Highway Materials Research Laboratory
132 Graham Avenue, Lexington 29, Ky.
April 15, 1952

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To: Dean D. V. Terrell
Director of Research

At the meeting of the Research Committee on February 1, 1951, the Research Laboratory was directed to make a study of drainage from the standpoint of rainfall-runoff characteristics and means for estimating the openings required in small bridges and culverts. Specifically it was noted that the present system of runoff coefficients applicable to Talbot's formula and assigned to different regions of the state was developed years ago, and we were asked to reevaluate the system. An evaluation on the basis of structures in service was suggested.

Early in the conduct of the work, 25 culverts well distributed over the state were chosen for specific study, and arrangements for developing generalized records of peak flow were established. All the gauges were located reasonably close to existing rain gauges in order to utilize those records.

At the same time, the observations of existing structures were carried out on a large scale. Attempts were made to get a reasonable amount of data concerning their performance under different storms, and to build up an organized basis for working backward from a known culvert opening and known drainage area to an applicable "C" factor - based on the estimated adequacy or inadequacy of the opening.

After about eight months were spent on field work, it became obvious that this approach alone could be misleading. Some more fundamental considerations must be added if the results were to represent any improvement over the present design system. Accordingly, steps were taken to increase the scope of the project, utilize more records that have been developed by agencies which specialize in work of this sort, make some accurate measurements of rainfall-runoff characteristics on at least one drainage area, and insert some theoretical though sound concepts into the problem.

This has been done, and the machinery for collecting and analyzing data has been fairly well developed. Probably the weakest link lies in the lack of interest and cooperation on the part of some Department employees who were designated as observers of the peak-stage indicators at the 25 culverts mentioned above. Some of these have given prompt attention to the records and service on the indicators, some have given inconsistent or half-hearted attention, and some have given no attention at all. We are renewing our efforts to collect information from these sources, and are asking the continued cooperation of District Engineers in carrying this out.

As a means for orienting our thoughts, establishing a systematic approach, and organizing the methods of keeping records for future use, a written description of the project was started early this year. With additions of some background information and pertinent observations of field conditions, the material was worked into the form of the attached report entitled, "A Study of Runoff From Small Drainage Areas and the Openings In Attendant Drainage Structures," by Eugene M. West and J. O. Cornell.

The report is essentially a report of plans as well as progress. A great deal had been found in the work thus far, but tangible results that will accomplish the purpose as it was given to us are still in the future. I believe that within a period of six months to one year we will have worked the data to a point where a much improved system of estimating required openings can be recommended; following that the work will be largely a matter of compiling records which will be usable in a reevaluation - perhaps ten years in the future.

Respectfully submitted,

L. E. Gregg
L. E. Gregg
Assistant Director of Research

LEG:DDC
Copies to: Research Committee Members
Mack Galbreath (4)

Commonwealth of Kentucky
Department of Highways

Report No. 1

on

A STUDY OF RUNOFF FROM SMALL DRAINAGE AREAS AND THE OPENINGS IN ATTENDANT DRAINAGE STRUCTURES

by

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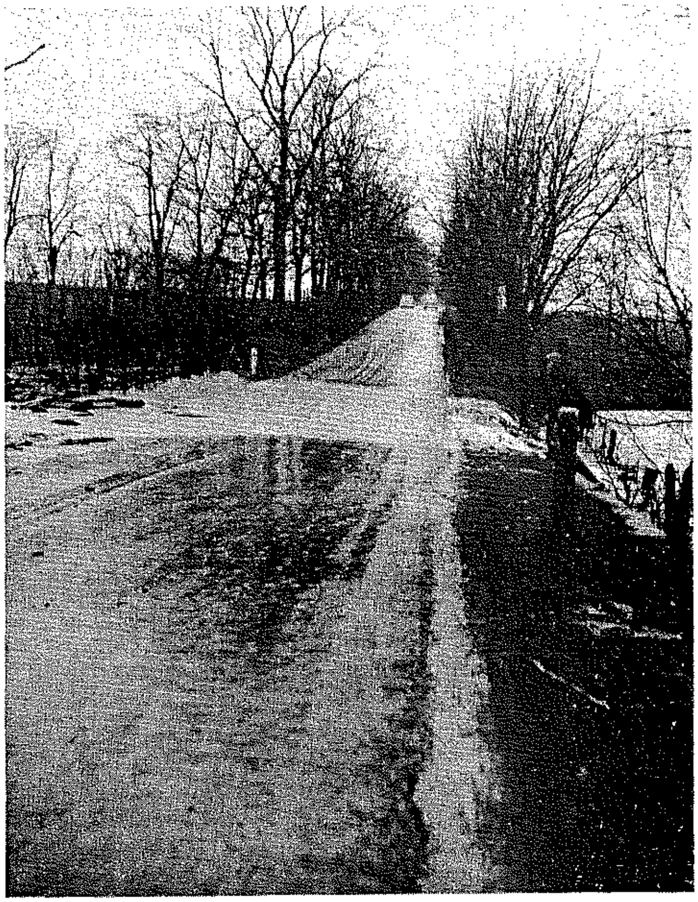
April, 1952



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ACKNOWLEDGMENT

The authors wish to acknowledge the contributions of Mr. W. A. Goodwin, formerly Research Engineer with the Kentucky Department of Highways, and now Assistant Research Engineer, College of Engineering, University of Tennessee. An initial draft of this manuscript was prepared largely through Mr. Goodwin's efforts, and in the planning of the project he made significant contributions through suggested procedures and the organization of a part of the reference material.

INTRODUCTION

In 1926, John T. Lynch read to the Kentucky Academy of Sciences a paper entitled, "The Relation Between Drainage Area and Waterway Required for Culverts and Small Bridges in Kentucky." The paper was based on a study of many small drainage structures then existing in the highway system, and a general evaluation of the performance of the structures in relation to rainfall and runoff from contributing watersheds.

As a result of this report, and in accordance with the suggestions contained in it, the Department of Highways adopted a system of runoff coefficients applicable to different sections of the state and usable in the empirical Talbot formula for computing the quantity of flow from a drainage area. This information was contained in the booklet of instructions for bridge and culvert surveys which has been in effect for almost 25 years.

From the beginning it was recognized that every small drainage area within a broad section of the state could not be adequately represented by a single runoff coefficient assigned to that entire section. However, very little data that could be used in making modifications for local conditions were available. Even so, guides and instructions (15)* applicable to drainage surveys carried a list of local conditions that should increase or decrease the "C" factors in any given locality, and it was suggested that modification be made by drainage engineers as experience accumulated.

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* - Numbers refer to list of references at the end of this report.

With a view toward integrating this experience, making further use of the many structures built since 1926, and establishing a more fundamental approach to the determination of probable runoff pertaining to small bridge and culvert design, it was requested that the Research Laboratory undertake a new study of drainage. This is the first report on that study.

For this report, much information had been taken from results of similar studies in other parts of the country, and a great deal of emphasis has been placed on the principles of hydrology and hydrologic analysis. The means for gathering new data have not yet been fully established, and results from that part which has been completed are limited. However, the report describes the approach which has been taken toward the problem, and outlines work which is visualized for the future.

HYDROLOGY AND HYDROLOGIC ANALYSIS

By definition, "hydrology is the science that deals with the processes governing the depletion and replenishment of the water resources of the land areas of the earth" (2). It deals with the occurrence and movement of water upon and beneath the earth's surface as well as through the air, and thus involves all the phases of the hydrologic cycle. It is a relatively new branch of the natural sciences with practically all the present advancement having been made within the present century. The concepts and methods employed in the approach to hydrologic problems are continually improving through research and continuous collection of statistical data.

The hydrologic cycle as influenced by the various movements of water in relation to the earth's surface, is illustrated pictorially in Fig. 1.

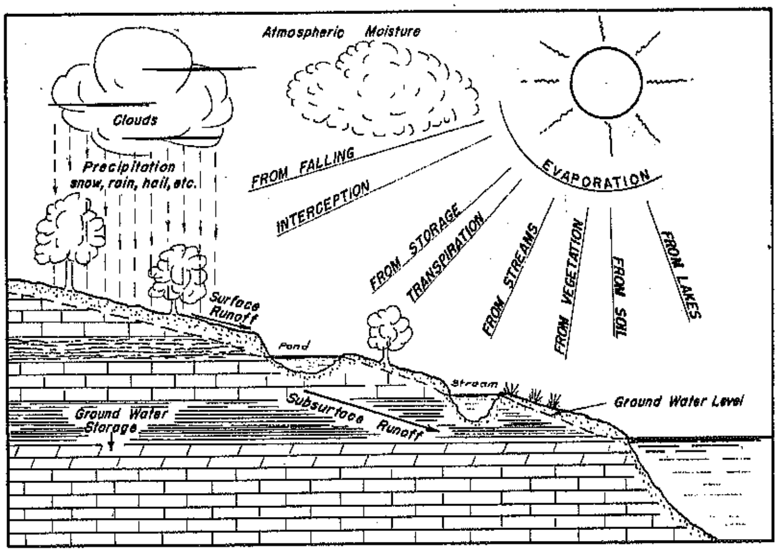


Fig. 1 - The Hydrologic Cycle.

Only a portion of the cycle can actually be considered in the solution of hydrologic problems, mainly because of the difficulties inherent in the measurement or evaluation of some minor losses such as evaporation, transpiration, and interception by vegetative cover.

Factors Influencing Rainfall-Runoff

Practically all applications of hydrology, and particularly those pertaining to the design of hydraulic structures, are dependent upon correlations between rainfall and ultimate surface runoff. Hydrologic analysis for this relationship involves as many measurements as possible, estimates for conditions that are not directly measurable, and calculation of the probable occurrence of rainfall based on past records.

Four specific factors and several miscellaneous factors have a bearing on the calculations and estimates.

Precipitation - Three features of rainfall are fundamental to hydrologic problems:

Intensity -	The rate at which rain falls for a given period, usually expressed as inches per hour.
Duration -	The time during which rainfall prevails at that rate, usually expressed in minutes.
Frequency -	The probable period of time within which combinations of intensity and duration repeat themselves, usually expressed in years.

Intensity and duration at any given location can be measured accurately with instruments, and frequently can be estimated on the basis of such measurements recorded over a period of years. Thus, the maximum combination of duration and intensity within a ten-year period may be termed a ten-year-storm, and when records are kept for a period of several decades, the probability of storms of a given magnitude occurring within a 10-, 25- or 50-year period can be computed. So far as design purposes are concerned, these would define the maximum precipitation anticipated within those periods of time.

Infiltration - The infiltration of water into the ground varies with the rainfall and the physiographic features of the land. For example, topography, permeability of the soils, vegetative cover, and other natural aspects of the land determine whether a small or large portion of the falling water infiltrates or runs off as surface drainage.

Infiltration capacity is the maximum rate at which rain can be absorbed into the soil, and this varies with conditions of rainfall. During a storm of considerable duration the quantity of infiltration is usually large at the beginning but decreases rapidly and becomes constant after a prolonged period. Rainfall intensity has an effect also, to the extent that a smaller portion of the total precipitation has an opportunity to enter the ground when rainfall is heavy than when it is light.

From the standpoint of rainfall-runoff characteristics, infiltration is a factor which represents a loss or a reduction in the percentage of total precipitation on a drainage area which contributes to flow in the stream serving that area. Even this can be vitiated if the duration of the storm is great enough for infiltrated water to become a part of subsurface drainage contributing to the stream at lower elevations.

Subsurface Runoff - Subsurface runoff is represented in the lateral movement of ground water that has infiltrated or in some manner passed beneath the earth's surface to reappear later as surface water at lower elevations through seeps, springs, artesion wells, and underground streams. In some localities subsurface runoff is the primary influence on stream flow, and in the great majority of cases it is a constant contributing factor.

Often the entire flow from a drainage area is in the form of subsurface runoff, the most outstanding example being the basin consisting entirely of one or more lime sinks. If a subsurface channel is the only outlet then the problem may often be directed toward the capacity of that outlet. However, where interest lies in the evaluation of subsurface drainage as a contribution to surface stream flow, estimates are difficult to make and measurements are practically impossible.

Surface Runoff - Surface runoff is that portion of the total precipitation remaining after the losses have been deducted. Waters that originated as surface runoff, plus the subsurface runoff entering a flow channel, constitute the total quantity that must be accommodated by a structure during a period of rainfall or peak flow. As in the case of infiltration, and in almost inverse proportion to it, the surface runoff is influenced by the character of the land and features related to the land.

In practically all instances the water that flows off the surface of the drainage basin determines the peak flow of a stream. That being the case, correlations sought in hydrologic analysis for small highway drainage structures are primarily dependent upon surface runoff during or immediately following an actual "peak" storm or a selected maximum design storm.

Miscellaneous Influences - Characteristics of drainage basin and of the storm reaching that basin cause large variations in the flow of a stream. Size and shape of the basin are, of course, major factors since the total quantity of water carried would be dependent upon both. Peak flow from a basin of some given size which was shaped such that surface runoff from all parts of the basin concentrated at the outlet simultaneously, would be much greater than flow from a basin of the same size but long and narrow in shape so that the time of travel for water from the several segments would be different. Under storms of a constant intensity and very long duration, these conditions would tend to equalize in their influence on peak flow.

In a similar way, a storm of given intensity moving across a long, narrow drainage area would afford a relatively short duration of fall on the area, and thus the total runoff would be smaller than if the storm traveled lengthwise over the watershed. It should even make a difference which direction the storm moved lengthwise over the area. A rainfall moving downstream for a given duration and at a certain intensity would probably cause a peak flow different from that of an equal storm moving upstream. Once again, if the rainfall continued for a long period of time these differences would tend to equalize.

For any given drainage area, and with all other factors remaining constant, a rainfall of high intensity and short duration would produce a high rate of runoff in comparison with a lower intensity rain of longer duration. Still, the peak flow in the stream could be greater with the less intense storm.

