MAP ACCURACY

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EDITOR'S NOTE: The Soil Conservation Service has completed their topographic mapping assignment for the War Department since this article was written.

WHAT IS the first question that arises in the mind of the average map user or map maker when he examines a new map, or one that he has not previously used? One can safely say that in most cases it will be, "How good is this map?" By that he really means, "How *accurate* is this map?" An individual who is neither a map user nor a map maker may be so impressed by the appearance of a map and the neatness and artistry of it that he will assume the accuracy to be unquestionable. The technician who uses maps and who produces them is generally more prudent and desires to have a definite answer to his question before he proceeds to measure from the map either distances, coordinates, directions, or elevations. He invariably needs to know how much reliance he can place on such measurements, and how much basic uncertainty he should make allowance for in interpreting his results. Then too, he knows, from either technical experience or training, or a combination of the two, that artistry and fine appearance are only the result of good drafting and careful reproduction, and can exist on a map which is otherwise grossly inaccurate.

The fundamental problem of defining map accuracy in terms which would be significant to map users is one which has given concern to engineers and mapmakers for almost a decade. In the history of the American Society of Photogrammetry this concern first became evident through a paper contributed by W. N. Brown in 1935, for publication in Volume I, Number 7, of the News Notes of the Society. About two years later, in the early part of 1937, the Society appointed a committee on Map Specifications and Tests, with G. D. Whitmore as chairman, to make a thorough study of the subject and to submit recommendations to the Society. The studies were completed and submitted in January 1939, and, as of January 18, 1940, the Society formally adopted the Map-Accuracy Specifications submitted by the committee. They were published in Volume VI, Number 1 of PHOTOGRAMMETRIC ENGINEERING. The excellent work done by that committee is attested to by the fact that the National Standard Map Accuracy Requirements now in use under the sponsorship of the Bureau of the Budget, Executive Office of the President, are, with minor variations, patterned along the same lines as the specifications promulgated by the Society.

Those requirements are quoted below:

1. *Horizontal accuracy.* For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000, or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well defined points only. "Well defined" points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings); etc. In general what is "well defined" will also be determined by what is plottable on the scale of the map within 1/100 inch. Thus while the

intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. In this class would come timber lines, soil boundaries, etc., etc.

2. *Vertical accuracy*, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

3. The accuracy of any map may be tested by comparing the positions of points whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested, and the extent of such testing.

4. Published maps meeting these accuracy requirements shall note this fact in their legends, as follows: "This map complies with the national standard map accuracy requirements."

5. Published maps whose errors exceed those aforestated shall omit from their legends all mention of standard accuracy.

6. When a published map is a considerable enlargement of a map drawing ("manuscript") or of a published map, that fact shall be stated in the legend. For example, "This map is an enlargement of a 1:20,000 scale map drawing," or "This map is an enlargement of a 1:24,000 scale published map."

7. To facilitate ready interchange and use of basic information for map construction among all Federal map-making agencies, manuscript maps and published maps, wherever economically feasible and consistent with the uses to which the map is to be put, shall conform to latitude and longitude boundaries, being 15 minutes of latitude and longitude, or $7\frac{1}{2}$ minutes, or $3\frac{3}{4}$ minutes in size.

June 10, 1941
Revised, April 26, 1943

In the summer of 1941, the War Department sponsored a large domestic topographic mapping program which employed facilities of the following Agencies: The Coast and Geodetic Survey, the Soil Conservation Service, the Tennessee Valley Authority, the Geological Survey, and the Forest Service. Work was initiated in the autumn of 1941. The finished maps were to comply with the General Specifications for War Department Mapping Program, from which all excerpts applicable to accuracy are quoted:

WAR DEPARTMENT

Office of the Chief of Engineers
Washington

GENERAL SPECIFICATIONS FOR WAR DEPARTMENT MAPPING PROGRAM

1. *GENERAL*

Reference is made to "Standard of Accuracy for a National Map Production Program," prepared by the Bureau of the Budget with the advice of Federal and map-using agencies, dated June 10, 1941, with which these specifications are in basic agreement.

2. *PRODUCTION*

The producing agency will furnish the War Department color separation drawings at scale of approximately 1/20,000 of each 7½ minute quadrangle assigned, complete and prepared for reproduction by photolithography. The production of finished maps will be the subject of a separate agreement.

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6. *SCALE*

The compilation scale will be approximately 1/20,000.

