and the velocity by the Manning formula is

$$V = \frac{1.486}{n} y^{\frac{2}{3}} s_0^{\frac{1}{2}}$$

By substitution and integration the discharge in a width of flow zy with depth y at the flow line of the gutter is

$$Q = \frac{1.486\, s_0^{\frac{1}{2}}}{n} \left(\tfrac{3}{8} z\right) y^{\frac{8}{3}} \quad \ldots\ldots\ldots (14)$$

In Equation (11) the numerical coefficient thus becomes $1.486(\frac{3}{8}) = 0.557$ instead of 0.468 as given in the paper and used in the computations of gutter flow.

The net result is that using equation (14) the discharge will be about 19 percent greater for an assumed value of n in a given gutter than would be computed using equations (10) and (11). In Conner's experiments the value of n computed by equation (14) averages about 0.020 as compared to 0.017 as reported (5).

Equation (14) may be considered as being mathematically correct for the case where the gutter, as on an airfield or on a wide median strip of a divided highway, has flat slopes on both sides. In that case the factor z is the ratio of the total width of water surface to the depth at the flow line; the section need not be symetrical about the flow line.

DEVELOPMENT OF DRAINAGE MAPS FROM AERIAL PHOTOGRAPHS

BY MERLE PARVIS

Research Engineer, Joint Highway Research Project, Purdue University
and
Senior Research Technician, State Highway Commission of Indiana

SYNOPSIS

This paper reports the development of techniques for compiling drainage maps of fine detail from aerial photographs of the several counties in Indiana. This work is a part of the current highway research program at Purdue University conducted by the State Highway Commission of Indiana and the Joint Highway Research Project and is believed to be the first application of the technique of airphoto analysis in producing drainage maps of a State on a county basis.

There has been a growing need for detailed drainage maps for use in the location, design, and construction of highway, airport and flood control projects. Such maps can be used by both technically trained and untrained personnel. Airphotos can be employed in the construction of detailed drainage maps.

The airphotos used for this work were taken in 1937–1943 in connection with the United States Department of Agriculture map program. Counties were covered by a series of north-south flight strips which overlapped about twenty percent. The airphoto prints of the counties were purchased from the Agriculture Adjustment Administration of the United States Department of Agriculture along with photographs of uncontrolled mosaics known as the county index sheets.

In order to translate the information available in airphotos into useful data for engineering purposes in the form of detailed drainage maps, it is necessary to correlate "patterns" observed in the airphotos with basic drainage principles gleaned from the study of the natural sciences of pedology, geology, physiography, geomorphology, and others. As a result of such a correlation, it has been possible to construct accurate drainage maps in a reasonably short period. Such maps cannot be duplicated by any other known method at a cost comparable in time and money.

Since there are no accurate base maps available for Indiana, one of the important developments in the study is that of transferring data from large-scale airphoto prints to the only available small-scale county base maps. Inaccuracies in the method of transfer were found to be small and relative in character. Vari-

ations in the distances between section corners and the locations of the section corners themselves, as recorded on the original base maps, necessitated scale adjustments in fitting the airphoto images to the base map.

The completed maps not only show the major streams and their principal tributaries, but indicate the courses of the drainage ways from their beginnings as field gullies at the watershed divides. Such maps have application in obtaining drainage areas for use in county and State highway construction, in airport construction, and in flood control projects.

DRAINAGE MAP CONSTRUCTION

Indiana does not have a complete and accurate base map of any type on which true projections of distances are represented. The only parts of the state which have been mapped with horizontal and vertical control are narrow bands along the navigable streams; namely, along parts of the Ohio and Wabash Rivers.

Base Map From Existing County Maps

The most accurate available base maps of Indiana counties are blue print copies of the General Highway and Transportation Maps which were prepared by the State Highway Commission of Indiana in co-operation with the U. S. Department of Agriculture and the Bureau of Public Roads (corrected to January 1, 1937) (see Fig. 1). For this program, cloth and paper tracings showing only section lines and boundaries of the one-inch-to-the-mile-scale maps are being used as drainage base maps.

Although the scale of the blueprint maps is indicated as one inch equals one mile, measurements of land sections on the maps show that the blue prints often are shrunken and that the average sections are not one inch square but about fifteen-sixteenths inch square. Typical sections are square, but the converging of the meridians, errors in the original survey, and errors in map layout have produced many irregular sections, some of which are considerably distorted. Defects occurring in the original base map at township lines are frequent and inconsistent with the actual ground layout registered by the airphotos. Figure 2 contains several sketches which illustrate some of the variations in section shapes contained on the maps.

Mosaic From Uncontrolled Airphotos

The airphotos of the counties are assembled in the project laboratories into uncontrolled mosaics by using alternate prints. This assembly is carried out by matching the separate prints as accurately as possible "without correlation, ground control or careful orientation"[1]. This operation is performed in order to obtain an overall "picture" of the drainage systems of the counties and for ease in marking the section corners (see Figure 3).

In the flat regions the individual prints usually fit together with a fair degree of accuracy and the alignment of the features in the overlap is satisfactory. In areas of rolling topography the prints are more difficult to fit together and poor alignment is obtained in the overlap since ground points were displaced from their true position due to the effect of perspective.[1] This condition may be caused by rough flight conditions, tilt of the plane, and up drafts, as well as by the differences in altitude of the plane in relation to the points on the ground. In addition, use of flight strips which were made on different days, possibly with the plane flying at different altitudes, results in other inaccuracies which also are exhibited in the joining of the prints into the mosaics. The general scale of the mosaic is approximately 3 in. equals 1 mile although this varies somewhat due to the foregoing reasons. As a result, the scale is found to vary from $2\frac{15}{16}$ to $3\frac{1}{16}$ in. equals 1 mile (see Fig. 4).