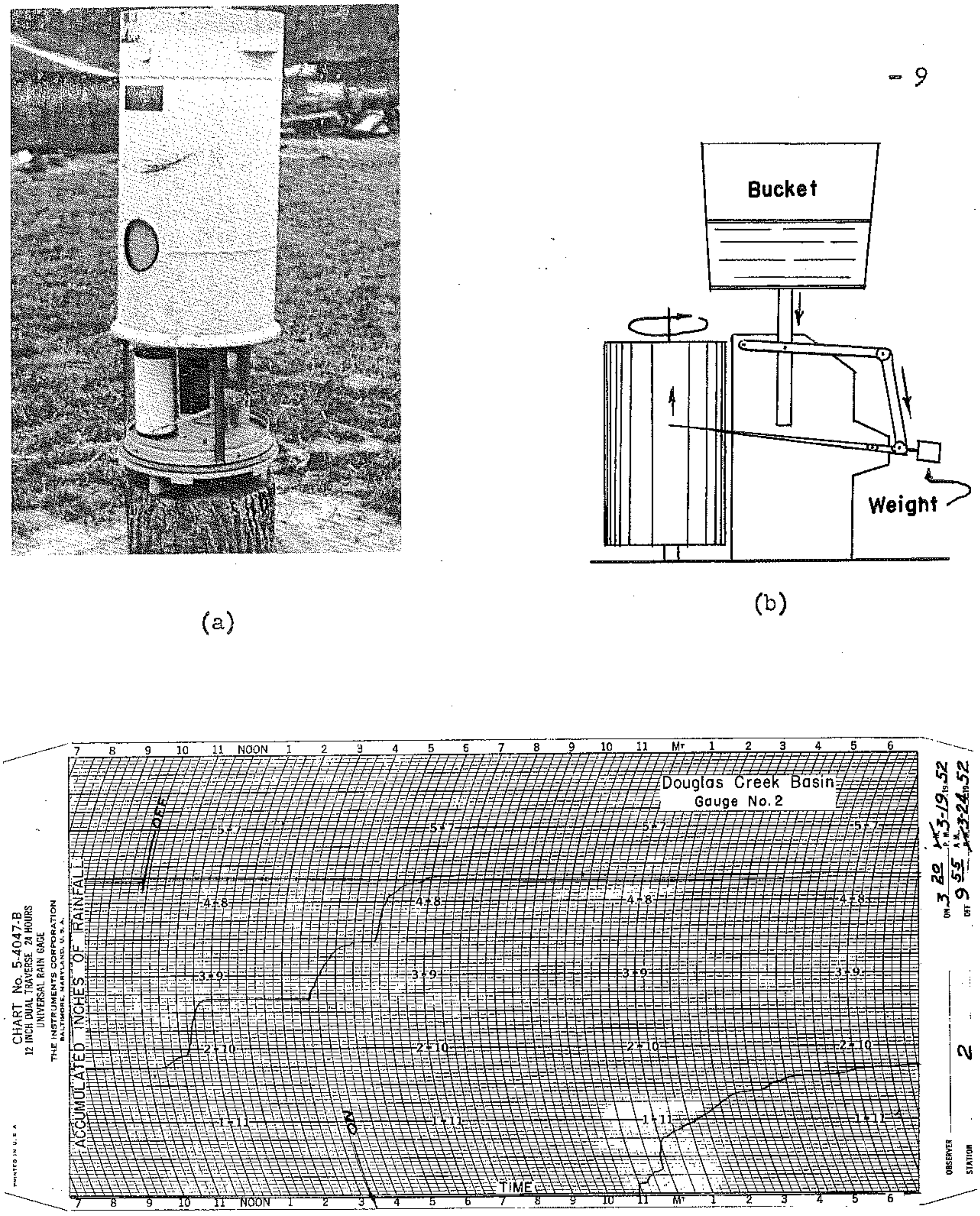
All the foregoing hydrologic principles indicate that for design purposes runoff rates and peak flows should be based on actual runoff measurement records whenever possible, but in the absence of such data the only recourse is some theoretical correlation of rainfall-runoff. Even then, the theoretical approach should be based on rainfall-runoff measurements taken under conditions comparable to those of the design drainage area.

Measuring Rainfall and Stream Flow

Stream flow and rainfall data are being continually accumulated and classified by various federal, state, local, and private agencies. In Kentucky, for example, there are more than 100 permanent rain-gauge stations operated by or contributing to the U.S. Weather Bureau, and all have produced records over a period of at least ten years. Several have records past 50 years. Stream flow records are about equally widespread, but most of these have been made for large streams and rivers with contributory watersheds several hundred square miles in size.

Actually, the greatest deficiency in records lies with the very few measurements of both types on areas small enough to have been covered completely by a measured storm for a reasonable length of time. This has been given more recognition during the past few years, and the installations on small watersheds are increasing.

Rainfall Measurements and Records - Two general types of gauges are used in the determination of rainfall-recording and non-recording. The latter is but a limited version of the recording gauge, and the only thing in its favor is the cost. Recording gauges, as illustrated in Fig. 2, are



(a)

(b)

(c)

Fig. 2. Recording rain gauge (a) with jacket lifted to show the mechanism, and (b) illustrated diagrammatically. The water is contained in a bucket at the top of the gauge, and weighed in such a manner thatthe variations in weight with time are converted to inches of rainfall and recorded on a chart, one of which is shown in (c).

made such that the occurrence and variation of rainfall with time is charted over a given period which is usually seven days or longer. Hence, the gauges require only a minimum of attention yet the record is positive with respect to time elements and increments of rainfall.

All records from the various stations are brought together and analyzed continuously for extended compilation and in some cases publication. Prior to the fall of 1951, the records of hourly rainfall from all the stations were published in a pamphlet entitled, "Climatological Data," issued monthly by the U.S. Weather Bureau. Several years ago more extensive publications of "Daily and Hourly Precipitation" were made up each month by the Weather Bureau in cooperation with the U.S. Corps of Engineers and the Department of Agriculture branch dealing with flood control, but that was discontinued in 1948.

Apparently, the measurements of rainfall have been continued at the same level for all stations, but the reduction of charts to hourly precipitation listings has been eliminated in the interest of economy. Thus, the records from all stations are on file, but they are no longer available to the public in usable form. This situation is a handicap in any statewide evaluation of rainfall-runoff characteristics mainly because of its effect on the determination of design storm conditions and to some extent because of its relation to the actual rainfall on watersheds within a broad area surrounding the gauge.

<u>Stream Gauging and Rating</u> - Actual runoff from a watershed can be determined by gauging the stream which serves as the outlet from the basin. The procedure consists of determinations for the rate of flow at the chosen

section, and correlation of that flow with various stages of depth. The rate of flow, usually expressed in cubic feet per second, is generally computed from velocity measurements made with a current meter (Fig. 3). Through a prescribed method (14) (16) of suspension of the meter in different segments across the channel, a mean velocity measurement can be defined by the revolutions of the meter in a certain time.

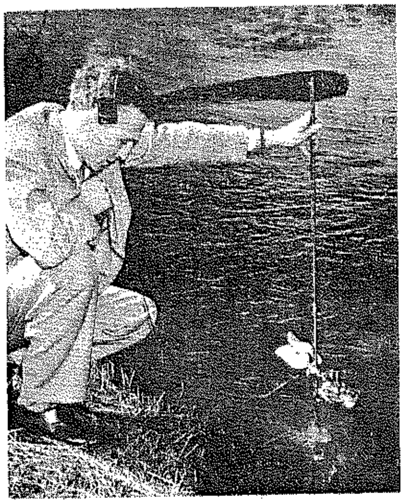
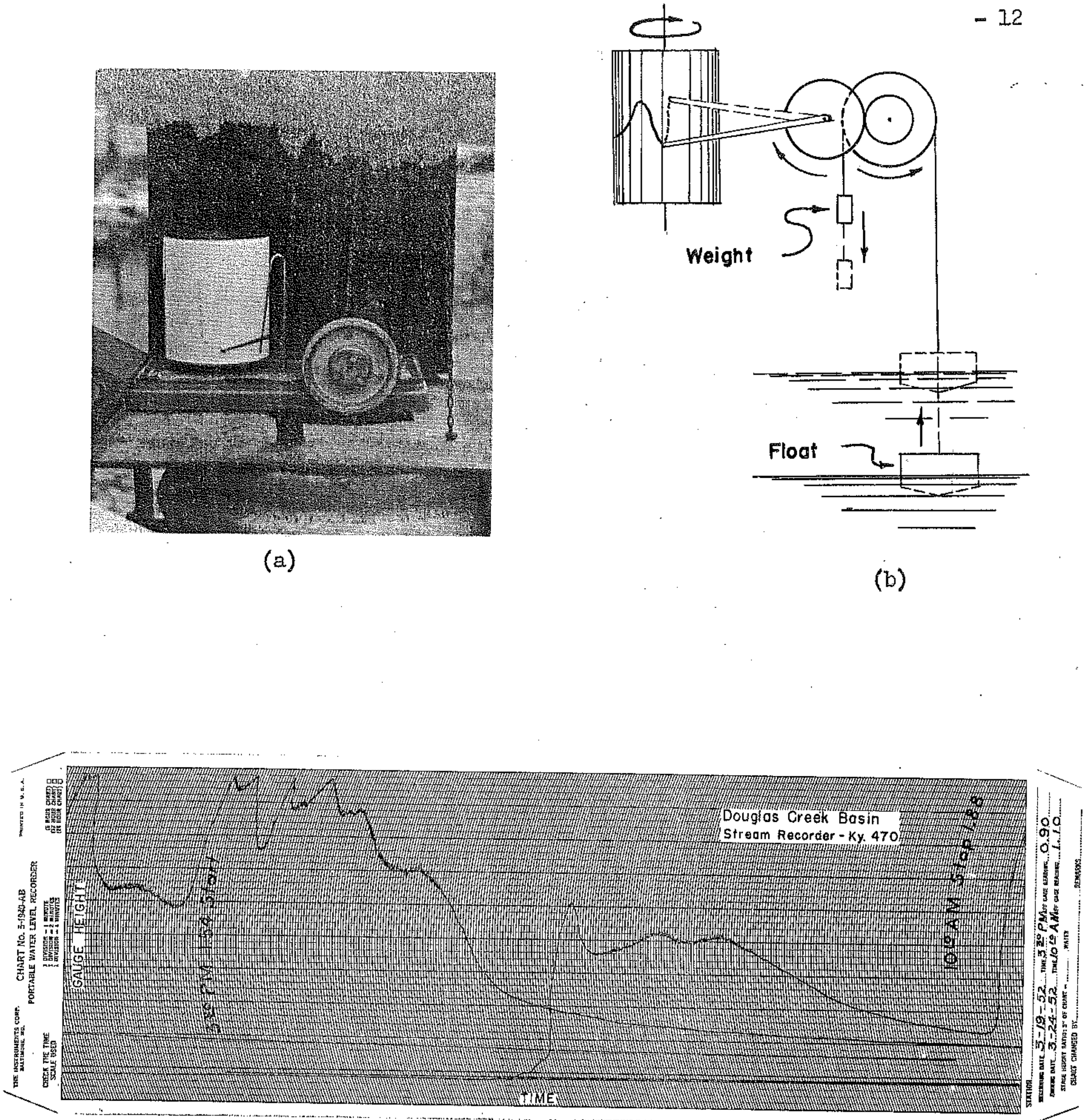


Fig. 3 One type of current meter used in the determination of stream velocities. These, in turn, may be converted to quantity of flow when the cross-sectional area of the channel has been measured.

The depth of flow or stage of the stream at the chosen sections can be obtained by direct manual measurement, but to maintain a continuous record of the runoff it is necessary to have a continuous record of the gauge height. Accordingly, reliable records can be made when an automatic gauge-height recorder has been installed and the zero reading of the gauge indexed with the lowest point of flow in the channel at the chosen section.



(a)

(b)

(c)

Fig. 4. Automatic gauge height recorder (a) with cover lifted to show the mechanism, and (b) illustrated diagrammatically. As the stream level rises the float is lifted and this motion is transferred by the linkage of the device to the needle which marks a chart (c) attached to the revolving cylinder. Fig. 11 shows a complete gauge installation.

An automatic gauge-height recorder, as illustrated in Fig. 4, is a mechanical device which records the variations in the stage on a graphic chart.

When a sufficient number of gauge height-discharge relations have been determined over a period of time, the stream may be rated by means of a rating curve such as the one illustrated in Fig. 5. This curve defines the characteristics of the stream at that point, and with such a curve established it is possible thereafter to obtain the discharge at any time by simply noting the gauge height.