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8. *PROJECTION*

Polyconic Projection, developed on the central meridian of the sheet, of accuracy to permit joining of adjacent sheets without error.

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10. *CONTROL*

Each 7½ minute quadrangle will contain at least one third order point in elevation and one in position.

11. *CONTOUR INTERNAL*

The contour interval will be 20, 40, 50 or 100 feet. The smaller interval will be used unless the plotted distance between contours drops to .02 inches. Only one contour interval will be used on a sheet.

12. *GRID*

Sheets will include a 1,000 yard grid drawn in accordance with Army Regulations 300-15 and Special Publication No. 59, U. S. Coast and Geodetic Survey.

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15. *ACCURACY*

a. The lines of the 1,000 yard military grid and all triangulation and traverse stations and bench marks will be located to within .005 inches of their computed positions with respect to the lines of latitude and longitude.

b. All easily identifiable and recoverable points depicted will appear within .02 inches of their true geographic positions, and 90% of all features will appear within .05 inches of their true geographic positions. No point will be more than .075 inches from its true geographic position.

c. 90% of all contour lines will show true elevations of the ground surface, as referred to the 1929 adjusted level net, North American Datum, within half a contour interval, and no contour elevation will be in error by more than a full contour interval.

It will be noted that the horizontal and vertical accuracy requirements of the War Department Specifications are in basic agreement with those of the National Standard Map Accuracy Requirements. In certain details the War Department specifications are more severe, since the horizontal requirement is that *all* easily identifiable and recoverable points shall be correct within .02 inch, and the vertical requirements permit no contour error greater than one interval. Therefore, topographic maps which comply with the War Department requirements will easily meet the provisions of the other specifications, and are eligible to bear the notation in the legend: "This Map Complies with the National Standard Map Accuracy Requirements."

The Division of Cartography of Soil Conservation Service has, for the past eighteen months, been engaged in completing, for the War Department, an extensive assignment of topographic mapping in the eastern part of the United States. The responsibility for making adequate accuracy tests throughout the assigned area and for determining the methods and techniques to be used in testing these maps was placed on the Soil Conservation Service as the producing agency. A step-by-step analysis of the specifications was obviously necessary, and is presented as such in the following discussion to portray a clear picture of the problem. Since any horizontal test of points on a map must necessarily be based on measurements made from the basic projection lines, it is obvious that the polyconic projection should be the first element checked. Inasmuch as projections on adjacent sheets must join "without error," (Paragraph 8-War Department Specifications) the projection must be correct within the limits of human plotting ability, when aided by a magnifier of moderate strength. That limit has generally been accepted as .005 inch. Therefore any projection is considered satisfactory when check distances between parallel and meridian intersections over all parts of the projection agree with values taken from the tables within the above tolerance. Overall diagonal measurements are also a necessary part of this check.

After determination that the basic polyconic projection is satisfactory, the military grid and all monumented stations shown on the map should be checked. There are two ways of accomplishing this. A pattern of military grid intersections and all of the monumented stations can be very carefully plotted with respect to the basic projection, and the difference between the check plottings and the existing points can be measured or, better yet, the positions of points to be checked can be scaled *from* the map with respect to the polyconic projection, and compared with the correct values. Since one can scale from a map more accurately than plot on a map, the latter method appeared preferable. The human uncertainty in reading a scale is estimated to be .002 inch. The permissible error for the points is .005 inch. Allowance has been made for that possible human error by adapting .007 inch as the maximum allowable difference between *scaled values* and correct values.

After these two checks have been completed the test for horizontal accuracy of identifiable and recoverable points appearing on the map remains to be made. Obviously, it would be far too costly and time-consuming to check all of such points shown on the map and hence it is practically necessary to resort to some method of sampling whereby the map is judged by the results obtained from testing representative areas selected more or less at random. The extent of survey lines established in the field for test purposes is influenced considerably by the intensity of the basic triangulation net and the availability of existing stations in optimum locations. In the area mapped by the Soil Conservation Service triangulation stations usually existed about eight airline miles apart, which generally amounted to ten or eleven miles apart following the roads between stations. For all tests, survey lines were started and were terminated at U. S. Coast and Geodetic Survey triangulation stations. Consequently, the average length of a horizontal test line was about ten miles.

