M. W. TINDER
COMMISSIONER OF HIGHWAYS

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

July 29, 1955

ADDRESS REPLY TO
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

ATTENTION: D.2.1.1.
D.1.7.

TO: D. V. Terrell
Director of Research

For the past four years the Division of Research has conducted studies in the field of drainage, with particular emphasis on means for estimating runoff from small drainage areas. You will recall that the project originated with a request that the methods for determining required sizes of openings in culverts and small bridges be re-evaluated and improved.

The first report on the work, dated April 15, 1952, was presented orally to the Research Committee shortly thereafter, and additional oral reports were made at meetings in January and December, 1954. Two graduate theses for credit toward M.S. degrees in Civil Engineering at the University have been developed from the project, and several discussions presented at highway conferences, at meetings of the Highway Research Board Committee on Surface Drainage, and elsewhere have been based on the studies. Finally, many of the results were worked into the revised Drainage Manual issued by the Division of Design last December, and scheduled for printing in final form in the near future.

The project is being concluded with the attached Report No. 2 on "A Study of Runoff From Small Drainage Areas and The Openings In Attendant Drainage Structures", by E. M. West and W. H. Sammons. The size of the report alone varifies the fact that a tremendous amount of data on the magnitude and probable recurrence interval of rainfall in all parts of the state have been developed. This has been done through lengthy statistical analyses of existing Weather Bureau records from all orders of stations in and immediately about Kentucky, and through the development of synthetic short-duration (as low as 5-minute) data for many stations at which only 24-hour amounts have been recorded.

By these procedures calculation of the rainfall appropriate for design estimates has been infinitely improved, and with the rainfall data serving as a basis the C and B factors (so-called runoff coefficients) for use in the Talbot and Dickens formulas have been modified. Aside from that modification, however, we have not been able to improve on the coefficients for these empirical methods, even though that was the original and only objective presented to the Research Division when the study was first requested.

With regard to the return period basis for determining the rainfall variable, it should be noted that the statistical procedure utilizing extreme values gives the answer only within certain limits. The accuracy of the prediction for all kinds of rainfall conditions is further limited by the fact that occasional excess precipitation that does not conform with the general trend of record at a station is ignored in the analysis of the station data; hence, it is not taken into account in calculating the amounts that can be expected to occur with different return periods.

This is noted not in criticism of the procedure, but in partial explanation of observed storms that far exceed predicted values. For example, it is not unusual within limited areas to experience twice within one year, or within a period of few years, storms having more than the calculated amount for a 500-year return period. This has occurred in several places within the state this year, sometimes causing considerable damage.

Almost invariably these are cloudburst conditions prevailing over a relatively small drainage area. As noted in the report, it is practically impossible to bring many of those situations within station influence even when there are more than 100 rain-gauging stations in the state, and from the standpoint of drainage facilities it is seldom feasible to design for them. Often, when there are records of such storms on drainage areas for which a culvert design is to be made, it is suggested that the opening be greatly increased beyond that determined by design estimates with the belief that excess runoff will be accommodated.

There are two principal fallacies in this reasoning, the first being the cost of overdesigning many structures in order to make certain of adequacy at the few that will ever be subjected to cloudburst flow. Damage from the excess flow would be less expensive. The second fallacy is more serious, since it involves subsequent reduction of the opening by the stream. As noted in the first report on this project, under ordinary yearly flow conditions streams tend to maintain only the amount of channel required, and at points where the opening is exceptionally wide - for example, at multiple barreled structures - the stream deposits debris in periods of normal or moderately high flow. Hence, often the extra opening provided in the design would not be available for conveying the water when excessive runoff occurred, and the structure would still be inadequate.

In my opinion the depth-duration-return period data, and the several other developments covered in this report and partially included in the Drainage Manual, represent significant improvements in drainage design procedures. Unfortunately, the designers are still severely handicapped by limitations inherent in the empirical methods of Talbot and Dickens. The best way to overcome this is to eliminate the need for relating rainfall and runoff, and instead base designs on discharge-return period relations developed from a large number of representative small drainage areas over a long period of time - preferably more than 12 years. That being the case, the Department should actively encourage agencies that specialize in the hydrologic field to establish as many as 100 permanent gauging stations on a variety of widespread streams having small drainage areas, and start accumulating the necessary record as quickly as possible. This would require about four times the number of stations now operated in Kentucky, and even if all were started now a system of drainage design on the most reliable basis would be at least 12 years in the future.

Although the project is concluded with this report, publication of certain detailed and valuable data from the study is planned within the next few weeks (see Reference Item 46). Beyond that, additional research on drainage, or more specifically hydraulics, is underway through model studies to establish inlet coefficients and other factors that are considered highly important to hydraulic design. The first report on that project should be available late this fall.

Respectfully submitted,

L. E. Gregg

L. E. Gregg
Assistant Director of Research

LEG:dl
Enc.
Copies to: Members of Research Committee

Commonwealth of Kentucky
Department of Highways

Report No. 2

on

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

by

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and

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Lexington, Kentucky

July, 1955

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FOREWORD

This is the second and concluding report on a research project by which methods for estimating runoff from small drainage areas have been studied, data pertaining to rainfall and runoff in Kentucky were collected, and adaptations of these methods and collected data to the design of openings in highway drainage structures were made. The first report was presented in April, 1952, shortly after the project was established.

During the intervening period effort has been made to create, improve, and expand facilities for measuring runoff from small drainage areas (smaller than 10 square miles in size) within the state. It has been and is recognized that statistical evaluation of a large volume of such records representing a variety of physiographic conditions and extending over a long period of time would provide the most reliable basis for design estimates. However, there are no stations gauging watersheds of this size in Kentucky which have periods of record greater than 5 years, and despite recent interest there are only 10 automatic recording stations currently accumulating record on small watersheds. Fortunately, installation of new stations has been increasing steadily during the past few years, and probably that trend will continue.

In contrast to the paucity of stream flow records, there is an abundance of rainfall records from stations in and about Kentucky, some of the records extending over a period of more than 40 years. This abundance, and the possibility it offered for reliably estimating the intensity and duration of rainfall that can be expected in different parts of the state within certain return periods or frequency intervals, centered interest on design methods that could be based largely on rainfall. As a preliminary step in the development of data for these methods, it was necessary to carefully reduce all the recorded rainfall measurements to a common basis for analysis, test the dependability of the data, and correlate the records from different stations in such a way that the pattern of anticipated rainfall could be established. Data from that analysis constitute a large part of this report. In turn, the data themselves were applied to revisions of drainage design criteria, and to broadening the basis on which designs can be made.

The authors have coordinated their efforts in carrying out different phases of the project and the preparation of this report. Mr. West was responsible for the field measurements, the installation of gauges and recorders at various sites, and in general the compilation of runoff records. The responsibility for compilation of rainfall records, the statistical analysis of those records, and the interrelating of rainfall data to other data was carried by Mr. Sammons.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the many individuals and governmental agencies for the splendid cooperation and assistance received throughout this project.

Outstanding contributions to the work were made by the U. S. Weather Bureau, U. S. Geological Survey, Bureau of Public Roads, Corps of Engineers, U. S. Army, and the Soil Conservation Service.

Assistance in the collection of data and compilation of results was received from various districts, zones and divisions within the Highway Department as well as from the several employees in the Division of Research who worked directly on the project.

Special acknowledgement is made to Messrs. E. J. Gumbel and W. D. Potter for their consultation, highly valuable data, and numerous aids to the analytical procedures that were made available to the authors.

INTRODUCTION

The estimation of runoff from a given watershed involves many variables, some of which are: rainfall rate, time of concentration, soil type, vegetative cover, size, shape and slope of the drainage area. An evaluation of most of these is difficult, and at best the calculated runoff based on relationships among them is recognized as grossly approximate. In the first progress report on this project (1)*, it was recommended that all measurements available, e.g., rainfall and stream discharge records, be used to analyze some of these variables. The project was directed toward the establishment of a more fundamental approach to the determination of probable runoff pertaining to small bridge and culvert design.

In an effort to evaluate the effects of some coefficients used in the common empirical formulas, a study was made of the peak rates of runoff and their relation to rainfall (2). All records for streams gauged in Kentucky were reviewed for drainage areas which were near culvert size but very few such areas were found. None had a period of record of more than 2 years and only three of these small streams, with a drainage area of less than 10 square miles, were being gauged. It was then decided that it would be necessary to use larger areas limited to sixty square miles and a minimum period of record of 10 years. Within the margins of this category six gauged areas were located. The largest of these had a drainage area of 59.9 square miles and the smallest 18.1 square miles.

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* Numbers in parentheses refer to the list of references and not the bibliography.

The distribution of these stations failed to cover all of the problem areas in the physiographic divisions of the state. However, it was estimated that among the areas included there were considerable differences in runoff characteristics. Different general types of cover were represented, and it was possible to attempt a correlation of rainfall with peak rates of runoff. The results of this study failed to indicate a significant relationship between rainfall and the peak rate of runoff. The peak rate of rainfall did not always produce the peak runoff rate and it became evident that factors other than rainfall were of primary importance.

It was found that one of the most significant variables in the entire rainfall-runoff relationship is the antecedent moisture condition* of the watershed. In the course of attempts to correlate rainfall with runoff, it was noted that there were wide variations in peak discharge because of these antecedent conditions, and that the influences of different soil types and cover were minimized to the point where their individual effects were not apparent.

In the light of these findings, it was concluded that a better approach to the problem of estimating design discharge would be a system based on discharge records. However, available records were from very few areas and small drainage areas were not adequately represented. It was then proposed that the discharge measuring program be expanded to include as many small watersheds as possible, the objective being to

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* See Glossary of Terms

ultimately provide records by which drainage area-discharge-return period relationships might be developed.

The importance of return period considerations in the design of culverts has been well known for a long period of time, its importance having been stressed in the first progress report on this project. The necessity of considering the return period of various events, in order to obtain significant correlations between drainage area and runoff, is further stressed and more fully treated in the present report.

It was recognized that discharge records could not be applied to a method of design based on these data from small areas, and it became evident that until a better system could be developed, the present approach based on empirical formulas would have to be continued. Although these methods were known to be unsatisfactory, it was felt that some refinement could be made by improving upon the single factor for which there was an appreciable record - the rainfall variable.

Analyses of rainfall records for Kentucky and records from a number of gauges outside the state have brought about a vast improvement in the treatment of rainfall in various empirical formulas. Prior to this work the only applicable information was Yarnell;s "Rainfall-Intensity-Frequency Data" (3), which dealt with the subject in general terms and utilized shorter periods of record than do the rainfall-intensity-return period relationships developed in the present project.

Further work has been done to determine the extent to which the available discharge records could be used. The Bureau of Public Roads and the United States Geological Survey have been instrumental in the advancement of this approach. Through a statistical treatment of discharge relationships it was found possible to estimate a design discharge for smaller watersheds based on records for larger areas (4). Attempts have been made to develop such a system for use in parts of this state and the work of Potter (5) in the Allegheny-Cumberland Plateau of Eastern Kentucky is representative of this system.

Although it has become necessary to discontinue further work along this line, significant contributions to this approach have been made by the Division of Research. Much of the data and correlations will be included in a Department publication planned for the near future, and this will be available for public use. In addition, more extensive and detailed data in the files of the Research Division could, with the consent of other contributing agencies, be made available to larger organizations dealing primarily with meterologic and hydrologic investigations.

The U.S.G.S. has recently increased the number of small drainage areas gauged in Kentucky (See Fig. 9) and much work is being done in the small watershed program by the Soil Conservation Service. These and possibly other agencies are in the process of developing a method for converting peak stage indicator data to peak discharge data (6). Operation and maintenance of the majority of 26 peak stage indicators as well as the test drainage area, of 5.31 square miles, on Douglas Creek near Hodgenville (established by the Division of Research) have been assumed by the U.S.G.S. in its regular program of surface water evaluation. It is believed that when broad coverage and an adequate period of record are developed through this entire undertaking, analyses may be made to determine basic factors for runoff from small areas in Kentucky.

Until the time when more reliable methods can be substantiated, the information contained in this report offer an improved approach to estimates of design discharge. Pertinent parts of the information have been incorporated in the Manual of Drainage prepared by the Division of Design and as noted previously, a much more elaborate presentation of the rainfall data is planned for publication soon (46). Finally, additional treatment of synthetic data developed from recorded data will be available on a limited basis (45) to those who have an interest in that phase of the work.

RAINFALL DEPTH-DURATION-RETURN PERIOD RELATIONSHIPS IN KENTUCKY

Following report No. 1 on this project in 1952, a program was initiated to bring the Rainfall Depth-Duration-Return Period data for the state of Kentucky up to date. The last previous study of a similar type had been made by Lynch in 1927 (7), and on the basis of limited data then available an isopluvial chart for one-day duration rainfall for a 15-year period was included in the pamphlet of Instructions for Bridge and Culvert Surveys prepared for use by Department location personnel (8). Since the average represented a return period of only 2 years, this chart had limited use.

Through correspondence and cooperation with the United States Weather Bureau, annual true maximum rainfall data were obtained for the following durations: 5, 10, 15, 30, 60 and 120 minutes, and 24 hours, with periods of record ranging from 1871 to 1951. The years 1903-1951 were selected as the network base period; other periods used were 1914-51, 1931-51 and 1940-51.

The network of rain gauging stations represented in the records comprised a total area of 166,400 square miles lying within parts of nine states surrounding Kentucky, in addition to Kentucky itself (See Fig. 1). Stations represented were:

Asheville, North Carolina
Cairo, Illinois
Chattanooga*, Tennessee
Cincinnati, Ohio
Columbus, Ohio
Dayton*, Ohio
Elkins, West Virginia
Evansville, Indiana
Indianapolis, Indiana
Knoxville, Tennessee
Lexington*, Kentucky
Little Rock, Arkansas
Louisville, Kentucky
Memphis, Tennessee
Nashville*, Tennessee
Parkersburg, West Virginia
St. Louis, Missouri
Wytheville*, Virginia

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* Annual True maximum data incomplete for these stations within 1903-51 period.

Fig. 1 - Location of the 18 First-Order Stations in the Network

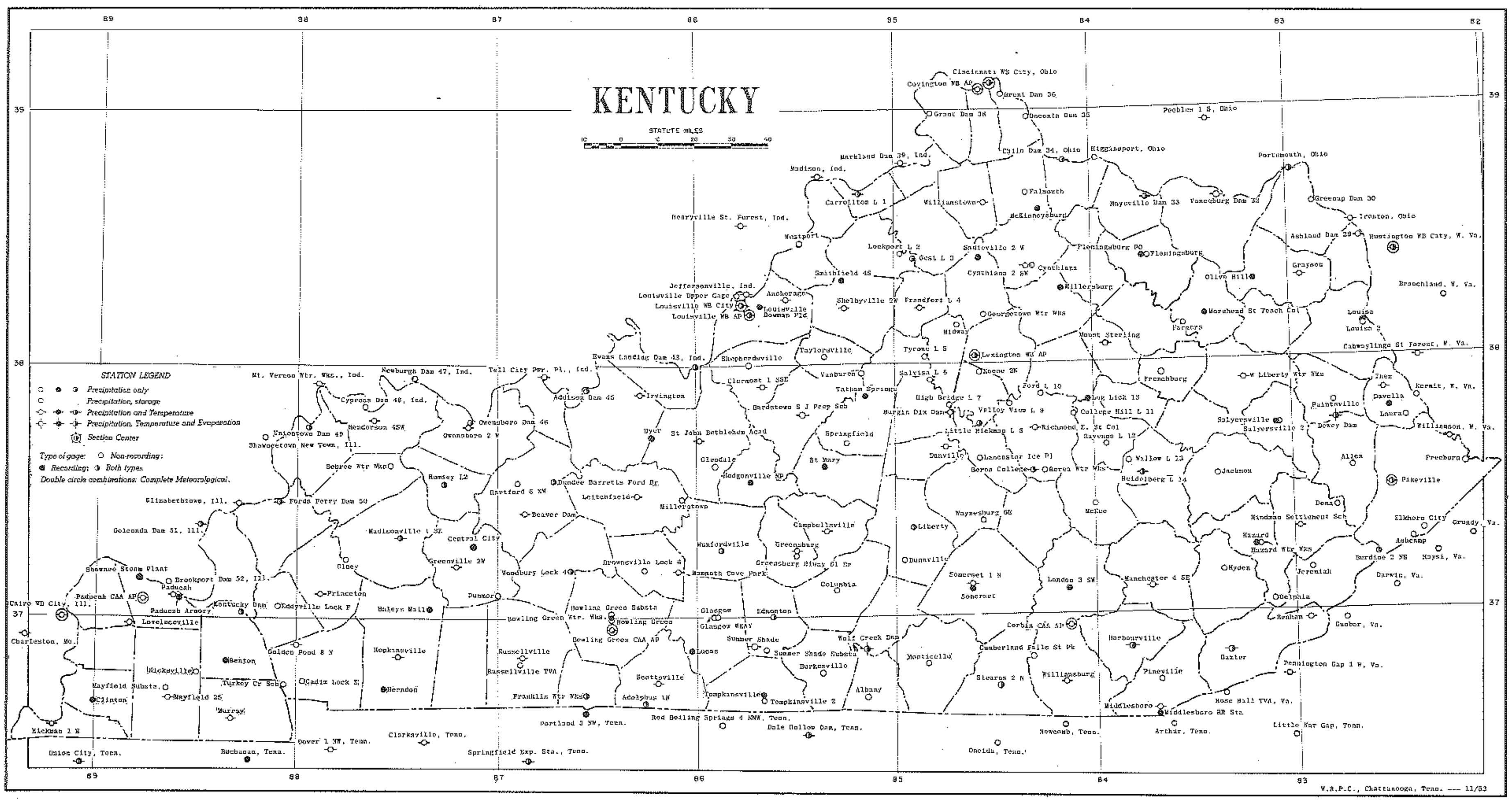

Fig. 2 - Locations of Meterological Stations in Kentucky

Throughout the report this group is termed the 18-station network of first-order stations, or more often just the "network".

Complete records were not available for the entire 1903-51 period for the five stations marked and referred to in the footnote on page 6. In all the cases except Wytheville, Virginia, charts from the gauges were on file with the National Weather Records Center at Asheville, North Carolina, but charts during certain periods had not been evaluated. This was so, since Wytheville had been reduced to a secondary status by the Weather Bureau in 1940.

Maximum annual 24-hour data were obtained for all the stations within the 1903-51 period, thus making comparisons on that basis possible. For the purpose of analysis for all the durations from 5 minutes to 24 hours as previously mentioned, the shorter periods of record were used and the data correlated with the data based on complete records from the other stations, even though it was recognized that this was not justified in the statistical evaluations. Despite the inconsistency, it was verified that a broader sample represented in the 18-station network would provide better correlations than a reduced sample from fewer stations based entirely on comparable periods of record.

Unfortunately Lexington, which is a most critical station for Kentucky, had the shortest period of record - 32 years (1903-34). Early in the work consideration was given to an arrangement for having the additional charts taken during the period 1934-51 evaluated by the Weather Records Center at the expense of the Highway Department or as an alternative obtaining the records on microfilm and making the evaluation with

Research Division personnel. The cost of either was regarded as prohibitive, and plans for completing the record at Lexington were abandoned. Research for the future will demand the use of a longer period of record for Lexington if this station is to be kept in the network.

To supplement the first-order network, data from 87 non-recording 24-hour stations and 54 recording stations were used in establishing correlations and developing synthetic data. The latter were covered in the period 1940-47 by "Daily and Hourly Precipitation Hydrologic Network Records for the Ohio River District," compiled by the U.S. Weather Bureau in cooperation with the Corps of Engineers and the United States Department of Agriculture. Since 1947 the same stations have been covered in Hydrologic Bulletins or publications of Climatological Data issued by the Weather Bureau. Locations of stations in the group (designated "recording" or "both types") are shown in Fig. 2.

For considerations of this rainfall study, the records from these 54 stations were worked for maximum annual 1, 2, and 24-"clock" hour durations and a period of record from 1940-51. In the future, if sufficient funds should become available, the traces on charts from these recording gauges could be processed for excessive precipitations* even more thoroughly than the records from the first-order network were processed in this study. From a tabulation of annual excessive precipitation, the maximum annual depths of rainfall could be tabulated for 5, 10, 15, 20, 30, 45, 60, 80, 100, 120, 150 and 180-minute durations, or for any other duration that might be desired. Under present circumstances, where only limited data had been extractedfrom the charts,

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* See Glossary

it was necessary to use adjusted 1, 2, and 24-clock hour depths of rainfall for a selected return period to calculate by correlation methods (based on the first-order network), "synthetic" depths for durations between 2-hour and 24-hour periods, as well as depths for selected durations less than 1-hour. The clock hour magnitudes were adjusted by correlation procedures prior to the development of synthetic data.

With regard to the non-recording 24-hour stations in Kentucky, there were 87 with periods of record greater than 9 years. A period of record from 1914 to 1951 was represented at 26 of these, the remaining 61 having lesser periods. In this study, data from these sources were used to create synthetic data based on correlations from the 18-station first-order network. It is pertinent to note also that these stations rather than the 9 appropriate first-order stations can serve as point references for depth of rainfall in application of the Dickens Formula.

Finally, in certain phases of the study data from 57 stations in neighboring states of the Ohio River Basin were compiled. These covered short periods of record (1940-47) for which rainfall for 1- and 2-clock hour durations were tabulated. Additional 24-hour records have been compiled by the U.S. Weather Bureau for use by the Bureau of Public Roads in extending analyses in the manner applied to the entire Allegheny-Cumberland Plateau section of the country by Potter (35). All this information, even though derived from stations outside the state, is applicable to correlations within the state and is available for that purpose.

For the most part depths of rainfall calculated from data from all the stations except those in the first-order network have been relegated to a separate publication and they do not appear in this report. Because of restrictions in time and the decision to terminate research in this field, correlations could not be carried to the point where a revised system of design based on rainfall-discharge relationships could be thoroughly investigated and established. However, the analyses that have been made are extremely valuable, for example in their use for determination of rainfall factors discussed later in the report and illustrated in Fig. 8. Thus the additional compilation of data from secondary stations are not discounted; rather, they are largely the reason for the separate publication which has been mentioned, the intent being to make the results of this effort generally available for others who may be able to carry out more extensive investigations in the future.

Depth-Return Period Relationships; First Order Network

Depth-duration and intensity-duration curves for 9 of the first-order stations are plotted in Figs. 12a-12r (Appendix A). These and comparable curves for the remaining 9 stations of the network were constructed from the data contained in Table 6. The stations for which curves are shown were used in determining the areal distribution of station influence by the Thiessen method discussed more fully later in this section of the report.

The process by which maximum annual extremes, tabulated by the U.S. Weather Bureau, were converted to the values listed in Table 6 was briefly as follows:

1. The theory of extreme values (11) defined the procedure, and special extreme probability graph paper (see Appendix C) was used in the analysis.

2. Values tabulated for the period of record were arranged in order of increasing magnitude, with the smallest assigned an order number m = 1 and the largest m = N, where N is the number of years of record.

3. The plotting position* of the ordered data were calculated by the formula:

$$\phi(x) = \frac{m}{N+1}$$

where $\phi(x)$is the frequency (as noted on the graph papers in Appendix C).

4. The N observed extreme values ordered in increasing magnitude were plotted on the special probability paper at their cumulative relative frequencies. (Note: on the selected paper they should form a linear trend about a straight line on the graph).

5. Parameters, represented by the data, were calculated in order to establish the representative curve or theoretical relationship between the variables of depth and return period as follows:

a. Sum and sum the squares of the N events
b. Determine the arithmetic mean
c. Calculate the standard deviation*
d. Using the method of orthogonal least squares (11) calculate the slope and mode.
e. Substituting in the formula

$$x = u + (1/a)y$$

where:
x = depth of rainfall for a specific return period
u = the mode (most common value) or the slope intercept of a straight line in terms of y
$1/a$ = slope or logarethmic rate of increase
y = reduced variate employed to linearize the frequency scale (values of y are given in Table 10 of Appendix D for selected return periods).

determine the theoretical prediction equation.

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* See Glossary

Substitution of appropriate y values from Table 10 gives the indicated depth of rainfall for different return periods, or the relationships can be taken directly from the desired curve or line of best fit drawn on the graph.

An example of results from such a calculation are shown in Fig. 3, where the depth-return period relations for a 2-hour duration were determined for the station at Louisville. Calculations were based on the period of record 1903-51. Pertinent values were:

Summation of observed values	=	72.69
Summation of squares of observed values ...	=	114.9875
Arithmetic mean	=	1.4835
Standard deviation	=	0.3823
Slope	=	0.3299
Mode	=	1.3027

From these, the theoretical prediction equation is expressed as $x = 1.3027 + 0.3299y$. Substitution of appropriate values of y from Table 10 gave the depths of rainfall corresponding to the selected return periods, as tabulated in Table 6, opposite Louisville, Kentucky, and below the 2-hour duration heading.

Also shown in Fig. 3 are the confidence bands or control curves defining the limits of relative departure of the most extreme values for a probability of 0.6827 (10, 11). This limit of 68 times in 100 was maintained throughout the study. In effect, this implies that the relationship expressed by the curve of best fit is not exact, but rather that the values can vary within a given range. For example, at Louisville the depth of rainfall corresponding to a 2-hour duration and 100-year return period (T)

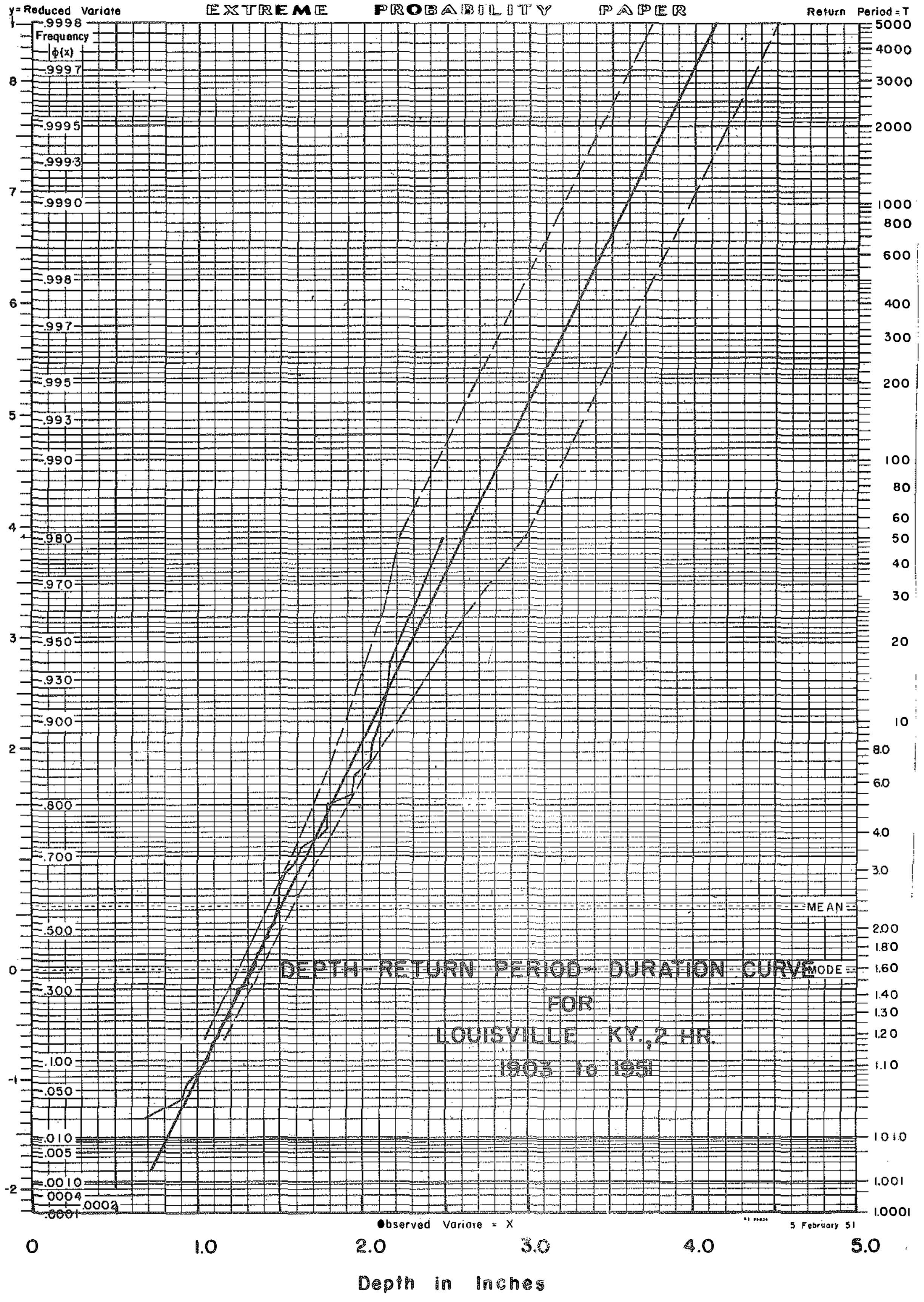

Fig. 3 - Annual two hour rainfall for Louisville, Kentucky, 1903-51

is 2.82 inches (Table 6). This value can vary ± 0.39 inch, as defined by the broken lines on both sides of the solid line in Fig. 3. Thus, the depth may be 2.43 to 3.21 inches 68 times in 100.

With regard to time, Louisville has 49 years of record and the 100-year, 2-hour rainfall is expected once in the next 50 years and it should not occur before 0.32 T nor after 3.13 T (10). This represents a period from 32 to 313 years. If, as is probable, it appears within that range, the 68 percent confidence limit has been maintained with regard to both magnitude and time.

Computation of Depth-Area Relationships

Rainfall over a small area has been found to vary with the square root of the area involved (12, 13, 14). The usual basic assumption is that rainfall at any point is representative of areas varying from a few acres to several square miles, depending upon the density and distribution of the station network. The qualification of this assumption depends upon a variety of factors, including meteorologic and topographic influences.

The simplest method of distribution is to apply the arithmetic mean of the depth of rainfall to the entire area in question. This is not recommended if variations in depth are greater than 25 to 50 percent.

The use of a weighed average* for computing rainfall over an area usually affords more accurate results than those obtained by an arithmetic average. Two common means of determining this weighed average are the Isohyetal Method* and the Thiessen Method* (15, 16, and 17).

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* See Glossary

In the Isohyetal Method, rainfall depths for each available station are plotted on a map, the probable position of even rainfall values is interpolated between stations, and equal values are connected by smooth lines. The construction of this pattern is similar to a contour map but, where topographic influence exist (e.g., mountain ranges between stations), a rigid arithmetic interpolation should not be followed. In such cases, the lines are modified to make allowance for these influences. The presence of outstanding topographic influences and the modifications thus introduced may cause this method to vary considerably from the Thiessen Method. As to the nature of the Isohyetal lines, there is a tendency for them to become closer together near high centers of rainfall.

The Thiessen Method is an arbitrary geometric procedure for determining the weight which will be assigned to each rainfall record within a given area. After these weights are known, they may be used repeatedly in computations of areal rainfall for various return periods for a watershed. With the Isohyetal Method, a separate pattern must be drawn and areas computed for each return period. The Thiessen Method is recommended for use until such time that Isohyetals for the various return periods can be drawn.

In the application of the Thiessen Method, Kentucky was divided into 9 polygons, each named for the first-order station concerned. These polygons constitute the Thiessen diagram for this state and are depicted in Fig. 11, Appendix A. When designing structure openings, one should first locate the polygon within which the drainage area in question is located, then proceed to the proper set of design curves to determine rainfall data for this area (Figs. 12a - 12r, Appendix A). In doing so, the designer should recognize that the polygons merely represent the results of a geometric distribution of station influence, and particularly near the boundary between polygons local conditions may make it more reasonable to design with data from the station in the adjacent polygon, rather than the station controlling the polygon within which the drainage area actually lies.

Development of Synthetic Short Duration Rainfall Depth-Return Period Data

Inasmuch as the record at secondary stations was generally limited to 24-hour amounts, the data from those sources could not be directly applied in the analysis for rainfall of shorter duration. However, through a correlation analysis based on the first-order network in its entirety, a reliable basis for developing synthetic data was established. In this way, short duration rainfall at any of the secondary stations could be predicted for any of the defined return periods.

Data from stations with similar periods of record may be used together for direct comparative purposes, provided both contain at least ten year's of record and the curve of observed data at the station of interest falls within the control curves applicable to the data from the station to which it is being compared. This means that all extreme values, the largest and the penultimate, should lie within the control curves. If some do not, probably they represent values in a period of record greater than the one being considered. Data from stations with dissimilar periods of record should never be compared directly, but they may be employed in the development of synthetic record.

Multilinear correlation was used to establish within the 18-station first-order network relationships of the parameters. Correlations were made between depths for the following durations:

24-hour vs. 2-hour
24-hour vs. 1-hour
2-hour vs. 1-hour
1-hour vs. 30 min., 15 min., 10-min., and 5 min.
30-min. vs. 15-min., and 10 min.
15-min. vs. 10-min., and 5 min.
10-min. vs. 5-min.

With these correlations established for the network as a unit, the 24-hour amounts from secondary stations could be used in conjunction with the prediction equations to calculate maximum rainfall of lesser duration that probably would have occurred at the secondary station within whatever return period was of interest.

An example of the correlation is contained in Fig. 4, where the depths for 2-hour versus 1-hour durations and a 100-year return period are compared. The previously calculated amounts from all the stations in the network (recorded in Table 6) were plotted, and a confidence limit of 68 times in 100 was maintained with a correlation coefficient* of at least 0.5 The line of best fit, established by the method of least squares, defined a prediction equation of

$$X_{12} = 0.576 + 0.661\, X_2,$$

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* See Glossary

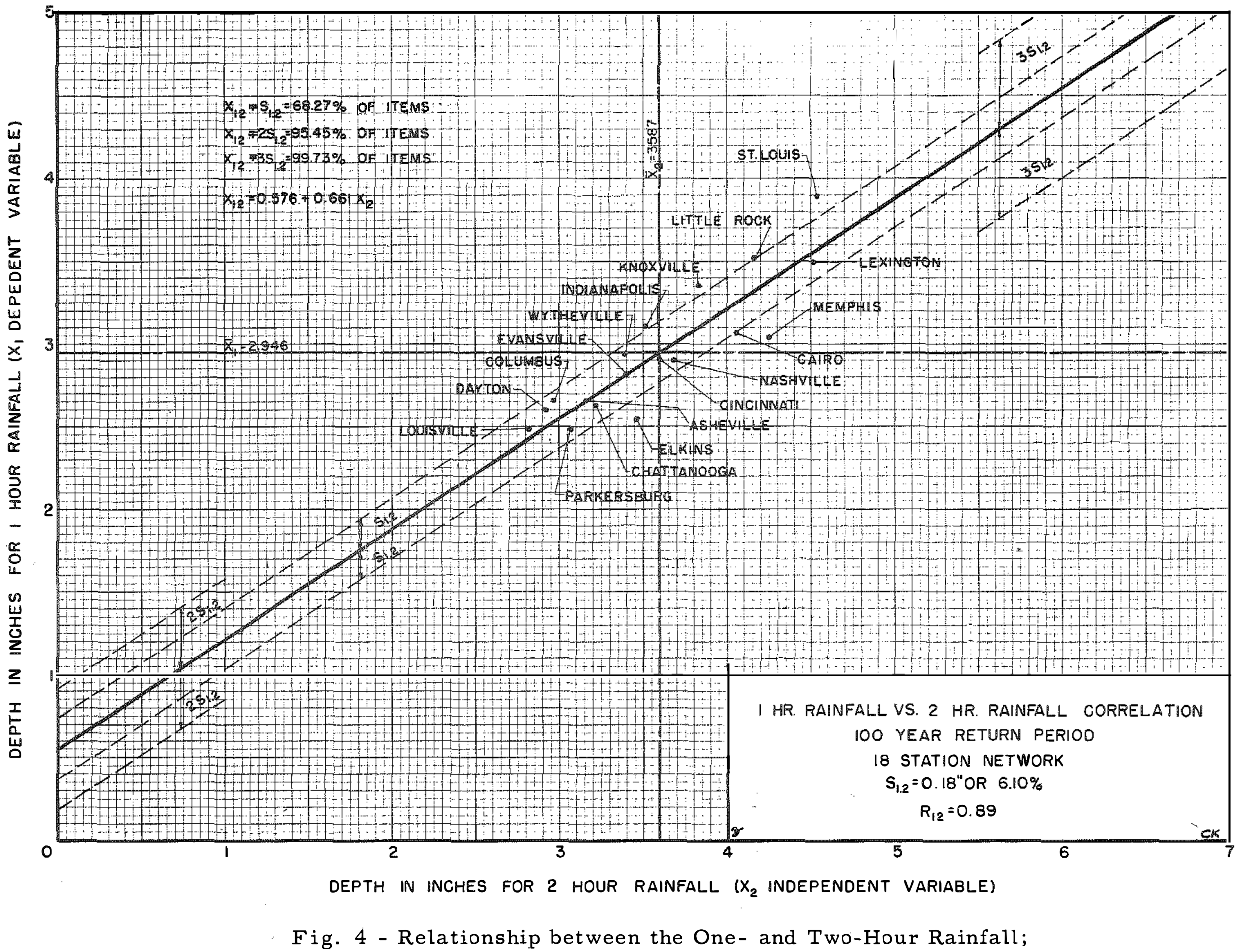

Fig. 4 - Relationship between the One- and Two-Hour Rainfall; 100-Year Return Period, 18-Station Network

where X_{12} = calculated (synthetic) depth of rainfall based on X_2

X_2 = Independent variable, depth in inches for a 2-hour duration and a return period of 100 years. (This value may be a synthetic depth based on the 24-hour, 100-year depth.)

with a standard error of estimate of ± 0.18 inch for 68 times in 100.

As an illustration, assume that for a secondary station a depth of 3.0 inches for a 2-hour duration has been determined for the 100-year return period, and it is desired to know what the 1-hour amount would be for the same return period. Enter the graph at $X_2 = 3.0$, proceed upwards to the intersection of the line of the prediction equation, then horizontally to the X_1 axis and read $X_1 = 2.55$ inches. Also, the prediction equation may be solved to obtain the value of X_{12}. Thus, this result in combination with the standard error of estimate, implies that 68 times in 100 the 1-hour maximum rainfall at that station will be no less than 2.37 inches and no more than 2.73 inches for the 100-year return period. For purposes of design the most appropriate value within this range would be a matter of engineering judgment. For a small drainage area either value could be satisfactory, but for a large area overdesign or underdesign could result from values selected within the given range. Perhaps most engineers would prefer overdesign and use 2.73 inches for the 1-hour maximum.

RAINFALL INTENSITY-RETURN PERIOD DATA APPLIED TO CURRENT METHODS OF DRAINAGE DESIGN

The limitations inherent in any method of estimating runoff through the use of empirical formulas have become rather widely recognized, and continued use of such methods in the design of drainage structures can be justified only on the basis of expediency. At the outset of this research it was intended that the work merely provide revised "C" factors for the Talbot Formula, but prior to the first progress report it was recognized that this was not feasible and hardly desirable. Following this it was hoped that a completely revised approach could be developed, but lack of records of runoff from small drainage areas precluded such a development at this time.

As a result of these restrictions, results of the rainfall study were applied to current procedures in order to increase their effectiveness. This involved adaptations of intensity and depth-return period relationships to the Talbot and Dickens Formulas in the case of culverts and small bridges, and to the Rational Formula in the design of storm sewers, gutters, and cross drains. These adaptations, some of which have been incorporated in the Manual of Drainage (36) recently issued by the Division of Design, represent major refinements in most of the approaches used to date, even though the methods themselves fall far short of perfection.

Application to the Rational Formula and Storm Drainage Design

Wide variations in runoff relationships are encountered in culvert design, however, such variations are minimized in storm sewer design. Therefore, runoff factors estimated from studies on various types of areas are reasonably reliable in the design of storm sewers (29). For example, in urban areas the watershed generally contained a significant percentage of roofed surfaces and pavements, which have a more or less standard imperviousness. This condition provides fairly uniform runoff conditions, and a method based on C values (or, runoff coefficients*) can be regarded sufficiently accurate provided rainfall is treated properly.

In the Rational method of estimating runoff, the variables in addition to those expressed by runoff coefficients are area of watershed and rainfall intensity. According to the formula, these are related as:

$$Q = CIA$$

where Q = runoff (cubic feet per second)

C = runoff coefficient (a ratio determined by the surface features of the watershed)

I = intensity of rainfall (inches per hour) for the time of concentration* (minutes) of the watershed.

A = drainage area (acres)

Area is subject to easy and accurate measurement, while the runoff coefficient can be no better than the estimates of surface conditions determining the proportion of precipitation falling on the area that ultimately reaches the point where the calculated discharge is applicable;

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* See Glossary

for example, the inlet of a storm sewer. Finally, the rainfall intensity and hence the duration appropriate for the solutions is dependent upon the time required for runoff from all parts of the drainage area to concentrate at the point in question.

As noted previously, there is limited variety of surface feautres in areas where this method is considered useful and C factors for this condition have been established within general limits. Ranges of C values often used in design work (24) are presented in Table 1.

Table 1 - Values of C for Different Types of Surfaces

Type of Surface	Value of C
All water tight roof surfaces	0.75 to 0.95
Asphalt runway pavements	0.80 to 0.95
Concrete runway pavements	0.70 to 0.90
Gravel or macadam pavements	0.35 to 0.70
Impervious soils (heavy)*	0.40 to 0.65
Impervious soils with turf*	0.30 to 0.55
Slightly pervious soils*	0.15 to 0.40
Slightly pervious soils with turf*	0.10 to 0.30
Moderately pervious soils*	0.05 to 0.20
Moderately pervious soils with turf*	0.00 to 1.10

* For slopes from 1 to 2 percent

In the four cases that do not involve soils, the factors are considered independent of slope of the surface. Generally these are applied in a modification of the Rational Formula (31), which is used as means for introducing slope considerations.

In the modified version, $Q = \frac{C}{f} IA$, with f representing the slope influence as follows:

Slope	f
0.5 or less	3.0
0.5-1.0	2.5
1.0 or greater	2.0

It should be noted that these and the values in Table 1 are recommended for use only with the Rational Formula, and they are not considered applicable to watersheds outside urban regions, except for unusual instances such as airports.

With regard to the rainfall intensity, a design return period should be selected, and the duration made equal to the time of concentration. A number of empirical equations can be used to approximate time of concentration, and various types of curves for this purpose have been developed. One such curve, based on data from studies of small agricultural watersheds (30), is presented in Fig. 13, Appendix A. In the example accompanying Fig. 13, the calculated time of concentration is 17 minutes, hence the value of intensity (I) that logically should be used in solving for the design discharge is the one corresponding to 17-minute duration at whatever station applies to the area where the design is being made.

Numerous approximations and assumptions are represented in the method even with these refinements, and other factors such as the direction of storm travel are not taken into account at all. Nevertheless, the Rational Method offers the most simple and feasible approach to storm drainage designs for the present and for some time to come, thus it is the procedure recommended when the watersheds are essentially urban.

Application to the Talbot Formula

Prior to the adoption of the 1954 Drainage Manual (36), solutions of the Talbot Formula were made by means of a table based on a constant rainfall value of 4 inches per hour with a constant time of concentration of one hour for all sizes of watersheds for the entire state (8). The fallacy of this assumption is evident in results of the rainfall study. In brief, designing for 4 inches per hour for all watersheds on a state-wide basis means that the return period represented in the design is dependent upon the location for which the design applies, and invariably the return period is far greater than almost any design warrants. Or conversely, if the Talbot Formula is used unmodified, the design will be very conservative for structures serving large drainage areas, and insufficient in cases where the areas are relatively small.

Examples of the fallacy are given in Table 2, where the implications of 4 inches per hour for a duration of rainfall of one hour are tabulated for the 9 stations represented in the Thiessen polygons of station influence in Kentucky. As noted, the return periods corresponding to 4 inches per hour for a one-hour duration range from 265 years at Lexington to 15,000 years at Louisville. In more useable terms, these values mean that in a situation where it is desired that the design be for a return period of 25 years, the factor of safety represented by the 4 inches per hour for a one-hour duration estimate would be 1.40 at Lexington and 2.02 at Louisville. Fortunately, those making drainage analyses by the Talbot Formula in the past have become

Table 2 - Relationship Between a 25-Year Return Period Base and The Return Periods Realized for Rainfall Intensities of 4 Inches Per Hour at Indicated First-Order Stations.

Station	Approximate Return Period For 4 In. Per Hr. Rainfall	Ratio of Return Period For 4 In. Per Hr. to 25-Yr. Return Period*
Cario, Illinois	1,050	1.62
Cincinnati, Ohio	5,500	1.90
Evansville, Indiana	3,200	1.83
Knoxville, Tennessee	370	1.45
Lexington, Kentucky	265	1.40
Louisville, Kentucky	15,000	2.02
Nashville, Tennessee	2,150	1.74
Parkersburg, W. Virginia	10,000+	2.00
Wytheville, Virginia	1,325	1.67

* This ratio is synoymous with the factor of safety employed in structural engineering design. In drainage design, based on a selected return period, the factor of safety should be 1.00.

accustomed to compensating for this source of error through adjusted designs based on personal judgment, the reduction or increase coming about through modification of the C factors encompassing variations in rainfall as well as variations in characteristics of the watershed.

In order to provide a more uniform basis for estimates, the Talbot Solution Table was revised and based on an intensity of 1 inch per hour. This information is presented in Table 7, Appendix A. By this revision, the Formula may be expressed as:

$$a = \frac{CA^{0.75}}{4}$$

where a = area of opening required (square feet)

C = runoff coefficient (a fraction less than 1.0)

A = drainage area (acres)

The table provides a solution for area of opening required with different C factors and an equivalent rainfall of 1 inch per hour for the time of concentration of the watershed.

To determine the rainfall intensity appropriate for any design situation, it is necessary to estimate the time of concentration for the watershed, as noted previously in discussions of the Rational Formula. With this serving as the duration, the intensity can be taken directly from the appropriate intensity-duration curve for the selected return period in the group Figs. 12a - 12r, Appendix A. The appropriate curve is selected by determining the Thiessen polygon in which the drainage area lies, and noting the information pertaining to the control station for that polygon. A design area of opening is calculated by multiplying the value taken from Table 7 times the value of intensity in inches per hour taken from Fig. 12.

With the influence of rainfall removed from the runoff coefficient, it is apparent that C values listed (8) in the past are not compatible with the method of solution which has just been discussed. Coefficients taken from Table 7, in order to be consistent with procedures in both cases, must be based on topography, soil conditions, and cover. Some recognized values, and the manner in which they may be applied, are given in Table 3 (32). Obviously, these are merely values considered representative in a very general way, and judgment should be exercised in their use.

It is well to recognize in passing that basically a runoff coefficient relates runoff to rainfall intensity, with all features of the drainage area thrown in at the time of measurement. Inasmuch as these features are quite variable with respect to antecedent conditions* on the watershed, distribution of rainfall intensity over the watershed, and numerous similar influences, there is no certain C factor that applies invariably to a certain area. This must be taken into account, particularly in determination of C values experimentally on test drainage areas, whenever work of that type is undertaken.

Values of C will increase as the intensity of rainfall increases from low values below 1 inch per hour, with C approaching unity as the intensity becomes very large. If the area of watershed being analyzed is very large, the variations in intensity would tend to increase.

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* See Glossary

Table 3 - Deductions From Unity to Obtain the Runoff Coefficient for Agricultural Areas.

Type of Area*	Value of Deductions
Topography:	
Flat land, with average slopes of 1 to 3 feet per mile.	0.30
Rolling land, with average slopes of 15 to 20 feet per mile.	0.20
Hilly land, with average slopes of 150 to 250 feet per mile.	0.10
Soil:	
Tight impervious clay	0.10
Medium combinations of clay and loam	0.20
Open sandy loam	0.40
Cover:	
Cultivated lands	0.10
Woodland	0.20

* Example:

Given: Flat land with average slopes of 1 to 3 feet per mile, open sandy loam and woodland.

Find C for above given conditions.

Solution:
1. - 1.0 - 0.3 = 0.7
2. - 1.0 - 0.4 = 0.6
3. - 1.0 - 0.2 = 0.8

C = 2.1 ÷ 3 = 0.7 avg. for area

Usually the calculation of a weighed coefficient, taking into account percentages of area of different types, is not warranted in this approximation of C.

In most storms, centers of high intensity would be localized, and the effect from this extreme condition with respect to the watershed as a whole would be slight. Since point rainfall is measured at a rain gauge, C values determined on very small experimental watersheds would tend to be too large when applied to considerably larger area. Possibly through studies similar to those conducted by the U. S. Army, Corps of Engineers (33), a reduction factor correlated with area of drainage basin could be developed for application to large areas.

With regard to the Modified Talbot Solution presented in Table 7, its use is not recommended for areas smaller than 100 acres or a time of concentration shorter than 10 minutes. The upper limit of use is between 1000 and 2000 acres, and an approximate time of concentration of 1 hour can be used for areas that size if the time of concentration is not readily obtainable from maps of the watershed. When the drainage basin becomes larger than this approximate limit, the Talbot Formula has little or no application; instead, personal judgment of the engineer should be used in lieu of stream discharge records, assuming such records are not available.

Application to the Dickens Formula

The Dickens Formula, $Q = BM^{0.75}$, is a variation of the Talbot type formula in that an empirical relationship is devised for the solution of design discharge rather than area of opening. In this case:

Q = discharge (cubic feet per second)

M = area of watershed (square miles)

B = coefficient

As indicated before when Talbot C factors were discussed, in reality the B coefficient can not be a constant, and it does not depend entirely on physical characteristics of the watershed. All conditions on the watershed, including the distribution of rainfall intensity, are actually involved in the true coefficient relating the two variables. However, for the purpose of design, a constant coefficient is assumed for a given area.

Solutions of the Dickens Formula, based on an equivalent depth of rainfall of 6 inches in 24 hours, are tabulated in Table 9, Appendix A. Numerical quantities of discharge are listed with respect to increasing drainage area, and 9 different values of coefficient B ranging from 75 to 375. Proper use of the formula then entails selection of a representative B value, in addition to the determination of rainfall appropriate for the area where the design is being made.

The latter involves rainfall factors for conversion from the base of 6 inches in 24 hours to an amount that will probably occur at the site within whatever return period is chosen for the design. Calculated 24-hour rainfalls for the 9 first-order stations controlling the Thiessen polygons for Kentucky and for various return periods from 2 to 100 years are listed in Table 8, Appendix A. The ratio of the calculated 24-hour rainfall divided by the base value of 6 inches in

24 hours is the rainfall factor (R_f) which applies to the locality. Thus, the design discharge is calculated as $Q = R_f \ BM^{0.75}$.

