PDHonline Course C678 (3 PDH)

Peak Rates of Runoff from Small Watersheds

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Peak Rates of Runoff from Small Watersheds

HDS 2

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Welcome to HDS 2-Peak Rates of Runoff from Small Watersheds.

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Statement of the Problem

An obviously basic problem in the design of bridges and culverts is that of estimating the volume of streamflow to be expected at peak periods. It has long been realized, among hydrologists, that differences in watershed area alone are insufficient to explain the wide variations in peak rates of runoff found to exist among watersheds. This is true even when these variations are limited to those within the boundaries of an area where the principal physiographic characteristics of watersheds are similar.

Strong evidence of this statement is given by the wide scatter of the plotted points shown in Figure 1, representing the relation of watershed area to peak streamflow of 10-year average recurrence interval for 96 gaged watersheds. (As will be explained later, the zones represented are areas of similar underlying rock formations.)

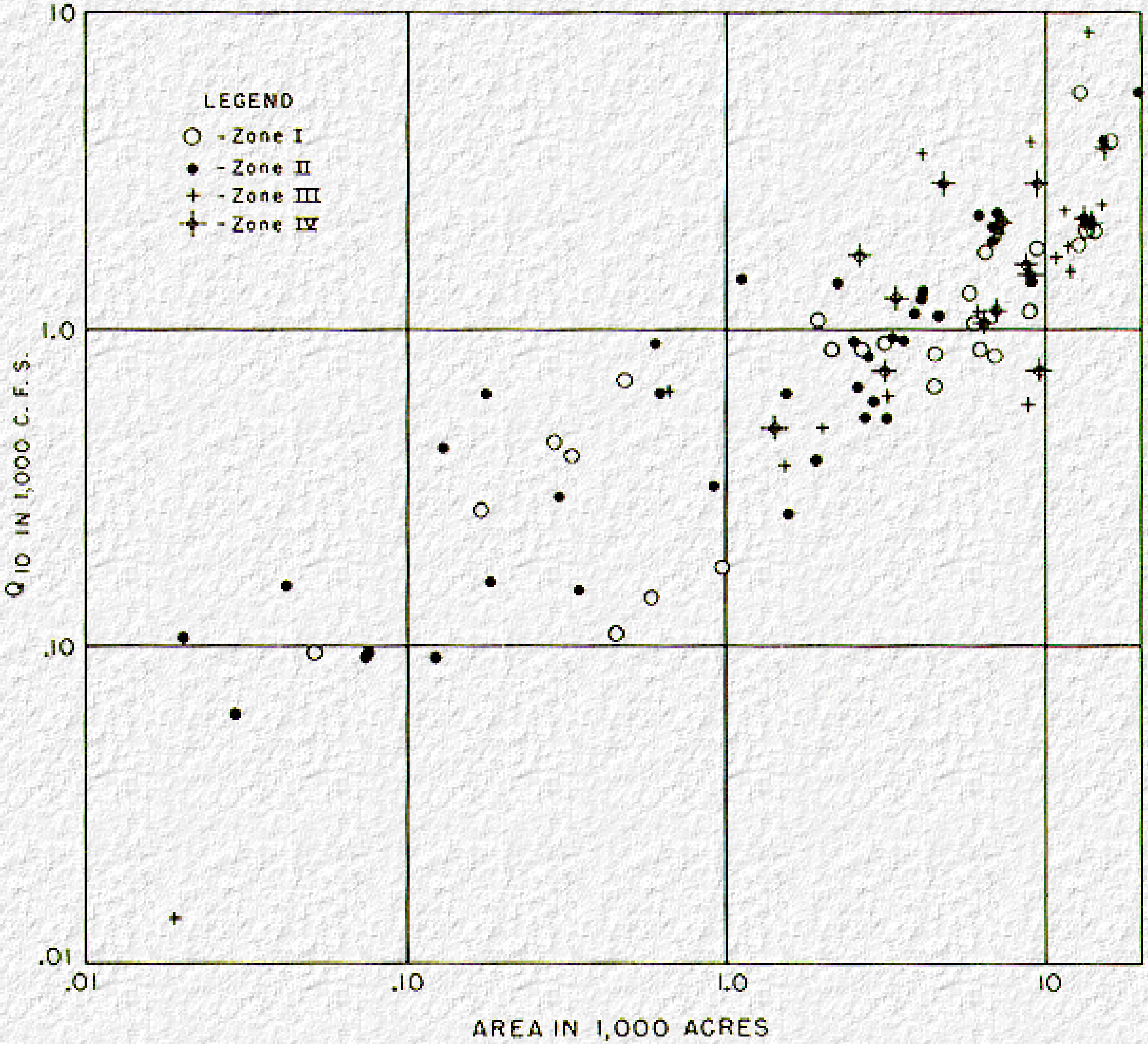

Figure 1. Q_{10} versus Watershed Area

While area alone has been found lacking as a measure of peak runoff, it has been discovered that if one or more precipitation indexes and some topographic index based on the length and slope of the principal stream channel were added to the watershed area factor as independent variables, the unexplained variation in the magnitude of the peak rates of runoff could oftentimes be reduced to workable limits.

Although this method was an improvement over the the results obtained by the consideration of watershed area alone, it still did not explain the large differences that many times occurred between some of the estimated peaks and the corresponding actual values derived from stream measurements. In these cases the differences might be no more than $\pm$20 percent of the estimate for 68 percent of the gaged watershed sample, but would be over 100 percent for 5 to 10 percent of the sample. This would suggest the action of some additional variables that remained fairly constant for most of the gaged sample but differed significantly for the 5 to 10 percent.

The research investigation reported here successfully determined the identity of these additional variables, and from it there has been developed a procedure for predicting runoff peaks from small watersheds in most of the United States east of the 105th meridianCroughly, east of Denver, Colo.

The evidence presented in this report might seem to provide a logical basis for the extrapolation of the relations and procedures developed to unsampled physiographic areas. It is realized, however, that only time and the measurements from hundreds of additional small watersheds could prove whether or not such extrapolation was justifiable. Unfortunately, the highway engineer cannot wait for such proof but must continue to design drainage structures for highway system improvements needed for our ever-expanding traffic. Although the objective of this investigation was to furnish assistance to the highway engineer, he should keep in mind that estimates obtained for watersheds in unsampled physiographic areas through the use of these relations and procedures should be considered as aids to engineering judgment rather than as proven figures.

Selection of Zones

It was originally intended to limit the investigation to an analysis, by physiographic areas, of the runoff records from gaged watersheds. An inventory of existing streamflow records made it apparent, however, that such a procedure would leave a large majority of physiographic areas with no representative sample of gaged watersheds. This led to the abandonment of the original plan and to a search for some other classification that would be much broader than the physiographic area and at the same time would offer some assurance of similarity of runoff relations within any one class.

Recent research (1, 5)[1] has shown that a high correlation exists between the physiographic characteristics of watersheds and the underlying rock formation for any given climatic environment. A high correlation has also been found to exist between the physiographic characteristics of watersheds and peak rates of runoff for any climatic environment. It follows, therefore, that a correlation should exist between peak rates of runoff, physiographic characteristics, and climate for watersheds underlain by similar rock formations. It was this assumption that led to a study which resulted in the selection of four zones of similar underlying rock formations in the areas from which the watershed samples were drawn.