Along the routes of the survey lines, survey ties were obtained to existing identifiable points such as centerline intersections of roads, and streams. Only those points which could be selected and marked on the ground with a probable uncertainty of less than three feet were considered and the selection was checked by having two individuals independently mark the point. A single test would, on an average, involve about fifteen or twenty of such points. Points fixed by acute-angle intersections of features, even if easily identifiable in the field, were in general not used, because of the uncertainty of marking such points on the map. There is another class of points which was excluded for test purposes. Where cultural or other features are in such close proximity on the ground that to delineate them in correct position on the map would result in lines being "crowded" too close together, or in being partially super-imposed on each other, the less important feature is arbitrarily moved away from the more important feature a slight distance on the map to preserve clarity and appearance. This is a standard drafting and editing procedure. Obviously points defined by features which have been so moved are not suitable for test purposes. Referring to the

.05 inch requirement in Paragraph 15 b. of the War Department Specifications regarding features shown on a map, it is believed that in compiling a map by standard methods from aerial pictures the correctness of position on the map of general features such as stream lines and woods lines is a function of the accuracy with which identifiable and recoverable map test points have been depicted. Therefore it has not been considered necessary to make specific checks on such features, other than obtaining an occasional convenient survey tie to a woods edge or a stream line. In general it has been found that features will be depicted on the map with no errors greater than those inherent in the map test points, assuming that all lines are drawn on a map compilation with the same care.

Geographic positions of the test points, as determined by the survey line, should of course be as close to the absolute values as reasonably possible, keeping in mind that the costs of survey lines increase sharply for higher order work. A survey line which would, after adjustment for closure was made, yield geographic map point positions correct within one or two feet was deemed adequate. For average distances of ten miles between triangulation stations, a third-order traverse, carefully extended, should give those results. Third-order standards call for a closure of 1 part in 5000, or better. Generally the closures of these test lines averaged around 1 part in 7500, with about 6 or 7 feet linear error of closure to distribute back through the successive courses. The practices of observing double-deflection angles, and taking tape tension and temperature readings were followed. Transits graduated to 30-second intervals were used, and frequent intermediate polaris observations were taken. Adjusted geographic positions along such a line may reasonably be considered correct within a foot or two.

Extreme care is necessary in obtaining from the map scaled geographic positions of test points. After correct identification has been made, a small needle-hole at the point serves very well for making measurements from the projection lines. In making these measurements two sets of readings were taken and averaged, and in case of appreciable disagreement, further readings were taken. Every effort was made to reduce the errors in marking points and in scaling co-ordinates to a minimum, and considering the scale at which the work was done, it is believed that the results were generally correct within 5 feet for marking and 3 feet for scaling, based on ground measure. A ten-power magnifier proved a material aid in these operations.

The criterion for a horizontal test consists of comparing positions scaled from the map with computed positions determined from field surveys. Before making the comparison it is pertinent to consider the total effect of the small increments of error which have been heretofore discussed. The possible errors may include 1 or 2 feet in field identification, 1 or 2 feet in computed coordinates of the survey line, 5 feet in marking points on the map, and 3 feet in scaling coordinates from the map. On the theory that the effect of these increments will not be entirely accumulative it is estimated that the total result may have an average uncertainty of plus or minus 6 feet. In other words, the "yardstick" for the test can, at a reasonable cost, be correct within an estimated 6 feet. It is believed that closer results would entail an unwarranted increase in costs and difficulty of execution. The final products to be delivered to the Corps of Engineers, War Department, are color separation drawings, scale 1:20,000. At that scale .02 inch equals 33 feet on the ground. Adding to this amount the estimated uncertainty of 6 feet mentioned above yields 39 feet as the maximum allowable linear difference between computed survey positions and scaled map positions.

In Figure 1, below, is shown a typical example of a horizontal and a vertical test, as planned and carried out for one $7\frac{1}{2}$ minute quadrangle. There are several ways in which the contours on a map can be checked. A straight or random profile line can be extended between two known geographically located stations with ground elevations obtained at known intervals along the line. A plotted pro-

