SPECIFICATIONS FOR TOPOGRAPHIC MAPPING

George D. Whitmore
Chief of Surveys, Maps and Surveys Division
Water Control Planning Department
Tennessee Valley Authority

THE purpose of this paper is to put before this Society a few thoughts on the subject of desirable specifications as to accuracy of planimetric and topographic mapping, with special reference to the experiences in the Tennessee Valley area. There seems to be almost unanimous agreement among cartographers, surveyors, and engineers that something in the way of standard mapping specifications is needed. There is such surprisingly unanimous opinion on this that the wonder is that something was not done about it long ago. It almost seems that the only question remaining to be solved now is: Exactly what shall these standards and specifications be? The Committee on Map Specifications and Tests is attempting to help find the proper answer.

It is not presumed, of course, that the finds of this Committee, or any recommendations of this Society, will necessarily be adopted and put into effect by the profession or by any particular mapping organization. It is believed, however, that whatever this Society finally publishes as desirable standards and specifications for mapping will have considerable weight in influencing others in gradual adoption of mapping standards. It so happens that the topographic mapping committee of the Surveying and Mapping Division of the American Society of Civil Engineers is studying the same problem. If it should happen that the recommendations of the two societies would coincide, then the recommendations would, of course, carry considerably more weight with the profession at large. Perhaps the body best able to give such standards official sanction is the Federal Board of Surveys and Maps. I am sure that the Board will welcome opinions from such groups as this Society, the American Society of Civil Engineers, as well as from individuals.

Perhaps at this point the discussion should be narrowed by limiting the term "map." As used in this paper the word "map" means one which has been plotted or compiled from actual surveys, whether these be ground or photographic, and is further limited to those maps commonly called "planimetric maps" and "topographic maps." Plans or plats which show dimensions and elevations by figures would thus not come under this definition of map; neither would the geographic or atlas maps which include railroad and highway route maps, textbook maps, and such.

The discussion is further limited to specifications and standards on *accuracy* only. We do not consider the function of this Committee to include map specifications for such items as completeness of information, type of symbols, quality of drafting and sketching, etc. We consider our assignment to be limited strictly to a study of desirable accuracy in planimetric and topographic maps.

WHY HAVE STANDARD MAPPING SPECIFICATIONS?

Perhaps some will wonder why after all we should need standard specifications for planimetric and topographic maps. There are many reasons, only a few of which need be mentioned. For one example, anyone engaged in wholesale mapping operations must constantly decide whether or not to accept previously completed surveys and maps of some other organization. If generally accepted map standards were available, a few simple tests would indicate at once whether or not such previously executed maps were up to standard, and thus determine immediately their fitness. Conversely, today we see the situation of many organizations making special-purpose maps of limited areas which may or may not be good enough to incorporate later into the basic quadrangle sheets of the nation. If standard specifications were available, these special-purpose maps could usually easily be made to conform, and thus eliminate later the need of completely redoing them.

Standard specifications are necessary also in order to compare the cost of one process against another, or the cost of one man's work against another's. Obviously, it is unfair and impractical to attempt such comparisons unless the maps being compared are equivalent in accuracy. It has been distressing at times to read published articles, some of them written by enthusiasts of photogrammetry, which compare photogrammetric maps with ground-survey maps, usually to the detriment of the latter. In most of these cases, as a matter of fact, the ground-survey map being compared was considerably substandard and could not under any conceivable set of standard specifications be termed a "standard map."

Also, the engineer or public using a map is entitled to have some idea as to just how accurate it is. Almost every engineer today, given a planimetric or topographic map to use, first has to ask the question, "Just how accurate is this map?" Usually no exact answer can be given. If the map was compiled by ground-survey methods, one usually looks for the name of the topographer as the best criterion as to how accurate the map is likely to be. The fact that one topographer's work is better than another, however, is not necessarily a reflection on the individual but rather on the fact that there were no specific standards available with which to conform.

