Drainage Studies from Aerial Surveys

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Aerial vertical 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.

Use of large-scale photographs for determining the placement of these culverts and other facilities connected with the collection and dispersion of surface water during runoff period is also discussed.

Methods, corrections to be applied, and techniques that 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 that can be expected.

● THIS PAPER proposes (a) to prescribe a method whereby stereoscopic pairs of aerial photographs can be used by field engineers with limited photogrammetric training for determining drainage areas accurate enough and in sufficient detail to be used in estimating culvert sizes, and (b) to consider the use of such photographs for the actual positioning of culverts and related drainage features with an accuracy sufficient to be used as a guide in design.

The investigation was confined to the southern part of the State of Arizona, but with minor changes the same methods should be applicable in other areas. No claims are made for originality in developing the techniques. No doubt they have been used before, but a presentation of the procedures developed and a summary of the results obtained may be of interest to many who are involved in the location of 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 smaller areas. Traversing 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 become very important in determining culvert sizes. During the rainy seasons storms are frequent and, though of short duration, are violent in nature. This characteristic plus the impervious nature of the soil and the sparse vegetation contribute to the rapid runoffs encountered in this section of the country. Normally dry washes suddenly become raging torrents, and in the flat desert regions washes frequently overflow the surrounding country. It is necessary therefore to provide adequate drainage across highways both to safeguard the highway against excessive erosion and to protect the surrounding land.

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

Arizona has found the Talbot equation for determining culvert sizes quite satisfactory. Here the character and slope of the terrain as well as the general shape of the watershed area are important. Its extent, and whether the runoff is confined or covers an extensive area, must also be considered. Experience, of course, counts much in selection of runoff coefficient for use in the equation and the size and placement of a culvert.

Drainage areas to be used in the application of this equation were, and in many cases, still are determined by measurement in the field or from existing maps. In the comparatively unsettled West suitable maps are scarce, not too accurate, and often lacking in sufficient detail to be reliable or useful. The recent 7½-min USC & GS quadrangle topographic maps are very helpful for this purpose 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. The figure is a section taken from a recent 7½-min quadrangle map with a contour interval of 40 ft. The solid black line shows the boundary of a drainage area as would be determined from the contour information given. The dashed black line shows the boundary of the area resulting from a stadia traverse run by regular field methods. A low ridge cuts transversely across the area with its crest along the dashed line. It so happens that the elevation along the top of the ridge is about 2,340 ft, while the elevation of the trough behind it to the east is around 2,330 ft. 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 suggests itself as a possible solution and the problem then resolves into the various possibilities open to the use of this medium. It is desirable to limit its use to such forms as are practical for field survey personnel with a minimum of photogrammetric training and to such equipment as can be available to such 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 mosiacs 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 contour maps compiled photogrammetrically are extremely desirable but they are generally of such limited extent as to impair their usefulness except for the smaller areas within their limits. For larger areas, manuscript maps compiled from existing photography at the scale of 1 in. =1 mi to be used in preparation of the general county highway maps are very useful when available, as in Arizona. Here again drainage detail is not sufficient for determining boundaries of the smaller areas. In many cases and especially for drainage area studies it therefore becomes desirable to photograph the region under consideration. Such photography is cheap and its cost can be saved many times over in time and labor. A scale of 2,000 ft per in. for normal size areas is generally satisfactory though a smaller scale can be used for areas of greater extent.

The following discussion is based primarily on the use of aerial photographs, as the use of other media, such as maps, requires no special comments. In addition it is limited to smaller areas that can be plotted on one or two strips of photography. 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 centerline of the highway is plotted on the photographs. On photography made before location of the survey centerline, this plotting will have to be done by photographic identification. On photography taken without control being premarked on the ground by photographic targets, scale can be determined with sufficient accuracy from existing features such as section lines, property lines, existing roads, or other features the length of which is known or can be determined. On photography where photographic targets appear as placed on control

