THE RELIEF DISPLACEMENT FACTOR IN FOREST AREA ESTIMATES BY DOT TEMPLETS ON AERIAL PHOTOGRAPHS

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INTRODUCTION

FORESTERS can often speed their estimates of forest or other land-class areas by estimating directly from vertical aerial photographs. These photos are increasingly useful. They are frequently used in surveys by transferring information obtained from photos to maps, and determining type areas by planimetering or other map-estimating methods. On extensive surveys, however, or when quick estimates are desired on intensive surveys, considerable time and cost savings are possible by estimating directly from photos. Even when transfer of types from photos to base maps is part of a survey procedure, there may be an advantage in making direct estimates of area. This may be true when the scale of the base map is too small to allow presentation of all small type areas readily identified on the photos, or when costs for detailed projection of all type areas onto a large-scale base map are not justified.

Dot templets made from transparent material provide one of the easiest and fastest methods for area estimation from aerial photographs. This method, or allied methods of area estimation—such as counting squares, or using proportional lengths-of-lines—has now largely replaced the use of the planimeter for area estimation from maps. Many technicians are now using dot templets, or templets containing squares, for similar computations from aerial photos. Incidentally, the potentialities and limitations of the dot-templet method generally apply to the use of square counts or the use of proportional lengths-of-lines for making area estimates from aerial photos.

SCOPE

The dot-templet method is easily and widely used, but certain assumptions necessary to its use, and certain limitations of photography operate to introduce inaccuracies in forest-area estimates. One of the greatest difficulties in making accurate estimates lies in the distortions of images on vertical photographs made over rough terrain. These distortions, called relief displacements, may contribute serious errors in area estimates. While this paper briefly considers errors from another important source—variations in average scale of individual photos—its chief concern is with relief displacement. It discusses the basic assumptions, potentialities, and limitations of the dot-templet method for estimating areas directly from vertical photographs. It also describes what one test of the method's accuracy over rough terrain revealed when certain precautions were taken to minimize errors from relief displacement.

BASIC ASSUMPTIONS

Alternative assumptions usually made in using dot templets are: (1) That each dot of a systematic pattern on a templet represents a constant unit of land area when overlaid on a photograph; (2) that each dot of either a systematic or random pattern on a templet is a pinpoint sample and represents only a proportion, not any predetermined amount, of the total area sampled. Procedure under the first assumption is best illustrated by use of templets on forest type maps when a 100 per cent count of squares is made, or when a dot centered in each square represents a constant unit of acreage. When this method is used directly on aerial photos, it may be advisable to make separate templets for each average scale of photography. Separate templets simplify computations since selection of appropriate templet patterns assures that each dot will represent even units of acreage. If a standard pattern of dot spacings was used for all photo scales, each dot would often represent fractional units. Direct area estimates from photos under the first assumption is particularly suitable for use on intensive surveys of small areas when photography is over flat terrain, and when a fair amount of ground control has been plotted on the photos. On extensive surveys, however, and where photography is over rough topography, it is generally advisable to make the second assumption that each dot is merely a sample. The computations of acreage under this procedure are obtained by simple percentages if the official total acreage in the area to be surveyed is known. Thus $Af=(nf/N)A$; where Af is the acreage of forest or other specific land class desired, A is the total acreage in the survey area, nf is the number of dots tallied as falling in the specific land class, and N is the total number of dots falling within the boundary of the survey area.

LIMITATIONS OF PHOTOGRAPHY

When considering the use of the dot-templet method on aerial photos, certain limitations of photography must be kept in mind. These limitations may affect the suitability or adaptability of the method to a particular job. (1) The small contact scale of most aerial photography available (1:20,000 or smaller) limits positive interpretation of many forest types. (2) Some variations in scale within a single photo are caused by tip and tilt of the plane or camera from the vertical, at the time of expossre. In other words, so-called "vertical" photographs are usually not taken precisely at right angles to the earth's surface, although the deviation from the vertical may be small. (3) Appreciable variations in the average scale of individual photos in a project may be caused by differences in flight altitude above the terrain or in ground elevation. These variations are usually most noticeable between photos in different flight lines. The scale ratio of photography, of course, is determined by focal length of lens divided by flight altitude above the ground. For example, standard 1:20,000 scale photography is usually obtained with an $8\frac{1}{4}$ inch (.6875) lens from 13,750 feet above the ground. For standard photography in rough country, an average datum plane (mean ground elevation) is usually estimated. Flight altitude is maintained above that datum plane. If the topography is quite variable, several datum planes may be estimated for different portions of the photo project. Flight lines are planned accordingly to produce approximately the same average scale of photography on all flight lines. (4) Differences in scale between various parts of a single photo taken over rough terrain are caused by relief displacement.