The grouping of physiographic areas into these four zones was based on the map prepared by the Soil Conservation Service, U.S. Department of Agriculture, in July 1950, entitled, Problem Areas in Soil Conservation, together with the descriptions of each problem area contained in unpublished manuscripts of the Soil Conservation Service.

The four zones are shown on the maps in Figure B-1a, Figure B-1b, Figure B-1c, and Figure B-1d, and are briefly described as follows:

- **Zone I.** Zone I includes areas underlain by either loess or glacial till; located for the most part in the Central Basin and in the central portion of the Great Plains.
- **Zone II.** Zone II includes areas underlain by sandstone and shale; located for the most part in scattered portions of the Appalachian-Ozark Highlands and in the southeast portion of the Great Plains.
- **Zone III.** Zone III includes areas underlain by limestone; located for the most part in the southerly portions of the Appalachian-Ozark Highlands, the Central Basin, and the Great Plains.
- **Zone IV.** Zone IV includes areas underlain by schist; located in the eastern portion of the Appalachian-Ozark Highlands.

[1]Italic numbers in parentheses refer to the references.

Areas Omitted from Investigation

The Atlantic and Gulf Coastal Plain was not included in this investigation except for those areas in the Middle and Upper Coastal Plain located in Alabama, Georgia, and Florida, and for those areas in the Blacklands Coastal Plain. With these exceptions, the areas in the Atlantic and Gulf Coastal Plain are underlain by alluvial material consisting largely of unconsolidated sands and gravel. They include the Florida Everglades and areas along the Gulf that have poorly defined drainage and are subject to salt-water flooding. The small sample of gaged watersheds available, all located on the northeast Atlantic coast, was considered too small to be representative of the above-described areas of the Coastal Plain.

With the exception of New England and portions of New York and New Jersey, the entire Appalachian-Ozark Highlands are included in this investigation. The excepted areas are all underlain by granite and the sample of gaged watersheds was considered too small to be representative.

The northern portion of the Central Basin, also excluded from this investigation, consists of areas of extensive peat bogs, areas of kames and kettleholes with poorly defined drainage, or areas that were once the beds of large glacial lakes. Also excluded were the flood plains of the major streams and the Kankakee Drainage Area in northwest Indiana and northeast Illinois.

The northern portion of the Great Plains, also excluded from this investigation, consists largely of areas of kames and kettleholes,with poorly defined drainage, the Badlands of North Dakota, and the Residual Plains of the Dakotas. Also excluded were the Nebraska Sand Hills.

Watershed Samples

The application of conclusions that might be drawn from the analysis of the runoff records from a sample of gaged watersheds to unsampled areas within a zone could only be justified if the assumptions already stated as to similarity of physiographic characteristics and hence runoff relations within a zone were valid.

Since an adequate test of their validity could not be made with the limited sample of gaged watersheds available for analysis, it was decided to base this phase of the investigation on the analysis of the physiographic characteristics of an additional sample of ungaged watersheds. This sample would be independent of the gaged watershed sample and, insofar as map coverage would permit, would be selected so as to give equal representation both as to location of the watersheds and as to their range in size.

Plan of the Report

The study of the ungaged watershed sample is reported in Part I, which follows this introduction; the study of the gaged watershed sample is reported in Part II. The list of references cited in these two parts follows thereafter. Next in order comes Part III, in which are presented some considerations regarding the procedure for estimating peak rates of runoff from small watersheds, developed from the investigations described in Part I and Part II. The procedure itself is presented in Part IV.

The zone and rainfall index maps and some of the graphs presented in this report are used in the procedure for estimating peak rates of runoff, and for convenience in practical office use they are placed following Part IV, at the back of the report. The figures involved, which are also cited in Part I and Part II, are Nos. B-1a, b, c, and d; B-2a, b, c, and d; C-1a, b, c, and d; D-1a and b; E-1; and E-3. The numbering used for these illustrations corresponds with the numbering of the steps in the procedure.

Go to Part I

Part I : HDS 2

Study of Ungaged Watershed Sample

Go to Part II

Selection of Sample

For the study of the ungaged watersheds the following procedure was used in selecting the ungaged sample, wherever map coverage permitted. Zone boundaries were superimposed on river basin maps (2). Using these, together with the index map sheets showing available U.S. Geological Survey topographical maps, three quadrangle maps were selected for each unit area of 1° latitude by 1° longitude. The selection was made by visual study, with the object of choosing quadrangle maps that gave fair distribution and that would provide the desired variation in size of watershed as described in the next paragraph.

One watershed was selected from each of these maps, each of these selections being for a watershed of a different size group. Three size groups were considered: Watersheds of approximately 1 square mile; watersheds with areas of approximately 3 to 5 square miles; and watersheds with areas of approximately 20 square miles. Thus each unit area of 1° latitude by 1° longitude was sampled by the selection of three different sized watersheds. In making these selections only watersheds that were free of lakes, swamps, and reservoirs were chosen. Table 1 shows the distribution of the ungaged watershed sample by zones and physiographic areas.

Precipitation and Topographic Indexes

The ungaged watershed sample was used to study, by zones, the possible relations that might exist between various precipitation and topographic indexes. The indexes selected for study were as follows:

> **Area of watershed, A**. The boundary of each watershed area was outlined on the topographic map and its area A was measured with a planimeter.
>
> **Precipitation index, P**. The precipitation index P was defined as the amount of precipitation, measured in inches of rainfall, that might be expected to be equaled or exceeded during a 60-minute period on an average of once in 10 years. Maps showing lines of equal value of P, shown in Figure B-2a, Figure B-2b, Figure B-2c, and Figure B-2d, were prepared from data published by the U.S. Weather Bureau (12, 13, 14). From these maps the value of P was determined for the lowest point of the principal stream channel in each watershed.
>
> **Topographic index, T.** The topographic index T was defined as the sum of the ratio of seven-tenths the length of the principal stream channel, measured from its lowest point, to the square root of its slope, plus the same ratio determined for the remaining three-tenths of its length (9, 10). Channel lengths were measured in miles and slopes in feet per mile.
>
> The designation number for each watershed, its location by zone and physiographic area, the area of the watershed in square miles, and the elevations and channel lengths necessary for the computation of T were all punched on cards and the values of T computed by an electronic digital computer.
>
> **Drainage density, D**. The drainage density D was defined as the ratio of the summation of the length of all stream channels within a watershed to the watershed area. The total mileage of stream channel was determined for each watershed from the topographic

maps by means of a map measurer. These total lengths, in miles, were then divided by the area of the watershed, expressed in thousands of acres, to obtain values of D.

Graphical Correlations

T vs. A and P

Graphical correlations of T vs. A and P were made for each zone. In order to obtain the greatest degree of homogeneity among the variables, watersheds from only one physiographic area within each zone were used in these correlations. In all cases the physiographic area selected was the one from which the largest sample had been drawn. For each of the sample watersheds in this area, values of T were plotted as ordinates on logarithmic graph paper against corresponding values of A. The value of P selected for each watershed was inscribed above the corresponding plotted point and lines of equal P were drawn so as to best fit the inscribed values, as shown in Figure D-1a and Figure D-1b.