Many Different Approaches

While it is true that most engineers seem to agree that there is a real need for standard mapping specifications, there seems to be no general agreement as to just what the fundamental basis of the specifications should be or the method of approach. During the past year, I have questioned many engineers and surveyors as to what would be the most logical basis for standard mapping specifications. A few of the different views expressed will be quoted to illustrate the many possible different approaches to this matter.

One suggestion was that the accuracy of the map should depend on the distribution and precision of the control surveys—that is, the more accurate and dense the control, the higher should be the accuracy expected in the map. Another somewhat similar idea often expressed is that the accuracy of the map should be allowed to vary with the distance from control—that is, the greater the distance from control, the less accurate the map would be. These views seem to be putting the cart ahead of the horse—control surveys would be governing the quality of the map. It seems more logical, from the mapping standpoint, to consider the map as the desired end product, and the control being incidental to the map. It would seem more reasonable to establish first the desired quality of map, then obtain sufficient control to insure that degree of accuracy in the map.

Another idea often expressed is that there should be one set of accuracy standards for all maps, regardless of scale. The basic idea here is that every planimetric or topographic map, regardless of scale, should have all well-defined cultural features plotted in correct horizontal position within some specified amount, say 1/50 or 1/40 inch, and that 80% or 90% of the contours should be correct within one-half the interval. Those who hold this view would publish the map on a scale and with a contour interval which would meet the specifications, regardless of original compilation scale—and the idea may have some merit. There are many cases, for example, where rather crudely executed stadia-topographic surveys have been plotted up on scales of 1″=100′, or 1″=50′, or even 1″=20′, where they really should have been drawn on much smaller scales; there just wasn't enough accuracy in the original field surveys to justify the large plotting scale. If the stadia distances were correct within ten feet, for example, positions on a 1″=50′ scale would be in error by $\frac{1}{5}$ inch. On the other hand, these same distance errors on a scale of 1″=400′ would cause only 1/80 inch error in position—similarly for contours. A rather crude topographic map showing 5 foot contours may be a very accurate map if only the 10 foot or 20 foot contours were drawn.

Then there are those who believe the degree of accuracy should be made to vary with the scale of the map. Some suggested that the larger the map scale, the greater the relative accuracy which should be required. Others suggested the exact opposite—that is, the smaller the scale, the greater the relative accuracy should be. To illustrate the latter idea, a map on a scale of 1:48,000 should have cultural features plotted in correct position within say 1/50 inch, while a map on a scale of 1:2,400 might be allowed say 1/20 inch. Similarly for contours, the larger the interval, the more exactly the contours should be plotted—i.e., 50 foot contours might be required to be accurate say 90% within $\frac{1}{2}$ interval, whereas 5 foot contours might be required to be only say 70% or 75% accurate within $\frac{1}{2}$ interval. Neither of these proposals seems to hit the spot exactly.

The idea which seems to be most preferred is to grade and label maps according to accuracy, with two or three grades or classifications. For instance, maps of the highest order of accuracy might be called "Grade A" maps, or "First-Order" maps; the next in order of accuracy being called "Grade B," or "Second-Order," etc. It has been specifically suggested that three orders of accuracy be established and designated in order as "Engineering Maps," "Standard Maps," and "Reconnaissance Maps." Under this plan, any map, regardless of its scale, which was constructed to the highest possible practical standards of accuracy, would thus be called an *Engineering Map*. As regards scale, however, it is probably true that maps of this class would ordinarily be confined to the larger scales, say from 1″=500′ on up to 1″=50′, or 1″=20′. Maps drawn to somewhat less rigid specifications would be called the *Standard Maps*, and these would ordinarily be in the intermediate scale range, say from about 1:6,000 to 1:62,500. Maps which were compiled to no particular specification, and were less accurate than the *Standard Maps*, would be labeled *Reconnaissance Maps*. These would ordinarily be confined to the smaller scales, say from 1:62,500 on down. But degree of accuracy and not plotting scale would be the criterion which would classify the map. Thus, there might be *Standard Maps* or *Reconnaissance Maps* on large scales, such as 1″=100′; and conversely, there might be *Engineering Maps* and *Standard Maps* on small scales, such as 1:125,000. This general idea also seems to have considerable merit.