Plotting Section Corners on The Mosaic

The section corners are indicated by a cross made with a red china-marking crayon (wax) on the airphoto mosaic. Section corners are located by comparing the landmarks and physical features on the base maps with those on the airphoto mosaics. A control check is made by scaling corresponding mile distances on both the base maps and the mosaics (usually to the nearest $\frac{1}{8}$ in.).

[1] Eardley, A. J., "Aerial Photographs: Their Use and Interpretation," p. 49, Harper and Bros., New York, 1941–42.

Section corners defined by intersecting roads and fences are easy to find. Likewise, no difficulty is experienced in finding the corners of a standard section since they are one mile apart. In many instances section corners can not be distinguished on the airphotos because of location in streams or wooded areas (see Fig. 5). Both narrow and wide sections, which were established at the time of the ground survey to compensate for errors in surveying, are difficult to distinguish from standard sections because the maps and the airphotos do not correspond. Offsets in section lines at meridian and base line changes often are accentuated to a greater degree on the map than on the airphoto; occasionally the reverse is true. Frequently, sections which are exactly 1 mile square are found to be marked on the map correctly; these also measure exactly 3 in. square in the airphotos.

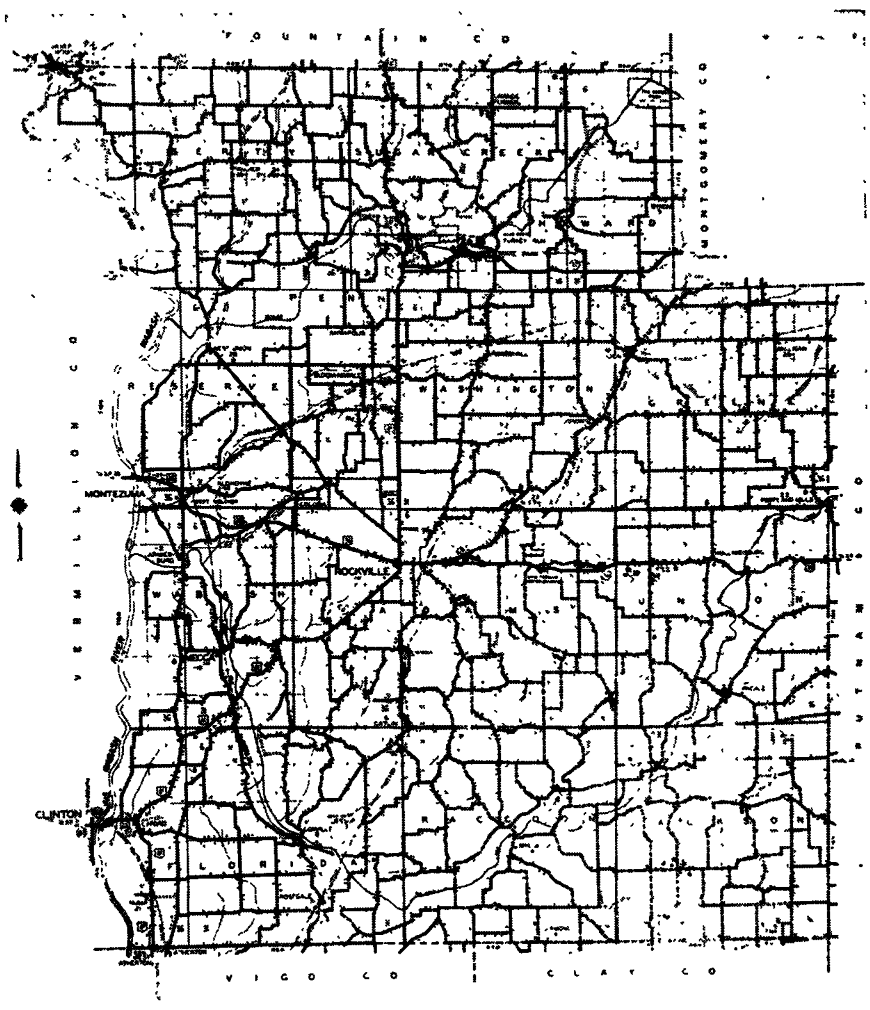


Figure 1. Reproduction of one of the General Highway and Transportation Maps Used as Base Maps for the Airphoto Drainage Research Mapping Program—Parke County, Indiana

