Drainage Studies from Aerial Surveys

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ABSTRACT: *Vertical aerial photographs examined stereoscopically provide a useful three-dimensional medium whereby drainage areas can be successfully determined with sufficient accuracy for the design of culverts for highway drainage.*

Discussed in the paper is the use of large-scale photographs for determining the placement of these culverts and other items concerned with the collection and dispersal of surface water during run-off periods.

Methods, corrections to be applied, and techniques which have been successfully employed, all of which are within the capabilities of the average field engineer with limited photogrammetric training and equipment, are described. Examples are given to show the degree of accuracy which can be expected.

INTRODUCTION

THE purpose of this paper is two-fold. The first is to prescribe a method whereby stereoscopic pairs of aerial photographs can be used by field engineers with limited photogrammetric training, for determining drainage areas with sufficient accuracy and detail for use in estimating culvert sizes. The second is to consider the use of such photographs for the actual positioning of culverts, bridges, dikes, channel changes and similar features of design with an accuracy sufficient for use as a guide in construction plans and estimates.

While the investigation was confined to the southern part of the State of Arizona, the same methods with minor differences should be applicable to other areas. No claims are made for originality in developing the following techniques. No doubt they have been used previously, but a presentation of the developed procedures will no doubt be interesting to many who are involved in locating modern highways and in other undertakings involving the location and design of drainage structures.

Drainage areas are usually determined by utilizing existing maps or by traversing each watershed. Both methods have their shortcomings. Maps can be unreliable or so lacking in detail as to preclude accurate determination of larger areas or any determination at all of the smaller areas. Traversing, either by stadia, plane-table, or transit and tape, is both time and labor consuming, especially in regions of rough terrain or where ground cover interferes.

In the arid Southwest, the extent and character of drainage areas are very important in determining culvert sizes. During the rainy seasons storms are frequent and although of short duration they can be violent in character. This characteristic plus the impervious nature of the soil and the sparseness of vegetation contribute to the rapid run-offs encountered in this section of the country. Washes which are normally dry suddenly become raging torrents, while in the flat desert regions, washes frequently overflow the surrounding areas. It is necessary therefore to provide adequate drainage across highways both to safeguard the highways against excessive erosion and to protect the surrounding land.

In the past much of this run-off was taken care of by constructing dips across the highways. When properly constructed and protected, these dips were both economical and satisfactory. However, with the rapid increase in amount and speed of traffic, and the increased importance of the highway in the economy of the country, the practicality of dips was decreased, and enforced delays to the motorist during flash floods were not only irksome but expensive. And of course on divided highways of the Interstate System and other heavily travelled limited-access facilities, such a treatment would be not only archaic but unworkable.

In Arizona it has been found that the Talbot equation for determining culvert sizes is quite satisfactory. This equation is an empirical formula based on a large number of observations. It works well with a flow velocity of ten feet per second or less and a

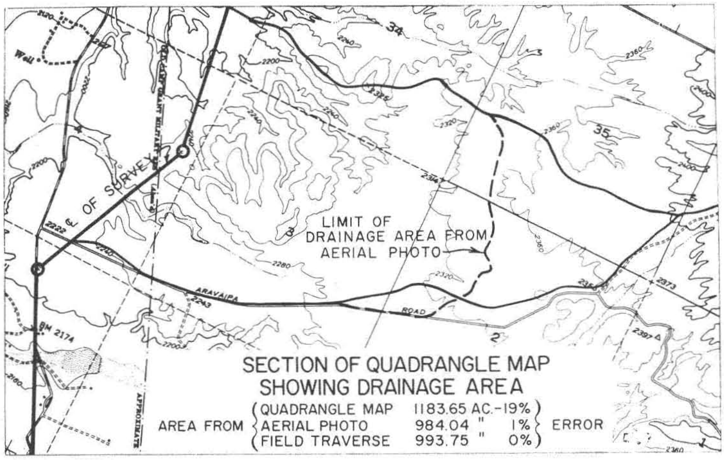

FIG. 1. Sketch illustrating the differences in drainage area extent which may occur between actual photographs and small-scale contour maps, due to excessive contour interval.

maximum rainfall of 4 inches per hour. The general formula is $A = C\sqrt[4]{M^3}$ where A is the area of the required waterway in square feet, M is the area drained in acres and C is a coefficient depending on the contour and character of the land drained. This coefficient varies from $C=1$ for steep rocky ground to $C=1/5$ or less for comparatively flat areas. Other formulas for determining waterway areas can of course be used.