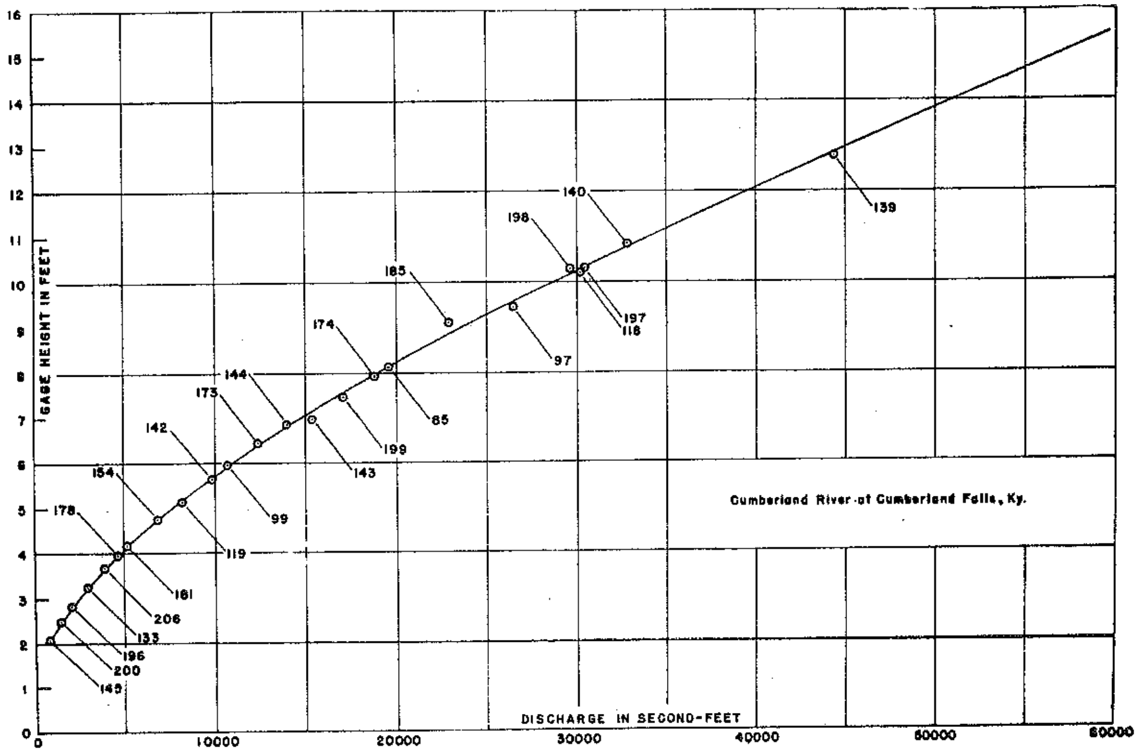


Fig. 5 Rating curve showing the relation between stage and discharge of the Cumberland River at Cumberland Falls, Kentucky. Data by Schrader (7).

On small drainage areas fairly accurate stream ratings or determinations of discharge at high flow can be established by dispensing with current meter measurements and placing peak-stage indicators in series - one at the inlet and one at the outlet of a culvert. Readings taken from the sticks in the indicators serve the purpose of slope-area computations for discharge by the Manning formula (6)(13)(17).

In cases where there are automatic rain gauges (one or more) placed on the watershed, and an automatic stream recorder or even the pair of peak-stage indicators measure attendant discharge, the rainfall-runoff characteristics are established directly. However, in view of the variable hydrologic influences discussed previously, one set of measurements is not sufficient to establish runoff under subsequent storms of given magnitude; it merely defines the runoff caused by one particular storm, and the next one may produce a different relationship. Thus, the more sets of readings taken and the longer the period of time represented, the more reliable the relationship, particularly where the information is to serve as a basis for estimating peak flow from other drainage areas having similar characteristics.

With regard to stream flow records as such, the U.S.G.S. operates approximately 100 gauging stations in Kentucky, and the data are published along with those from other states in "Water Supply Papers" which are issued annually. Although practically all the gauges are located on streams much larger than those spanned by small bridges and culverts, the records are valuable in hydrologic analysis of small drainage areas as indicators of peak-flow frequency.

Analysis for Peak Flow Conditions

Almost invariably when a structure of any sort involving hydrologic influences is planned, there are no rainfall-runoff data from the project location; or if there are such data, the period of time covered is limited. Hence, prediction and estimation are inherent in hydrologic analysis. The several influences have been summarized and interrelated in numerous curves, charts, graphs, formulas, and other modes of expression all directed toward one thing - the maximum flow from a drainage area under any combination of circumstances. Each approach is in essence a theory by which the flow can be predicted, and it goes without saying that the discharge calculated by means of one theory will rarely check that by another for some given problem.

Flood Frequency Determinations - First in the line of predictions or estimates is the frequency of flood flow, or in the case of runoff calculations, the storm frequency. If records have been kept for some period of time at the project location, it is possible through one of numerous approaches to estimate the frequency of flood flow at that point. This is done by projection of data far past the period of time represented by the records. If measurements have not been made at the location in question or under circumstances reliably similar to it, then the problem involves estimates of runoff which in turn involves estimates of storm frequency.

Frequency is a factor that enters at the design stage when it is necessary to establish the quantity of flow the structure must accommodate without fail. Thus, common practice is to design for a 10-year, 25-year or perhaps some other period up to a 100-year flood flow; likewise, to calculate discharge produced by a 10-, 25- or 100-year storm. Contrary to conditions implied, this does not mean that the flow or storm so selected is anticipated only once and no more during the described interval. Instead, it essentially defines "...the average interval of time within which... (a given flood)...will be equaled or exceeded once in the mean" (3).

For the most part, frequency methods are based on flow measurements from widely scattered streams and drainage basins, and inasmuch as they are limited in numbers, comparability, and the time over which they were taken, the results are approximate at best. The procedure used in determination of frequency should be selected and applied by someone well versed in the theory and experienced in the use of such data. It involves more than just direct calculations from formulus on which there is fairly general agreement.

In brief, the recurrence interval of a flood of given magnitude may be expressed as:

$$T = \frac{N + 1}{M}$$

where: T = Recurrence interval in years

N = Number of years of record

M = Order of magnitude assigned to the storm in a series

As a means of illustration, Dalrymple (17) uses the following example: "Assume a discharge of 1000 sec. ft. in 1850; the record begins in 1910, but the above stands as 'maximum known' until 1938, when a discharge of 2000 sec. ft. was recorded. Hence, plotting positions* (up to and including the 1946 flood) would be:

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* - Authors Note: position of points on a special type graph of discharges versus recurrence intervals, thus defining a flood frequency curve.

Max. flood in 95 yr. period	$\frac{95 + 1}{1}$	96 yr.	2000 sec. ft.
2nd highest in 95 yr. period	$\frac{95 + 1}{2}$	48 yr.	1000 sec. ft.
2nd highest in 35 yr. period	$\frac{35 + 1}{2}$	18 yr.	800 sec. ft.
3rd highest in 35 yr. period	$\frac{35 + 1}{3}$	12 yr.	600 sec. ft.

etc.".

This, of course, includes a known maximum falling outside the years of record, which is a case that is probably seldom met.

The recurrence intervals thus determined are an expression of the percent chance that a storm of any magnitude will occur within the interval thus calculated. After records have been kept for that period or longer in the future, the relationship calculated in the same manner would be different. It should be noted that different interpretations of the records can be made in assigning the order of magnitude of the floods, and it makes a difference whether just annual peak flows or flows exceeding a given base value are used in this determination.

Other expressions of flood frequency, such as those relating momentary peaks to mean annual peaks, are used in estimating, and also rainfall frequency has been variably expressed. By one approach, comparable with that representing flood frequency, the recurrence interval of rainfall of given intensity is:

$$T = \frac{N}{M - 1/2}$$

In this case, M is referred to the order of magnitude of recorded rainfall during a selected time of duration. As a minimum, ten years of record should be available before these approaches are considered reasonably valid.

In the choice of design discharge or a design storm for highway drainage structures, consideration should be given to the location and importance of the project, the class of road, the economic loss and inconvenience to traffic involved, and the influence on adjoining property. It is a recognized fact that few, if any, small drainage structures can be economically made equal to all storms. California (5), for example, has a recommended design criterion by which a culvert will flow full while accommodating a 10-year storm, and serious damage will be avoided with the flow from a 100-year storm.

Empirical Formulas - There are several long-established flood-flow formulas which have been or are used in the estimation of runoff. Most workers in the field who rely on formulas develop confidence in one or more of these approaches, and introduce into them a great deal of experience and judgement. Unless they are treated in this way, or a system of assigned factors based on experience and judgement is available, the formulas are practically worthless.

One of the most prominent of these is the Talbot formula which was the basis for the original work in Kentucky by Lynch. It is the present basis for hydraulic design of culverts. This formula, which was developed from a study of railroad bridges in the Mississippi Valley, is expressed as:

$$a = C\,A^{\frac{3}{4}}$$

where: a = Required area of waterway in square feet

A = Drainage area in acres

C = An empirical factor representing all other conditions influencing runoff

Naturally the factor "C" is always the point of principal concern in the application of the formula. Originally the "C" values were set roughly at 1/3 for flat, 2/3 for rolling, an 1.0 for hilly terain, but in its application to Kentucky the formula with these values inserted was soon recognized as seriously inaccurate. Obviously, it should be because too many variables - such as rainfall, soils or rock formations, vegetation, etc. - were ignored.

The work by Lynch was directed toward the establishment of "C" values to fit different parts of the state, and as a result the state was zoned for these factors ranging from 0.4 to 2.0, as shown in a map (Fig. 19) in the Appendix of this report. For the past ten years these values have been applied largely without modification, although it was noted in the Lynch report and in subsequent instructional material (15) that modifications should be made to the maximum extent permissible by observations, experience and records.

A variation of the Talbot formula directed toward design discharge instead of design opening is the so-called Dickens formula. This is stated as:

$$Q = C A^{\frac{3}{4}}$$

Here the assumption that discharge Q (in cubic feet per second) is proportional to the 3/4 power of drainage area (in square miles), merely changes the relations for simpliefied computation and injects velocity as a direct influence in the "C" factor. The same need for experience and judgement remains.

A number of other formulas with an equal amount of "unknowns" represent in the runoff factors have been proposed for flood-flow estimates, and in some cases prominent conditions formerly included in the general "C" factors have been separated and given recognition as measurable quantities. One example is the *Burkli-Ziegler* formula which states that:

$$Q = A\ R\ C\ (S/A)^{\frac{1}{4}}$$

where: Q = Discharge quantity in cubic feet per second

A = Drainage area in acres

R = Intensity of rainfall in inches per hour during a storm of design frequency

S = Average slope of the ground contained in the drainage area in feet per 1000 feet

C = Runoff coefficient

Values of "C" applicable to this combination range from about 0.20 for open, sandy farmland, where infiltration would be great, to about 0.75 for urban business districts where there is practically no infiltration. The formula was developed primarily from observations and records in urban areas, with a view toward storm sewer design. Its application to design of culverts in rural sections is undoubtedly valid, provided the different factors have been evaluated sufficiently for such areas. Because of the manner of recognition for the separate variables, this approach may be termed semi-rational.

It occupies a middle ground between the old condensed formulas which are generalized statements of hydrologic relationships, and the more recent approaches by which separate evaluations of the factors are attempted individually and then related through a general equation.

Rational Method - The so-called rational method of approach (18), was a logical step in the development of hydrologic analysis when accumulated observations and records were numerous and representative enough to become statistically significant. Once more the general equation relates discharge to area, with rainfall intensity and the always present "C" factor or runoff coefficient determining the relationship. The general equation is stated simply as:

$$Q = C\ i\ A$$

where: Q = Discharge in cubic feet per second

i = Average rainfall intensity in inches per hour

A = Drainage area in acres

C = Runoff factor

Not all the variables lie within the runoff coefficient, and that coefficient itself is expressly defined as the ratio of maximum peak flow per acre divided by the rate of rainfall throughout the "period of concentration." Similarly rainfall intensity is related to time of concentration of the drainage area, and to the storm frequency characteristics.

Specifically, rainfall intensity is the average rate of rainfall divided by the entire area during the time of concentration for the drainage area. Time of concentration, in turn, is the time required for the water to flow from the furthermost point in the drainage area to the outlet. It represents the time interval from the beginning of a rain until the peak discharge is obtained at the outlet, and of course this is influenced by slope, roughness, and shape of both the watershed and the channel. All are separately evaluated on the basis of analyzed records and measurements from a variety of streams and drainage areas in different parts of the country.

Obviously, the calculated discharge is no better than the data representing the separate factors. Fortunately, records have been accumulated at an accelerated rate during the past 20 years, and these increased the possibilities for accurate evaluation of the factors. As a result, modifications of the original rational approach have developed (19).

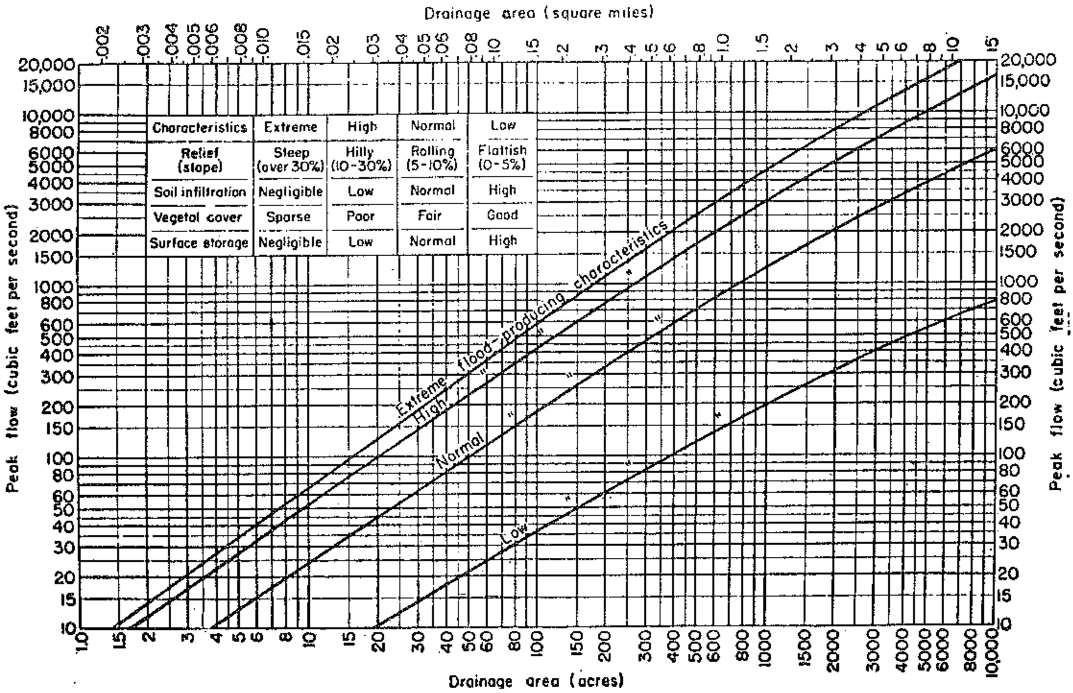
The time of concentration, now a recognized fundamental concept in all peak runoff determinations, is a measurable factor but one that is difficult to evaluate when there are no measurements. Because of the fact that recorder measurements are seldom available for project locations, considerable emphasis has been placed on development of formulas for the solution of times of concentration representative of drainage areas having different characteristics.