The limitation of average photo scale upon interpretation of detail is an important consideration, but may be ignored if only broad land classes are to be interpreted. Most commercial forest land, for example, may be readily identified by stereoscopic study on photo scales of 1:20,000, or even smaller. On the other hand, errors in interpretation of detailed forest types may be serious when small-scale photos are used. Thus judicious consideration of scale limitation is important when any application of the dot-templet method is proposed for use in combination with detailed type interpretation.

The effects of tilt upon variations in photo scale may be ignored on most Forest Survey projects, provided dot samples are confined within the effective area of each photo—as described later under "Normal Steps for Applying Method." Scale distortions from tilt are negligible on standard vertical photo projects except on the extreme edges of photographs.

The most important limitations of photography upon application of the dot-templet method result from average scale variations between photos or scale variations in single photos due to relief displacement. Area distortions from these sources may be ignored only on a carefully executed photo project over flat country. Some procedures are suggested later for minimizing errors due to scale distortions over rough topography; at this point the scale distortions on photo indexes and mosaics are briefly considered.

Either photo indexes or mosaics of flat country may be used to advantage in in the dot-templet method. Yet a brief study of photo indexes, or an uncontrolled mosaic of rough country, reveals scale differences and area distortions which affect the accuracy of any area determinations made directly from such photo compilations. The most obvious discrepancies in scale are apparent on photo indexes.

These indexes are usually photographic reductions of laydowns of original contact photographs which have been overlapped by approximate matchings of photo detail common to several photographs. Since only the overlapped edges of contact photos are visible, the reproduction exhibits the most distorted parts of photo detail. Some details of the terrain are masked by overlaps, and other details are duplicated on different portions of several exposed photos. Uncontrolled mosaics of good quality, where the central portions of contact photos have been used in the compilation, exhibit less hidden or duplicated detail, but contain area distortions due to relief displacement. Despite these objections, both photo indexes and uncontrolled mosaics are useful mediums for quick application of the dot-templet method, if accuracy objectives are not too rigidly defined (when errors of 10 per cent or more in area estimates are tolerable). And if controlled mosaics are available, now a rare case on Forest Survey projects, the method may be applied to obtain rapid area estimates with a high degree of accuracy (when tolerable errors are within 1 or 2 per cent). Controlled mosaics have smaller scale distortions than any other photo compilations.

Whenever either photo indexes or mosaics are available and considered for application of the dot-templet method, it may be appropriate to consider the alternative of using contact prints. Frequently contact photos are readily available, and the extra time required for use of the individual photos may be more than compensated by gains in accuracy. The dot-templet method is not a time-consuming procedure in any event. An advantage of using contact photos is that details are sharper than in indexes or reproduced mosaics, since they are contacts from original negatives, and the scale is generally larger. Stereoscopic study may also be used with contact photos to aid interpretation. Another prime advantage of using contact photos is that errors due to relief displacement may be minimized, as described later under "Scale distortions and relief displacement."

NORMAL STEPS FOR APPLYING METHOD

For extensive surveys to sample systematically areas the size of counties, or large working circles, and where several hundred or more photos may be involved in the coverage, the following steps may be followed:

(1) The minimum number of items of sample (dots) to be taken within the survey unit is predetermined. This number is based upon the maximum sampling error assumed to be tolerable for area estimates of the desired types or land classes. It also hinges upon an assumption of the approximate acreage proportion

of the entire area made up of those land classes. By using these assumed values, the required number of dots can be calculated by a simple statistical formula,

$$N = \frac{(100 - P)38,400}{P(AE)^2},$$

where N = number of dots,
P = assumed per cent of all land in survey unit that is in land class for which area estimates are desired,
AE = allowable error in per cent of P (excluding the possibility of a 1 in 20 chance in sampling).

For example: If 70 per cent is the assumed proportion of forest land in a survey unit, and if it is important that the estimated proportion be correct (excluding the possibility of a 1 in 20 chance) within 2 per cent of the 70 per cent—by substituting in the formula—

$$N = \frac{30(38,400)}{70 \times 4} = 4,128 \text{ dots required.}$$

(2) The approximate number of photos to be used is determined. In the usual case, where all photos in a stereoscopic coverage are to be used, this will be the total number of photos with centers falling within the survey unit. This number can be determined by referring briefly to a photo index or line index of the photo project.

