-land owners buy sets of aerial photographs for their holdings, to use directly as maps, or for accurate maps made from them by engineering methods. Extension talks and timber-development plans are greatly facilitated by using photographs as a basis for mutual understanding between the landowner and the forester. Discussions with landowners may be centered on areas in need of planting, planning a cutting program, the best location for roads and firebreaks, or the sale or purchase of a tract of timber. Correctly interpreted, recent photographs can yield as much information in a few hours as weeks of ground travel would collect.

## RESEARCH

Forest Service research activities are classified according to the following divisional lines: Forest management, range research, forest influences, forest fire control, forest products, and forest economics, including the nation-wide Forest Survey. Maps are used to a greater or less degree in all phases of research. Since aerial photographs afford a suitable and efficient method of recording wild-land conditions, including topography and cover, they are basic to map preparation and to studies of all problems of forest and range lands.

In forest-management research, aerial photographs are a working tool in preparing forest type, stand-size, and condition maps for experimental forests as a basis for a research program and physical improvements, such as telephone lines, roads, trails, and fire lines. For larger areas, they are useful in selecting stands for yield and growth studies or any large-scale sampling of specific types or conditions, in detecting and locating insect damage, such as the spruce budworm, in showing the extent of spoil-bank areas in mining sections such as those in Ohio and Pennsylvania, in studies of watershed management, and in the correlation of soil types, forest types, and sites. They are also used effectively in appraising the relative merits of different areas, and the ultimate selection of some for experimentation. They obviate the necessity for much costly and time-consuming foot travel. Examples of such use are appraisals of the San Dimas Experimental Forest in California, the Sunday Creek Coal Company lands in southeastern Ohio, and the Tallahatchie area in northeast Mississippi.

Range research employs aerial photographs in resource surveys of experimental areas very much as National-Forest Administration employs them for surveys of large areas. They are used in detailed range studies of small areas as well. The Starkey Experimental Forest and Range Area in Oregon provides an example. The study installed there is to determine the proper intensity and method for the grazing of cattle in ponderosa pine forests. It involves setting up and periodically sampling 12 pastures averaging about 760 acres in area. The pastures each contain a single watershed and have a close resemblance as to vegetation and topography. The vegetation on the area is roughly 60 per cent grazeable ponderosa pine forest, 20 per cent mixed conifer forest too dense for cattle grazing, and 20 per cent grassland and meadow openings. Types are broken up and intermingled, making it difficult to determine their area and location in each pasture by ground methods without detailed surveys. Through study of aerial photographs in the field, detailed and reliable type and drainage maps were made of the area. This greatly helped in planning pasture locations. Photographs were used also to facilitate sampling the vegetation. For example, plot cluster sampling points were marked on the photographs, and the prints were then used in the field initially to establish and mark the plots, and later to relocate them for the periodic reexamination required by the study.

In the flood control surveys, aerial photographs are used for the purpose of selecting small watersheds on which measuring gages are set up, to determine whether the cover and drainage characteristics are representative of larger areas. They are used to delineate flood plains and to determine the kind and quantity of capital improvements, both agricultural and nonagricultural. Flood lines at various river stages are often drawn on photographs of flood plains; thus the areas inundated and the damageable property between the lines are delineated. The data can be used in estimating flood damages.

Aerial photographs are also used to locate sampling points on large watersheds, for the purpose of identifying current soil and cover conditions. The data are needed in preparing programs of improvement and in determining the influence of soil and cover factors on runoff.

For forest-influences research, aerial photographs are used to identify certain topographic and cover features which are considered criteria for the selection of watersheds to be put under study.

Forest-economics and forest-products research have need for maps and aerial photographs in studies involving land and timber utilization. The project in this group making the greatest use of aerial photographs is the Forest Survey. This survey includes an inventory of all forest land in the United States to determine the area and condition of such land, the volume and quality of standing timber, ownership, annual growth of new timber crops, annual depletion of timber by cutting and destructive agents such as insects, and the potential requirements for a variety of wood products obtained from the forests. In view of the wide use of aerial photographs in this work, the technique will be discussed in some detail.