Still another suggestion is that the accuracy of the map should be made dependent on the method used. This seems to be another case of cart before the horse, letting method control result, and does not seem to be a desirable approach.

Then there is the widely held but narrow view that the immediate use to which the map is to be put should determine the accuracy required in the map. Without doubt, this is the policy which governs most of the miscellaneous special-purpose maps being constructed today. (This policy does not, and could not, of course, apply to the national basic maps, such as the topographic quadrangles of the U. S. Geological Survey.) This seems to be a case of shortsightedness and false economy, since most special-purpose maps, at very slight increase in cost, could be made equivalent to certain accuracy standards and thus be usable from then on for all map purposes. If standard specifications are made available, no doubt most of these miscellaneous special-purpose maps will be made to conform.

The foregoing gives a general idea of just a few of the many different conceptions expressed by qualified and experienced engineers on the subject of how to go about setting up standard specifications on mapping. Strange to say, however, when we begin to ask, "Exactly what shall the specifications be?," we seem to get fewer different viewpoints. In any case, it is apparent after a year of frequent and pointed inquiries and rather intense study of the subject that this particular Committee has tackled a man-size job.

How Can Practical Accuracy Specifications Be Determined?

One of the first questions which must be answered, of course, is just what accuracy is practical. Fortunately, there is being accumulated an immense amount of data on this subject. During the last 20 to 25 years, there have been numerous mapping contracts executed by reliable organizations whose work has been tested before acceptance. The projects covered by such mapping contracts include dozens of city, county, and metropolitan district areas; flood-control and irrigation districts; power developments, and similar projects. The maps were made by several different methods, including straight plane-table, combination plane-table and photogrammetric, and stereoscopic machines. The original specifications and the test results are available for most of these surveys.

The surveying and mapping activities of the Tennessee Valley Authority also offer a mass of data helpful to this subject. The Authority's program has necessarily required all kinds of surveys and maps, executed by almost every known method. Furthermore, samples of every type of map by every used process have been directly and indirectly tested as to accuracy. These tests have been mostly of two kinds: (1) the horizontal position accuracy of well-defined cultural points (planimetric), by comparing co-ordinates scaled from the map with correct co-ordinates determined by traverse or triangulation; and (2) the accuracy of contours, by comparing elevations interpolated from the contours with actual elevations determined by field survey. Incidentally, the Maps and Surveys Division of the Authority believes that it pays to test all work, or select samples of each kind of work, whether its own or contracted work.

The maps and methods of the Authority which have been so tested include: first, and perhaps most famous, the planimetric mapping project of the Tennessee Valley basin, covering about 42,000 square miles of area, and handled as a co-operative project with the U. S. Geological Survey. The maps were compiled by the radial-line method, from both five-lens and single-lens pictures, drawn to the scale of 1:24,000 and requiring about 800 quadrangle sheets. Innumerable tests on these maps as to the position accuracy of well-defined cultural points have been and are still being made.

Then there is the cadastral surveying program of the Authority which includes large-scale cadastral surveys and plats for land-acquisition purposes, totaling about one million acres to date, the areas so surveyed falling in five different states. These were compiled largely from single-lens photographs with considerable ground control, using very precise radial-line work to convert photographs to maps. Hundreds of tests as to the plotting positions of well-defined cultural points have been made on these maps. Except for the occasional cases of outright blunders in plotting or identifying, it may be said that better than 90% of the cultural points shown on the cadastral maps are plotted in correct position within 1/50 inch. In connection with this work, we have also tested on a smaller area the co-ordinates of photographic points whose locations were established by the slotted-templet method and found the results to be substantially the same.