Charts and Graphs - Mainly through the rational method or variations of that method, some agencies or states have developed charts and graphs from which the desired flow requirements or openings can be taken when the various influencing factors have been measured or estimated. Outstanding in the highway field are those proposed and used by Ohio, California (4) (5), and the Bureau of Public Roads (6).

Whenever possible, the charts reflect local conditions, and the numerical values of the scales on the chart were based on studies of these local conditions. The Bureau of Public Roads chart, which is shown in Fig. 6, necessarily is more general than those developed within a given state. However, the curves were derived from measured and recorded data, with certain assumptions interjected.

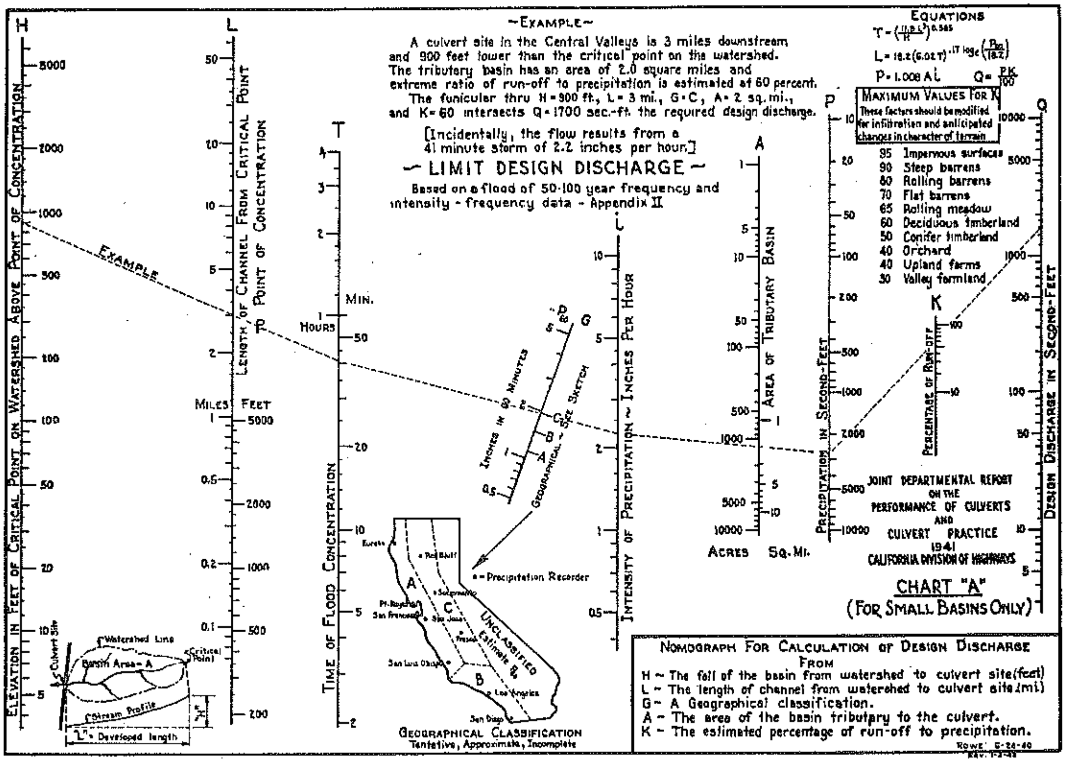
Use of the chart for a given problem involves classification of the drainage area in accordance with the tabulated characteristics in the upper left of Fig. 6, and a new line of flood-producing characteristics may be drawn in by interpolation between the existing curves if conditions warrant it. After the curve of flood-producing characteristics is selected, the peak flow is read directly from the curve where it intersects the vertical line representing the size of the drainage area.

This, as noted, in the discharge produced by a one-hour rainfall of 2.75 inches, and to convert to discharge under a different rainfall the value picked from the chart is multiplied by the ratio of the design rainfall to the 2.75 inch rain for which the chart was drawn. Experience gained through rainfall-runoff measurements could be used for local adaptations of the chart, by merely plotting in the recorded values accumulated over a period of several years. If the information is to be applied within a broad region, then the records should cover several drainage areas having a variety of characteristics.



Characteristics	Extreme	High	Normal	Low
Relief (slope)	Steep (over 30%)	Hilly (10-30%)	Rolling (5-10%)	Flattish (0-5%)
Soil infiltration	Negligible	Low	Normal	High
Vegetal cover	Sparse	Poor	Fair	Good
Surface storage	Negligible	Low	Normal	High

Fig. 6. Bureau of Public Roads chart for estimating peak runoff from storms of 25-year frequency having one-hour rainfall of 2.75 inches (6).


~EXAMPLE~

A culvert site in the Central Valleys is 3 miles downstream and 900 feet lower than the critical point on the watershed. The tributary basin has an area of 2.0 square miles and extreme ratio of run-off to precipitation is estimated at 60 percent.

The funicular thru H = 900 ft., L = 3 mi., G = C, A = 2 sq. mi., and K = 60 intersects Q = 1700 sec.-ft. the required design discharge.

[Incidentally, the flow results from a 41 minute storm of 2.2 inches per hour.]

~ LIMIT DESIGN DISCHARGE ~

Based on a flood of 50-100 year frequency and intensity - frequency data - Appendix II

EQUATIONS

$T = \left(\frac{11.9 L^3}{H}\right)^{0.385}$

$i = 18.2(6.02T)^{.17 \log_e\left(\frac{P_{60}}{18.2}\right)}$

$P = 1.008 A i$ $Q = \frac{PK}{100}$

MAXIMUM VALUES FOR K

These factors should be modified for infiltration and anticipated changes in character of terrain

95	Impervious surfaces
90	Steep barrens
80	Rolling barrens
70	Flat barrens
65	Rolling meadow
60	Deciduous timberland
50	Conifer timberland
40	Orchard
40	Upland farms
30	Valley farmland

JOINT DEPARTMENTAL REPORT ON THE PERFORMANCE OF CULVERTS AND CULVERT PRACTICE 1941 CALIFORNIA DIVISION OF HIGHWAYS

CHART "A"
(FOR SMALL BASINS ONLY)

NOMOGRAPH FOR CALCULATION OF DESIGN DISCHARGE FROM

H ~ The fall of the basin from watershed to culvert site (feet)
L ~ The length of channel from watershed to culvert site (mi)
G ~ A Geographical classification.
A ~ The area of the basin tributary to the culvert.
K ~ The estimated percentage of run-off to precipitation.

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FIGURE 2. Chart A for calculation of "design discharge" by a new formula in nomographic form

Fig. 7. California chart for the calculation of design discharge (5).

One of the most extensive published works involving a chart relating various factors, is the one carried out by California (5) a few years ago. As a result of those studies, a recommended approach to determination of runoff was summarized in a nomographic chart. The chart, as illustrated in Fig. 7, has the state divided into four graphical classifications, and the variables are related in accordance with a series of mathematical equations somewhat on the order of the rational method.

For a situation within any one of the geographical zones, four principal variables (which are measurable) determine the positions on the graph. These variables, as noted in the lower right corner of Fig. 7, are:

1. Fall of the basin or channel from the furthermost point to the culvert site in feet.
2. Length of the channel from the furthermost point to the culvert site in miles.
3. Drainage area in either square miles or acres.
4. Estimated percentage of runoff in relation to the precipitation.

All the conditions are based on a 41-minute storm of 2.2 inches per hour, and the coverage is limited to drainage basins 10 square miles or smaller in area.

It should be noted that most of the factors involved in the empirical formulas or the rational approach previously discussed are represented in the combination of equations interrelated by this chart. The runoff coefficient "K" in this case corresponds to the "C" factor in several other formulas, and time of concentration enters in the same manner as it did in the first rational approach, but its mathematical expression is considerably different. The chart, in essence, represents a rational evaluation of runoff factors peculiar to different sections of California, and integration of those factors in a solution for probable runoff from a storm of about 50 to 100 year frequency.

Unit Hydrograph - One of the most fundamental methods for determining surface runoff under different rainfall conditions is the unit-hydrograph method. This is applicable only when data have been collected by stream gauges and rain gauges, for a definite runoff-time relation must be known before the unit hydrograph is established.

The theory from which the unit hydrograph method was derived, makes use of three basic principles:

1. For a given drainage basin, the duration of surface runoff is essentially constant for all unit storms regardless of their intensity or of differences in the total volume of surface runoff.

2. For a given drainage basin, if two uniform-intensity storms of the same length produce different total volumes of surface runoff, then the rates of surface runoff at corresponding time "t" after the beginning of two storms are in the same proportion to each other as the total volume of surface runoff.

3. The time distribution of surface runoff from a given storm period is independent of concurrent runoff from atecedent storm periods.

The term, unit storm, refers to any storm of such duration that its surface runoff is equal to or greater than that of any storm of shorter duration. For every drainage basin, there is a certain unit storm period such that all storms of that duration or less, the period of surface runoff will be the same regardless of the intensity. The period of rise is approximately the same for all unit storm intensities.

Similarity between imaginary unit hydrographs is illustrated in Fig. 8. The significance lies in the fact that arithmetic expansion of the measured hydrograph for a light rainfall produces an outline which nearly duplicates the measured unit hydrograph for the heavy rainfall. This being so, hydrologic data for any unit storm may be projected for a very close approximation of runoff from much larger storms on the same drainage area.

In determining the surface runoff by means of the unit hydrograph theory, it should be recognized that the relationships are not absolutely fixed and the principles do not include all the influencing factors. However, it has been accepted that the errors introduced by disregarding these influences are usually minor, and the method is regarded as a sound approach to one phase of runoff determinations.

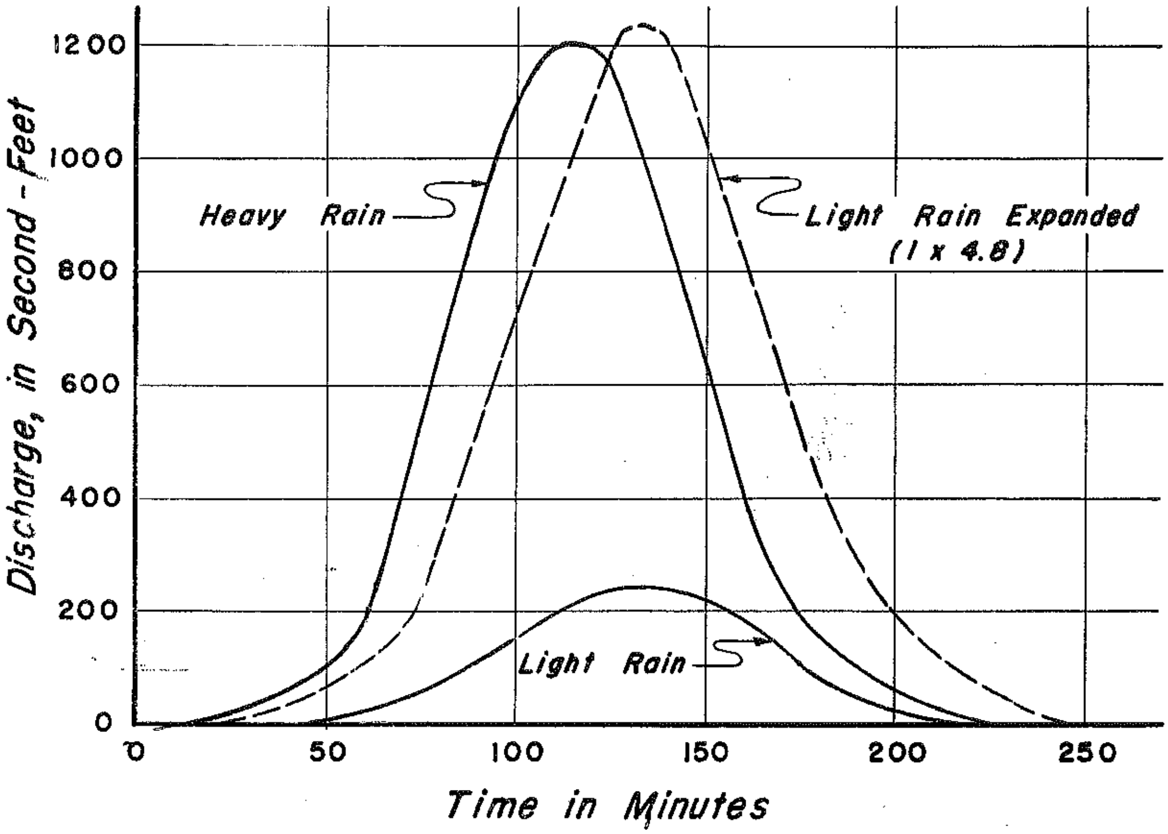


Fig. 8. Simplified hydrographs relating discharge and time for a given drainage area. Note the indicated similarity of measured and calculated graphs representing heavy rainfall.

INVESTIGATIONAL METHODS

The procedures which have been used thus far in this study are in four different categories according to the type of observations and the records involved. None of the four by itself is a significant basis for estimating rainfall-runoff conditions statewide, but in combination they provide a fairly broad coverage. In some categories additional coverage is planned, and in all categories the records will be compiled over a period from six months to several years.