Table 1. Distrbuion of Ungaged Watershed Sample by Zones and Physiographic Areas

Zone and Physiographic Area	Number of Watersheds
Zone I:	
Glaciated shale and sandstone area of New York, Pennsylvania, and Ohio.	22
Central claypan area	19
Iowa-Illinois deep loess drift area	18
Total, Zone I	**59**
Zone II:	
Allegheny-Cumberland Plateau	43
Michigan-Indiana-Ohio till plain	29
Western Kentucky-Southern Indiana sandstone and shale area	6
Total, Zone II	**78**
Zone III:	
Appalachian valleys and ridges	34
Northern Ozarks	24
Total, Zone III	**58**
Zone IV:	
Piedmont Plateau	39
Blue Ridge Mountains	12
Total, Zone IV	**51**
Grand Total, all zones	**246**

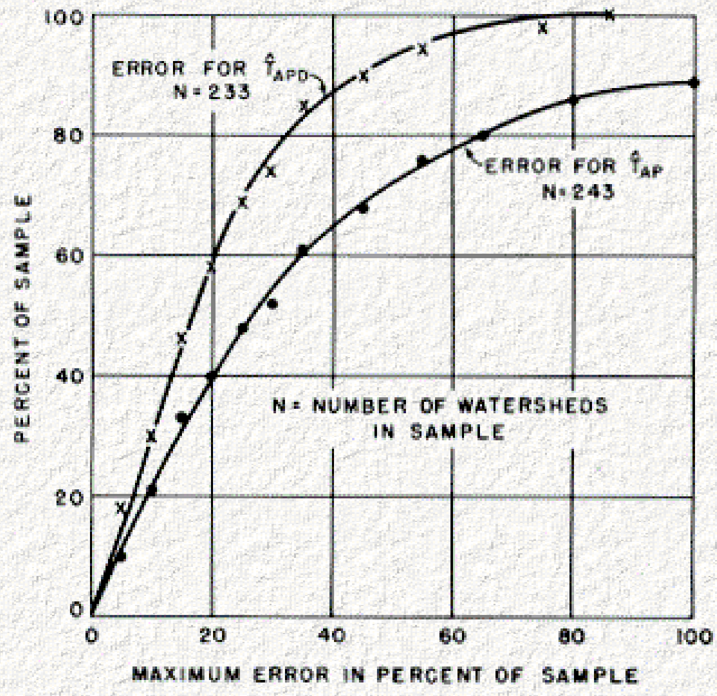

Figure 2. Error Distribution for $\hat{T}_{AP}$ and $\hat{T}_{APD}$ for all Ungaged Watersheds

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Error

A measure of the accuracy with which a correlation graph estimates a dependent variable for any one watershed is obtained by comparing the estimate with the observed value. The difference between the estimated and observed value expressed as a percentage of the estimate,

$$[(\text{estimate-observed value}) / \text{estimate}] \times 100$$

is referred to in this study as the error in the estimated value of the variable. The distribution of the absolute values of these errors for any watershed sample is a measure of the precision that might be expected from the correlation graphs in estimating the value of the dependent variable for similar watershed samples.

A distribution-of-error graph for any watershed sample is obtained by dividing the absolute error into groups. Starting with 0-5 percent, the range of each succeeding group is increased by some fixed percentage, as 0-10 percent, 0-15 percent, etc. The number of watersheds in each group, expressed as a percentage of the number of watersheds in the sample, is plotted against the upper limit of the corresponding error group and an average curve fitted by eye to the plotted points. The standard error for the watershed sample is the error indicated by the curve for 68 percent of the sample. The errors may be said to be distributed normally when the distribution curve is a reverse or ogee curve and when 95 percent of the watershed sample has errors that are equal or less than two standard errors and 100 percent of the sample has errors no greater than three standard errors.

Using the correlation graphs in Figure D-1a and Figure D-1b, and the tabulated values of A and P, estimates of T as a function of A and P, (that is, $\hat{T}_{AP}$), were obtained for each of the 243 ungaged watersheds. The difference between these estimated values and the measured values of T were expressed as a percentage of the estimate and tabulated as the error in $\hat{T}_{AP}$. Using the procedure outlined in the preceding paragraph, the distribution of these errors was computed and is shown in the lower curve in Figure 2. The fact that the maximum error for 68 percent of the watersheds was $\pm$44 percent while that for 11 percent of the watersheds exceeded 100 percent led to the conclusion that A and P alone were insufficient to explain the large variations in T that might be expected within a zone of homogeneous lithology.

Watershed Maturity

Melton (6) found that the maturity of the drainage basins played an important part in establishing correlations that might exist between certain physiographic characteristics. He defined the term, in the sense that he used it, as follows:

"A 'mature' drainage basin is considered to be a basin whose every channel has developed a watershed with smooth slopes extending to the divides. No implication about erosional history is intended, nor is it implied that a steady state of some feature of the basin is a necessary condition for maturity." (6 p. 36.)

If Melton's conclusions were valid, physiographic characteristics of watersheds could be expected to vary as some function of precipitation and degree of maturity even when located within a zone of homogeneous lithology. A comparison of topographic maps definitely indicated a considerable variation in the degree of maturity among watersheds within the same physiographic area, and an even greater variation between watersheds located in different physiographic areas within the same zone.

T vs. A, P, and D

In order to study the possible relation between degree of maturity and T, A, and P, it was first necessary to select some measurable physiographic characteristic that would reflect differences in maturity. The characteristic found to be most satisfactory for this purpose was drainage density, D.

Accordingly, for each zone, the values obtained for $\hat{T}_{AP}$ were plotted as ordinates on logarithmic graph paper against the corresponding measured values of T. The value of D for each watershed was inscribed above the corresponding plotted point and lines of equal D were drawn so as to best fit the inscribed values. Figure 3 shows the graph derived for Zone II. With the exception of the slope of the lines of equal D and the length of the log-cycle used to determine their spacing, this graph is typical of those derived for the other three zones.

Using these correlation graphs and the values of $\hat{T}_{AP}$ and D, a new estimate of T as a function of A, P, and D ($\hat{T}_{APD}$) was obtained for each watershed. As in the case of $\hat{T}_{AP}$, the error in values of $\hat{T}_{APD}$ was taken as the difference between $\hat{T}_{APD}$ and the measured value of T, expressed as a percentage of the estimated value.

The upper curve in Figure 2 shows the distribution of the errors in $\hat{T}_{APD}$ for the 233 watersheds for which values of D were compiled. This curve indicates that the addition of the variable D to the correlations had not only eliminated practically all of the excessive errors but also had reduced the maximum error for 68 percent of the watersheds from $\pm$44 percent to $\pm$24 percent.

Variations in Measurements of D

No statistical test other than the plotting of a distribution-of-error graph for $\hat{T}_{APD}$ was considered justified in view of the many uncertainties surrounding the determination of D. These uncertainties stem primarily from the lack of precision in the definition of what constitutes a stream channel and are aggravated by the variations in detail found among topographic maps.

Definitions of what constitutes a stream channel vary from the consideration of only those channels shown as a blue line on the topographic map to the inclusion of every set of V-shaped contours (3, 4, 7, 8). The number of channels shown on a topographic map as a blue line was found to vary widely and seemed to depend either on the judgment of the cartographer who drew the map or on the number of channels where water was present at the time the survey was made. On the other hand, when every set of V-shaped contours was considered to be a stream channel, the value of D for any watershed was found to vary with the amount of detail shown on the topographic map. This in turn was found to depend on the scale of the map, the contour interval used, and whether the map was based on ground surveys or on aerial photographs.