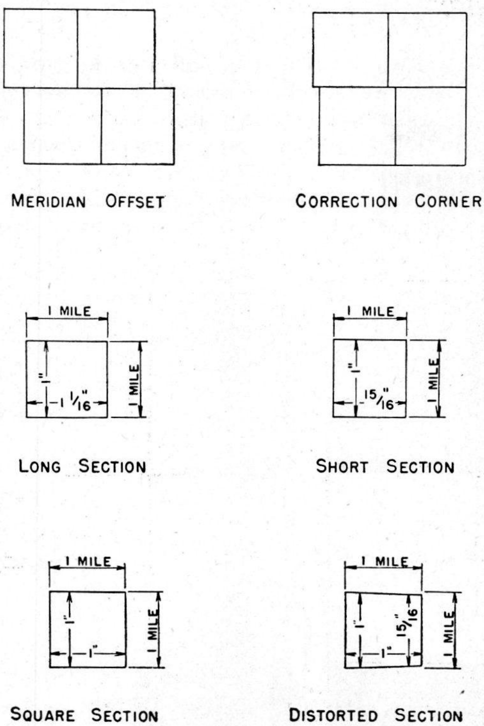
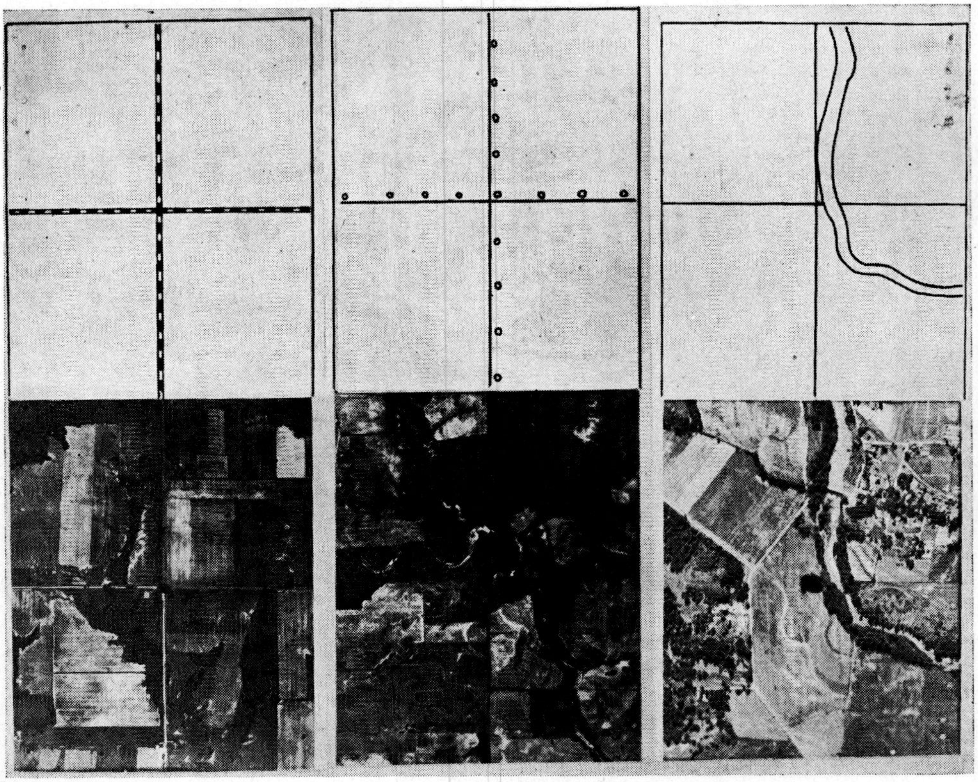


Figure 2. Variations in Section Sizes and Shapes as Recorded on the Base Maps

Figure 4. Variations in Scale of Airphotos. Note the lack of alignment in the roads where the photos are joined.

Figure 3. Uncontrolled Mosaic of the South Half of Parke County, Indiana (Copy of County Index Sheet)

Such corresponding accuracy contributes greatly to ease of mapping (see Fig. 6). Some sections measure square on the map but appear on the airphoto as rectangular, or vice versa. These sections may have been surveyed square and due to tilt of the plane appear distorted on the airphotos. In conjunction with the location of the section corners on the airphotos, the section numbers are marked on the airphotos. This facilitates accurate transfer of data from the airphotos to the base map.



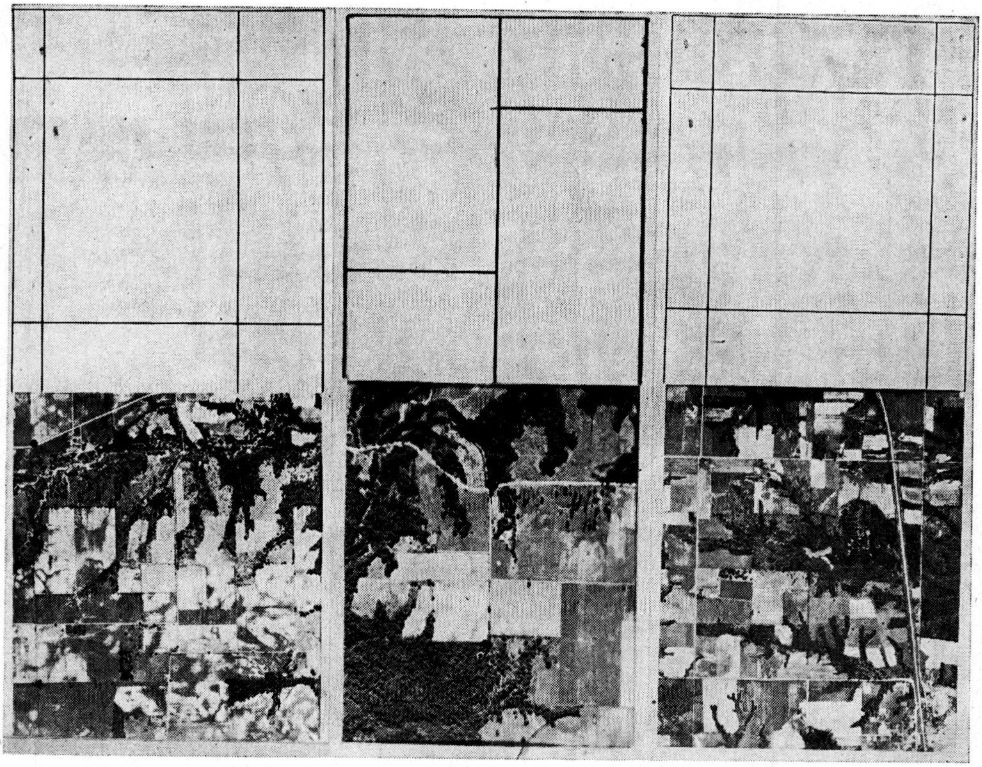
A B C

Figure 5. A. Well Marked Section Corners Located at Road Intersections. B. Well Marked Section Corners Located at Fence Intersections. C. Poorly Marked Section Corners Located in a Stream Bed.