Analysis of records from 44 stream-gauging stations (on watersheds ranging from 18 to 942 square miles in area), and the numerous secondary rain-gauging stations throughout the state, showed a tendency for B to vary with the size of drainage area and return period approximately as follows:

Area of Watershed (sq. mi.)	B for Selected Return Period			
	10	25	50	100
1-10	500	515	530	540
11-100	400	420	430	440
101-300	360	375	380	380
301-500	340	355	355	360
501-1000	320	330	340	340

Also, variations in B logically occur with respect to different sections of the state, and some correlations based on physiographic regions referred to as problem areas in Fig. 14 (Appendix ~~A~~B) were made. Using a value of B = 375 and expressions of Q in cubic feet per second per square mile, the data indicated that 0.75 as the exponent of M (expressing the slope of the line of correlation of discharge in cubic feet per second versus drainage area in square miles) was too small in all the areas analyzed except B-16. There was no stream discharge data from the Jackson Purchase (mostly A-7 area) with which a study of discharge relations applicable to that region could be made.

Strictly speaking, solutions of the Dickens Formula given in Table 9 should be used with B = 375 only in Area B-16 where it leads to a conservative design, and possibly Area A-7. Elsewhere the B values that would provide reasonably accurate estimates are not known, but additional separate correlations could be made to establish usable values.

Because of the influence of slope of the regression line established by the correlation, the Dickens Formula and values listed in Table 9 are not recommended for use when the drainage area is smaller than 5 square miles. As noted at the close of Table 9, the formula may be used for areas greater than those tabulated; i. e., greater than 700 square miles.

APPLICATION OF RAINFALL INTENSITY-RETURN PERIOD DATA TO OTHER METHODS OF DESIGN

In addition to the three approaches currently used by the Department for drainage design, two other methods were examined or evaluated in the light of data developed in the rainfall study. No innovations in the methods themselves were intended or attempted. Within the limits to which the methods have been developed or studied, they are considered applicable to drainage designs at present, and certainly valuable for comparing designs made by methods previously described.

Potter Multiple Correlation Method

Through an analysis of runoff data from 51 watersheds in the Allegheny-Cumberland Plateau* ranging from 100 to 350,000 acres in size, and a correlation of this information with area and topography of the watersheds as well as rainfall data from 89 widely scattered stations in the region, W. D. Potter (4) developed an equation and nomograph (Fig. 5) for solution of discharge from drainage areas above 100 acres.

The relationships expressed by the nomograph were determined by multiple correlations in which 10-year peak discharge at the stream gauging station on each of the watersheds was taken as the dependent variable. Two rainfall factors, an area factor, and a slope factor were taken as the independent variables. In the ultimate solution for the regression curve, expressed as:

$$Q = 0.038\ A^{1.170}\ T^{-.554}\ W$$

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* A physiographic subprovince in the eastern United States encompassing portions of New York, Pennsylvania, Ohio, Maryland, West Virginia, Alabama, and Tennessee in addition to Eastern Kentucky.

the two rainfall factors are combined in a single factor W. Lines of equal value of W within that part of Kentucky contained in the Allegheny-Cumberland Plateau, as developed by Potter, are drawn in Fig. 6.

With this information available, application of the method is as follows:

1. <u>Factor A</u> - Determination of the area in acres.
2. <u>Factor W</u> - Locate the watershed within the region shown in Fig. 6, and select the value applicable to the watershed, or largest portion of the watershed if it is large.
3. <u>Factor T</u> - From a U. S. G. S. topographic map, or other accurate contour map of the watershed, measure the length (in miles) of the principal stream from the site of the proposed culvert or bridge to the headwater or uppermost point of the channel. This should be taken as the point where a definite channel begins regardless of whether flow at the point is continuous or intermittant. If a U. S. G. S. map is used, the length of the stream should include that portion shown as a broken blue line.

   Divide the total length into a lower reach which is 0.7 of the total, and an upper reach consisting of the remainder or 0.3 of the total length. From the contours establish the differences in elevation between the upper and lower limit of each reach. Compute the average slope of each reach as the fall of the stream channel (in feet) divided by the length of the channel (in miles). Divide the length of channel for each reach by the square root of the corresponding slope, and add the quotients, as follows:

$$T = \frac{0.7L}{\sqrt{\frac{X}{0.7L}}} + \frac{0.3L}{\sqrt{\frac{Y}{0.3L}}}$$

where: L = length of stream (miles)
X = difference in elevation (feet) of the streambed at the culvert site and at 0.7 L upstream.
Y = difference in elevation (feet) of the streambed at 0.7 L and at the headwater.

The so-called topographic factor thus obtained is purely empirical, and has no meaningful units.

4. Solution by Nomograph - For solution of the equation by nomograph, place a straightedge between the values of area A and rainfall factor W, and mark its intersection with the "turning line". Connect this point with value of topographic factor T, and read the peak rate of runoff Q (in cubic feet per second) for a 10-year recurrence interval.

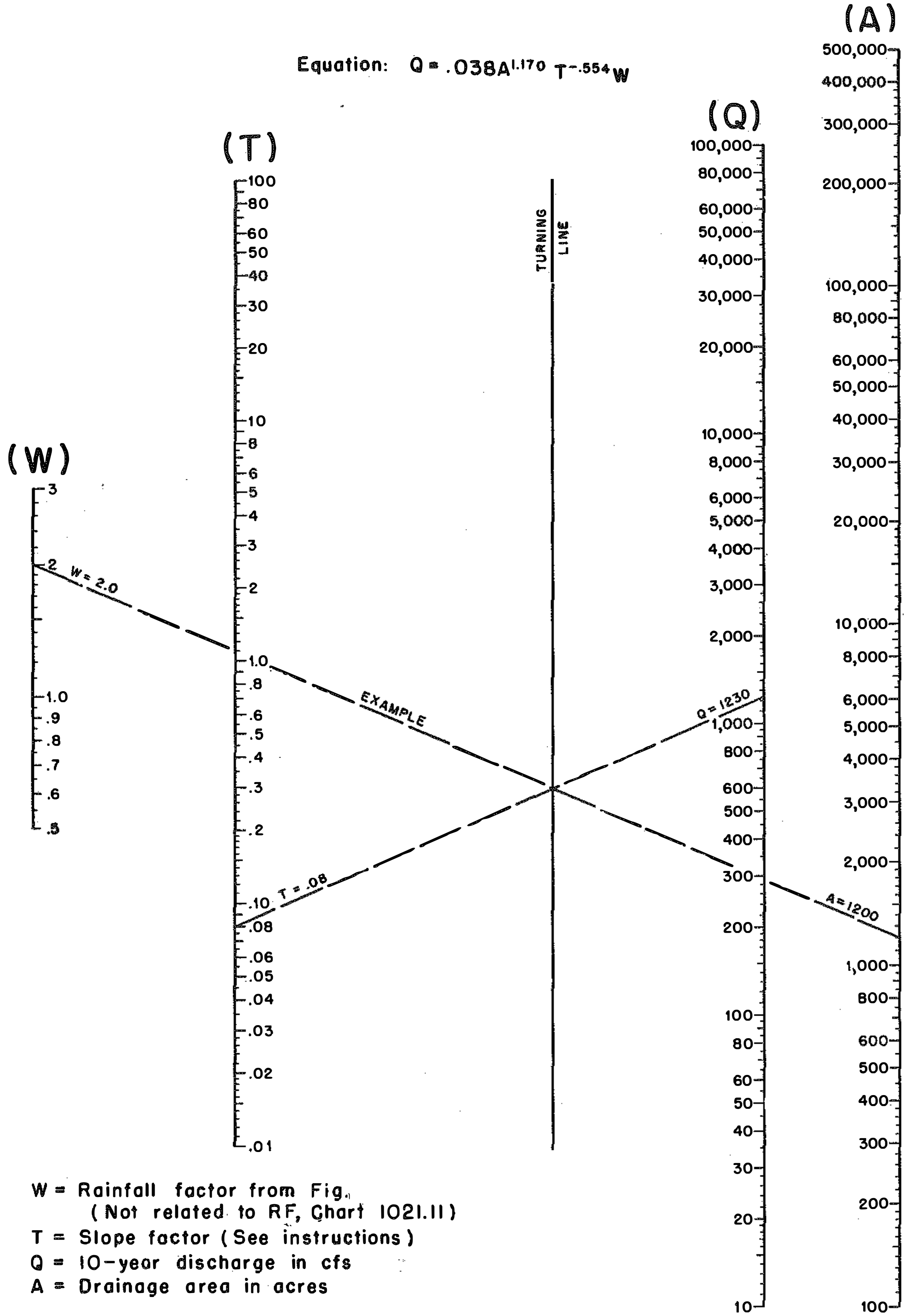
To convert from a 10-year to 25-year recurrence interval, the value of Q is multiplied by a constant 1.26, as noted in Fig. 6. Similarly, a constant 1.46 is used to obtain the design discharge for a 50-year return period. Additional constants, which can be used to estimate peak discharges for selected return periods based on the 10-year value, may be calculated from the following equation:

$$x = 0.3721 + 0.2785y$$

This formula is based on the three known constants that were correlated with the reduced variate (y) for their respective return periods. Values of y are selected from Table 10 (Appendix D) for the particular return periods.

Statistical tests made by Potter on the data from the entire region which he considered have shown that in 67 times out of 100 the use of Fig. 5 and a distribution of rainfall factors comparable to Fig. 6

Equation: $Q = .038A^{1.170}\,T^{-.554}\,W$



W = Rainfall factor from Fig.
(Not related to RF, Chart 1021.11)
T = Slope factor (See instructions)
Q = 10-year discharge in cfs
A = Drainage area in acres

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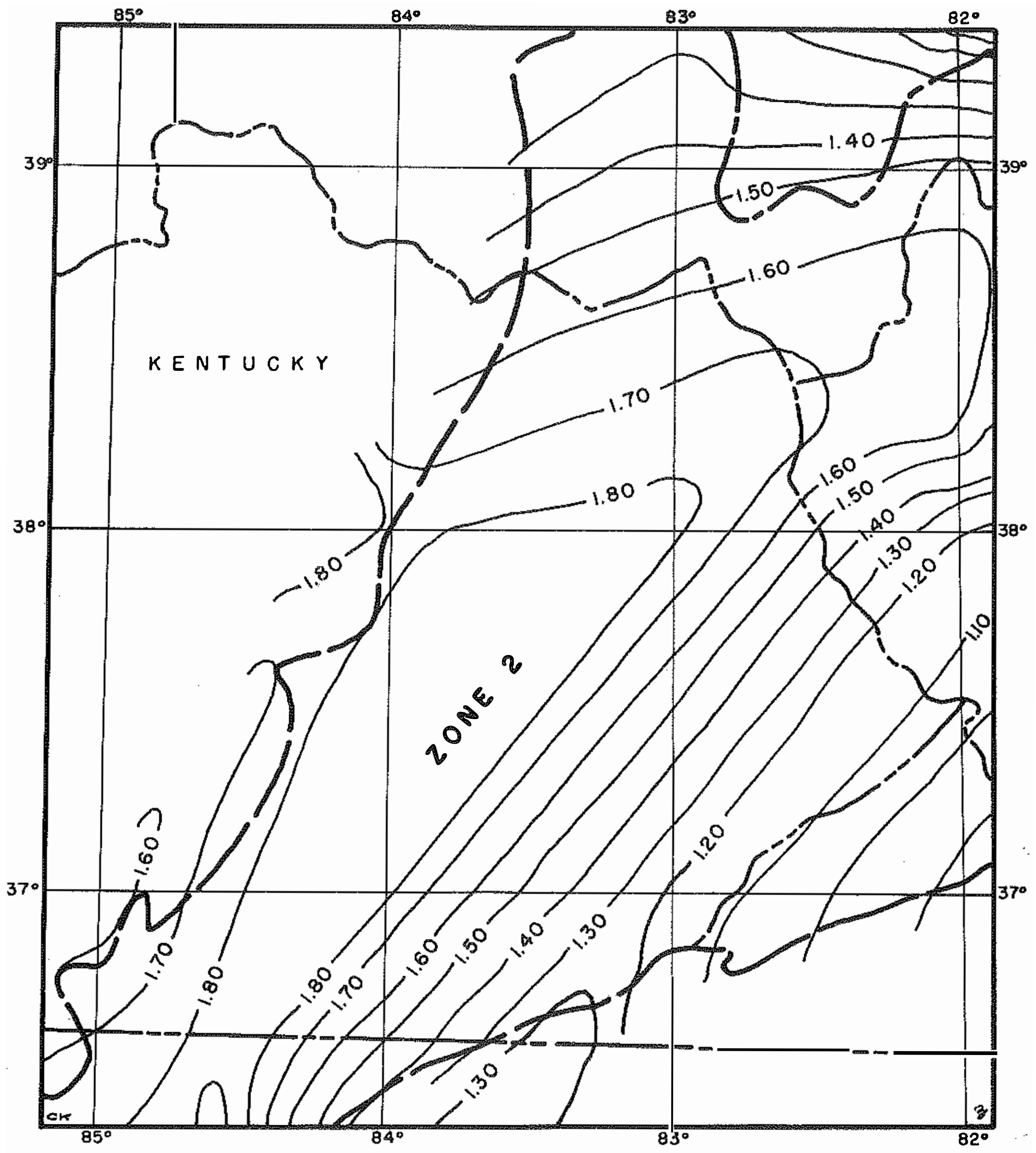
Fig. 5 - **NOMOGRAPH FOR DISCHARGE IN ALLEGHENY-CUMBERLAND PLATEAU**



ALLEGHENY—CUMBERLAND
PLATEAU

ZONE 2

10-yr. Q×1.26=25-yr. Q
10-yr. Q×1.46=50-yr. Q

LEGEND

Boundary of Allegheny-Cumberland Plateau
Zone Boundary
1.00 Values of "W" for use with Nomograph (Fig. 5)

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Fig. 6 - Rainfall Factors for Peak Rates of Runoff for the B-15 Physiographic Region in Kentucky

(but extending throughout the region) may be expected to give values of Q_{10} that vary not more than 18 percent from the true values.

Both Fig. 5 and Fig. 6 apply only to watersheds with mixed cover, such as croplands, pastures, and woods. Although the proportions of watershed represented in each of these three classifications vary considerably throughout the Plateau, the effect of these variations on peak rates of runoff was found to be negligible for rates with recurrence intervals of ten or more years.

Wherever more than 10 percent of the total watershed consists of industrial or urban areas, or if wooded portions of the watershed have been subjected to numerous fires, the peak rates will be greater than those obtained from Fig. 5 and Fig. 6. Likewise the peak rates will be less if there are appreciable swamp and lake areas, or if regulatory reservoirs or stream diversions lie within the watershed.

Rainfall - Land Use Method

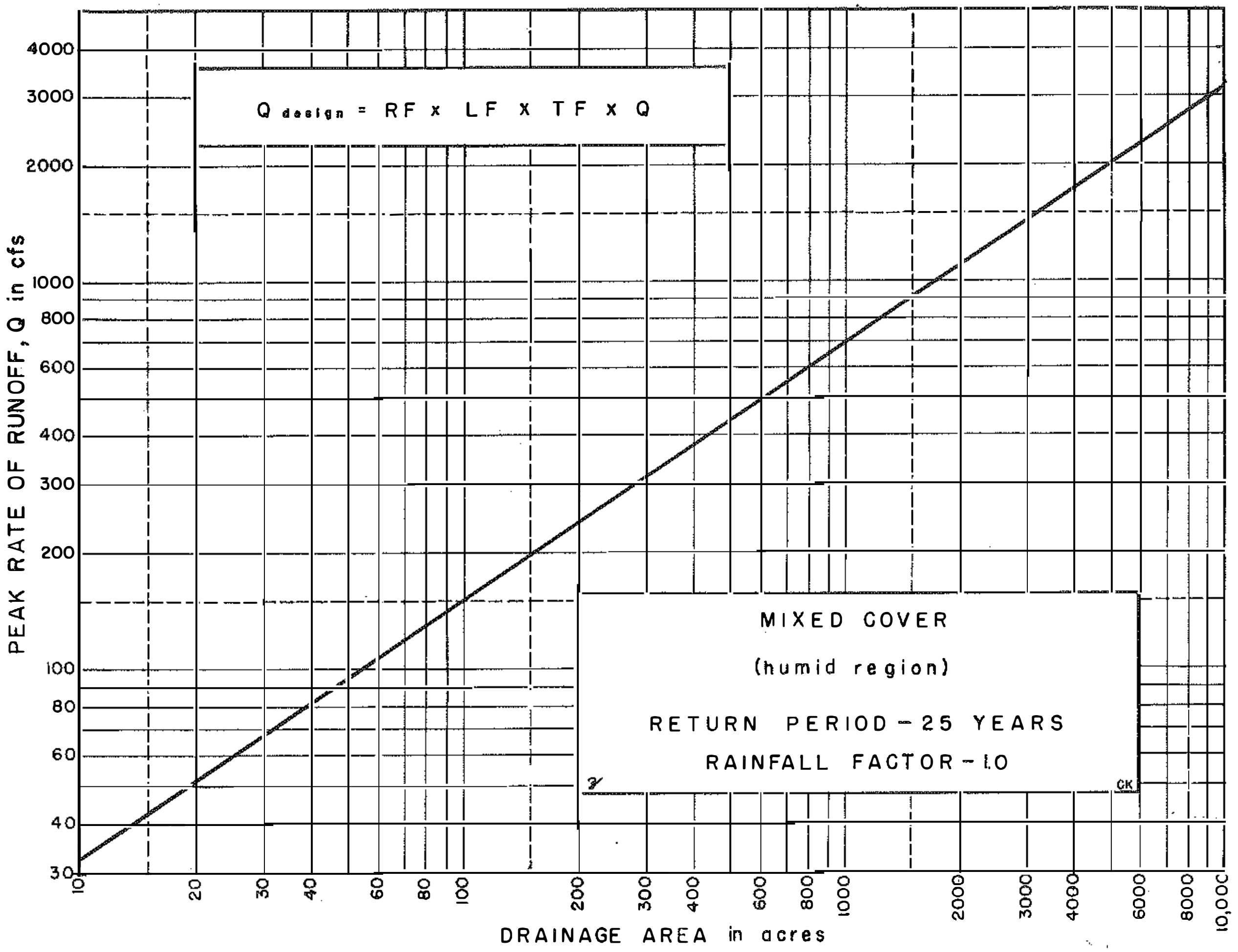
Several organizations have utilized existing rainfall data and other information relating to land use in the development of estimating procedures based on records from stream-gauging stations. Often these generalize on the land-use conditions, and rely on measured peak rates of runoff from relatively large drainage areas even though the situation of interest is with small watersheds. Better data for application to small watersheds are obtained from drainage areas the size of those to which the design procedure is to be adapted. One such application was made by Izzard (34) (44) for watersheds under 1000 acres in size.

With Izzard's application serving as an example, discharge records from 44 streams in Kentucky as well as numerous records from streams in adjacent states were used to develop a set of information relating peak rates of runoff to the size of drainage area for watersheds under 10,000 acres in size. A curve and related data from this development are contained in Fig. 7. This represents a downward revision of Rainfall Factors presented by Izzard (which were based on Yarnall's (3) curves), and also considerable revision in the Return Period Factors. Land Use and Slope Factors were taken directly from Izzard's publication without revision, there being no new data pertinent to Kentucky on which a revision could be based.

The areal distribution of Rainfall Factors for the state is shown in Fig. 8. These values were based partially on synthetic 1-hour non-recording stations (45), and partially on data from the 18 first-order stations. In a solution for design discharge using Fig. 7, a Rainfall Factor for the area in question can be taken directly from the isopluvial lines in Fig. 8. It should be noted, however, that this distribution represents a broad interpretation from the station data, and therefore should not be considered minutely accurate for the division of drainage areas within counties, for example, or even at the boundaries between counties.

The factors for Land Use in the table on Fig. 7 are given for three classifications of slope. Factors for slope exceeding 2 percent originated from data from the Soil Conservation Service (35), and they are reasonably reliable. The Factors for flat and very flat land slopes are estimates based primarily on the effect of slope toward increasing surface detention and channel storage. Therefore these values should be subject to correction wherever substantiating data are available.

1021.10-A



RAINFALL FACTOR (RF) See Figure 1021.11-A

LAND USE AND SLOPE FACTOR (LF)

Land Slope	Steep over 2%	Flat 0.2%	Very flat, no ponds
1.00% Cultivated (row crops)	1.2	0.8	0.25
Mixed cover	1.0	0.6	0.2
Pasture	0.6	0.4	0.1
Woods, deep forest litter	0.3	0.2	0.05

RETURN PERIOD FACTORS (TF)

Return period yrs.	5	10	25	50	100
Factor TF	0.70	0.83	1.00	1.13	1.25

EXAMPLE

570 ACRES NEAR LATITUDE 38°18' AND LONGITUDE 83°03'. MIXED COVER, STEEP OVER 2% DESIGN RETURN PERIOD 25,50,100 YRS.

Solution: (SEE EQUATION ON GRAPH)

$Q_{25} = 0.79 \times 1.0 \times 1.00 \times 475 = 375$

$Q_{50} = Q_{25} \times 1.13 = 417$

$Q_{100} = Q_{25} \times 1.25 = 469$

SOURCE

Derived from thirty seven watersheds in Kentucky. Land use and slope factors from Izzard "Estimating Peak Rates of Runoff-Bridge and Culvert Design," American Society of Civil Engineers 1952. For use in Physiographic Regions A-7, B-15, B-16, B-17, and B-18.

Fig. 7 - Peak Rates of Runoff for Watersheds Under 10,000 Acres

Return Period Factors tabulated on Fig. 7 were derived by solution of the formula:

$$TF = 0.4309 + 0.1784y$$

which represents the relationships of return periods in the data from the 18-station network and the 44 stream-gauging stations mentioned previously. By this formula the Factor for any return period may be obtained by inserting the reduced variate (y) listed in Table 10, Appendix D, opposite the return period desired, and solving the equation.

In essence, the curve in Fig. 7 implies that on the average, the peak rate of runoff from a drainage area of given size is equaled or exceeded once in 25 years, where the cover is mixed (as previously defined) and the location is within the humid region of the United States where rainfall of 2.75 inches per hour has a return period of 25 years.

The effect of soil type on peak rates of runoff has not been clearly established. For that reason there are no factors relating variable soil condition to the design discharge, as is the case with land use. Probably, the antecedent conditions, including rain or snow fall, temperatures, and other factors of similar nature, largely offset differences in soil characteristics as such. However, differences in underlying materials, particularly in regions where bedrock is near the surface, are not as greatly susceptible to this influence. At any rate, with the exception of localized cloudburst conditions during summer months, maximum peak discharges in Kentucky always occur within the first four calendar months.

Use of the data in Figs. 7 and 8 for design is feasible, particularly on watersheds from 100 to 1000 acres in size. If an area greater than

1000 acres is considered the Land Factor should be close to that for mixed cover. An illustration of this method of design is given by the example on the right in Fig. 7.

Miscellaneous Applications

Where one of the usual empirical formulas for estimating peak discharge is used, it may be helpful to compare the solution that is obtained with results of one of the methods based on Figs. 5 and 6, or Figs. 7 and 8. If there is a Peak Discharge - Return Period - Duration Curve for a gauging station in a stream nearby, this curve is also a good basis for comparison. The recommendation that comparisons be made is based on the fact that recently developed procedures are more directly dependent upon observed data and longer periods of record than are the empirical procedures. Thus, if considerable background in the use of empirical methods has been accumulated, this background may be utilized yet the solutions may be judged on the basis of more recent developments in data and techniques.

Where comparisons of this type are made, using several different formulas, disparity in answers for design Q is always impressive. Even more than the numerical differences in discharge (in c.f.s.), the differences in return periods represented by the amounts indicate the broad range of estimates encompassed by the various empirical procedures.

For the purpose of illustration, the Rainfall-Land Use Method (Figs. 7 and 8) is used as a basis for comparison, and assumed circumstances for a design problem are as follows:

Drainage Area = 160 acres
Location - Cynthiana N.E. quadrangle, approx.
Lat. 38° 47', Long. 84° 16'
Length of Major Stream = 3750 feet (Defined Channel)
Elevation of Headwater = 860 feet
Elevation of Culvert = 780 feet
Land Features - well drained, mixed cover, area fan-shaped
Direction of Flow - SSE
Major Storm Direction - E. to N. W. (across the watershed) for Jan.-April period.

From the given data, the slope of the channel is determined as 0.0213 ft. per ft. and, the constant $K = \frac{L}{\sqrt{S}}$ as 26,000. By means of Fig. 13, Appendix A, it is found that the time of concentration for the watershed is 18 minutes.

Inasmuch as this watershed lies within the Lexington Thiessen Polygon, the Lexington Intensity-Duration Curves (Fig. 12j, Appendix A), are used to obtain the following relationships between return period and intensity.

T	Intensity (in. per hr.)
2	2.52
5	3.50
10	4.13
25	4.91
50	5.52
100	6.10

The Rainfall Factor from Fig. 8 is 0.84, and the Land Use Factor from Fig. 7 is 1.0. Also, from Fig. 7 a peak rate of runoff Q = 200 c.f.s. is read opposite 160 acres in the diagram.

By the Rainfall-Land Use Method the design discharge for three different return periods are:

$$Q_{10} = 0.84 \times 1.0 \times 0.83 \times 200 = 139 \text{ c.f.s.}$$
$$Q_{25} = 0.84 \times 1.0 \times 1.0 \times 200 = 168 \text{ c.f.s.}$$
$$Q_{100} = 0.84 \times 1.0 \times 1.25 \times 200 = 210 \text{ c.f.s.}$$

These values of Q for their respective return periods are plotted on the overlay of Fig. 15d to define the line termed "Discharge". Results in terms of c.f.s. calculated by other formulas are placed on this line to determine the return periods corresponding to the indicated values of flow. Comparison is based only on the Q for the 25-year return period in each case, although others could be made.

The results calculated by various formulas or curves, including those now used for drainage design and discussed earlier in this report, and the indicated return period on Fig. 15d, are as follows:

Formula or Method	Q (c.f.s.)	Indicated Return Period (yr.)
Rational (C = 0.40)	314	1000 +
(C = 0.15)	118	5
Modified Rational -		
(C = 0.40)	157	17
Dickens (B = 375)*	123	6
B.P.R. Curves -		
1021.10 & 1021.11	250	400
Burkli-Ziegler -		
(C = 0.31)	147	12
(C = 0.20)	95	3 -

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* 24-Hr. Rainfall (T = 25) is 5.56 inches (See Lexington in Table 8, Appendix A).

Viewed from the standpoint of return period the results are much more wide spread than the calculated amounts of discharge imply. However, even on the basis of c.f.s. to be accommodated the spread is great enough to seriously affect the design that would actually be made for a drainage facility.

Obviously, the most elusive and most influential factor causing the differences in the majority of cases is the so-called coefficient of runoff. Unfortunately this is the factor most difficult to evaluate even by means of controlled drainage test plots. That being the case, the futility of establishing a uniform and reliable design procedure for the state as a whole based on any empirical formula is well illustrated.

SIGNIFICANT RELATIONSHIPS AND OBSERVATIONS

During this study there were a number of observations which should be of considerable interest to those engaged in the fields of hydraulics, hydrology, and drainage design. Disqussion of these points is based on analyses of data from former investigations by other agencies and investigations by the Division of Research including the study which is being reported, and interpretation of the present results. These points of interest are considered to be of primary concern in the advancement of this and similar projects.

The first of these pertains to the maximum annual peak rates of runoff*. It has been determined through analyses of runoff records for Kentucky that for large areas, almost all the peak rates of runoff occur during the first four months of the year. Noteable exceptions to this, especially for drainage areas not more than a few square miles in size, are the cloudburst conditions that are sometimes widespread in summer months. Cloudbursts tend to be localized and irregular in frequency of occurrence, and designing for them is generally believed to be impractical. Therefore, discussion of peak rates of runoff have, in this report, proceeded without mention of cloudburst conditions.

The fact that most peak rates of runoff occur within the first four months of the year may not hold much interest for the experienced observer. However, this knowledge is of particular advantage in making

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* See Glossary of Terms.

detailed studies of runoff. Maintenance of study areas of considerable size could be eliminated during the remaining eight months of the year, and the amount of data to be analyzed and interpreted would be greatly reduced.

Another important aspect is the selection of an appropriate return period for design purposes. Before any attempt is made to design a drainage structure, it is necessary to establish this return period so that rainfall data can be used. Relationships among rainfalls having various return periods can serve as a guide to selection of design return periods (See Figs. 16a-j and Tables 10, 10a and 10b; Appendix D).

Recommendations have been made by several agencies (25, 36, 37 and 38) with regard to the return period to be employed for primary and secondary roads which are subject to limitations on the excess flow that can be tolerated. For example, damage to adjacent property or destruction of embankments are less important with some roads and in some localities than they are with others having different characteristics. A few of these suggestions appear in Table 4, below. This Table (25) can serve as a guide in the selection of the appropriate return period for which the discharge will govern in the design:

Table 4 - Design Return Periods for Various Types of Structures.

Type of Structure	Design Return Period
Bridges on important highways, or where backwater may cause excessive property damage or result in loss of the bridge.	50 to 100 years
Bridges on less important roads or culverts on important roads.	25 years
Culverts on secondary roads, storm sewers or side ditches.	5 to 10 years
Storm-water inlets, gutter flow.	1 to 2 years*

* If of short duration, ponding can be tolerated.

Some organizations recommend a 50-year return period for design of primary roads in urban areas where excessive discharge could cause considerable damage and seriously impair the utility of the road, even for a short period of time. In the case of primary or secondary roads in rural areas a design return period of 10 to 25 years may be adequate. For side ditches and gutters, a shorter return period should be considered; between 2 and 10 years, depending upon location and cost of repairs. Proposed design return period estimates should be checked for magnitudes corresponding to some longer return period, and the damages estimated. It is possible that the extensive cost of damages or danger to human life would necessitate increasing the size of the structure (46).

After a culvert has been sized, it is well to check the stream channel to determine the ability of the downstream section to accommodate the flow that has been estimated. In some cases, a culvert might be designed to carry the expected runoff from a given area but the downstream channel could be incapable of carrying the flow and ponding would result. Therefore, culvert sizing would not be determined by the runoff produced from the area but rather by the degree of ponding. If ponding exists, the design of a structure is controlled by the tailwater elevation, and the downstream conditions must be checked (43).

Considerable effort has been and is being made to recognize and evaluate factors other than design discharge having a bearing on the hydraulic design of culverts. Until recently the tendency has been to regard a solution of the design discharge as a solution for the entire problem. Consequently, little regard was given the hydraulic principles involved in transmitting the estimated discharge through the structure to the other side of the roadway.

The usual objective in the design of most highway culverts is to provide a structure to accommodate a flow with the least amount of head (or none at all). When headwater is of small significance, design is for the most economical size. Actually, a number of factors determine the flow characteristics of water in a culvert. These include slope, size, shape, length, roughness, headwater and tailwater elevation, and inlet and outlet slope (25 and 43). All of these must be considered in the hydraulic design.

St. Anthony Falls Hydraulic Research Laboratory (University of Minnesota) has published a number of interesting and informative papers on culvert hydraulics. In one of these (40), culverts are classified on the basis of the point at which flow in the structure is controlled, and the several variables influencing the point of control.

> "When the culvert inlet serves as a control section, the relationship between head and discharge is independent of the characteristics of the barrel or outlet and depends only upon the geometry of the inlet. For culverts on a mild slope, flowing partly full, the control is at the outlet and the head-discharge relationship depends upon the characteristics of the barrel as well as the geometry of the inlet. When the culvert flows full, unless it is very short, the barrel friction provides the control and the head-discharge is dependent upon all of the design variables.
>
> "The importance of inlet design as related to culvert capacity hinges to a large extent upon the position of the control section. For inlet control, the geometry of the inlet has a very significant influence upon the head required for a given discharge. A square-edge inlet causes separation and promotes full utilization of the barrel for flow. As a result of the availability of additional head in the culvert,

> the required water surface elevation in the headwater pool is reduced - frequently very significantly reduced. When the control is at the outlet or when barrel friction acts as the control, the geometry of the inlet becomes far less significant."

A review of this and other publications dealing with the flow of water through culverts points out the necessity for an understanding and full utilization of the hydraulic principles so that proper design of drainage structures may be accomplished. Preliminary to these considerations, however, is the "proper" application of hydrologic data in the determination of the peak discharge that must be accommodated by the structure.

CONCLUDING STATEMENT AND RECOMMENDATIONS

As noted previously, current methods of estimating design discharge are inadequate because of the extremely limited data from actual field investigations that can be applied in estimating peak rate of runoff based on the rate of rainfall. As a result of this project, possibilities for accurately predicting the quantity of precipitation that can be expected at different points in the state have been greatly enhanced. However, because of the lack of basic data, little could be done to improve "coefficients" necessary in calculating discharge by the various empirical methods.

Likewise, the almost complete lack of records for stream flow, particularly from small watersheds, have prevented any progress toward developing a fundamental method of estimating discharge on the basis of recorded stream flow. Such a method is regarded as the ultimate goal toward which future drainage research should be directed.

Recognizing the lack of basic data, but aware of the need for immediate improvements, it was considered necessary to continue the use of past methods for estimating design discharge which are based on rainfall records until sufficient stream gauging records from small watersheds can be obtained. This involves not only a large number of stations well distributed, but also a considerable time interval since the minimum period of record generally considered necessary for the determination of the mean annual peak discharge is 12 years.

Therefore, for the rainfall variable, the intensity-duration-return period relationships were developed for many localities throughout the state and considerable progress was made in isolating this variable.

In conjunction with the rainfall, the time of concentration variable was investigated with regard to its application and methods of estimating its value.

Existing methods of estimating time of concentration are approximations, based on meager data derived several years ago. Possibilities of making actual field measurements to establish better methods and more reliable data were considered. In this respect, small portable discharge-measuring devices were studied, and a combination rain and stream gauge which records on the same clock and chart was devised. However, because of the magnitude of the project and time involved it was not considered feasible to continue this approach, especially since this value is a part of the rainfall design method which is considered an expediency to be used only until new methods based on discharge measurements can be developed.

Throughout the project effort has been made to foster the collection of stream-flow data from small areas. Beginning with the establishment of the peak-stage indicators previously discussed (See Fig. 10) this effort soon led to development of the test area near Hodgenville. Later the Division of Research was instrumental in the establishment of a small area gauging station at Noble, Kentucky, where the Laboratory has been maintaining a rain gauge for approximately three years. At the time the peak-stage indicators were accepted by the U.S.G.S. for service and maintenance in their surface water program, inclusion of the Bear Branch drainage area at Noble and the Douglas Creek area near Hodgenville was recommended. Permanent stream-gauging stations

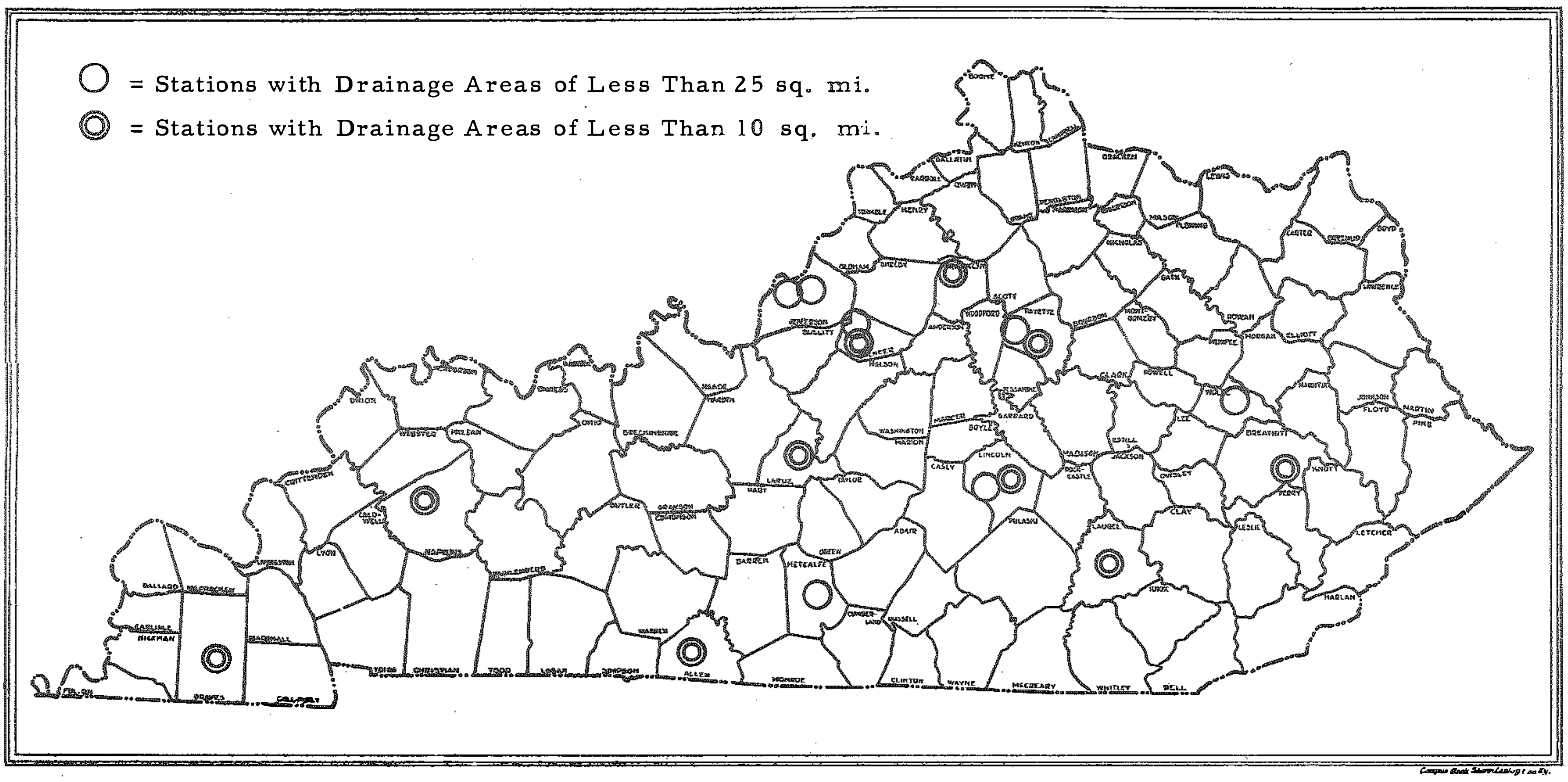

Fig. 9 - Location of Stream Gauging Stations for Small Watersheds in Kentucky (Maintained by the U.S. Geological Survey and Cooperating Agencies).

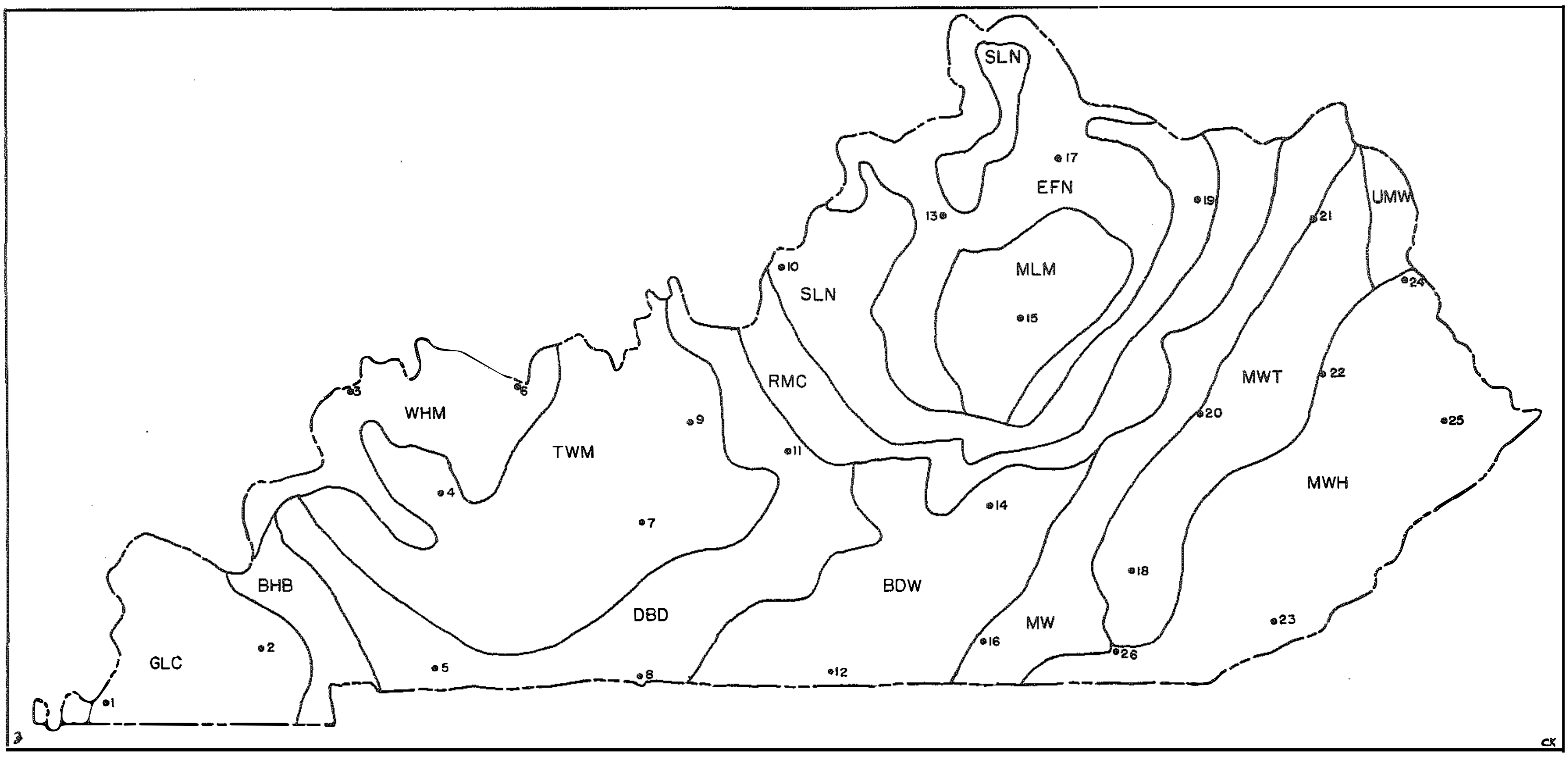

Fig. 10 - Location of Peak Stage Indicators in Various Soil Regions in Kentucky (Soil Regions by W. S. Ligon)

were installed by the U.S.G.S. at both locations, and they are now a part of the 17-station group in Kentucky (See Fig. 9) now operated by that agency.

In view of the importance of adequate stream-gauging records to the development of a reliable and lasting procedure for the design of small drainage structures, increasing support - financial and otherwise - for that program by the Department of Highways is recommended. Until conditions make possible designs on that basis, it is necessary to adhere to procedures based on rainfall intensity, duration, and return periods. From that standpoint, the data developed through this project makes possible numerous improvements in the existing methods of drainage design.

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APPENDIX A

CHARTS AND TABULATIONS APPLICABLE TO METHODS OF DESIGN

Table 6 - Calculated Rainfall For Various Return Periods at 18 First-Order Stations.

Fig. 11 - Thiessen Diagram for Kentucky.

Fig. 12a-12r - Depth-Duration and Intensity-Duration Curves for Cairo, Cincinnati, Evansville, Knoxville, Lexington, Louisville, Nashville, Parkersburg, and Wytheville.

Fig. 13 - Chart for Determining Time of Concentration.

Table 7 - Area of Waterway Calculated by Modified Talbot Formula.

Table 8 - Calculated 24-Hour Rainfall for Nine First-Order Stations (Based on Period of Record 1903-1951).

Table 9 - Discharge Calculated by Dickens Formula.