In this study, in measuring the values of D for the watershed sample in Zone II, stream channels were taken to be those shown as a blue line on the topographic map plus those that were equally well defined by the contours. For Zone I watersheds, the concept of what constituted an "equally well defined" channel was broadened to include channels that would not have been included in the Zone II measurements. This concept was still further broadened for the Zone III watersheds. In Zone IV, where the variation between map scales and contour interval was the greatest, all channels indicated by V-shaped contours were assumed to be stream channels.

Because of the changing concept of what constituted a stream channel, measurements of D were not comparable as between zones. They were considered to be fairly comparable, however, within Zones I, II, and III. The maps for the watersheds in these zones were, for the most part, 15 minute quadrangles with a scale of 1:62,500 and a contour interval of 10 or 20 feet. Subjectivity was kept to a minimum by having all of the measurements made by one individual. In Zone IV, the great variation in the scale and contour interval of the maps necessitated the division of the watershed sample into three map classes and the preparation of a separate correlation graph for each map class. The three map classes were those having: A 20-foot contour interval and a scale of 1:62,500; a 10-foot contour interval and a scale of 1:24,000; and a 40- or 50-foot contour interval and a scale of 1:24,000.

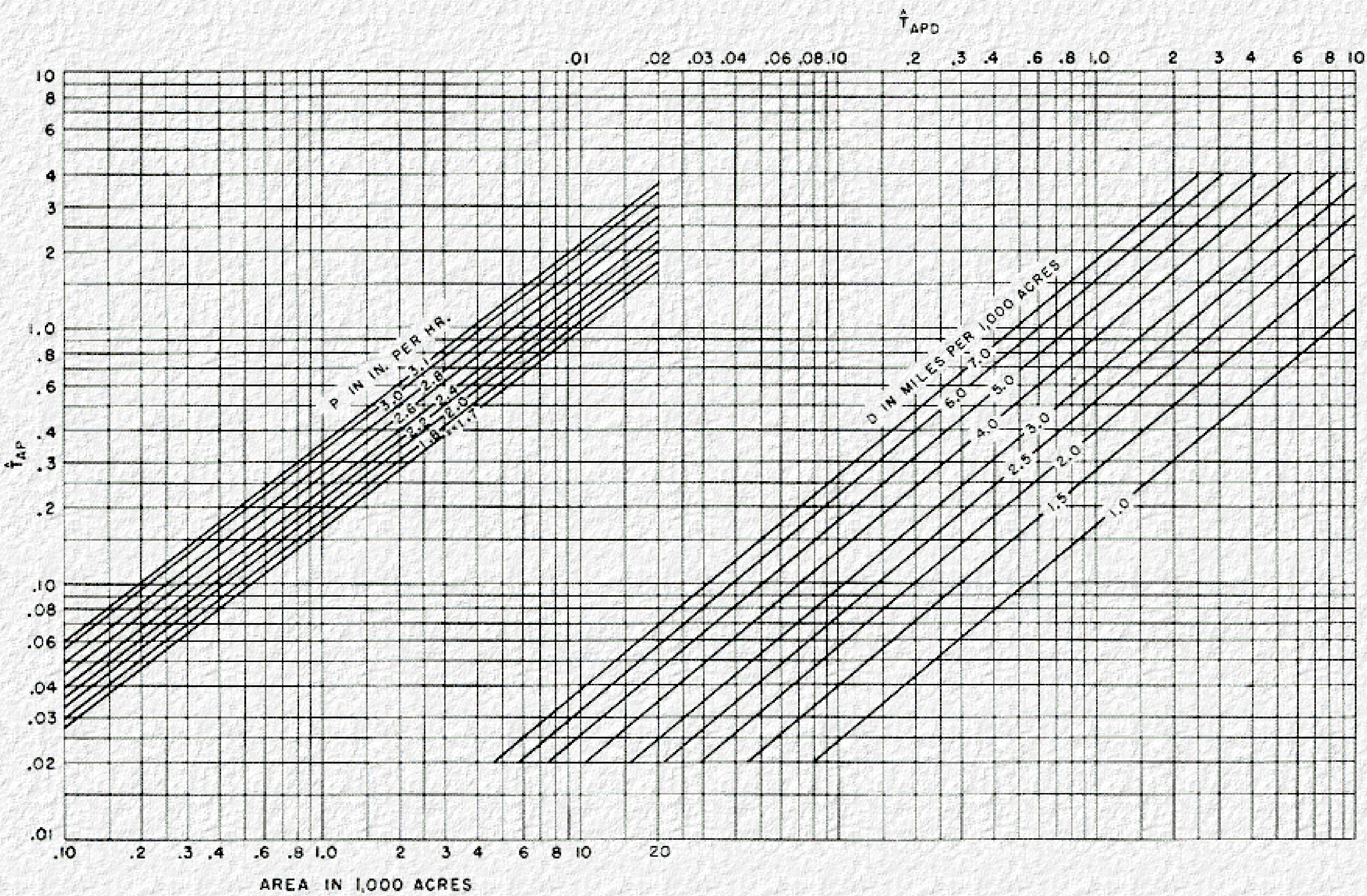

Figure 3. Relations between T, A, P, and D, for Zone II

Conclusions

The foregoing discussion points up the difficulties that are encountered when drainage density is used as one of the variables in correlation studies. However, the elimination of the large percentage of excessive errors and the reduction of the maximum error for 68 percent of the watersheds from ±44 percent to ±24 percent were considered to be too marked an improvement in precision to have been caused wholly by variations in D that could be ascribed to subjectivity or differences in map detail. It was therefore concluded that within a zone of homogeneous lithology a high degree of correlation did exist between T and D and that T could be said to vary inversely as some function of D.

If the above conclusions were true, then a large error in $\hat{T}_{AP}$ would indicate a watershed that had different drainage characteristics than those for which the error was small. If the relations between the magnitude of peak rates of runoff and these two sets of drainage characteristics were also different, then those differences might very well account for the large errors in estimates of peak rates experienced for a small percentage of sample watersheds in many peak rate studies, referred to in the introduction of this report.

Go to Part II

Part II : HDS 2

Study of Gaged Watershed Sample

Go to Part III

Selection of Sample

The second part of this investigation was made with a sample of gaged watersheds in an attempt to further verify the suppositions stated in Part I, and to develop a procedure that would compensate for large errors in estimates of peak rates that might be due to differences in drainage characteristics. To be of practical use to the highway engineer the second objective had to be attained without the use of D as one of the required variables. The subjectivity and variations due to differences in map detail, coupled with the fact that a considerable portion of the country is still unmapped, made the use of D in estimating flood peaks to be of doubtful value.

The sample of gaged watersheds was screened from an inventory of all available streamflow records for watersheds having a size range of from 1 to 16,000 acres and located east of the 105th meridian. The screening was undertaken because it was desired to consider only natural, mixed-cover watersheds typical of the general area, and for that reason the following types were excluded: (1) Watersheds with manmade controls such as diversions or storage reservoirs; (2) watersheds with 1 percent or more of the area in lakes, swamps, or excessive flood-plain storage; (3) watersheds with 20 percent or more of the area in urban development; and (4) experimental watersheds with controlled land use when such land use varied throughout the period of runoff record or was different from the prevailing land use ascribed to mixed-cover watersheds in the vicinity. Table 2 lists the location, area, and period of runoff record for the gaged watershed sample selected for each of the four zones.