(3) An appropriate templet pattern is chosen and etched on transparent material. For this purpose, thin, clear cellulose acetate is ideal. The number of dots required divided by the number of sample photos will, of course, indicate the number of dots to use in the templet. When this quotient is not an even whole number, the next largest whole number should be used for number of dots in the pattern. This insures that at least the minimum number of items of sample will be obtained; and the introduction of an extra dot into a templet pattern increases the time required for tallying dots only slightly. The dots may be spaced approximately uniformly in any arbitrary manner which will permit the pattern to be centered over the central portion of a photo. If the procedure aims to sample every photo in a stereoscopic coverage, there is a theoretical limit for placement of dots within a rectangular effective area of approximately 6.3 inches by 3.6 inches in the center of a photo. This theoretical consideration assumes the use of standard 9- by 9-inch photos and the maintenance of 60 per cent overlap of photos along the flight line and 30 per cent overlap of photos in adjacent flight lines. Such an effective area insures that no ground detail is sampled twice (on overlapping photos), if theoretical flight overlaps were maintained. Operational photography, however, cannot be maintained precisely at these standards, and over rough topography variations in overlap are considerable. Overlap between adjacent flights over rough topography may vary all the way from 5 per cent to 50 per cent on portions of standard photo projects. Therefore, to minimize chances for the samples taken on several photos to overlap on common areas of terrain, it is advisable to confine the templet pattern to an area no larger than approximately 4.5 inches by 2.5 inches. When such a pattern is centered over a photo so that the long axis of the pattern is perpendicular to the flight line, there would be no chance for duplication of sampling by adjacent photos unless the overlap exceeds 70 per cent in line of flight or exceeds 50 per cent between flights.

(4) The dot templet is overlaid on each photo in turn. It should be oriented in the same manner over each photo. One of the simplest methods of accomplishing this orientation is to etch index marks on the templet. These can be matched with the fiducial marks (or reference points) that appear in all photos (generally on the photo edges). If there be used a rectangular pattern, similar to that described above, the long axis of the pattern should be oriented perpendicular to the flight line. Figure 1 shows a dot templet overlaid properly on an aerial photo.