Table 6 - Calculated Rainfall for Various Return Periods at 18 First-Order Stations (Based on Indicated Periods of Record)

STATION	Return Period	RAINFALL													
		Depth For Duration - Inches							Intensity For Duration - in. per hr.						
	T - yrs.	5 Min.	10 Min.	15 Min.	30 Min.	1 Hr.	2 Hr.	24 Hr.	5 Min.	10 Min.	15 Min.	30 Min.	1 Hr.	2 Hr.	24 Hr.
Asheville, N. C.	2	0.38	0.61	0.76	1.03	1.19	1.36	2.59	4.53	3.69	3.06	2.06	1.19	0.68	0.11
	5	0.49	0.79	0.98	1.36	1.58	1.84	3.82	5.82	4.73	3.94	2.72	1.58	0.92	0.16
N = 49	10	0.56	0.91	1.13	1.58	1.84	2.16	4.63	6.68	5.43	4.52	3.15	1.84	1.08	0.19
	25	0.65	1.05	1.32	1.85	2.17	2.56	5.66	7.76	6.31	5.26	3.70	2.17	1.28	0.24
1903-1951	50	0.71	1.16	1.45	2.06	2.42	2.86	6.42	8.57	6.97	5.81	4.11	2.42	1.43	0.27
	100	0.78	1.27	1.59	2.26	2.66	3.16	7.18	9.37	7.62	6.35	4.52	2.66	1.58	0.30
Cairo, Illinois	2	0.39	0.63	0.79	1.10	1.39	1.69	3.29	4.62	3.77	3.17	2.20	1.39	0.85	0.14
	5	0.49	0.80	1.01	1.39	1.84	2.33	4.37	5.88	4.81	4.03	2.78	1.84	1.16	0.18
N = 49	10	0.56	0.92	1.15	1.59	2.14	2.75	5.08	6.70	5.49	4.61	3.17	2.14	1.37	0.21
	25	0.65	1.06	1.33	1.83	2.52	3.28	5.98	7.75	6.36	5.33	3.66	2.52	1.64	0.25
1903-1951	50	0.71	1.17	1.47	2.01	2.79	3.67	6.65	8.53	7.00	5.87	4.02	2.79	1.84	0.28
	100	0.78	1.27	1.60	2.19	3.07	4.06	7.31	9.30	7.64	6.41	4.38	3.07	2.03	0.30
Chattanooga, Tenn.	2	0.42	0.65	0.82	1.12	1.38	1.66	3.40	4.98	3.92	3.26	2.24	1.38	0.83	0.14
	5	0.53	0.84	1.06	1.45	1.78	2.18	4.29	6.41	5.02	4.22	2.89	1.78	1.09	0.18
N = 46	10	0.61	0.96	1.21	1.67	2.05	2.52	4.88	7.35	5.76	4.86	3.33	2.05	1.26	0.20
	25	0.71	1.11	1.42	1.94	2.39	2.96	5.62	8.54	6.68	5.66	3.88	2.39	1.48	0.23
1903-1948	50	0.79	1.23	1.56	2.15	2.65	3.28	6.17	9.43	7.37	6.26	4.29	2.65	1.64	0.26
	100	0.86	1.34	1.71	2.35	2.90	3.60	6.72	10.30	8.06	6.85	4.70	2.90	1.80	0.28
Cincinnati, Ohio	2	0.39	0.59	0.74	0.95	1.18	1.42	2.65	4.70	3.53	2.96	1.91	1.18	0.71	0.11
	5	0.49	0.76	0.97	1.29	1.57	1.90	3.45	5.86	4.58	3.89	2.58	1.57	0.95	0.14
N = 49	10	0.55	0.88	1.13	1.51	1.83	2.22	3.98	6.63	5.28	4.52	3.03	1.83	1.11	0.17
	25	0.63	1.03	1.33	1.80	2.15	2.62	4.65	7.60	6.16	5.31	3.59	2.15	1.31	0.19
1903-1951	50	0.69	1.14	1.47	2.01	2.39	2.92	5.15	8.32	6.81	5.90	4.01	2.39	1.46	0.21
	100	0.75	1.24	1.62	2.21	2.63	3.22	5.65	9.04	7.46	6.48	4.43	2.63	1.61	0.24
Columbus, Ohio	2	0.36	0.56	0.69	0.89	1.07	1.25	2.11	4.27	3.36	2.76	1.79	1.07	0.63	0.09
	5	0.46	0.73	0.92	1.23	1.50	1.71	2.74	5.48	4.37	3.68	2.45	1.50	0.86	0.11
N = 49	10	0.52	0.84	1.07	1.45	1.77	2.02	3.16	6.28	5.04	4.29	2.89	1.77	1.01	0.13
	25	0.61	0.98	1.26	1.72	2.13	2.40	3.69	7.29	5.88	5.05	3.45	2.13	1.20	0.15
1903-1951	50	0.67	1.08	1.41	1.93	2.39	2.69	4.08	8.04	6.51	5.62	3.86	2.39	1.34	0.17
	100	0.73	1.19	1.55	2.14	2.65	2.97	4.47	8.79	7.13	6.19	4.27	2.65	1.48	0.19
Dayton, Ohio	2	0.37	0.57	0.71	0.94	1.15	1.36	2.38	4.39	3.45	2.86	1.87	1.15	0.68	0.10
	5	0.45	0.70	0.88	1.22	1.53	1.78	3.09	5.38	4.19	3.53	2.45	1.53	0.89	0.13
N = 40	10	0.50	0.78	0.99	1.41	1.79	2.06	3.56	6.04	4.68	3.97	2.83	1.79	1.03	0.15
	25	0.57	0.88	1.13	1.65	2.11	2.41	4.16	6.87	5.30	4.54	3.31	2.11	1.20	0.17
1912-1951	50	0.62	0.96	1.24	1.83	2.35	2.67	4.60	7.48	5.77	4.95	3.66	2.35	1.33	0.19
	100	0.67	1.04	1.34	2.01	2.59	2.92	5.04	8.09	6.22	5.37	4.02	2.59	1.46	0.21
Elkins, West Va.	2	0.36	0.56	0.69	0.90	1.10	1.32	2.32	4.35	3.36	2.77	1.79	1.10	0.66	0.10
	5	0.45	0.70	0.87	1.18	1.49	1.89	3.25	5.45	4.22	3.48	2.35	1.49	0.95	0.14
N = 49	10	0.51	0.80	0.99	1.36	1.74	2.27	3.87	6.18	4.79	3.94	2.72	1.74	1.14	0.16
	25	0.59	0.92	1.13	1.59	2.07	2.75	4.65	7.10	5.52	4.53	3.19	2.07	1.38	0.19
1903-1951	50	0.65	1.01	1.24	1.77	2.31	3.11	5.24	7.78	6.05	4.96	3.54	2.31	1.55	0.22
	100	0.70	1.10	1.35	1.94	2.55	3.46	5.81	8.46	6.58	5.40	3.88	2.55	1.73	0.24
Evansville, Ind.	2	0.40	0.62	0.77	1.06	1.36	1.59	2.96	4.76	3.70	3.09	2.12	1.36	0.80	0.12
	5	0.47	0.74	0.93	1.35	1.75	2.08	3.91	5.62	4.41	3.72	2.69	1.75	1.04	0.16
N = 49	10	0.52	0.81	1.04	1.54	2.01	2.39	4.53	6.19	4.88	4.15	3.07	2.01	1.20	0.19
	25	0.58	0.91	1.17	1.77	2.33	2.80	5.32	6.92	5.48	4.68	3.55	2.33	1.40	0.22
1903-1951	50	0.62	0.99	1.27	1.95	2.57	3.10	5.91	7.45	5.92	5.07	3.90	2.57	1.55	0.25
	100	0.67	1.06	1.37	2.13	2.81	3.39	6.49	7.98	6.36	5.47	4.26	2.81	1.70	0.27
Indianapolis, Ind.	2	0.38	0.60	0.75	1.01	1.30	1.52	2.53	4.61	3.62	3.02	2.02	1.30	0.76	0.11
	5	0.48	0.75	0.96	1.34	1.78	2.05	3.33	5.70	4.50	3.84	2.68	1.78	1.03	0.14
N = 49	10	0.54	0.85	1.10	1.56	2.11	2.41	3.85	6.42	5.08	4.38	3.13	2.11	1.20	0.16
	25	0.61	0.97	1.27	1.84	2.51	2.86	4.52	7.34	5.82	5.07	3.68	2.51	1.43	0.19
1903-1951	50	0.67	1.06	1.40	2.05	2.81	3.19	5.01	8.01	6.37	5.58	4.10	2.81	1.60	0.21
	100	0.72	1.15	1.52	2.25	3.11	3.52	5.50	8.68	6.92	6.09	4.51	3.11	1.76	0.23
Knoxville, Tenn.	2	0.38	0.61	0.79	1.03	1.31	1.51	2.88	4.56	3.65	3.14	2.06	1.31	0.75	0.12
	5	0.47	0.77	1.04	1.47	1.86	2.13	3.77	5.64	4.64	4.16	2.94	1.86	1.06	0.16
N = 49	10	0.53	0.88	1.21	1.76	2.22	2.54	4.35	6.36	5.29	4.84	3.52	2.22	1.27	0.18
	25	0.61	1.02	1.42	2.12	2.68	3.06	5.09	7.27	6.11	5.69	4.24	2.68	1.53	0.21
1903-1951	50	0.66	1.12	1.58	2.39	3.02	3.45	5.64	7.94	6.72	6.32	4.78	3.02	1.72	0.23
	100	0.72	1.22	1.74	2.66	3.36	3.83	6.18	8.61	7.32	6.95	5.32	3.36	1.91	0.26
Lexington, Kentucky	2	0.36	0.56	0.69	0.95	1.19	1.47	2.80	4.27	3.33	2.77	1.90	1.19	0.73	0.12
	5	0.45	0.73	0.94	1.37	1.81	2.29	4.13	5.37	4.38	3.75	2.75	1.81	1.14	0.17
N = 32	10	0.51	0.84	1.10	1.65	2.21	2.83	5.01	6.09	5.07	4.40	3.31	2.21	1.41	0.21
	25	0.58	0.99	1.31	2.01	2.72	3.51	6.12	7.01	5.94	5.22	4.02	2.72	1.76	0.26
1903-1934	50	0.64	1.10	1.46	2.27	3.10	4.02	6.95	7.69	6.59	5.83	4.54	3.10	2.01	0.29
	100	0.70	1.21	1.61	2.53	3.48	4.52	7.76	8.36	7.23	6.43	5.06	3.48	2.26	0.32
Little Rock, Ark.	2	0.42	0.66	0.83	1.17	1.57	1.90	3.57	4.98	3.95	3.33	2.34	1.57	0.95	0.15
	5	0.50	0.80	1.01	1.49	2.09	2.51	5.06	6.00	4.82	4.05	2.98	2.09	1.26	0.21
N = 49	10	0.56	0.90	1.13	1.70	2.44	2.91	6.05	6.67	5.39	4.52	3.40	2.44	1.46	0.25
	25	0.63	1.02	1.28	1.96	2.88	3.42	7.30	7.52	6.11	5.12	3.92	2.88	1.71	0.30
1903-1951	50	0.68	1.11	1.39	2.17	3.20	3.80	8.23	8.15	6.64	5.57	4.33	3.20	1.90	0.34
	100	0.73	1.20	1.50	2.36	3.52	4.17	9.15	8.78	7.18	6.01	4.73	3.52	2.09	0.38
Louisville, Ky.	2	0.39	0.61	0.74	0.97	1.20	1.42	2.90	4.72	3.64	2.94	1.94	1.20	0.71	0.12
	5	0.51	0.76	0.94	1.27	1.55	1.80	3.84	6.11	4.59	3.78	2.54	1.55	0.90	0.16
N = 49	10	0.59	0.87	1.08	1.47	1.77	2.04	4.46	7.02	5.21	4.33	2.94	1.77	1.02	0.19
	25	0.68	1.00	1.26	1.72	2.06	2.36	5.24	8.18	6.00	5.03	3.44	2.06	1.18	0.22
1903-1951	50	0.75	1.10	1.39	1.91	2.27	2.59	5.83	9.04	6.59	5.54	3.81	2.27	1.29	0.24
	100	0.82	1.19	1.51	2.09	2.48	2.82	6.41	9.89	7.17	6.05	4.18	2.48	1.41	0.27
Memphis, Tennessee	2	0.40	0.62	0.77	1.07	1.37	1.79	3.71	4.82	3.74	3.08	2.14	1.37	0.90	0.15
	5	0.51	0.81	1.02	1.45	1.82	2.45	5.32	6.12	4.86	4.08	2.90	1.82	1.22	0.22
N = 49	10	0.58	0.93	1.18	1.70	2.11	2.88	6.38	6.97	5.60	4.74	3.41	2.11	1.44	0.27
	25	0.67	1.09	1.39	2.02	2.48	3.43	7.73	8.06	6.54	5.57	4.05	2.48	1.72	0.32
1903-1951	50	0.74	1.21	1.55	2.26	2.76	3.84	8.73	8.86	7.29	6.19	4.52	2.76	1.92	0.36
	100	0.81	1.32	1.70	2.50	3.03	4.25	9.72	9.66	7.92	6.80	4.99	3.03	2.12	0.40
Nashville, Tenn.	2	0.43	0.66	0.82	1.09	1.35	1.64	3.11	5.16	3.98	3.28	2.18	1.35	0.82	0.13
	5	0.53	0.82	1.01	1.41	1.76	2.18	3.85	6.39	4.95	4.06	2.82	1.76	1.09	0.16
N = 47	10	0.60	0.93	1.14	1.62	2.03	2.55	4.34	7.20	5.59	4.57	3.24	2.03	1.27	0.18
	25	0.69	1.07	1.31	1.89	2.38	3.01	4.96	8.23	6.40	5.23	3.78	2.38	1.50	0.21
1905-1951	50	0.75	1.17	1.43	2.09	2.63	3.35	5.42	8.99	7.01	5.71	4.18	2.63	1.67	0.23
	100	0.81	1.27	1.55	2.29	2.89	3.68	5.88	9.75	7.60	6.19	4.57	2.89	1.84	0.24
Parkersburg, W. Va.	2	0.38	0.58	0.72	0.93	1.09	1.30	2.23	4.50	3.46	2.88	1.86	1.09	0.65	0.09
	5	0.49	0.75	0.95	1.22	1.47	1.77	2.96	5.89	4.52	3.80	2.44	1.47	0.89	0.12
N = 49	10	0.57	0.87	1.10	1.41	1.71	2.09	3.45	6.80	5.22	4.40	2.82	1.71	1.04	0.14
	25	0.66	1.02	1.29	1.65	2.02	2.48	4.06	7.96	6.11	5.17	3.30	2.02	1.24	0.17
1903-1951	50	0.73	1.13	1.43	1.83	2.25	2.78	4.52	8.82	6.77	5.74	3.66	2.25	1.39	0.19
	100	0.81	1.24	1.57	2.00	2.48	3.07	4.97	9.67	7.42	6.30	4.01	2.48	1.54	0.21
St. Louis, Missouri	2	0.40	0.63	0.79	1.09	1.46	1.76	2.83	4.80	3.78	3.17	2.17	1.46	0.88	0.12
	5	0.48	0.78	1.00	1.49	2.11	2.51	4.21	5.80	4.67	4.00	2.99	2.11	1.25	0.18
N = 49	10	0.54	0.88	1.14	1.76	2.54	3.00	5.12	6.46	5.27	4.55	3.53	2.54	1.50	0.21
	25	0.61	1.00	1.31	2.10	3.09	3.62	6.28	7.30	6.01	5.25	4.21	3.09	1.81	0.26
1903-1951	50	0.66	1.09	1.44	2.36	3.49	4.08	7.14	7.93	6.57	5.76	4.72	3.49	2.04	0.30
	100	0.71	1.19	1.57	2.61	3.89	4.54	7.99	8.55	7.12	6.27	5.22	3.89	2.26	0.33
Wytheville, Virginia	2	0.35	0.55	0.68	0.95	1.16	1.36	2.36	4.18	3.28	2.72	1.89	1.16	0.68	0.10
	5	0.43	0.70	0.92	1.35	1.64	1.90	3.14	5.20	4.19	3.67	2.70	1.64	0.95	0.13
N = 38	10	0.49	0.80	1.07	1.62	1.95	2.26	3.66	5.88	4.80	4.29	3.23	1.95	1.13	0.15
	25	0.56	0.93	1.27	1.95	2.34	2.72	4.32	6.74	5.56	5.08	3.91	2.34	1.36	0.18
1903-1940	50	0.61	1.02	1.42	2.20	2.64	3.05	4.80	7.37	6.13	5.67	4.41	2.64	1.53	0.20
	100	0.67	1.12	1.56	2.45	2.93	3.39	5.29	8.00	6.70	6.25	4.90	2.93	1.69	0.22

Notes on Fig. 11:

Each polygon contains the following percentages of this state's total area:

Polygon Identification	Percent Area*
(a) Cairo, Illinois	8.52
(b) Cincinnati, Ohio	4.75
(c) Evansville, Indiana	11.91
(d) Knoxville, Tennessee	8.77
(e) Lexington, Kentucky	35.91
(f) Louisville, Kentucky	13.48
(g) Nashville, Tennessee	11.91
(h) Parkersburg, W. Virginia	1.13
(i) Wytheville, Virginia	3.62

* These values were used in computing the state weighed averages given in Table 8, Appendix A.

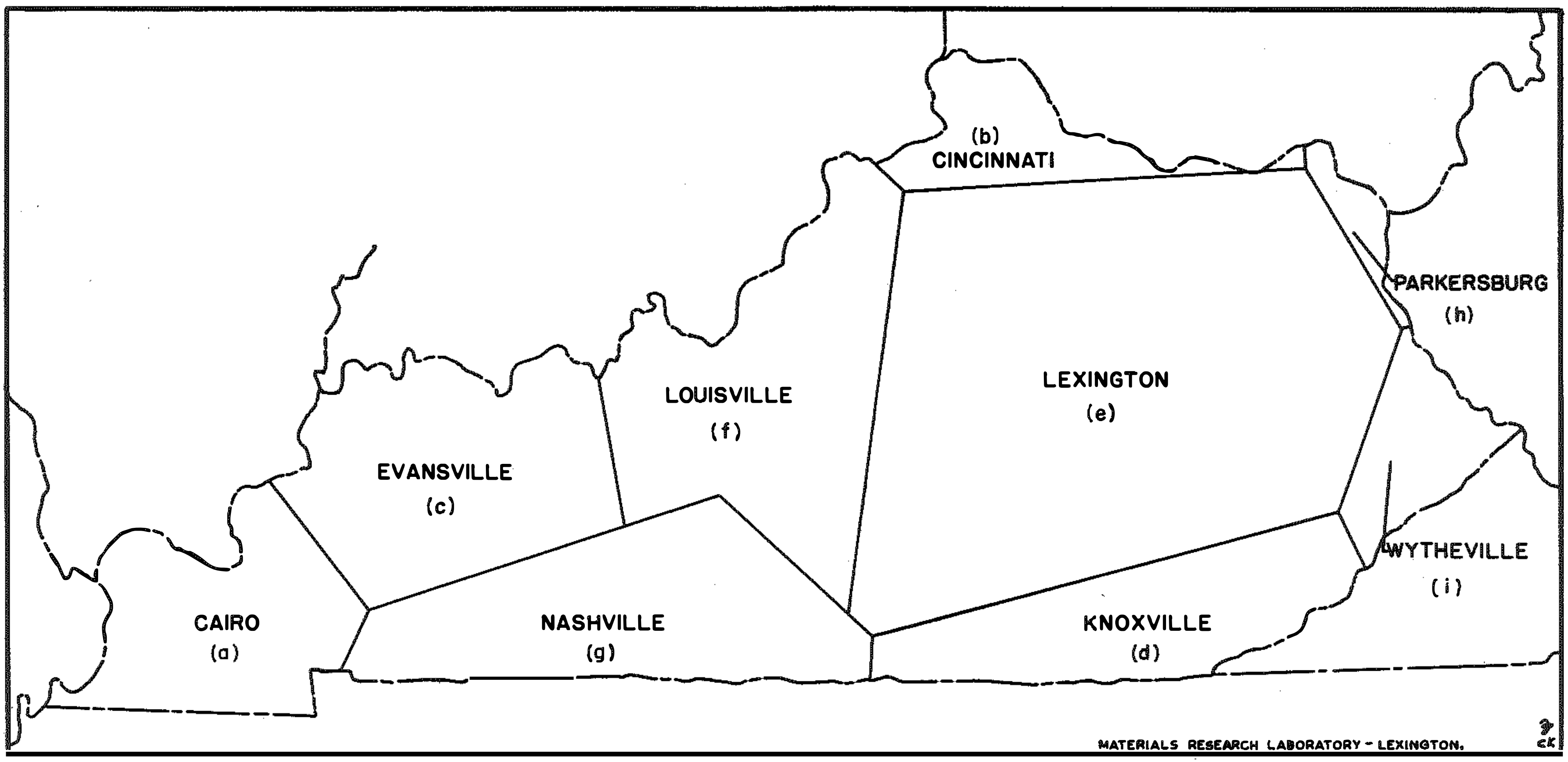

Fig. 11 - Thiessen Diagram for Kentucky (Based on First-Order Station Network)

Notes on Fig. 12a-12r:

The use of the Depth-Duration and Intensity-Duration Curves in these illustrations is demonstrated by the following example:

> Determine the rainfall depth or intensity in the Cairo polygon for a 17-minute time of concentration (See notes on Fig. 13).
>
> This is accomplished by entering the duration scale of Fig. 12a or 12b at the 17-minute point and proceeding upward to the curves for each return period. The values are then tabulated in the following manner:

Return Period (T)	Depth (in.)	Intensity* (in. per in.)
2	0.85	3.00
5	1.08	3.80
10	1.23	4.33
25	1.42	5.00
50	1.56	5.52
100	1.70	6.00

* These figures may be checked by setting 60/17 in a calculator and multiplying each depth value by this factor.

> These values are plotted at their respective return periods, with the use of Fig. 15a, 15c or 15d. If calculated correctly, they should form a straight line (see line Rainfall in Fig. 15a, Appendix C). If this is not so, an average line should be constructed.

In Figs. 12c, e, f, g, h, l, m, n, o, p, q and r note the presence of dots plotted on these graphs. These dots represent the calculated values taken from Table 6, Appendix A. In these cases, an attempt was made to obtain a family of symmetrical curves, rather than to draw the curves to conform to the exact position of the plotted value.

Since data necessary for the use of the Depth-Duration Curves will not be presented in this report, an example of their application will not be presented here.