Marking Photos For Drainage

Flight strips are selected from the mosaics and with the aid of a pocket stereoscope every distinguishable drainage way is marked on the airphotos using a dark blue china-marking crayon. (It is well to note that in marking the prints the lines should be as heavy as possible especially in thickly wooded areas.) In rolling terrain these drainage ways are easily distinguished by stereo-vision and no difficulty is experienced in marking them. Although some prints of flat areas are in good stereo-vision, considerable difficulty is experienced in determining intermittent drainage. This is especially true in the alluvium along major streams; however, this is considered relatively unimportant, for in such areas frequent flooding often changes the drainage pattern.

The assembled mosaics (using alternate prints) are marked for drainage. All of the drainage on each alternate print is marked even though part of the area is in the overlap covered by the adjacent print. Much repetition is required by this procedure, but is considered necessary in order that marks on the overlapping portion of one photo can be placed on the table in front of the observer to light the prints being marked and by careful manipulation of the lamp, it has been found that the light can be reflected at a proper angle



A B C

Figure 6. A. Example of a Narrow Section. B. Sections That Do Not Have a Common Corner (Meridian Correction). C. Example of a Square Section.

checked against the marks on the corresponding portion of the other photo in the transferring operation. This aids in maintaining continuity of lines on the final map.

Minute dissection in areas of intense erosion makes marking a tedious process because the amount of exhibited fine detail is almost unlimited (see Fig. 7). Following the drainage ways from the rolling areas across the alluvium of the stream valleys is an exacting procedure (see Fig. 8).

Because of the exacting and tedious nature of the work and the possibility of developing eyestrain it has been found that such items as lighting, table height, and chair comfort are very important. By using a student lamp

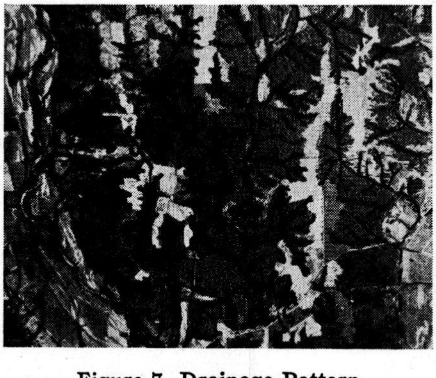


Figure 7. Drainage Pattern Characteristic of Hilly Areas

to aid materially in locating the gullies on the prints. From the standpoint of comfort the desk-table and office chair have proved to be proper equipment. In order to avoid errors due to fatigue caused by eye strain and

Figure 8. Drainage Pattern Characteristic of Flat Areas

miles each in order to handle the map conveniently. These small working drawings were traced in pencil on tracing paper from the large working drawing and the sections numbered in the proper sequence. However, inking the tracing-paper county working drawings and using them intact has been proved to be a better method.

Mechanics of Transfer

In constructing maps from airphotos, the past practice at the Joint Highway Research Project has been to follow such methods of data transfer as direct tracing, use of a sketchmaster, use of a pantograph, and sketching by eye. Each was found to contain numerous errors, both mechanical and human, which resulted in questionable accuracy. After considerable experimenting with lenses and projection equipment, it was found that airphoto data could be transferred at a reduction

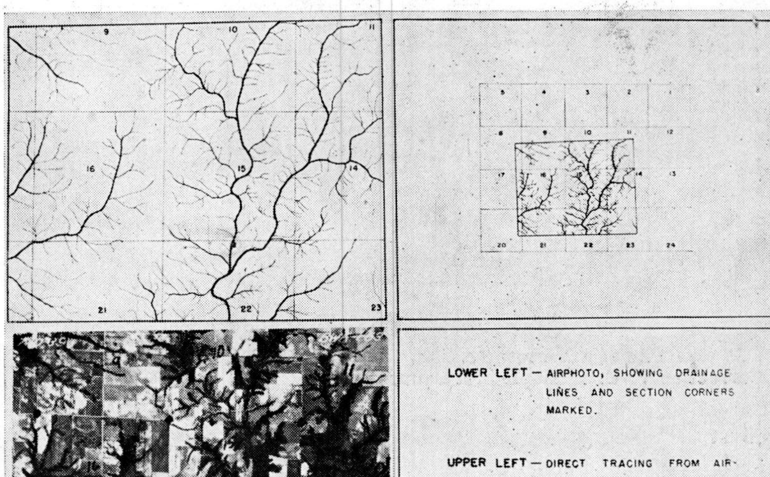


Figure 9. Comparison of Scales of Tracings Made from Airphotos. Map in upper right was made directly, at the reduced scale, from the airphoto in lower left by means of a reflectoscope.

cramped posture, short work periods are recommended.

Working Drawings

At first it was thought necessary to divide a county into townships or plots of 36 sq.

in size of from 3 in. per mile to 1 in. per mile merely by proper adjustment of the objective lens of a reflectoscope (see Fig. 9). This idea was used in the design of a reflection device, built around a classroom reflectoscope mounted on a sliding shelf, in which the image of the photo was transmitted through a lens system and prism onto a pane of plate glass. This device will be referred to as the transfer table (see Figs. 10 and 11). The images were recorded in pencil on the working drawings previously prepared on tracing paper. Small adjustments to fit the images to the scale of the working drawings are made by extending or retracting the reflectoscope extension and by changing the position of the entire projector by the manipulation of the sliding shelf. A focusing adjustment of the lens aid in image definition.

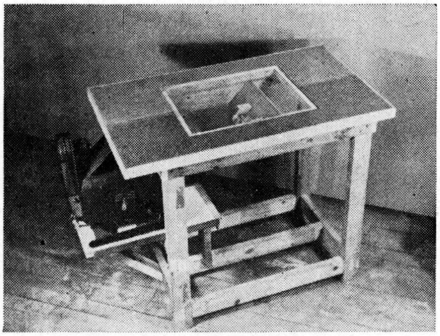


Figure 10. Transfer Table With a Classroom Reflectoscope in Place

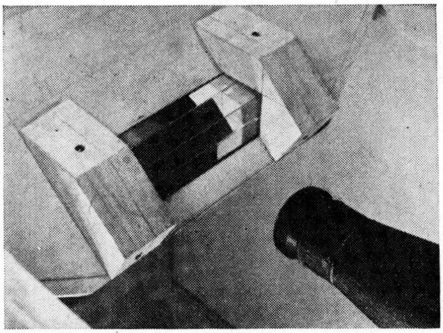


Figure 11. Details of the Prism and Objective Lens of the Reflectoscope

A commercial "Vertical Reflecting Projector,"[2] is on the market.