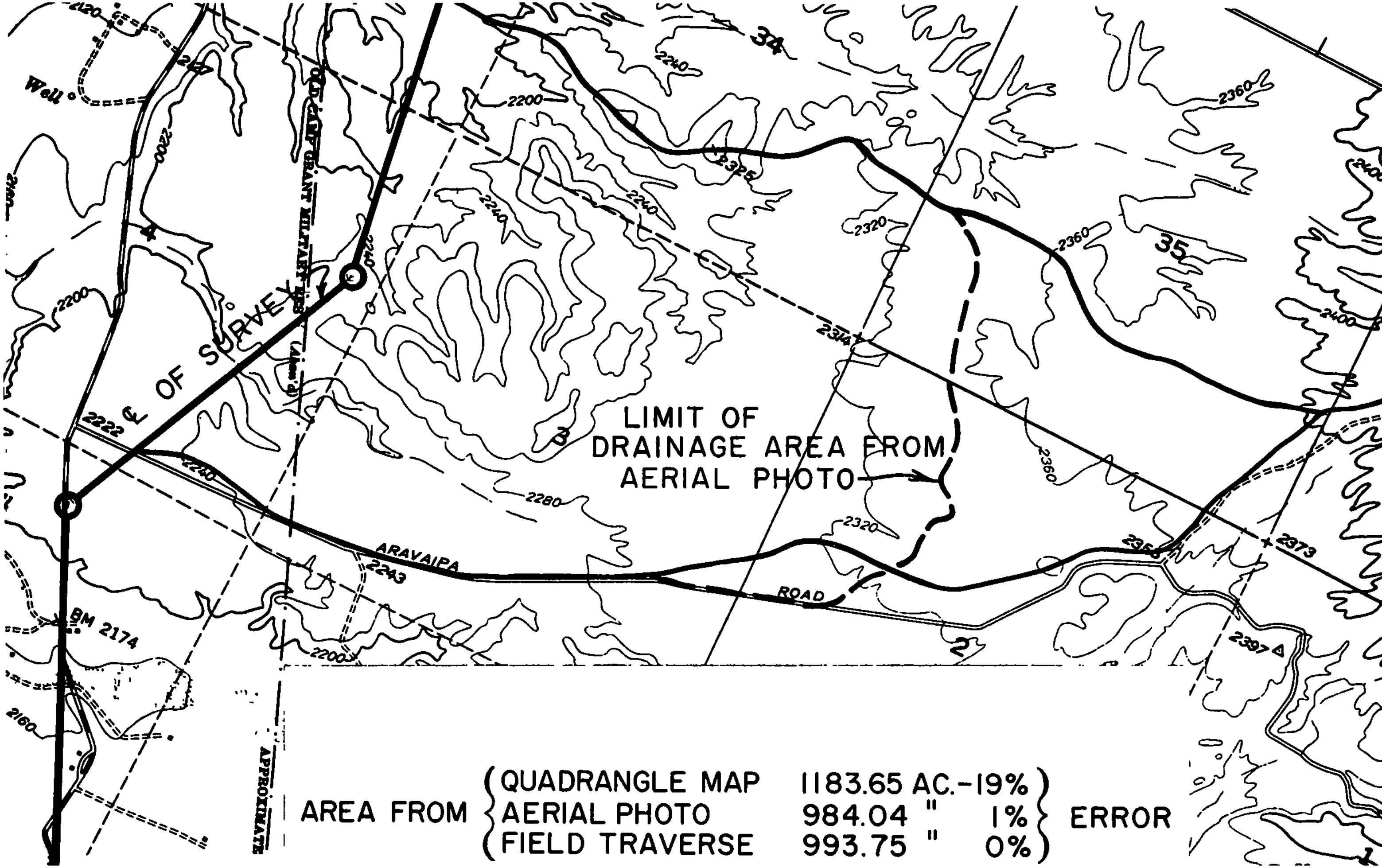

Figure 1. Section of quadrangle map showing drainage area.

points, the scale can be easily determined, and as placing of photographic targets before photography is becoming more and more prevalent this will frequently be the case.