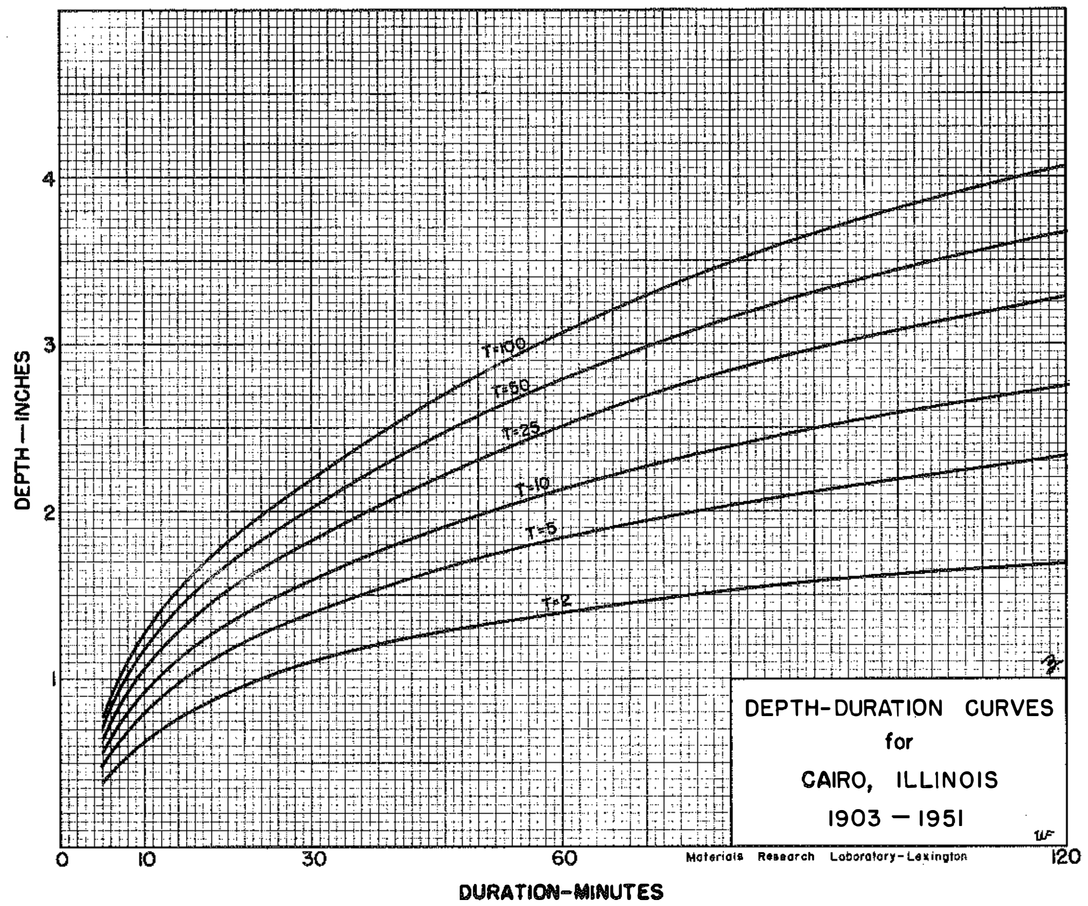

Fig. 12a

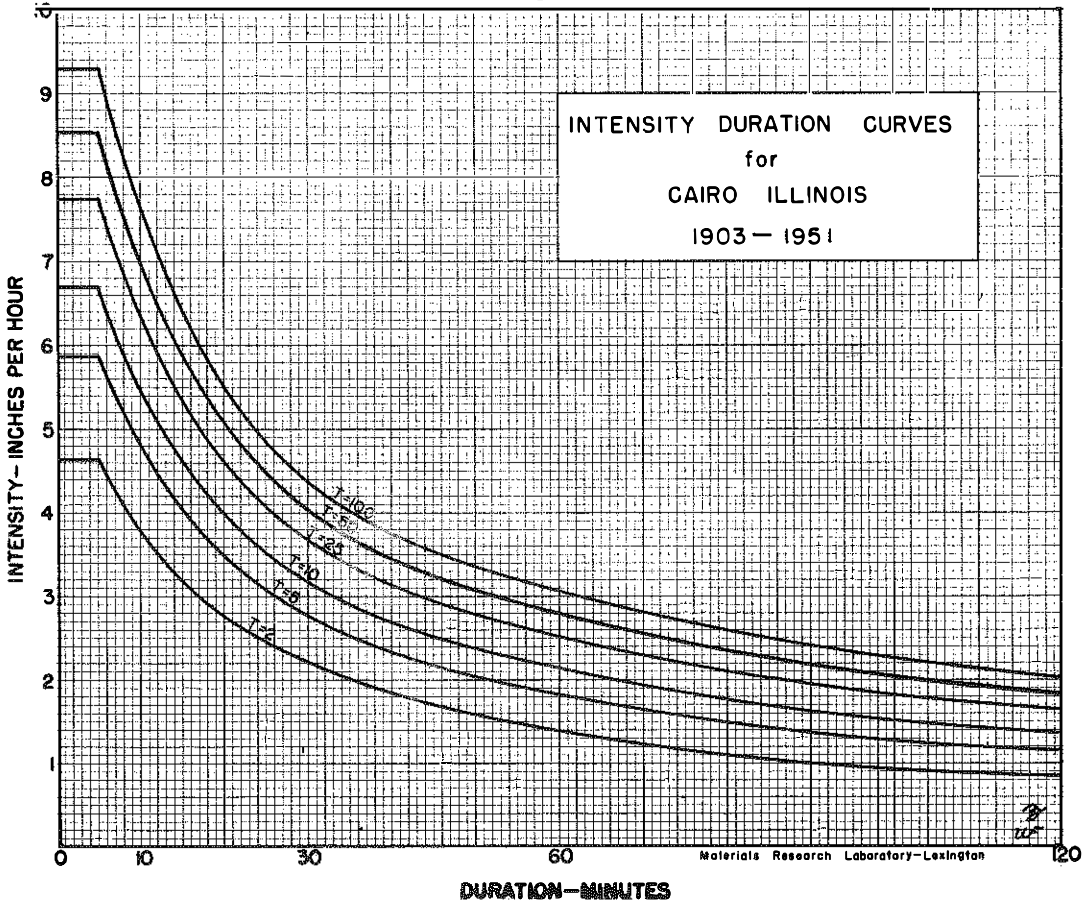

Fig. 12b

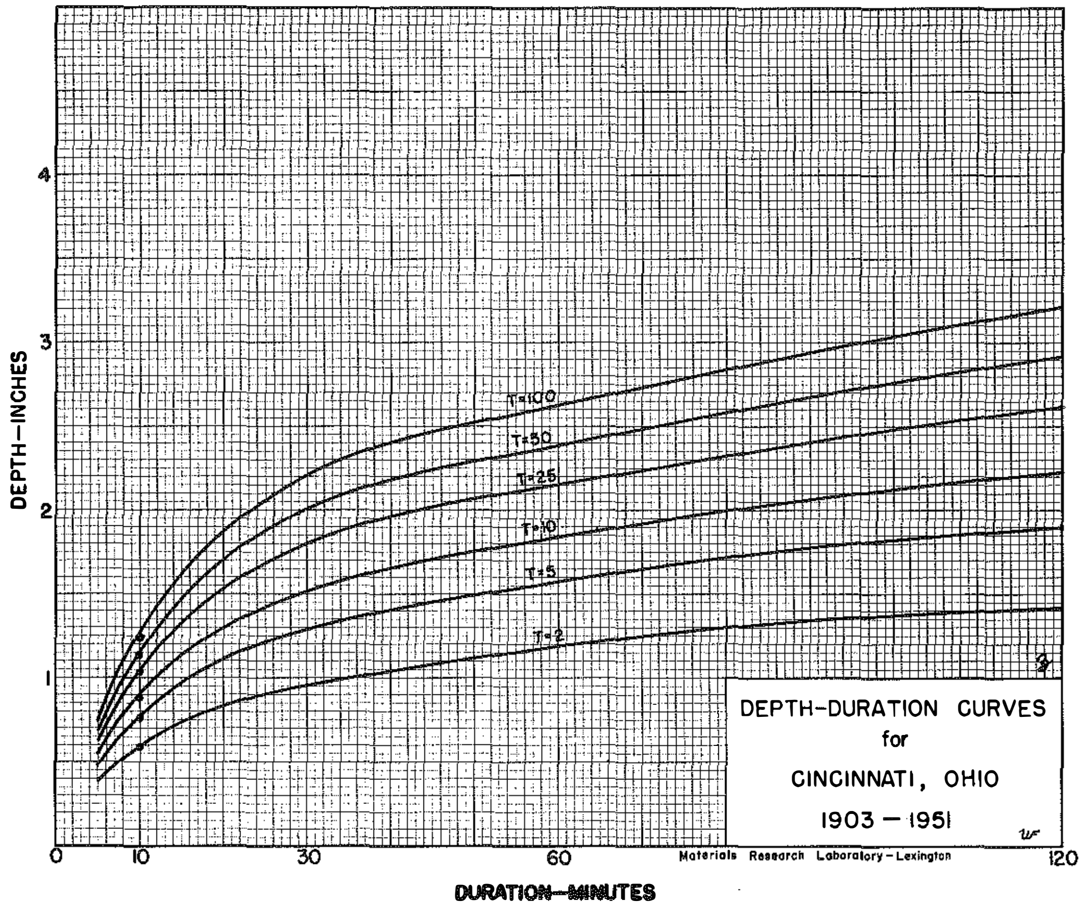

Fig. 12c

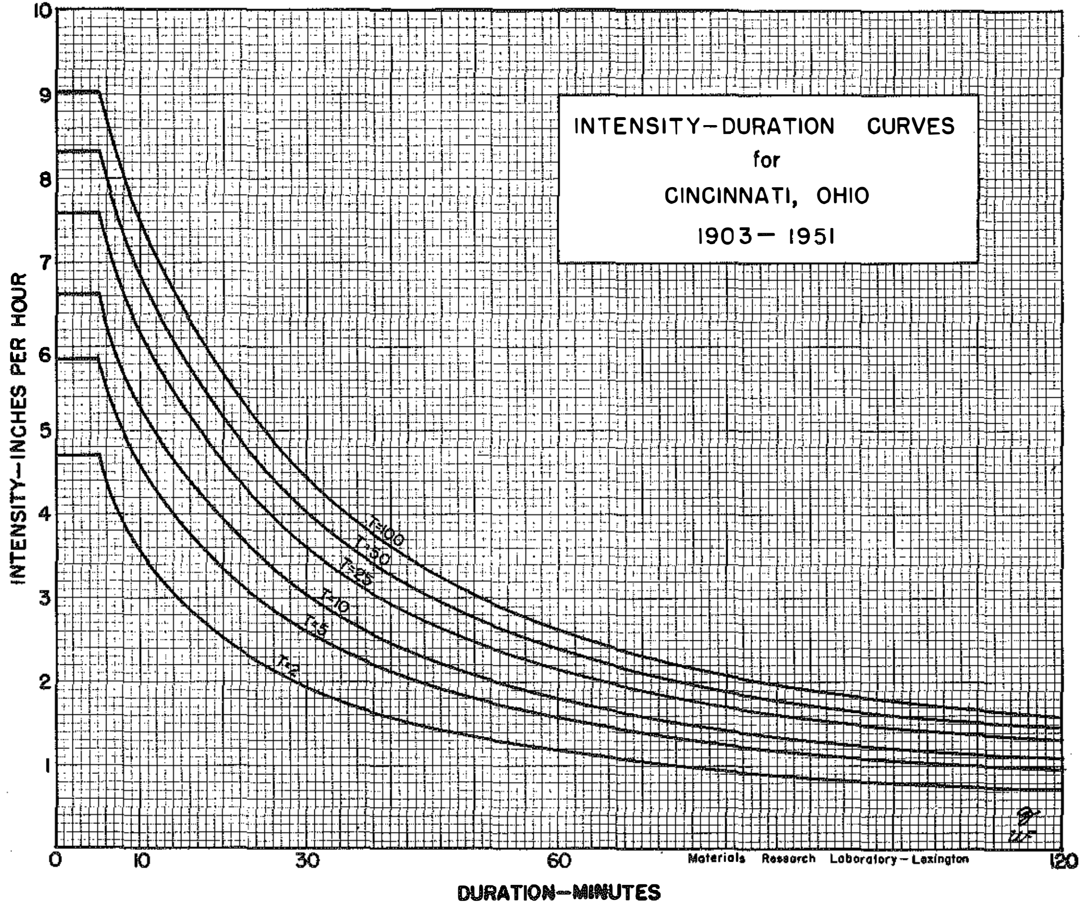

Fig. 12d

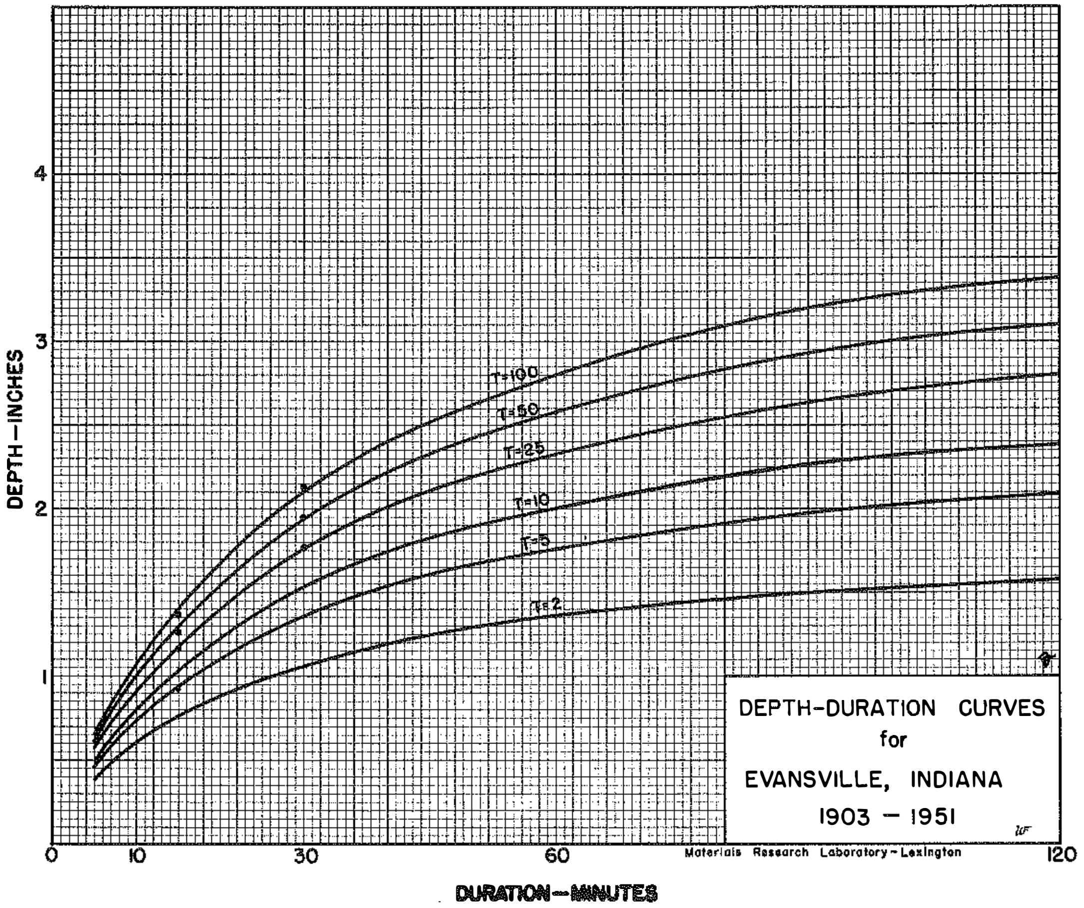

Fig. 12e

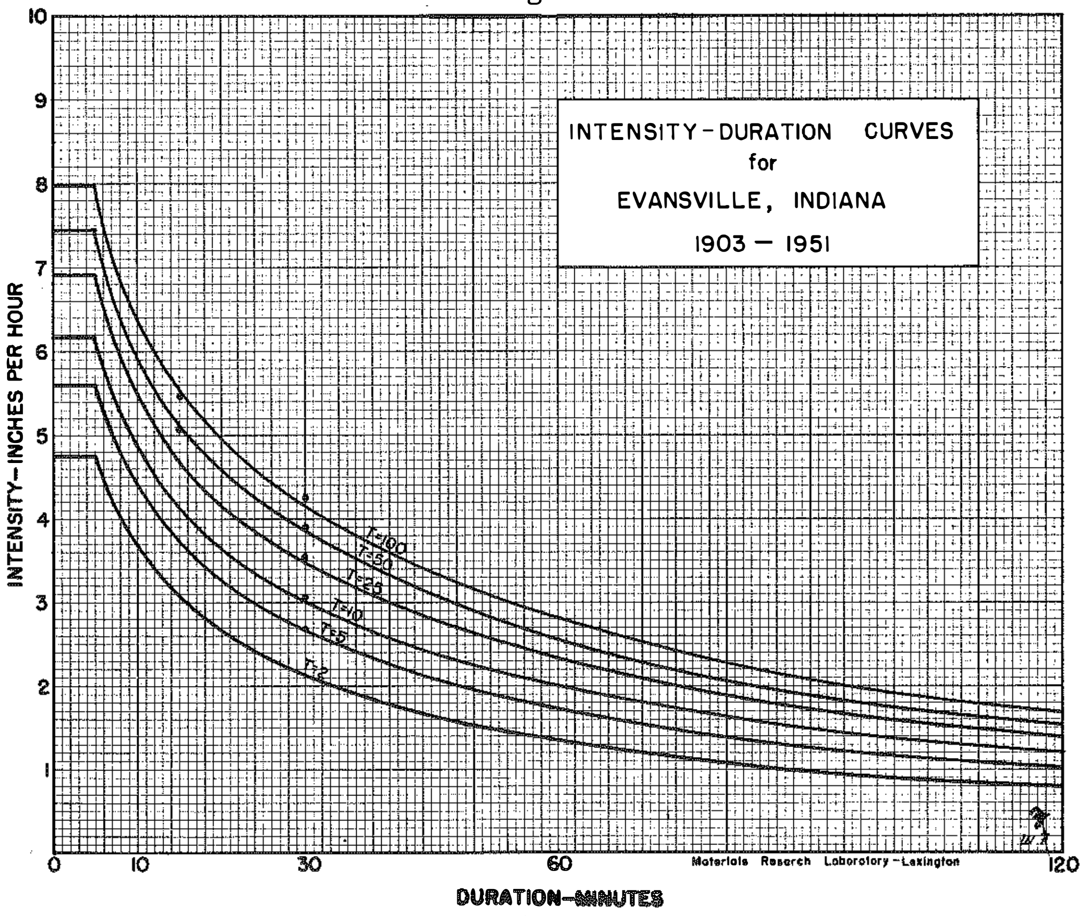

Fig. 12f

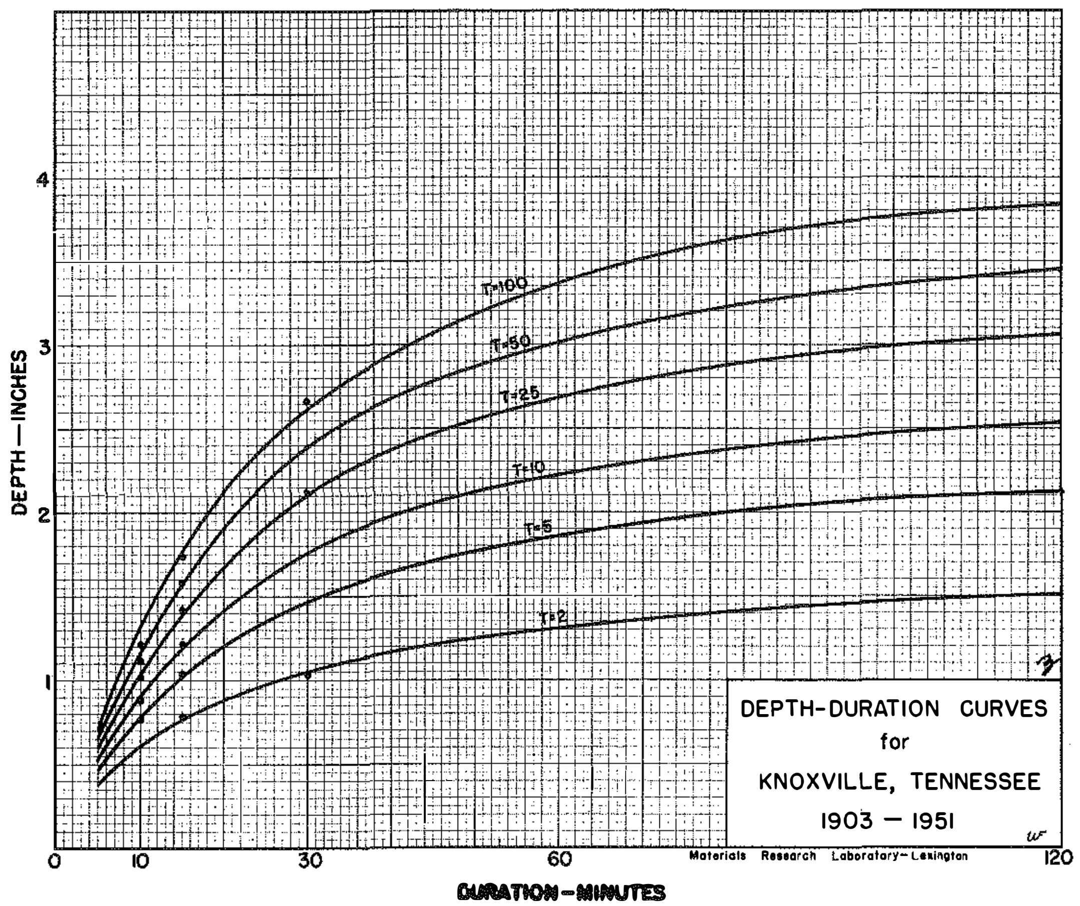

Fig. 12g

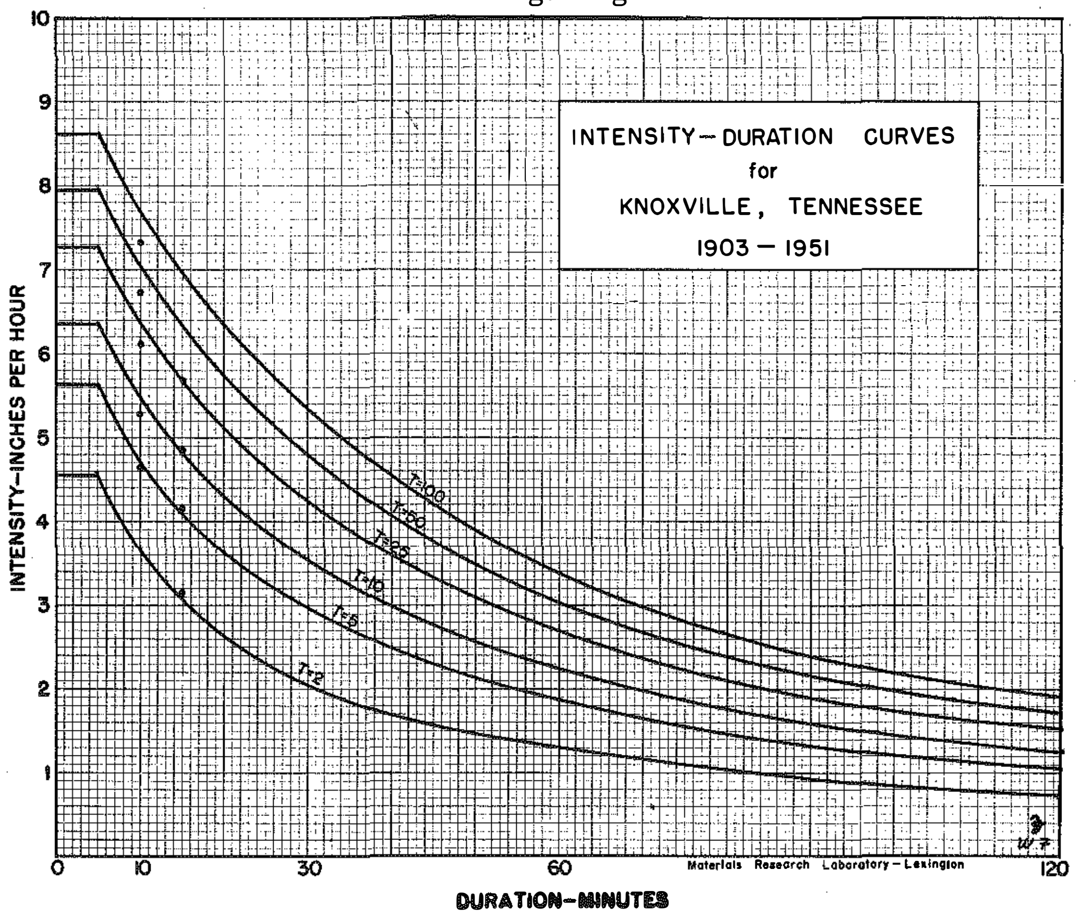

Fig. 12h

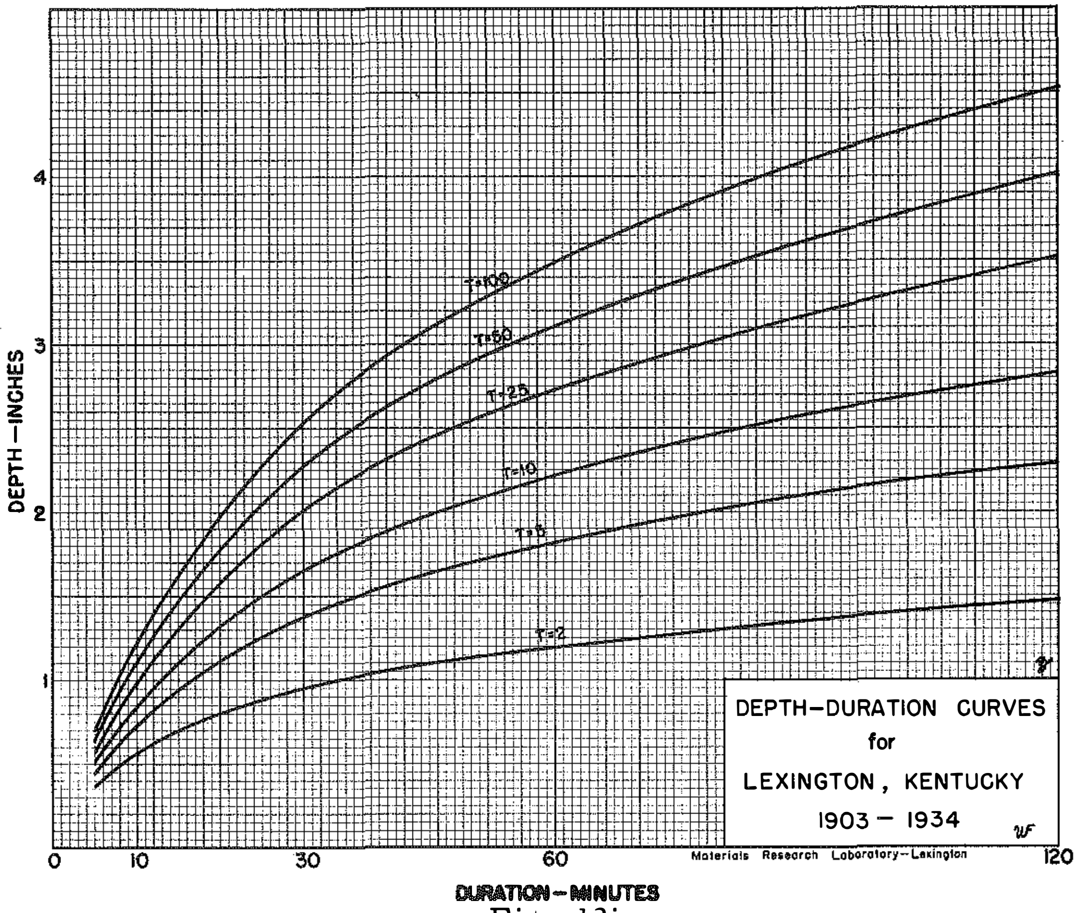

Fig. 12i

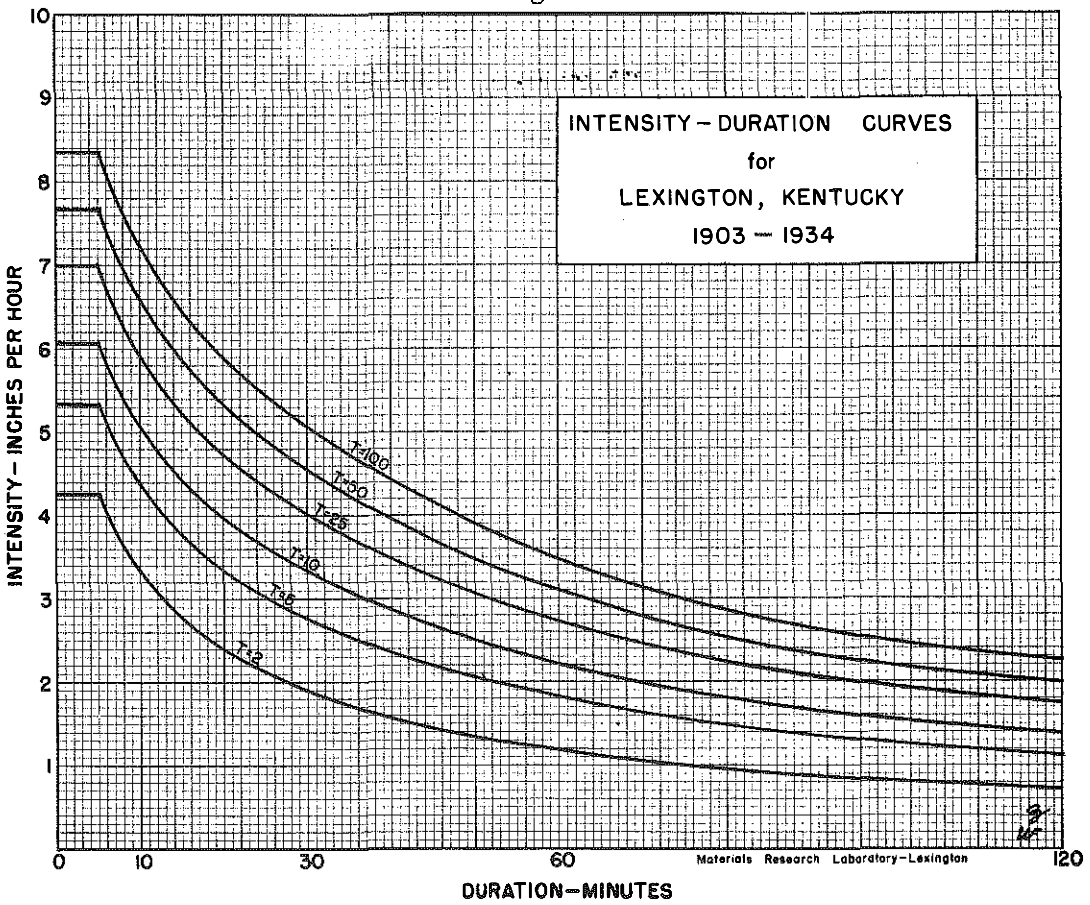

Fig. 12j

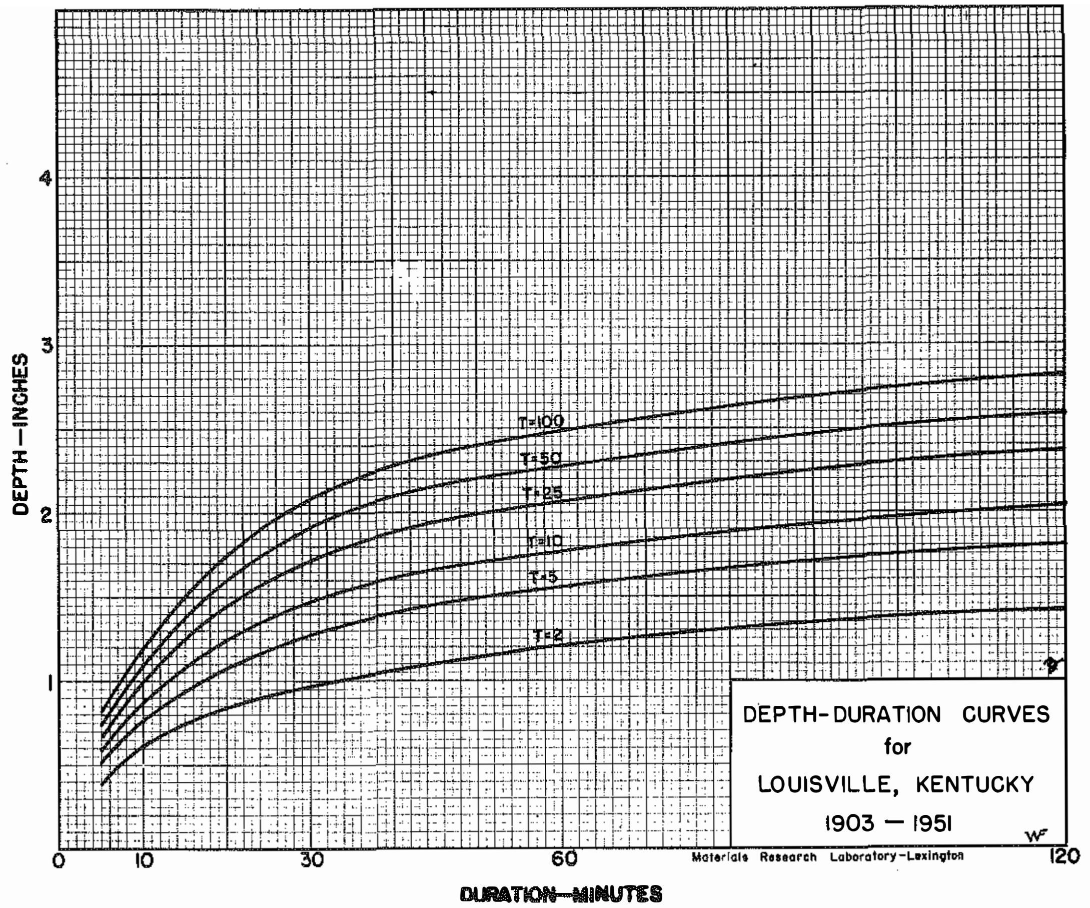

Fig. 12k

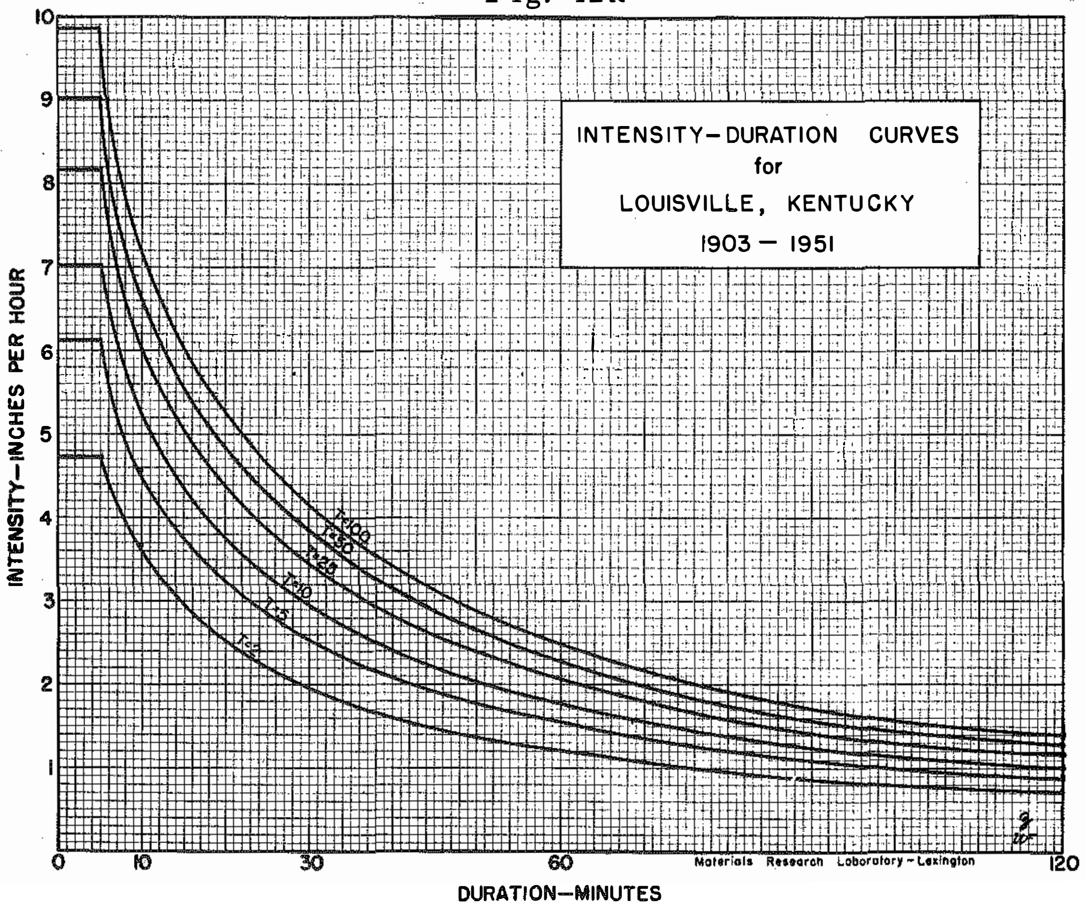

Fig. 12l

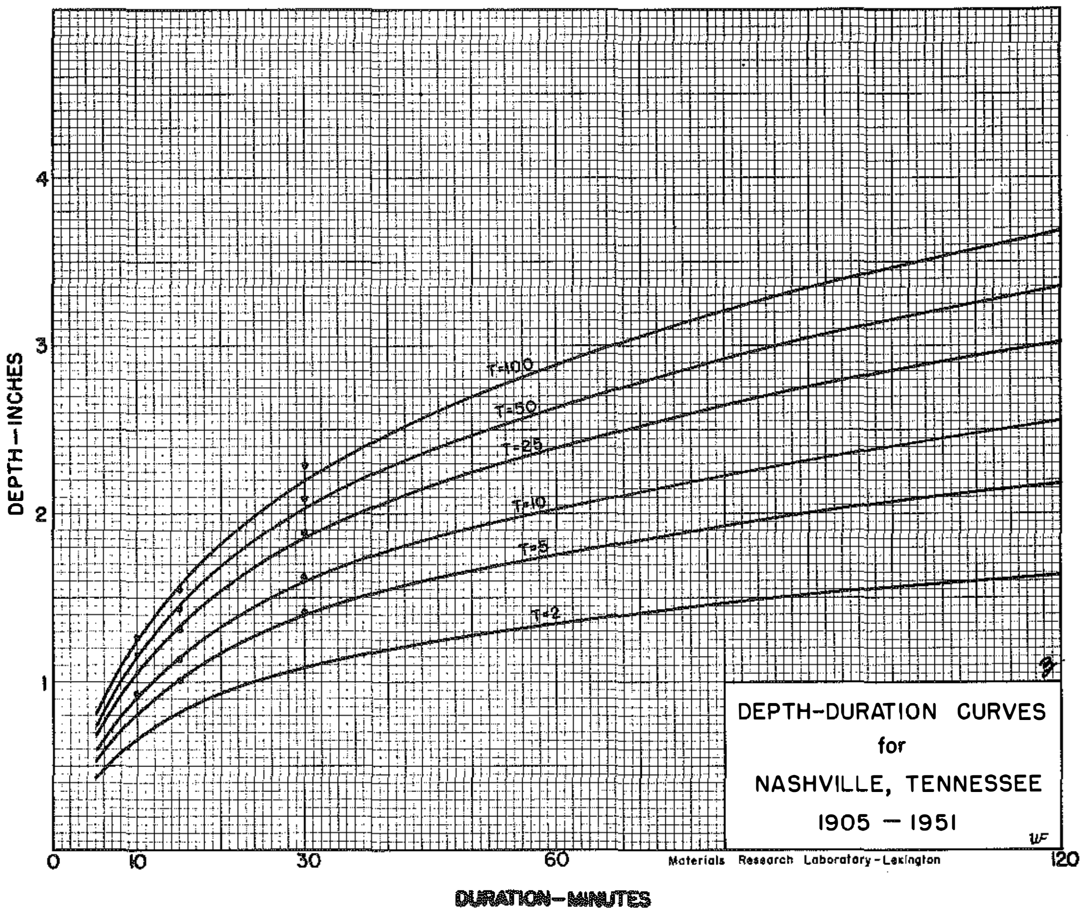

Fig. 12m

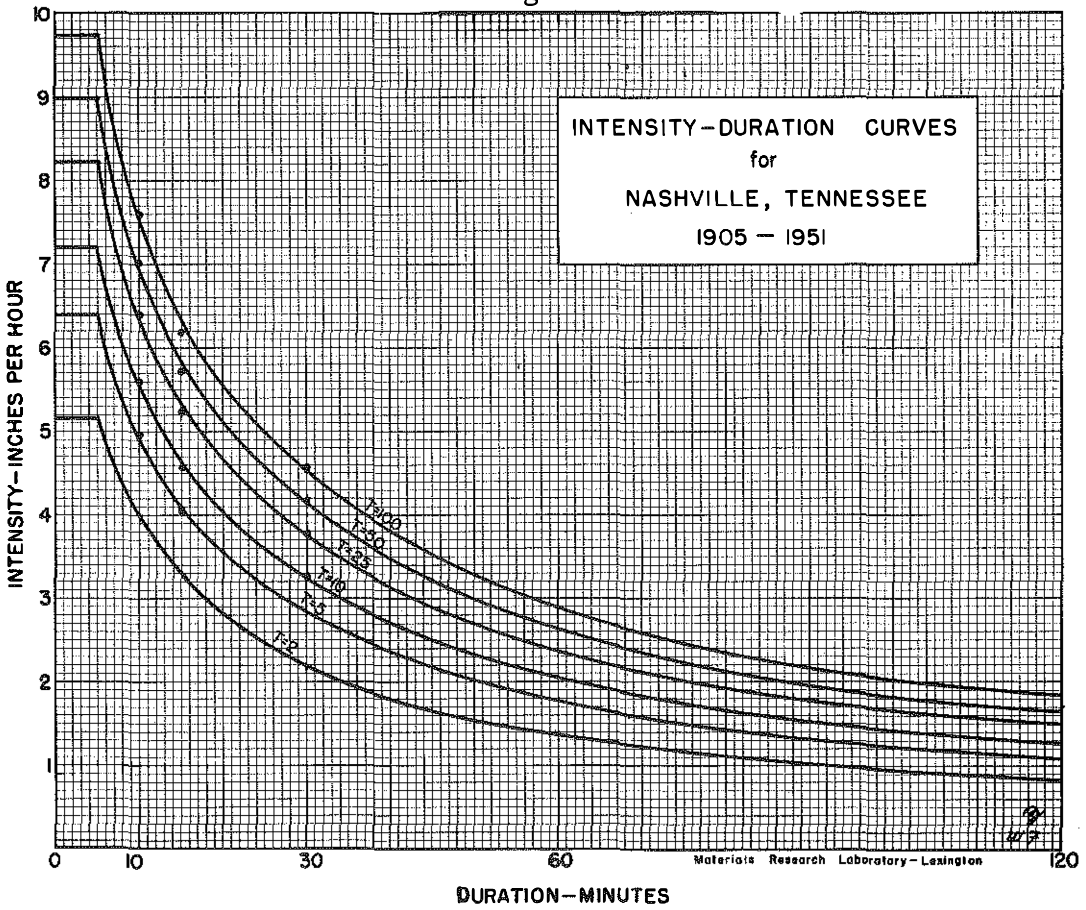

Fig. 12n

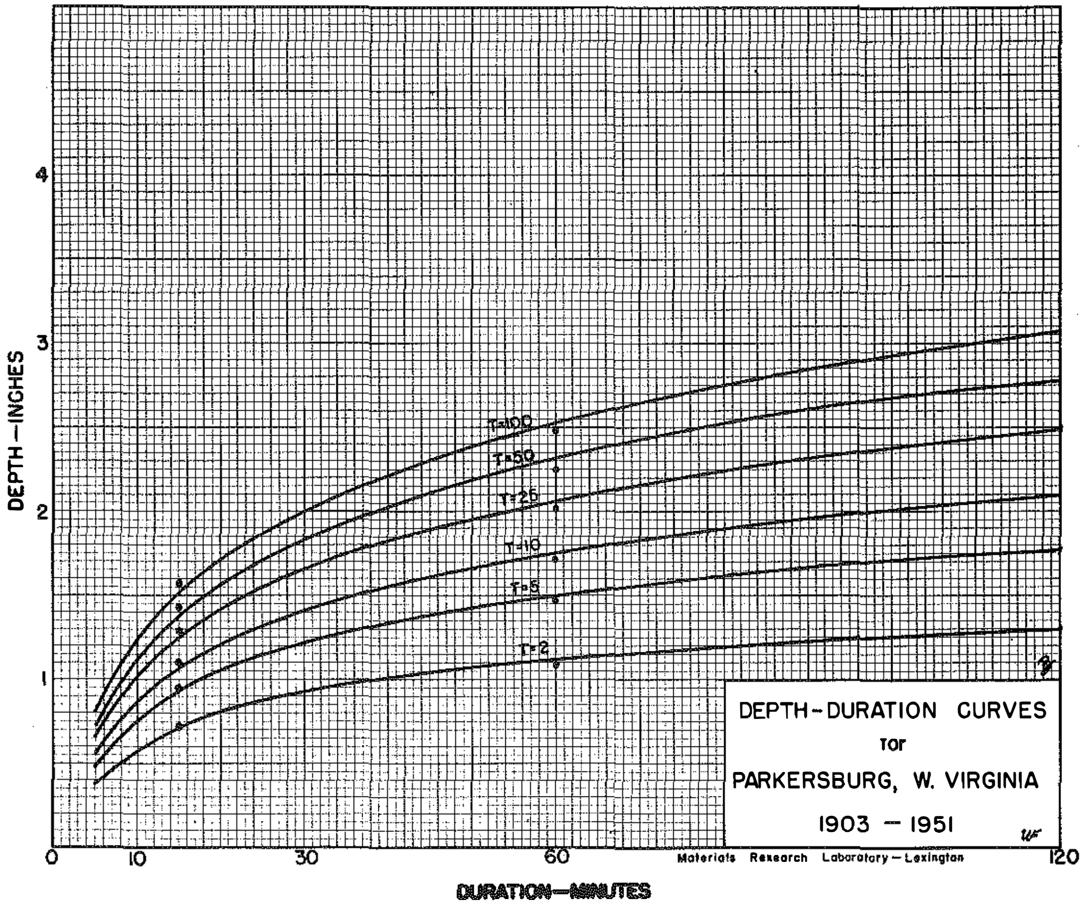

Fig. 12o

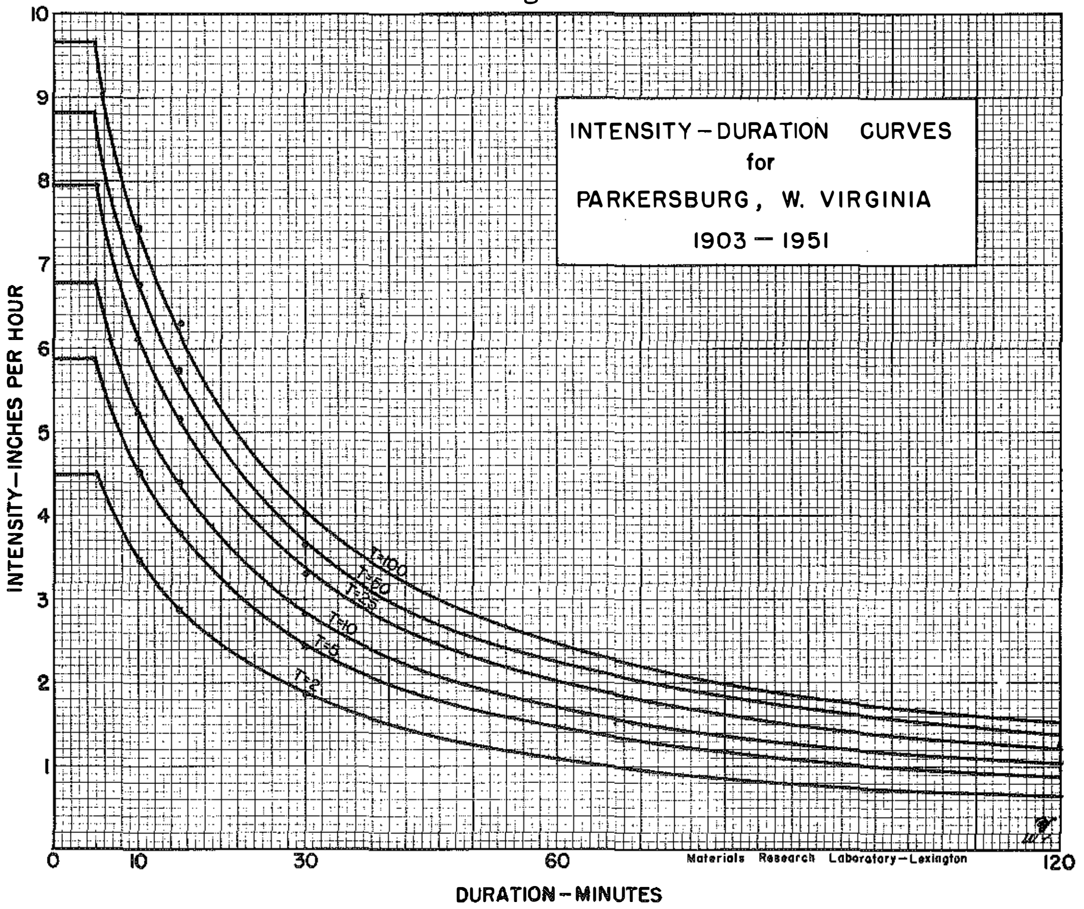

Fig. 12p

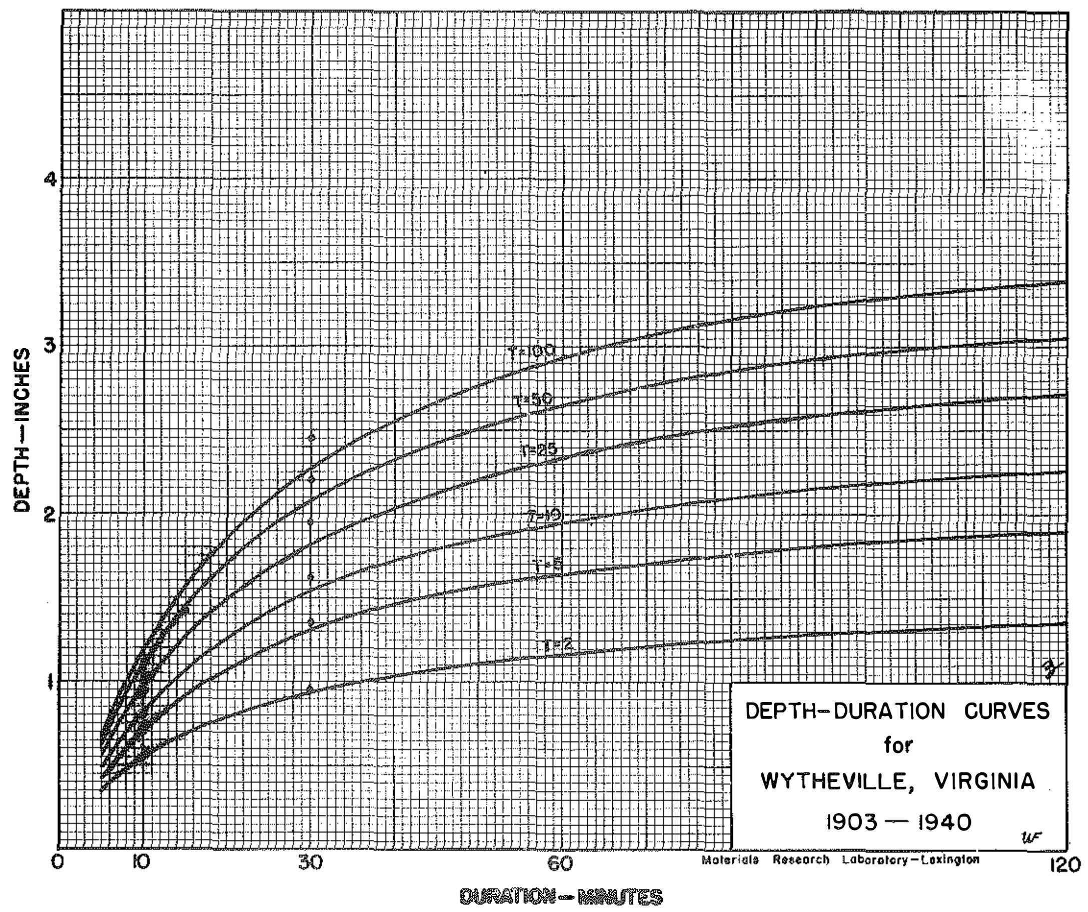

Fig. 12q

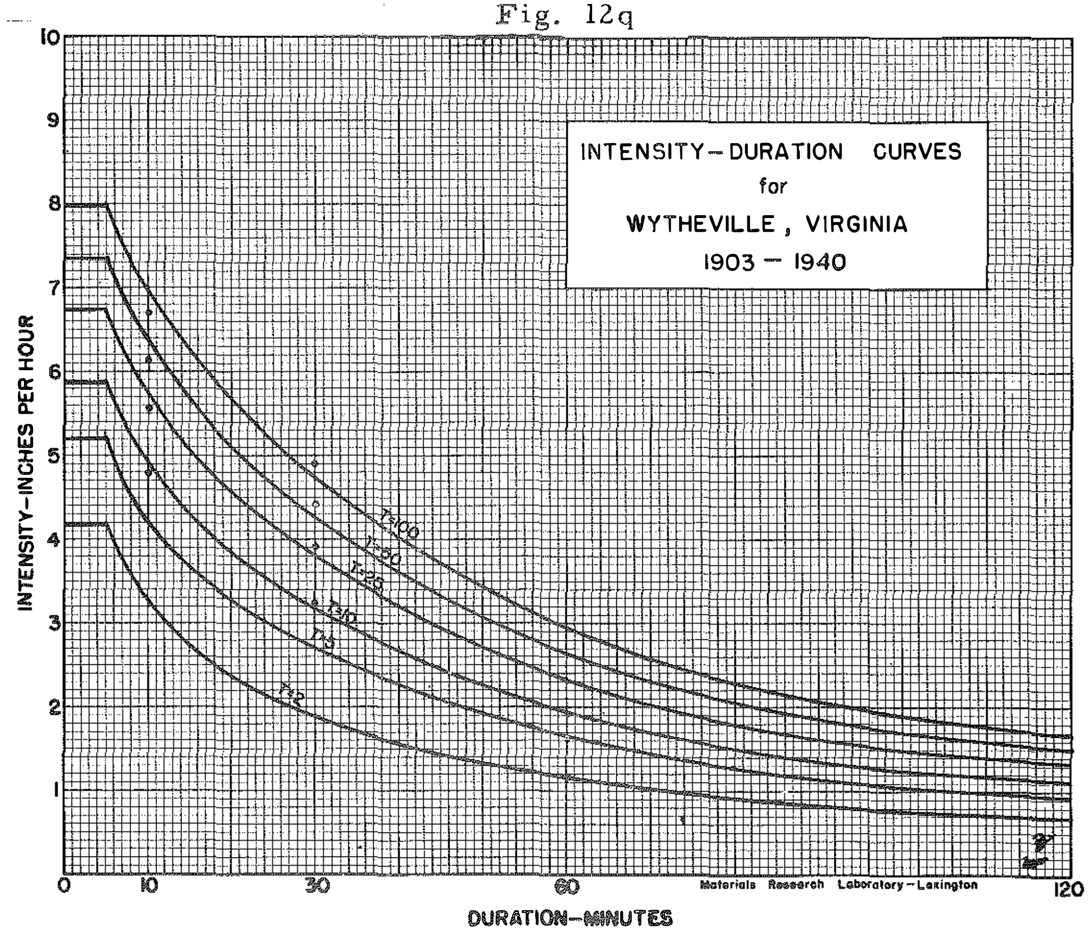

Fig. 12r

Notes on Fig. 13:

The time of concentration involves time for overland flow as well as time necessary for channel flow. In Fig. 13 only channel flow is considered, and the length (L) is a measure of the defined channel shown on maps.

The difference in elevation represents the difference between the headwater of the stream channel and the point of entrance into the structure.

Example: Determine the time of concentration for a stream which has a maximum length of travel (L) of 3,000 feet and a difference in elevation (H) of 50 feet. The slope (S) is equal to H/L. The constant (K) is first determined as follows:

$$K = \frac{L}{\sqrt{S}} \quad \text{or} \quad \sqrt{\frac{L^3}{H}}$$

$$K = \frac{3000}{\sqrt{\frac{50}{3000}}}$$

$$K = \frac{3000}{\sqrt{0.0166}}$$

K = 23,300 or 23.3 thousands

Enter the graph in Fig. 13 with 23.3 on the K scale. Proceed upward to the curve, and horizontally to the T_c scale and read approximately 17 minutes as the time of concentration (it makes little difference whether 17.0 or 17.5 minutes is used).

The curve on this figure maximizes the intensity since it represents a lower envelope curve of the original raw data (the smaller the time of concentration the larger the intensity).

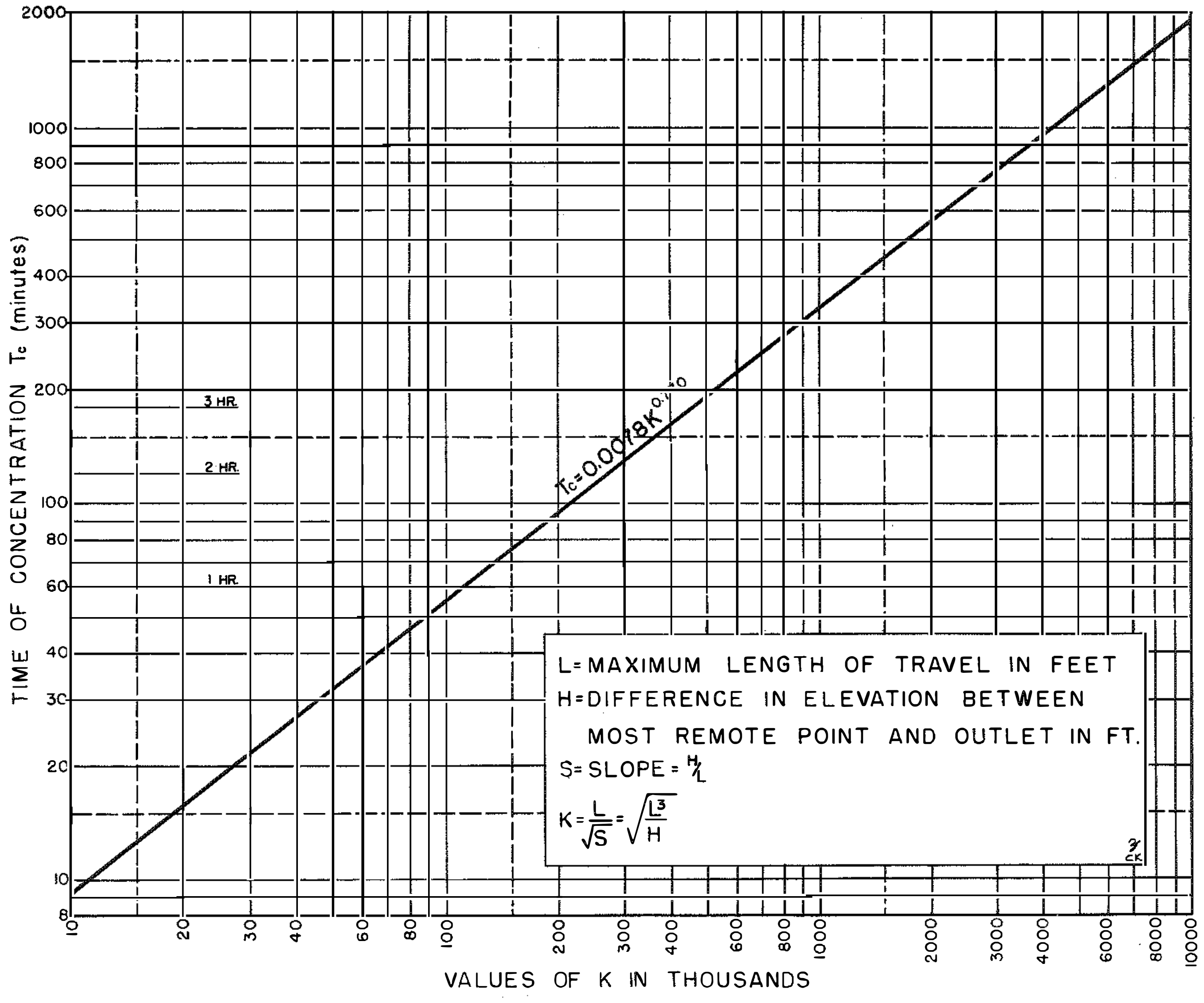

Fig. 13 - Time of Concentration for Small Agricultural Drainage Basins

Notes on Table 7:

Table 7 was compiled on the assumption that the original Talbot Formula

$$A = CA^{0.75}$$

is based on a rainfall intensity of 4 in. per hour after Talbot's maximum intensity formula

$$i = \frac{360}{t + 30}$$

where t = 60 minutes duration or time of concentration.

This table represents the area of opening required for one inch of rainfall per hour. The use of Table 7 is illustrated by the following example:

> Assuming a watershed drainage area in the Cairo Thiessen Polygon of 400 acres, with a stream length (L) of 3000 feet and a difference in elevation (H) equal to 50 feet (illustrated in Fig. 13); find the area in square feet of the opening required. For this purpose assume $C = 0.8$ and T_c = 17 minutes (from the Cairo Intensity-Duration Curve for selected return periods).
>
> From Table 7, opposite 400 acres and under $C = 0.8$, the value of 17.89 square feet is found. This value represents the requirement with a rainfall intensity of one inch per hour. Next, select at least three return periods from the curve, plotted on extreme probability paper (overlay), for an intensity of 17 minutes duration, as in Fig. 15a, Appendix C. For example, using the following return periods and their respective intensities:
>
> $T = 2$
> $T = 25$
> $T = 100$
>
> $T_2 = 3.00$ in. per hr.
> $T_{25} = 5.00$ in. per hr.
> $T_{100} = 6.00$ in. per hr.

And, from the formula:

$$A_{design} = TA^{0,75}C$$

$$A_2 = (3.00)\ (17.89)\ (0.8) = 43 \text{ sq. ft.}$$
$$A_{25} = (5.00)\ (17.89)\ (0.8) = 72 \text{ sq. ft.}$$
$$A_{100} = (6.00)\ (17.89)\ (0.8) = 86 \text{ sq. ft.}$$

The sheet of extreme probability paper is used to plot the area of opening for the respective return periods and a straight line is drawn. If these points fall in a straight line, the calculations are correct.

The results of the example given above are scattered about the line labeled "Area" (of waterway opening) in Fig. 15a, Appendix C. With this line, the return period of any required opening can be found in the same manner that the return period for a given discharge is determined. This fact points up the unrealistic approach represented by the Talbot formula, since the return period of an area of opening has no significance in itself; it would have some significance expressed as the discharge for which an area of opening is adequate.

Table [illegible] Area Of Waterway Calculated By Modified Talbot Formula And Based On An Equivalent Rainfall Intensity Of One Inch Per Hour

$$a = \frac{CA^{0.75}}{4}$$

DRAINAGE AREA	AREA OF WATERWAY — a (sq. ft.) FOR C =											
-A acres	1.0	0.9	0.8	0.7	2/3	0.6	0.5	0.4	1/3	0.3	0.2	0.1
2	0.42	0.38	0.34	0.29	0.28	0.25	0.21	0.17	0.14	0.13	0.08	0.04
3	0.57	0.51	0.46	0.40	0.38	0.34	0.28	0.23	0.19	0.17	0.11	0.06
4	0.71	0.64	0.57	0.49	0.47	0.42	0.35	0.28	0.24	0.21	0.14	0.07
5	0.84	0.75	0.67	0.59	0.56	0.50	0.42	0.33	0.28	0.25	0.17	0.08
6	0.96	0.86	0.77	0.67	0.64	0.58	0.48	0.38	0.32	0.29	0.19	0.10
7	1.08	0.97	0.86	0.75	0.72	0.65	0.54	0.43	0.36	0.32	0.22	0.11
8	1.19	1.07	0.95	0.83	0.79	0.71	0.59	0.48	0.40	0.36	0.24	0.12
9	1.30	1.17	1.04	0.91	0.87	0.78	0.65	0.52	0.43	0.39	0.26	0.13
10	1.41	1.27	1.12	0.98	0.94	0.84	0.70	0.56	0.47	0.47	0.28	0.14
11	1.51	1.36	1.21	1.06	1.01	0.91	0.76	0.60	0.50	0.45	0.30	0.15
12	1.61	1.45	1.29	1.13	1.07	0.97	0.81	0.64	0.54	0.48	0.32	0.16
13	1.71	1.54	1.37	1.20	1.14	1.03	0.86	0.68	0.57	0.51	0.34	0.17
14	1.81	1.63	1.45	1.27	1.21	1.09	0.90	0.72	0.60	0.54	0.36	0.18
15	1.91	1.71	1.52	1.33	1.27	1.14	0.95	0.76	0.64	0.57	0.38	0.19
16	2.00	1.80	1.60	1.40	1.33	1.20	1.00	0.80	0.67	0.60	0.40	0.20
17	2.09	1.88	1.67	1.47	1.40	1.26	1.05	0.84	0.70	0.63	0.42	0.21
18	2.18	1.97	1.75	1.53	1.46	1.31	1.09	0.87	0.73	0.66	0.44	0.22
19	2.28	2.05	1.82	1.59	1.52	1.37	1.14	0.91	0.76	0.68	0.46	0.23
20	2.36	2.13	1.89	1.66	1.58	1.42	1.18	0.95	0.79	0.71	0.47	0.24
21	2.45	2.21	1.96	1.72	1.63	1.47	1.23	0.98	0.82	0.74	0.49	0.25
22	2.54	2.29	2.03	1.78	1.69	1.52	1.27	1.02	0.85	0.76	0.51	0.25
23	2.63	2.36	2.10	1.84	1.75	1.58	1.31	1.05	0.88	0.79	0.53	0.26
24	2.71	2.44	2.17	1.90	1.81	1.63	1.36	1.08	0.90	0.81	0.54	0.27
25	2.80	2.52	2.24	1.96	1.86	1.68	1.40	1.12	0.93	0.84	0.56	0.28
26	2.88	2.59	2.30	2.01	1.92	1.73	1.44	1.15	0.96	0.86	0.58	0.29
27	2.96	2.67	2.37	2.07	1.97	1.78	1.48	1.18	0.99	0.89	0.59	0.30
28	3.04	2.74	2.43	2.13	2.03	1.83	1.52	1.22	1.01	0.91	0.61	0.30
29	3.12	2.81	2.50	2.19	2.08	1.87	1.56	1.25	1.04	0.94	0.62	0.31
30	3.20	2.88	2.56	2.24	2.14	1.92	1.60	1.28	1.07	0.96	0.64	0.32
31	3.28	2.96	2.63	2.30	2.19	1.97	1.64	1.31	1.09	0.99	0.66	0.33
32	3.36	3.03	2.69	2.35	2.24	2.02	1.68	1.35	1.12	1.01	0.67	0.34
33	3.44	3.10	2.75	2.41	2.29	2.07	1.72	1.38	1.15	1.03	0.69	0.34
34	3.52	3.17	2.82	2.46	2.35	2.11	1.76	1.41	1.17	1.06	0.70	0.35
35	3.60	3.24	2.88	2.52	2.40	2.16	1.80	1.44	1.20	1.08	0.72	0.36
36	3.67	3.31	2.94	2.57	2.45	2.20	1.84	1.47	1.22	1.10	0.73	0.37
37	3.75	3.38	3.00	2.63	2.50	2.25	1.88	1.50	1.25	1.13	0.75	0.38
38	3.82	3.44	3.06	2.68	2.55	2.29	1.91	1.53	1.27	1.15	0.76	0.38
39	3.90	3.51	3.12	2.73	2.60	2.34	1.95	1.56	1.30	1.17	0.78	0.39
40	3.98	3.58	3.18	2.78	2.65	2.39	1.99	1.59	1.33	1.19	0.80	0.40
41	4.05	3.65	3.24	2.84	2.70	2.43	2.03	1.62	1.35	1.22	0.81	0.41
42	4.12	3.71	3.30	2.89	2.75	2.47	2.06	1.65	1.37	1.24	0.82	0.41
43	4.20	3.78	3.36	2.94	2.80	2.52	2.10	1.68	1.40	1.26	0.84	0.42
44	4.27	3.84	3.42	2.99	2.85	2.56	2.14	1.71	1.42	1.28	0.85	0.43
45	4.34	3.91	3.47	3.04	2.90	2.61	2.17	1.74	1.45	1.30	0.87	0.43
46	4.42	3.97	3.53	3.09	3.94	2.65	2.21	1.77	1.47	1.32	0.88	0.44
47	4.49	4.04	3.59	3.14	2.99	2.69	2.24	1.80	1.50	1.35	0.90	0.45
48	4.56	4.10	3.65	3.19	3.04	2.74	2.28	1.82	1.52	1.37	0.91	0.46
49	4.63	4.17	3.70	3.24	3.09	2.78	2.32	1.85	1.54	1.39	0.93	0.46
50	4.70	4.23	3.76	3.29	3.13	2.82	2.35	1.88	1.57	1.41	0.94	0.47
51	4.77	4.29	3.82	3.34	3.18	2.86	2.38	1.91	1.59	1.43	0.95	0.48
52	4.84	4.36	3.87	3.39	3.23	2.90	2.42	1.94	1.61	1.45	0.97	0.48
53	4.91	4.42	3.93	3.44	3.27	2.95	2.46	1.96	1.64	1.47	0.98	0.49
54	4.98	4.48	3.98	3.49	3.32	2.99	2.49	1.99	1.66	1.49	1.00	0.50
55	5.05	4.54	4.04	3.53	3.37	3.03	2.52	2.02	1.68	1.51	1.01	0.50
56	5.12	4.61	4.09	3.58	3.41	3.07	2.56	2.05	1.71	1.54	1.02	0.51
57	5.19	4.67	4.15	3.63	3.46	3.11	2.59	2.07	1.73	1.56	1.04	0.52
58	5.25	4.73	4.20	3.68	3.50	3.15	2.63	2.10	1.75	1.58	1.05	0.52
59	5.32	4.79	4.26	3.72	3.55	3.19	2.66	2.13	1.77	1.60	1.06	0.53
60	5.39	4.85	4.31	3.77	3.59	3.23	2.69	2.16	1.80	1.62	1.08	0.54
61	5.46	4.91	4.36	3.82	3.64	3.27	2.73	2.18	1.82	1.64	1.09	0.55
62	5.52	4.97	4.42	3.87	3.68	3.31	3.76	2.21	1.84	1.66	1.10	0.55
63	5.59	5.03	4.47	3.91	3.73	3.35	2.80	2.24	1.86	1.68	1.12	0.56
64	5.66	5.09	4.52	3.96	3.77	3.39	2.83	2.26	1.89	1.70	1.13	0.57
65	5.72	5.15	4.58	4.01	3.82	3.43	2.86	2.29	1.91	1.72	1.14	0.57
66	5.79	5.21	4.63	4.05	3.86	3.47	2.89	2.32	1.93	1.74	1.16	0.58
67	5.85	5.27	4.68	4.10	3.90	3.51	2.93	2.34	1.95	1.76	1.17	0.58
68	5.92	5.33	4.74	4.14	3.95	3.55	2.96	2.37	1.97	1.78	1.18	0.59
69	5.99	5.39	4.79	4.19	3.99	3.59	2.99	2.39	2.00	1.80	1.20	0.60

Table 7 Cont'd.

Note: For Equivalent Rainfall Rate of 1 In. per hour.

DRAINAGE AREA -*A* *acres*	AREA OF WATERWAY– *a (sq. ft.)* FOR C = 1.0	0.9	0.8	0.7	2/3	0.6	0.5	0.4	1/3	0.3	0.2	0.1
70	6.05	5.45	4.84	4.24	4.03	3.63	3.02	2.42	2.02	1.82	1.21	0.60
71	6.11	5.50	4.89	4.28	4.08	3.67	3.06	2.44	2.04	1.83	1.22	0.61
72	6.18	5.56	4.94	4.32	4.12	3.71	3.09	2.47	2.06	1.85	1.24	0.62
73	6.24	5.62	4.99	4.37	4.16	3.75	3.12	2.50	2.08	1.87	1.25	0.62
74	6.31	5.68	5.05	4.42	4.20	3.78	3.15	2.52	2.10	1.89	1.26	0.63
75	6.37	5.73	5.10	4.46	4.25	3.82	3.19	2.55	2.12	1.91	1.27	0.64
76	6.44	5.79	5.15	4.50	4.29	3.86	3.22	2.57	2.14	1.93	1.29	0.64
77	6.50	5.85	5.20	4.55	4.33	3.90	3.25	2.60	2.17	1.95	1.30	0.65
78	6.56	5.90	5.25	4.59	4.37	3.94	3.28	2.62	2.19	1.97	1.31	0.66
79	6.62	5.96	5.30	4.64	4.42	3.97	3.31	2.65	2.21	1.99	1.32	0.66
80	6.69	6.02	5.35	4.68	4.46	4.01	3.34	2.67	2.23	2.01	1.34	0.67
81	6.75	6.08	5.40	4.72	4.50	4.05	3.38	2.70	2.25	2.02	1.35	0.68
82	6.81	6.13	5.45	4.77	4.54	4.09	3.41	2.72	2.27	2.04	1.36	0.68
83	6.87	6.19	5.50	4.81	4.58	4.12	3.44	2.75	2.29	2.06	1.37	0.69
84	6.94	6.24	5.55	4.86	4.62	4.16	3.47	2.77	2.31	2.08	1.39	0.69
85	7.00	6.30	5.60	4.90	4.67	4.20	3.50	2.80	2.33	2.10	1.40	0.70
86	7.06	6.35	5.65	4.94	4.71	4.24	3.53	2.82	2.35	2.12	1.41	0.71
87	7.12	6.41	5.70	4.98	4.75	4.27	3.56	2.85	2.37	2.14	1.42	0.71
88	7.18	6.46	5.75	5.03	4.79	4.31	3.59	2.87	2.39	2.15	1.44	0.72
89	7.24	6.52	5.80	5.07	4.83	4.35	3.62	2.90	2.41	2.17	1.45	0.72
90	7.31	6.57	5.84	5.11	4.87	4.38	3.65	2.92	2.44	2.19	1.46	0.73
91	7.37	6.63	5.89	5.16	4.91	4.42	3.68	2.95	2.46	2.21	1.47	0.74
92	7.43	6.68	5.94	5.20	4.95	4.46	3.71	2.97	2.48	2.23	1.48	0.74
93	7.49	6.74	5.99	5.24	4.99	4.49	3.74	2.99	2.50	2.25	1.50	0.75
94	7.55	6.79	6.04	5.28	5.03	4.53	3.77	3.02	2.52	2.26	1.51	0.75
95	7.61	6.85	6.09	5.33	5.07	4.56	3.80	3.04	2.54	2.28	1.52	0.76
96	7.67	6.90	6.13	5.37	5.11	4.60	3.83	3.07	2.56	2.30	1.53	0.77
97	7.73	6.95	6.18	5.41	5.15	4.64	3.86	3.09	2.58	2.32	1.54	0.77
98	7.79	7.01	6.23	5.45	5.19	4.67	3.89	3.11	2.60	2.34	1.56	0.78
99	7.85	7.06	6.28	5.49	5.23	4.71	3.92	3.14	2.62	2.35	1.57	0.78

Recommended Lower Limit of Use

100	7.91	7.12	6.32	5.53	5.27	4.74	3.95	3.16	2.64	2.37	1.58	0.79
102	8.02	7.22	6.42	5.62	5.35	4.81	4.01	3.21	2.67	2.41	1.60	0.80
104	8.14	7.33	6.51	5.70	5.43	4.88	4.07	3.26	2.71	2.44	1.63	0.81
106	8.26	7.43	6.61	5.78	5.50	4.96	4.13	3.30	2.75	2.48	1.65	0.83
108	8.38	7.54	6.70	5.86	5.58	5.02	4.19	3.35	2.79	2.51	1.68	0.84
110	8.49	7.64	6.79	5.94	5.66	5.10	4.25	3.40	2.83	2.55	1.70	0.85
112	8.61	7.75	6.88	6.02	5.74	5.16	4.30	3.44	2.87	2.58	1.72	0.86
114	8.72	7.85	6.98	6.10	5.81	5.23	4.36	3.49	2.91	2.62	1.74	0.87
116	8.84	7.95	7.07	6.18	5.89	5.30	4.42	3.53	2.94	2.65	1.77	0.88
118	8.95	8.06	7.16	6.26	5.97	5.37	4.48	3.58	2.98	2.68	1.79	0.90
120	9.06	8.16	7.25	6.34	6.04	5.44	4.53	3.63	3.02	2.72	1.81	0.91
122	9.18	8.26	7.34	6.42	6.12	5.51	4.59	3.67	3.06	2.75	1.84	0.92
124	9.29	8.36	7.43	6.50	6.19	5.57	4.64	3.72	3.10	2.79	1.86	0.93
126	9.40	8.46	7.52	6.58	6.27	5.64	4.70	3.76	3.13	2.82	1.88	0.94
128	9.51	8.56	7.61	6.66	6.34	5.71	4.76	3.81	3.17	2.85	1.90	0.95
130	9.62	8.66	7.70	6.74	6.42	5.77	4.81	3.85	3.21	2.89	1.92	0.96
132	9.74	8.76	7.79	6.82	6.49	5.84	4.87	3.89	3.24	2.92	1.95	0.97
134	9.85	8.86	7.88	6.89	6.56	5.91	4.92	3.94	3.28	2.95	1.97	0.98
136	9.96	8.96	7.96	6.97	6.64	5.97	4.98	3.98	3.32	2.99	1.99	1.00
138	10.07	9.06	8.05	7.05	6.71	6.04	5.03	4.03	3.36	3.02	2.01	1.01
140	10.18	9.16	8.14	7.12	6.78	6.11	5.09	4.07	3.39	3.05	2.04	1.02
142	10.28	9.26	8.23	7.20	6.86	6.17	5.14	4.11	3.43	3.08	2.06	1.03
144	10.39	9.35	8.31	7.27	6.93	6.24	5.20	4.16	3.46	3.12	2.08	1.04
146	10.50	9.45	8.40	7.35	7.00	6.30	5.25	4.20	3.50	3.15	2.10	1.05
148	10.61	9.55	8.49	7.43	7.07	6.36	5.30	4.24	3.54	3.18	2.12	1.06
150	10.72	9.64	8.57	7.50	7.14	6.43	5.36	4.29	3.57	3.21	2.14	1.07
152	10.82	9.74	8.66	7.58	7.21	6.49	5.41	4.33	3.61	3.25	2.16	1.08
154	10.93	9.84	8.74	7.65	7.29	6.56	5.46	4.37	3.64	3.28	2.19	1.09
156	11.04	9.93	8.83	7.72	7.36	6.62	5.52	4.41	3.68	3.31	2.21	1.10
158	11.14	10.03	8.91	7.80	7.43	6.68	5.57	4.46	3.71	3.34	2.23	1.11
160	11.25	10.12	9.00	7.87	7.50	6.75	5.62	4.50	3.75	3.37	2.25	1.12
162	11.35	10.22	9.08	7.95	7.57	6.81	5.68	4.54	3.78	3.41	2.27	1.14
164	11.46	10.31	9.17	8.02	7.64	6.87	5.73	4.58	3.82	3.44	2.29	1.15
166	11.56	10.41	9.25	8.09	7.71	6.94	5.78	4.62	3.85	3.47	2.31	1.16
168	11.67	10.50	9.33	8.17	7.78	7.00	5.83	4.67	3.89	3.50	2.33	1.17
170	11.77	10.59	9.42	8.24	7.85	7.06	5.89	4.71	3.92	3.53	2.35	1.18
172	11.87	10.69	9.50	8.31	7.92	7.12	5.94	4.75	3.96	2.56	2.38	1.19

Table 7 Cont'd.

Note: For Equivalent Rainfall
Rate of 1 in. per hour.

DRAINAGE AREA -*A*	AREA OF WATERWAY— a(*sq. ft.*) FOR C =											
acres	1.0	0.9	0.8	0.7	2/3	0.6	0.5	0.4	1/3	0.3	0.2	0.1
174	11.98	10.78	9.58	8.38	7.98	7.19	5.99	4.79	3.99	3.59	2.40	1.20
176	12.08	10.87	9.66	8.46	8.05	7.25	6.04	4.83	4.03	3.62	2.42	1.21
178	12.18	10.96	9.75	8.53	8.12	7.31	6.09	4.87	4.06	3.66	2.44	1.22
180	12.29	11.06	9.83	8.60	8.19	7.37	6.14	4.91	4.10	3.68	2.46	1.23
182	12.39	11.15	9.91	8.67	8.26	7.43	6.19	4.96	4.13	3.72	2.48	1.24
184	12.49	11.24	9.99	8.74	8.33	7.49	6.24	5.00	4.16	3.75	2.50	1.25
186	12.59	11.33	10.07	8.81	8.39	7.55	6.30	5.04	4.20	3.78	2.52	1.26
188	12.69	11.42	10.15	8.88	8.46	7.62	6.35	5.08	4.23	3.81	2.54	1.27
190	12.79	11.51	10.24	8.96	8.53	7.68	6.40	5.12	4.26	3.84	2.56	1.28
192	12.89	11.60	10.32	9.03	8.60	7.74	6.45	5.16	4.30	3.87	2.58	1.29
194	13.00	11.70	10.40	9.10	8.66	7.80	6.50	5.20	4.33	3.90	2.60	1.30
196	13.10	11.80	10.48	9.17	8.73	7.86	6.55	5.24	4.36	3.93	2.62	1.31
198	13.20	11.88	10.56	9.24	8.80	7.92	6.60	5.28	4.40	3.96	2.64	1.32
200	13.30	11.97	10.64	9.31	8.86	7.98	6.65	5.32	4.43	3.99	2.66	1.33
204	13.50	12.14	10.80	9.45	9.00	8.10	6.75	5.40	4.50	4.05	2.70	1.35
208	13.69	12.32	10.95	9.58	9.13	8.22	6.85	5.48	4.56	4.11	2.74	1.37
212	13.89	12.50	11.11	9.72	9.26	8.33	6.94	5.56	4.63	4.17	2.78	1.39
216	14.09	12.68	11.27	9.86	9.39	8.45	7.04	5.63	4.70	4.22	2.82	1.41
220	14.28	12.85	11.42	10.00	9.52	8.57	7.14	5.71	4.76	4.28	2.86	1.43
224	14.48	13.03	11.58	10.13	9.65	8.68	7.24	5.79	4.82	4.34	2.90	1.45
228	14.67	13.20	11.74	10.27	9.78	8.80	7.33	5.87	4.89	4.40	2.93	1.47
232	14.86	13.38	11.89	10.40	9.91	8.92	7.43	5.94	4.95	4.46	2.97	1.49
236	15.05	13.55	12.04	10.54	10.04	9.03	7.53	6.02	5.02	4.52	3.01	1.50
240	15.24	13.72	12.20	10.67	10.16	9.15	7.62	6.10	5.08	4.57	3.05	1.52
244	15.43	13.89	12.35	10.80	10.29	9.26	7.72	6.17	5.14	4.63	3.09	1.54
248	15.62	14.06	12.50	10.94	10.42	9.37	7.81	6.25	5.21	4.69	3.12	1.56
252	15.81	14.23	12.65	11.07	10.54	9.49	7.91	6.32	5.27	4.74	3.16	1.58
256	16.00	14.40	12.80	11.20	10.67	9.60	8.00	6.40	5.33	4.80	3.20	1.60
260	16.19	14.57	12.95	11.33	10.79	9.71	8.09	6.47	5.40	4.86	3.24	1.62
264	16.37	14.74	13.10	11.46	10.92	9.82	8.19	6.55	5.46	4.91	3.27	1.64
268	16.56	14.90	13.25	11.59	11.04	9.94	8.28	6.62	5.52	4.97	3.31	1.66
272	16.74	15.07	13.40	11.72	11.16	10.05	8.37	6.70	5.58	5.02	3.35	1.67
276	16.93	15.24	13.54	11.85	11.28	10.16	8.46	6.77	5.64	5.08	3.38	1.69
280	17.11	15.40	13.69	11.98	11.41	10.27	8.56	6.84	5.70	5.13	3.42	1.71
284	17.30	15.56	13.84	12.11	11.53	10.38	8.65	6.92	5.76	5.19	3.46	1.73
288	17.48	15.73	13.98	12.23	11.65	10.49	8.74	6.99	5.83	5.24	3.50	1.75
292	17.66	15.89	14.13	12.36	11.77	10.60	8.83	7.06	5.89	5.30	3.53	1.77
296	17.84	16.06	14.27	12.49	11.89	10.70	8.92	7.14	5.95	5.35	3.57	1.78
300	18.02	16.22	14.42	12.61	12.01	10.81	9.01	7.21	6.01	5.41	3.60	1.80
305	18.25	16.42	14.60	12.77	12.16	10.95	9.12	7.30	6.08	5.47	3.65	1.82
310	18.47	16.62	14.78	12.93	12.31	11.08	9.23	7.39	6.16	5.54	3.69	1.85
315	18.69	16.82	14.95	13.08	12.46	11.22	9.35	7.48	6.23	5.61	3.74	1.87
320	18.92	17.02	15.13	13.24	12.61	11.35	9.46	7.56	6.30	5.67	3.78	1.89
325	19.14	17.22	15.31	13.40	12.76	11.48	9.57	7.65	6.38	5.74	3.83	1.91
330	19.36	17.42	15.48	13.55	12.90	11.61	9.68	7.74	6.45	5.81	3.87	1.94
335	19.58	17.62	15.66	13.70	13.05	11.75	9.79	7.83	6.53	5.87	3.92	1.96
340	19.79	17.82	15.84	13.86	13.20	11.88	9.90	7.92	6.60	5.94	3.96	1.98
345	20.01	18.01	16.01	14.01	13.34	12.01	10.01	8.01	6.67	6.00	4.00	2.00
350	20.18	18.16	16.15	14.13	13.46	12.11	10.09	8.07	6.73	6.05	4.04	2.02
355	20.45	18.40	16.36	14.31	13.63	12.27	10.22	8.18	6.82	6.13	4.09	2.04
360	20.66	18.60	16.53	14.46	13.77	12.40	10.33	8.26	6.89	6.20	4.13	2.07
365	20.88	18.79	16.70	14.61	13.92	12.53	10.44	8.35	6.96	6.26	4.18	2.09
370	21.09	18.98	16.87	14.76	14.06	12.65	10.55	8.44	7.03	6.33	4.22	2.11
375	21.30	19.17	17.04	14.91	14.20	12.78	10.65	8.52	7.10	6.39	4.26	2.13
380	21.52	19.37	17.21	15.06	14.34	12.91	10.76	8.61	7.17	6.46	4.30	2.15
385	21.73	19.56	17.38	15.21	14.49	13.04	10.86	8.69	7.24	6.52	4.35	2.17
390	21.94	19.75	17.55	15.36	14.63	13.16	10.97	8.78	7.31	6.58	4.39	2.19
395	22.15	19.94	17.72	15.51	14.77	13.29	11.08	8.86	7.38	6.65	4.43	2.22
400	22.36	20.12	17.89	15.65	14.91	13.42	11.18	8.94	7.45	6.71	4.47	2.24
405	22.57	20.31	18.06	15.80	15.05	13.54	11.28	9.03	7.52	6.77	4.51	2.26
410	22.78	20.50	18.22	15.95	15.19	13.67	11.39	9.11	7.59	6.83	4.56	2.28
415	22.99	20.69	18.39	16.09	15.32	13.79	11.49	9.19	7.66	6.90	4.60	2.30
420	23.19	20.87	18.56	16.24	15.46	13.92	11.60	9.28	7.73	6.96	4.64	2.32
425	23.40	21.06	18.72	16.38	15.60	14.04	11.70	9.36	7.80	7.02	4.68	2.34
430	23.61	21.25	18.89	16.52	15.74	14.16	11.80	9.44	7.87	7.08	4.72	2.36
435	23.81	21.43	19.05	16.67	15.88	14.29	11.91	9.53	7.94	7.14	4.76	2.38
440	24.02	21.62	19.21	16.81	16.01	14.41	12.01	9.61	8.01	7.21	4.80	2.40
445	24.22	21.80	19.38	16.96	16.15	14.53	12.11	9.69	8.07	7.27	4.84	2.42
450	24.43	21.98	19.54	17.10	16.28	14.66	12.21	9.77	8.14	7.33	4.89	2.44
455	24.63	22.17	19.70	17.24	16.42	14.78	12.31	9.85	8.21	7.39	4.93	2.46
460	24.83	22.35	19.87	17.38	16.55	14.90	12.42	9.93	8.28	7.45	4.97	2.48
465	25.03	22.53	20.03	17.52	16.69	15.02	12.52	10.01	8.34	7.51	5.01	2.50
470	25.24	22.71	20.19	17.66	16.82	15.14	12.62	10.09	8.41	7.57	5.05	2.52
475	25.44	22.89	20.35	17.81	16.96	15.26	12.72	10.18	8.48	7.63	5.09	2.54

Table 7 Cont'd.