The character and slope of the terrain is therefore important. Its extent and whether the run-off is confined, or covers an extensive area, must also be considered. Experience counts much in selection of the run-off coefficient for use in the equation and in selecting the size of the culvert and determining its placement.

Drainage areas to be used in the application of this equation were, and still are in many cases, determined by measurement in the field or from existing maps. In the comparatively unsettled West suitable maps are scarce, are not too accurate, and many are lacking in sufficient detail to be reliable or useful. The recent $7\frac{1}{2}$-minute quadrangle topographic maps published by the United States Geological Survey are very helpful and are quite accurate. Unfortunately they are not now plentiful and in many cases the contour interval is too large to ensure a true determination of the drainage area boundaries.

Figure 1 illustrates how errors could inadvertently occur in outlining an area where the contour interval is too great. Shown is a section taken from a recent $7\frac{1}{2}$-minute quadrangle map with a contour interval of 40 feet. The solid black line shows the boundary of a drainage area as it would be determined from the contour information given. The dashed black line shows where the boundary differs from the solid black line as the result of a stadia traverse run in the field by regular field methods. A low ridge cuts transversely across the area with its crest along the dashed black line. It so happens that the elevation along the ridge is about 2,340 feet, while the elevation of the trough behind it to the east is around 2,330 feet. The contours on the map therefore give no indication that such a ridge exists. The effect of this ridge on the drainage area is clearly evident in the figure.

DETERMINING DRAINAGE AREAS

Aerial photography naturally is suggested as a possible solution to the problem which then is resolved into the various possibilities open to the use of this medium. It is desirable to limit its use to such forms as are usable by field survey personnel who have a minimum of photogrammetric training and to such equipment as can be made available to those men.

Where an area has been photographed for reconnaissance survey purposes the aerial photographs thus secured can be used, particularly where the drainage area is of considerable extent. Photographic mosaics can also be used but the three-dimensional effect attained from stereoscopic examination of pairs of aerial photographs is very desirable in tracing the boundaries of watershed areas. The contours of topographic maps compiled photogrammetrically are extremely useful but the maps are generally of such limited extent that they are of little value except for very small areas. For larger areas and when available, as in Arizona, manuscript maps compiled from existing photography at the scale of one-mile-to-one-inch for use in preparing the general county highway maps, are very useful. But here again drainage detail is not sufficient for determining the boundaries of the smaller areas. In many cases therefore it becomes desirable to photograph the region under consideration, especially for drainage area studies. Such photography is inexpensive and its cost can be saved many times over in time and labor. A scale of 2000 feet-per-inch for normal size areas is generally satisfactory although a smaller scale can be used for areas of greater size. Large scale photography might be considered in some instances, and for small areas the large scale in many cases would be desirable. But as the scale is increased the coverage is decreased and the larger areas become unwieldly in size.

The following discussion is based primarily on the use of aerial photographs, as the use of other media, such as maps, requires no special comment. The discussion is also limited to small and medium-size areas which can be plotted on one or two strips of photographs. Larger areas can perhaps best be determined by other methods—such as on existing quadrangle maps or on drainage maps especially prepared in the photogrammetric laboratory.

First the scale of the photography is determined and the centerline of the highway is plotted on the photographs. On photography made prior to the location of the survey center line, this plotting will have to be done by photographic identification. On photography taken without control being premarked on the ground by photographic targets, the scale can be determined with sufficient accuracy from existing features—such as section lines, property lines, existing roads or other configurations where the length is known or can be determined. On photography where photographic targets appear as placed on control points, the scale of course can be easily determined; this will frequently be the case as placement of photographic targets prior to photography is becoming more and more a prevalent practice.