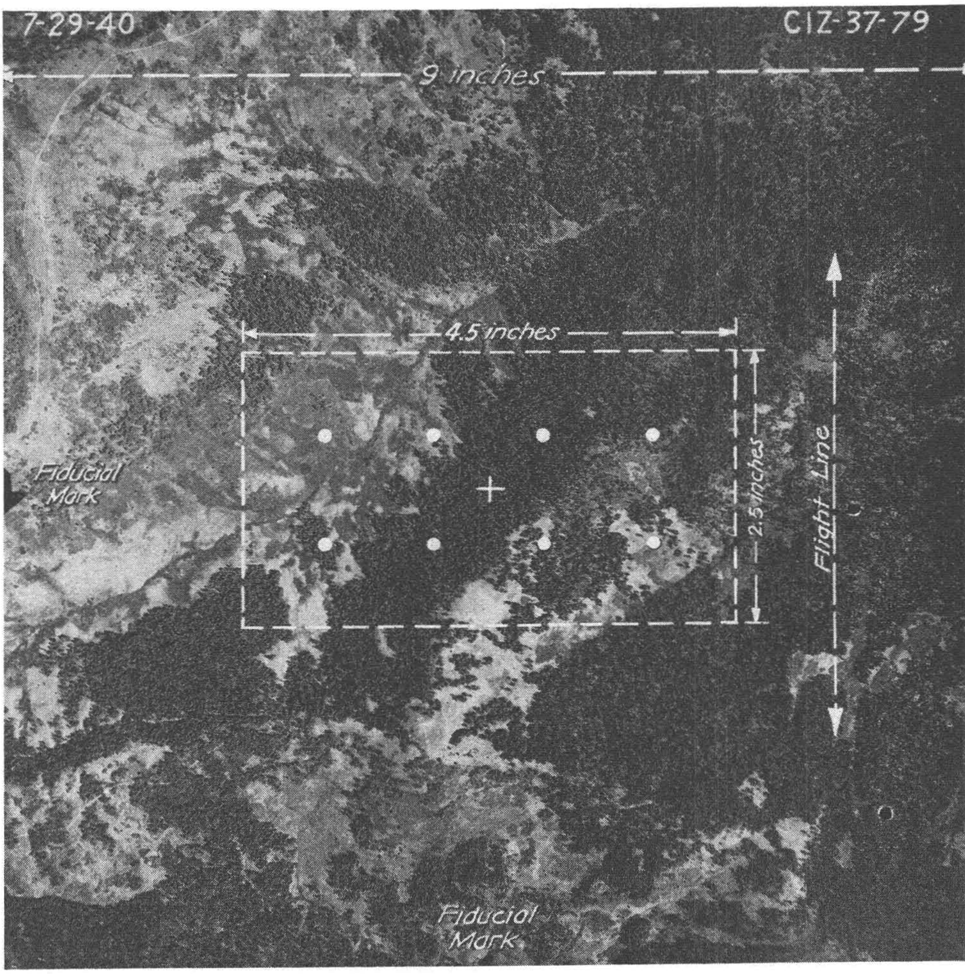


FIG. 1. Conventional aerial photo reduced from 1:20,000 scale, showing proper orientation of dot templet. The pattern illustrated provides eight samples per photo at locations indicated by dots. The photo center is indicated by a small cross. To avoid duplication in sampling, all dot samples normally should be confined within the rectangular area indicated by the broken lines.

(5) A tally is kept of the dots falling over any forest or other land class for which area estimates are desired. The ratio of all dots tallied in a particular category to the total of all dots falling within the survey project boundary gives the percentage of land in that category.

Whenever photography approaches the theoretical standard over flat topography, this procedure closely approximates a systematic sampling scheme by clusters of samples. The dot samples within all clusters then are equally spaced over ground detail. Intervals between clusters are also constant along flight lines, and between flight lines, although the constant interval may be different along flight lines than that between flight lines. No bias in area estimates, due to distribution of samples, is possible under these conditions.

MODIFICATIONS FOR NONSTANDARD PHOTOGRAPHY

The distribution of samples is modified whenever the photo coverage varies from the theoretical standard even over flat topography. Thus it is appropriate to consider the possibilities on a more typical operational photo project. In this project, differences in flight altitude, effects of windage, and variations in flying speed or direction cause variability in photo intervals, overlap, and skewing of flight lines, as well as variations in photo scale. The intervals between dot samples of ground detail within any individual cluster would be constants. Yet each different photo scale would have a different constant. Also the intervals between clusters would vary, being controlled by the differences in overlap and the skewing of flight lines. Actually these variations are small on the normal photo project, and are subject to random elements beyond any control by the surveyor. They can be considered logically as random and compensating modifications of a systematic sampling scheme whenever a sizable number of photos is to be used.

These same elements, however, might introduce significant bias into a sampling design for an intensive survey, where a small number of photos are used. For example, assume that the photos are from two flight lines only in what, presumably, is a standard photo project flown at 1:20,000 scale. The surveyor assumes in planning the sampling design that both flights are 1:20,000 scale; but the true situation is that only one flight is at that scale—the other being at a scale of 1:15,840. This is an extreme example of actual variation in average scale of photography (approximately 3 inches to 1 mile and 4 inches to 1 mile). It is conceivable if we assume that an $8\frac{1}{4}$ inch focal length of lens has been used with different flight altitudes for the two flights—approximately 14,000 feet and 11,000 feet above the ground, respectively. If both flights had normal photo overlaps, the equivalent ground distance between photo centers would be slightly over 1.1 miles at the 1:20,000 scale and 0.9 of a mile at 1:15,840 scale. Thus more dot samples would be obtained per unit of distance along the flight line at the 1:15,840 scale, and this greater intensity of sampling would bias the estimates in favor of the predominating type patterns along that flight line.

A careful preliminary inspection of photo indexes and photo overlaps would indicate whether variations in photography are likely to cause serious bias in a systematic dot-sampling method. If this promises to be the case, there are several courses which might be taken to avoid bias in sampling. One course, and the most time consuming, would be to discard the dot-templet method, delineate types on the photographs, and project them to common scale onto a base map. Another course is possible if the survey project can be subdivided easily into blocks for which official acreages are known, and if each block corresponds to a zone of approximately uniform photo coverage. A separate dot-templet pattern could be determined for each block to provide the same over-all intensity of sampling on the project. This procedure, however, would probably be an awkward solution to the problem. If the photography was of a poor standard with serious variations, a large amount of time would be required to define block boundaries and to compute reliable acreage figures for each block. Where good base maps are available, the most promising course might be to cover the base map of the survey unit with a dot pattern, and project photo detail at each dot position over that base. This projection could be accomplished with a planimetric or stereo plotter using topographic features visible on both base map and photos as control. The dots could then be tallied according to the type detail projected at each location. This course would also be more time consuming than the use of simple dot templets.