Note: For Equivalent Rainfall
Rate of 1 in. per hour.

DRAINAGE AREA	AREA OF WATERWAY– o *(sq. ft.)* FOR C =											
-*A* *acres*	1.0	0.9	0.8	0.7	2/3	0.6	0.5	0.4	1/3	0.3	0.2	0.1
480	25.64	23.07	20.51	17.95	17.09	15.38	12.82	10.25	8.55	7.69	5.13	2.56
485	25.84	23.25	20.67	18.09	17.22	15.50	12.92	10.33	8.61	7.75	5.17	2.58
490	26.04	23.43	20.83	18.23	17.36	15.62	13.02	10.42	8.68	7.81	5.21	2.60
495	26.24	23.61	20.99	18.37	17.49	15.74	13.12	10.50	8.75	7.87	5.25	2.62
500	26.43	23.79	21.15	18.50	17.62	15.86	13.22	10.57	8.81	7.93	5.29	2.64
505	26.63	23.97	21.31	18.64	17.75	15.98	13.32	10.65	8.88	7.99	5.33	2.66
510	26.83	24.15	21.46	18.78	17.89	16.10	13.41	10.73	8.94	8.05	5.37	2.68
515	27.03	24.32	21.62	18.92	18.02	16.22	13.51	10.81	9.01	8.11	5.41	2.70
520	27.22	24.50	21.78	19.06	18.15	16.33	13.61	10.89	9.07	8.17	5.44	2.72
525	27.42	24.68	21.94	19.19	18.28	16.45	13.71	10.97	9.14	8.23	5.48	2.74
530	27.62	24.85	22.09	19.33	18.41	16.57	13.81	11.05	9.21	8.28	5.52	2.76
535	27.81	25.03	22.25	19.47	18.54	16.69	13.91	11.12	9.27	8.34	5.56	2.78
540	28.01	25.20	22.40	19.60	18.67	16.80	14.00	11.20	9.34	8.40	5.60	2.80
545	28.20	25.38	22.56	19.74	18.80	16.92	14.10	11.28	9.40	8.46	5.64	2.82
550	28.39	25.55	22.71	19.88	18.93	17.04	14.20	11.36	9.46	8.52	5.68	2.84
555	28.59	25.73	22.87	20.01	19.06	17.15	14.29	11.44	9.53	8.58	5.72	2.86
560	28.78	25.90	23.02	20.15	19.19	17.27	14.39	11.51	9.59	8.63	5.76	2.88
565	28.97	26.08	23.18	20.28	19.32	17.38	14.49	11.59	9.66	8.69	5.80	2.90
570	29.16	26.25	23.33	20.42	19.44	17.50	14.58	11.67	9.72	8.75	5.83	2.92
575	29.36	26.42	23.48	20.55	19.57	17.61	14.68	11.74	9.79	8.81	5.87	2.94
580	29.55	26.59	23.64	20.68	19.70	17.73	14.77	11.82	9.85	8.86	5.91	2.96
585	29.74	26.76	23.79	20.82	19.83	17.84	14.87	11.90	9.91	8.92	5.95	2.97
590	29.93	26.94	23.94	20.95	19.95	17.96	14.96	11.97	9.98	8.98	5.99	2.99
600	30.31	27.28	24.25	21.22	20.21	18.18	15.15	12.12	10.10	9.09	6.06	3.03
610	30.69	27.62	24.55	21.48	20.46	18.41	15.34	12.28	10.23	9.21	6.14	3.07
620	31.06	27.96	24.85	21.74	20.71	18.64	15.53	12.43	10.35	9.32	6.21	3.11
630	31.44	28.29	25.15	22.01	20.96	18.86	15.72	12.58	10.48	9.43	6.29	3.14
640	31.81	28.63	25.45	22.27	21.21	19.09	15.91	12.72	10.60	9.54	6.36	3.18
650	32.18	28.96	25.75	22.53	21.46	19.31	16.09	12.87	10.73	9.65	6.44	3.22
660	32.55	29.30	26.04	22.79	21.70	19.53	16.28	13.02	10.85	9.77	6.51	3.26
670	32.92	29.63	26.34	23.05	21.95	19.75	16.46	13.17	10.97	9.88	6.58	3.29
680	33.29	29.96	26.63	23.30	22.19	19.97	16.65	13.32	11.10	9.99	6.66	3.33
690	33.66	30.29	26.93	23.56	22.44	20.19	16.83	13.46	11.22	10.10	6.73	3.37
700	34.02	30.62	27.22	23.82	22.68	20.41	17.01	13.61	11.34	10.21	6.80	3.40
710	34.39	30.95	27.51	24.07	22.93	20.63	17.19	13.76	11.46	10.32	6.88	3.44
720	34.75	31.27	27.80	23.32	23.17	20.85	17.37	13.90	11.58	10.42	6.95	3.47
730	35.11	31.60	28.09	24.58	23.41	21.07	17.56	14.04	11.70	10.53	7.02	3.51
740	35.47	31.92	28.38	24.83	23.65	21.28	17.74	14.19	11.82	10.64	7.09	3.55
750	35.83	32.25	28.66	25.08	23.89	21.50	17.91	14.33	11.94	10.75	7.17	3.58
760	36.19	32.57	28.95	25.33	24.12	21.71	18.09	14.48	12.06	10.86	7.23	3.62
770	36.54	32.89	29.23	25.58	24.36	21.93	18.27	14.62	12.18	10.96	7.31	3.65
780	36.98	33.21	29.52	25.83	24.60	22.14	18.45	14.76	12.30	11.07	7.38	3.69
790	37.25	33.53	29.80	26.08	24.84	22.35	18.63	14.90	12.42	11.18	7.45	3.73
800	37.61	33.85	30.08	26.32	25.07	22.56	18.80	15.04	12.54	11.28	7.52	3.76
810	37.96	34.16	30.37	26.57	25.31	22.78	18.98	15.18	12.65	11.39	7.59	3.80
820	38.31	34.48	30.65	26.82	25.54	22.99	19.15	15.32	12.77	11.49	7.66	3.83
830	38.66	34.79	30.93	27.06	25.77	23.20	19.33	15.46	12.89	11.60	7.73	3.87
840	39.01	35.11	31.21	27.31	26.01	23.40	19.50	15.60	13.00	11.70	7.80	3.90
850	39.36	35.42	31.48	27.55	26.24	23.61	19.68	15.74	13.12	11.81	7.87	3.94
860	39.70	35.73	31.76	27.79	26.47	23.82	19.85	15.88	13.23	11.91	7.94	3.97
870	40.05	36.04	32.04	28.03	26.70	24.03	20.02	16.02	13.35	12.01	8.01	4.00
880	40.39	36.35	32.31	28.28	26.93	24.24	20.20	16.16	13.46	12.12	8.08	4.04
890	40.75	36.67	32.60	28.52	27.16	24.45	20.37	16.30	13.58	12.22	8.15	4.07
900	41.08	36.97	32.86	28.76	27.39	24.65	20.54	16.43	13.69	12.32	8.22	4.11
910	41.42	37.28	33.14	28.99	27.61	24.85	20.71	16.57	13.81	12.43	8.28	4.14
920	41.76	37.59	33.41	29.23	27.84	25.06	20.88	16.71	13.92	12.53	8.35	4.18
930	42.10	37.89	33.68	29.47	28.07	25.26	21.05	16.84	14.03	12.63	8.42	4.21
940	42.44	38.20	33.95	29.71	28.29	25.46	21.22	16.98	14.15	12.73	8.49	4.24
950	42.78	38.50	34.22	29.95	28.52	25.67	21.39	17.11	14.26	12.83	8.56	4.28
960	43.12	38.80	34.49	30.18	28.74	25.87	21.56	17.25	14.37	12.93	8.62	4.31
970	43.45	39.11	34.76	30.42	28.97	26.07	21.73	17.38	14.48	13.04	8.69	4.35
980	43.79	39.41	35.03	30.65	29.19	26.27	21.89	17.52	14.60	13.14	8.76	4.38
990	44.12	39.71	35.30	30.89	29.42	26.47	22.06	17.65	14.71	13.24	8.82	4.41

Assumed Time of Concentration of 1 Hour Satisfactory For Use With Drainage Areas Between 1000 and 2000 Acres.

1000	44.46	40.01	35.57	31.12	29.64	26.67	22.23	17.78	14.82	13.34	8.89	4.45
1005	44.62	40.16	35.70	31.24	29.75	26.77	22.31	17.85	14.86	13.39	8.92	4.46
1010	44.79	40.31	35.83	31.35	29.86	26.87	22.40	17.92	14.93	13.44	8.96	4.48
1015	44.96	40.46	35.97	31.47	29.97	26.97	22.48	17.98	14.99	13.49	8.99	4.50

Table 7 Cont'd.

Note: For Equivalent Rainfall
Rate of 1 in. per hour.

DRAINAGE AREA -*A*	AREA OF WATERWAY- *a (sq. ft.)* FOR C =											
acres	1.0	0.9	0.8	0.7	2/3	0.6	0.5	0.4	1/3	0.3	0.2	0.1
1020	45.12	40.61	36.10	31.59	30.08	27.07	22.56	18.05	15.03	13.54	9.02	4.51
1025	45.29	40.76	36.23	31.70	30.19	27.17	22.64	18.12	15.10	13.59	9.06	4.53
1030	45.45	40.91	36.36	31.82	30.30	27.27	22.73	18.18	15.15	13.64	9.09	4.55
1035	45.62	41.06	36.50	31.93	30.41	27.37	22.81	18.25	15.21	13.69	9.12	4.56
1040	45.78	41.21	36.63	32.05	30.52	27.47	22.89	18.31	15.26	13.74	9.16	4.58
1045	45.95	41.35	36.76	32.16	30.63	27.57	22.97	18.38	15.32	13.78	9.19	4.60
1050	46.11	41.50	36.89	32.28	30.74	27.67	23.06	18.45	15.37	13.83	9.22	4.61
1055	46.28	41.65	37.02	32.39	30.85	27.77	23.14	18.51	15.41	13.88	9.26	4.63
1060	46.44	41.80	37.15	32.51	30.96	27.87	23.22	18.58	15.48	13.93	9.29	4.64
1065	46.61	41.95	37.29	32.62	31.07	27.96	23.30	18.64	15.54	13.98	9.32	4.66
1070	46.77	42.09	37.42	32.74	31.18	28.06	23.39	18.71	15.59	14.03	9.35	4.68
1075	46.94	42.24	37.55	32.85	31.29	28.16	23.47	18.77	15.64	14.08	9.39	4.69
1080	47.10	42.39	37.68	32.97	31.40	28.26	23.55	18.84	15.70	14.13	9.42	4.71
1085	47.26	42.54	37.81	33.08	31.51	28.36	23.63	18.90	15.75	14.18	9.45	4.73
1090	47.43	42.68	37.94	33.20	31.62	28.46	23.71	18.97	15.81	14.23	9.49	4.74
1095	47.59	42.83	38.07	33.31	31.73	28.55	23.79	19.04	15.86	13.28	9.52	4.76
1100	47.75	42.98	38.20	33.43	31.83	28.65	23.88	19.10	15.92	14.33	9.55	4.78
1120	48.40	43.56	38.72	33.88	32.27	29.04	24.20	19.36	16.13	14.52	9.68	4.84
1140	49.05	44.14	39.24	34.33	32.70	29.43	24.52	19.62	16.35	14.71	9.81	4.90
1160	49.69	44.72	39.75	34.78	33.13	29.82	24.84	19.88	16.56	14.91	9.94	4.97
1180	50.33	45.30	40.27	35.23	33.56	30.20	25.17	20.13	16.78	15.10	10.07	5.03
1200	50.97	45.87	40.78	35.68	33.98	30.58	25.48	20.39	16.99	15.29	10.19	5.10
1220	51.61	46.45	41.28	36.12	34.40	30.96	25.80	20.64	17.20	15.48	10.32	5.16
1240	52.24	47.02	41.79	36.57	34.83	31.34	26.12	20.90	17.41	15.67	10.45	5.22
1260	52.87	47.58	42.30	37.01	35.25	31.72	26.44	21.15	17.62	15.86	10.57	5.29
1280	53.50	48.15	42.80	37.45	35.67	32.10	26.75	21.40	17.83	16.05	10.70	5.35
1300	54.14	48.72	43.31	37.90	36.09	32.48	27.07	21.66	18.04	16.24	10.83	5.41
1320	54.75	49.27	43.80	38.32	36.50	32.85	27.37	21.90	18.25	16.42	10.95	5.48
1340	55.37	49.83	44.30	38.76	36.91	33.22	27.68	22.15	18.46	16.61	11.07	5.54
1360	55.99	50.39	44.79	39.19	37.32	33.59	27.99	22.40	18.66	16.80	11.20	5.60
1380	56.60	50.94	45.28	39.62	37.74	33.96	28.30	22.64	18.87	16.98	11.32	5.66
1400	57.22	51.50	45.78	40.05	38.14	34.33	28.61	22.89	19.07	17.16	11.44	5.72
1420	57.83	52.05	46.26	40.48	38.55	34.70	28.92	23.13	19.28	17.35	11.57	5.78
1440	58.44	52.60	46.75	40.91	38.96	35.06	29.22	23.38	19.48	17.53	11.69	5.84
1460	59.05	53.14	47.24	41.33	39.36	35.43	29.52	23.62	19.68	17.71	11.81	5.90
1480	59.65	53.69	47.72	41.76	39.77	35.79	29.83	23.86	19.88	17.90	11.93	5.96
1500	60.26	54.23	48.20	42.18	40.17	36.15	30.13	24.10	20.08	18.08	12.05	6.02
1520	60.86	54.77	48.69	42.60	40.57	36.52	30.43	24.34	20.29	18.26	12.17	6.08
1540	61.46	55.31	49.17	43.02	40.97	36.88	30.73	24.58	20.49	18.44	12.29	6.14
1560	62.06	55.85	49.64	43.44	41.37	37.23	31.03	24.82	20.68	18.62	12.41	6.20
1580	62.65	56.39	50.12	43.86	41.77	37.59	31.32	25.06	20.88	18.80	12.53	6.25
1600	63.25	56.92	50.60	44.27	42.16	37.95	31.62	25.30	21.08	18.97	12.65	6.32
1620	63.84	57.45	51.07	44.69	42.56	38.30	31.92	25.54	21.28	19.15	12.77	6.38
1640	64.43	57.98	51.54	45.10	42.95	38.66	32.21	25.77	21.48	19.33	12.89	6.44
1660	65.02	58.51	52.01	45.51	43.34	39.01	32.51	26.01	21.67	19.50	13.00	6.50
1680	65.60	59.04	52.48	45.92	43.74	39.36	32.80	26.24	21.87	19.68	13.12	6.56
1700	66.19	59.57	52.95	46.33	44.12	39.71	33.09	26.48	22.06	19.86	13.24	6.62
1720	66.77	60.09	53.41	46.74	44.51	40.06	33.38	26.71	22.26	20.03	13.35	6.68
1740	67.35	60.62	53.88	47.15	44.90	40.41	33.68	26.94	22.45	20.21	13.47	6.75
1760	67.93	61.14	54.35	47.55	45.29	40.76	33.97	27.17	22.64	20.38	13.50	6.79
1780	68.51	61.66	54.81	47.96	45.67	41.11	34.26	27.40	22.84	20.55	13.70	6.85
1800	69.09	62.18	55.27	48.36	46.06	41.45	34.54	27.63	23.03	20.73	13.82	6.91
1820	69.66	62.70	55.73	48.76	46.44	41.80	34.83	27.86	23.22	20.90	13.93	6.97
1840	70.24	63.21	56.19	49.16	46.82	42.14	35.12	28.09	23.41	21.07	14.05	7.02
1860	70.81	63.73	56.65	49.56	47.20	42.48	35.40	28.32	23.60	21.24	14.16	7.08
1880	71.38	64.24	57.10	49.96	47.58	42.83	35.69	28.55	23.79	21.41	14.28	7.14
1900	71.95	64.75	57.56	50.36	47.96	43.17	35.97	28.79	23.98	21.58	14.39	7.19
1920	72.51	65.26	58.01	50.76	48.34	43.51	36.26	29.01	24.17	21.75	14.50	7.25
1940	73.08	65.77	58.46	51.16	48.72	43.85	36.54	29.23	24.36	21.92	14.62	7.31
1960	73.64	66.28	58.91	51.55	49.10	44.19	36.82	29.46	24.55	22.09	14.73	7.36
1980	74.21	66.79	59.36	51.94	49.47	44.52	37.10	29.68	24.74	22.26	14.84	7.42
2000	74.77	67.29	59.81	52.34	49.84	44.86	37.38	29.91	24.92	22.43	14.95	7.48

Recommended Upper Limit of Use

2020	75.35	67.82	60.28	52.75	50.23	45.21	37.68	30.14	25.12	22.61	15.07	7.54
2040	75.89	68.30	60.71	53.12	50.59	45.53	37.94	30.35	25.30	22.77	15.18	7.59
2060	76.44	68.80	61.15	53.51	50.96	45.87	38.22	30.58	25.48	22.93	15.29	7.64
2080	77.00	69.30	61.60	53.90	51.33	46.20	38.50	30.80	25.67	23.10	15.40	7.70
2100	77.55	69.80	62.04	54.29	51.70	46.53	38.78	31.02	25.85	23.27	15.51	7.76
2120	78.11	70.30	62.49	54.68	52.07	46.36	39.05	31.24	26.04	23.43	15.62	7.81

Table 7 Cont'd.

Note: For Equivalent Rainfall Rate of 1 in. per hour.

DRAINAGE AREA -A acres	AREA OF WATERWAY— a (sq. ft.) FOR C =											
	1.0	0.9	0.8	0.7	2/3	0.6	0.5	0.4	1/3	0.3	0.2	0.1
2140	78.66	70.79	62.93	55.06	52.44	47.20	39.33	31.46	26.22	23.60	15.73	7.87
2160	79.21	71.29	63.37	55.45	52.81	47.53	39.61	31.68	26.40	23.76	15.84	7.92
2180	79.76	71.78	63.81	55.83	53.17	47.86	39.88	31.90	26.59	23.93	15.95	7.98
2200	80.33	72.30	64.27	56.23	53.56	48.20	40.17	32.13	26.78	24.10	16.07	8.03
2220	80.85	72.77	64.68	56.60	53.90	48.51	40.43	32.34	26.95	24.26	16.17	8.09
2240	81.40	73.26	65.12	56.98	54.27	48.84	40.70	32.56	27.13	24.42	16.28	8.14
2260	81.94	73.75	65.56	57.36	54.63	49.17	40.97	32.78	27.31	24.58	16.39	8.19
2280	82.49	72.24	65.99	57.74	54.99	49.49	41.24	33.00	27.50	24.75	16.50	8.25
2300	83.03	74.73	66.42	58.12	55.35	49.82	41.52	33.21	27.68	24.91	16.61	8.30
2320	83.57	75.21	66.86	58.50	55.71	50.14	41.79	33.43	27.86	25.07	16.71	8.36
2340	84.11	75.70	67.29	58.88	56.07	50.47	42.06	33.64	28.04	25.23	16.82	8.41
2360	84.65	76.18	67.72	59.25	56.43	50.79	42.32	33.86	28.22	25.39	16.93	8.46
2380	85.19	76.67	68.15	59.63	56.79	51.11	42.59	34.07	28.40	25.56	17.04	8.52
2400	85.76	77.15	68.58	60.01	57.15	51.43	42.86	34.29	28.57	25.72	17.14	8.57
2420	86.26	77.63	69.01	60.38	57.51	51.76	43.13	34.50	28.75	25.88	17.25	8.63
2440	86.79	78.11	69.43	60.75	57.86	52.08	43.40	34.72	28.93	26.04	17.36	8.68
2460	87.33	78.59	69.86	61.13	58.22	52.40	43.66	34.93	29.11	26.20	17.47	8.73
2480	87.86	79.07	70.29	61.50	58.57	52.71	43.93	35.14	29.29	26.36	17.57	8.79
2500	88.39	79.55	70.71	61.87	58.93	53.03	44.19	35.36	29.46	26.52	17.68	8.84
2520	88.92	80.03	71.13	62.24	59.28	53.35	44.46	35.57	29.64	26.68	17.78	8.89
2540	89.45	80.50	71.56	62.61	59.63	53.67	44.72	35.78	29.82	26.83	17.89	8.94
2560	89.97	80.98	71.98	62.98	59.98	53.98	44.99	35.99	29.99	26.99	17.99	9.00
2580	90.50	81.45	72.40	63.35	60.03	54.30	45.25	36.20	30.17	27.15	18.10	9.05
2600	91.03	81.92	72.82	63.72	60.68	54.62	45.51	36.41	30.34	27.31	18.21	9.10
2620	91.55	82.40	73.24	64.09	61.03	54.93	45.78	36.62	30.52	27.47	18.31	9.16
2640	92.08	82.87	73.66	64.45	61.38	55.25	46.04	36.83	30.69	27.62	18.42	9.21
2660	92.60	83.34	74.08	64.82	61.73	55.56	46.30	37.04	30.87	27.78	18.52	9.26
2680	93.12	83.81	74.50	65.18	62.08	55.87	46.56	37.25	31.04	27.94	18.62	9.31
2700	93.64	84.28	74.91	65.55	62.43	56.18	46.82	37.46	31.21	28.09	18.73	9.36
2720	93.66	84.29	74.92	65.56	62.44	56.19	46.83	37.46	31.22	28.10	18.73	9.37
2740	93.71	84.34	74.97	65.59	62.47	56.22	46.85	37.48	31.24	28.11	18.74	9.37
2760	95.20	85.68	76.16	66.64	63.46	57.12	47.60	38.08	31.73	28.56	19.04	9.52
2780	95.71	86.14	76.57	67.00	63.81	57.43	47.86	38.29	31.90	28.71	19.14	9.57
2800	96.23	86.61	76.98	67.36	64.15	57.74	48.11	38.49	32.08	28.87	19.25	9.62
2820	96.74	87.07	77.40	67.72	64.50	58.05	48.37	38.70	32.25	29.02	19.35	9.67
2840	97.26	87.53	77.81	68.08	64.84	58.36	48.63	38.90	32.43	29.18	19.45	9.73
2860	97.77	87.99	78.22	68.44	65.18	58.66	48.89	39.11	32.59	29.33	19.55	9.78
2880	98.28	88.46	78.63	68.80	65.52	58.97	49.14	39.31	32.76	29.49	19.66	9.83
2900	98.80	88.92	79.04	69.16	65.86	59.28	49.40	39.52	32.93	29.64	19.76	9.88
2920	99.31	89.38	79.45	69.51	66.20	59.58	49.65	39.72	33.10	29.79	19.86	9.93
2940	99.82	89.83	79.85	69.87	66.54	59.89	49.91	39.93	33.27	29.94	19.96	9.98
2960	100.32	90.29	80.26	70.23	66.88	60.19	50.16	40.13	33.44	30.10	20.06	10.03
2980	100.83	90.75	80.67	70.58	67.22	60.50	50.42	40.33	33.61	30.25	20.17	10.08
3000	101.34	91.21	81.07	70.94	67.56	60.80	50.67	40.54	33.78	30.40	20.27	10.13
3020	101.85	91.66	81.48	71.29	67.90	61.11	50.92	40.74	33.95	30.55	20.37	10.18
3040	102.35	92.12	81.88	71.65	68.23	61.41	51.18	40.94	34.12	30.71	20.47	10.24
3060	102.86	92.57	82.29	72.00	68.57	61.71	51.43	41.14	34.29	30.86	20.57	10.29
3080	103.36	93.02	82.69	72.35	68.91	62.02	51.68	41.34	34.45	31.01	20.67	10.34
3100	103.86	93.48	83.09	72.70	69.24	62.32	51.93	41.55	34.62	31.16	20.77	10.39
3120	104.37	93.93	83.49	73.06	69.58	62.62	52.18	41.75	34.79	31.31	20.87	10.44
3140	104.87	94.38	83.89	73.41	69.91	62.92	52.43	41.95	34.96	31.46	20.97	10.49
3160	105.37	94.83	84.29	73.76	70.24	63.22	52.68	42.15	35.12	31.61	21.07	10.54
3180	105.87	95.28	84.69	74.11	70.58	63.52	52.93	42.35	35.29	31.76	21.17	10.59
3200	106.37	95.73	85.09	74.46	70.91	63.82	53.18	42.55	35.46	31.91	21.27	10.64
3220	106.86	96.18	85.49	74.80	71.24	64.12	53.43	42.75	35.65	32.06	21.37	10.69
3240	107.36	96.63	85.89	75.15	71.57	64.42	53.68	42.94	35.79	32.21	21.47	10.74
3260	107.86	97.07	86.29	75.50	71.91	64.71	53.93	43.14	35.95	32.36	21.57	10.79
3280	108.35	97.52	86.68	75.85	72.24	65.01	54.18	43.34	36.12	32.51	21.67	10.84
3300	108.85	98.05	87.08	76.19	72.57	65.31	54.42	43.54	36.28	32.65	21.77	10.88
3320	109.34	98.41	87.48	76.54	72.90	65.61	54.67	43.74	36.45	32.80	21.87	10.93
3340	109.84	98.85	87.87	76.89	73.22	65.90	54.92	43.93	36.62	32.95	21.97	10.98
3360	110.33	99.30	88.26	77.23	73.55	66.20	55.17	44.13	36.78	33.10	22.07	11.03
3380	110.82	99.74	88.66	77.58	73.88	66.55	55.46	44.33	36.94	33.28	22.16	11.08
3400	111.31	100.18	89.05	77.92	74.21	66.79	55.66	44.53	37.10	33.39	22.26	11.13
3420	111.80	100.62	89.44	78.26	74.54	67.08	55.90	44.72	37.27	33.54	22.36	11.18
3440	112.29	101.09	89.84	78.61	74.86	67.38	56.15	44.92	37.43	33.69	22.46	11.23
3460	112.78	101.51	90.23	78.95	75.19	67.67	56.39	45.11	37.59	33.84	22.56	11.28
3480	113.27	101.95	90.62	79.29	75.51	67.96	56.64	45.31	37.76	33.98	22.65	11.34
3500	113.76	102.47	91.01	79.63	75.84	68.26	56.88	45.50	37.92	34.13	22.75	11.38
3520	114.25	102.82	91.40	79.97	76.16	68.55	57.12	45.70	38.09	34.27	22.85	11.42
3540	114.73	103.26	91.79	80.31	76.49	68.84	57.37	45.89	38.24	34.45	22.95	11.47
3560	115.22	103.70	92.18	80.65	76.81	69.13	57.61	46.09	38.41	34.57	23.04	11.52

Table 7 Cont'd.

Note: For Equivalent Rainfall
Rate of 1 in. per hour.

DRAINAGE AREA -*A* acres	AREA OF WATERWAY— *a (sq. ft.)* FOR C = 1.0	0.9	0.8	0.7	2/3	0.6	0.5	0.4	1/3	0.3	0.2	0.1
3580	115.71	104.13	92.64	80.99	77.14	69.42	57.85	46.28	38.57	34.71	23.14	11.57
3600	116.19	104.57	92.95	81.33	77.46	69.71	58.09	46.48	38.73	34.86	23.24	11.62
3620	116.67	105.01	93.34	81.67	77.78	70.00	58.39	46.67	38.89	35.00	23.33	11.67
3640	117.16	105.44	93.73	82.01	78.10	70.29	58.58	46.86	39.05	35.15	23.43	11.72
3660	117.64	105.87	94.11	82.35	78.43	70.58	58.82	47.06	39.21	35.32	23.53	11.76
3680	118.12	106.31	94.50	82.68	78.75	70.87	59.06	47.25	39.37	35.44	23.62	11.81
3700	118.60	106.74	94.88	83.02	79.07	71.22	59.30	47.44	39.53	35.58	23.72	11.86
3720	119.08	107.17	95.27	83.36	79.39	71.45	59.54	47.63	39.69	35.72	23.82	11.91
3740	119.56	107.61	95.65	83.69	79.71	71.74	59.78	47.82	39.85	36.17	23.91	11.96
3760	120.04	108.04	96.03	84.03	80.05	72.02	60.02	48.02	40.01	36.01	24.01	12.00
3780	120.52	108.47	96.42	84.36	80.35	72.31	60.26	48.21	40.17	36.16	24.10	12.05
3800	121.00	108.90	96.80	84.70	80.66	72.60	60.50	48.40	40.33	36.30	24.20	12.10
3820	121.48	109.33	97.18	85.03	80.98	72.88	60.74	48.59	40.49	36.44	24.30	12.15
3840	121.95	109.76	97.56	85.37	81.30	73.17	60.98	48.78	40.65	36.58	24.39	12.20
3860	122.43	110.18	97.94	85.70	81.62	73.46	61.21	48.97	40.81	36.73	24.48	12.24
3880	122.90	110.61	98.32	86.03	81.94	73.74	61.45	49.16	40.97	36.87	24.58	12.29
3900	123.38	111.04	98.70	86.36	82.25	74.03	61.69	49.35	41.13	37.01	24.68	12.34
3920	123.85	111.47	99.08	86.70	82.57	74.31	61.93	49.54	41.28	37.16	24.77	12.38
3940	124.33	111.89	99.46	87.03	82.88	74.60	62.16	49.73	41.44	37.30	24.86	12.43
3960	124.80	112.32	99.84	87.36	83.20	74.88	62.40	49.92	41.60	37.44	24.96	12.48
3980	125.27	112.74	100.22	87.69	83.51	75.16	62.64	50.11	41.76	37.58	25.05	12.53
4000	125.74	113.17	100.59	88.02	83.83	75.45	62.87	50.30	41.91	37.72	25.15	12.57
4050	126.92	114.23	101.54	88.84	84.61	76.15	63.46	50.77	42.31	38.08	25.38	12.69
4100	128.09	115.28	102.48	89.66	85.40	76.86	64.05	51.24	42.70	38.43	25.62	12.81
4150	129.26	116.34	103.41	90.48	86.18	77.56	64.63	51.70	43.09	38.78	25.85	12.93
4200	130.43	117.39	104.34	91.30	86.95	78.26	65.22	52.17	43.48	39.13	26.09	13.04
4250	131.59	118.43	105.27	92.12	87.73	78.96	65.80	52.64	43.86	39.48	26.32	13.16
4300	132.75	119.48	106.20	92.93	88.50	79.65	66.38	53.10	44.25	39.82	26.55	13.28
4350	133.91	120.52	107.13	93.74	89.27	80.34	66.95	53.56	44.64	40.17	26.78	13.39
4400	135.06	121.55	108.05	94.54	90.04	81.04	67.53	54.02	45.02	40.52	27.01	13.51
4450	136.21	122.59	108.97	95.35	90.81	81.73	68.10	54.48	45.40	40.86	27.24	13.62
4500	137.36	123.62	109.88	96.15	91.57	82.41	68.68	54.94	45.78	41.21	27.47	13.74
4550	138.50	124.65	110.80	96.95	92.33	83.10	69.25	55.40	46.17	41.55	27.70	13.85
4600	139.64	125.68	111.71	97.75	93.09	84.78	69.82	55.86	46.55	41.89	27.93	13.96
4650	140.78	126.70	112.62	98.54	93.85	84.47	70.39	56.31	46.92	42.23	28.16	14.08
4700	141.91	127.72	113.53	99.34	94.61	85.15	70.96	56.76	47.30	42.57	28.38	14.19
4750	143.04	128.74	114.43	100.13	95.36	85.82	71.52	57.22	47.68	42.91	28.61	14.30
4800	144.17	129.75	115.34	100.92	96.11	86.50	72.08	57.67	48.06	43.25	28.83	14.42
4850	145.29	130.76	116.24	101.70	96.86	87.18	72.65	58.12	48.43	43.59	29.06	14.53
4900	146.42	131.77	117.13	102.49	97.61	87.85	73.21	58.57	48.80	43.92	29.28	14.64
4950	147.53	132.78	118.03	103.27	98.36	88.52	73.77	59.01	49.18	44.26	29.51	14.75
5000	148.65	133.78	118.92	104.06	99.10	89.19	74.32	59.46	49.55	44.60	29.73	14.86
5120	151.32	136.19	121.06	105.92	100.88	90.79	75.66	60.53	50.44	45.40	30.26	15.13
5440	158.61	142.75	126.89	111.02	105.74	95.16	79.30	63.44	52.87	47.58	31.72	15.80
5760	165.29	148.76	132.24	115.71	110.20	99.18	82.65	66.12	55.10	49.59	33.06	16.53
6080	172.13	154.92	137.71	120.49	114.76	103.28	86.07	68.85	57.38	51.64	34.43	17.21
6400	178.89	161.00	143.11	125.22	119.26	107.33	89.44	71.55	59.63	53.66	35.78	17.89
7040	192.14	172.93	153.71	134.50	128.09	115.28	96.07	76.86	64.05	57.64	38.43	19.21
7680	205.10	184.59	164.08	143.57	136.73	123.06	102.55	82.04	68.37	61.53	41.02	20.51
8320	217.79	196.01	174.23	152.45	145.19	130.67	108.89	87.11	72.60	65.34	43.56	21.78
8960	230.23	207.21	184.19	161.16	153.49	138.14	115.12	92.09	76.74	69.07	46.05	23.02
9600	242.46	218.22	193.97	169.72	161.64	145.48	121.23	96.98	80.82	72.74	48.49	24.25

Notes on Table 8:

Table 8 presents the calculated 24-hour rainfall for 9 selected stations for the period 1903-51. Note (in Table 8) that two average amounts are given for the selected return periods. One of these, the state average, is comprised of the arithmetic average with each station given a weight of one. The other, the state weighed average, was obtained by percentage weights assigned to polygons of the Thiessen Diagram shown in Fig. 11, Appendix A.

In the use of Table 8, the assumption is made that the Dickens Formula

$$Q = BM^{0.75}$$

where Q = peak discharge, c.f.s.
B = coefficient
and M = the drainage area in square miles

is true only for 6 inches of rainfall in 24 hours. Other workers have used 3, 4 or 5 inches in 24 hours as a base rainfall for this equation. The return period of 6 inches in a 24-hour duration for the state average is approximately 90 years; for the state weighed average, approximately 57 years. Both have the same return period relationship for a return period of approximately 1.18 years.

The coefficient (B) should be determined from recommended tabulated values (p. 27 of text), or calculated by a procedure similar to that shown in Table 3.

Table 8 - Calculated 24-Hour Rainfall For 9 First Order Stations (Based on Period of Record 1903-1951).

For Use With Dickens Formula

	Depth in Inches For 24-Hours For Various Return Periods					
Station	2	5	10	25	50	100
Cairo, Ill.	3.29	4.37	5.08	5.98	6.65	7.31
Cincinnati, Ohio	2.65	3.45	3.98	4.65	5.15	5.65
Evansville, Ind.	2.96	3.91	4.53	5.32	5.91	6.49
Knoxville, Tenn.	2.88	3.77	4.35	5.09	5.64	6.18
Lexington, Ky.	2.72	3.85	4.61	5.56	6.26	6.96
Louisville, Ky.	2.90	3.84	4.46	5.24	5.83	6.41
Nashville, Tenn.	3.09	3.83	4.32	4.94	5.40	5.85
Parkersburg, W. Va.	2.23	2.96	3.45	4.06	4.52	4.97
Wytheville, Va.	2.31	3.05	3.54	4.16	4.62	5.08
State Average	2.79	3.67	4.26	5.00	5.55	6.10
*Rainfall Factor	0.463	0.612	0.710	0.833	0.925	1.02
State Weighed Average	2.86	3.83	4.48	5.30	5.91	6.51
*Rainfall Factor	0.477	0.638	0.747	0.883	0.985	1.08

* "Rainfall Factor" equals inches per 24 hours for return period divided by 6 inches per 24 hours.

Notes on Table 9:

Following the principles laid down for the Dickens Formula under Notes on Table 8, a correction factor based on 24-hour rainfall must be applied to discharge values taken from Table 9 (This table is for 6 inches in 24 hours).

A rainfall factor must be employed to compensate for variation in rainfall from station to station. Since the selected base was 6 inches, all rainfall amounts must be divided by this value; the resultant ratio is then multiplied by the discharge (Q) from Table 9. This computation can be illustrated by the following example:

> Assume a drainage area of 50 sq. mi. and a coefficient of 375, in the Cairo Polygon, A-7 problem area (See Figs. 11 & 14). The design is to be based on a return period of 25 years. From Table 8, Appendix A, the rainfall for T = 25 is found to be 5.98 inches. The rainfall factor is computed as
>
> $$QF = \frac{5.98}{6.00} \quad \text{or approximately } 0.997$$
>
> From Table 9, under M = 50 and B = 375, a discharge value of 7051.1 c.f.s. is obtained. Then, by application of the formula
>
> $$Q_{design} = QF\ BM^{0.75}$$
>
> $$Q_{25} = (0.997)(7051.1)$$
> $$Q_{25} = 7,000 \text{ c.f.s. (ca)}$$

A balanced hydraulic design should be attempted. If 3 or more return periods are considered, they should plot in a straight line on extreme probability paper, Appendix C. An approximation of the return periods for other discharges (based on T = 25) can be made by application of the following return period factors (QF)* if only the Q_{25} is known:

$$QF = 0.3211 + 0.2126y$$

Where y is the reduced variate value selected from Table 10, Appendix D.

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* QF is the ratio between average peak discharges for selected return periods and will be referred to as returnperiod factors, ratios, etc., hereafter. The use of the prefix or suffix of discharge should not lead to an ambiguous interpretation since the magnitude of the return period is always implied.

Return Period, T =

2	5	10	25	50	100
Ratio* to 25-Year Return Period, QF =					
0.40	0.64	0.80	1.00	1.15	1.30

Example:

Given $Q_{25} = 7,000$ c.f.s., find Q_5 and Q_{100}

$Q_5 = Q_{25}\,(0.64)$

$= (7,000)\,(0.67)$

$Q_5 = 4,480$ c.f.s. (approx.)

and $Q_{100} = Q_{25}\,(1.30)$

$= (7,000)\,(1.30)$

$Q_{100} = 9,100$ c.f.s. (approx.)

It should be borne in mind that this procedure yields approximate values only (i.e., the actual values taken from a recent state wide study, for Q_5 and Q_{100} are 5100 and 8600 c.f.s. respectively). Considering the confidence limits for 68 in 100 times, the rainfall of 5.98 in. can vary plus or minus 0.74 in. The return period of T = 25 can thus vary from 12 to 52 years. The expected range of variation (68 in 100 times) is 8 to 78 years.

Table 9 is recommended for use in the range from 5 to 2,000 sq. miles, however, the version presented in this report does not exceed 700 sq. miles.

Since most of the annual peak discharges occur in the first four months of the year, it is therefore suggested that B = 375 (minimum) be employed in problem area A-7, and not less than 265 for B-16. Additional recommended values are given on page 27 in the text.

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* See footnote, page 8-A.

Table 9 Discharge Calculated By Dickens Formula And Based On An Equivalent Depth Of Rainfall Of 6 Inches In 24 Hours.