Click here to view Table 2- Gaged Watershed Sample: Location, Area, and Period of Record

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Frequency Studies

Frequency studies of the maximum annual peak rates of runoff were made for each watershed. In order to minimize the error that might result from the many short periods of runoff record, relations between peak rates of high and low frequency (11) were used to obtain values of peaks that could be expected to be equaled or exceeded on an average of once in 10 years (Q_{10}) and once in 50 years (Q_{50}) above relations had previously been determined from a sample of 69 gaged watersheds located east of the 105th meridian and having runoff records of from 26 to 40 years.

It had been found that when the maximum annual peaks for these watersheds were plotted on external probability paper, they defined two straight-line frequency curves. The lower curve was defined as the average curve for peak rates whose average recurrence interval was less than 5 years and the upper as the average curve for peaks with recurrence intervals equal to or greater than 5 years. A high degree of correlation had been found to exist between the 10-year peak as defined by the lower curve and the 10- and 50-year peaks on the upper curve. To use these relations it was only necessary to determine the 10-year peak on the lower frequency curve. Since the latter curve was fairly well defined by even short periods of runoff records, it was possible to obtain a precision for values of Q_{10} and Q_{50} (on the upper curve) that otherwise would have been obtained only if all of the runoff records had been for 26 years or longer.

Click here to view Table 3- Basic Data and Values of $\hat{T}_{AP}$ and $\hat{Q}_{10(ATP)}$ for Group 1 Watersheds

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Tests of Homogeneity of Drainage Characteristics

For each of the gaged watersheds, values of T were computed from measurements taken from USGS topographic maps. Values of P were selected from the precipitation maps (Figure B-2a, Figure B-2b, Figure B-2c, and Figure B-2d) corresponding to the location of the gaging station for each watershed.

The study of ungaged watersheds had provided an easy procedure for detecting differences in drainage characteristics. Such differences had been found to be reflected in the magnitude of errors in values of $\hat{T}_{AP}$. It was now proposed to utilize this procedure to determine whether or not differences in drainage characteristics, as measured by errors in $\hat{T}_{AP}$ also be reflected in the magnitude of errors in estimated values of Q_{10}. Accordingly, the correlation graphs of T vs. A and P, derived, as described in Part I, from the ungaged watershed sample and shown in Figure D-1a and Figure D-1b, were used in conjunction with values of A and P to obtain a value of $\hat{T}_{AP}$ for each of the gaged watersheds. The error in values of $\hat{T}_{AP}$ was then expressed as a percentage of $\hat{T}_{AP}$.

Preliminary studies indicated that differences in drainage characteristics, as expressed by errors in $\hat{T}_{AP}$, had no significant effect on the magnitude of Q_{10} when these errors were less than approximately $\pm$30 percent. (This conclusion was later tested with the final correlation graphs for Q_{10} and was found to be substantially correct.) This figure of $\pm$30 percent was therefore used to sort the watershed sample for each zone into two groups. The first group, with errors in $\hat{T}_{AP}$ less than $\pm$30 percent, contained the watersheds with drainage characteristics similar to those of the watersheds on which the correlation graphs were based. The second group, with errors in $\hat{T}_{AP}$ of $\pm$30 percent or more, contained the watersheds whose drainage characteristics differed in varying degrees from those of the first group. These two groups are hereafter referred to as Group 1 and Group 2.

Click here to view Table 4- Basic Data and Values of $\hat{T}_{AP}$ and $\hat{Q}_{10(ATP)}$ for Group 2 Watersheds

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G

raphical Correlations

Q_{10} VS. A, T, and P. If the watersheds from both groups had been used to determine correlations between Q_{10} and A, T, and P, the resulting correlation would not have been the best average for any one set of drainage characteristics. Instead, they would have been the best average for the various drainage characteristics in the mixed sample. In other words, the correlations would have been dependent on the distribution of drainage characteristics in the sample used. Since the distribution of these characteristics could vary widely between samples, such correlations would have been of doubtful value in providing a stable base for the comparison of errors in estimated values of Q_{10}.

If, instead of the above procedure, only watersheds in Group 1 for each zone were used to establish correlations between Q_{10} and A, T, and P, such correlations would represent the best average for just one set of drainage characteristics; namely, that for which the error in $\hat{T}_{AP}$ was less than $\pm$30 percent.

Accordingly, only Group 1 watersheds in each zone were used in the preparation of correlation graphs of Q_{10} versus A, T, and P, which are shown in Figure C-1a, Figure C-1b, Figure C-1c, and Figure C-1d. The procedures used in the preparation of these graphs were the same as those described in Part I for the T versus A, P, and D graphs. Tabular values of A, T, and P were then used in conjunction with the Q_{10} correlation graphs to obtain estimates of Q_{10} as a function of A, T, and P (designated as $\hat{Q}_{10(ATP)}$ for both Group 1 and Group 2 watersheds.

These estimates were compared with the corresponding values of Q_{10} derived from the frequency studies and the differences or errors expressed as percentages of the estimates, as shown in Table 3 and Table 4.

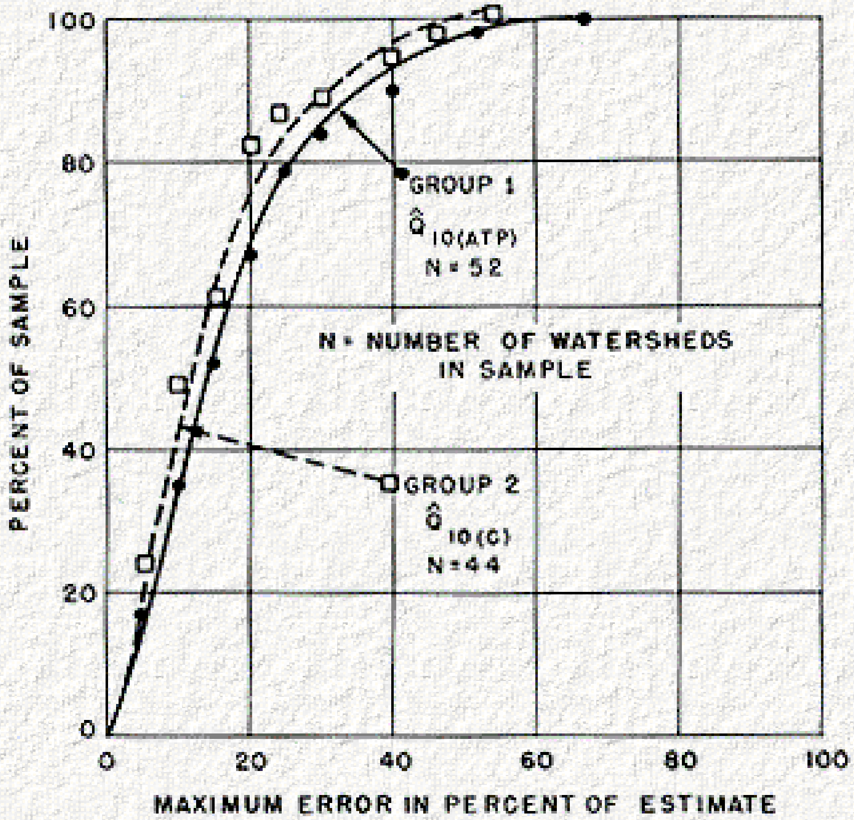

Figure 4. Error Distribution for $\hat{Q}_{10(ATP)}$ for Group 1 Watersheds and for $Q_{10(C)}$ for Group 2 Watersheds