On extensive jobs, a survey unit might be covered by portions of several photo projects, in which case there is a possibility that different focal lengths of lenses may have been used for the several projects. The large majority of vertical photography, now available in the United States for Forest Survey purposes, has been taken with an $8\frac{1}{4}$-inch focal-length lens. However, photography by other focal lengths is available in some areas. For example, six-inch focal lengths are being used extensively. Insofar as photography over flat or gentle topography is concerned, the focal length will introduce no problems in use of the dot-templet method. But photography by short focal lengths over rough topography increases the scale distortions from relief displacement. And, regardless of focal length, relief displacement should usually be considered when photography is over mountainous terrain. Therefore, this problem merits some detailed discussion.

SCALE DISTORTIONS AND RELIEF DISPLACEMENT

One of the clearest explanations of relief displacement is given in Whitmore's *Elements of Photogrammetry*.[1] The following paragraph is quoted verbatim, and most of the material in four subseqsent paragraphs (including the illustration of relief displacement) is from that book (pp. 46–50):

"A vertical photograph has the general appearance of a map, but the conditions that must exist to make such a photograph an accurate map do not prevail in practical aerial photographic work. The only points that will be in their proper relative positions on an aerial photograph are the points on the datum plane, which is the horizontal plane selected as a reference level for computing the scale of the photograph. Objects that are higher than the datum plane and are not vertically beneath the camera will be located too far from the center of the resulting photograph. On the other hand, objects that are lower than the datum plane and are not vertically beneath the camera will be located too near the center of the resulting photograph. This characteristic of aerial photographs is called *relief displacement, or displacement of images because of relief*. Relief displacement follows definite geometrical laws and can be readily computed."

The equation for relief displacement is:

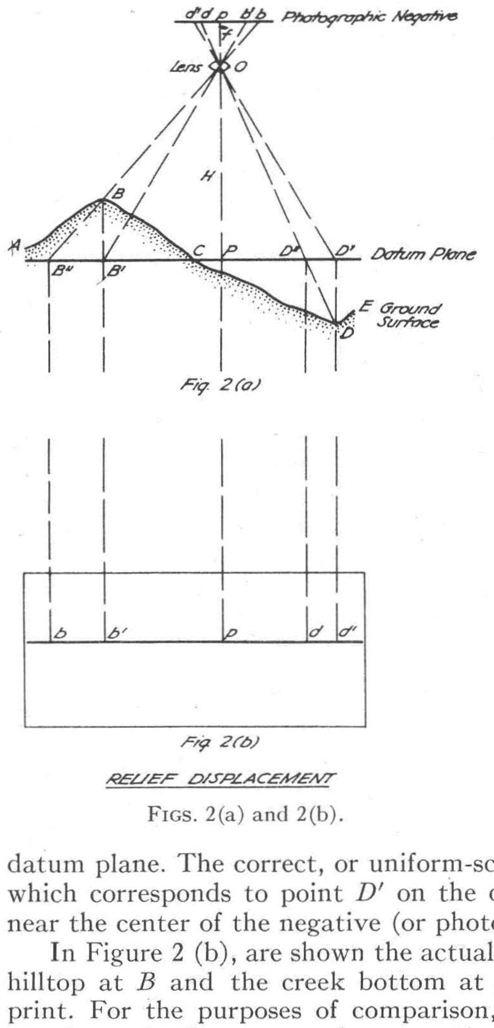
$$rd = hl/H$$

where rd = relief displacement of point on photo (in inches),
h = height of point above or below datum plane (in feet),
H = height of airplane above datum plane (in feet),
l = distance on photo from photo center to image of point under consideration (in inches).

Figure 2 shows a diagrammatic illustration (exaggerated) of the effect of relief displacement on an aerial photo. The line $ABCDE$, in Figure 2 (a), represents a section of the ground surface, which includes the top of a hill at B and a creek bottom at D. The datum plane $B''B'CPD''D'$ is at an elevation approximately midway between the extreme elevations of the ground surface. Vertically above point P and at a height H above the datum plane is the lens O

[1] Whitmore, George D. *Elements of Photogrammetry,* 136 pp. illus. International Textbook Co., Scranton, Pa. 1941.

of the camera; and at a height above the lens equal to the focal length f is the focal plane $d'dpb'b$, or the position of the film or negative. A point that lies in the datum plane and is vertically below the lens of camera is called the *plumb point;* and a point that lies in the plane of an untilted aerial photograph and is on a vertical line through the lens is called the *photo center* or *principal point* of the photo. The following discussion assumes the photography is untilted.



FIGS. 2(a) and 2(b).