All of the work has been directed toward evaluation and possibly revision of the present basis for estimating the size of openings required in small bridges, culverts, or cross-drains. Because they are fundamental to the problem, rainfall-runoff determinations have been given primary emphasis; however, the greater amount of effort has gone into surveys of existing structures, the intent being to evaluate their performance in relation to runoff factors assumed at the time of design. As an adjunct to the surveys, attention has been given to several features which are extraneous to runoff determinations but still of considerable influence on the efficiency of a structure and its ability to accommodate water flowing from the drainage basin.

Peak-Stage Indicators

At the outset of the project, a simple and inexpensive way of measuring the height of flow in culverts was sought, in order to establish some record of flow conditions in many structures scattered throughout the state.

As a result, peak-stage indicators of the type shown in Fig. 9 were adopted.

These devices consist of a length of 2-inch galvanized pipe capped top and bottom, and containing a 1-inch square measuring stick held erect by a clamp on the top cap. The bottom cap is perforated with several 1/8-inch holes to admit water as the stream rises. A Mixture of lamp black and ground cork placed in the pipe rises with the water level, and ultimately leaves a mark at the elevation of the peak stream stage. An indicator was bolted to one wing at the inlet of each structure selected, as indicated in Fig. 9.

Twenty-five locations listed in Table 1 and shown by red dots on the map labeled Fig. 20 (see Appendix) were selected for these measurements. The selections were made on the basis of uniform coverage of the state, variations represented in sizes and types of structures, and proximity to existing rain gauges. In every case the location chosen was within a distance of 5 miles from a rain gauge.

Indicators were placed at both the inlet and outlet of two or three of the structures as a means of providing for computations of runoff from slope-area determinations applied to the Manning formula (see page 14). In lieu of this arrangement, vertical stripes of whitewash were painted at intervals of 5 feet along the inside of the culvert in an attempt to define the crest. Stripes of this description are shown with the peak stage indicator illustrated in Fig. 9.

Obviously installations of this type are limited in their possibilities for correlation between rainfall and runoff, but a rough estimate

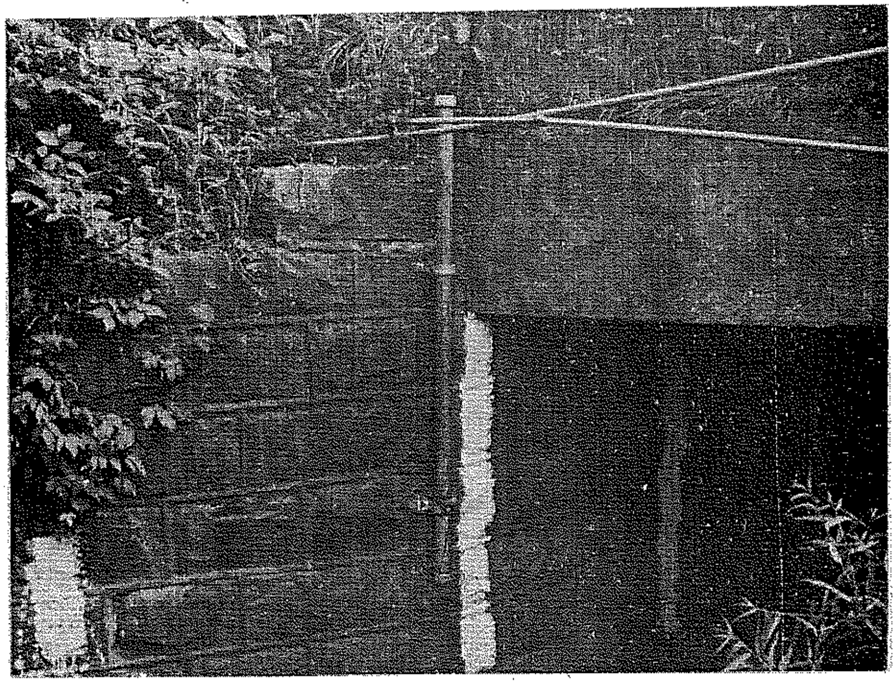


Fig. 9. Peak stage indicator and series of whitewash stripes for indication of flow through the culvert during periods of excessive runoff.

Table 1 - Location of Peak Stage Indicators

Dist.	Road	Culvert Description	Location
1	U.S. 51	Dbl. 12x6 R.C.	Near N. City Limit - Hickman
	Ky. 95	Trpl. 8x7 R.C.	0.5 Mi. N. of Jct. with Ky. 58
	Ky. 107	Dbl. 10x8 R.C.	3.5 Mi. N. of Herndon
2	Ky. 141	Dbl. 10x7 R.C. 30° Skew Left	5.8 Mi. from Jct. U.S. 60
	Ky. 147	Dbl. 10x8 R.C.	3.5 Mi. N. of Madisonville
	U.S. 60	10x5 R.C. 45° Skew Left	3.9 Mi. W. City Lim. Owensboro
	KY. 71	12x7 Stone Masonry	7.4 Mi. N. Warren County Line
	U.S. 31-W	8x8 R.C.	1.7 Mi. S. of Franklin
3	U.S. 60	Dbl. 12x9 R.C.	2.5 Mi. E. City Limit St. Mathews
4	Ky. 401	6x6 R.C.	4.2 Mi. from Jct. With Ky. 86
	U.S. 31-E	20' Span 45° Skew, Right	3.25 Mi. E. Hodgenville
6	Ky. 35	Dbl. 6x6 R.C.	2.5Mi.S. Monterey @ Old Cedar Ch.
	Ky. 35	Dbl. 10x5 R.C.	2.9 Mi. N. Jct. With Ky. 70.
	Clays Mill Rd.	12x4 R.C.	0.4 Mi.S. of Jct. U.S.68@Lexington
	Ky. 52	8x6 R. C.	1 Mi. E. of Bridge at Beattyville
7	U.S. 460	10x7 Stone Masonry	2.25Mi. W. of Salyersville
	U.S. 119	20x7 R.C.	0.7 Mi. E. of Pikeville
8	U.S. 27	12x8 R. C. 30° Skew left	2.5Mi. S. of Pendleton Co. Line
	Ky. 57	8x6 R. C.	7 Mi. N. of Flemingsburg
	U.S. 60	Dbl. 8x6 Stone Masonry 45° Skew Left	1.5 Mi. W. of Olive Hill
	U.S. 23	20' Single Span	At Two Mile Creek
9	Ky. 63-100	16x8 C	1.25 Mi. S. of Tompkinsville
	Ky. 92	- - -	0.3Mi.E. Jct Ky.90@Monticello
	U.S. 25	Dbl. 14x8 R.C.	3 Mi. N. of London
	U.S. 119	16x10 Stone Masonry	3.3 Mi. W. of Loyall

can be made if the rainfall data taken from the recorded not more than 5 miles away are applied to the drainage area contributing to the structure. Inasmuch as the peak stage indicator merely records the maximum level regardless of the time at which it occurred, there is no possibility of determining fundamental rainfall-runoff characteristics with different storms.

Sections in the approach channels to these structures were taken by a party sent to the field, and arrangements for observing and servicing the indicators were made through the Divisions of Construction and Maintenance. Department personnel working in the localities were designated for this service, and they were provided instructions and printed post cards upon which they could record their observations and mail them to the Research Laboratory immediately. A record from the locality was requested for each day that a rainfall of at least 1 inch occurred in the 24-hour period.

Test Drainage Area

A more fundamental approach to the measurement of runoff is represented in a model test drainage area. Through the cooperation of the Louisville District Office, U.S. Corps of Engineers, five rain gauges and an automatic stream recorder were made available for the collection of data. These were installed on a drainage basin (Douglas Creek) contributing to a triple 14x10 reinforced concrete culvert on SR 470 in Larue County. The basin, which is 7.32 square miles in area, is gently rolling, largely cultivated, and oblong in shape as indicated on the airphoto layout in Fig. 10.

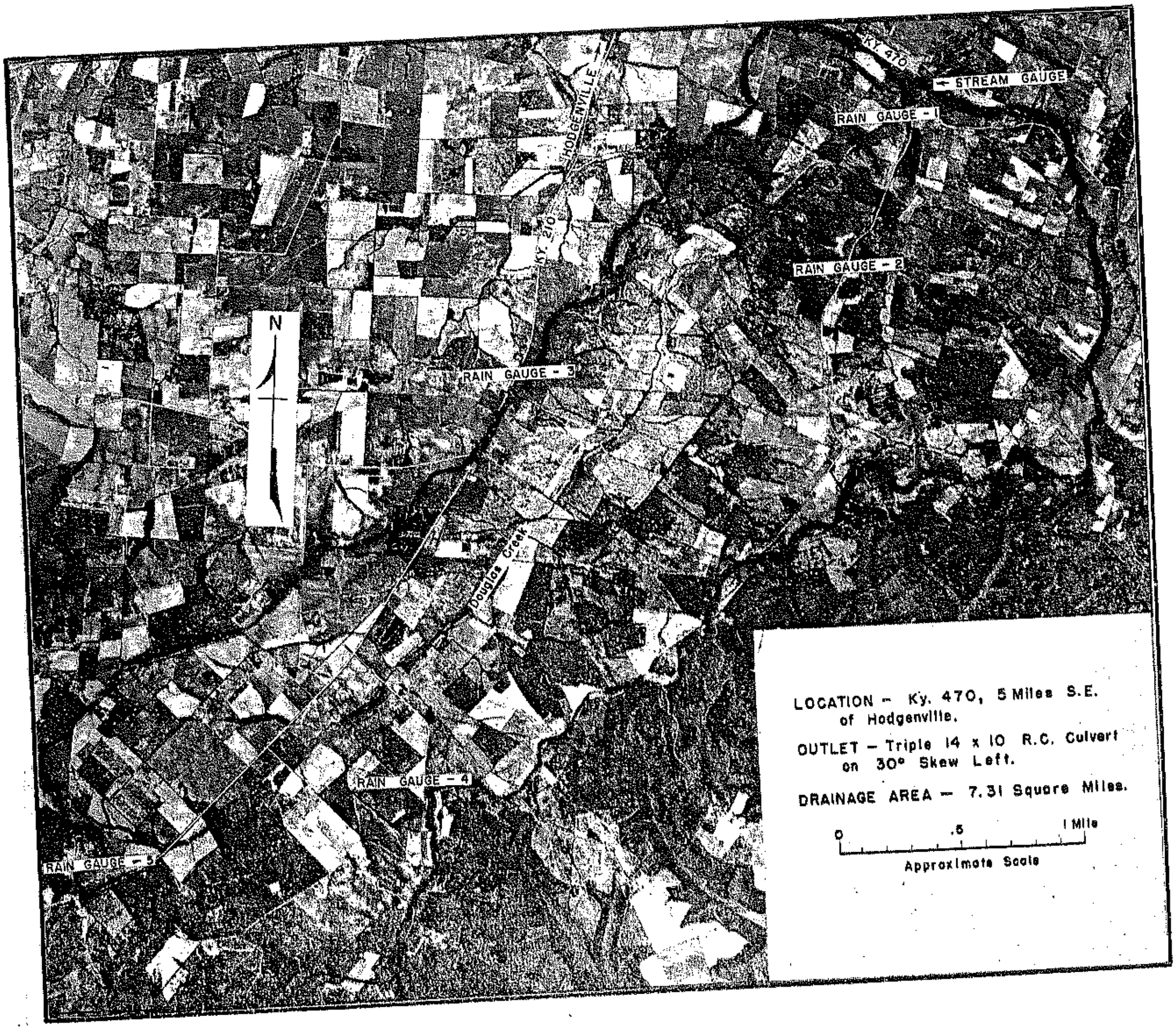


Fig. 10. Airphoto layout of the Test Drainage Area in Larue County.

Inasmuch as the rain gauges are all of the automatic recording type, the time, intensity, and duration of rainfall is being measured constantly, and the stream recorder is measuring and recording runoff concurrently. Hence, fundamental features such as time of concentration are represented in the information which is accumulating.

The gauges were placed in operation about the middle of December, 1951, and left in the care of a Department employee from the Elizabethtown District Office who resides in Hodgenville. The charts are changed and the buckets of the rain gauges emptied once a week unless heavy rainfall requires more frequent servicing of the gauges. Charts are mailed to the Research Laboratory where they are "worked up" into rainfall-gauge height relations.

Thus far the velocity of stream flow has not been measured with a current meter under sufficiently variable conditions to establish a rating curve for the stream, but this is being carried out as opportunities present themselves. When that is completed, gauge-height recordings will be converted directly to runoff in cubic feet per second.

While this more elaborate approach is by far the best method of compiling rainfall-runoff data, possibilities for widespread application to culvert evaluations are limited. The cost of establishing and maintaining a group of several installations of this type is fairly great* and the extent to which data from each area can be projected to other areas ostensibly similar would need be determined. The errors introduced in assumptions of transfer from one place to another could vitiate a great

* Probably two or three rain gauges would be sufficient, and five were placed on the Douglas Creek test area only for the purpose of studying distribution of rainfall intensities within an area that size.

deal of the accuracy obtained in the original measurements.

As indicated later in this report, and shown on the map in Fig. 20, there are nine other test areas within the state operated by the U.S.G.S. or the Department of Conservation in cooperation with the U.S.G.S. Free flow of information from one department to another is assured, so in effect there are ten small areas generally well distributed which are producing this type of data for application to the culvert area problem. At the moment, consideration is being given to locations of two additional areas in the Highway Department program, one in the southeastern part of the state and another in the Purchase area.

Evaluation of Data from Other Sources

Kentucky is in a particularly fortunate position from the standpoint of records in general, and the length of time covered by the records. Some of the earliest stream flow measurements were made within the state, the station at Cumberland Falls, for example, carrying back to 1907. Even though all but the most recent records pertain exclusively to major streams and very large drainage areas, they may be found valuable in work on small areas because of the possibilities for establishing flood frequencies.

Apparently the records have not been thoroughly analyzed from the standpoint of flood frequencies, or at least the only published information refers to Kentucky in a very general way. In all probability, work of this nature is in progress or has been done in connection with some of the large flood control projects carried out during the past few years. If so, the results would have a bearing on considerations of flood frequency on small drainage basins.