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 of the overlapping areas and preferably on the one on which the entire area occurs. On larger areas that 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 there is moderate relief or where the drainage areas are not of great extent, such 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 places where differences of elevation are not too great, 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 ft or more within the limits of the drainage area, however, adjustments should be made for relief displacement. If this is not done excessive error can easily occur. In such cases it is more feasible and convenient to transfer the drainage areas and other pertinent features from the photographs onto tracing paper. Elevations required around the perimeter of each area for making the adjustments can be determined from the photographs with sufficient accuracy by means of parallax measurements using either a parallax bar or engineer's scale. Necessary measurements can then be made and the adjusted areas drawn and planimetered on the tracing. If USGS or USC & GS topographic maps of sufficient detail and accuracy of the area are available, these elevations can be taken directly from the contours on the maps with a considerable saving in time. Other means of obtaining the elevations would be acceptable as elevations to the nearest 50 ft will be accurate enough.

Relief displacement can then be easily determined to a selected datum by radial plot and the drainage area thus adjusted for relief displacement can be plotted and planimetered as usual, computing its extent to a scale as computed by the elevation of the datum plane selected. It appears to be more convenient, though not necessary, to select this datum plane so that it will pass through one of the lower elevations along the centerline of the survey as plotted on each photographic print.

Corrections for tilt are not necessary where the vertical photographs do not contain more tilt than 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 over 3 percent because of tilt would be unlikely.

Drainage areas in flat desert or similar regions are more difficult to determine than in places where topography is rolling or rugged. This is due partly to the relief and partly to shifting channels sometimes altering an individual area considerably during storm periods. Also the enormous amount of sediment carried down these shallow channels during a cloudburst will frequently fill a shallow wash and cause the stream to cut another channel and perhaps to cross over to an adjacent area. Close examination of aerial photographs will discover these occurrences or their possibilities much better than determination 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 determinable from aerial photographs, other vital quantitative data and qualitative information may be obtained.' All of these data are not obtainable from topographic maps and are difficult and expensive to ascertain by investigation methods on the ground.

Aerial vertical 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 essential components of a judicial analysis of a specific drainage problem. They cannot be obtained from topographic maps or easily obtained in the field.

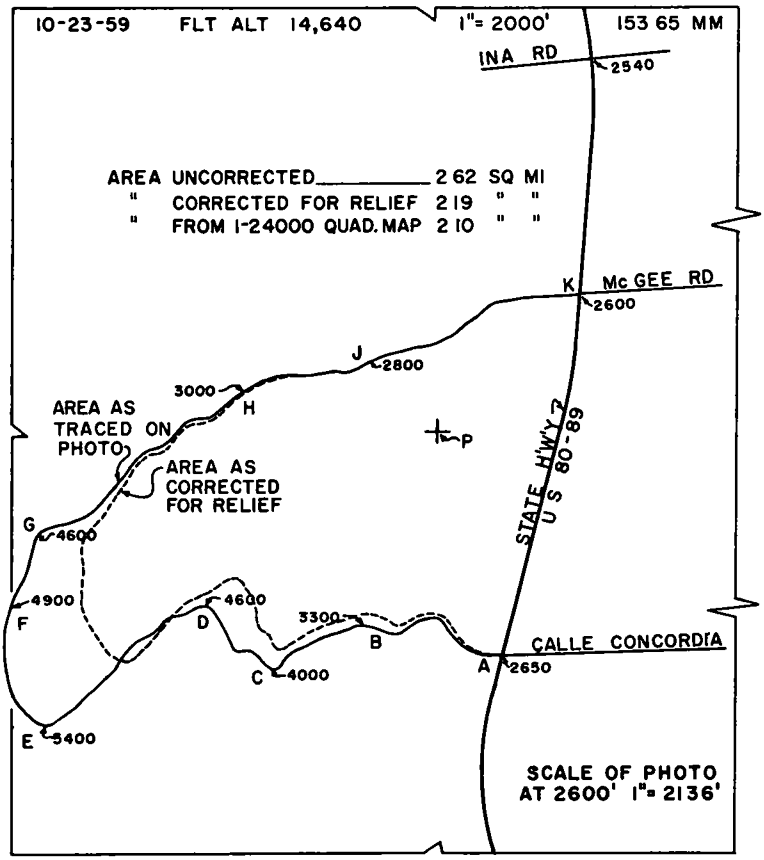

Figure 2. Effect of relief.