### FOREST SURVEY

Aerial photographs, often called "airphotos," are used by the Forest Survey in four important ways. They are aids in classifying land into cover types, in measuring the area in each classification, and in preparing forest type maps. They substitute for maps in locating field plots. Although over-all volume estimates of timber tracts have been made entirely from aerial photographs, the Forest Survey, requiring greater volume sampling accuracy, has not yet adopted this technique exclusively. It also has need for detailed information such as volume by species and diameter class, cull percentage, and growth measurements, not readily obtainable from photographs. This information can be had only by observations or measurements made on the ground.

The procedures used by the Forest Survey, as well as the nature of the data taken from airphotos, vary considerably among the forest experiment stations which carry on the project in the field. The procedure at the Central States Forest Experiment Station, Columbus, Ohio, will serve as an example. This station determines the forest area by major classifications, and selects a number of sample plots to be measured in the field for volume and growth information. The three major steps are (1) determination of the forest and nonforest area, (2) measurement of the area in each major forest classification, and (3) selection of the sample plots to be measured on the ground.

The measurement of forest and nonforest area is based on a plot tally made on single airphotos. A templet having a predetermined number of 1-acre circular plots, evenly distributed over the average net area of the photographs, is oriented over the fiducial points of each print. The plot centers falling on forest and on nonforest areas are separately counted. This plot count furnishes a proportion which is then applied to the land area of a county or state as shown in "Areas of the United States, 1940," by the U. S. Bureau of the Census, to determine the acreage of forest land. Men can easily be trained to make this forest-nonforest classification. Because the cost is low—less than one-fourth cent per plot examined—2,000 to 3,000 plots in a single county can be classified without great expense.

Then the forest area is studied more intensively by examining 1-acre circular plots under stereoscope. These have already been selected at the time of the forest-nonforest classification, when the centers were pin-pricked on the photograph through holes in the templet, circled, and numbered for easy identification. The plots are classified into three stand-size classes and three forest sites. The stand-size classes are defined as follows:

Saw timber—stands of trees averaging 1,500 board feet or more of net volume per acre.

Pole timber—stands of trees averaging less than 1,500 board feet of net volume per acre, but with more than 30 trees per acre that are 5 inches or more in diameter at breast height.

Seedling-sapling—stands of trees not qualifying as either saw timber or pole timber.

The site classifications are:

Upland dry site—ridge tops; upper three-fourths of the southerly facing slopes; upper one-fourth of the northerly facing slopes.

Upland moist site—coves, ravines; lower one-fourth of the southerly facing slopes; lower three-fourths of the northerly facing slopes.

Bottomland site—alluvial bottoms and low benches.

Plots are classified into stand-size classes by means of certain measurements made on airphotos. These are (1) the average total height of dominant trees, (2) the average crown diameter of the dominant trees, and (3) the proportion of the ground area covered by crowns of the dominant trees. Approximate total plot volume must be estimated in order to classify plots into stand-size classes. For this purpose, an aerial volume table has been constructed which correlates the foregoing measurements with plot volumes measured on the ground. The photo-interpreter uses these tables to make the rough estimate of plot volumes in order to separate saw-timber stands from other stands.

Site classification is based entirely on variations in topography that can be recognized easily under stereoscope. Sites thus classified are helpful in plot classification, because timber volume is closely correlated with them. In other methods of survey, species are often used as a basis for site classification, but they are difficult to identify on panchromatic photographs.

At the time of this stereo classification, small plot record cards (Figure 1) are filled out and grouped according to stand-size and site classifications. The proportion of the total number of cards falling in a given stand-size and site classification, when multiplied by the total forest area in a given group of counties, gives the estimated area for that classification. Because the total cost of making this estimate is 20 to 25 cents per plot, only a limited sample is selected from the total number classified as forest plots. Ordinarily 200 to 400 are examined per county.