Drainage area boundaries should be plotted stereoscopically using a pocket or mirror stereoscope and a red pencil. It is necessary to trace the boundary on only one overlapping area and preferably the one on which the entire area occurs. On larger areas which extend over adjacent flight strips, care should be taken in transferring the watershed boundaries from the edge of one photograph to another. This should be done preferably by radial plot to minimize errors. Where the elevations within an area vary by less than 200 feet, or where the drainage areas are not of great extent, these areas can be planimetered directly on the photographs and converted to acres or square miles according to the average scale as determined. For larger areas and where differences of elevation are still within the approximate 200 foot range, a scale based on an average elevation of the drainage area to be considered can be used, and the area converted on this basis.

Where there is a difference in elevation of 200 feet or more within the limits of the drainage area, adjustments should be made for image displacement due to relief. If this is not done errors may occur which could materially affect the size of a culvert or waterway. In such cases it is more feasible and convenient to transfer the drainage areas and other pertinent features from the photographs onto tracing paper before the adjustments are made.

In order to determine these adjustments the displacement formula $d_e = rh/H$ is used. In this d_e is the displacement due to relief, r is the distance on the photograph from the principal point to the image of the top of the object, h is the ground elevation of the object and H is the flight height of the photograph relative to the same elevation datum as h. Elevations around the perimeter of each area, as required for making the adjustments, can be determined from the photographs with sufficient accuracy by means of parallax measurements using either a parallax bar or an engineer's scale. Necessary measurements can then be made and the adjusted areas drawn and planimetered on the tracing. If topographic maps of sufficient detail and accuracy of the area are available, the elevations can be taken directly from the contours on these maps with a considerable saving in time. Other means of obtaining the elevations would also be acceptable as elevations to the nearest 50 feet will be accurate enough.

Relief displacement can then be easily determined to a selected datum applying the above formula and the corrections made as in Figure 2. The drainage area thus adjusted can be planimetered as usual, computing its extent to a scale as determined by elevation of the datum plane selected. It appears to be more convenient, although not necessary, to select this datum plane so that it will pass through one of the lower elevations along the center-line of the survey as plotted on each photographic print.

Corrections for tilt are not necessary where

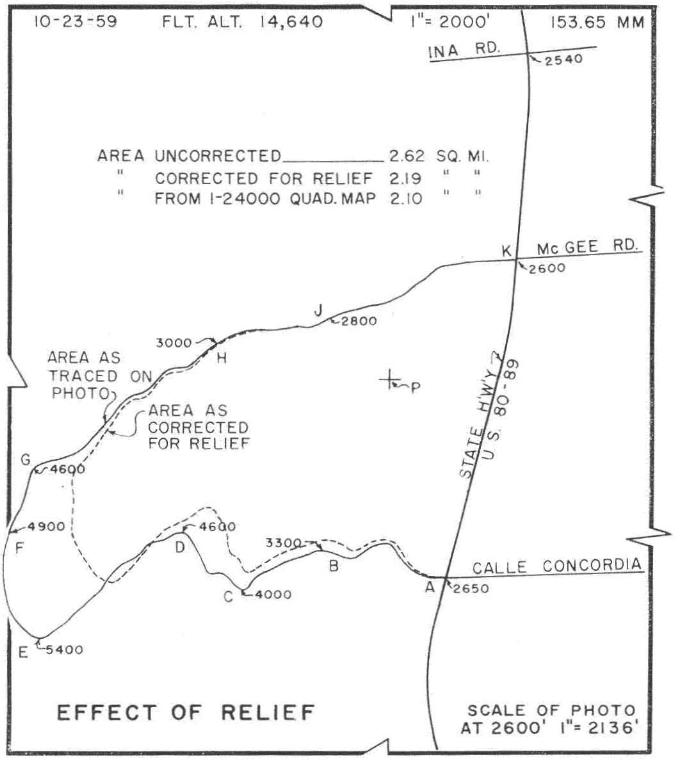

FIG. 2. Sketch illustrating effect of excessive relief on drainage area extent with the result of corrections made by application of the displacement formula.

the vertical photographs do not contain more tilt than is allowed by the usual specifications. Moreover, corrections for tilt require some ground survey data, are quite complicated to make, and are generally beyond the understanding of field engineers to compute. Any errors in drainage area due to tilt in vertical photographs should not exceed the limits of accuracy required. Investigations have shown that error in area in excess of 3 per cent because of tilt is unlikely.