Ground cover, depending on type and intensity, reduces the runoff volume and retards the runoff velocity. When viewed stereoscopically, aerial photographs enable the engineer to determine precisely not only the amount of cover but also its character and type. 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 structure-opening sizes and shape.

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, fast draining characteristics. These require structures of considerable headroom. 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 runoff and act as dispersal areas preceding the site in the drainage channel where the drainage structure must be placed. When this happens, the drainage structure opening may be reduced somewhat from the size indicated by the factor obtained from the drainage area only. When aerial photographs are used, these drainage features are easily and accurately determined and result in a better and more economically drained highway.

EXAMPLES OF DRAINAGE AREA DETERMINATION

Figure 2 shows 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 and the difference in elevation between the low and high points of the area to be measured amounts to 2,750 ft over a distance of about 0.8 mi. Slopes are very rugged and determination of the area by ordinary field methods would be extremely difficult. The photographs were taken from a flight height of approximately 12,000 ft with a 6-in. focal length lens. Scale was estimated from known distances along the highway.

This photograph was chosen because of the extreme conditions encountered and because a recent 7½-min USC & GS quadrangle map was available that could be used for comparison. At the time the photograph was taken there was no intention of using it

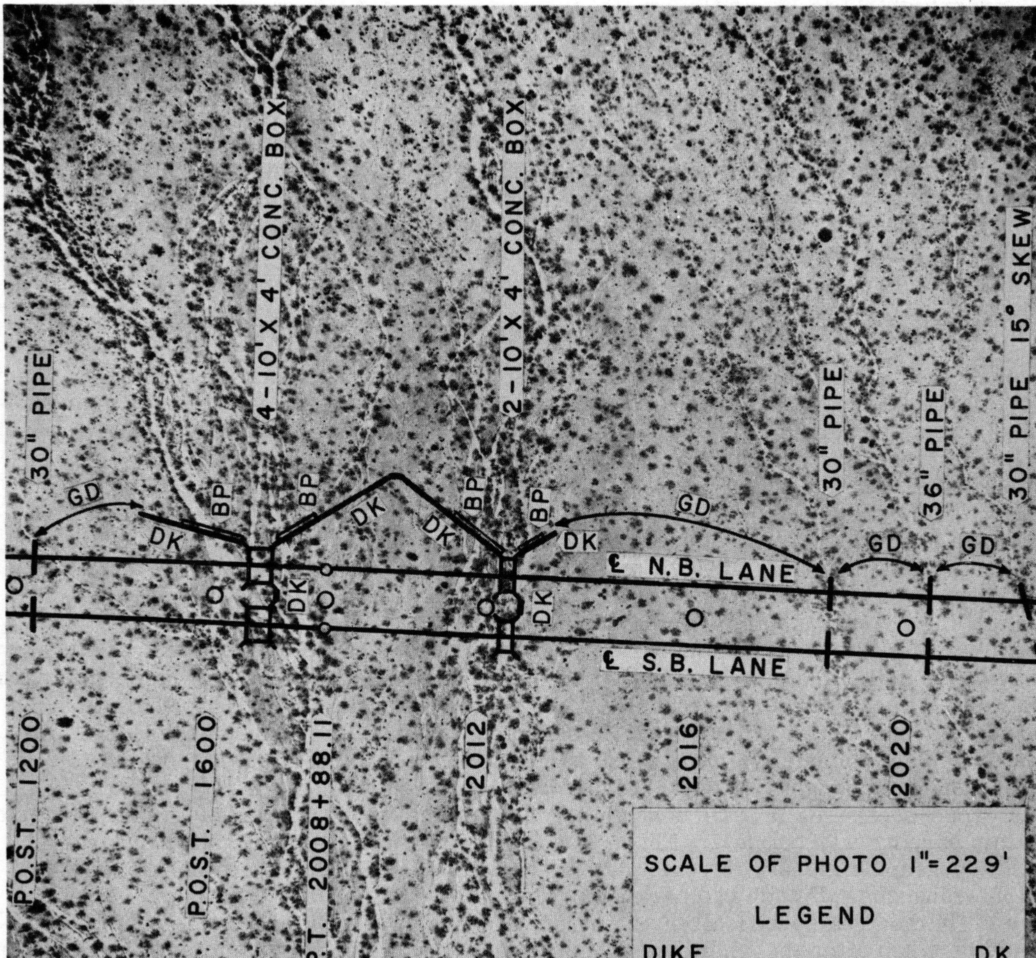

Figure 3. Drainage layout.

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 limitations, there was only a difference of 0.09 sq mi between the area computed from the quadrangle map and from the photograph after correction for relief displacement as shown. This is an error of only 4.3 percent, assuming the area computed from the quadrangle map is correct. Without relief displacement correction, the error would be in the neighborhood of 25 percent. This is of course an extreme condition. Much better accuracy could be expected in the majority of cases.

On one recent project 6.4 mi long, 50 separate drainage areas were considered with an aggregate area of 11,567 acres. Although relief was moderate, the country was difficult to traverse and it would have taken three men at least two weeks to measure the areas out by transit and stadia. The areas were plotted on existing photographs with a scale of 2,000 ft per in. on which targets marking control point positions appeared and 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. This could have been avoided if the original photographic coverage had been extended to cover the entire area. Comparisons made with existing 7½-min quadrangle maps in this area showed a difference of under 0.5 percent. A stadia survey made of one area of 984 acres (Fig. 1) took two men one full day to complete and showed a difference of under 1 percent between the field survey and the area as taken from the photograph. Savings here in both time and labor are apparent.