A proportion of the plots in each stereo classification is selected for field measurement. Because the Forest Survey is primarily interested in timber volume, the saw-timber stands sampled most intensively are those on bottomland sites, which ordinarily have the largest volume per acre. Stand-size and site classes with little volume and small variation are sampled most lightly. Each plot selected for field sampling is numbered, and its center is indicated precisely

| Photo # BA-3-114 | | | Plot # 1 | | Field Plot # | | | |
|---|---|---|---|---|---|---|---|---|
| Saw X Timber 2 | Poles 3 | Seeds- Saps 4 | Vol. | No Vol. | Photo Site | U1 | L2 X | B 3 C |
| Winter | C | CH | H | Nonfor. | | | | |
| Av. Ht. Dom. Tree | Av. Crown Width Dom. Tree 0-9 | 10-14 | 15-19 | 20-24 | 25-29 | 30+ | %Crown Density | |
| 0 - 19' | | | | | | | 0- 9 | |
| 20 - 29' | | | | | | | 10-19 | |
| 30 - 39' | | | | | | | 20-29 | |
| 40 - 49' | | | | | | | 30-39 | |
| 50 - 59' | | | | | | | 40-49 | |
| 60 - 69' | | | X – | 3000 | | | 50-59 | |
| 70 - 79' | | | | | | | 60-69 | |
| 80 - 89' | | | | | | | 70-79 | X |
| 90 - 99' | | | | | | | 80-89 | |
| 100-109' | | | | | | | 90-99 | |
| 110-119' | | | | | | | P.I. | |

FIG. 1. Plot record card for a saw-timber stand on a moist site. Trees average 65 feet in total height and 17 feet average crown diameter. The stand is 75 per cent stocked and averages 3000 board feet per acre.

by a circle on the photograph. The approximate location of each plot is also marked on a county road map to help field crews in finding it. By a similar method, a smaller sample of nonforest plots is selected in order to check the proportion of nonforest areas reverting to forest.

A list of the plots to be field-examined, together with the stereo-pairs of airphotos on which they are located and the county road map, is forwarded to a field crew. The crew establishes a 0.2-acre circular plot on the ground, exactly concentric with the 1-acre circular plot on the photographs, and makes prescribed observations and measurements regarding the trees on the plot. These field data include tree species, diameter, number of logs, percentage of cull, rate of growth, and quality of logs. The cost of these field plot samples averages $15 to $20.

Space does not permit a detailed discussion of field procedure in plot measurement or office methods of compiling the data. The entire survey design, however, is pointed toward making major use of aerial photographs so as to reduce the number of expensive field plots and yet obtain a satisfactory survey. In Missouri, for example, 100,000 plots were examined on photographs to determine forest area, 25,000 were stereo-examined to determine the proportion of the forest area in each major land classification, and only 2,000 plots were examined on the ground to get timber volume and growth information.

In the survey procedure described, only a generalized forest type map is contemplated. Detailed maps can be made from photos, but the cost would probably be several times the funds available.

## PHOTO-INTERPRETING AIDS

A forester who is also an experienced photo-interpreter can, by examination of photographs under stereoscope and without measurements of any kind, roughly segregate stands into the size classes defined above. But this classification is far more reliable if based on a few simple photogrammetric measurements. Chief among these is the measurement of the average total height of the dominant trees.

Total tree height is measured by means of a parallax wedge (Figure 2) printed on glass plate or film. When the wedge is properly oriented over a pair of photographs and the whole viewed stereoscopically, the converging lines of the wedge will appear to blend into one at the ground level of the stereoscope model. These blended lines slope steeply upward until they finally separate