Actually the rainfall records will probably have a greater bearing on analyses for small basins, because of the necessity of establishing runoff factors which can be applied in emperical formulas or graphs. This is so, since the actual stream measurements are so limited and extend over so few years. Storm frequencies will be the object of greater interest under those conditions.

The excellent coverage with rainfall records should provide highly reliable storm frequency data if the procedures for estimating frequency are valid. As noted previously, and shown in Fig. 20, there are more than 100 stations in Kentucky with records extending beyond ten years. The longest record (Louisville) is slightly in excess of 80 years, and 70 of the stations have more than 25 years of record. Obviously many of these will not provide more than just the total amount of rainfall per 24 hours because the automatic gauge was of comparatively recent origin. Nevertheless 25-year records with measured intensities and durations should be abundant, and a complete set of records covering a period greater than the last ten years is assured because such information is already on file in the Research Laboratory.

Analysis of rainfall records for storm frequency determinations is considered a portion of this project, and to that extent, atleast, data from other sources will have a primary bearing on the end results. It has been noted, too, that the information from other gauging stations and test areas throughout the state will contribute materially to the data on measured rainfall-runoff characteristics.

The extent to which information from studies of culverts in other states can be applied in Kentucky is not known. In general, highway organization do not have a well-founded approach to the problem, and indications are that most of them assume C factors based on experience and apply Talbot's formula. A few have made outstanding developments, and reports of those developments have been drawn upon for background in formulating this program.

Survey of Existing Structures

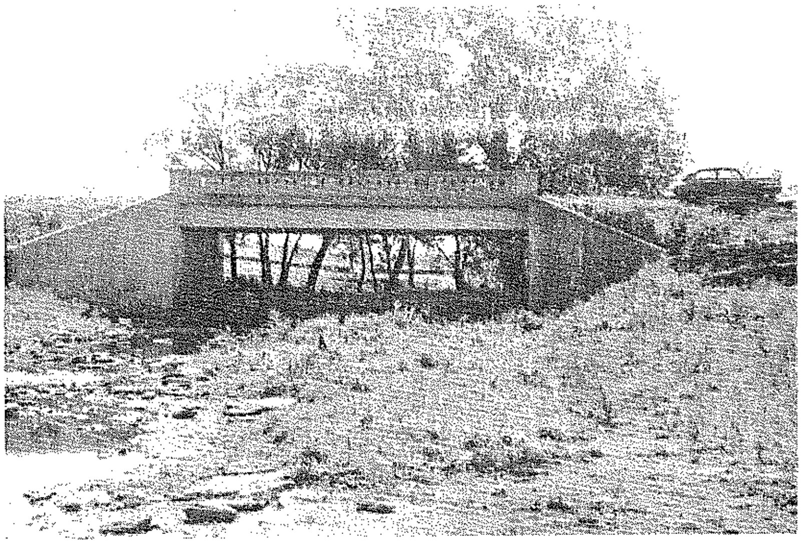
Theoretically culverts in service offer excellent bases for judging design methods provided dependable information is available. Simple adequacy of the structure can, of course, be evaluated by determining whether there was ever a time when the opening was not large enough to accommodate all the water that reached it. However, this is not a good criterion for judging the practical adequacy of the structure, because the rainfall conditions that caused flow exceeding the capacity may represent a 100-year storm - an unreasonably high design standard. There is also the possibility that the structure was greatly overdesigned and would never flow full, not to mention being over topped.

Several conditions limit the practicality of studying culverts in service, working the design problem backward, and arriving at a decision on the adequacy of the design. Almost invariably it is necessary to depend on persons living in the vicinity for estimates of the peak flow conditions; if these estimates are accurate, memory usually places the time at about one year or another, and then it is practically impossible to correlate the flow with any measured rainfall, even in a general way. Under those circumstances, the observed conditions apply to just the particular structure and drainage basin, or to a situation which is practically identical.

Although existing structures alone offer little that is usable in determining rainfall-runoff characteristics of drainage areas, they do provide evidence that is pertinent to design. Any condition influencing the efficiency of performance has a bearing on the adequacy of size determinations. Thus, these conditions were given considerable attention during the survey of several hundred culverts which have been inspected to date.

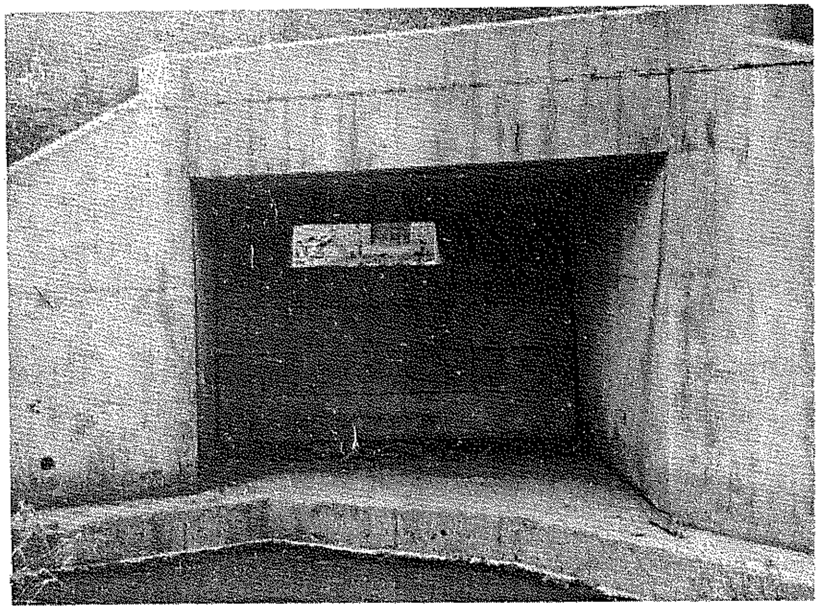
Obstructions - Most of the obstructions which restrict flow, and effectively reduce the size of the opening, are created by nature. Often an obstruction is deliberately placed by a private individual, probably without any thought of its effect on the drainage way. An example of such conditions are illustrated in Fig. 12. Obviously, there is no possibility for designing against erection of livestock barriers, but some machinery for controling encroachments of this type is important to the adequate design and functioning of drainage structures.

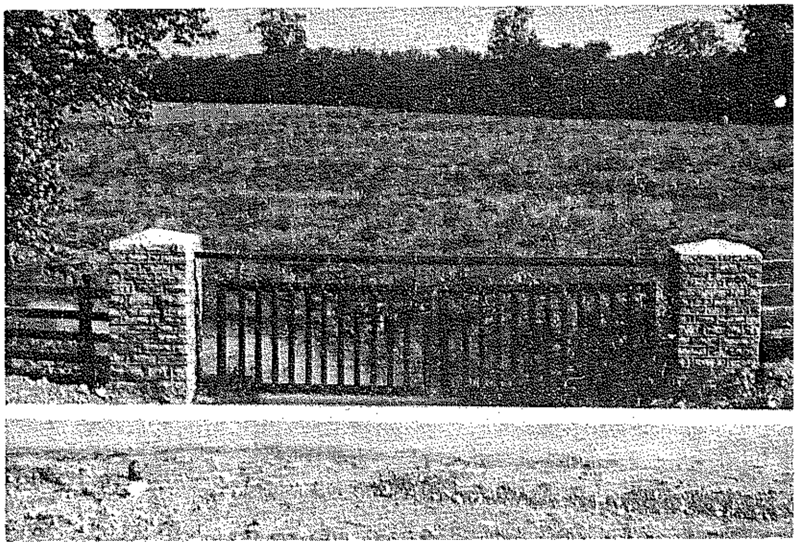
Natural obstructions in the form of debris and vegetation are illustrated in Fig. 13. Frequent inspection and vigorous maintenance offer the solution for reduced capacity in this case, and allowances in design are impractical. On the other hand, obstructions through natural silting (Fig. 14) can often be combatted at the design stage. The load of a stream is dropped only at points where the velocity is reduced, and oftentimes silting at the entrance to structures indicates openings that are too large or at least too wide. Culverts with multiple openings seem to be particularly vulnerable to this action, probably because of eddy currents and the proportions and limited operating heads - as discussed later.



(a)

(b)





(c)

Fig. 12. Culvert capacities are often reduced greatly by the erection of livestock barriers. Reductions of 1/3 to 2/3 design capacity are represented in (a) and (b). Desirable mounting of barriers is illustrated in (c).

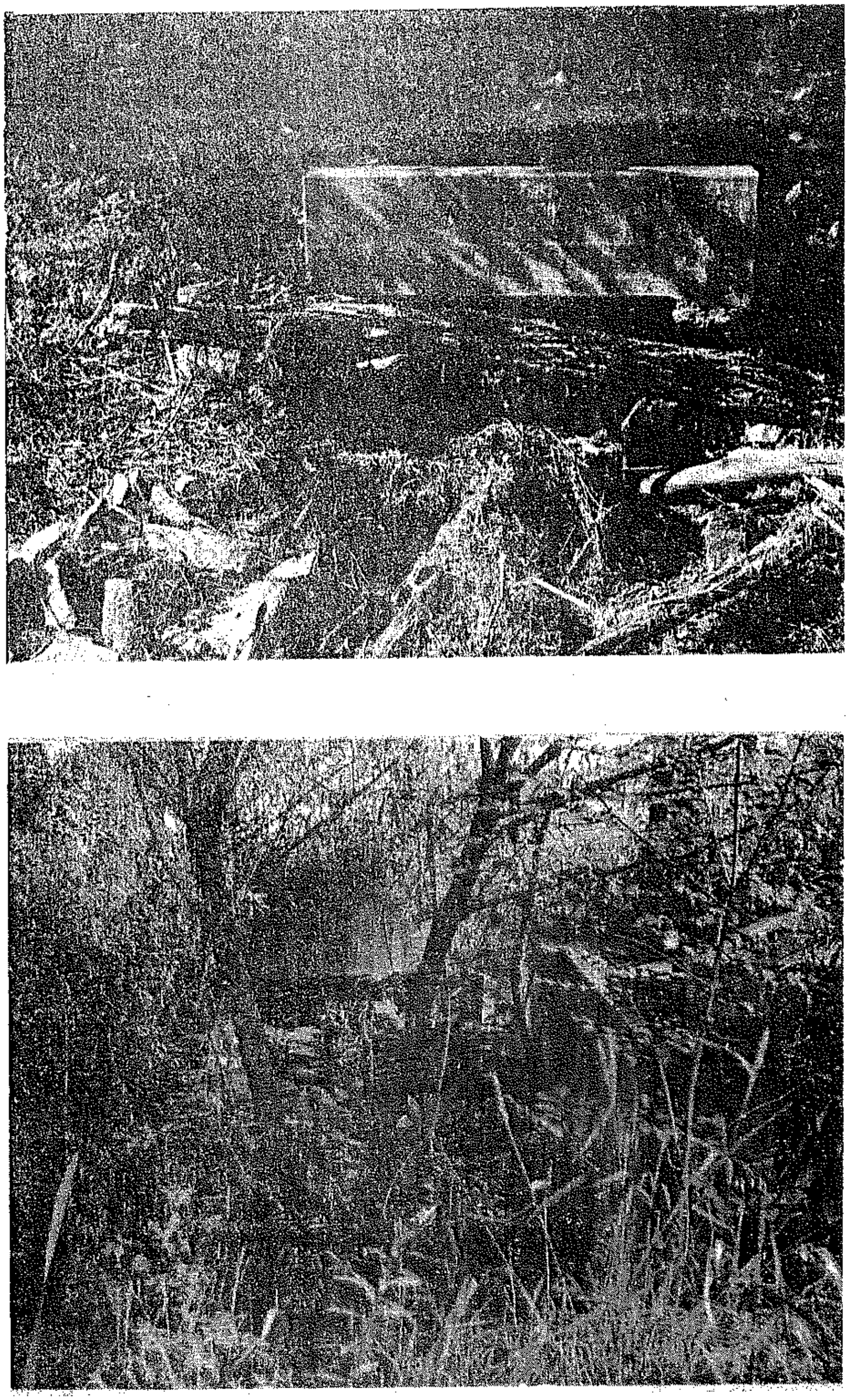
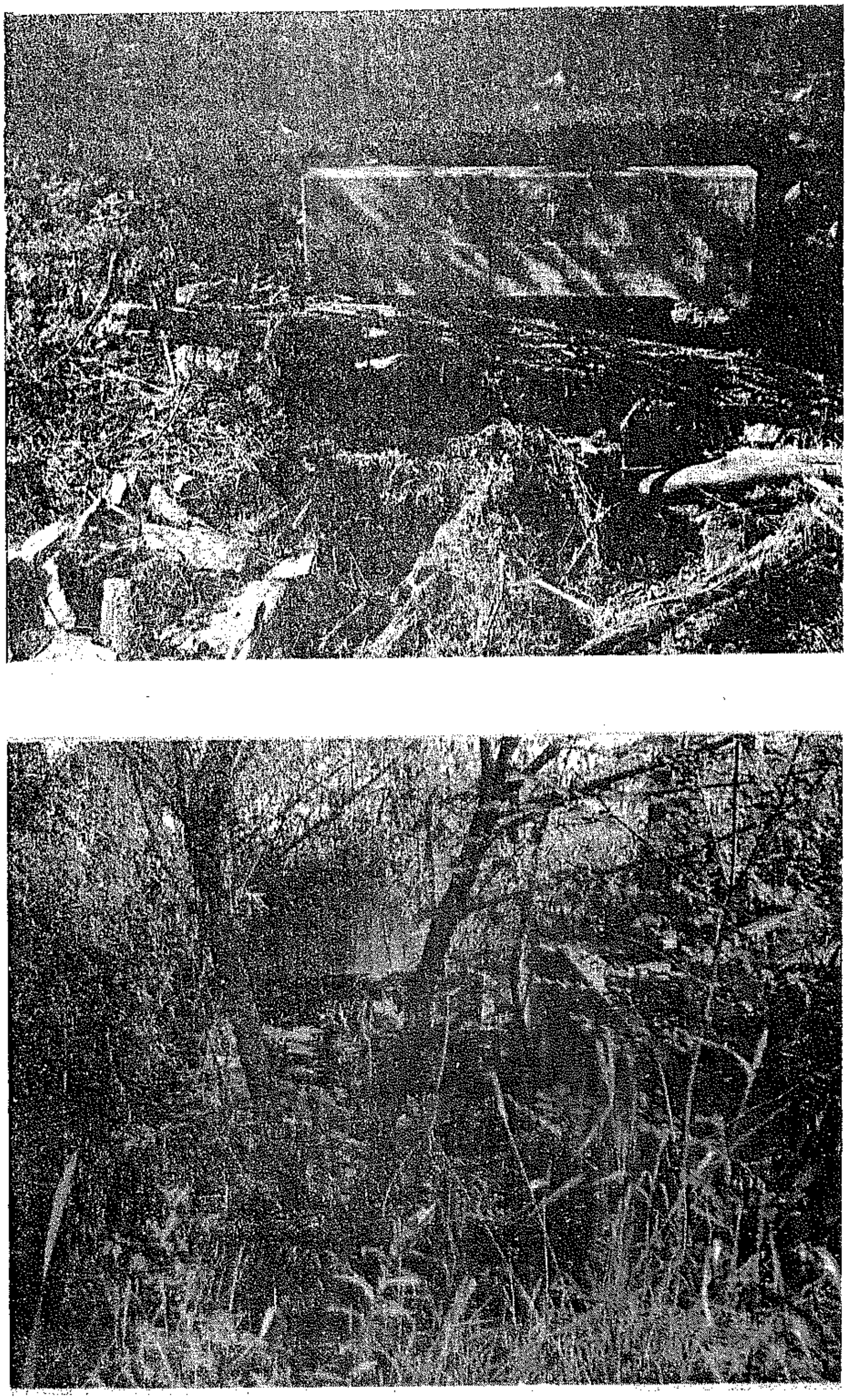