Drainage areas in flat desert or similar regions are more difficult to determine than where topography is rolling or rugged, due partly to the lack of relief and partly to the fact that shifting channels during storm periods will sometimes alter the smaller areas to a considerable extent. This is particularly true where the area under consideration is only a part of a larger major area. Also the enormous amount of sediment carried down these shallow channels during a cloudburst will frequently fill a shallow wash and will cause the stream to cut out another channel with perhaps a cross-over into an adjacent area. Close examination of aerial photographs will make these occurrences evident or their possibilities known much better than can be determined in the field. Abandoned channels will be evident and in many cases future behavior of the stream flow can be predicted.

Other Drainage Data Obtainable from Aerial Photographs

In addition to quantitative data pertaining to drainage area size which is determinable from aerial photographs, other vital quantitative data and qualitative information may be obtained. Not only are all of these data not obtainable from topographic maps, but they are difficult and expensive to ascertain by investigative methods on the ground.

Vertical aerial photography viewed stereoscopically is particularly adaptable to the determination of type and extent of ground cover, and the extent of ponding and water retarding features of each drainage area. These features are vital factors regarding surficial drainage and are essential components of a judicial analysis of a specific drainage problem. They cannot be obtained from topographic maps or easily obtained in the field.

Ground cover, the extent being dependent on the type and intensity, reduces the run-off volume and retards the run-off velocity. When veiwed stereoscopically, aerial photographs make possible the engineer determining the amount and extent of ground cover, the exposure and the ground slope. He can also to some extent determine the character and type of the cover. This knowledge is important in identifying underlying types of soil, and judging internal drainage characteristics of soils. All of these are essential for accurate determination of sizes and shapes of structure openings.

Ponding or retarding of water above drainage structure openings is another significant factor to consider in the structure design. Some drainage channels, whether wide or narrow, are deep with steep and fast drainage characteristics. These require structures of considerable head room. Other areas are extensively wide and flat in character and may be broken by a large lake. Such areas tend to collect large amounts of surficial run-off and to act as dispersal areas up above the site in the drainage channel where the drainage structure must be placed. Where this happens the structure opening may be reduced somewhat from the larger size indicated by the factor obtained from the drainage area only, i.e. without reduction. When aerial photographs are used these drainage features are easily and accurately determined and result in a better and more economically drained highway area.

Examples of Drainage Area Determination

Figure 2 illustrates the amount of drainage boundary displacement that can occur due to extreme relief. At this point the existing highway is adjacent to the Santa Catalina Mountains; the elevation difference between the low and the high points of the area to be measured amounts to 2,750 feet in a distance of approximately 0.8 mile. Slopes are very rugged and the determination of the area by ordinary field methods would be extremely difficult. The photographs were taken from a flight height of approximately 12,000 feet with a six inch focal-length lens. Scale was estimated from known distances along the highway.

This photograph was chosen because of the extreme conditions encountered and because there was available a recent $7\frac{1}{2}$-minute quadrangle map which could be used for comparison. At the time the photography was obtained there was no intention of use for other than pictorial purposes. It should be noted that the drainage area as sketched was not completely covered by the photograph, and it was necessary to estimate the upper limits of the boundary. The boundary was determined stereoscopically from this and an adjacent photograph.

In spite of the described limitations, there was only 0.09 of a square mile difference between the area computed from the quadrangle map and from the photography after correction for relief displacement as shown. This is an error of only 4.3 per cent, assuming the area as computed from the quadrangle map to be correct. Without relief displacement correction, the error would have been in the neighborhood of 25 per cent. This is of course an extreme condition and much better accuracy can be expected in the majority of cases.