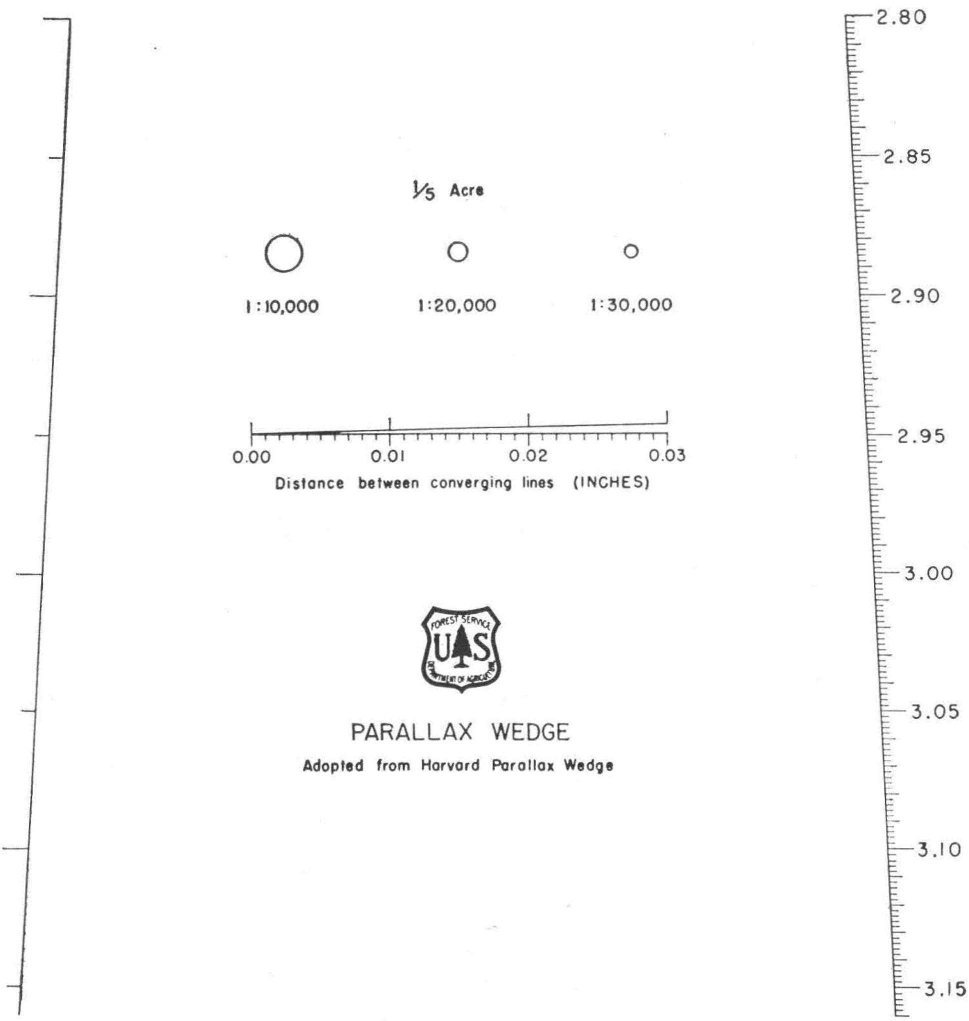


FIG. 2. Parallax wedge for measuring tree heights.

TABLE 1.—Change in elevation per thousandth of an inch of parallax difference by airbase and photo scale

| Airbase (Inches) | Photo scale[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 18.5 | 19.0 | 19.5 | 20.0 | 20.5 | 21.0 | 21.5 | 22.0 | 22.5 |
| | | | | | *Feet* | | | | |
| 2.2 | 5.7 | 5.9 | 6.0 | 6.2 | 6.3 | 6.5 | 6.6 | 6.8 | 7.0 |
| 2.3 | 5.5 | 5.6 | 5.7 | 5.9 | 6.0 | 6.2 | 6.3 | 6.5 | 6.7 |
| 2.4 | 5.3 | 5.4 | 5.5 | 5.7 | 5.8 | 6.0 | 6.1 | 6.3 | 6.4 |
| 2.5 | 5.1 | 5.2 | 5.3 | 5.5 | 5.6 | 5.7 | 5.8 | 6.0 | 6.2 |
| 2.6 | 4.8 | 5.0 | 5.1 | 5.3 | 5.4 | 5.5 | 5.6 | 5.8 | 5.9 |
| 2.7 | 4.6 | 4.8 | 4.9 | 5.1 | 5.2 | 5.3 | 5.4 | 5.6 | 5.7 |
| 2.8 | 4.5 | 4.6 | 4.7 | 4.9 | 5.0 | 5.1 | 5.2 | 5.4 | 5.5 |
| 2.9 | 4.3 | 4.4 | 4.5 | 4.8 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 |
| 3.0 | 4.2 | 4.3 | 4.4 | 4.6 | 4.7 | 4.8 | 4.9 | 5.0 | 5.1 |
| 3.1 | 4.0 | 4.1 | 4.2 | 4.4 | 4.6 | 4.6 | 4.7 | 4.8 | 4.9 |
| 3.2 | 3.9 | 4.0 | 4.1 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 |
| 3.3 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 |
| 3.4 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 |
| 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 |
| 3.6 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 |
| 3.7 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 |
| 3.8 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 |
| 3.9 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 |
| 4.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.8 |
| 4.1 | 3.1 | 3.2 | 3.3 | 3.4 | 3.4 | 3.5 | 3.6 | 3.7 | 3.7 |
| 4.2 | 3.0 | 3.1 | 3.2 | 3.3 | 3.3 | 3.4 | 3.5 | 3.6 | 3.6 |
| 4.3 | 3.0 | 3.1 | 3.2 | 3.3 | 3.3 | 3.4 | 3.5 | 3.6 | 3.6 |