$Q = BM^{0.75}$

DRAINAGE AREA M sq. mi.	DISCHARGE — Q (cu. ft. per sec.) FOR B =								
	375	340	300	265	225	190	150	110	75
0.523	230.6	209.1	184.5	163.0	138.4	116.9	92.3	67.7	46.1
0.531	233.3	211.5	186.6	164.8	140.0	118.2	93.3	68.4	46.7
0.539	235.9	213.9	188.7	166.7	141.5	119.5	94.4	69.2	47.2
0.547	238.5	216.3	190.8	168.6	143.1	120.8	95.4	70.0	47.7
0.555	241.1	218.6	192.9	170.4	144.7	122.2	96.5	70.7	48.2
0.562	243.4	220.7	194.7	172.0	146.0	123.3	97.4	71.4	48.7
0.570	246.0	223.0	196.8	173.8	147.6	124.6	98.4	72.2	49.2
0.578	248.6	225.4	198.9	175.7	149.2	126.0	99.4	72.9	49.7
0.586	251.2	227.7	200.9	177.5	150.7	127.3	100.5	73.7	50.2
0.594	253.7	230.0	203.0	179.3	152.2	128.6	101.5	74.4	50.7
0.602	256.3	232.4	205.0	181.1	153.8	129.9	102.5	75.2	51.3
0.609	258.7	234.5	206.9	182.8	155.2	131.1	103.5	75.9	51.7
0.617	261.1	236.7	208.9	184.5	156.6	132.3	104.4	76.6	52.2
0.625	263.6	239.0	210.9	186.3	158.2	133.6	105.4	77.3	52.7
0.633	266.1	241.3	212.9	188.1	159.7	134.8	106.4	78.1	53.2
0.641	268.6	243.6	214.9	189.8	161.2	136.1	107.4	78.8	53.7
0.648	270.8	245.6	216.7	191.4	162.5	137.2	108.3	79.4	54.2
0.656	273.3	247.8	218.7	193.2	164.0	138.5	109.3	80.2	54.7
0.664	275.8	250.1	220.7	194.9	165.5	139.8	110.3	80.9	55.2
0.672	278.3	252.4	222.7	196.7	167.0	141.0	111.3	81.6	55.7
0.680	280.8	254.6	224.6	198.4	168.5	142.3	112.3	82.4	56.2
0.688	283.3	256.8	226.6	200.2	170.0	143.5	113.3	83.1	56.7
0.695	285.4	258.8	228.4	201.7	171.3	144.6	114.2	83.7	57.1
0.703	287.9	261.0	230.3	203.5	172.7	145.9	115.2	84.5	57.6
0.711	290.4	263.3	232.3	205.2	174.2	147.1	116.1	85.2	58.1
0.719	292.8	265.5	234.2	206.9	175.7	148.4	117.1	85.9	58.6
0.727	295.2	267.7	236.2	208.6	177.1	149.6	118.1	86.6	59.0
0.734	297.4	269.6	237.9	210.1	178.4	150.7	118.9	87.2	59.5
0.742	299.8	271.8	239.8	211.9	179.9	151.9	119.9	87.9	60.0
0.750	302.2	274.0	241.8	213.6	181.3	153.1	120.9	88.7	60.4
0.758	304.6	276.2	243.7	215.3	182.8	154.3	121.9	89.4	60.9
0.766	307.0	278.4	245.6	217.0	184.2	155.6	122.8	90.1	61.4
0.773	309.1	280.3	247.3	218.5	185.5	156.6	123.7	90.7	61.8
0.781	311.5	282.5	249.2	220.2	186.9	157.8	124.6	91.4	62.3
0.789	313.9	284.6	251.1	221.8	188.4	159.1	125.6	92.1	62.8
0.797	316.3	286.8	253.1	223.5	189.8	160.3	126.5	92.8	63.3
0.805	318.7	290.0	255.0	225.2	191.2	161.5	127.5	93.5	63.7
0.812	320.8	290.8	256.6	226.7	192.5	162.5	128.3	94.1	64.2
0.820	323.1	293.0	258.5	228.4	193.9	163.7	129.3	94.8	64.6
0.828	325.5	295.1	260.4	230.0	195.3	164.9	130.2	95.5	65.1
0.836	327.9	297.3	262.3	231.7	196.7	166.1	131.1	96.2	65.6
0.844	330.2	299.4	264.2	233.3	198.1	167.3	132.1	96.9	66.0
0.852	332.6	301.5	266.0	235.0	199.5	168.5	133.0	97.5	66.5
0.859	334.6	303.4	267.7	236.5	200.8	169.5	133.8	98.1	66.9
0.867	336.9	305.5	269.5	238.1	202.2	170.7	134.8	98.8	67.4
0.875	339.3	307.6	271.4	239.7	203.6	171.9	135.7	99.5	67.9
0.833	341.6	309.7	273.3	241.4	205.0	173.1	136.6	100.2	68.3
0.891	343.9	311.8	275.1	243.0	206.3	174.2	137.6	100.9	68.8
0.898	345.9	313.6	276.7	244.5	207.6	175.3	138.4	101.5	69.2
0.906	348.2	315.7	278.6	246.0	208.9	176.4	139.3	102.2	69.6
0.914	350.5	317.8	280.4	247.7	210.3	177.6	140.2	102.8	70.1
0.922	352.8	319.9	282.3	249.3	211.7	178.8	141.1	103.5	70.6
0.938	357.4	324.0	285.9	252.6	214.5	181.0	143.0	104.8	71.5
0.953	361.7	327.9	289.4	255.6	217.0	183.3	144.7	106.0	72.3
0.969	366.2	332.1	293.0	258.8	219.7	185.6	146.5	107.4	73.2
0.984	370.5	335.9	296.4	261.8	222.3	187.7	148.2	108.7	74.1
1.00	375.0	340.0	300.0	265.0	225.0	190.0	150.0	110.0	75.0
1.02	380.6	345.1	304.5	269.0	228.4	192.8	152.2	111.6	76.1
1.03	383.4	347.6	306.7	270.9	230.0	194.3	153.4	112.5	76.7
1.05	388.4	352.2	310.8	274.5	233.1	196.8	155.4	113.9	77.7
1.06	391.8	355.2	313.4	276.8	235.1	198.5	156.7	114.9	78.4
1.07	394.5	357.7	315.6	278.8	236.7	199.9	157.8	115.7	78.9
1.09	400.0	362.7	320.0	282.7	240.0	202.7	160.0	117.3	80.0
1.11	405.5	367.7	324.4	286.6	243.3	205.5	162.2	119.0	81.1
1.13	409.6	371.4	327.7	289.5	245.8	207.5	163.9	120.2	81.9
1.14	413.7	375.1	331.0	292.4	248.2	209.6	165.5	121.4	82.7
1.16	419.2	380.0	335.3	296.2	251.5	212.4	167.7	123.0	83.8

Table 9 Cont'd

DRAINAGE AREA -M sq. mi.	DISCHARGE — Q *(cu. ft. per sec.)* FOR B = 375	340	300	265	225	190	150	110	75
1.17	421.9	382.5	337.5	298.1	253.1	213.7	168.7	123.7	84.4
1.19	427.3	387.4	341.8	301.9	256.4	216.5	170.9	125.3	85.5
1.20	429.9	389.9	344.0	303.8	258.0	217.8	172.0	126.1	86.0
1.22	435.3	394.7	348.2	307.6	261.2	220.6	174.1	127.7	87.1
1.23	438.0	397.1	350.4	309.5	262.8	221.9	175.2	128.5	87.6
1.25	443.3	401.9	354.7	313.3	266.0	224.6	177.3	130.0	88.7
1.27	448.6	406.8	358.9	317.0	269.2	227.3	179.4	131.6	89.7
1.28	451.3	409.2	361.0	318.9	270.8	228.6	180.5	132.4	90.3
1.30	456.6	413.9	365.2	322.6	273.9	231.3	182.6	133.9	91.3
1.31	459.2	416.3	367.3	324.5	275.5	232.7	183.7	134.7	91.8
1.33	464.4	421.1	371.5	328.2	278.7	235.3	185.8	136.2	92.9
1.34	467.0	423.5	373.6	330.0	280.2	236.6	186.8	137.0	93.4
1.36	472.3	428.2	377.8	333.7	283.4	239.3	188.9	138.5	94.5
1.38	477.5	432.9	382.0	337.4	286.5	241.9	191.0	140.1	95.5
1.39	480.1	435.3	384.0	339.2	288.0	243.2	192.0	140.8	96.0
1.41	485.2	439.9	388.2	342.9	291.1	245.8	194.1	142.3	97.0
1.42	487.8	442.3	390.2	344.7	292.7	247.2	195.1	143.1	97.6
1.44	492.9	446.9	394.4	348.4	295.8	249.8	197.2	144.6	98.6
1.45	495.5	449.3	396.4	350.2	297.3	251.1	198.2	145.4	99.1
1.47	500.6	453.9	400.5	353.8	300.4	253.7	200.3	146.9	100.1
1.48	503.2	456.2	402.5	355.6	301.9	254.9	201.3	147.6	100.6
1.50	508.3	460.9	406.6	359.2	305.0	257.5	203.3	149.1	101.7
1.52	513.3	465.4	410.7	362.8	308.0	260.1	205.3	150.6	102.7
1.53	515.9	467.7	412.7	364.6	309.5	261.4	206.4	151.3	103.2
1.55	520.9	472.3	416.7	368.1	312.6	263.9	208.4	152.8	104.2
1.56	523.5	474.6	418.8	369.9	314.1	265.2	209.4	153.5	104.7
1.57	526.0	476.9	420.8	371.7	315.6	266.5	210.4	154.3	105.2
1.58	528.5	479.2	422.8	373.5	317.1	267.8	211.4	155.0	105.7
1.59	531.0	481.4	424.8	375.2	318.6	269.0	212.4	155.8	106.2
1.60	533.9	483.7	426.8	377.0	320.1	270.3	213.4	156.5	106.7
1.61	536.0	486.0	428.8	378.8	321.6	271.6	214.4	157.2	107.2
1.62	538.5	488.2	430.8	380.5	323.1	272.8	215.4	158.0	107.7
1.625	539.7	489.3	431.8	381.4	323.8	273.5	215.9	158.3	107.9
1.63	541.0	490.5	432.8	382.3	324.6	274.1	216.4	158.7	108.2
1.64	543.5	492.7	434.8	384.0	326.1	275.4	217.4	159.4	108.7
1.65	545.9	495.0	436.8	385.8	327.6	276.6	218.4	160.1	109.2
1.66	548.4	497.2	438.7	387.5	329.1	277.9	219.4	160.9	109.7
1.67	550.9	499.5	440.7	389.3	330.5	279.1	220.4	161.6	110.2
1.68	553.4	501.7	442.7	391.0	332.0	280.4	221.3	162.3	110.7
1.69	555.9	504.0	444.7	392.8	333.5	281.6	222.3	163.1	111.2
1.70	558.3	506.2	446.6	394.5	335.0	282.9	223.3	163.8	111.7
1.71	560.8	508.4	448.6	396.3	336.5	284.1	224.3	164.5	112.2
1.72	563.2	510.7	450.6	398.0	337.9	285.4	225.3	165.2	112.6
1.75	570.6	517.3	456.5	403.2	342.3	289.1	228.2	167.4	114.1
1.78	577.9	524.0	462.3	408.4	346.7	292.8	231.2	169.5	115.6
1.81	585.2	530.6	468.1	413.5	351.1	296.5	234.1	171.7	117.0
1.84	592.4	537.1	474.0	418.7	355.5	300.2	237.0	173.8	118.5
1.875	600.9	544.8	480.7	424.6	360.5	304.4	240.3	176.3	120.2
1.91	609.3	552.4	487.4	430.5	365.6	308.7	243.7	178.7	121.9
1.93	614.0	556.7	491.2	433.9	368.4	311.1	245.6	180.1	122.8
1.97	623.6	565.4	498.9	440.7	374.1	315.9	249.4	182.9	124.7
2.00	630.7	571.8	504.5	445.7	378.4	319.5	252.3	185.0	126.1
2.03	637.8	578.2	510.2	450.7	382.7	323.1	255.1	187.1	127.6
2.06	644.8	584.6	515.8	455.7	386.9	326.7	257.9	189.1	129.0
2.09	651.8	591.0	521.5	460.6	391.1	330.3	260.7	191.2	130.4
2.125	660.0	598.4	528.0	466.4	396.0	334.4	264.0	193.6	132.0
2.16	668.1	605.8	534.5	472.2	400.9	338.5	267.3	196.0	133.6
2.19	675.1	612.1	540.1	477.1	405.1	342.0	270.0	198.0	135.0
2.22	682.0	618.4	545.6	482.0	409.2	345.6	272.8	200.1	136.4
2.25	688.9	624.6	551.1	486.8	413.4	349.1	275.6	202.1	137.8
2.28	695.8	630.9	556.6	491.7	417.5	352.5	278.3	204.1	139.2
2.31	702.7	637.1	562.1	496.5	421.6	356.0	281.1	206.1	140.5
2.34	709.5	643.3	567.6	501.4	425.7	359.5	283.8	208.1	141.9
2.375	717.4	650.5	573.9	507.0	430.5	363.5	287.0	210.4	143.5
2.41	725.3	657.6	580.3	512.6	435.2	367.5	290.1	212.8	145.1
2.44	732.1	663.8	585.7	517.4	439.3	370.9	292.8	214.8	146.4
2.47	738.8	669.9	591.1	522.1	443.3	374.3	295.5	216.7	147.8
2.50	745.6	676.0	596.5	526.9	447.3	377.8	298.2	218.7	149.1
2.53	752.3	682.1	601.8	531.6	451.4	381.1	300.9	220.7	150.5
2.56	750.9	688.1	607.2	536.3	455.4	384.5	303.6	222.7	151.8
2.59	765.6	694.1	612.5	541.0	459.0	387.9	306.2	224.6	153.1
2.625	773.4	701.2	618.7	546.5	464.0	391.8	309.3	226.9	154.7

Table 9 Cont'd

DRAINAGE AREA M sq. mi.	DISCHARGE — Q (cu. ft. per sec.) FOR B = 375	340	300	265	225	190	150	110	75
2.66	781.1	708.2	624.9	552.0	468.6	395.7	312.4	229.1	156.2
2.69	786.7	714.2	630.1	556.6	472.6	399.1	315.1	231.1	157.5
2.72	794.3	720.1	635.4	561.3	476.5	402.4	317.7	233.0	158.8
2.75	800.8	726.1	640.6	565.9	480.5	405.7	320.3	234.9	160.2
2.78	807.4	732.0	645.9	570.5	484.4	409.1	322.9	236.8	161.5
2.81	813.9	737.9	651.1	575.1	488.3	412.4	325.6	238.7	162.8
2.84	820.4	743.8	656.3	579.7	492.9	415.7	328.2	240.6	164.1
2.88	829.0	751.7	663.2	585.9	497.4	420.0	331.6	243.2	165.8
2.91	835.5	757.5	668.4	590.4	501.3	423.3	334.2	245.1	167.1
2.94	842.0	763.5	673.6	595.0	505.2	426.6	336.8	247.0	168.4
2.97	848.4	769.2	678.7	599.5	509.0	429.8	339.4	248.9	169.7
3.00	854.8	775.1	683.9	604.1	512.9	433.1	341.9	250.8	171.0
3.03	861.2	780.8	689.0	608.6	516.7	436.4	344.5	252.6	172.2
3.06	867.6	786.6	694.1	613.1	520.6	439.6	347.0	254.5	173.5
3.09	874.0	792.4	699.2	617.6	524.4	442.8	349.6	256.4	174.8
3.125	881.4	799.1	705.1	622.9	528.8	446.6	352.6	258.5	176.3
3.16	888.8	805.8	711.0	628.1	533.3	450.3	355.5	260.7	177.8
3.19	895.1	811.6	716.1	632.5	537.1	453.5	358.0	262.6	179.0
3.22	901.4	817.3	721.1	637.0	540.8	456.7	360.6	264.4	180.3
3.25	907.7	823.0	726.2	641.4	544.6	459.9	363.1	266.2	181.5
3.28	914.0	828.7	731.2	645.9	548.4	463.1	365.6	268.1	182.8
3.31	920.2	834.4	736.2	650.3	552.1	466.3	368.1	269.9	184.0
3.34	926.5	840.0	741.2	654.7	556.0	469.4	370.6	271.8	185.3
3.375	933.8	846.6	747.0	659.9	560.3	473.1	373.5	273.9	186.8
3.41	941.0	853.2	752.8	665.0	564.6	476.8	376.4	276.0	188.2
3.44	947.2	858.8	757.8	669.4	568.3	479.9	378.9	277.9	189.4
3.47	953.4	864.4	762.7	673.7	572.0	483.0	381.4	279.7	190.7
3.50	959.6	870.0	767.7	678.1	575.8	486.2	383.8	281.5	191.9
3.53	965.7	875.6	772.6	682.5	579.4	489.3	386.3	283.3	193.1
3.56	971.9	881.2	777.5	686.8	583.1	492.4	388.8	285.1	194.4
3.59	978.0	886.7	782.4	691.1	586.8	495.5	391.2	286.9	195.6
3.625	985.2	893.2	788.1	696.2	591.1	499.1	394.1	289.0	197.0
3.66	992.3	899.7	793.8	701.2	595.4	502.8	396.9	291.1	198.5
3.69	998.4	905.2	798.7	705.5	599.0	505.8	399.4	292.9	199.7
3.72	1004.5	910.7	803.6	709.8	602.7	508.9	401.8	294.6	200.9
3.75	1010.5	916.2	808.4	714.1	606.3	512.0	404.2	296.4	202.1
3.78	1016.6	921.7	813.3	718.4	610.0	515.1	406.6	298.2	203.3
3.81	1022.6	927.2	818.1	722.7	613.6	518.1	409.1	300.0	204.5
3.84	1028.7	932.7	822.9	726.9	617.2	521.2	411.5	301.7	205.7
3.875	1035.7	939.0	828.6	731.9	621.4	524.8	414.3	303.8	207.1
3.91	1042.7	945.4	834.2	736.8	625.6	528.3	417.1	305.9	208.5
3.94	1048.7	950.8	839.0	741.1	629.2	531.3	419.5	307.6	209.7
3.97	1054.7	956.2	843.7	745.3	632.8	534.4	421.9	309.4	210.9
4.00	1060.7	961.7	848.5	749.5	636.4	537.4	424.3	311.1	212.1
4.03	1066.6	967.1	853.3	753.7	640.0	540.4	426.6	312.9	213.3
4.06	1072.6	972.5	858.1	758.0	643.5	543.4	429.0	314.6	214.5
4.09	1078.5	977.8	862.8	762.1	647.1	546.4	431.4	316.4	215.7
4.125	1085.4	984.1	868.3	767.0	651.3	549.9	434.2	318.4	217.1
4.16	1092.3	990.4	873.9	771.9	655.4	553.4	436.9	320.4	218.5
4.19	1098.2	995.7	878.6	776.1	658.9	556.4	439.3	322.1	219.6
4.22	1104.1	1001.1	883.3	780.2	662.5	559.4	441.6	323.9	220.8
4.25	1110.0	1006.4	888.0	784.4	666.0	562.4	444.0	325.6	222.0
4.28	1115.9	1011.7	892.7	788.5	669.5	565.4	446.3	327.3	223.2
4.31	1121.7	1017.0	897.4	792.7	673.0	568.3	448.7	329.0	224.3
4.34	1127.6	1022.3	902.1	796.8	676.5	571.3	451.0	330.8	225.5
4.375	1134.4	1028.5	907.5	801.6	680.6	574.8	453.8	332.8	226.9
4.41	1141.2	1034.7	913.0	806.4	684.7	578.2	456.5	334.8	228.2
4.44	1147.0	1040.0	917.6	810.6	688.2	581.1	458.8	336.5	229.4
4.47	1152.8	1045.2	922.2	814.7	691.7	584.1	461.1	338.2	230.6
4.50	1158.6	1050.5	926.9	818.8	695.2	587.0	463.4	339.9	231.7
4.53	1164.4	1055.7	931.5	822.8	698.6	590.0	465.8	341.6	232.9
4.56	1170.2	1061.0	936.1	826.9	702.1	592.9	468.1	343.3	234.0
4.59	1176.0	1066.2	940.8	831.0	705.6	595.8	470.4	344.9	235.2
4.625	1182.5	1072.1	946.0	835.6	709.5	599.1	473.0	346.9	236.5
4.66	1189.4	1078.4	951.5	840.5	713.6	602.6	475.8	348.9	237.9
4.69	1195.1	1083.6	956.1	844.5	717.1	605.5	478.0	350.6	239.0
4.72	1200.9	1088.8	960.7	848.6	720.5	608.4	480.3	352.2	240.2
4.75	1206.6	1094.0	965.3	852.6	723.9	611.3	482.6	353.9	241.3
4.78	1212.3	1099.1	969.8	856.7	727.4	614.2	484.9	355.6	242.5
4.81	1218.0	1104.3	974.4	860.7	730.8	617.1	487.2	357.3	243.6
4.84	1223.7	1109.5	978.9	864.7	734.2	620.0	489.5	358.9	244.7
4.875	1230.3	1115.5	984.2	869.4	738.2	623.4	492.1	360.9	246.1

Table 9 Cont'd

DRAINAGE AREA -M sq. mi.	DISCHARGE — Q *(cu. ft. per sec.)* FOR B =								
	375	340	300	265	225	190	150	110	75
4.91	1236.9	1121.5	989.5	874.1	742.2	626.7	494.8	362.8	247.4
4.94	1242.6	1126.6	994.1	878.1	745.6	629.6	497.0	364.5	248.5
4.97	1248.2	1131.7	998.6	882.1	748.9	632.4	499.3	366.1	249.6
Recommended Lower Limit of Use									
5.00	1253.9	1136.9	1003.1	886.1	752.3	635.3	501.6	367.8	250.8
5.03	1259.5	1142.0	1007.6	890.1	755.7	638.2	503.8	369.5	251.9
5.06	1265.2	1147.1	1012.1	894.0	759.1	641.0	506.1	371.1	253.0
5.09	1270.8	1152.2	1016.6	898.0	762.5	643.9	508.3	372.8	254.2
5.125	1277.3	1158.1	1021.9	902.6	766.4	647.2	510.9	374.7	255.5
5.16	1283.9	1164.0	1027.1	907.3	770.3	650.5	513.5	376.6	256.8
5.19	1289.5	1169.1	1031.6	911.2	773.7	653.3	515.8	378.2	257.9
5.22	1295.0	1174.2	1036.0	915.2	777.0	656.2	518.0	379.9	259.0
5.25	1300.6	1179.2	1040.5	919.1	780.4	659.0	520.2	381.5	260.1
5.28	1306.2	1184.3	1045.0	923.0	783.7	661.8	522.5	383.1	261.2
5.31	1311.8	1189.3	1049.4	927.0	787.1	664.6	524.7	384.8	262.4
5.34	1317.3	1194.4	1053.8	930.9	790.4	667.4	526.9	386.4	263.5
5.375	1323.8	1200.2	1059.0	935.5	794.3	670.7	529.5	388.3	264.8
5.41	1330.2	1206.1	1064.2	940.0	798.1	674.0	532.1	390.2	266.0
5.44	1335.8	1211.1	1068.6	943.9	801.5	676.8	534.3	391.8	267.2
5.47	1341.3	1216.1	1073.0	947.8	804.8	679.6	536.5	393.4	268.3
5.50	1346.8	1221.1	1077.4	951.7	808.1	682.4	538.7	395.1	269.4
5.53	1352.3	1226.1	1081.8	955.6	811.4	685.2	540.9	396.7	270.5
5.56	1357.8	1231.1	1086.2	959.5	814.7	688.0	543.1	398.3	271.6
5.59	1363.3	1236.1	1090.6	963.4	818.0	690.7	545.3	399.9	272.7
5.625	1369.7	1241.9	1095.8	967.9	821.8	694.0	547.9	401.8	273.9
5.66	1376.1	1247.6	1100.9	972.4	825.6	697.2	550.4	403.7	275.2
5.69	1381.5	1252.6	1105.2	976.3	828.9	700.0	552.6	405.3	276.3
5.72	1387.0	1257.6	1109.6	980.2	832.2	702.7	554.8	406.9	277.4
5.75	1392.5	1262.5	1114.0	984.0	835.5	705.5	557.0	408.5	278.5
5.78	1397.9	1267.4	1118.3	987.9	838.7	708.3	559.2	410.1	279.6
5.81	1403.3	1272.4	1122.7	991.7	842.0	711.0	561.3	411.6	280.7
5.84	1408.8	1277.3	1127.0	995.5	845.3	713.8	563.5	413.2	281.8
5.875	1415.1	1283.0	1132.1	1000.0	849.1	717.0	566.0	415.1	283.0
5.91	1421.4	1288.8	1137.1	1004.5	852.9	720.2	568.6	416.9	284.3
5.94	1426.8	1293.7	1141.5	1008.3	856.1	722.9	570.7	418.5	285.4
5.97	1432.2	1298.6	1145.8	1012.1	859.3	725.7	572.9	420.1	286.4
6.00	1437.6	1303.4	1150.1	1015.9	862.6	728.4	575.0	421.7	287.5
6.03	1443.0	1308.3	1154.4	1019.7	865.8	731.1	577.2	423.3	288.6
6.06	1448.4	1313.2	1158.7	1023.5	869.0	733.9	579.4	424.9	289.7
6.09	1453.8	1318.1	1163.0	1027.3	872.3	736.6	581.5	426.4	290.8
6.125	1460.0	1323.8	1168.0	1031.8	876.0	739.7	584.0	428.3	292.0
6.16	1466.3	1329.4	1173.0	1036.2	879.8	742.9	586.5	430.1	293.3
6.19	1471.6	1334.3	1177.3	1039.9	883.0	745.6	588.7	431.7	294.3
6.22	1477.0	1339.1	1181.6	1043.7	886.2	748.3	590.8	433.2	295.4
6.25	1482.3	1344.0	1185.9	1047.5	889.4	751.0	592.9	434.8	296.5
6.33	1496.5	1356.8	1197.2	1057.5	897.9	758.2	598.6	439.0	299.3
6.41	1510.7	1369.7	1208.5	1067.6	906.4	765.4	604.3	443.1	302.1
6.48	1523.0	1380.9	1218.4	1076.3	913.8	771.7	609.2	446.8	304.6
6.56	1537.1	1393.7	1229.7	1086.2	922.3	778.8	614.8	450.9	307.4
6.64	1551.2	1406.4	1241.0	1096.2	930.7	786.0	620.5	455.0	310.2
6.72	1565.2	1419.1	1252.1	1106.0	939.1	793.0	626.1	459.1	313.0
6.80	1579.1	1431.7	1263.3	1115.9	947.5	800.1	631.6	463.2	315.8
6.875	1592.2	1443.6	1273.7	1125.1	955.3	806.7	636.9	467.0	318.4
6.95	1605.2	1455.3	1284.1	1134.3	963.1	813.3	642.1	470.8	321.0
7.03	1619.0	1467.9	1295.2	1144.1	971.4	820.3	647.6	474.9	323.8
7.11	1632.8	1480.4	1306.2	1153.8	979.7	827.3	653.1	479.0	326.6
7.19	1646.6	1492.9	1317.2	1163.6	987.9	834.3	658.6	483.0	329.3
7.27	1660.3	1505.3	1328.2	1173.3	997.6	841.2	664.1	487.0	332.1
7.34	1672.3	1516.2	1337.8	1181.7	1003.4	847.3	668.9	490.5	334.5
7.42	1685.9	1528.6	1348.7	1191.4	1011.5	854.2	674.4	494.5	337.2
7.50	1699.5	1540.9	1359.6	1201.0	1019.7	861.1	679.8	498.5	339.9
7.58	1713.1	1553.2	1370.5	1210.6	1027.9	868.0	685.2	502.5	342.6
7.66	1726.6	1565.5	1381.3	1220.2	1036.0	874.8	690.7	506.5	345.3
7.73	1738.5	1576.2	1390.8	1228.5	1043.1	880.8	695.4	510.0	347.7
7.81	1751.9	1588.4	1401.6	1238.0	1051.2	887.6	700.8	513.9	350.4
8.00	1783.8	1617.3	1427.0	1260.6	1070.3	903.8	713.5	523.3	356.8
8.50	1866.8	1692.6	1493.4	1319.2	1120.1	945.8	746.7	547.6	373.4
9.00	1948.6	1766.7	1588.8	1377.0	1169.1	987.3	779.4	571.6	389.7

Table 9 Cont'd

DRAINAGE AREA -M	DISCHARGE — Q *(cu. ft. per sec.)* FOR B =								
sq. mi.	375	340	300	265	225	190	150	110	75
9.50	2029.2	1839.8	1623.4	1434.0	1217.5	1028.1	811.7	595.2	405.8
10.00	2108.8	1912.0	1687.0	1490.1	1265.3	1068.4	843.5	618.6	421.8
11.00	2265.0	2053.6	1812.0	1600.6	1359.0	1147.6	906.0	664.4	453.0
12.00	2417.8	2192.1	1934.2	1708.6	1450.7	1225.0	967.1	709.2	483.6
13.00	2567.4	2327.8	2053.9	1814.3	1540.4	1300.8	1026.9	753.1	513.5
14.00	2714.1	2460.8	2171.3	1918.0	1628.5	1375.1	1085.6	796.1	542.8
15.00	2858.2	2591.5	2286.6	2019.8	1714.9	1448.2	1143.3	838.4	571.6
16.00	3000.0	2720.0	2400.0	2120.0	1800.0	1520.0	1200.0	880.0	600.0
17.00	3139.6	2846.5	2511.6	2218.6	1883.7	1590.7	1255.8	920.9	627.9
18.00	3277.1	2971.2	2621.7	2315.8	1966.2	1660.4	1310.8	961.3	665.4
19.00	3412.7	3094.2	2730.2	2411.6	2047.6	1729.1	1365.1	1001.1	682.5
20.00	3546.5	3215.5	2837.2	2506.2	2127.9	1796.9	1418.6	1040.3	709.3
21.00	3678.7	3335.4	2943.0	2600.0	2207.2	1863.9	1471.5	1079.1	735.7
22.00	3809.3	3453.8	3047.5	2691.9	2285.6	1930.1	1523.7	1117.4	761.9
23.00	3938.5	3570.9	3150.8	2783.2	2363.1	1995.5	1575.4	1155.3	787.7
24.00	4066.2	3686.7	3253.0	2873.4	2439.7	2060.2	1626.5	1192.8	813.2
25.00	4192.6	3801.3	3354.0	2962.7	2515.5	2124.2	1677.0	1229.8	838.5
26.00	4317.8	3914.8	3454.2	3051.2	2590.7	2187.7	1727.1	1266.6	863.6
27.00	4441.8	4027.2	3553.4	3138.8	2665.1	2250.5	1776.7	1302.9	888.4
28.00	4564.6	4138.5	3651.7	3225.6	2738.7	2312.7	1825.8	1338.9	912.9
29.00	4686.3	4248.9	3749.0	3311.7	2811.8	2374.4	1874.5	1374.6	937.3
30.00	4806.9	4358.3	3845.5	3396.9	2884.1	2435.5	1922.7	1410.0	961.3
31.00	4926.7	4466.9	3941.3	3481.5	2956.0	2496.2	1970.7	1445.2	985.3
32.00	5045.4	4574.5	4036.3	3565.4	3027.2	2556.3	2018.2	1480.0	1009.1
33.00	5163.2	4681.3	4130.5	3648.7	3097.9	2616.0	2065.3	1514.5	1032.6
34.00	5280.1	4787.3	4224.1	3731.3	3168.0	2675.2	2112.0	1548.8	1056.0
35.00	5396.1	4892.4	4316.9	3813.2	3237.6	2734.0	2158.4	1582.8	1079.2
36.00	5511.3	4996.9	4409.1	3894.7	3306.8	2792.4	2204.5	1616.7	1102.3
37.00	5625.8	5100.7	4500.6	3975.6	3375.5	2850.4	2250.3	1650.2	1125.2
38.00	5739.4	5203.8	4591.6	4055.9	3443.7	2908.0	2295.8	1683.6	1147.9
39.00	5852.3	5306.1	4681.9	4135.6	3511.4	2965.2	2340.9	1616.7	1170.5
40.00	5964.5	5407.8	4771.6	4214.9	3578.7	3022.0	2385.8	1749.6	1192.9
41.00	6076.0	5508.9	4860.8	4293.7	3645.6	3078.5	2430.4	1782.3	1215.2
42.00	6186.8	5609.4	4949.5	4372.0	3712.1	3134.7	2474.7	1814.8	1237.4
43.00	6297.0	5709.3	5037.6	4449.9	3778.2	3190.5	2518.8	1847.1	1259.4
44.00	6406.5	5808.6	5125.2	4527.3	3843.9	3246.0	2562.6	1879.2	1281.3
45.00	6515.4	5907.2	5212.3	4604.2	3909.2	3301.1	2606.1	1911.2	1303.1
46.00	6623.7	6005.5	5299.0	4680.7	3974.2	3356.0	2649.5	1943.0	1324.7
47.00	6731.4	6103.1	5385.1	4756.9	4038.8	3410.6	2692.6	1974.5	1346.3
48.00	6838.5	6200.2	5470.8	4832.5	4103.1	3464.8	2735.4	2006.0	1367.7
49.00	6945.1	6296.9	5556.1	4907.9	4167.1	3518.9	2778.0	2037.2	1389.0
50.00	7051.1	6393.0	5640.9	4982.8	4230.7	3572.5	2820.4	2068.3	1410.2
51.00	7156.6	6488.7	5725.3	5057.4	4294.0	3626.0	2862.7	2099.3	1431.3
52.00	7261.6	6583.9	5809.3	5131.5	4357.0	3679.2	2904.6	2130.1	1452.3
53.00	7366.1	6678.6	5892.9	5205.4	4419.7	3732.2	2946.4	2160.7	1473.2
54.00	7470.1	6772.9	5976.1	5278.9	4482.1	3784.9	2988.0	2191.2	1494.0
55.00	7573.6	6866.7	6058.9	5352.0	4544.2	3837.2	3029.4	2221.6	1514.7
56.00	7676.7	6960.2	6141.3	5424.8	4606.0	3889.5	3070.7	2251.8	1535.3
57.00	7779.3	7053.2	6223.4	5497.3	4667.6	3941.5	3111.7	2281.9	1555.9
58.00	7880.2	7144.8	6304.2	5568.7	4728.1	3992.7	3152.1	2311.5	1576.0
59.00	7960.5	7217.5	6368.4	5625.4	4776.3	4033.3	3184.2	2335.1	1592.1
60.00	8084.3	7329.8	6467.5	5712.9	4850.6	4096.1	3233.7	2371.4	1616.9
61.00	8185.1	7421.2	6548.1	5784.2	4911.1	4147.1	3274.0	2401.0	1637.0
62.00	8285.6	7512.3	6628.5	5855.2	4971.4	4198.0	3314.2	2430.4	1657.1
63.00	8386.1	7603.4	6708.9	5926.2	5031.7	4249.0	3354.4	2459.9	1677.2
64.00	8485.1	7693.2	6788.1	5996.2	5091.1	4299.1	3394.0	2489.0	1697.0
65.00	8584.5	7783.3	6867.6	6066.4	5150.7	4349.5	3433.8	2518.1	1716.9
66.00	8683.5	7873.0	6946.8	6136.3	5210.1	4399.6	3473.4	2547.2	1736.7
67.00	8781.7	7962.1	7025.4	6205.8	5269.0	4449.4	3512.7	2576.0	1756.3
68.00	8880.0	8051.2	7104.0	6275.2	5328.0	4499.2	2552.0	2604.8	1776.0
69.00	8977.9	8139.9	7182.3	6344.4	5386.7	4548.8	3591.1	2633.5	1795.6
70.00	9075.2	8228.2	7260.1	6413.1	5445.1	4598.1	3630.1	2662.1	1815.0
71.00	9172.1	8316.1	7337.7	6481.6	5503.3	4647.2	3668.8	2690.5	1834.4
72.00	9265.1	8400.4	7412.1	6547.4	5559.1	4694.3	3706.0	2717.8	1853.0
73.00	9365.6	8491.5	7492.5	6618.4	5619.4	4745.2	3746.2	2747.2	1873.1
74.00	9461.2	8578.2	7569.0	6685.9	5676.7	4793.7	3784.5	2775.3	1892.2
75.00	9553.5	8661.8	7642.8	6751.1	5732.1	4840.4	3821.4	2802.4	1910.7
76.00	9652.5	8751.6	7722.0	6821.1	5791.5	4890.6	3861.0	2831.4	1930.5
77.00	9747.7	8838.0	7798.2	6888.4	5848.6	4938.9	3899.1	2859.3	1949.5
78.00	9842.2	8923.6	7873.8	6955.2	5905.3	4986.7	3936.9	2887.1	1968.4
79.00	9936.7	9009.3	7949.4	7022.0	5962.0	5034.6	3974.7	2914.8	1987.3

Table 9 Cont'd

DRAINAGE AREA -M sq. mi.	DISCHARGE — Q(cu. ft. per sec.) FOR B =								
	375	340	300	265	225	190	150	110	75
80.00	10031.1	9094.9	8024.9	7088.6	6018.7	5082.4	4012.4	2942.5	2006.2
81.00	10125.0	9180.0	8100.0	7155.0	6075.0	5130.0	4050.0	2970.0	2025.0
82.00	10218.7	9265.0	8175.0	7221.2	6131.2	5177.5	4087.5	2997.5	2043.7
83.00	10311.7	9349.3	8249.4	7287.0	6187.0	5224.6	4124.7	3024.8	2062.3
84.00	10405.1	9434.0	8324.1	7353.0	6243.1	5271.9	4162.0	3052.2	2081.0
85.00	10497.7	9518.0	8398.2	7418.4	6298.9	5318.9	4199.1	3079.3	2099.5
86.00	10590.4	9601.9	8472.3	7483.9	6354.2	5365.8	4236.1	3106.5	2118.1
87.00	10682.2	9685.2	8545.8	7548.8	6409.3	5412.3	4272.9	3133.5	2136.4
88.00	10774.5	9768.9	8619.6	7614.0	6464.7	5459.1	4309.8	3160.5	2154.9
89.00	10866.0	9851.8	8692.8	7678.6	6519.6	5505.4	4346.4	3187.4	2173.2
90.00	10957.5	9934.8	8766.0	7743.3	6574.5	5551.8	4383.0	3214.2	2191.5
91.00	11048.2	10017.1	8838.6	7807.4	6628.9	5597.8	4419.3	3240.8	2209.6
92.00	11139.7	10100.0	8911.8	7872.1	6683.8	5644.1	4455.9	3267.7	2227.9
93.00	11230.5	10182.3	8984.4	7932.6	6738.3	5690.1	4492.2	3294.2	2246.1
94.00	11320.9	10264.3	9056.7	8000.1	6792.5	5735.9	4528.3	3320.8	2264.2
95.00	11410.9	10345.9	9128.7	8063.7	6846.5	5781.5	4564.3	3347.2	2282.2
96.00	11500.9	10427.5	9200.7	8127.3	6900.5	5827.1	4600.3	3373.6	2300.2
97.00	11590.5	10508.7	9272.4	8190.6	6954.3	5872.5	4636.2	3399.9	2318.1
98.00	11680.1	10590.0	9344.1	8254.0	7008.1	5917.9	4672.0	3426.2	2336.0
99.00	11769.4	10670.9	9415.5	8317.0	7061.6	5963.1	4707.7	3452.3	2353.9
100.00	11858.5	10751.7	9486.8	8380.0	7115.1	6008.3	4743.4	3478.5	2371.7
101.00	11947.1	10832.1	9557.7	8442.6	7168.3	6053.2	4778.8	3504.5	2389.4
102.00	12036.0	10912.6	9628.8	8505.4	7221.6	6098.2	4814.4	3530.6	2407.2
103.00	12124.5	10992.9	9699.6	8568.0	7274.7	6143.1	4849.8	3556.5	2424.9
104.00	12212.6	11072.8	9770.1	8630.3	7327.6	6187.7	4885.0	3582.4	2442.5
105.00	12300.4	11152.3	9840.3	8692.3	7380.2	6232.2	4920.1	3608.1	2460.1
106.00	12388.1	11231.9	9910.5	8754.3	7432.9	6276.6	4955.2	3633.8	2477.6
107.00	12475.9	11311.5	9980.7	8816.3	7485.5	6321.1	4990.3	3659.6	2495.2
108.00	12563.2	11390.7	10050.6	8878.0	7537.9	6365.4	5025.3	3685.2	2512.6
109.00	12650.2	11469.6	10120.2	8939.5	7590.1	6409.5	5060.1	3710.7	2530.0
110.00	12737.2	11548.4	10189.8	9001.0	7642.3	6453.5	5094.9	3736.3	2547.4
111.00	12823.9	11627.0	10259.1	9062.2	7694.3	6497.4	5129.5	3761.7	2564.8
112.00	12910.5	11705.5	10328.4	9123.4	7746.3	6541.3	5164.2	3787.1	2582.1
113.00	12996.7	11783.7	10397.4	9184.3	7798.0	6585.0	5198.7	3812.4	2599.3
114.00	13083.0	11861.9	10466.4	9245.3	7849.8	6628.7	5233.2	3837.7	2616.6
115.00	13169.2	11940.1	10535.4	9306.3	7901.5	6672.4	5267.7	3863.0	2633.8
116.00	13254.7	12017.6	10603.8	9366.7	7952.8	6715.7	5301.9	3888.1	2650.9
117.00	13340.2	12095.2	10672.2	9427.1	8004.1	6759.1	5336.1	3913.1	2668.1
118.00	13425.7	12172.7	10740.6	9487.5	8055.4	6802.4	5370.3	3938.2	2685.1
119.00	13511.2	12250.2	10809.0	9547.9	8106.7	6845.7	5404.5	3963.3	2702.2
120.00	13596.4	12327.4	10877.1	9608.1	8157.8	6888.8	5438.5	3988.3	2719.3
121.00	13681.1	12404.2	10944.9	9668.0	8208.7	6931.8	5472.5	4013.1	2736.2
122.00	13765.9	12481.1	11012.7	9727.9	8259.5	6974.7	5506.3	4038.0	2753.2
123.00	13850.2	12557.6	11080.2	9787.5	8310.1	7017.5	5540.1	4062.7	2770.0
124.00	13934.6	12634.1	11147.7	9847.1	8360.8	7060.2	5573.8	4087.5	2786.9
125.00	14018.9	12710.4	11215.1	9906.7	8411.3	7102.9	5607.6	4112.2	2803.8
126.00	14103.0	12786.7	11282.4	9966.1	8461.8	7145.5	5641.2	4136.9	2820.6
127.00	14187.0	12862.9	11349.6	10025.5	8512.2	7188.1	5674.8	4161.5	2837.4
128.00	14270.6	12938.7	11416.5	10084.6	8562.4	7230.4	5708.2	4186.0	2854.1
129.00	14353.5	13013.8	11482.8	10143.1	8612.1	7272.4	5741.4	4210.4	2870.7
130.00	14437.5	13090.0	11550.0	10202.5	8662.5	7315.0	5775.0	4235.0	2887.5
131.00	14520.7	13165.5	11616.6	10261.3	8712.4	7357.2	5808.3	4259.4	2904.1
132.00	14603.6	13240.6	11682.9	10319.9	8762.2	7399.2	5841.4	4283.7	2920.7
133.00	14686.5	13315.8	11749.2	10378.5	8811.9	7441.2	5874.6	4308.0	2937.3
134.00	14769.4	13390.9	11815.5	10437.0	8861.6	7483.1	5907.7	4332.3	2953.9
135.00	14851.9	13465.7	11881.5	10495.3	8911.1	7524.9	5940.7	4356.5	2970.4
136.00	14934.4	13540.5	11947.5	10553.6	8960.6	7566.7	5973.7	4380.7	2986.9
137.00	15016.5	13615.0	12013.2	10611.7	9009.9	7608.3	6006.6	4404.8	3003.3
138.00	15098.6	13689.4	12078.9	10669.7	9059.2	7650.0	6039.4	4428.9	3019.7
139.00	15180.7	13763.9	12144.6	10727.7	9108.4	7691.6	6072.3	4453.0	3036.3
140.00	15262.5	13838.0	12210.0	10785.5	9157.5	7733.0	6105.0	4477.0	3052.5
141.00	15344.2	13912.1	12275.4	10843.3	9206.6	7774.4	6137.7	4501.0	3068.8
142.00	15425.6	13985.9	12340.5	10900.8	9255.4	7815.6	6170.2	4524.8	3085.1
143.00	15507.4	14060.0	12405.9	10958.5	9304.4	7857.1	6202.9	4548.8	3101.5
144.00	15588.4	14133.5	12470.7	11015.8	9353.0	7898.1	6235.3	4572.6	3117.7
145.00	15669.7	14207.2	12535.8	11073.3	9401.8	7939.3	6267.9	4596.5	3133.9
146.00	15750.4	14280.3	12600.3	11130.3	9450.2	7980.2	6300.1	4620.1	3150.1
147.00	15831.4	14353.8	12665.1	11187.5	9498.8	8021.2	6332.5	4643.9	3166.3
148.00	15912.0	14426.9	12729.6	11244.5	9547.2	8062.1	6364.8	4667.5	3182.4
149.00	15992.0	14500.0	12744.1	11301.5	9595.6	8102.9	6397.0	4691.2	3198.5
150.00	16073.1	14572.9	12858.5	11358.3	9643.8	8143.7	6429.2	4714.8	3214.6
151.00	16153.5	14645.8	12922.8	11415.1	9692.1	8184.4	6461.4	4738.4	3230.7

Table 9 Cont'd

DRAINAGE AREA	DISCHARGE — Q(cu. ft. per sec.) FOR B =								
-M sq. mi.	375	340	300	265	225	190	150	110	75
152.00	16233.8	14718.6	12987.0	11471.9	9740.3	8225.1	6493.5	4761.9	3246.7
153.00	16313.3	14790.7	13050.6	11528.0	9787.9	8265.4	6525.3	4785.2	3262.7
154.00	16393.5	14863.4	13114.8	11584.7	9836.1	8306.0	6557.4	4808.8	3278.7
155.00	16473.4	14935.9	13178.7	11641.2	9884.0	8346.5	6589.4	4832.2	3294.7
156.00	16552.9	15007.9	13242.3	11697.4	9931.7	8386.8	6621.2	4855.5	3310.5
157.00	16632.0	15079.7	13305.6	11753.3	9979.2	8426.9	6652.8	4878.7	3326.4
158.00	16711.9	15152.1	13369.5	11809.7	10027.1	8467.4	6684.8	4902.2	3342.4
159.00	16791.0	15223.8	13432.8	11865.6	10074.6	8507.4	6716.4	4925.4	3358.2
160.00	16870.1	15295.6	13496.1	11921.6	10122.1	8547.5	6748.1	4948.6	3374.0
161.00	16949.3	15367.3	13559.4	11977.5	10169.6	8587.6	6779.7	4971.8	3389.9
162.00	17028.4	15439.1	13622.7	12033.4	10217.0	8627.7	6811.4	4995.0	3405.7
163.00	17107.1	15510.5	13685.7	12089.0	10264.3	8667.6	6842.9	5018.1	3421.4
164.00	17185.5	15581.5	13748.4	12144.4	10311.3	8707.3	6874.2	5041.1	3437.1
165.00	17256.4	15645.8	13805.1	12199.5	10353.8	8743.2	6902.6	5061.9	3451.3
166.00	17342.6	15724.0	13874.1	12255.5	10405.6	8787.0	6937.0	5087.2	3468.5
167.00	17421.0	15795.0	13936.8	12310.8	10452.6	8826.6	6968.4	5110.2	3484.2
168.00	17499.0	15865.8	13999.2	12366.0	10499.4	8866.2	6999.6	5133.0	3499.8
169.00	17577.0	15936.5	14061.6	12421.1	10546.2	8905.7	7030.8	5155.9	3515.4
170.00	17655.0	16007.2	14124.0	12476.2	10593.0	8945.1	7062.0	5178.8	3531.0
171.00	17733.0	16077.9	14186.4	12531.3	10639.8	8984.7	7093.2	5201.7	3546.6
172.00	17810.6	16148.3	14248.5	12566.2	10686.4	9024.0	7124.2	5224.4	3562.1
173.00	17888.2	16218.7	14310.6	12641.0	10732.9	9063.4	7155.3	5247.2	3577.6
174.00	17965.5	16288.7	14372.4	12695.6	10779.3	9102.5	7186.2	5269.9	3593.1
175.00	18043.0	16359.0	14434.4	12750.3	10825.8	9141.7	7217.2	5292.6	3608.6
176.00	18120.4	16429.1	14496.3	12805.1	10872.2	9181.0	7248.1	5315.3	3624.1
177.00	18197.6	16499.2	14558.1	12859.7	10918.6	9220.1	7279.0	5338.0	3639.5
178.00	18274.5	16568.9	14619.6	12914.0	10964.7	9259.1	7309.8	5360.5	3654.9
179.00	18351.4	16638.6	14681.1	12968.3	11010.8	9298.0	7340.5	5383.1	3670.3
180.00	18428.2	16708.3	14742.6	13022.6	11056.9	9337.0	7371.3	5405.6	3685.6
181.00	18505.1	16778.0	14804.1	13077.0	11103.1	9375.9	7402.0	5428.2	3701.0
182.00	18581.6	16847.3	14865.3	13131.0	11149.0	9414.7	7432.6	5450.6	3716.3
183.00	18658.1	16916.7	14926.5	13185.1	11194.9	9453.5	7463.3	5473.1	3731.6
184.00	18734.6	16986.1	14987.7	13239.1	11240.8	9492.2	7493.9	5495.5	3746.9
185.00	18810.8	17055.1	15048.6	13292.9	11286.5	9530.8	7524.3	5517.8	3762.2
186.00	18887.3	17124.4	15109.8	13347.0	11332.4	9569.5	7554.9	5540.3	3777.5
187.00	18963.4	17193.5	15170.7	13400.8	11378.0	9608.1	7585.4	5562.6	3792.7
188.00	19039.1	17262.1	15231.3	13454.3	11423.5	9646.5	7615.7	5584.8	3807.8
189.00	19115.3	17331.2	15292.2	13508.1	11469.2	9685.1	7646.1	5607.1	3823.1
190.00	19191.0	17399.8	15352.8	13561.6	11514.6	9723.4	7676.4	5629.4	3838.2
191,00	19266.8	17468.5	15413.4	13615.2	11560.1	9761.8	7706.7	5651.6	3853.4
192.00	19342.1	17536.9	15473.7	13668.4	11605.3	9800.0	7736.9	5673.7	3868.4
193.00	19417.9	17605.5	15534.3	13722.0	11650.7	9838.4	7767.2	5695.9	3883.6
194.00	19493.3	17673.9	15614.6	13775.2	11696.0	9876.6	7797.3	5718.0	3898.7
195.00	19568.6	17742.2	15654.9	13828.5	11741.2	9914.8	7827.5	5740.1	3913.7
196.00	19643.6	17810.2	15714.9	13881.5	11786.2	9952.8	7857.5	5762.1	3928.7
197.00	19719.0	17878.6	15775.2	13934.8	11831.4	9991.0	7887.6	5784.2	3943.8
198.00	19794.0	17946.6	15835.2	13987.8	11876.4	10029.0	7917.6	5806.2	3958.8
199.00	19868.6	18014.2	15894.9	14040.5	11921.2	10066.8	7947.5	5828.1	3973.7
200.00	19943.6	18082.2	15954.8	14093.5	11966.2	10104.7	7977.4	5850.1	3988.7
205.00	20316.4	18420.2	16253.1	14356.9	12189.8	10293.6	8126.6	5959.5	4063.3
210.00	20686.9	18756.1	16549.5	14618.7	12412.1	10481.4	8274.8	6068.2	4137.4
215.00	21055.1	19090.0	16844.1	14879.0	12633.1	10667.9	8422.1	6176.2	4211.0
220.00	21421.5	19422.2	17137.2	15137.9	12852.9	10853.6	8568.6	6283.6	4284.3
225.00	21785.6	19752.3	17428.5	15395.2	13071.4	11038.1	8714.3	6390.5	4357.1
230.00	22147.5	20080.4	17718.0	15650.9	13288.5	11221.4	8859.0	6496.6	4429.5
235.00	22507.9	20407.1	18006.3	15905.6	13504.7	11404.0	9003.2	6602.3	4501.6
240.00	22866.0	20731.8	18292.8	16158.6	13719.6	11585.4	8146.4	6707.4	4573.2
245.00	23222.3	21054.8	18577.8	16410.4	13933.4	11765.9	9288.9	6811.9	4644.5
250.00	23577.0	21376.5	18861.6	16661.1	14146.2	11945.7	9430.8	6915.9	4715.4
255.00	23929.5	21696.1	19143.6	16910.2	14357.7	12124.3	9571.8	7019.3	4785.9
260.00	24280.9	22014.7	19424.7	17158.5	14568.5	12302.3	9712.4	7122.4	4856.2
265.00	24687.0	22382.9	19749.6	17445.5	14812.2	12479.2	9874.8	7241.5	4937.4
270.00	24977.6	22646.4	19982.1	17650.9	14986.6	12655.3	9991.1	7326.8	4995.5
275.00	25323.8	22960.2	20259.0	17895.5	15194.3	12830.7	10129.5	7428.3	5064.8
280.00	25668.4	23272.7	20534.7	18139.0	15401.0	13005.3	10267.4	7529.4	5133.7
285.00	26011.5	23583.8	20809.2	18381.5	15606.9	13179.2	10404.6	7630.0	5202.3
290.00	26353.1	23893.5	21082.5	18622.9	15811.9	13352.3	10541.3	7730.3	5270.6
295.00	26692.9	24201.5	21354.3	18863.0	16015.7	13524.4	10677.2	7829.9	5338.6
300.00	27031.9	24508.9	21625.5	19102.5	16219.1	13696.2	10812.8	7929.4	5406.4
305.00	27369.0	24814.6	21895.2	19340.8	16421.4	13867.0	10947.6	8028.2	5473.8
310.00	27704.6	25118.9	22162.7	19577.9	16622.8	14037.0	11081.9	8126.7	5540.9
315.00	28039.1	25422.1	22431.3	19814.3	16823.5	14206.5	11215.7	8224.8	5607.8

Table 9 Cont'd

DRAINAGE AREA -M sq. mi.	DISCHARGE — Q(cu. ft. per sec.) FOR B =								
	375	340	300	265	225	190	150	110	75
320.00	28372.1	25724.1	22697.7	20049.6	17023.3	14375.2	11348.9	8322.5	5674.4
325.00	28704.0	26025.0	22963.2	20284.2	17222.4	14543.4	11481.6	8419.8	5740.8
330.00	29034.7	26324.8	23227.8	20517.9	17420.8	14710.9	11613.9	8516.8	5806.9
335.00	29364.0	26623.4	23491.2	20750.6	17618.4	14877.8	11745.6	8613.4	5872.8
340.00	29692.1	26920.9	23753.7	20982.4	17815.3	15044.0	11876.8	8709.7	5938.4
345.00	30019.1	27217.3	24015.3	21213.5	18011.5	15209.7	12007.6	8805.6	6003.8
350.00	30344.6	27512.5	24275.7	21433.5	18206.8	15374.6	12137.8	8901.1	6068.9
355.00	30669.4	27806.9	24535.5	21673.0	18401.6	15539.1	12267.7	8996.3	6133.9
360.00	30992.6	28100.0	24794.1	21901.5	18595.6	15702.9	12397.0	9091.2	6198.5
365.00	31314.7	28392.0	25051.8	22129.1	18788.8	15866.1	12525.9	9185.7	6262.9
370.00	31636.1	28683.4	25308.9	22356.2	18981.7	16029.0	12654.4	9279.9	6327.2
375.00	31956.0	28973.4	25564.8	22582.2	19173.6	16191.0	12782.4	9373.8	6391.2
380.00	32275.1	29262.8	25820.1	22807.7	19365.1	16352.7	12919.0	9467.4	6455.0
385.00	32593.1	29551.1	26074.5	23032.5	19555.9	16513.8	13037.2	9560.6	6518.6
390.00	32910.0	29838.4	26328.0	23256.4	19746.0	16674.4	13164.0	9653.6	6582.0
395.00	33226.1	30125.0	26580.9	23479.8	19935.7	16834.6	13290.4	9746.3	6645.2
400.00	33541.1	30410.6	26832.9	23702.4	20124.7	16994.2	13416.4	9838.7	6708.2
405.00	33855.0	30695.2	27084.0	23924.2	20313.0	17153.2	13542.0	9930.8	6771.0
410.00	34168.1	30979.1	27334.5	24145.5	20500.9	17311.8	13667.2	10022.6	6833.6
415.00	34480.1	31262.0	27584.1	24366.0	20688.1	17469.9	13792.0	10114.2	6896.0
420.00	34791.0	31543.8	27832.8	24585.6	20874.6	17627.4	13916.4	10205.4	6958.2
425.00	35101.1	31825.0	28080.9	24804.8	21060.7	17784.6	14040.4	10296.3	7020.2
430.00	35410.5	32105.5	28328.4	25023.4	21246.3	17941.3	14164.2	10387.1	7082.1
435.00	35718.7	32385.0	28575.0	25241.2	21431.2	18097.5	14287.5	10477.5	7143.7
440.00	36026.2	32663.8	28821.0	25458.6	21615.8	18253.3	14410.5	10567.7	7205.2
445.00	36333.0	32941.9	29066.4	25675.3	21799.8	18408.7	14533.2	10657.7	7266.6
450.00	36638.6	33219.0	29310.9	25891.3	21983.2	18563.6	14655.4	10747.3	7327.7
455.00	36943.5	33495.4	29554.8	26106.7	22166.1	18718.0	14777.4	10836.8	7388.7
460.00	37247.6	33771.1	29798.1	26321.7	22348.6	18872.1	14899.0	10926.0	7449.5
465.00	37552.5	34047.6	30042.0	26537.1	22531.5	19026.6	15021.0	11015.4	7510.5
470.00	37852.5	34319.6	30282.0	26749.1	22711.5	19178.6	15141.0	11103.4	7570.5
475.00	38156.2	34595.0	30525.0	26963.8	22893.8	19332.5	15262.5	11192.5	7631.2
480.00	38456.2	34867.0	30765.0	27175.8	23073.8	19484.5	15382.5	11280.5	7691.2
485.00	38756.2	35139.0	31005.0	27387.7	23253.8	19636.5	15502.5	11368.5	7751.2
490.00	39056.2	35411.0	31245.0	27599.8	23433.8	19788.5	15622.5	11456.5	7811.2
495.00	39352.5	35679.6	31482.0	27809.1	23611.5	19938.6	15741.0	11543.4	7870.5
500.00	39652.5	35952.6	31722.0	28021.1	23791.5	20090.6	15861.0	11631.4	7930.5
510.00	40245.0	36488.8	32196.0	28439.8	24147.0	20394.8	16098.0	11805.2	8049.0
520.00	40833.8	37022.6	32667.0	28855.8	24500.3	20689.1	16333.5	11977.9	8166.8
530.00	41422.5	37556.4	33138.0	29271.9	24853.5	20987.4	16569.0	12150.6	8284.5
540.00	42007.5	38086.8	33606.0	29685.3	25204.5	21283.8	16803.0	12322.2	8401.5
550.00	42588.8	38613.8	34071.0	30096.0	25553.2	21578.3	17035.5	12492.7	8517.8
560.00	43170.0	39140.8	34536.0	30506.8	25902.0	21872.8	17268.0	12663.2	8634.0
570.00	43747.5	39664.4	34998.0	30914.9	26248.5	22165.4	17499.0	12832.6	8749.5
580.00	44321.3	40184.6	35457.0	31320.4	26592.8	22456.1	17728.5	13000.9	8864.3
590.00	44891.3	40701.4	35913.0	31723.2	26934.8	22744.9	17956.5	13168.1	8978.3
600.00	45461.3	41218.2	36369.0	32126.0	27276.8	23033.7	18184.5	13331.5	9092.3
610.00	46027.5	41731.6	36822.0	32526.1	27616.5	23320.6	18411.0	13501.4	9205.5
620.00	46593.8	42245.0	37275.0	32926.3	27956.3	23607.5	18637.5	13667.5	9318.8
630.00	47156.3	42755.0	37725.0	33323.8	28293.8	23892.5	18862.5	13832.5	9431.3
640.00	47715.0	43261.6	38172.0	33718.6	28629.0	24175.6	19086.0	13996.4	9543.0
650.00	48273.8	43768.2	38619.0	34113.5	28964.3	24458.7	19309.5	14160.3	9654.8
660.00	48828.8	44271.4	39063.0	34505.7	29297.3	24739.9	19531.5	14323.1	9765.8
670.00	49383.8	44774.6	39507.0	34897.9	29630.3	25021.1	19753.5	14485.9	9876.8
680.00	49935.0	45274.4	39948.0	35287.4	29961.0	25300.4	19974.0	14647.6	9987.0
690.00	50486.3	45774.2	40389.0	35677.0	30291.8	25579.7	20194.5	14809.3	10097.3
700.00	51033.8	46270.6	40827.0	36063.9	30620.3	25857.1	20413.5	14969.9	10206.8

Table May Be Extended to 2,000 sq. mi. area

APPENDIX B

MAJOR SOIL PROBLEM AREAS IN KENTUCKY

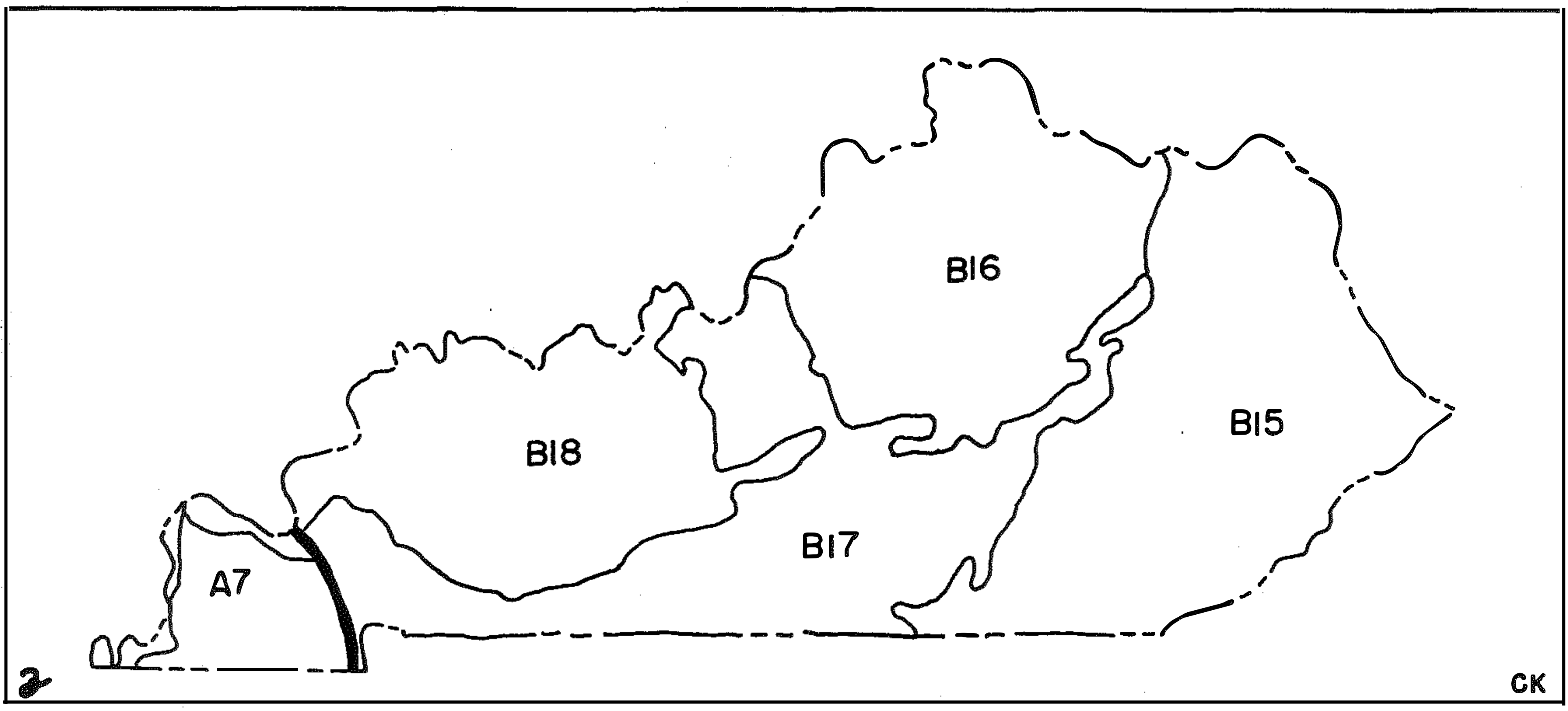

Fig. 14 - Major Problem Areas in Physiographic Regions in Kentucky

DESCRIPTIONS OF MAJOR SOIL CONSERVATION PROBLEM AREAS IN KENTUCKY*

A-7, Loess Hills and Terraces

"This area is a mixture of loess hills and river terraces. The loess hills are generally low. They have an elevation of little over 400 feet but seldom exceed 500 feet. The surrounding terraces and flood plain areas have an elevation of about 300 feet.