On one recent project—6.4 miles long—50 separate drainage areas were considered; these had an aggregate area of 11,567 acres. Although the relief was moderate the country was difficult to traverse; to measure the areas by transit and stadia would have required the time of three men for at least two weeks. The areas were plotted on existing photographs of approximately 2,000 feet per inch scale on which targets marking control point positions appeared; these were plotted and computed by one man in about two days with greater detail than would have resulted from regular field methods.

Relief differential was moderate and it was not necessary to correct for displacement of watershed boundaries due to this factor. In three cases the larger drainage areas encountered extended beyond the limits of the photographs and it was necessary to determine these on existing topographic maps. Comparisons with existing $7\frac{1}{2}$-minute quadrangle maps in this area showed a difference of under 0.5 per cent. A stadia survey over one area of 984 acres (that shown in Figure 1) took two men one full day to complete and showed a difference of under 1 per cent between the field survey and the area as taken from the photograph. The savings here in both time and labor are obvious.

Positioning of Culverts and Related Drainage Features

After the drainage areas have been determined, it becomes necessary to select the proper size of structure and to locate it on the ground in the most desirable and economical position. Generally this is done by field examination of each drainage channel along the center line of the survey, measuring or

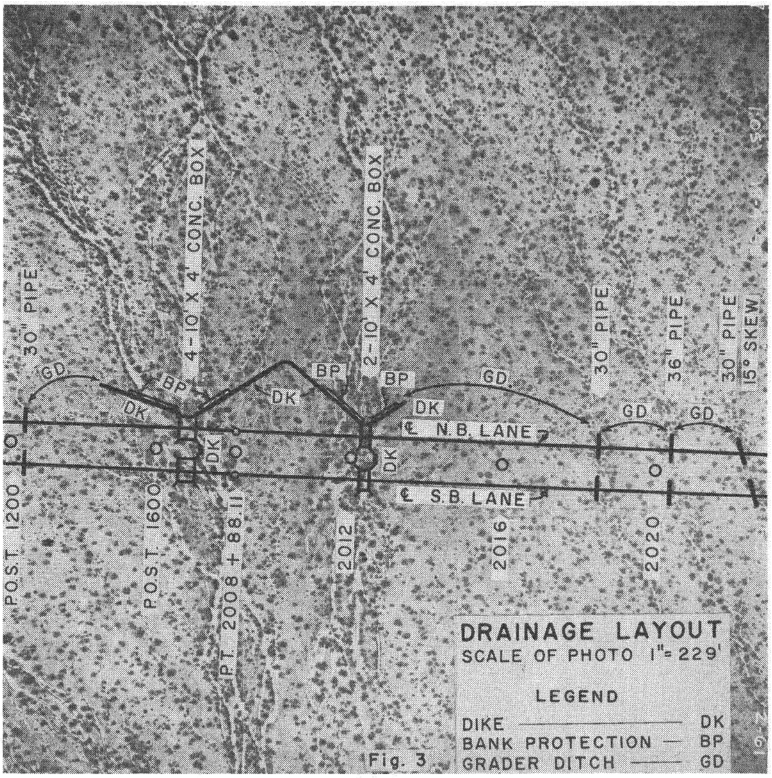

FIG. 3. Drainage layout detailed on an aerial photograph showing method of placement of structures, dikes and other drainage features.

estimating the stationing, estimating the angle of skew and making sufficient notes so the structure can be designed and incorporated in the plans.

There is nothing wrong with this method. It has worked for years, but it is time-consuming and frequently it is difficult to determine exactly the most desirable place in which to construct the culvert, especially where vegetation along the stream is thick or where the channel is complexly divided or braided.

Through use of aerial photographs of suitable scale, culverts can be positioned accurately and in many cases better than by examination on the ground. Photographs of a large scale are desirable. Those at 250 feet per inch have proved quite satisfactory. This scale is large enough to supply needed detail while coverage is sufficient to follow the course of a stream far enough to place the culvert in its most efficient position, and to determine the need for dikes, channel changes or other items to assure the control of the stream flow.