Fig. 13. Accumulations of floating debris or growth of vegetation in the channel and within the right of way are common obstructions to stream flow. In effect the design capacity of the culvert has been reduced although the structure is capable of carrying more water than reaches it under these conditions.



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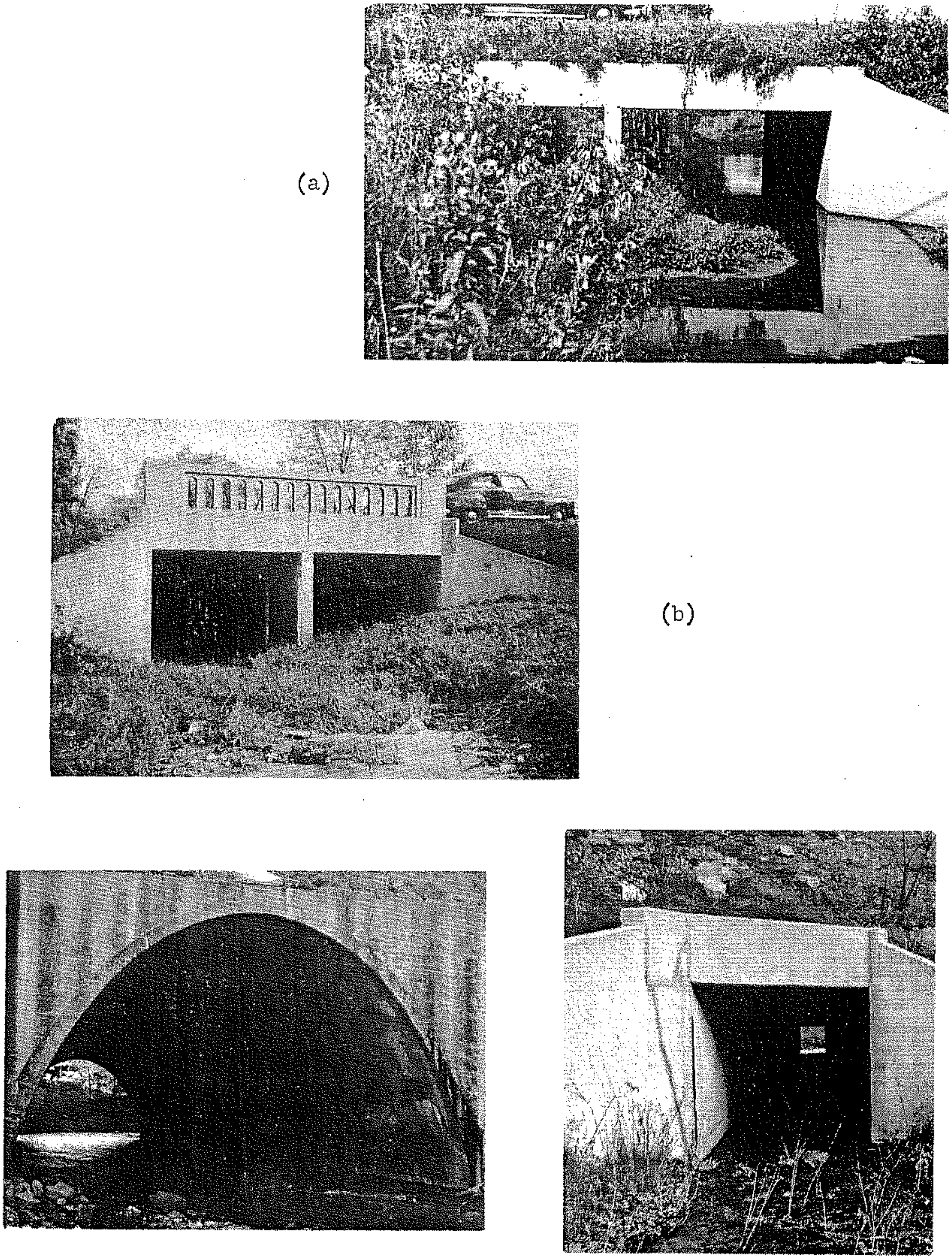


(a)

(b)

(c)

(d)

Fig. 14. Silting in the approach channel or within part of a culvert is generally evidence that the structure has greater capacity than the stream can utilize. Veolocities are reduced and load is dropped at the structure. Thereafter, only a portion of the total opening carries water, and in the case of multiple structures one or more segments often become closed. Note the open channels in (c) and (d).

Alignment - The better the structure is aligned with the approach channel the less possibility there is for development of interference at the structure itself. At many locations, particularly in regions of rough terrain, possibilities for alignment with the channel become limited. Undoubtedly, the situation then becomes a compromise between increased capacity to accommodate poor alignment and a change in location or skew in the interest of hydraulic efficiency (see Fig. 15).

Inlet and Outlet Conditions - Some desirable and undesirable conditions at the inlets and outlets of culverts are illustrated in Figs. 16 and 17. Abrupt changes in the direction of flow at either the inlet or outlet creates turbulence and seriously affects the rate at which water can pass through the opening. Extremely undesirable conditions from the standpoint of turbulence are represented in Figs. 16(a) and 17(c). In contrast, the excellent arrangements for collecting the water at the inlets shown in Fig. 16 (d to f) and for discharging it from the outlet illustrated in Fig. 17(a) practically preclude any serious turbulence.

The design of wing walls and other channelizing features for complete efficiency would be different for each individual structure, and this is obviously beyond reason. However, a wide variation in shapes and proportions on design standards should bring most inlets and outlets within the range of reasonable hydraulic efficiency.

Proportion and Effective Head - Occasional operation of culverts under a head is desirable and beneficial provided other considerations will permit it. Not only can effective openings be reduced under such circumstances, but the stream tends to clear its channel and remove material that may otherwise develop an obstruction.

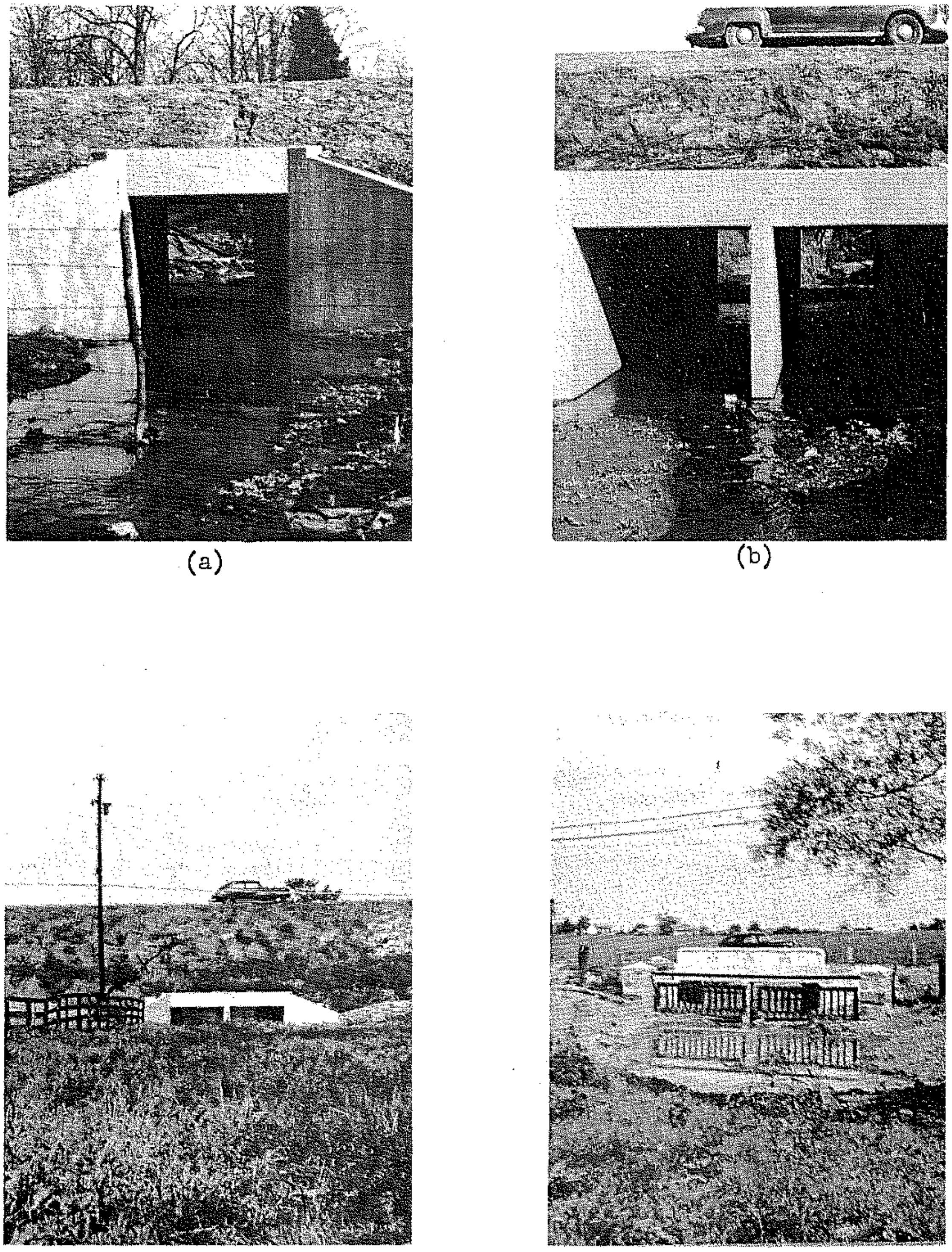
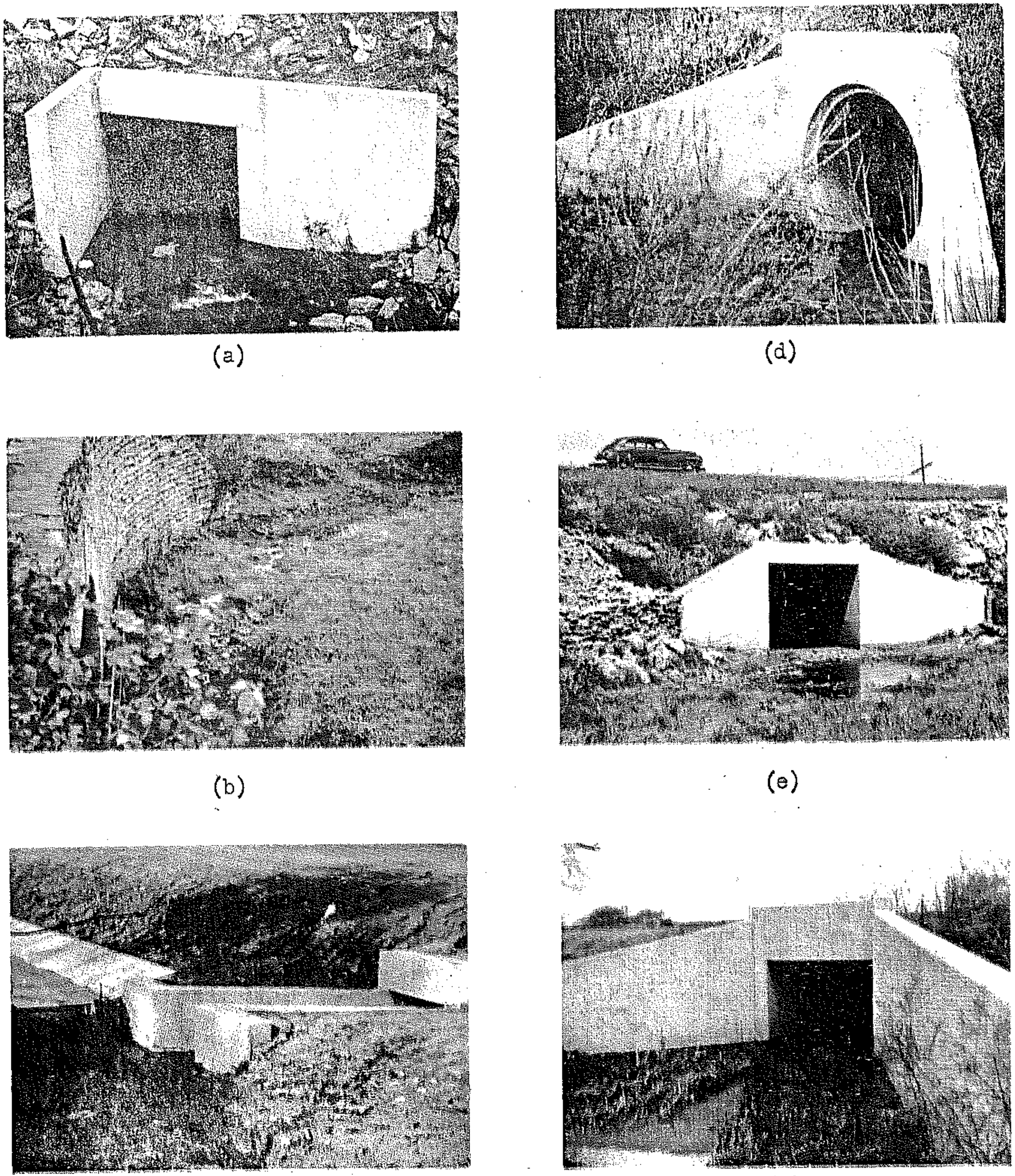


Fig. 15. Poor alignment with the approach channel reduces the hydraulic efficiency of a culvert by setting up eddy currents and reducing velocities. The views (a) and (b) are looking upstream through the culverts and into hillsides immediately beyond, and in situation (c) where the view is downstream the approach channel is far to the right rather than in direct alignment with the culvert. A desirable situation is shown in (d).