An airphoto to be transferred is inserted in the projector and the section corners of the image are adjusted so that they correspond to those on the working drawing. The blue drainage lines are then traced in pencil onto the working drawing (see Fig. 12). The airphoto is shifted in the projector so that its entire area produces an image on the working drawing thereby making it possible to transfer all of its drainage lines. An adjacent airphoto is then inserted and the procedure is repeated. The overlap of images proves beneficial in determining the proper scale adjustment. So long as the image of the airphoto section corners coincide with section corners of the working drawings, the transferring operation progresses smoothly. If distortions exist, either in the airphoto or in the working drawing, the section corners will not coincide. In such instances, those sections which do coincide are transferred first and the distorted ones are filled in after the images are expanded or reduced by adjustment of the lens system of the reflectoscope. Duplicate drainage lines in the overlapping areas of adjacent airphotos are made to coincide by similar adjustment of the reflectoscope. Thus the continuity of the drainage system is maintained.

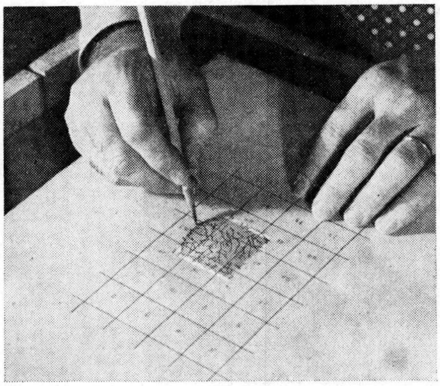


Figure 12. Working Drawing, Drainage Lines, and Projected Image of the Original Airphoto

The pencil working drawings are then traced in ink onto the prepared cloth county base map. Map symbols are identified by a legend (see Fig. 13). Major streams are shown by double lines, perennial creeks by heavy single lines, and intermittent drainage ways by light single lines. Solid lines give a clearer and more accurate picture of the drainage system than dashed lines. Cities and incorporated towns are indicated by areas bounded by dotted lines and cross-hatched with fine lines;

[2] "Photographic Instruments and Equipment, Cartographic Apparatus," Catalogue, Saltzman, Inc., New York, 1945.

small circles represent other towns and villages. When available, approximate elevations of the several towns are shown in small figures inclosed in parentheses; these elevations are usually railroad track elevations presumably at the depots in the various towns and cities. State and federal highways are indicated by heavy dotted lines. Section lines are shown by light solid single lines, and congressional township corners are indicated

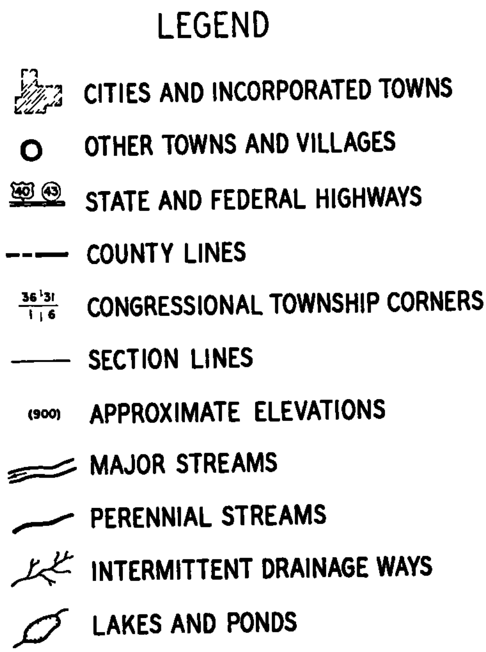


Figure 13. Established Symbols for Indicating Drainage Features and other Pertinent Data on the Drainage Maps

by numbering four adjacent sections. County lines are shown as "short dash-long dash" heavy lines. Lakes and ponds are shown as lightly shaded areas bounded by solid lines. The names of the major streams and their principal tributaries are added to facilitate the use of the maps. County names identify the respective maps.

Completed Maps

Figures 14, 15 and 16 are photographs of completed county drainage maps. Vermillion County, Indiana, lies within the region mantled by Wisconsin drift. The absence