[1] A reciprocal expressed in thousands of feet, i.e. 1/18,500, 1/19,000, etc.

some distance above the surface of the model. The parallax difference between the ground level and the top of a given tree is read on the graduated sloping line. Tree height in feet is determined by a simple formula or by use of a conversion table (Table 1). Using aerial photographs at a scale of 1:20,000 and this wedge, a skilled photo-interpreter can, in two cases out of three, measure tree heights with an error of less than ±10 feet.

Under ideal conditions, equal accuracy could probably be obtained by use of the shadow-measuring technique, but in the Central States Forest Survey men found tree shadows difficult to measure in wooded, hilly areas, and often too short for accurate results. Therefore, they prefer the parallax wedge, which can be dropped down through a hole in the crown canopy, and is not seriously affected by steepness of slope or time of photography.

Photogrammetrists frequently ask why we do not use one of the more complicated and more accurate floating-dot-type parallax-measuring devices. On 1:20,000 photographs, the heights obtained by the floating dots and the finely graduated micrometer scale may be no more accurate in reality than those obtained with a parallax wedge. In the first case, the photo-interpreter must adjust the floating dots to the ground line and to the tip of the tree, and in the second, he must read the line graduations opposite the ground line and the tip of the tree. In either case the limiting factor is the keenness of the photo-interpreter's stereoscopic perception. Among the reasons for preferring the parallax wedge instead of the floating dots are its simplicity in use and speed of operation, while giving results sufficiently accurate for survey purposes.

Another measurement necessary in classifying forest stands is the diameter of tree crown. This measurement is made with the dot-type crown-diameter scale (Figure 3). This scale is printed on transparent film, and consists of a series of dots varying in diameter by 0.0025 inch. In using this scale, the photo interpreter selects the dot equal in size to the photo-image of the average tree crown. The actual tree crown diameter is then determined from a conversion table. Crown diameters are usually measured on the dominant trees of the sample plot. Interpreters can be expected to classify crown diameters consistently by 5-foot classes. Obviously, this measurement is most dependable where stands are even-aged and crowns are more nearly of one size.

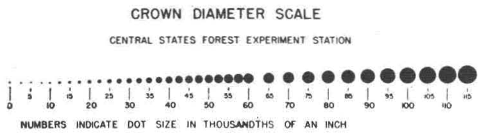


FIG. 3. Dot-type crown diameter scale.

The third useful tree or stand measurement is the proportion of ground surface covered by tree crowns of the dominant stand. This measurement is made for each 1-acre sample plot by comparing the photo image of the plot viewed in stereoscope with a crown density scale. (Figure 4). This scale consists of columns of squares containing black dots covering 5 to 95 per cent of the area of the square. Dots in the two outside columns are distributed randomly while those in the center column are mechanically spaced. The area of each square should equal 1 acre at the scale of the photographs used. Although care must be taken to compare only tree crowns—and not shadows—with the scale, the variation of this reading among interpreters seldom exceeds 10 per cent.

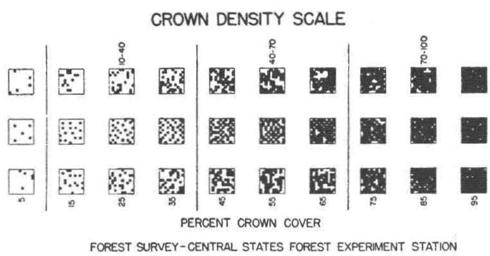


FIG. 4. Crown density scale.