If cross-sectioning is to be done photogrammetrically, vertical photographs secured for this purpose will be ideal. These can also be used for the preparation of large-scale topographic maps with contours at a sufficiently small interval for bridge sites and interchanges. If such photography is not to be secured, it will probably be necessary to fly the area specifically for the drainage study. In any event the photographs should be taken after the center line has been run and after the area has been targeted so that the center-line can be accurately positioned and can be stationed on the photographs, and also so that the exact scale of the photography can be determined. Narrow Chart-Pak stripping is ideal for delineating the center-line so it will be seen on the photographs. Besides being clean to handle it can be applied more rapidly than a wax, china marking-type pencil.

Culverts can now be spotted with considerable accuracy, skew determined and necessary dikes, channel changes and other detail spotted. Bridge sites can be studied and tentative bridge positions determined. Later using the same photography and in preparation for the bridge design, large-scale topographic maps can be made of the bridge sites.

In many cases areas subject to flooding can be noted on the photographs, and an engineer practiced in photographic interpretation can spot other potential areas where serious trouble might be encountered during peak run-off periods.

It should not be inferred that all field work can be eliminated by use of the described methods. While it will be desirable to examine many culvert sites on the ground before construction plans are completed, the field trips can be planned at more convenient times and they will progress much more rapidly than would ordinarily be the case. In some cases where ground cover is extremely thick the method may not be practical or might require more detailed field checking.

After all drainage studies have been made it would be desirable to ink the placements permanently on a set of the photographic prints. The photographs will not only be valuable to design engineers while preparing the construction plans but also of value to construction engineers and engineering crews when the highway is being built. Figure 3 shows one print prepared in this manner. Tabs were used on the print for stationing and other information in the interest of clarity on the halftone reproduction. Red ink or tempera normally used would make this refinement unnecessary.

In this instance cost and time are not as critical as in drainage area determinations. Drainage studies are generally made by the location engineer during survey progress and while the crew is otherwise engaged. There is a saving in cost and time, however, and better, more efficient, and more workable drainage systems will result from this method.

Papers Wanted for Photogrammetric Engineering

My objective as Editor is that each issue of PHOTOGRAMMETRIC ENGINEERING contain at least two technical papers that the reader will find understandable and helpful in his use of or interest in photogrammetry. That sounds like an easy job. Actually it is very difficult because the Publications Committee doesn't receive an ample supply of the papers particularly needed. Accordingly I ask for help by the readers of this Journal.

The difficulty is not a general insufficiency in the number of papers but an inadequate diversification in either or both of (1) papers which are understandable and helpful to those with little or no experience in photo use and (2) papers where the primary objective is a use other than topographic mapping. But even for the highly technical papers on such as topographic mapping there is some difficulty in getting all phases covered adequately.

A listing of the uses for which papers are desired would be very long. Even then it would be incomplete. The list includes such as the inventory, planning, development and utilization of land and resources—a tremendous field. Also many phases of the design, planning, construction and maintenance of engineering structures and work—this has been poorly covered in past issues. Also hydrography, hydrology, flood control, geography, geology, soil conservation, drainage, anatomy, surgery, dentistry, criminology, fire and police protection, highway safety, disease and pest control, meterology, outerspace, satellite tracing, astronomy, architecture, oceanography, deep-sea surveys and floor, volume measurement, beach protection and erosion, nautical charting, the utilization, appraisals, taxation and assessment of land, photo-geology, glaciers, Arctica and Antarctica, permafrost, mechanical and machine design, property surveying and boundaries.

Each reader who knows of or is making a use of photos that he thinks may be somewhat unknown to others in a similar occupation or valuable to present non-users of photos is urged to write me and send a brief description of this use. After consideration by the Committee Chairman, decision will be made on whether to arrange for preparing a technical paper.

THEODORE W. NORCROSS *Editor*