A vertical line through the point B at the center of the hilltop intersects the datum plane at B'. If the horizontal scale on the negative (or photo print) were uniform for all elevations, point B and B' would have to coincide on the negative. However, point B actually appears on the negative at point b, which corresponds to point B'' on the datum plane; and if it were possible to see point B' on the negative, that point would appear at point b'. In other words, because point B is above the datum plane, its image b on the negative is too far from the photo center p of the negative, and the scale of the negative (or photo print) varies because of relief displacement.

In a similar manner, the point D, which is below the datum plane, appears on the negative at d. This position corresponds to point D'' on the datum plane. The correct, or uniform-scale position of D on the negative is d', which corresponds to point D' on the datum plane. Thus the image d is too near the center of the negative (or photo).

In Figure 2 (b), are shown the actual positions, b and d, of the images of the hilltop at B and the creek bottom at D, as they would appear on a photo print. For the purposes of comparison, the horizontal distances in view (b) are shown to the same scale as are the horizontal distances along the datum plane in view (a). The correct positions, b' and d', of B and D are also indicated in view (b), although they would not appear in an actual photograph.

The relationships described here are used to derive the equation previously given for relief displacement. Four important principles here are: (1) It is not necessary to consider whether a point on the ground is above or below the datum plane in order to determine the amount of relief displacement. (2) It is helpful to remember that the image is too near the photo center if the point on the ground is below the datum plane, and is too far from the photo center if the point on the ground is above the datum plane. (3) The amount of displacement is directly proportional to the elevation of a point above the datum plane and to the distance from the photo center to the image of the point. The amount of displacement is inversely proportional to flight altitude. (4) The displacement of images is always radially from the photo center.

MODIFICATIONS FOR ROUGH TOPOGRAPHY, WITH EXAMPLES

It is evident that innumerable variations in scale distortion from relief displacement occur on a single photograph of rough topography. Before discussing the effects of scale variation from this source upon application of the dot-templet method, it might be emphasized that the effects of relief displacement may be ignored whenever only one dot per templet is used. In this case, presumably, the dot is centered to fall over detail of terrain at the photo center—eliminating the relief displacement factor. The only possible bias from effects of rough topography might be due to variations in average scale of photos or in distances between photo centers discussed previously under "Modifications for nonstandard photography." Ordinarily, however, the sampling design requires that more than one dot per templet be taken as a sample. This may be necessary either because the total number of photos in the survey project is far fewer than the number of samples required, or because only a fraction of the total number of photos is to be sampled in order to reduce photo handling time.

Only a few typical examples of the relief displacement problem are considered here. In selecting these examples several realistic basic premises have been made: (1) The photography is over typical steep topography, similar to that in the more mountainous and forested parts of the western United States. (2) The photo coverage is at an average contact scale of 1:20,000, taken with an $8\frac{1}{4}$-inch focal-length lens. Thus the flight altitude (H in the equation) averages 13,750 feet above the ground or datum plane. (3) The topography has a total range of 4,000 feet in elevation, or lies within a range of $\pm 2{,}000$ feet from the datum plane. (Thus an extreme value for h in the equation might be 2,000 feet.) (4) Extremes of topographic slopes sometimes are as great as 75 per cent for continuing average grades over horizontal distances as great as half a mile. (This does not preclude slopes which may be considered steeper over much shorter distances.) However, slopes of 35–40 per cent, or about $37\frac{1}{2}$ per cent, are closer to the average for continuing average grades over horizontal distances as great as half a mile. This premise means that the extreme value of 2,000 feet for h in the equation might be realized in some situations where a dot sample falls upon ground detail at half a mile, horizontally, from the plumb point. It also means that the value for h will not often exceed 1,000 feet for a dot sample falling upon ground detail at half a mile from the plumb point. (5) A sampling templet will be used in which no dots in the pattern are spaced farther than 1.585 inches from the photo center. At a photo scale averaging 1:20,000, this would place such dots upon ground detail approximately half a mile, horizontally, from the plumb point. The assumption that such a templet be used is reasonable, if the surveyor follows the suggestions, given previously, that the templet pattern be restricted within an effective area of the photo. This assumes, also, a normal situation, in which the desired sampling intensity does not require that a maximum templet area of 4.5 by 2.5 inches be completely filled with dots.

In the problem examples given below, two constants have been assumed in the equation for relief displacement hl/H. It is assumed that H is 13,750 feet and l is 1.585 inches. The variable factor is h. From the premises above, the largest value for h is taken as 2,000 feet, and a more frequent value for this factor is taken as 1,000 feet. The substitution of 2,000 feet for h yields a figure of 0.23 inch for relief displacement of images on the photo. When 1,000 feet is substituted for h, the value for relief displacement is only 0.115 inch.