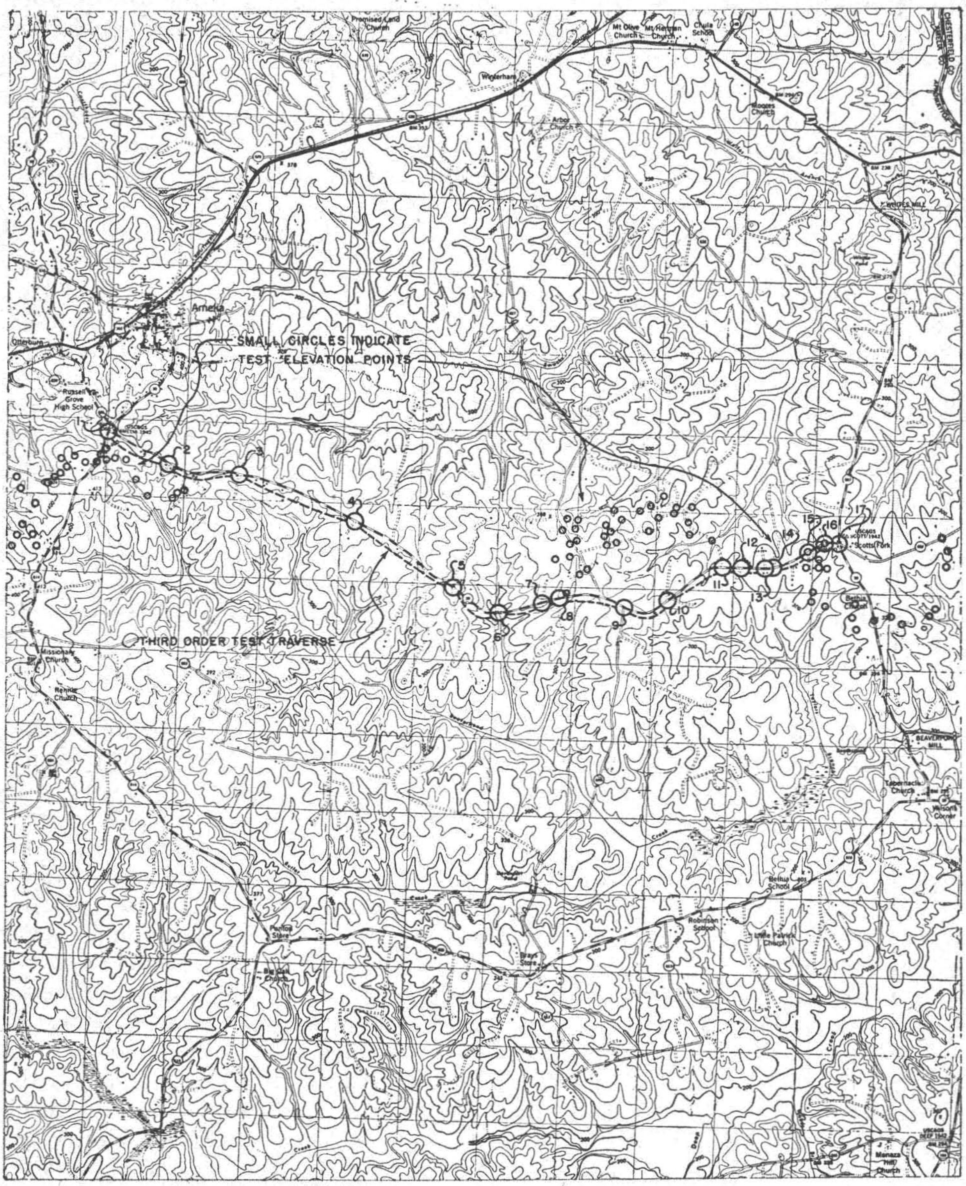

FIG. 1. Plan of Horizontal and Vertical Map Tests.

file of the survey line can then be compared with a profile plotted from the map between the same two stations. The relative agreement between the two plotted ground surfaces is a measure of the correctness of contours. Another method consists of locating the horizontal positions by random survey line, of a number of scattered points on the ground, and obtaining instrumental elevations at the points. The points could then be plotted on the map by their geographic coordinates, and map elevations derived by interpolation from the contours. Comparison of map elevations against ground elevations would indicate the accuracy of contours. Both of those methods seemed rather costly and time-consuming. They were used in certain cases in this work but a third method, which was generally used on the maps produced by Soil Conservation Service, will be described in detail. It proved to be economical, rapid, and convenient.