"Soils on the hills are usually well drained. They are deep and are subject to considerable erosion. Gullies usually cut deep and straight-sided. Lands are only moderately productive but are responsive to treatment.

"The river terrace lands are derived in part from material from loess hills and while more uniform than the alluvial lands to the east are still considerably mixed.

"Big drainage ditches are common throughout the area. The road system is not well developed and many sections are closed during wet seasons because of incomplete secondary drainage systems.

"The land is not fully developed agriculturally. Cotten is a common crop; also corn and grain. Many of the farmers are share-cropers".

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* From unpublished manuscript from the files of the Soil Conservation Service, U. S. Department of Agriculture.

B-15, Allegheny - Cumberland Plateau

"The Allegheny - Cumberland Plateau, occupying 48,708,500 acres is on the Western slope of the Appalachian uplift. It extends westward from the Allegheny-Cumberland front where it passes through Central Pennsylvania, Western Maryland, Eastern West Virginia, Eastern Kentucky, Eastern Tennessee and Northcentral Alabama to the western edge where it merges into the central basin of Ohio and the Highland Rim of Kentucky, Tennessee and Alabama. The eastern edge of the Plateau top is 2500 to 3500 feet above sea level with a few ridges or mountains extending to 3800 to 4000 feet. The western part is 1000 to 1500 feet above sea level. The Plateau along the eastern edge has somewhat flattened tops with deep narrow stream gorges. The western part is severely dissected into comparatively narrow ridges and V-shaped valleys along which the terrace and bottom lands have a limited development. The relief is gently undulating or rolling to hilly and steeply sloping with little flattish relief. It has a typical dendritic drainage pattern. The rock formations are mainly gray alternating beds of acid shale and sandstone with some thin-bedded limestone and calcareous shale of carboniferous age. These formations are resting in a clear-horizontal position. The slope of the formations is so gradual that except for a few minor anticlines and cynclines it is not noticeable. Use: 18.5 percent cultivated; 15 percent grassland; 50 percent woodland; 8 percent miscellaneous. About 8.5 percent is public ownership.

"The climate is cool, temperate, and humid. Winters are cold; summers mild. Rainfall 40 to 50 inches. The frost-free season is 120 to 150 days in the high plateau; 140 to 170 days from the northern to southern part. Due to steep relief the runoff is rapid in spite of the large acreage of forest and grass cover. Original forest cover was oak, hickory, walnut, poplar, and maple with ash, beech, birch, and hemlock in gorges, spruce on the high elevations, and pitch pine on southern reaches. A fairly large acreage is in National and State forests.

"The soils are residual. Under forest cover they have a thin mat of organic matter on the surface more or less mixed at the bottom with mineral soil materials. This rests on brown to gray-brown mallow soil which passes at about 8 inches into a yellow-brown friable subsoil, passing at 24 to 48 inches into partly disintegrated parent material. Over extensive areas bedrock comes within the 3-foot soil profile. Soils contain much shaly, channery, and flaggy pieces of rock materials, and in places a noticeable amount of stone, usually sandstone.

"Although there is still a considerable area in forest and wood lots, much of the land is cleared and used for general farming, dairying, stock-raising (beef cattle and sheep), and orcharding (apples). Under this system of farming, a large percentage of the land is in pasture. Crop yields are fairly good where manure, lime and fertilizer are used. These practices are in common usage.

"The climatic differences from north to south in the stretch of some 800 miles are responsible for variations in the agriculture of the area."

B-16, Kentucky Blue Grass and Nashville Basin Area

"This area consists of two separate basins. (1) Blue Grass Region of Kentucky located in the North Central part of Kentucky and extending north across the Ohio River into southwest Ohio and southeastern Indiana. It is encased in the south by the "knobs", the eroded edge of the Highland Rim which stands several hundred feet above the Kentucky Plain. (2) The Nashville Basin or Central Basin of Tennessee is entirely encompassed by the Highland Rim, a somewhat higher plateau. Total area 8,446,000 acres.

"The elevation ranges from 500 to 800 feet above sea level. Precipitation of 40 to 45 inches is well distributed throughout the growing season. The annual average temperature is 57 to 59 degrees F. The length of the average growing season is 180 to 190 days in Kentucky and 200 to 210 days in Tennessee. The soils are residual, derived mainly from limestone, shaly limestone, and marl, rather high in phosphate. They are deep, medium to moderately heavy textured, moderately permeable, acid to alkaline in reaction. Gently undulating to rolling, and uniformly well drained. Some shallow soils to bedrock in places. Severe sheet and gully erosion in spots.

"General farming and stockraising. Crops are corn, wheat, oats, tobacco, and cowpeas. Hay crops are timothy, redtop, clover and alfalfa. Bluegrass pastures are common. Forests consist of hardwoods - white oak, hickory, walnut, ash and tulip poplar.

Land Use: 35 percent cultivated; 30 percent grassland; 20 percent woodland; 5 percent miscellaneous and 5 percent public owned."

B-17, Highland Rim, Knobs and Associated Limestone Areas

"This is really an extension of the Knobs Area. The general level is fairly uniform and about 1,000 feet above sea level. The relief of the Knobs (eastern and northern part) is broken and rough. That of the limestone areas is rolling. The soils in the southern part are derived from cherty limestone. They are generally reddish in color and only moderately productive. Sink holes, usually small but occasionally large, are very common in the area.

"The soils of the northern part are derived from a better grade of limestone, chert is less common. Sink holes are rare. Soils are generally productive and are responsive to good treatment. Agriculture is largely of subsistence type with corn, grain and hay being most common crops. The land has good potential for grass production and an increase in livestock production."

B-18, Western Kentucky-Southern Indiana Sandstone and Shale Areas

"This problem area consists of a fairly low, highly dissected plateau, located in Western Kentucky and Southern Indiana. This high dissection gives it a rolling to hilly appearance, although numerous fairly level remnants of the old plateau are still intact. Elevations range from 500 to 1200 feet above sea level. Rock formation consists of sandstone and shale. Coal is present and the southern part of the area is known as the Western Kentucky Coal Fields.

"Rainfall averages 40 to 50 inches. Temperatures average about 75 degrees during the summer months and 35 degrees during winter. The growing season ranges from 160 to 190 days.

"The soils are residual from sandstone and shale. They are variable in depth and texture. Ridgetop soils are usually moderately deep, having medium textured surface soils, and moderately heavy subsoils. Subsoils are moderate to slow in permeability, resulting in poorly drained areas where ridgetops are broad and flat. Hillside soils are often shallow and contain numerous fragments of the underlying sandstone and shales. Surface textures are usually medium and often quite thin. Subsoils have moderate to moderately rapid permeability.

"The area contains terrace soils, particularly in the western part near the Ohio River. Many of these are underlain by silts and clays. Both well and poorly drained soils are common. The poor drainage results from the heavy clay subsoils and substrata.

"Soils are acid in reaction and are low in inherent fertility.

"Erosion, both sheet and gulley, is pronounced wherever the land has been cropped or pastured. Some of the most severely eroded lands of Indiana."

APPENDIX C

EXAMPLES OF EXTREME PROBABILITY PAPER AND THEIR USE

The material composing this Appendix consists of four samples of extreme probability paper used by the Highway Materials Research Laboratory in the analysis of rainfall and discharge data. The sample shown in Fig. 15a is a paper* consisting of the following four scales:

1. The reduced variate (y), (the independent variable)
2. The frequency ϕ (x), (an independent variable)
3. The return period (T), (an independent variable)
4. The observed variate (x), (the dependent variable)

Scales 1, 2 and 3 may be interconverted by the use of the formulas

$$y = -\ln(-\ln \phi(x)),$$

and $$T = \frac{1}{1 - \phi(x)}$$

The <u>mode</u> is at approximately 1.58 years on the return period scale, 36.788 percent on the frequency scale, and zero on the reduced variate scale. The <u>mean</u> is 2-1/3 years on the return period scale, and 0.5772 (Euler's Constant) on the reduced variate scale. The observed variate scale (the dependent variable) is arithmetic and is used for the experimental distribution, i.e. depth of rainfall for a selected duration (inches per hour, inches per 24-hour, etc.)

The paper of Fig. 15b is similar to that of Fig. 15a except that the observed variate scale is logarithmic rather than arithmetic. It is used for the limited distribution described by Gumbel in "Statistical Theory of Draughts" and was supplied by him.

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* Developed from Dr. E. J. Gumbel's Extreme Probability Papers, by the Climatology Unit, Environmental Protection Section, Research and Development Branch, Military Planning Division, Office of the Quartermaster General.

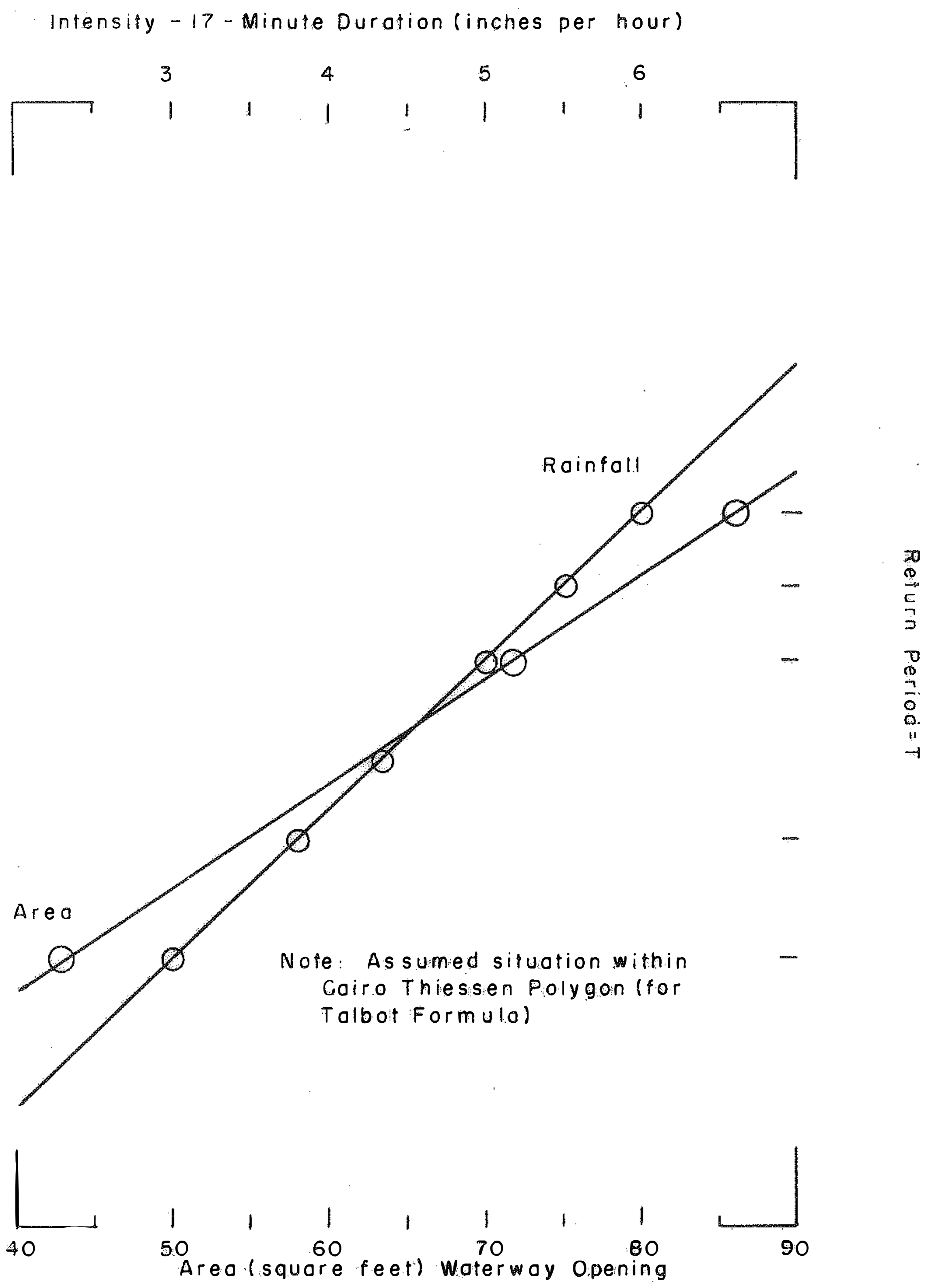
Fig. 15c represents a paper furnished by the U. S. Geological Survey and has only two scales:

1. the arithmetic or observed scale (x)
2. the recurrence interval (T)

The sample shown in Fig. 15d was developed by Dr. E. J. Gumbel and first proposed by R. W. Powell (See Bibliography Hydrology Item 34). With the exception of their orientation, the scales of this paper are identical with those of Fig. 15a.

The overlay accompanying Fig. 15a was used in the solution of the problem presented with Table 7 (Appendix A). In this instance, the line labeled Area (of waterway opening) is involved. This overlay was also used with the example illustrating the use of Fig. 12a-12r (Appendix A); the line Rainfall is the result of this application.

The overlay for Fig. 15d was used in conjunction with miscellaneous applications of rainfall intensity-return period data to various methods of design (see p. 37). The lines drawn from plotted data (on the overlay) form the basis for comparing calculated discharges by different methods on the basis of indicated return periods.



Note: Assumed situation within Cairo Thiessen Polygon (for Talbot Formula)

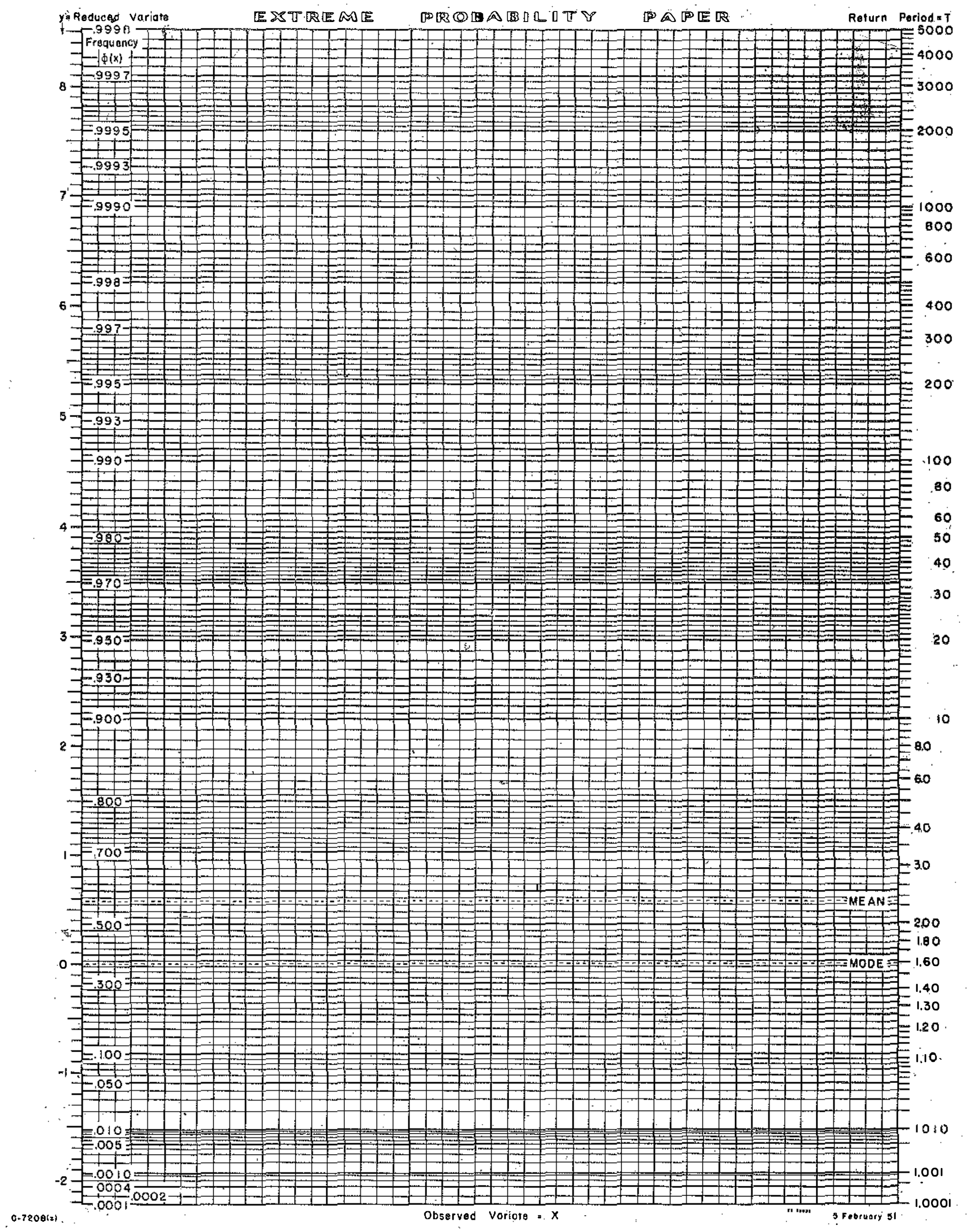


Fig. 15a - Specimen of Extreme Value Probability Paper Used by the Highway Materials Research Laboratory (Courtesy of E. J. Gumbel)

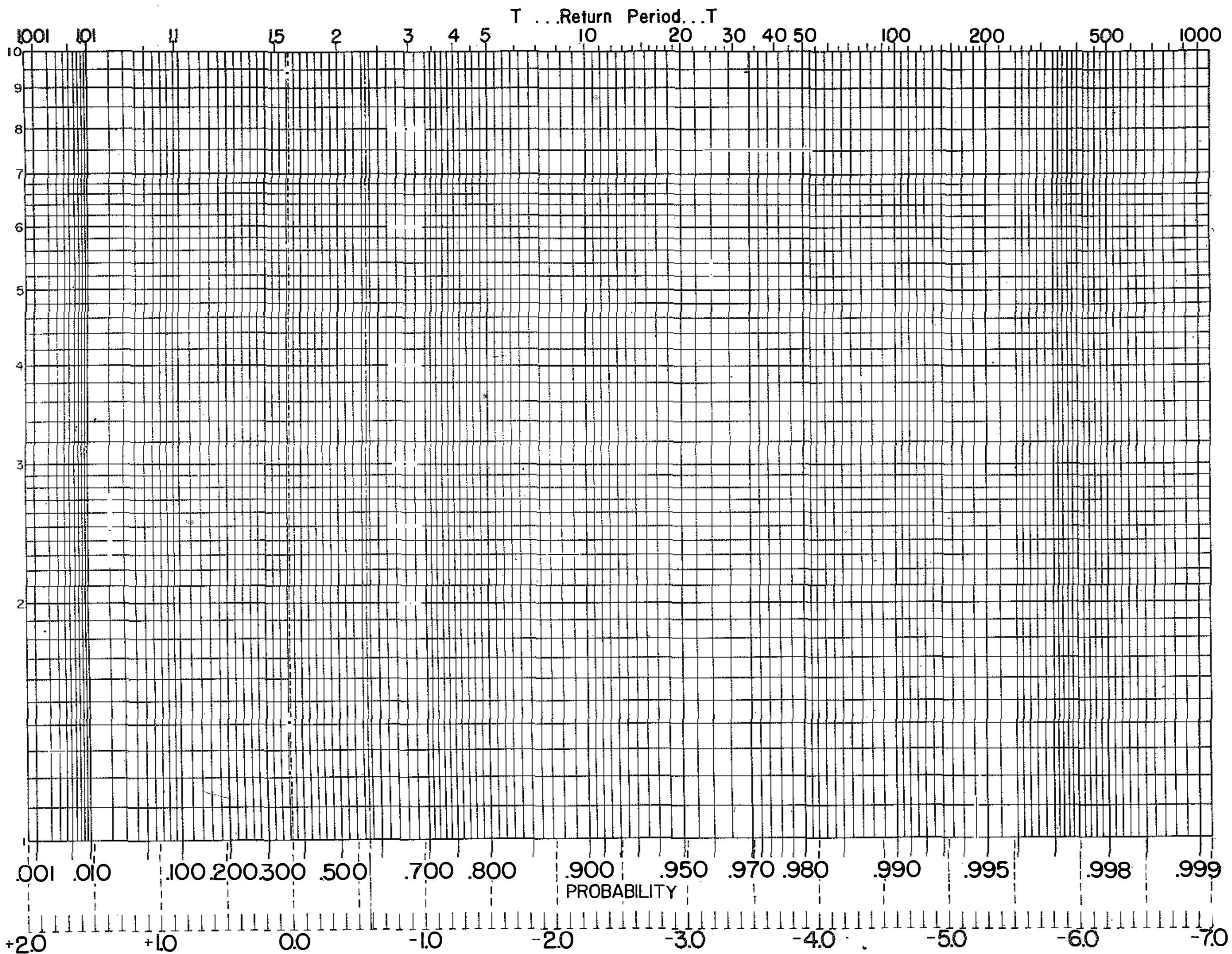
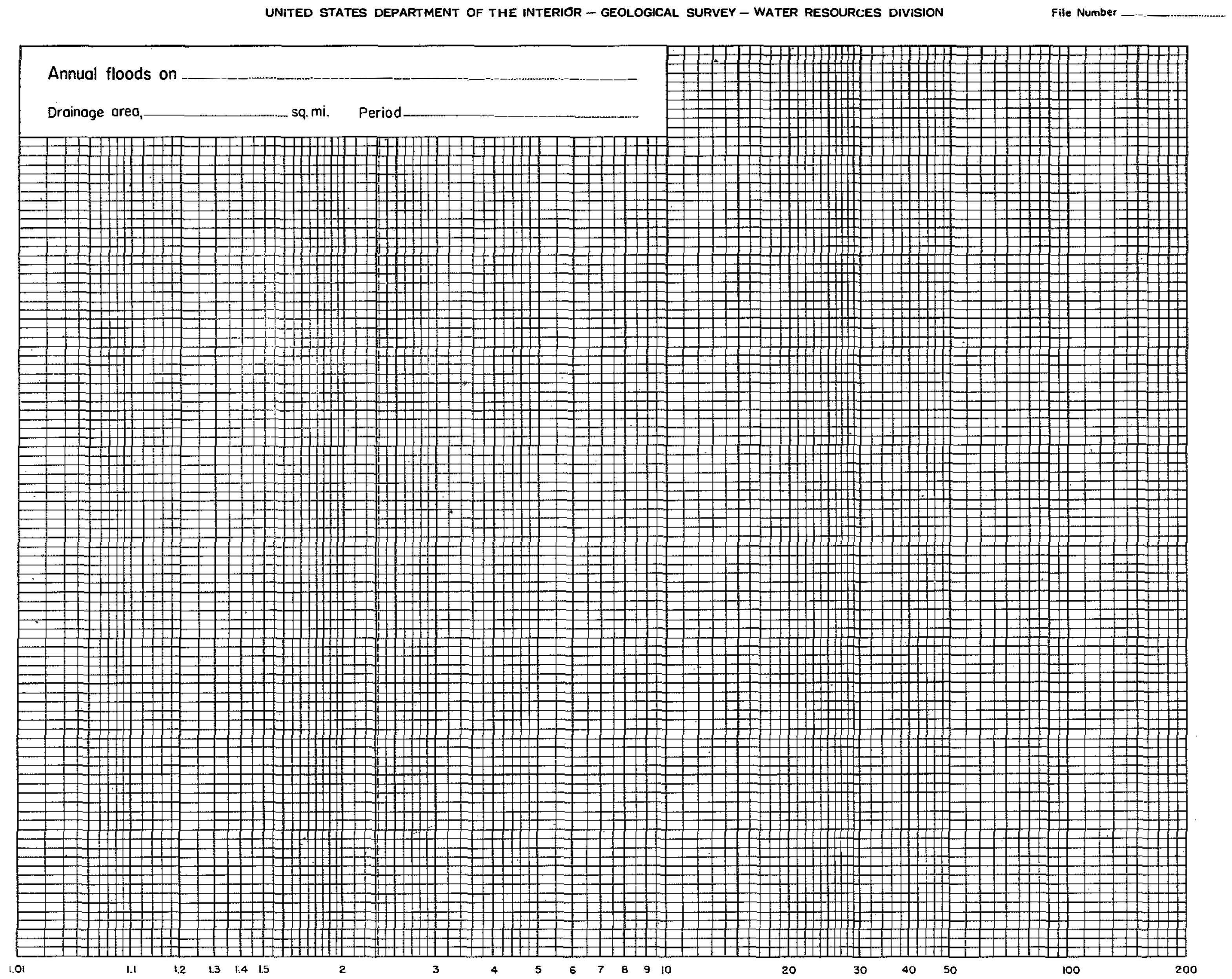


Fig. 15b Specimen of extreme value probability paper used by the Highway Materials Research Laboratory (Courtesy of E.J. Gumbel)



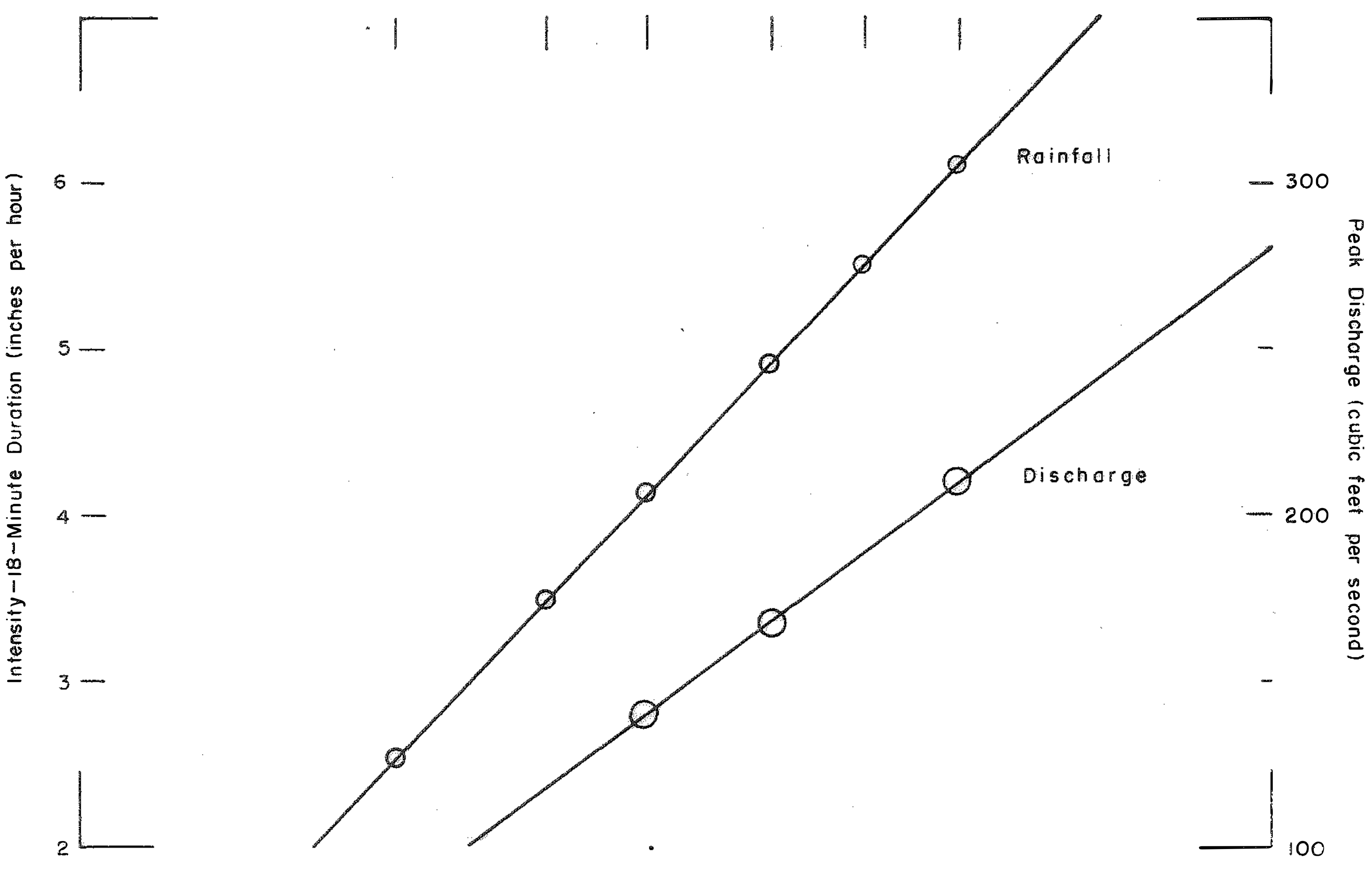
UNITED STATES DEPARTMENT OF THE INTERIOR – GEOLOGICAL SURVEY – WATER RESOURCES DIVISION

File Number __________

Annual floods on __________

Drainage area, __________ sq. mi. Period __________

Fig. 15c - Specimen of Extreme Value Probability Paper Used by the United States Geological Survey


Intensity-18-Minute Duration (inches per hour)
2
3
4
5
6
Rainfall
Discharge
Peak Discharge (cubic feet per second)
100
200
300

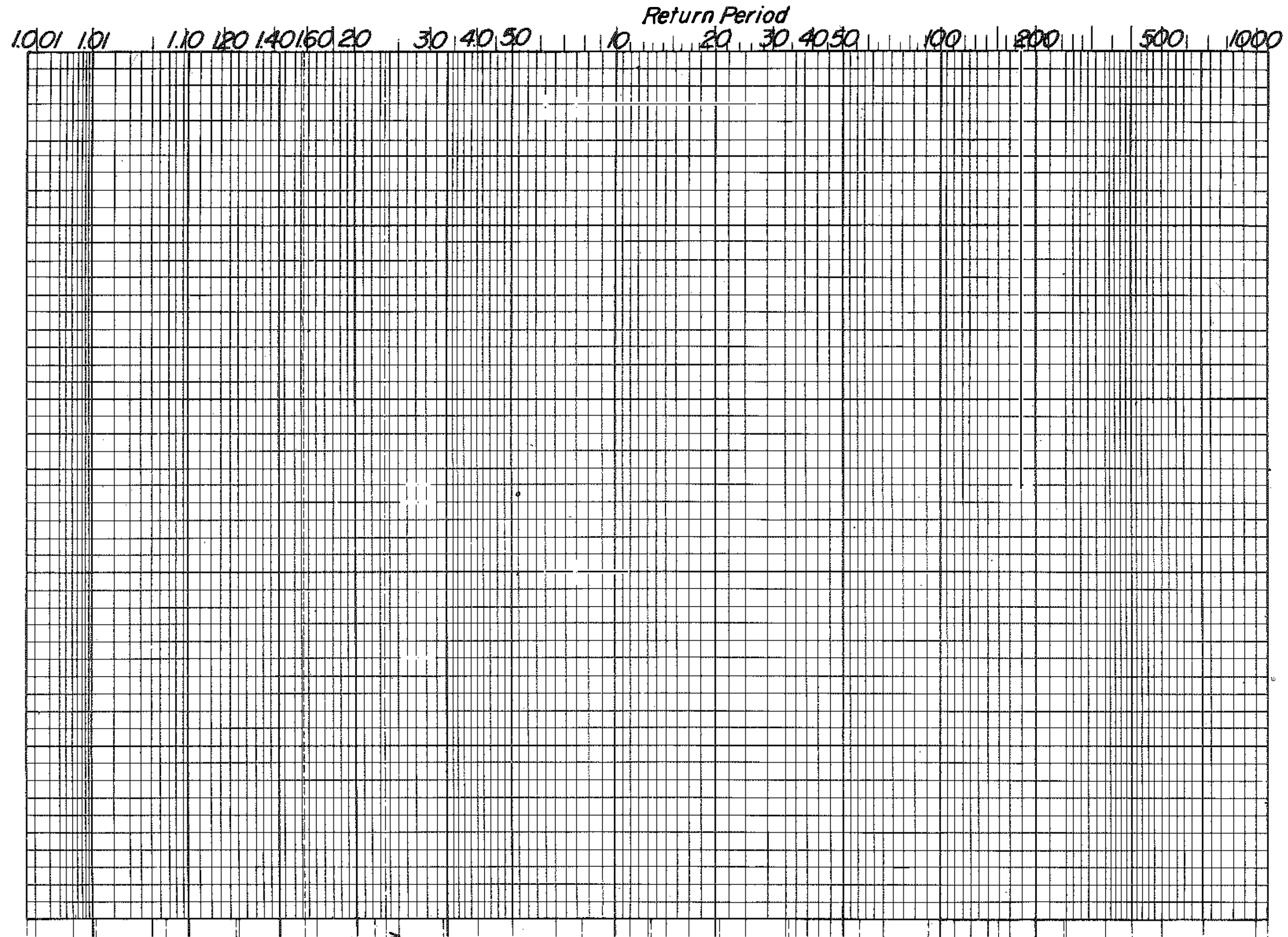


Fig. 15d - Specimen of Extreme Value Probability Paper Used by the Highway Materials Research Laboratory (Courtesy of E. J. Gumbel)

APPENDIX D

DATA FOR DETERMINATION OF RATIOS BETWEEN AMOUNTS OF RAINFALL FOR DIFFERENT RETURN PERIODS FOR 18-STATION FIRST-ORDER NETWORK

Table 10 - Values of the Reduced Variate For Use With Theoretical Straight Line Equation.

Fig. 16a-16h - Graphical Relationships and Equations For Network Average Rainfall Depths (For Selected Return Periods).

Fig. 17 - Standard Rainfall Intensity-Duration Curves for Kentucky.

Notes on Table 10:

The theoretical straight line on extreme probability paper is defined by Gumbel (9) with the equation:

$$x = u + (1/a)\,y$$

where x = observed variate

u = mode

$1/a$ = logarithmetic rate of increase (slope)

y = reduced variate

and $y = a\,(x - u)$

or $y = -\ln(-\ln \phi(x))$

$$T = \frac{1}{1 - \phi(x)}$$

and $\phi(x) = \dfrac{T - 1}{T}$

The frequency ($\phi(x)$) was calculated for selected values of the return period (T). It was then necessary to obtain values of the reduced variate (y) with the use of a table of iterated natural logarithms (42).

At the mode (u), y is equal to zero. The mode has a return period of approximately 1.58 years. Table 10 can be used in any case where the reduced variate is the independent variable.

Table 10 - Values of the Reduced Variate (y) for Use With Theoretical Straight Line $x = u + (1/a)\,y$

Return Period in Years (T)	Reduced Variate (y)	Return Period in Years (T)	Reduced Variate (y)	Return Period in Years (T)	Reduced Variate (y)	Return Period in Years (T)	Reduced Variate (y)
1.5	-0.09405	56	4.01636	55	5.04015	1000	6.90725
2	0.36651	57	4.03421	60	5.10288	50	6.95606
3	0.90272	58	4.05176	65	5.10288	1100	7.00261
4	1.27189	59	4.06900	70	5.13281	50	7.04704
5	1.49994	60	4.08594	175	5.16188	1200	7.08972
6	1.70199	61	4.10261	80	5.19014	50	7.13050
7	1.86983	62	4.11901	85	5.21762	1300	7.16979
8	2.01342	63	4.13514	90	5.24434	50	7.20755
9	2.13890	64	4.15101	95	5.27037	1400	7.24387
10	2.25037	65	4.16664	200	5.29581	50	7.27891
11	2.35062	66	4.18202	10	5.34473	1500	7.31286
12	2.44171	67	4.19717	20	5.39134	50	7.34565
13	2.52520	68	4.21210	30	5.43591	1600	7.37748
14	2.60223	69	4.22680	40	5.47855	50	7.40820
15	2.67375	70	4.24130	250	5.51946	1700	7.43817
16	2.74049	71	4.25559	60	5.55874	50	7.46715
17	2.80305	72	4.26967	70	5.59657	1800	7.49522
18	2.86193	73	4.28356	80	5.63301	50	7.52275
19	2.91752	74	4.29726	90	5.66814	1900	7.54942
20	2.97020	75	4.31078	300	5.70213	50	7.57541
21	3.02022	76	4.32411	10	5.73496	2000	7.60065
22	3.06787	77	4.33727	20	5.76676	2100	7.64948
23	3.11335	78	4.35026	30	5.79757	2200	7.69615
24	3.15685	79	4.36308	40	5.82746	2300	7.74047
25	3.19853	80	4.37574	350	5.85652	2400	7.78300
26	3.23855	81	4.38823	60	5.88470	2500	7.82385
27	3.27702	82	4.40059	70	5.91215	2600	7.86320
28	3.31407	83	4.41278	80	5.93885	2700	7.90075
29	3.34980	84	4.42483	90	5.96487	2800	7.93740
30	3.38429	85	4.43673	400	5.99021	2900	7.97248
31	3.41763	86	4.44849	20	6.03904	3000	8.00640
32	3.44989	87	4.46012	40	6.08565	3200	8.07084
33	3.48115	88	4.47161	60	6.13015	3400	8.13159
34	3.51146	89	4.48297	80	6.17277	3600	8.18858
35	3.54089	90	4.49421	500	6.21361	3800	8.24262
36	3.56946	91	4.50532	20	6.25286	4000	8.29393
37	3.59725	92	4.51633	40	6.29062	4200	8.34284
38	3.62427	93	4.52719	60	6.32705	4400	8.38932
39	3.65051	94	4.53794	80	6.36219	4600	8.43387
40	3.67625	95	4.54859	600	6.39608	4800	8.47659
41	3.70126	96	4.55911	25	6.43695	5000	8.51709
42	3.72564	97	4.56954	50	6.47618	5500	8.61273
43	3.74945	98	4.57983	75	6.51396	6000	8.69964
44	3.77272	99	4.59004	700	6.55035	6500	8.78027
45	3.79544	100	4.60012	25	6.58549	7000	8.85379
46	3.81767	5	4.64916	50	6.61944	7500	8.92345
47	3.83941	10	4.69589	75	6.65224	8000	8.99274
48	3.86068	15	4.74056	800	6.68399	8500	9.04884
49	3.88152	20	4.78330	25	6.71480	9000	9.10540
50	3.90193	125	4.82431	50	6.74463	9500	9.15977
51	3.92193	30	4.86369	75	6.77363	10,000	9.21029
52	3.94154	35	4.90153	900	6.80185	15,000	9.61785
53	3.96078	40	4.93805	25	6.82924	20,000	9.90346
54	3.97964	45	4.97325	50	6.85598	25,000	10.12661
55	3.99817	150	5.00726	75	6.88197	50,000	10.81977

The derivation of ratios between amounts of rainfall for different return periods may be achieved by at least two methods. One method is based on the ratios of the absolute mean of the deviations from the group mean and has been used by Potter in his development of peak rates of runoff for the Allegheny-Cumberland Plateau (See Figs. 5 and 6). The second method makes use of a direct ratio between the mean of the amounts for various return periods and lends itself directly to the same solution as the former method.

The second method is particularly suited to the development of additional relationships between amounts for any return period. This is possible because the network average amounts are linear when plotted on extreme probability paper at their respective return periods. Thus an equation may be developed for selected durations so that network average amounts may be calculated for any return period. The final ratios between amounts are independent of the duration of rainfall, therefore, Figs. 16a-16h will define the relationships between return periods (amounts) for any duration. These figures have been derived from the 1-hour rainfall and have been checked against the 5, 10, 15, 30 and 120-minute and 24-hour durations. Following are the basic equations for the network average rainfall:

x = network average depth of rainfall (inches)

5-min.
$x = 0.3540 + 0.0854y$

10-min.
$x = 0.552 + 0.1410y$

15-min.
$x = 0.6841 + 0.1890y$

30-min.
$x = 0.9039 + 0.2983y$

1-hour $x = 1.1232 + 0.3963y$	2-hour $x = 1.3386 + 0.4890y$
3-hour* $x = 1.4972 + 0.5438y$	6-hour* $x = 1.7761 + 0.6432y$
9-hour* $x = 1.9602 + 0.7073y$	12-hour* $x = 2.1050 + 0.7532y$
18-hour* $x = 2.3259 + 0.8226y$	24-hour $x = 2.4906 + 0.8774y$

In all cases, y is the reduced variate for selected return periods taken from Table 10.

An example will demonstrate the use of the above equations in deriving the relationships shown on Figs. 16a-16h.

Assume that the equations for 1-hour and 24-hour are to be compared to determine the ratio between the 100-year return period amount and the 2-year return period amount. Table 10-a and Fig. 16b gives the <u>answer</u> as <u>2.32.</u>

$T = 100$ 1-hour

$x = 1.1232 + 0.3963y$

where $y = 4.60012$ (use 4.60)

$x = 2.94764$ inches

$T = 2$ 1-hour

$x = 1.1232 + 0.3963y$

where $y = 0.36651$ (use 0.37)

$x = 1.268753$

* Synthetic, based on Depth-Duration-Return Period Curves.

Table 10-a - Ratios Between the Means of Amounts For Various Return Periods.

Return Period, T = 2	5	10	25	50	100
A. Ratio to Amount For 2-Year Return Period:					
1.00	1.36	1.59	1.89	2.11	2.32
B. Ratio to Amount For 5-Year Return Period:					
0.74	1.00	1.17	1.39	1.55	1.71
C. Ratio to Amount For 10-Year Return Period:					
0.63	0.85	1.00	1.19	1.32	1.46
D. Ratio to Amount For 25-Year Return Period:					
0.53	0.72	0.84	1.00	1.12	1.23
E. Ratio to Amount For 50-Year Return Period:					
0.48	0.64	0.75	0.90	1.00	1.10
F. Ratio to Amount For 100-Year Return Period:					
0.43	0.58	0.68	0.81	0.91	1.00

The use of Table 10-a is illustrated by the following examples:

Example 1 - For the design of a storm-water inlet or gutter, a 2-year return period (See Table 4) is used. According to Table 10-a, if the amount for the 10-year return period were actually assumed in the design, the calculated result would represent 59 percent over-design.

Example 2 - Assume the design for a bridge or a culvert on a road for for which Table 4 recommends T = 25, to be checked by T = 100 for damage resulting from high water. For T = 100, a ratio of 1.23 or 23% greater than the amount for T = 25 would be the answer. As for the 59% over-design in Example 1, a return period of approximately 900 years would be realized if the same had been employed in this example.

Thus, it is evident that in the selection of a design return period it is of importance to consider the economic aspects involved and the relationship between the respective return periods.

The ratio between T_{100}/T_2 is

$$\frac{2.94764}{1.268753} = 2.3233 \text{ or } \underline{\underline{2.32}}$$

Now checking with the 24-hour equation

$$x_{100} = 6.53196 \text{ inches} \qquad x_2 = 2.811252$$

$$\text{the ratio} = 2.3235 \text{ or } \underline{\underline{2.32}}$$

Thus we can verify or develop the relationships between amounts for <u>any</u> return period.

To demonstrate the use of the ratios between return periods (amounts), Table 10b was developed. This table shows the calculated synthetic amounts of rainfall which were calculated from the known or actual values (underscored) for three durations at Charlotte, N. C. The actual values were taken from Table 9 of Reference (45). The ratios used were calculated or taken from Figs. 16a-16h. Table 10b demonstrates the proper use of the ratios, i. e., in all cases under the 5-year return period the best estimate was based on the ratio and the actual amount for the 10-year return period~~s~~ (for 24-hour, 4.80 inches, 10-year depth times 0.85 (ratio) yields the 4.08 inches for the 5-year depth). Similarly all other values may be verified. Summarizing and using the 24-hour, 5-year return period as an example, the range of the synthetic estimates is 4.00 inches to 4.30 inches, the first being based on the 100-year return period actual depth (6.89 inches) and the latter is based on the 1.58-year return period actual depth (2.81 inches).