(a)

(d)

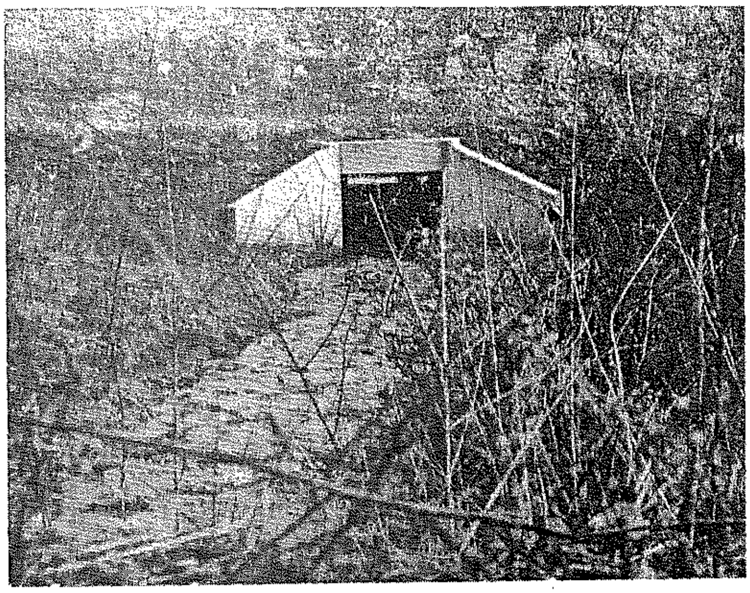
(b)

(e)

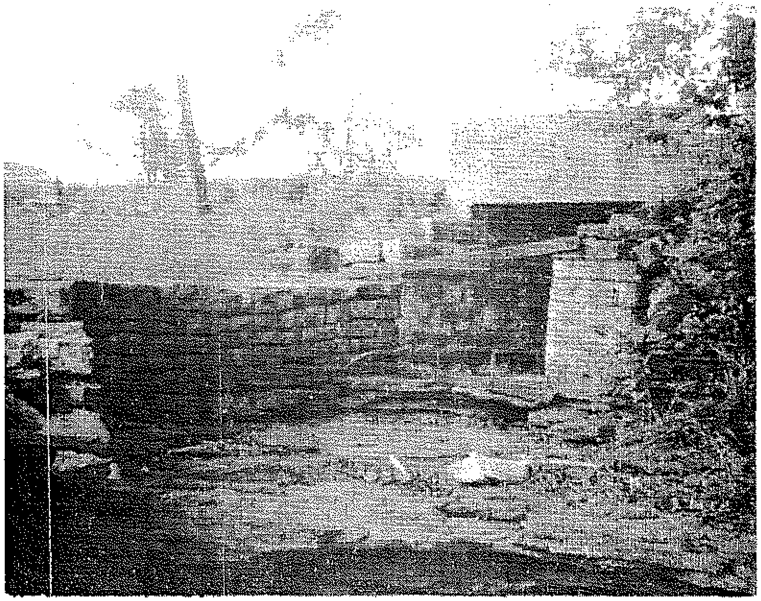
(c)

(f)

Fig. 16. If the channel is not obstructed and the culvert is aligned to maximum advantage, flow will be retarded at the inlet only if it is poorly arranged for collection of the water. Note the contrast between inlets (a) - (c) and inlets (d) - (f).



(a)



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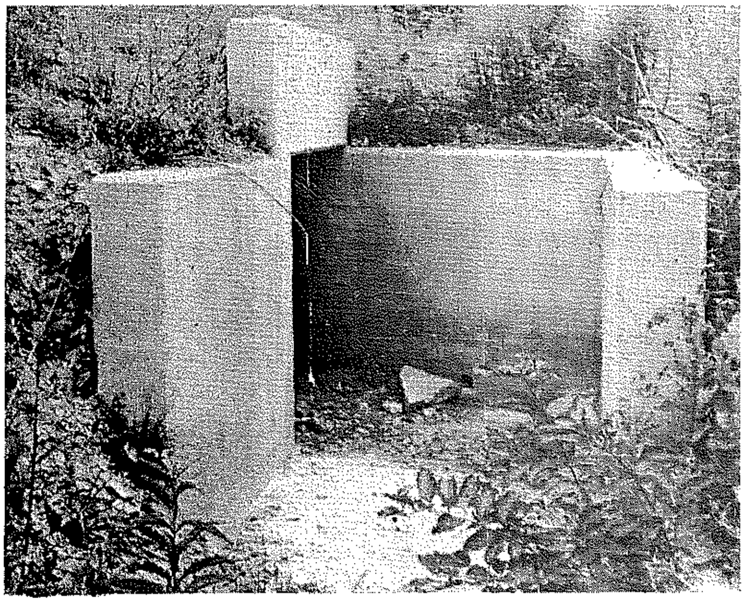


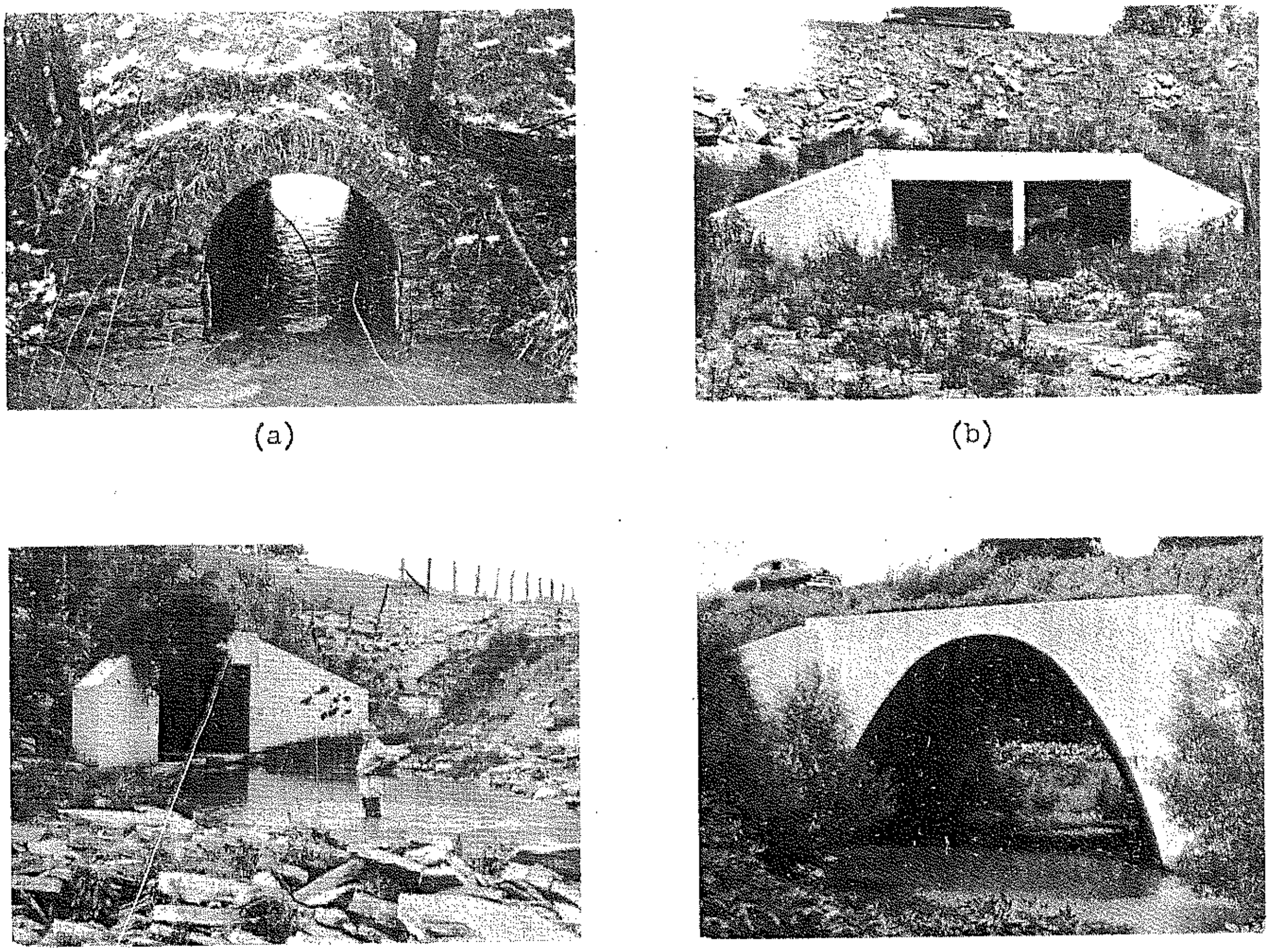
(c)

Fig. 17. Culvert Outlets should provide unretarded flow, otherwise the design capacity is effectively reduced. This series of photographs illustrate (c) extremely poor, (b) meidocre to poor, and (a) satisfactory outlet conditions. Sometimes abrupt changes in course are necessary at the outlet, but hydraulic efficiency can be greatly increased if the change is brought about gradually.

Efficiency is increased with the increased velocity. As an example, a stream with a peak flow of 500 cubic feet per second would require 250 square feet of opening if the culvert is proportioned and arranged so that flow is accommodated at a velocity of 2 feet per second. If the proportions are changed, and the structure is permitted to operate under a head causing flow at a velocity of 10 feet per second, the required area is reduced to 50 square feet.

Obviously, the effects of backwater elevations must always be regarded under these circumstances, but contrary to most popular opinions, the culvert which carries all the flow without temporarily impounding water at the fill is not always a desirable or well-designed structure. Also, contrary to usual assumptions, the velocity of flow in any structure not operating under a head seldom exceeds 4 feet per second.

Some conditions related to proportions and velocities are illustrated in Fig. 18.



(a) (b)

(c) (d)

Fig. 18. Modern grades and high fills make possible designs that will let a culvert function under a head occasionally. This is desirable, provided damage to abutting property can be avoided. Not only is the effective capacity for a given sized opening increased, but the channel is scoured and kept clean as long as there is no accumulation of debris too large to pass.

The proportions as well as the sizes of openings are involved. In situation (b), for example, the same effective capacity could have been obtained with a slight increase in height, and elimination of one of the openings. The culvert in (c) has obviously operated under fairly high heads as evidenced by the stilling basin formed by the stream on the outlet side.

RECOMMENDATIONS

The project has not progressed to the point where any change in the system of runoff factors can be proposed; however, the records available and observations made thus far indicate that a revised system extending beyond the range of the Talbot formula can be developed. If at all possible, factors fundamental to rainfall-runoff characteristics - such as storm frequency, shape as well as size of the drainage area, times of concentration, infiltration as related to soils or rock formations, and the like - should be given separate recognition.

Possibilities for separate evaluation of factors will be greatly enhanced by the new state-wide topographic survey, which is scheduled for completion within the next two or three years. Added to this is the complete air photo coverage from which numerous features of a drainage area can be taken. With these available, a great deal of the conditions entering separate evaluations would be available in the office and would not require additional observations in the field.

In order to avoid complicated formulas which could be cumbersome in use, consideration should be given to charts or graphs similar to those discussed earlier in the report. These would represent merely a set of separate solutions combined and integrated for easy application. Undoubtedly, the pertinent records of rainfall and stream flow in Kentucky equals in number and exceeds in years of observations the records on which other satisfactory systems have been based (California, for example). That being the case, the approach with separate factors and charted solutions appears promising.

Establishment of two additional test areas in the state, one in the southeastern portion and another in the far west is recommended. The distribution of test basins now in progress (see Fig. 20) leaves these two regions without fundamental data. It is possible that, after records have been made for a period of several months at one of these locations, the gauge could be moved and temporarily installed at other locations to give check information under storms that could be rated on the basis of records in the vicinity.

Conditions affecting the performance of structures in service warrant consideration, for in some instances attempts at reasonable designs of culvert openings are futile and practically worthless when obstructions, characteristics of the channel, inletsor outlets, and other factors materially reduce the capacity below the design value.

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APPENDIX