We are concerned here with determining how far a pattern of samples of ground detail is modified by effects of relief displacement upon photo scale, and how far this pattern deviates from the normal pattern of samples obtained when the photo scale is uniformly 1:20,000. Specifically, we want to know the amount of error caused by relief displacement in plotting a dot upon ground detail at half a mile from the plumb point.

Thus the values for relief displacement are multiplied by the photo-scale factor (1 inch on the photo equals 1,667 feet on the ground) to determine the amount of error in placement of the sample upon ground detail. The error in placement is ± 383 feet (slightly less than 6 chains) when h is 2,000 feet, and only ± 191 feet (approximately 3 chains) when h is 1,000 feet. The signs + or − are used here to denote that the error in placement may be either away from or towards the plumb point. The displacement of images caused by relief, of course, may be either way from a photo center, depending upon whether the sample point lies above or below the datum plane.

The extreme error in placement of approximately 6 chains might contribute appreciably to bias in sampling under the following conditions: Where relatively few photos are used; where the total number of samples taken is small; where the type pattern is complex, areas of types are small, and types are stratified according to elevation. These conditions are most likely probabilities on some small, intensive survey projects; and in this case errors in placement of only a few chains could contribute to bias in sampling for area estimation. However, on an extensive project with many samples, regardless of complexity of type pattern, it is unlikely that relief displacement would contribute to any appreciable bias in sampling. There are several logical reasons for this.

(1) Even though a large number of sample observations are affected to some extent by relief displacement, the actual errors in placement of the samples tend to be compensating. Displacement of samples away from the plumb point would be balanced by an approximately equal number of displacements, of the same magnitude, towards the plumb point. It is emphasized that, though the position of a plumb point with reference to the datum plane has no bearing upon the amount of relief displacement, it does control the approximate horizontal placement of a dot sample. Therefore, it is well to remember that the plumb point or photo center, may fall in any random manner over the topographic pattern. In other words, the slope may be either upward or downward along the radial lines between plumb point and dot-sample points. Thus, regardless of the position of a plumb point with respect to the datum plane, there is a random chance that a sample may fall either above or below the datum plane.

(2) The chances are that most displacements would be far less in magnitude than those illustrated here, for many samples would fall on ground detail much closer than 1,000 feet to the datum plane. Obviously the smaller the value of h, the more negligible becomes the displacement, and, when h approaches zero, the error due to relief displacement also approaches zero.

(3) In the examples cited, the value of l has been taken as constant. In other words, only dots falling on the extreme edge of a normal templet pattern have been considered. Quite probably at least a fair proportion of the dots in a normal templet pattern would be spaced to fall less than 1.585 inches from the photo center, or less than half a mile, horizontally, from the plumb point. And with a reduction in the value of l, there is a corresponding reduction in the amount of relief displacement.

PRACTICAL TEST FOR ERRORS FROM RELIEF DISPLACEMENT

The tentative conclusion is reached under the premises given above, that relief displacement may be considered as a random factor which may slightly modify an extensive systematic dot sampling scheme in a random manner. It is unlikely to contribute appreciably to bias in sampling. The validity of this conclusion is supported by a test of the dot-templet method made by the Pacific Northwest Forest and Range Experiment Station.

In this test, a tally of the seven main forest and nonforest types in the area covered was made by simple dot templets. Conditions of photography and topography were similar to those outlined for the problem examples. Then a second tally was made using planimetric templets and stereoscopic pairs of photos.[2] This was a more time-consuming procedure designed to sample the same area with the same theoretical, systematic distribution of samples, but eliminating any error due to relief displacement. Five hundred different dot positions over photo detail were tallied (and checked for accuracy of tally) by each method and identified by number. Thus five hundred pairs of observations were available on portions of photo detail that would be identical paired pinpoints only when no relief displacement was obtained. In a number of cases, relief displacement slightly affected the exact placement of dots over photo detail by the simple templets. Yet in only 3 out of the 500 was the error in placement enough to change the tally according to main type. And 2 of these 3 errors in tally of types were compensating.