Errors in $\hat{Q}_{10(ATP)}$. A distribution-of-error graph, the solid-line curve in Figure 4, was prepared for the absolute errors in the values of $\hat{Q}_{10(ATP)}$ for the 52 watersheds in Group 1. This graph indicates these errors to be normally distributed, with the maximum error for 68 percent of the sample being $\pm$20 percent, that for 95 percent of the sample being $\pm$42 percent, and that for 99 percent of the sample being $\pm$60 percent. On the other hand, an examination of Table 4 shows that, for the Group 2 watersheds, 64 percent of those with negative errors in $\hat{T}_{AP}$ equal to or greater than 30 percent had corresponding negative errors in $\hat{Q}_{10(ATP)}$ greater than 100 percent. Likewise, 88 percent of those with positive errors in $\hat{T}_{AP}$ equal to or greater than 30 percent had corresponding positive errors in $\hat{Q}_{10(ATP)}$ of from 56 percent to 95 percent.

The above comparisons indicated that the error in $\hat{T}_{AP}$ could be used successfully to determine whether or not the correlation graphs for Q_{10} versus A, T, and P could be expected to provide estimates within the limits of error shown by the solid-line curve in Figure 4. They also indicated that some relation must exist between errors in $\hat{Q}_{10(ATP)}$ and differences between drainage characteristics. If it could now be shown that a relation existed between the errors in $\hat{T}_{AP}$ for the Group 2 watersheds and the corresponding errors in $\hat{Q}_{10(ATP)}$, it would be possible to use such a relation to determine a coefficient that would compensate for the errors in the estimates of Q_{10}

Q_{10}/ $\hat{Q}_{10(ATP)}$ vs. T/ $\hat{T}_{AP}$. In order to explore this possibility, values of Q_{10}/ $\hat{Q}_{10(ATP)}$ for each of the Group 2 watersheds were plotted as ordinates on log-log graph paper against corresponding values of T/ $\hat{T}_{AP}$. (The values are shown in Table 5.) It was found that the plotted points defined curves that were identical for all zones for values of T/ $\hat{T}_{AP}$ equal to or greater than 1.0 but differed for Zone IV watersheds for values of T/ $\hat{T}_{AP}$ less than 1.0. Average curves were fitted by eye to the two sets of plotted points, as shown in Figure E-1

No attempt was made to determine the reason for the deviation in the relation between Q_{10}/ $\hat{Q}_{10(ATP)}$ and T/ $\hat{T}_{AP}$ for Zone IV watersheds for values of T/ $\hat{T}_{AP}$ less than 1.0. The feet that all of these watersheds were located near the crest of the Blue Ridge Mountains, where the slopes were very steep, suggests that additional variables such as basin relief or maximum valley side slopes may have materially affected the above relation.

Click here to view Table 5- Values of T/ $\hat{T}_{AP}$, Q_{10}/ $\hat{Q}_{10(ATP)}$, C, and $\hat{Q}_{10(C)}$ for Group 2 Watersheds

Errors in $Q_{10(C)}$. A test was next made of the efficiency with which the relations, as expressed by the two Q_{10}/ $\hat{Q}_{10(ATP)}$ versus T/ $\hat{T}_{AP}$ curves, could be expected to compensate for errors in estimates of Q_{10}. For each of the Group 2 watersheds, values of T/ $\hat{T}_{AP}$ were used in conjunction with the curves to obtain corresponding values of Q_{10}/ $\hat{Q}_{10(ATP)}$, designated as coefficients C. These values of C were used as multipliers for corresponding values of Q_{10}/ $\hat{Q}_{10(ATP)}$ to obtain new estimates of Q_{10}. These new estimates were designated as $Q_{10(C)}$ and were compared with corresponding values of Q_{10} as obtained from frequency studies of the runoff record. The error in $\hat{Q}_{10(C)}$ was taken as the difference between $\hat{Q}_{10(C)}$ and Q_{10} expressed as a percentage of $\hat{Q}_{10(C)}$ (Table 5). The distribution of these errors for the 44 watersheds in Group 2 is shown by the dash-line curve in Figure 4. This curve indicates these errors to be normally distributed with the maximum error for 68 percent of the watersheds being ±17 percent, that for 95 percent of the watersheds being ±38 percent, and that for 99 percent being ±55 percent.

A comparison of the above errors with those for the uncorrected values of $\hat{Q}_{10(ATP)}$ where the maximum error for 68 percent of the watersheds was well over 100 percent, led to the following conclusions: First, that a high degree of correlation must exist between errors in $\hat{T}_{AP}$ and corresponding errors in $\hat{Q}_{10(ATP)}$; and second, that such a correlation can be used successfully to compensate for the effect of differences in drainage characteristics on peak rates of runoff.