Then there are the many miscellaneous topographic surveys and maps incidental to large dam and reservoir developments. Under these we have: first, the large-scale, white-paper plane-table topography of dam sites, campsites, cities and towns located along future reservoir shore lines, cemeteries to be relocated, highway and railroad relocations, etc., these surveys totaling about 35,000 acres, mostly plotted on metal-mounted sheets. Such surveys are plotted on scales ranging from 1″ = 200′ up to 1″ = 20′, with contour intervals of from 5 feet to 1 foot. Dozens of tests, mainly by the test-profile method, have been made on these maps. Almost without exception, such work has checked better than: 90% of all well-defined cultural features correct within 1/50 inch, and 90% of contours correct within $\frac{1}{2}$ the contour interval.

The second group of topographic surveys incidental to reservoir development includes scales of from 1″ = 500′ (1:6,000) down to 1″ = 2,000′ (1:24,000). They include the so-called flowage topography of proposed reservoir areas, preliminary topography for campsites and townsites, for large parks, etc., and cover more than 200,000 acres. The principal method used has been to contour ratioed single-lens photographs by plane-table, then project these to previously prepared planimetric base compiled by radial-line methods. Numerous tests on these maps show that they also will usually come within the specification: 90% on all well-defined cultural points correct within 1/50 inch, and 90% of contours correct within $\frac{1}{2}$ the interval.

Finally, and perhaps of most interest to the subject of topographic mapping specifications, is the valley topographic mapping program now under way, much of this work being handled co-operatively with the Geological Survey. This program, which contemplates 1:24,000 scale topographic quadrangle sheets of the entire basin, totaling about 40,000 square miles, has so far utilized five different processes. The principal process utilizes the Multiplex Aero-projector described in Mr. Pendleton's article which appears in this Magazine. The second stereoscopic method utilizes the Stereoplanigraph, this work being done by contract with private operator. The third method uses ground-survey and photogrammetric processes, is limited to relatively flat terrain, and includes contouring ratioed photographs in the field, then projecting these field-delineated photographs to planimetric map base sheets compiled by radial-line method. The fourth method, ground-survey also, uses a radial-line planimetric map sheet as a field plane-table base sheet for the addition of contours. The fifth method, and at this time least preferred for the 1:24,000 scale, is simply straight white-paper plane-table work.

The topographic map sheets resulting from each and every one of these processes have been thoroughly inspected and sample tested. The first three processes (the two stereoscopic processes and the ratioed-photograph-planimetric-base method) show uniformly better than 85% of well-defined cultural points in correct co-ordinate position within 1/50 inch, and better than 85% correct within $\frac{1}{2}$ the contour interval.

Contour Intervals Must Be Sensibly Selected

The contour intervals used on these 1:24,000 scale topographic quadrangles run from 5 feet and 10 feet for the plane-table ground surveys in flatter terrain, 20 feet for machine plotting in gently rolling and medium terrain, with 40 foot and 20 foot intervals for the mountainous terrain. In any such discussion as this, it has to be assumed that the contour interval has been selected with good judgment to properly fit the steepness of terrain and the scale of the map. Otherwise, obviously, any specification as to contour accuracy becomes meaningless. Incidentally, it is interesting to note that on practically every topographic map completed by the Authority, it has been found necessary to utilize dotted half-interval contours in order to bring out necessary topographic detail in flatter areas. On almost every map sheet, after the basic interval has been selected to fit most of the terrain, certain flat areas, such as valley flood plains, or plateaus, or critical places such as saddles and passes, have been discovered where the half-interval contour was a practical necessity in order to make the map most useful for the planning engineer's use.