Before definite conclusions may be made on accuracy limitations of the method, other tests should be made. They should compare results of a simple dot-templet method with results of a planimetric templet method and with area estimates of types accurately projected on maps. This comparison with map projections would allow evaluation of the bias introduced by average scale variation between photos into the dot-templet method. The tests should be over a variety of type patterns. For one of the factors that may be assumed to contribute to errors in area estimation by simple templets is hard to evaluate by theory alone. This is the tendency for types to be stratified according to elevational levels over the topographic pattern. In many forest regions, commercial timber types tend to occur on the lower slopes of mountains, and noncommercial forest or nonforest types tend to occur on the upper slopes of mountains. An overly simplified, theoretical example that might be assumed in this connection is: On a photo taken over mountain topography all the nonforest types were above the datum plane for photography and all the commercial forest types were below that datum plane. A sample of type detail by simple dot templets on such a photo would certainly bias the tally in favor of the nonforest types. These areas would be reproduced at larger scale on the photo than areas below the datum plane. The effects of errors in area estimation caused by relief displacements are not compensating in this case, since all the displacements of images of nonforest types were outward from the photo center, and all displacements of images of commercial forest types were inward.

It is interesting to note that in the practical test referred to previously—where seven type classes were recognized and tallied separately—the effects of this kind of bias might have been expected to appear in the results. We might assume that the 0.2 per cent of error in the tally by simple templets (the 1 out of 500 tallies that was not compensated) was due to a stratification of type classes according to elevational levels. In that test the photos were of typical rough topography in the western part of the United States. Subalpine and high-elevation brush and grass types, as well as commercial timber types, were represented. If other tests on photos of rough topography prove that the magnitude of error in area estimation by simple dot templets is not appreciably

[2] A description of method for using planimetric templets for locating dot samples is given in the following publication: Hartman, Fred J. "A Simplified Method for Locating Sample Plots on Aerial Photographs." *Station Note No. 3, Northeastern Forest Experiment Station,* 610 Bankers Securities Bldg., Philadelphia 7, Pa. June 20, 1947. 3 pp. illus.

greater than in this test, it is questionable whether more time-consuming means of area estimation is required to meet practical standards of accuracy on extensive surveys.

PARTICULAR POINTS OF EMPHASIS

Two aspects of the dot-templet method not illustrated in the problems need emphasis. It is important in selecting a templet pattern, where relief displacement is involved, to avoid spacing any dots too far from the photo center, particularly if only a few samples are to be taken. Obviously the error in placement of a sample caused by relief displacement increases directly with the increase in distance from the photo center (l). Another point to remember is that this error in placement varies inversely with the flight altitude (H). This suggests the importance of focal lengths of photography. It also indicates why lenses with long focal lengths produce photographs which are more satisfactory for delineation and compilation of forest-type areas in rough country. To illustrate, assume that the 1:20,000 scale photography, available for the foregoing problems, had been taken with a 6-inch focal-length lens. Then the flight altitude (H) would average only 10,000 feet above the ground. The relief displacement for the extreme example, where h is 2,000 feet and l is 1.585 inches, would be 0.317 inch; and the error in placement of the sample over ground detail would be increased to 8 chains. On the other hand, if the 1:20,000 scale photography had been taken with a 12-inch focal-length lens, the flight altitude would average 20,000 feet. Then the extreme example of relief displacement, with h and l as constants, would be only 0.158 inch; and the error in placement of the sample over ground detail would be only 4 chains.

CONCLUSIONS

The conclusions are that the simple dot-templet method is a rapid and accurate means for estimating areas of forest or other types that may be identified on vertical aerial photographs. The method is particularly applicable to extensive surveys in which relatively large numbers of contact photos and samples are used. Estimates to a high degree of accuracy may be obtained easily, even on intensive surveys, when the photo coverage approximates standard specifications and is over flat or gentle topography. The method must be applied judiciously to obtain reliable area estimates whenever photography is obviously substandard, with poorly matched or broken flight lines, or when photography is over mountainous terrain. In all cases where photography is over rough topography, and particularly where it is also taken with a short focal-length lens, the dot-templet pattern should be clustered near the photo center. This reduces possibilities for sampling bias due to scale changes caused by relief displacement. Although many of the errors caused by relief displacement are compensating, an uncompensated error in type estimation accrues from this source whenever types are stratified according to elevational level. Nevertheless, if subsequent tests support the conclusions indicated by one preliminary test, the method may be satisfactory, even where relief displacement is a factor, for getting area estimates on extensive surveys within practical limits of error.

In regions of rough topography, the method is not recommended for use under the following conditions: Where a precisely systematic sample is required; where very intensive surveys are desired; or where very narrow limits of sampling error are prescribed. In such conditions, the use of more time-consuming methods, such as the use of planimetric templets on photos or the projection of type boundaries to base maps for area determinations, is recommended.