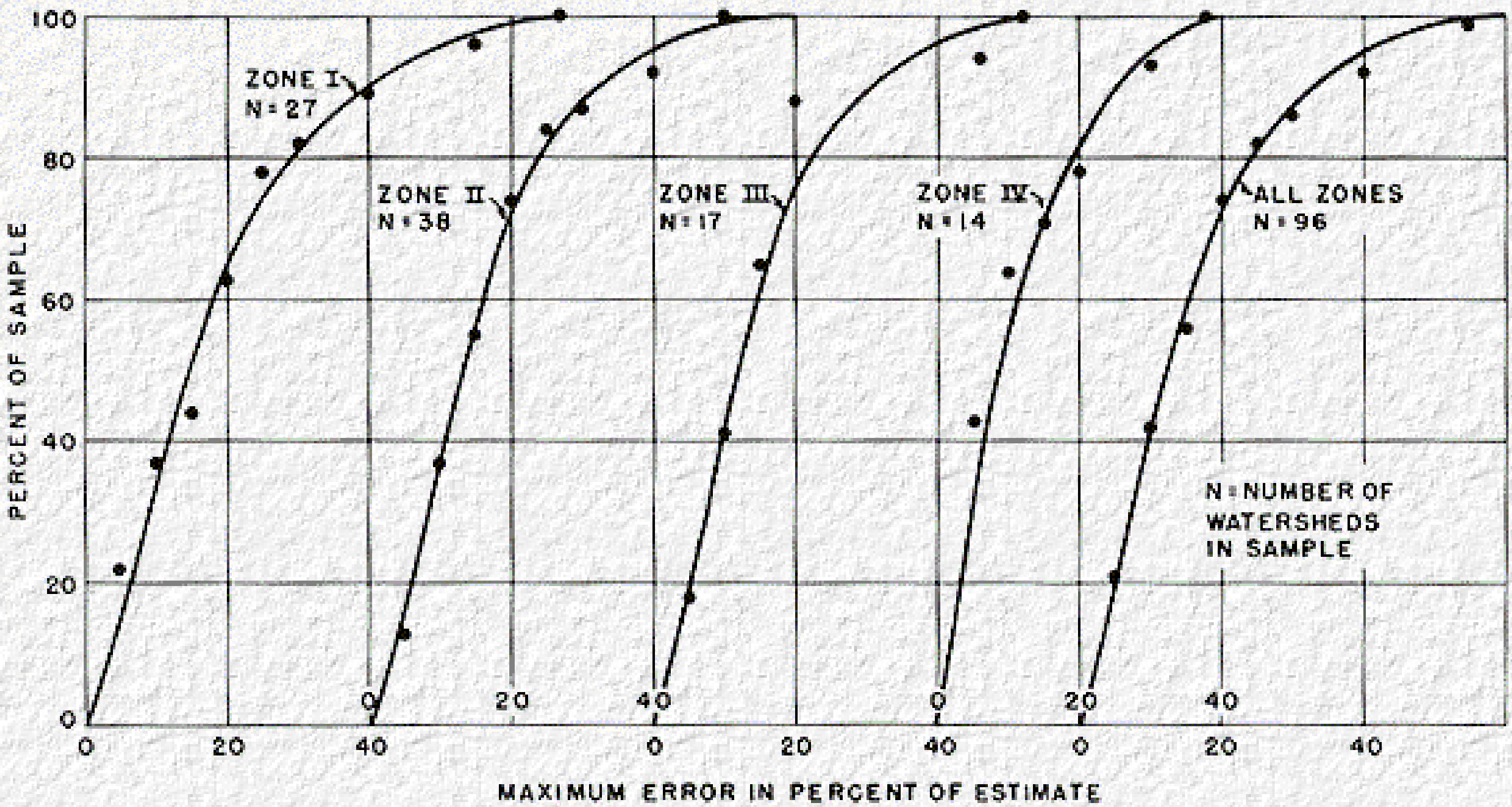

Figure 5. Error Distribution for $\hat{Q}_{10(ATP)}$ by Zones for Entire Gaged Watershed Sample

Precision Distribution-of-error graphs had been made for errors in the values of $\hat{Q}_{10(ATP)}$ for Group 1 watersheds and in the values of $\hat{Q}_{10(C)}$ for Group 2 watersheds (Figure 4). No significant difference had been found in the precision of the estimates that could be expected for the two groups. A study was next made to see if a difference in precision could be expected as between zones. For this study, distributions of the errors in the final estimate of Q_{10} using $\hat{Q}_{10(ATP)}$ for Group 1 watersheds and $\hat{Q}_{10(C)}$ for Group 2 watersheds, were compiled for the entire sample of 96 watersheds and for the watersheds in each zone (Figure 5, Table 3 and Table 5).

A comparison of the curves in Figure 5 shows the maximum error that could be expected for 68 percent of the entire sample to be $\pm$18 percent while for the four zones this error varied from $\pm$14 percent for Zone IV to $\pm$22 percent for Zone I. Since the error for any one zone varied from that for the entire sample by no more than 4 percentage points, it was concluded that no significant difference in the precision could be expected as between zones.

In addition to the distribution-of-error graphs, one other test was made of the precision that could be expected from estimates of peak rates derived from the above procedures.

For each value of $\hat{Q}_{10}$ using $\hat{Q}_{10(ATP)}$ or $\hat{Q}_{10(C)}$ corresponding values of the estimated 50-year peak ($\hat{Q}_{50}$) were obtained from the graph shown in Figure E-3. (This graph was derived from relations previously established between high and low frequency curves, as described under "Frequency Studies" at the beginning of Part II.)

These values obtained from Figure E-3, together with the maximum peak for the period of runoff record, are tabulated in the last two columns of Table 6. Table 7 shows the distribution of the gaged watershed sample by periods of runoff record, together with the number of watersheds for each period where the maximum recorded peak equaled or exceeded the estimated 50-year peak.

If the period of record had been the same for all 95 watersheds, and if each period had been independent of the others, then the entire array could have been considered as a random sample of 95 such periods of record. This being so, the number of periods that contained at least one peak that was equal to or greater than that having an average recurrence interval of 50 years, when expressed as a ratio of the total number of periods, should have equaled the cumulative probability that such an event would occur. In other words, the observed frequency should have equaled the theoretical probability.

The first of the above suppositions was approximated by weighing each period of record by the number of watersheds to which it pertained and dividing the sum of these weighted items by the total number of watersheds to obtain the weighted mean period of record. Although the 95 periods of runoff records are probably not 100-percent independent, the fact that they are widely distributed over 16 States (Table 7) would make the assumption that they are nearly so seem reasonable.

The weighted mean period of record for the 95 watersheds was found to be 14 years. The theoretical cumulative probability that an event which occurs with an average frequency of p will be equaled or exceeded at least once in a period of N years may be derived from the binomial distribution and is equal to $1 - (1-p)^N$. The probability, therefore, for an average frequency of once in 50 years, or 0.02, and a value of N equal to 14 years is $1-(0.98)^{14}$, or 0.25. In other words, 25 percent of the 95 periods of 14 years of record, or 24 such periods, should include at least one maximum annual peak equal to or greater than the 50-year peak. Table 7 shows that the observed frequency or number of periods of record that contained at least one peak that was equal to or greater than the estimated 50-year peak ($\hat{Q}_{50}$) was 23. This number, expressed as a ratio of the 95 total periods of record, is 0.24.

This same close agreement between the theoretical probability and the observed frequency was also found when the 95 watersheds were divided into two groups and comparisons made for each group. The first of these divisions considered the 41 watersheds with periods of record of from 6 to 10 years as one group and the remaining 54 watersheds as the second group. The weighted mean period of record for the first group was 9 years and the theoretical probability was 0.17. The observed frequency was also 7/41 =0.17. For the second group, the weighted mean period of record was 18 years. The theoretical probability was 0.30, which was just equal to the observed frequency of 16/54=0.30.

A second division of the 95 watersheds was made in which the first group consisted of the 47 watersheds with periods of record of from 6 to 12 years and the second group the remaining 48 watersheds. The weighted mean period of record for the first group was 9 years. The theoretical probability was 0.17 while the observed frequency was 9/47=0.19. The weighted mean period of record for the second group was 19 years. The theoretical probability was 0.32, while the observed frequency was 14/48= 0.29.

If the estimated values of the 50-year peak, $\hat{Q}_{50}$, had been consistently higher than the true values, it would be expected that the observed frequency or number of periods of record that included at least one peak equal or greater than $\hat{Q}_{50}$ would be less than the theoretical probability. Conversely, the observed frequency would be expected to be greater than the theoretical probability if the values of $\hat{Q}_{50}$ had been less than the true values. The close agreement between theoretical probability and observed frequency for the above comparison was taken as an indication that the estimated values of $\hat{Q}_{50}$ must closely approach the true values. Since the determination of $\hat{Q}_{50}$ involved the use of all of the procedures and relations used in this investigation, including those used in the frequency studies, this close agreement between theoretical probability and observed frequency is also an indication of the soundness of those procedures and relations.

Click here to view Table 6- Comparison of Estimated Values of Q_{10} and Q_{50} with Maximum Q of Record, for Gaged Watershed Sample

S

ummation

The logical development of this research study may be summarized as follows. Within a zone of homogeneous lithology there is a close relation between T, A, and P for any watershed sample in which the drainage characteristics are similar. This relation would not be the same, however, for other watershed samples that are representative of different drainage characteristics.