Table 10-b - Actual and Synthetic Depths of Rainfall Based on Selected Return Periods and Different Durations at Charlotte, N. C. (From Return Period Ratios in Appendix D for Method A).

	Actual** and Synthetic Rainfall Depth (Inches) Based on Selected Return Periods							
Durations	1.58	2	2.33	5	10	25	50	100
	2.81	3.18	3.37	4.30	5.03	5.99	6.69	7.36
	2.79*	3.13	3.35	4.26	4.98	5.92	6.60	7.26
	2.77	3.14*	3.30	4.22	4.95	5.87	6.57	7.26
24-Hour	2.73	3.06	3.27*	4.14	4.84*	5.75	6.42	7.08
	2.69	3.02	3.22	4.08*	4.80	5.71	6.34	7.01
	2.65	2.99	3.16	4.06	4.74	5.64	6.32	6.94
	2.63	3.01	3.20	4.01	4.70	5.64*	6.27	6.90*
	2.62	2.96	3.17	4.00	4.69	5.58	6.27*	6.89
	1.05	1.19	1.26	1.61	1.88	2.24	2.50	2.75
	1.03*	1.16	1.24*	1.58	1.84	2.19	2.45	2.69
	1.02	1.16*	1.22	1.56	1.83	2.17	2.43	2.68
	1.00	1.12	1.19	1.51	1.77	2.10	2.34	2.58
30-Minute	0.97	1.10	1.17	1.48*	1.74	2.07	2.30	2.54
	0.95	1.08	1.14	1.46	1.71*	2.03	2.27	2.50
	0.94	1.08	1.15	1.44	1.69	2.02*	2.25	2.48*
	0.94	1.06	1.14	1.43	1.68	2.00	2.25*	2.47
	0.39	0.44	0.47	0.60	0.70	0.83	0.93	1.02
	0.37*	0.42	0.45*	0.57	0.67	0.79	0.89	0.97
	0.37	0.42*	0.44	0.56	0.66	0.78	0.88	0.97
	0.34	0.38	0.41	0.52	0.61*	0.72	0.81	0.89
5-Minute	0.32	0.37	0.39	0.49*	0.58	0.69	0.77	0.85
	0.31	0.35	0.37	0.48	0.55	0.66	0.74*	0.81
	0.30	0.35	0.37	0.46	0.54	0.65*	0.72	0.79*
	0.29	0.33	0.35	0.45	0.52	0.62	0.70	0.77

* Indicates that this synthetic value is the best approximation of the actual value.

** Actual values taken from Reference 45 are underscored.

It is evident from this table that under average conditions the best estimates may be made for return periods adjacent but below the base return period amount.

With regard to design, it is important that the engineer be aware of the relationship existing between the rainfall for various return periods as summarized above in Table 10b. Assuming that an arbitrary standard of $T = 25$ has been established for bridges on moderately important roads or culverts on important roads, what is the relationship between this standard and the other return periods? Consider Table 10a, which applies to the mean values for the First-Order Network as a whole. As noted in Part D of this table, the amount for $T = 25$ has a ratio of 1.00 and for $T = 2$, a ratio of 0.53 (or 47% smaller than that for $T = 25$), whereas for $T = 100$ the ratio is 1.23 or 23% greater than the amount for the 25-year return period. The equation for this section of Table 10a is:

$$x = 0.4700 + 0.1657y$$

where x = ratio to amount for 25-year return period value

and y = reduced variate (from Table 10 for a particular return period)

Similar solutions can be made with the equations on the face of the graphs in Figs. 16a through 16b.

Notes on Figs. 16a through 16h:

If values of the ratios between the means of amounts for various return periods (given in Table 10-a) are plotted on extreme probability paper, the result would be a series of straight lines which could be defined in terms of the reduced variate (y). Equations given in Figs. 16a through 16h were derived by the theory of least squares. For an approximate solution, these curves may be used directly. A more accurate solution may be obtained by solving the equations for the reduced variate (y). The following is an example of the use of Fig. 16f:

> Assume, for a particular station, a 24-hour rainfall (T = 25) of 6.00 inches. However, the state average (See Table 8, Appendix A) is 5.00 inches. If one desires to know the return period at this station of the 6.00-in. rainfall based on the state average, then the following ratio must first be determined:
>
> $$x = \frac{6.00}{5.00}$$
>
> $$x = 1.200$$
>
> This ratio is then applied to the equation in Fig. 16f:
>
> $$x = u + (1/a)y$$
>
> or $$1.20 = 0.4700 + 0.1657y$$
>
> and $$y = 4.4055$$
>
> From Table 10, it can be seen that if $y = 4.4055$, the return period is approximately 82 years (in whole years).

Although the ratios for various return periods are not the same in magnitude, discharge relationships are based on the same principle as rainfall relationships. An extensive study has been made for discharge relationships but will not be published in this report. Information is available at the Highway Materials Research Laboratory.

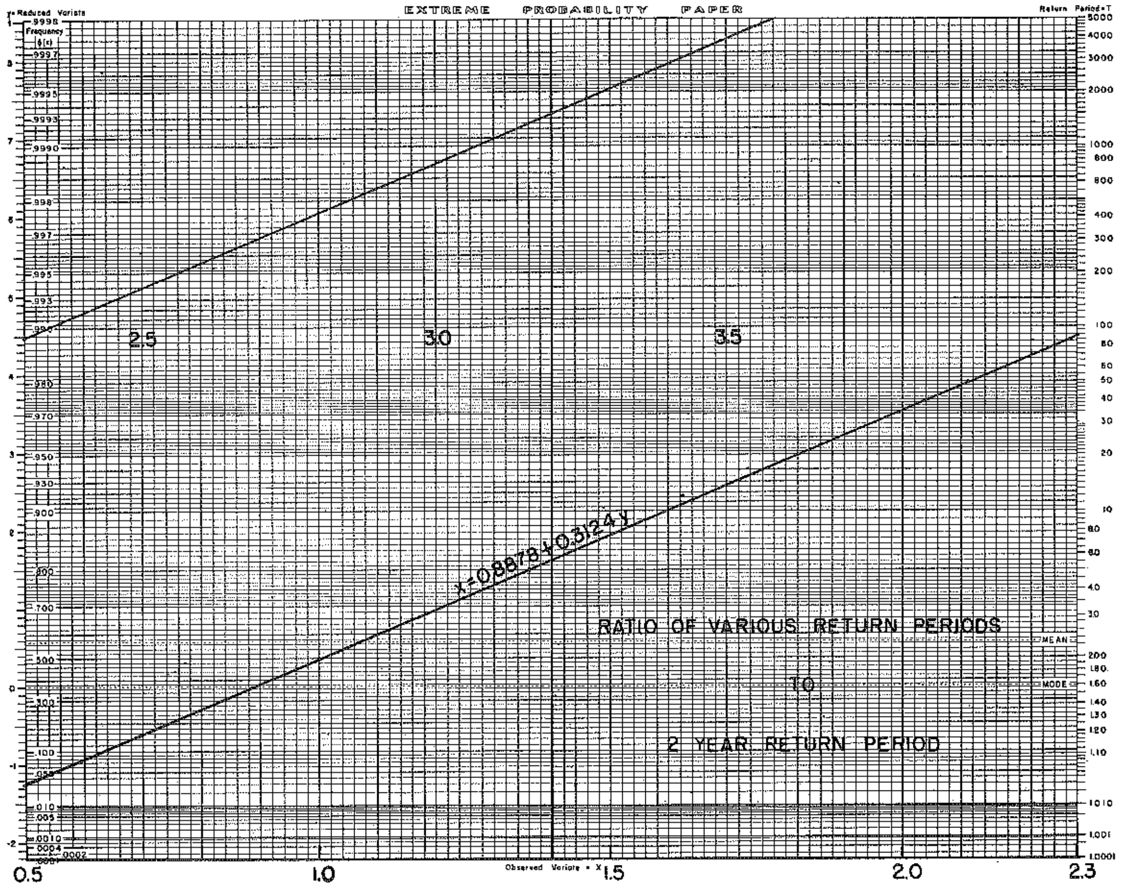


Fig. 16b Ratio to 2 Year Return Period

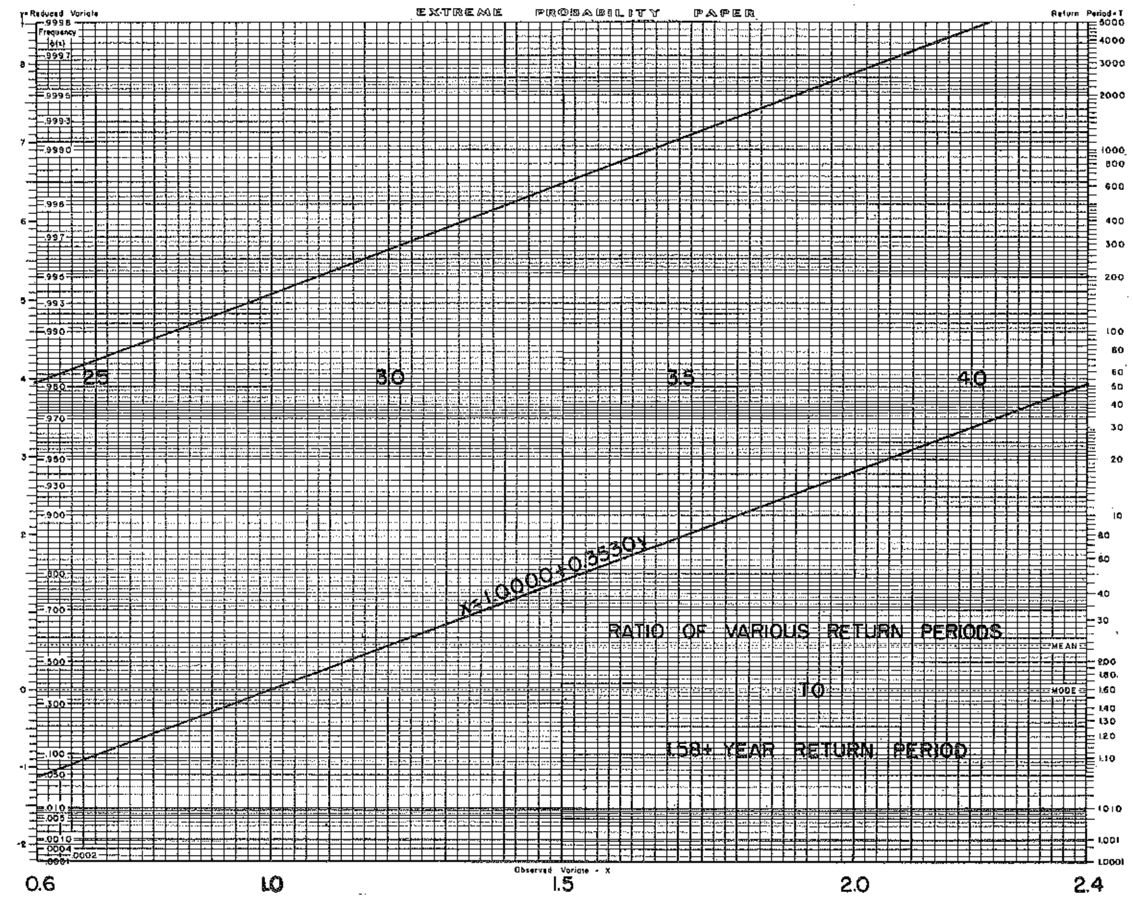


Fig. 16a Ratio to 1.58+ Year Return Period

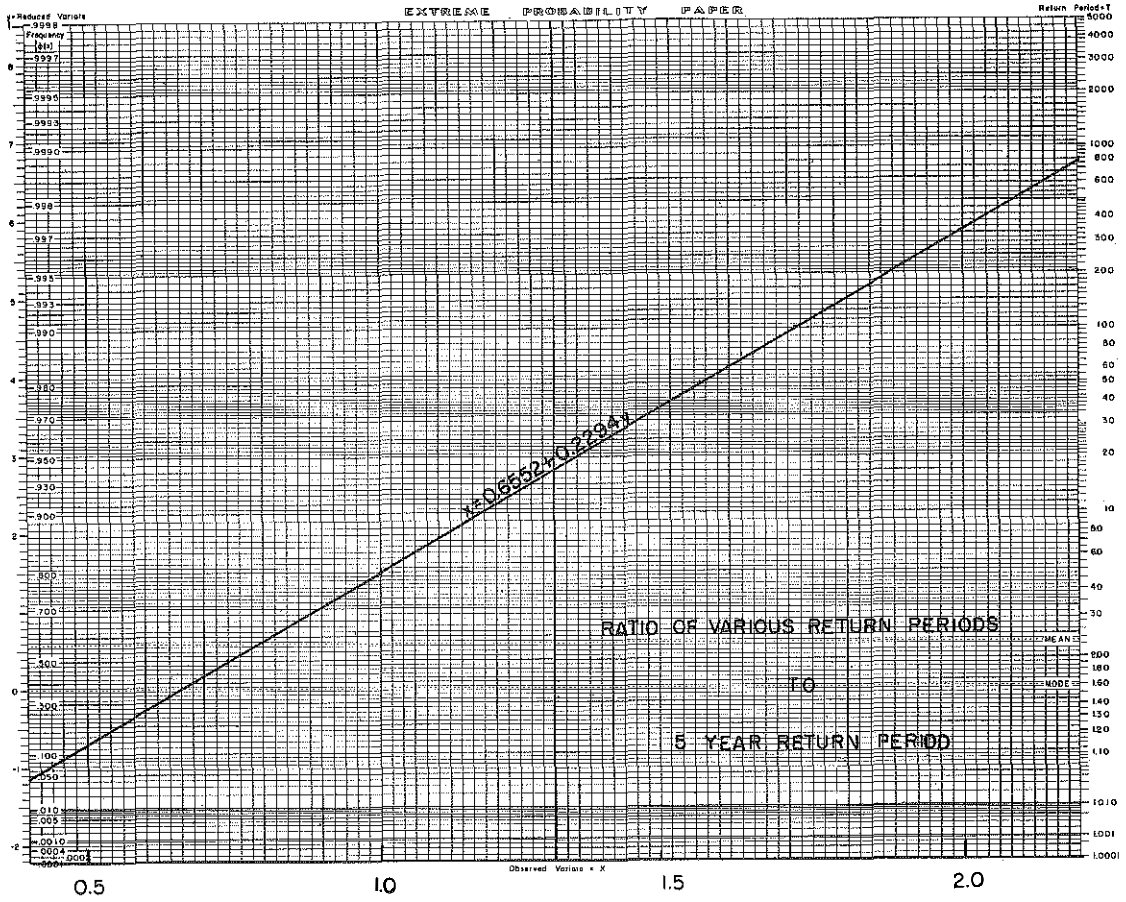


Fig. 16d Ratio to 5 Year Return Period

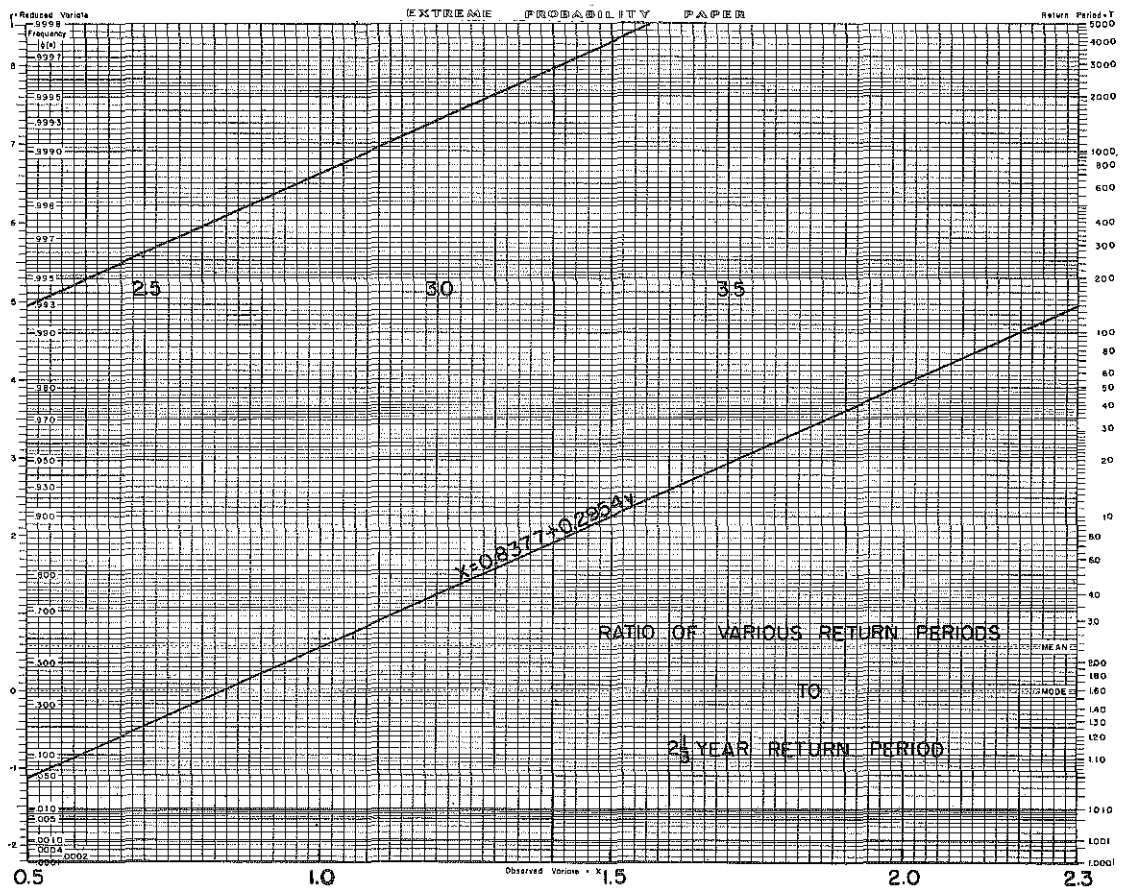


Fig. 16c Ratio to $2\frac{1}{3}$ Year Return Period

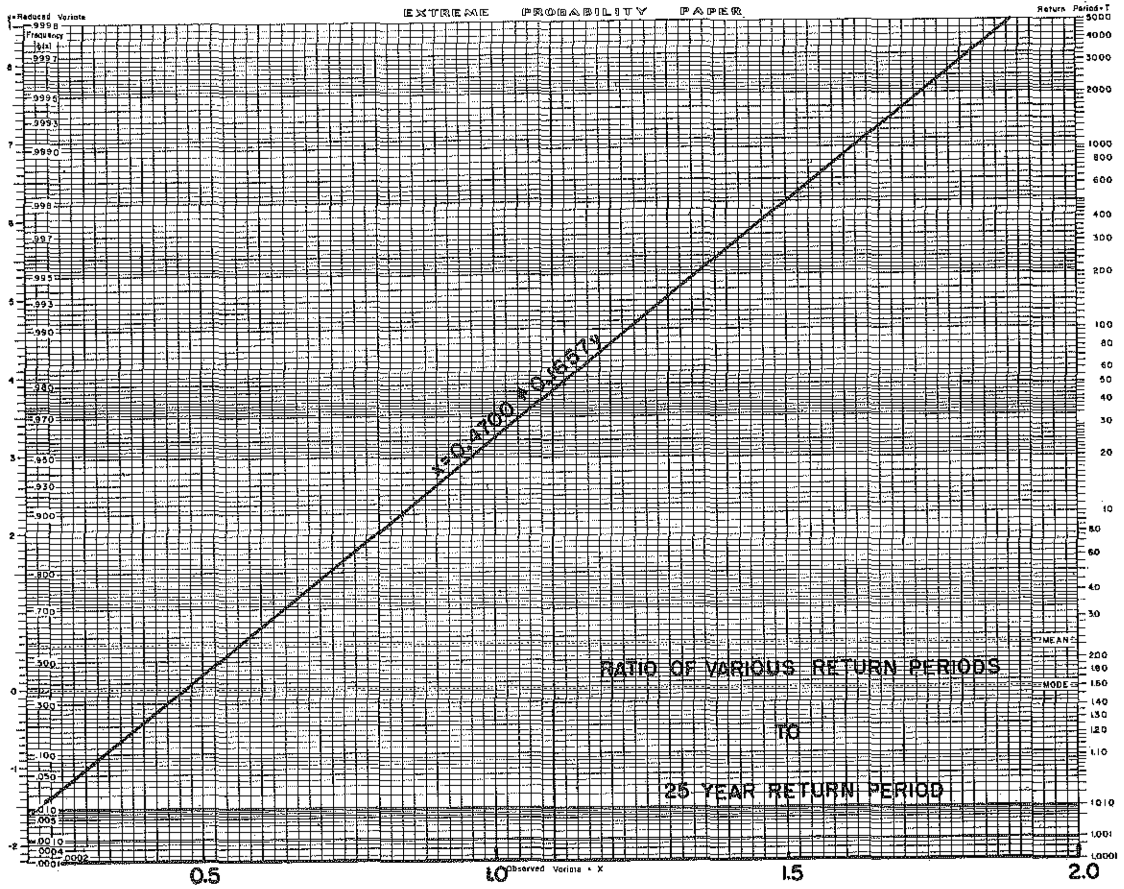


Fig. 16f **Ratio to 25 Year Return Period**

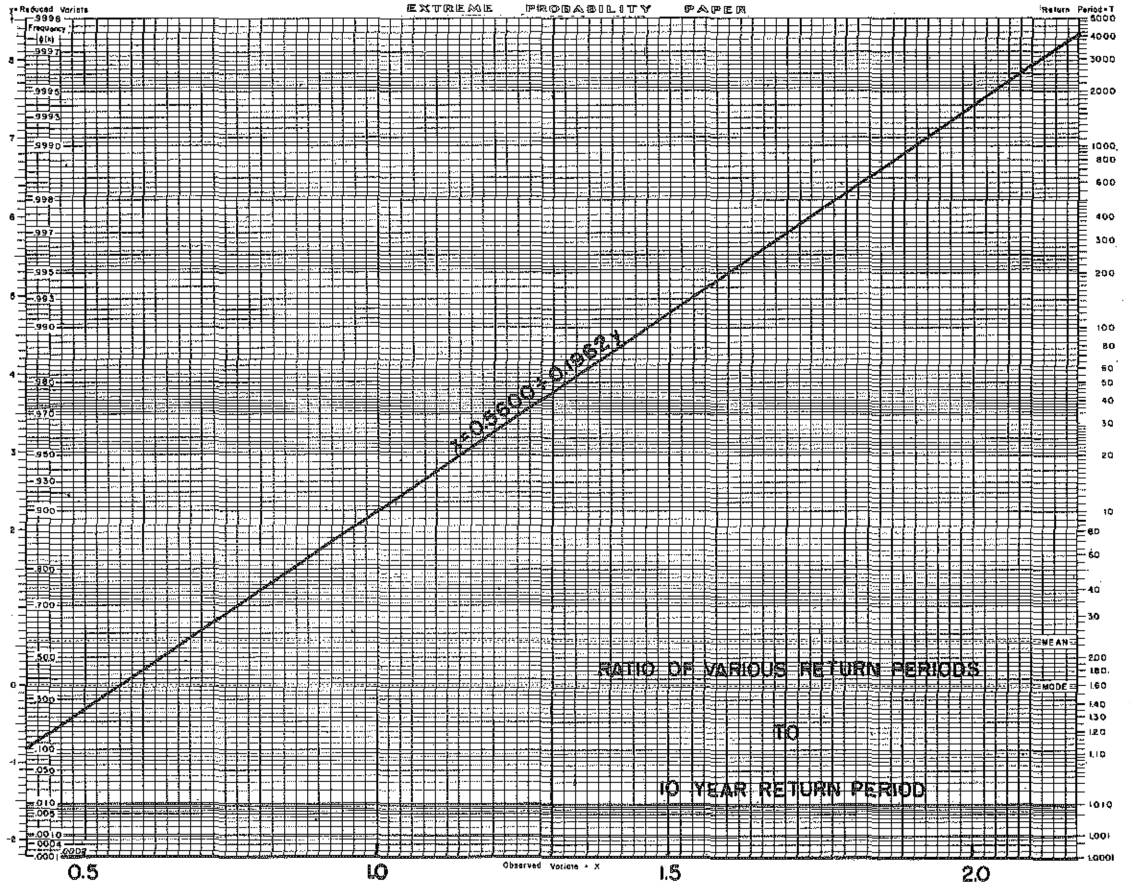


Fig. 16e **Ratio to 10 Year Return Period**

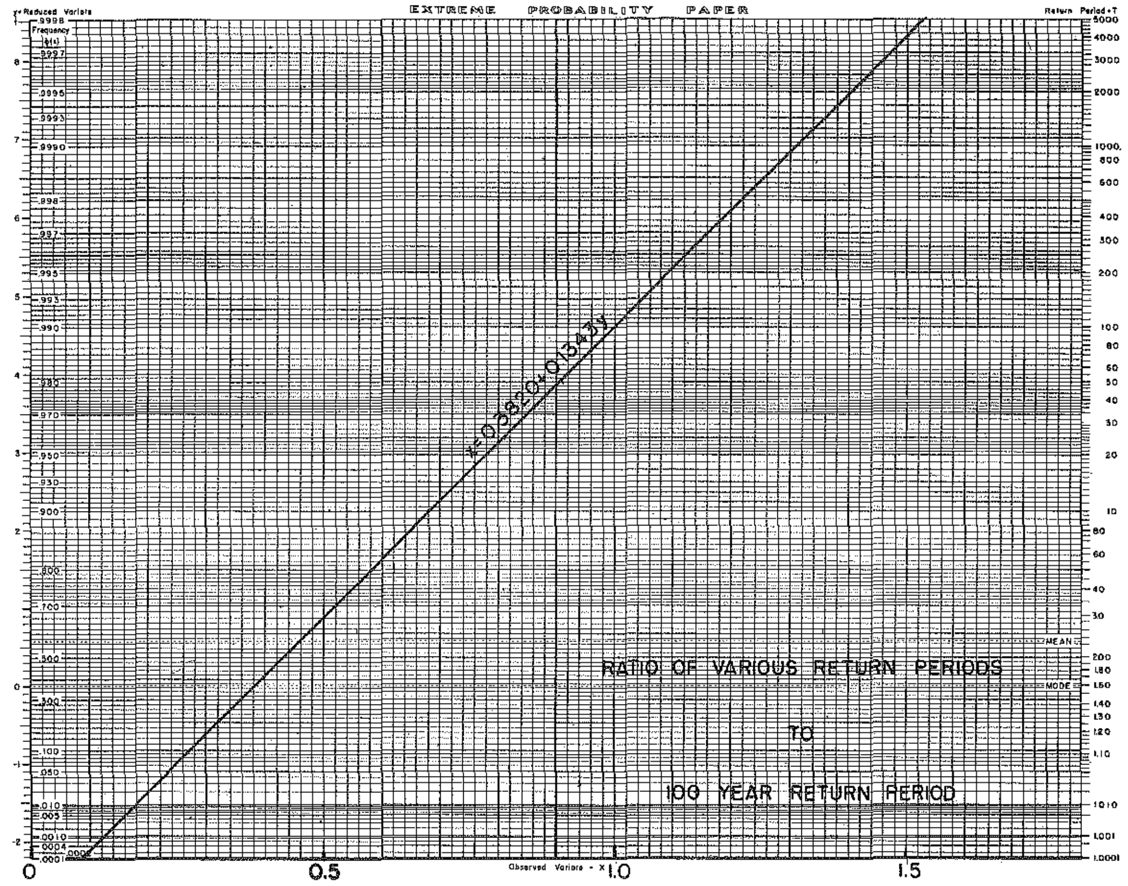


Fig. 16h Ratio to 100 Year Return Period

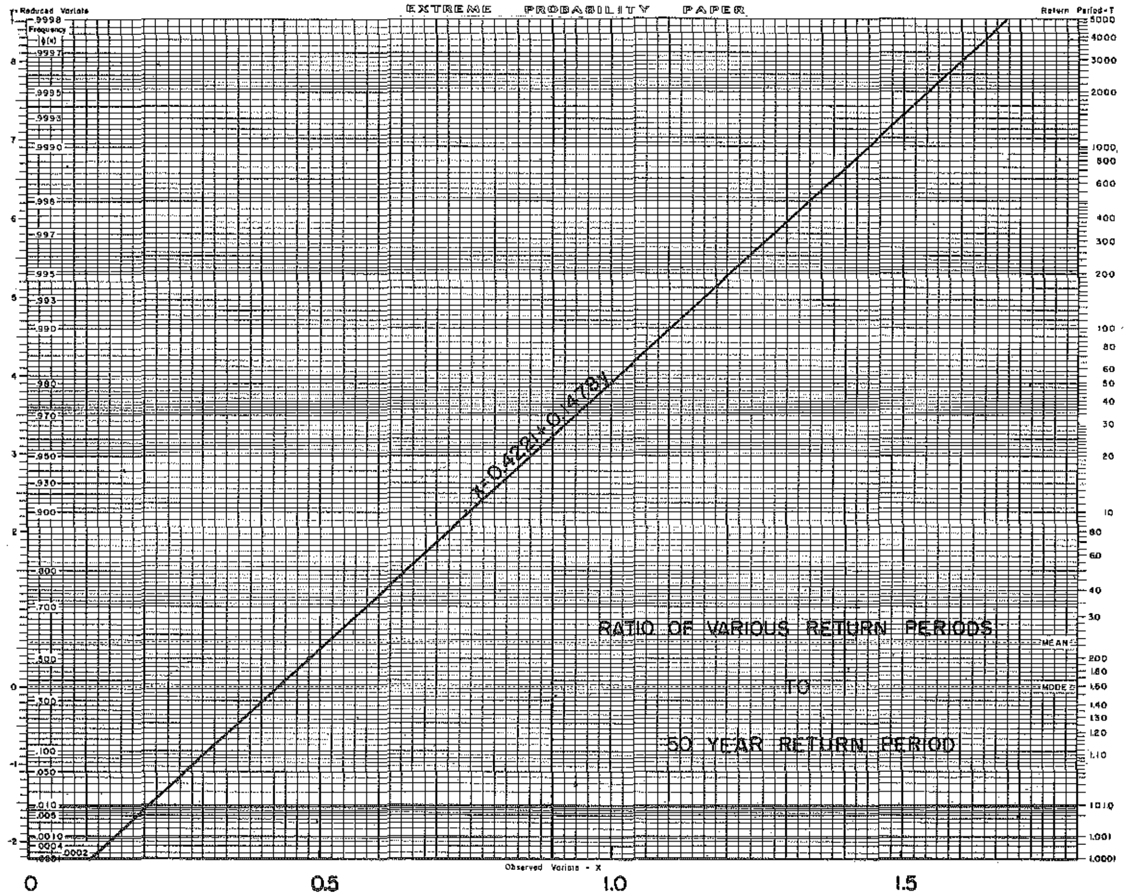


Fig. 16g Ratio to 50 Year Return Period

Notes on Fig. 17:

A procedure which can be used to estimate intensities for 5-min. to 24-hr. duration utilizes Fig. 8, "Rainfall Factors for Kentucky", as a 25-year, 1-hour isohyetal map with Fig. 17. This method may be illustrated by the following example:

Given:

Location of watershed-latitude 38° 18'
longitude 83° 03'

Find:

100-year, 20-minute rainfall intensity (T_{100}, 20-min.)

From Fig. 8 the rainfall factor (RF) is found to be 0.79. By definition,

$$RF = \frac{\text{25-year, 1-hour rainfall}}{\text{2.75 in. per hr.}}$$

Therefore,

$$\text{25-year, 1-hour} = (0.79)(2.75)$$

$$T_{25}\text{, 1-hour} = 2.1725 \text{ inches}$$

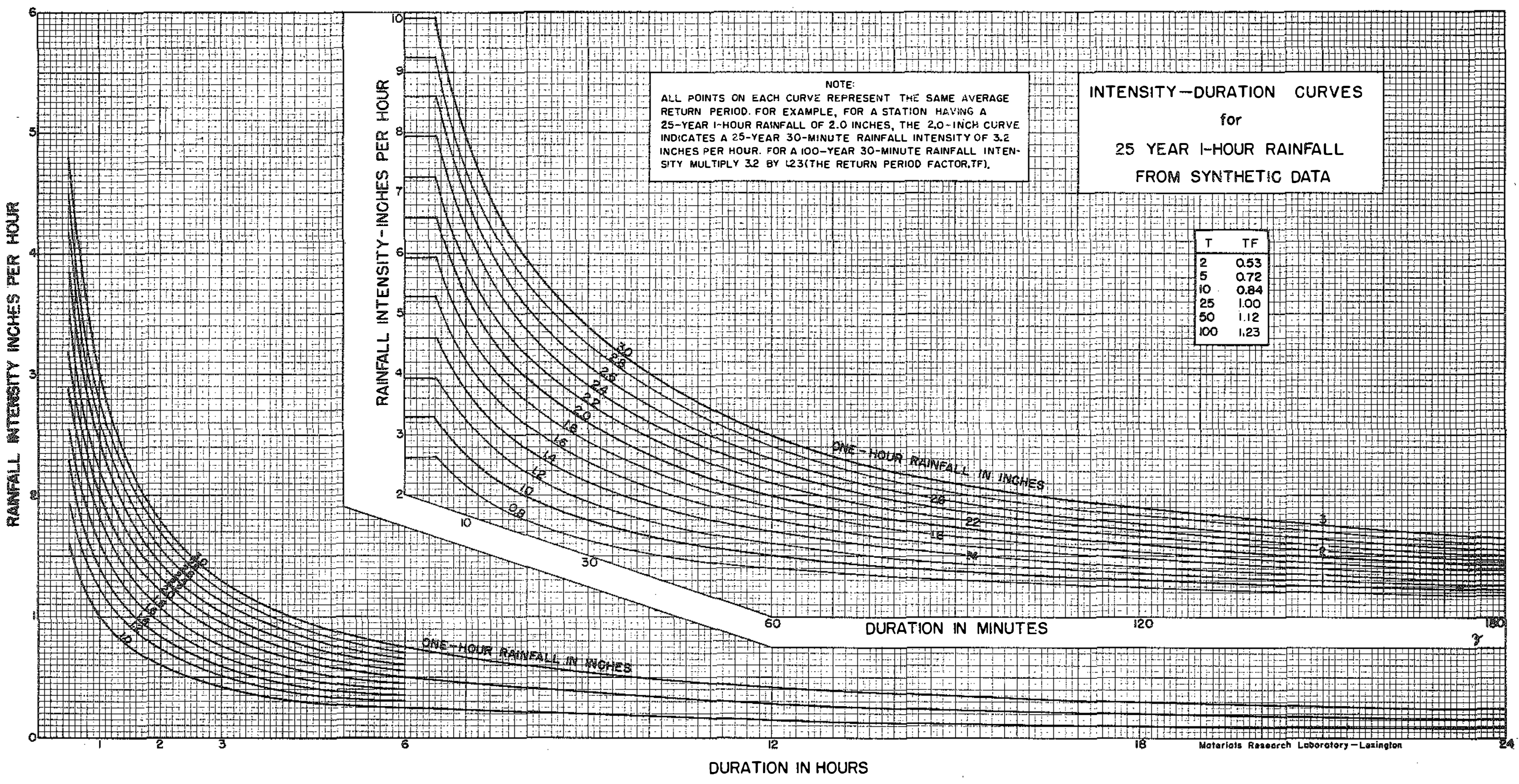
Entering Fig. 17 at the 60-min. duration, proceed upward to the 2.2 curve (for T_{25}, 1-hour). Follow this curve to the intersection of the 20-min. duration line and read 4.3 inches on the rainfall intensity scale. This value represents a 25-year, 20-min. intensity (T_{25}, 20-min.).

From Fig. 16f or from the inserted table on Fig. 17 select a return period factor (TF) for 100 years.

$$TF = 1.23$$

then, T_{100}, 20-min. = (4.3) (1.23) = 5.3 in. per hr.

By a similar procedure amounts for additional durations and return periods can be calculated. When three or more such periods are involved, they may be plotted on an overlay of Fig. 15a, 15c or 15d. These points should always approximate a straight line on this paper; otherwise, an error in procedure is evident. From a straight line drawn through the points, amounts for additional return periods may be estimated for the duration involved.


INTENSITY—DURATION CURVES
for
25 YEAR 1-HOUR RAINFALL
FROM SYNTHETIC DATA

NOTE:
ALL POINTS ON EACH CURVE REPRESENT THE SAME AVERAGE RETURN PERIOD. FOR EXAMPLE, FOR A STATION HAVING A 25-YEAR 1-HOUR RAINFALL OF 2.0 INCHES, THE 2.0-INCH CURVE INDICATES A 25-YEAR 30-MINUTE RAINFALL INTENSITY OF 3.2 INCHES PER HOUR. FOR A 100-YEAR 30-MINUTE RAINFALL INTENSITY MULTIPLY 3.2 BY 1.23 (THE RETURN PERIOD FACTOR, TF).

T	TF
2	0.53
5	0.72
10	0.84
25	1.00
50	1.12
100	1.23

Fig. 17 - Standard Rainfall Intensity-Duration Curves for Kentucky.

GLOSSARY

air mass - extensive body of air approximating horizontal homogeneity, identified as to source region and subsequent modifications.

annual rainfall - the total number of inches of rainfall occurring in one year at a particular station.

area-depth curve - curve showing, for a given duration, the relation of maximum average depth to size of area within a storm or storms, (also called depth-area curve).

average depth - mean depth of precipitation over an area; obtained from the arithmetical or weighted mean of the depths at points within the area.

average error - the arithmetical mean of all errors or deviations, regardless of sign, measured as departures from an accepted "true" value or mean.

coefficient of variation - (C_v) - a measure of relative variability, equal to the standard deviation expressed as a percentage of the mean.

cold front - front at which relatively colder air displaces warmer air.

comparative data - periodic summary of the annual and monthly means or normals of various meteorological elements at a station.

constant - a symbol whose range consists of only one value.

correlation coefficient (r) - a measure of the proportion of one variable's variation which is associated with the variation in another variable.

cumulonimbus - massive cloud with great vertical development, upper part having fibrous texture and spreading out in the shape of an anvil; the thunderstorm cloud.

cyclone - a circulation around relatively low pressure at the center, counter-clockwise in the Northern and clockwise in the Southern Hemisphere.

design discharge - the Q value for which the structure is designed for a specific recurrence interval or return period: T_{10}, T_{25}, T_{50}, etc.

depth-area-duration data - combination of area-depth and duration-depth relations; also called time-area-depth-data.

diurnal variation - change in the value of an element during each day.

duration rainfall - the time that rain continues to fall at a certain rate (inches per duration).

duration-depth curve - curve showing, for a given size of area, the relation of maximum average depth to duration within a storm or storms; also called depth-duration curve.

effective precipitable water (W_E) - the greatest amount of precipitable water that can be removed from a column of air by a specifically defined process.

effective rainfall - that portion of the total rainfall which finally reaches streams and rivers.

estimating equation (or prediction equation) - the straight line (running through a scatter diagram) which has been fitted so that the sum of the squares of the vertical deviations from it is less than from any other straight line. A line fitted in this manner is usually considered by statisticians to be the best line with which to estimate values of the variable plotted on the vertical axis, when those of the other variable are known, or if it is assumed that the relationship is a straight line.

excessive rainfalls - those equal to or greater than certain limits or specified limiting values of precipitation.

$d = 0.01t + 0.20$ (See Table 5)
d = depth in inches; t = time or duration in minutes.

first-order station - meteorological observatory making continuous records or hourly readings of pressure, temperature, wind, sunshine, and precipitation, and also visual observations of clouds at fixed hours.

frequency ($\phi(x)$ or $m/(n+1)$) - if m is arranged in the order of increased magnitude.

frequency factor K in the equation: $X = \bar{X} + S_x K$ or $\frac{X}{\bar{X}} = 1 + K C_v$

K is defined by Gumbel as:

$$-1/S_n \left[\bar{y}_n + \ln \ln \left(1 + 1/(T-1)\right)\right]$$

K is defined by Chow as;

$$-\frac{\sqrt{6}}{\pi}\left\{\gamma + \ln\left[\ln T - \ln(T-1)\right]\right\}$$ where $\gamma = 0.5772157$ Euler's Constant.

Table 5 - Standards of Excessive Precipitation*

DURATION		EQUAL TO OR LESS THAN	DURATION		EQUAL TO OR LESS THAN
HOURS	MINUTES		HOURS	MINUTES	
1/12	5	.25"	7	420	4.40"
1/6	10	.30"	8	480	5.00"
1/4	15	.35"	9	540	5.60"
1/3	20	.40"	10	600	6.20"
1/2	30	.50"	11	660	6.80"
2/3	40	.60"	12	720	7.40"
5/6	50	.70"	13	780	8.00"
1	60	.80"	14	840	8.60"
1-1/6	70	.90"	15	900	9.20"
1-1/3	80	1.00"	16	960	9.80"
1-1/2	90	1.10"	17	1020	10.40"
1-2/3	100	1.20"	18	1080	11.00"
1-5/6	110	1.30"	19	1140	11.60"
2	120	1.40"	20	1200	12.20"
3	180	2.00"	21	1260	12.80"
4	240	2.60"	22	1320	13.40"
5	300	3.20"	23	1380	14.00"
6	360	3.80"	24	1440	14.60"

JLT

* $(.01T + .20)$

front - surface of discontinuity or transition zone between two air masses, intersecting the ground (or another frontal surface) as a line or transition zone.

high - anticyclone.

histogram - block diagram with blocks having bases representing a class interval and heights proportional to the class frequency.

hurricane - specifically, a storm producing wind speeds in excess of 75 mph; generally, a cyclone of tropical origin.

hydrostatic pressure - pressure due to weight.

hyetograph - bar graph in which increments of rainfall are arranged chronologically.

infiltration - process whereby rainfall passes through the ground surface.

infiltration capacity - the maximum rate at which rain can be absorbed into a soil as rain falls. This rate is large at the beginning of a storm, then rapidly decreases and finally becomes a constant quantity.

intensity, rainfall - the rate at which rain falls during a given period usually measured in inches per hour.

isoceraunic - line of equal thunderstorm frequency (or thunderstorm day frequency).

isochrone - line of simultaneous time of beginning or ending.

isohyet - line of equal depth of precipitation.

isohyet-area curve - see minimum-rainfall curve.

isoline - line connecting equal values.

local (shower or thunderstorm) - occurring sporadically; not general.

low - cyclone.

mass curve - curve of cumulative values through time.

moisture, antecedent - moisture condition of the soil prior to the storm or peak runoff occurrence under consideration.

maximum annual peak rate of runoff - the maximum value of cfs (or, inches per duration) that occurs in one year for a specific duration.

maximum annual rainfall - the maximum value (in inches) that occurs in one year for a specific duration.

mean $(\bar{X})$ - is the arithmetic mean

mean deviation - mean of the deviations (disregarding sign) from an average value, usually the mean.

minimum-rainfall curve - similar to area-depth curve, except that ordinates represent minimum instead of average depths within the areas; also called isohyet-area curve.

mode (u) - the value around which the items tend to concentrate.

mountain wind - down-slope wind resulting from the greater nocturnal radiational cooling of the air in contact with the mountain slope than of the free air at the same level above the valley.

multiple correlation - measurement of the proportion of one's variable's variation which is associated with the variations in two or more other variables.

N - the number of events (months, years, etc.).

normal - average value of a meteorological element over a period of years sufficiently long to make the average acceptable as a standard from which to measure departures from normal.

normal distribution - a frequency distribution of observations of a variable determined by random causes.

occluded front - portion of the front surface (warm or cold) remaining in contact with the ground after the cold front has overtaken the warm front and lifted the air in the warm sector aloft.

orographic - caused by topographic slope.

percentage-depth-area curve - an area-depth curve, with depths plotted as percentages of depth over a specified area, usually the largest.

percentage frequency (%F) - ratio, expressed in percent, of items or occurrences in one class or interval to total of items or occurrences in all classes or intervals compared.

percentage probability (%P) - probability expressed in percent; percentage of certainty of occurrence; the number of occurrences out of 100 chances.

percent standard error (%SE) - ratio of standard error to the mean, expressed as a percentage.

planimeter - mechanical integrator for measuring plane area.

plotting position - $m/(N + 1)$ - position of an event on probability paper where m is arranged in order to increasing magnitude.

point rainfall - rainfall recorded by one gauge.

probability - ratio of the average or expected number of occurrences to the total number of matematically possible occurrences.

probable error - the value of error which divides all the observational errors into two classes of equal frequency and therefore of equal probability.

precipitation,antecedent - precipitation that occurred prior to the particular rainstorm under consideration.

precipitation,effective - that portion of the total rainfall which reaches streams and rivers, directly or indirectly.

rank (m) - position of a statistical event (arranged in order of increasing magnitude).

recurrence interval (RI) - the average interval of time within which a given peak discharge or rainfall will be equaled or exceeded, e.g., a 10-year RI rainfall will be equaled or exceeded on an average of once every 10 years, or more accurately, 10 times in 100 years (See Return Period).

$$RI = \frac{N + 1}{m}$$

reduced variate- $y = -\ln(-\ln \phi(x))$ where $\phi(x) = \frac{m}{N + 1}$

reduction (of meteorological observations) - conversion of observed values to more comparable values by reference to a standard base by computation.

regression coefficient - the rate of change of the dependent variable with respect to the independent variable; the slope of the regression line.

regression line - a line expressing the relation between two variables.

relative humidity (RH) - ratio of actual water-vapor content to saturation content or total water-vapor capacity, expressed as a percentage.

return period (T) - sometimes called recurrence interval, which is defined as the average interval of time within which the magnitude of a hydrologic event (X) will be equaled or exceeded once on the average.

$$T = 1/(1-\phi(x)) \text{ or } \frac{N+1}{n}$$

ridge - V or U shaped isolines bounding relatively high values, usually of pressure.

right (or positively) skewed distribution - an asymmetrical distribution of observations about a central value, characterized by high frequencies of the lower values.

root-mean-square - the square root of the arithmetical mean of the squared items.

runoff - the contribution from precipitation to streamflow.

S - summation of events or items

SX - summation of the observed variates

SX^2 - summation of the squares of the observed variates

runoff coefficient - $\frac{\text{peak rate of runoff for a given return period}}{\text{average rainfall intensity of the same return period}}$

slope (1/a) - the logarithmic rate of increase or the slope of the theoretical straight line on extreme probability paper.

S_n - the expected standard deviation of reduced extremes

standard error of estimate - ($s_{1.2}$) - a measure of the amount of variability in the dependent variable that we have failed to account for by our estimating equation, but it is stated in terms of the original data (in our case, inches of rainfall per duration). $s_{1.2}$ may be expressed as a percentage of the dependent variable arithmetic mean.

standard deviation - S_x - the average deviation from the mean computed by taking the square root of the arithmetical mean of the squares of the individual deviations. (For small samples, it is the square root of the quotient obtained by dividing the sum of the squared deviations by one less than the number of deviations).

station, weather bureau - the following types of weather bureau stations are engaged in the collection of precipitation data and related meteorological data:

(1) first-order stations - (staffed by commissioned weather bureau personnel), taking detailed observations at intervals determined by the station's mission.

(2) second order stations[1] - (staffed by part-time employees), taking detailed observations at 6-hour or 3-hour intervals.

(3) airway stations[1] - taking on-call observations in connection with airway operations. (Some of these stations are operated by the CAA but records are kept by the Weather Bureau).

(4) river and rainfall stations[1] - taking river-stage and rainfall observations, usually for use by river forecasting centers.

(5) crop stations[1] - taking observations for use by the Weather Bureau in connection with its services to growers of various crops.

(6) fruit-frost stations[1] - taking observations for local use in forecasting frost in fruit-growing areas.

(7) climatological and hydroclimatic stations[1] - (including unpaid cooperative observers), taking observations of temperature and precipitation for general climatological, hydrologic, and other uses.

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[1] Called Secondary Stations in this report.

(8) evaporation stations[1] - taking observations of evaporation from pans.

Requests for data or information concerning first-order stations ((1) above) should be directed to the station involved or the appropriate section center. Requests for data or information concerning all sub-stations ((2), (3), (5), (6), (7) and (8) above) should be directed to the appropriate state section center. The area hydrologic engineers as field representatives of the Washington office provide liaison with the other Federal agencies concerning expansion of the network and operation of stations. The records processing centers transcibe all recorder charts and publish the state "Climatological Data" bulletins mentioned above. Matters concerning reporting networks ((4) above) should be referred to the appropriate river district office.

storm profile - vertical section through an isohyetal pattern, with distance from center as abscissa and corresponding depth of precipitation as ordinate.

synoptic - showing the distribution of meteorlogical elements over an area at a given moment, e. g., a synoptic chart.

Thiessen Method of weighting - method for determining the average depth of precipitation over an area by the construction of Thiessen polygons, by means of which the individual observations are areally weighted.

Thiessen polygon - geometrical figure drawn by plotting perpendicular bisectors between adjacent precipitation stations. These bisectors form closed areas around each station and together form a network of contiguous polygons, for each of which the enclosed station's precipitation is considered representative.

time of concentration (t_c) - the estimated time required for runoff to flow from the most distant point of drainage area to the point at which the discharge is to be determined, thus giving a peak discharge.

trace - half or less than .01 inch of precipitation.

tropical storm - cyclone of tropical origin; hurricane.

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[1] Called Secondary Stations in this report.

variable - a number symbol which may take on any value in a set of values which is called its range.

variable dependent (X_1) - axis or Y-axis - that which is dependent on another variable or variables; usually designated as variable or variables.

variable independent (X_2, X_3, etc., or X-axis - that which is known and is used to predict the dependent variable.

variates - values obtained by taking observations or measurements on one or more variables. In general, statistical data are obtained in this manner. For example, in computing the average monthly rainfall of a region the variable is rainfall and the amount of rainfall for any month is variate.

variations:

explained variation (S x_{12}- that part of the total which is explained by the relationship between X_2 and X_1; the deviation from the mean of a computed value.

total variation - explained variation + unexplained variation

unexplained variation - (S $x_{1,2}$) - that part of the total which remains unaccounted for after X_2 is taken into consideration; it is the deviation of the actual value from the computed value.

warm front - from at which relatively warmer air replaces colder air.

weighed average (used in Thiessen method and Rational Formula) - rainfall for a basin computed by multiplying each station precipitation amount by its assigned percentage of area and totaling; the results are usually more accurate than the arithmetic average.

X - theoretical or observed event

$\bar{y}_n$ - expected mean of the reduced extreme.

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