General Conclusions as to Practical Accuracy

The mass of information resulting from all of the afore-described tests convinces one that it is entirely possible, and usually practical, to construct maps to conform to definite standards at reasonable and fair costs, provided that the method best suited to the type of terrain has been selected, and provided also that common sense and good judgment have been used in the selection of the contour interval. Judging by all of these test results, then, it appears evident that maps can be drawn so that: for planimetry, 90% of all well-defined cultural points will be in correct map position within 1/50 inch; and for contours, 90% of all elevations will be correct within $\frac{1}{2}$ the interval. That is not to say, however, that such specifications are desirable for all classes and grades of planimetric and topographic maps. Perhaps slightly more rigid specifications would be called for on some classes of work, and perhaps slightly less exacting specifications would be more practical for the general intermediate-scale or small-scale basic maps. The Authority, when it becomes necessary to advertise for bids for a certain amount of mapping under the topographic program, had to make a decision on this point.

Actual Contract Specifications

In drawing up the specifications for bids, the conclusion was reached that for the 1:24,000 scale quadrangle sheets, slightly less rigid specifications would be more practical and entirely satisfactory. As actually advertised, these specifications provide for accuracy as follows:

1. Cultural Features: Well-defined cultural features shall be considered as correctly plotted if 95% of those tested do not exceed 1/50 inch on the 1:24,000 scale from the true horizontal positions.

2. Contours: (It is necessary to explain here that this particular contract calls for two contour intervals on the map, one regular contour interval of 40 feet, with occasional half-interval contours of 20 feet to be shown dotted. These half-interval contours are to be indicated in the flatter valley bottoms, on plateaus, and at important saddles and passes in the mountains.) The specification then is that: "On 40-foot-interval areas, 90% of all elevations interpolated from the map shall be correct within $\frac{1}{2}$ the contour interval (20 feet), with not more than 2% exceeding the full interval. On the 20-foot-interval areas, 75% of all elevations interpolated from the map shall be correct within $\frac{1}{2}$ the interval

(10 feet), with not more than 5% exceeding the full interval. Except that: In the case of cliffs, caves, embankments, etc., where these specifications might be unfair and impracticable, contours will be considered accurately located on the map if they do not vary more than 1/50 inch from the correct horizontal position. Except, also, any contour which could be brought within the vertical tolerance by shifting its plotted location 1/50 inch shall be considered from the most favorable position."

Note that in regard to the contour specifications, some allowance has been made for horizontal position errors of contours, especially in the case of vertical cliffs, embankments, etc. Based on a small amount of sample testing to date, it is believed that these specifications will be satisfactorily met.

Status of Test Work to Date

As the first formal step in the preparation of a report by the Map Specifications Committee, a copy of these specifications was sent to the Committee members with the request that each one review the specifications and send in comments as quickly as possible, commenting especially on:

1. The desirable required position accuracy in the plotting of all well-defined cultural features.
2. The reasonableness of the contour specifications.
3. The best methods of testing for accuracy.

Replies have been received to date from six of the ten Committee members, representing four different mapping agencies of the federal government, and one mapping contractor. A general digest of the replies indicates that a majority feels that this actual contract specification is reasonable, and might very well become the basis for the Committee's recommendations for certain types of maps. One of the replies protested somewhat that the accuracy called for was a little too difficult to get in actual practice.

The next step in the Committee's program should be to canvass the members on the most logical approach to the whole subject. Having determined that, we shall then have to settle the questions of exact features and quantities to include in the specifications. The Committee members will have at their disposal all of the test results possible to secure. It is hoped that within this year some sort of a definite recommendation on this subject can be given to the Society. It would seem then that the Society officials should circulate the Committee's report to the Society's members for comments, after which it would be revised in accordance with majority opinion, and finally submitted for whatever use the Society chooses to make of it.

Testing Procedure Also Important

If standard specifications ever do come into use, then the preferred method of testing map results also becomes important. There is not time in this discussion to go into that matter. It can be said, however, that considerable information on testing methods is also being secured.