These three measurements can be correlated with gross board-foot or cubic-foot per-acre volumes obtained from measurements made on field plots. The resulting table will aid in plot classification based on volume per acre. The example shown here (Table 2) was prepared from Illinois survey data. The data represent the mean gross volume of many field plots having the same photogrammetric measurements. Field observations or measurements are necessary to determine cull or defect percentages by species. Although volume tables needed for commercial aerial cruising have not yet been made at the Central States Station, tables patterned after the one illustrated probably will prove to be a practical approach.

One of the problems, confronting most foresters who use airphotos, is the need for a rapid method of determining scale. Few are trained photogrammetrists, and even the simplest procedure or formula for scale determination, may prove to be baffling or time consuming. In most of the Central States region, the terrain is relatively level, and roads and fences usually follow section

TABLE 2.—Gross volume per acre of stands in four crown-diameter classes by total tree height and crown cover[1]

| Tree height (Feet) | Crown Cover (Per cent) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 |
| | | | | | *Hundred board feet* | | | | | |
| **10–14-Foot Crown Diameter** | | | | | | | | | | |
| 45 | | | | | | | | | | 1 |
| 50 | | | | | | | | | 2 | 6 |
| 55 | | | | | 2 | 5 | 7 | 8 | 10 | 14 |
| 60 | | 1 | 3 | 7 | 10 | 12 | 14 | 15 | 17 | 21 |
| 65 | 2 | 7 | 12 | 14 | 17 | 19 | 21 | 23 | 25 | 29 |
| 70 | 5 | 13 | 17 | 21 | 24 | 27 | 29 | 30 | 32 | 37 |
| 75 | 9 | 21 | 25 | 29 | 32 | 35 | 37 | 38 | 40 | 45 |
| 80 | 13 | 27 | 32 | 36 | 38 | 42 | 43 | 45 | 48 | 52 |
| 85 | 16 | 35 | 40 | 44 | 47 | 49 | 51 | 53 | 56 | 61 |
| **15–19-Foot Crown Diameter** | | | | | | | | | | |
| 40 | | | | | | | | | 1 | 4 |
| 45 | | | | | 1 | 3 | 5 | 6 | 8 | 12 |
| 50 | | | 2 | 6 | 9 | 11 | 13 | 14 | 16 | 19 |
| 55 | 2 | 7 | 11 | 14 | 17 | 19 | 21 | 22 | 24 | 28 |
| 60 | 6 | 14 | 17 | 20 | 24 | 27 | 28 | 30 | 32 | 37 |
| 65 | 9 | 21 | 26 | 29 | 33 | 36 | 37 | 38 | 41 | 46 |
| 70 | 13 | 28 | 33 | 37 | 40 | 43 | 45 | 46 | 48 | 53 |
| 75 | 17 | 36 | 41 | 45 | 48 | 51 | 53 | 55 | 57 | 62 |
| 80 | 20 | 43 | 48 | 52 | 55 | 58 | 61 | 63 | 65 | 70 |
| 85 | 24 | 51 | 56 | 61 | 64 | 67 | 69 | 71 | 73 | 79 |
| 90 | 28 | 60 | 65 | 68 | 73 | 76 | 78 | 80 | 84 | 92 |
| 95 | 33 | 67 | 72 | 77 | 82 | 86 | 89 | 92 | 95 | 103 |
| 100 | 36 | 77 | 82 | 88 | 93 | 98 | 101 | 104 | 108 | 118 |
| **20–24-Foot Crown Diameter** | | | | | | | | | | |
| 30 | | | | | | | | | | 4 |
| 35 | | | | | | 2 | 4 | 6 | 8 | 11 |
| 40 | | | 2 | 5 | 8 | 11 | 12 | 13 | 15 | 19 |
| 45 | 2 | 6 | 10 | 13 | 16 | 18 | 20 | 22 | 24 | 27 |
| 50 | 5 | 13 | 17 | 20 | 24 | 27 | 28 | 30 | 32 | 37 |
| 55 | 9 | 21 | 26 | 29 | 32 | 36 | 37 | 39 | 41 | 46 |
| 60 | 13 | 28 | 33 | 38 | 41 | 43 | 45 | 47 | 49 | 54 |
| 65 | 18 | 38 | 43 | 47 | 49 | 53 | 54 | 57 | 58 | 64 |
| 70 | 21 | 46 | 50 | 54 | 58 | 61 | 63 | 65 | 68 | 73 |
| 75 | 25 | 53 | 58 | 64 | 67 | 70 | 72 | 74 | 77 | 83 |
| 80 | 29 | 62 | 66 | 72 | 76 | 79 | 81 | 83 | 87 | 94 |
| 85 | 33 | 70 | 76 | 81 | 85 | 90 | 93 | 95 | 99 | 108 |
| 90 | 38 | 80 | 86 | 93 | 98 | 102 | 106 | 108 | 114 | 125 |
| 95 | 42 | 90 | 97 | 105 | 110 | 117 | 122 | 125 | 133 | 148 |
| 100 | 49 | 101 | 110 | 120 | 129 | 136 | 141 | 150 | 158 | 179 |
| 105 | 60 | 117 | 129 | 140 | 152 | 163 | 172 | 180 | 191 | 217 |
| 110 | 65 | 137 | 152 | 170 | 188 | 200 | 209 | 218 | 231 | 270 |
| 115 | 80 | 163 | 188 | 205 | 228 | 241 | 260 | 270 | 295 | 340 |