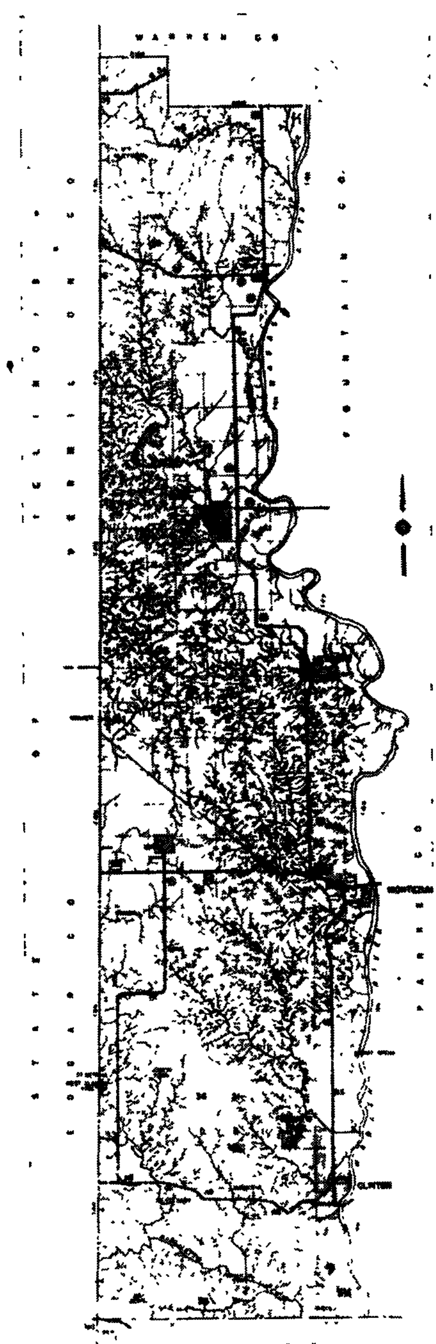


Figure 14. Drainage Map of Vermillion County, Indiana

of drainage ways indicates either undissected upland (in the western part of the county), or alluvial bottom land (adjacent to the Wabash river), or granular terraces (between the river alluvium and the valley wall). The dendritic ever, the drainage of the entire county is influenced by the exposed and underlying rocks (sandstone and shale). Consequently, the drainage pattern of the county is minutely dendritic.

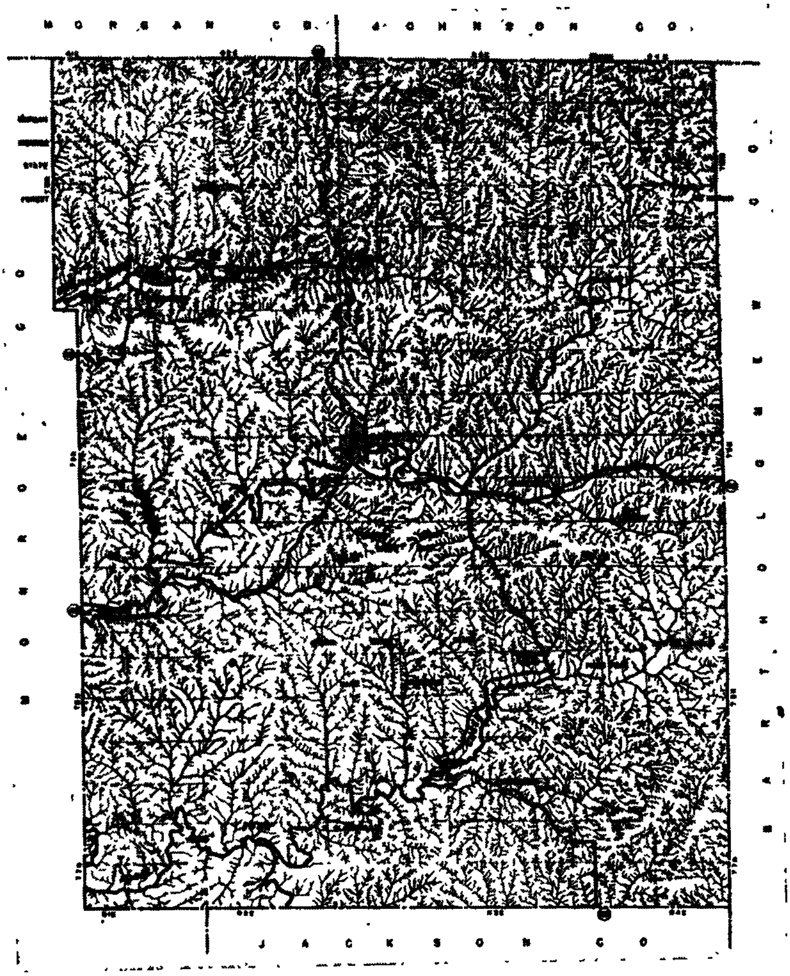


Figure 15. Drainage Map, Brown County, Indiana

nature of the remainder of the drainage map reflects the influence of the underlying sandstone and shale upon the eroding glacial drift which covers it.

The surface rocks of the central and western part of Brown County, Indiana, are unglaciated sandstone and shale. The surface covering of the northern and southeastern parts of the county is Illinoian glacial drift. However, the drainage of the entire county is influenced by the exposed and underlying rocks (sandstone and shale). Consequently, the drainage pattern of the county is minutely dendritic.

A portion of the Shelbyville Moraine (the terminal moraine of the Wisconsin glacier) occupies the northwest corner of Vigo County. The surface material of the eastern and southern parts of the county is Illinoian glacial drift (modified in places by thin loess). Between the silty alluvium bottom lands along the Wabash River and the uplands are wide terraces of sand and gravel; these terrace areas are conspicuous by the absence of drainage lines on the map.

Uses of the Drainage Maps

Drainage maps indicate the relief features of ridges and valleys by showing the exact location of all drainage ways; consequently, acres. This acreage estimate can be used in standard run-off formulas for calculating waterway areas in highway and airport structure design. Likewise, the location, definition, and measured areas of an entire stream system can be used in the design of flood control projects.