POSITIONING OF CULVERTS AND RELATED DRAINAGE FEATURES

After the drainage areas have been determined, it becomes necessary to select the proper size structure and to locate it on the ground in the most desirable and economical position. Generally this is done by examining each drainage channel along the centerline of the survey, measuring or estimating the stationing, estimating the angle of skew, and making sufficient notes so that 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 difficult to determine the exact position where it would be most desirable to construct the culvert, especially when vegetation along the stream is thick or the channel is complexly divided or braided.

Culverts can be positioned accurately on aerial photographs of suitable scale and in many cases better than by examination on the ground. Photographs of a large scale are desirable. Those at 250 ft per in. have proved quite satisfactory. This scale is large enough to supply detail and coverage is sufficient to follow the course of a stream far enough to place the culvert in its most efficient position and determine the need for dykes, 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 centerline has been run, the area photographically targeted so the centerline can be accurately positioned and stationed on the photographs, and their exact scale determined. Narrow Chart-Pak striping is ideal for delineating the centerline so that it will be seen on the photographs. Besides being clean to handle, it can be applied more rapidly than a wax, china-marking pencil.

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

In many cases, areas subject to flooding can be spotted on the photographs and an engineer practiced in photographic interpretation can spot other potentially dangerous areas where trouble might be encountered during peak runoff periods.

It is not to be inferred that all field work can be eliminated by use of these methods. It will be desirable to examine many culvert sites on the ground before the construction plans are completed. These field trips can be planned at more convenient times and will progress much more rapidly than would ordinarily be the case. In some cases where ground cover is extremely thick the method might 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 they will be valuable to construction engineering crews when the highway is being built. Figure 3 shows one print prepared in this manner. In the interest of clarity on the halftone reproduction, tabs were used on the print for stationing and other information. 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 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.

CONCLUSIONS

It appears that aerial photographs can be used to considerable advantage in determining drainage areas and deciding on the placement of culverts. Results based on comparisons with other methods indicate that indicate that with ordinary care accuracy can be assured. Use of aerial photographs for these purposes should be anticipated far enough in advance so that the photography will be available when required. Necessary extension of aerial photography flights for other purposes should also be considered so that adequate photographic coverage can be obtained.