Aerial photographic enlargements, scale 1:12,000 were utilized to locate the horizontal positions of points for which survey elevations were obtained. On almost every aerial photograph there are numerous images of objects such as road intersections, stream junctions, points where trials cross drainage, corners of woods, fence corners, buildings, small lone trees, and other points which can be definitely and easily identified in the field. These points can be plotted on the map of the area with very little error, when relief is low, by using an optical projector to reduce images on the aerial enlargement to the exact scale of the map. Then, elevations of the ground at these points, obtained by instrumental means, will afford adequate data to make a vertical check. The level lines should, of course, start from and end on established terminal bench marks. In actual practice, the existing pattern of bench marks somewhat governs the selection of test areas, consideration necessarily being given to the proximity of a sufficient number of easily identifiable picture points of the type mentioned above, along the proposed route. Usually, the vertical test of one map involved the use of about 3 enlargements, with not less than 60 test points involved. As the instrumental levels were being extended in the field, the points at which test elevations were obtained were identified and marked on the photographic enlargements. Level lines were required to "close" on terminal bench marks sufficiently correct to assure that after adjustments were made all intermediate elevations would be accurate to the nearest foot.

As mentioned above, optical projectors were used to plot the test elevation points on a copy of the map base which showed culture, drainage, and contours. The photographs were successively placed in the projector and the focus was adjusted so that the roads and other cultural features on the pictures exactly coincided with the plotted positions of those features on the map base, in and around the immediate area of each test. The test elevation points were then marked on the map base, and numbered. The final step consisted of interpolating test point elevations from the map, and comparing them with the ground elevations. Again referring to Figure 1, the plan of a typical vertical test is shown.

At this point in the discussion it is pertinent to remember that a horizontal error of .02 inch is permissible on any part, or the whole, of the map. Now, if a vertical test were made of a map on which the culture and drainage were geographically in error by .02 inch throughout the area, that error would affect the results of the vertical test exactly the same as if the horizontal location of each vertical test point was in error by .02 inch. Compensation for this possibility can be made by assuming that any part of the map *may* be in error horizontally by .02 inch, and by shifting the vertical test points that amount in the most favorable direction. Expressed mathematically, at the scale of 1:20,000, the increment of elevation so derived will be equal to the slope of the ground in percent times 33 feet. Thus, for a 20% slope the increment would be 6.6 feet. While utilizing this increased tolerance would, of course, better the results of any vertical check, the shifting of points in this manner was only done in a few cases. Although the allowance for this additional tolerance has not been specifically mentioned in the War Department Specifications it has been understood that, since they are in basic agreement with the National Standard Map Accuracy Requirements, uniformity in this respect was desirable.

This method of making an accuracy test of contours appears practicable only in areas where the relief is moderate, and would not be recommended for use where a test area on one photograph had elevation differences of more than 200 feet. However, in areas where there is relief exceeding that amount, it would be practicable to transfer the points from the pictures to the map by radial intersection methods, provided the map had been made by use of those methods as was the case in this assignment, thus eliminating the horizontal displacement caused by relief. On maps made with stereo-photogrammetric instruments, those instruments could be used to locate the vertical test points. In either case the field work could be conducted in the same manner as outlined.

Any method of testing a map is necessarily some type of a sampling process. The selection of techniques employed, the interpretation of results obtained, and the intensity of samples taken are matters on which sound engineering judgement of different individuals could logically present divergence of opinion. The characteristics of the terrain covered might have an important bearing on the procedures selected. Other factors might exert an influence. The combination of techniques discussed in this paper are not advanced as being the ideal answer to the problem, but merely as the answer which appeared to the Soil conservation Service to offer the best means to satisfy three major considerations for the areas which were mapped:

1. Provide adequate assurance that the maps being produced meet the accuracy requirements of the specifications.
2. Keep the costs within reasonable limits.
3. Permit expeditious execution. If necessary two parties can be concurrently assigned to a single test; one to extend levels; the other to execute field work for the horizontal test.

The general intents of both the War Department Specifications and the National Standard Map Accuracy Requirements appear to be that each mapping organization shall exercise its own judgement in selecting the methods for executing tests, and in determining the pattern and intensity of sample tests. It would seem that a standardization of testing methods based on the recommendations and experience of the several government agencies involved would now be a desirable addition to the specifications. The promulgation of accuracy specifications for maps, with provision for appropriate notation in the map legend indicating compliance with those specifications represents a very progressive innovation for map production in the United States. However, a high degree of map standardization will only be attained if the individual tests are made in a generally uniform manner by all producers of maps, and if there is about the same frequency of testing throughout the areas mapped by the various organizations. This could readily be accomplished by prescribing in the specifications methods of test execution for both field work and office analysis, with provision for suitable alternate methods for different types of terrain and for varying concentrations of basic control.