[1] Based on Illinois data. Compiled from photo measurements of tree height, crown diameter, and crown cover; and from field estimates of volume.

TABLE 2.—(*Continued*)

| Tree height (Feet) | Crown cover (Per cent) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 |
| | *Hundred board feet* | | | | | | | | | |
| | 25–29-Foot Crown Diameter | | | | | | | | | |
| 30 | | | | | 1 | 3 | 5 | 7 | 8 | 13 |
| 35 | | | 3 | 7 | 9 | 12 | 13 | 14 | 17 | 20 |
| 40 | 2 | 7 | 11 | 14 | 17 | 19 | 21 | 23 | 25 | 29 |
| 45 | 7 | 15 | 18 | 22 | 26 | 28 | 29 | 32 | 34 | 38 |
| 50 | 10 | 23 | 27 | 31 | 35 | 37 | 38 | 40 | 43 | 47 |
| 55 | 14 | 32 | 36 | 40 | 43 | 46 | 48 | 49 | 51 | 57 |
| 60 | 19 | 40 | 45 | 48 | 52 | 54 | 57 | 58 | 61 | 66 |
| 65 | 23 | 48 | 52 | 57 | 61 | 64 | 66 | 68 | 70 | 77 |
| 70 | 27 | 56 | 61 | 66 | 70 | 72 | 75 | 77 | 80 | 88 |
| 75 | 31 | 65 | 70 | 75 | 80 | 83 | 86 | 89 | 93 | 100 |
| 80 | 35 | 73 | 79 | 85 | 90 | 95 | 98 | 100 | 105 | 115 |
| 85 | 40 | 83 | 91 | 98 | 102 | 108 | 111 | 115 | 120 | 133 |
| 90 | 45 | 95 | 102 | 110 | 117 | 124 | 128 | 134 | 140 | 158 |
| 95 | 51 | 107 | 116 | 126 | 136 | 145 | 152 | 158 | 168 | 191 |
| 100 | 59 | 124 | 137 | 152 | 164 | 178 | 187 | 192 | 207 | 232 |
| 105 | 69 | 146 | 163 | 186 | 199 | 212 | 222 | 232 | 250 | 295 |
| 110 | 82 | 178 | 199 | 220 | 242 | 266 | 287 | 300 | 325 | 370 |
| 115 | 100 | 216 | 242 | 280 | 310 | 340 | 355 | 370 | 385 | 435 |
| 120 | 122 | 270 | 320 | 360 | 380 | 410 | 425 | 440 | 470 | 505 |

and quarter-section lines. Measured ground distances are therefore readily available, and the only unknown is photograph distance. The aerial photo scale (Figure 5) is designed to convert photograph distance to a representative fraction (photo scale). To determine the representative fraction of any given photograph, the zero of the scale line is placed over one section line, and the graduation nearest the next section line is noted. If this is 20 the representative fraction is 1:20,000. The shortest distance between parallel section lines must be used. If desired, the representative fraction can be determined by the distances between fences on "forty" lines, using the portion of the scale based on $\frac{1}{4}$-mile distances. The aerial photo scale is not only simple to use, but determines empirically the correct scale for lines on any part of the photograph.