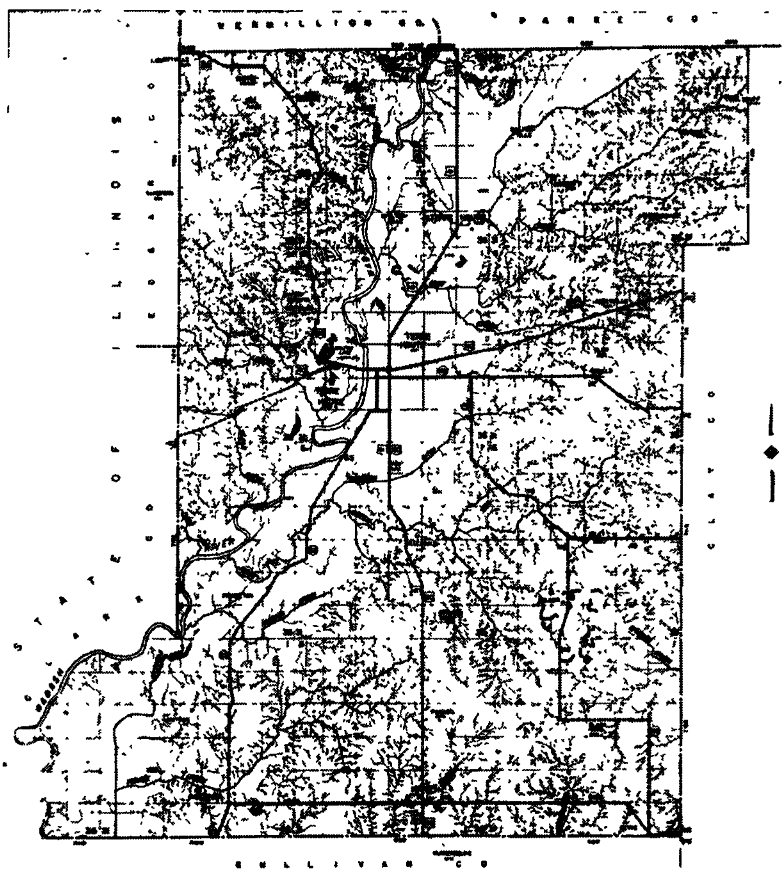


Figure 16. Drainage Map Of Vigo County, Indiana

the route of a projected highway can be planned to avoid many deep gullies. Drainage maps also indicate the size and shape of the many watershed areas; the detail is fine enough that the limits of each area can be defined accurately. Individual watershed areas, or portions of them, can be planimetered and the acreage closely determined. For instance, the shaded portion of the map in Figure 17 measures approximately 5,400

Because of insufficient waterway area of bridges and low profile of road approaches, many county roads are made impassable by inundation or damaged severely during stream floods (see Figure 18). Even state and federal highways, having low roadway embankment profiles across the alluvium of stream valleys, are often damaged by flash floods (see Figure 19). Occasionally the crowding of a great volume of flood water through a small bridge opening produces scour in the stream bed resulting in damage to the structure (see Figure 20). Had detailed drainage maps been available at the time these

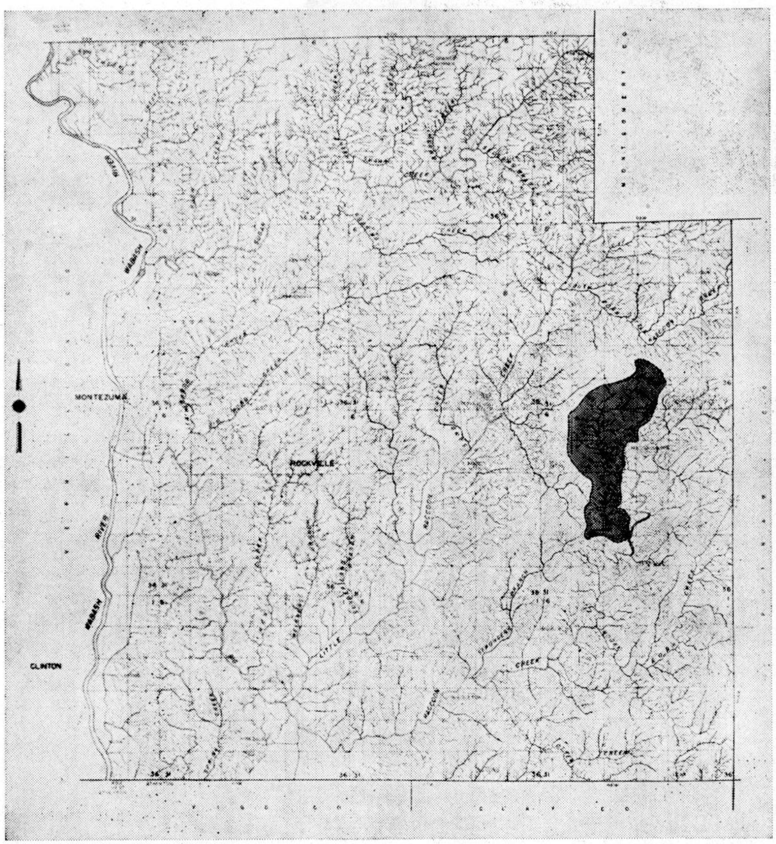


Figure 17. Complete Drainage Area of a Tributary of Big Racoon Creek in Parke County, Indiana. The area measures approximately 5400 acres.

structures were built, it would have been possible to have designed them adequately.

Cost of Constructing Drainage Maps

Accurate maps can be constructed in a reasonably short period of time. Table 1 presents the total number of hours and the time distribution required in the construction of the drainage map of Parke County, Indiana. Other mapping methods tried at the Joint Highway Research Project have proved to be time consuming and more or less unsatisfactory for accurate transfer of data. The total time consumed on the drainage map of Parke County, was 318 hr including the time of staff members and student assistants. Seventy-five percent of the time, or 238 hr, was staff member time; and 25 percent, or 80 hr, was student time. Of the 238 hr of staff

Figure 18. Washout in County Road Due to Stream Flooding

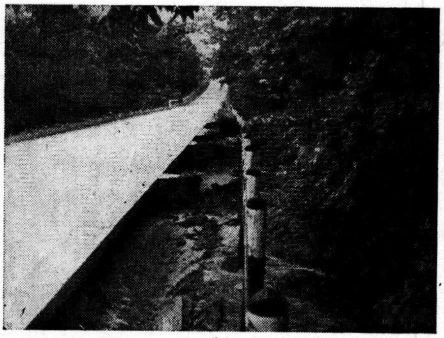


Figure 19. The subgrade of this bridge approach has been partially washed out by a flash flood.