Another problem that confronts foresters attempting to use aerial photo-

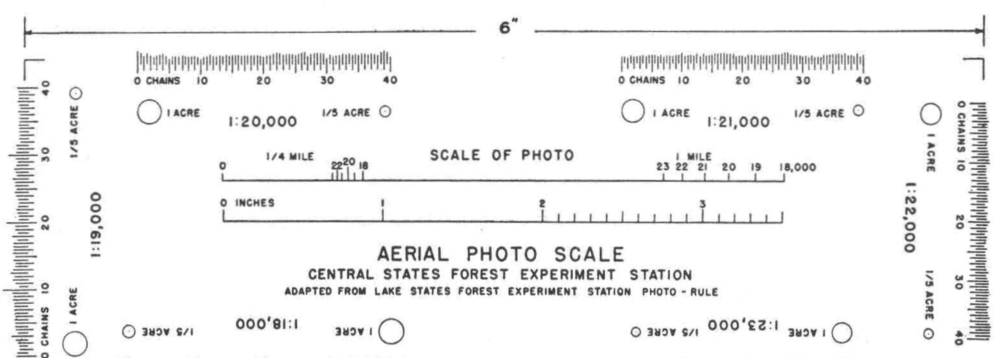


FIG. 5. Aerial photo scale.

graphs is the lack of new flights at a scale suitable for the measurement of forest stands. Some of the National and State Forests have been photographed for land classification purposes at 1:20,000 or even 1:15,000 scale. More often the flight was made for mapping purposes at 1:26,000 to 1:50,000 scale. Suitable though such photographs are for topographic mapping, the scale is not large enough for accurate measurements of forest trees and stands. Foresters should learn to use small-scale photographs for maps, medium-scale photographs for general and reconnaissance-type surveys, and either strip or pin-point photographs at much larger scale for detailed stand measurements of selected sample plots. A system closely paralleling this has been successfully employed for years on highway, airport, and other engineering projects.

## CONCLUSION

Aerial photographs are being used more and more in forestry work, both administrative and research. At least a working knowledge of techniques of interpreting them will be desired by most foresters to help achieve greater effectiveness on the job.

# AERIAL PHOTOGRAPHS AND THE SOIL CONSERVATION SERVICE

*Edward W. Magruder, Civil Engineer, Division of Cartography, Soil Conservation Service, U. S. Department of Agriculture, Beltsville, Maryland*

WHEN Dr. H. H. Bennett, the world's greatest living exponent of soil conservation, finally succeeded in his crusade for the passage of some sort of government conservation measure and the Soil Conservation Act of 1935 was enacted by Congress, it is probable that aerial photography was the furthest from his mind. It is very doubtful that he realized the enormity of the boost he was about to give to the pigmy which was to grow into the giant that aerial photography has become. In 1934–35, a few of the present day companies were in existence together with a number of smaller aerial photographers, and together they were putting out photographs and making small uncontrolled mosaics, but there was no incentive to put any great amount of investment, either in time or money into the development of better equipment.

Plotting machines were available but were not being used to any great extent. Considerable mosaic work had been done, but no large scale mapping, using single lens photography, had been attempted until in 1935, after the passage of the above mentioned act. In that year the Soil Conservation Service of the Department of Agriculture advertised for and awarded contracts for aerial photography of 79 small demonstration areas, as they were then called, totaling 5,273 square miles. The largest of these areas was 129 square miles and the smallest 27 square miles. The photographs were to be flown at a scale of 1:15,840, the negatives were to be 7″×9″, and the camera was to be single lens. This photography cost the Soil Conservation Service approximately $14.00 per square mile.

The quality of the photographs was not too good, but the contractors, realizing that here was the beginning of a better era for them, began striving to improve their product, and have thus achieved today's excellent results.