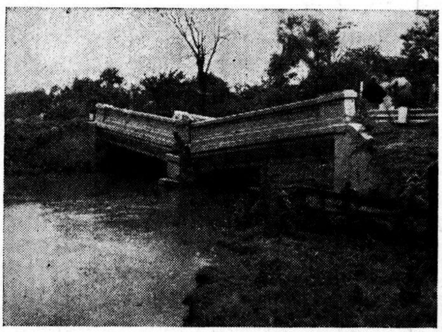


Figure 20. Bridge Failure Due to Scour Because of Insufficient Waterway Area

TABLE 1
TIME DISTRIBUTION DATA REQUIRED FOR DRAINAGE MAPPING, PARKE COUNTY, INDIANA

Item	Staff		Student	
	Hours	%	Hours	%
Mosaic Assembly	5	2	1	1
Section Corners, Marking	6	3		
Working Map				
a. County			25	31
b. Township			4	5
Drainage				
a. Marking	151	63	5	6
b. Transferring	76	32	2	3
c. Tracing Final Map			43	54
Total	238	100	80	100
Staff	238	75		
Student	80	25		
	318	100		

member time, 63 percent, or 151 hr, was required for marking drainage on the airphotos. Transferring drainage from the marked airphotos to the working maps required 32 percent of the time, or 76 hr. Miscellaneous operations of assembling the airphoto mosaic and marking section corners amounted to 5 percent, or 11 hr, of the total staff member time. Of the 80 hr spent by students in the various operations, 31 percent, or 25 hr, was spent in preparing the base map used in this study; 54 percent, or 43 hr, was spent in drafting the final map (tracing the working drawings); and 15 percent, or 12 hr, was spent in performing various miscellaneous operations in connection with mosaic assembly, preparation of township working drawings, marking drainage, and transferring drainage data from the airphotos to the working drawings.

CONCLUSIONS

On the basis of results obtained from experimental work in developing techniques and the completion of drainage maps for several counties in Indiana, certain conclusions have been reached:

1. Detailed drainage maps having a high degree of accuracy can be constructed by means of airphoto interpretation.

2. The cost of these drainage maps make them feasible from an economic standpoint, since contact aerial photographs are generally available at low cost, and the maps can be constructed in a reasonably short time with improvised equipment.

3. These drainage maps are of engineering value:

a. Because these maps show topographic irregularities and because they show the exact location and extent of all drainage ways, they present information concerning watershed areas, stream valleys, ridges, highly dissected regions, and flat areas. This information can be used in connection with preliminary surveys of flood control, highway, and airport locations.

b. The detail of these maps is fine enough that the limits of each watershed area can be defined accurately; therefore, drainage areas can be measured and the data used in the design of flood control, highway, and airport structures.

It is believed that the procedures followed in the preparation of these maps will expedite the construction of many more drainage maps to meet the increased demand for such engineering aids.

Acknowledgments

The author wishes to acknowledge, with sincere appreciation, the assistance given by all those who have helped in the preparation of this study. Special acknowledgments are due: Professor K. B. Woods, Associate Director of the Joint Highway Research Project for his valuable suggestions and review of the report; Members of the Joint Highway Research Project Advisory Board, for their active interest in furthering this study; and Mr. R. E. Frost, Research Engineer, for his guidance in the study and for his photographic assistance in preparing illustrative material

All airphotos used in connection with the preparation of this report automatically carry the following credit line: "Photographed for Field Service Branch—PMA—U. S. D. A."

USE OF STREAM-FLOW RECORDS IN DESIGN OF BRIDGE WATERWAYS

By Tate Dalrymple

Hydraulic Engineer, Water Resources Branch, U. S. Geological Survey

SYNOPSIS

The experience of the past few years has demonstrated that results obtained by use of the common formulas for sizes of bridge waterways have not been entirely satisfactory. Some structures have been underdesigned while others have been overdesigned. There is a present need for a method of computing bridge openings that is based upon a more sound evaluation of the basic factors than is contained in the formulas that have been used in the past.

The most logical basis for design of a structure that is to provide passage for the "water traffic" is the definite record of that traffic, stream-flow records. To calculate properly the size of a bridge opening requires among other things, a knowledge of the physical characteristics of the stream and its channel, the relation of the elevation of water surface to the discharge, and the magnitude and frequency of occurrence of flood discharges. From this information the factors to be computed are: the drop in water surface between a selected cross section in the approach channel and the bridge site, the drop in water surface through the bridge, the maximum height to which water may rise just upstream from bridge, the amount of backwater caused by bridge, and the velocities that will be produced. The results of these computations, reduced to a family of curves, furnish a basis for selection of the proper size of bridge opening. The final selections should be governed by the policy controlling the designing engineer in respect to frequency, hydraulic requirements, factor of safety, and economic considerations.

The physical characteristics of the stream channel can be ascertained by a relatively simple survey. The cross sectional area of the channel and its conveyance capacity, as computed from Manning's equation, should be recorded as curves, plotting each against elevations. The relation of water surface elevation to discharge is best expressed by a curve called a "rating curve." Defining such a curve involves the measurement of the discharge of the stream at a number of elevations, and is a basic relationship of a stream-gaging station. If the bridge site is at or near such a station it is a simple problem to define the rating curve at the site, but if there is no nearby gaging station an approximate rating curve can be made by transferring from another station or by a suitable analytical process.

The selection of the discharge to be used in the design should be guided by a knowledge of flood frequencies. The present practice of the Geological Survey in computing flood frequencies provides for the systematic compilation of the data and computation of plotting positions by a simple equation. Due to simplicity, the annual flood method makes it more attractive than the partial duration series method. Annual flood data are plotted on Gumbel graphs, although for general purposes the kind of graduation is of no great importance. However,