If a correlation between T, A, and P were established for a sample of watersheds having homogeneous drainage characteristics, then the difference between an estimate of T, obtained from such a correlation, and the measured value of T may be used as a test of the similarity or the degree of dissimilarity of the drainage characteristics of any other watershed.

When the correlations used in estimating T and those used in estimating Q_{10} are based on watershed samples having similar drainage characteristics, and when these correlations are used to estimate these variables for watersheds having different drainage characteristics, then a close relation exists between the resulting errors in the estimate of T and the corresponding errors in the estimate of Q_{10}. This relation, together with the errors in the estimate of T, may be used to compensate for the effect of various drainage characteristics on the magnitude of peak rates of runoff.

Click here to view Table 7- Distribution of Gaged Watershed Sample Periods of Runoff Record and by States

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Go to Part III

Part III : HDS 2

Considerations In Use of Estimating Procedure

Go to Part IV

Before presenting the actual procedure for estimating peak rates of runoff, developed as a result of the investigations described in Part I and Part II, it is well to discuss some of the considerations and limitations involved.

Frequency and Recurrence Interval

It is important for the highway engineer to have a clear understanding of just what is meant by frequency and by recurrence interval. Unless otherwise specified these terms, as used in the text, tables, and graphs of this report, refer to average frequency or average recurrence intervals.

If, for a long period of time, say 1,000 years, a count was made of the number of annual events that equaled or exceeded some specified value, and this count was divided by the 1,000 years, then the quotient would be the average frequency of such events. The reciprocal of the average frequency would be the average recurrence interval. Thus, if we were to say that a flood of 500 c.f.s. or more occurs with a frequency of Q_{10}, we would mean that such a flood would occur on the average of once in 10 years, and the total occurrences in 1,000 years would be 1,000/10 = 100. The average frequency would be the number of occurrences divided by the period of time; that is, 100/1,000=0.10.

It should be noted that average frequency does not fix the sequence of the events nor does it give any indication of the magnitude of these events above the chosen minimum. Thus, in the above example, the first 10 years might have included three floods equal to or greater than 500 c.f.s.; the next 10 years none at all; etc. Likewise, the three floods in the first 10 years might have been peaks with average recurrence intervals, for example, of 50, 200, and 500 years.

Risk Factor

It is possible to compute the probability of a peak of any average recurrence interval being equaled or exceeded at least once in any specified time interval. Thus, for example, there is a probability of 0.64 that a 10-year peak will be equaled or exceeded at least once during any 10 year period. Table 8 gives probabilities for various average recurrence intervals and for various time periods.

These probabilities may be considered as risk factors since they represent the risk of damage and destruction that the highway engineer is willing to take in the design of a drainage structure. Obviously this risk will vary with the importance of the highway and with the individual locations of the drainage structure.

For example, assume a secondary highway with an expected life of 25 years. An investigation might show that a culvert, designed so that no damage would result from a 10-year peak, would cause some flooding of the highway but with no appreciable damage for a 50-year peak, but would cause considerable damage, including the washing out of a portion of the highway fill, for a 200-year peak. The decision of the highway engineer in this case might have been based on the following reasoning. The risk of a peak equal to or greater than the 200-year peak occurring during the estimated life of the highway (25 years) is only 0.12 (from Table 8) or 12 chances in 100. This risk is justified in view of the fact that the additional cost of a culvert designed to carry such a peak would be large when compared with the estimated damage that might otherwise result.

Although the risk of a peak equal to or greater than the 50-year peak occurring during the estimated 25-year life of the highway is considerably greater than for the 200 year peak (0.40 or 4 chances in 10), this risk is also justified since the damage that would result from the temporary flooding of a secondary highway would be moderate.The culvert would be designed, therefore, for a 10-year peak.

The decision would have been different, however, if the investigation had shown that considerable damage would have resulted from peaks equal to or greater than the 50-year peak, or if the highway had been an interstate highway with heavy traffic volume and with an estimated life of 50 years. In such cases the culvert might have been designed for a 50-year peak for the secondary highway and for a 200-year or even a 500-year peak for the interstate highway.

Failure to consider the effect of these higher peaks in conjunction with the risk factor involved might very well result in loss of an entire drainage structure within only a few years after the completion of the highway. While it is true that economic considerations may preclude a design that would forestall any possible flood damage, consideration should be given to the higher peaks and an attempt made to so design the structure that damage from occurrence of such peaks would be kept at a minimum.

Table 8. Probabilities for Various Average Recurrence Intervals and Time Periods

Average Recurrence Intervals in Years	Probability That Event will be Equaled or Exceeded at Least Once in any Period of--			
	10 years	20 years	25 years	50 years
10------------------------	0.64	0.88	0.93	0.99
20------------------------	.40	.64	.72	.92
50------------------------	.18	.33	.40	.64
100---------------------	.10	.18	.22	.40
200---------------------	.05	.10	.12	.22
500---------------------	.02	.04	.05	.10

Go to Part IV

Explanation of Procedure

In the introduction to this report, it was stated that watershed area alone is insufficient to explain the wide variations in the magnitude of peak rates of runoff. This was graphically demonstrated in Figure 1. Two indexes, in addition to the area index A, were found necessary to account for the wide variation in the magnitude of the 10-year peaks; a topographic index T. and a precipitation index P. A coefficient C was also needed to compensate for the effect of differences in drainage characteristics among watersheds. Investigations that led to the quantification of these variables have been described in Part I and Part II.

To use these variables to estimate, for a proposed stream crossing, the peak rate of runoff that may be expected for average recurrence intervals of 10 years or greater, the procedure that follows may be used. The steps of the procedure are arranged in logical order, and the maps and graphs cited are grouped at the end of Part IV and are assigned numbers that correspond with the steps to which they are applicable. A suggested recording form for the procedure follows this group of maps and graphs.

Step A. Use of Topographic Map

Locate the site of the proposed stream crossing on a U.S. Geological Survey topographic map or any other available accurate contour map.

A-1. Record the latitude and longitude of the crossing to the nearest minute.

A-2. Outline the boundary of the watershed that drains to the proposed crossing, on the map, and planimeter its area. Record the area in 1,000-acre units.

A-3a. Measure the length, in miles, of the principal stream from the site of the proposed crossing to the headwater. The headwater, or uppermost point on the stream, should be taken as the point where a definite channel begins, regardless of whether or not streamflow at this point is intermittent. If a U.S. Geological Survey map is used, the length of stream should include that portion shown as either a solid or broken blue line. Divide the length of the principal stream into two reaches, the lower reach being 0.7 of the total length and the upper reach the remaining 0.3.

A-3b. From the contours, determine the elevation of the stream channel at the upper and lower limits of each reach. The streamfall for each reach is the difference between the upper and lower contour elevations for that reach.

A-3c. 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.

A-3d. Divide the length of stream channel for each of the two reaches, measured in miles, by the square root of the corresponding slope, and add the quotients. Record this sum as the topographic index T. Expressed algebraically, using L as the length of stream channel and S_1 and S_2 as the slopes of the upper and lower reaches respectively,

$$T = 0.3L \div \sqrt{S_1} + 0.7L \div \sqrt{S_2}$$

Step B. Use of Figures B-1 and B-2

Using the recorded latitude and longitude (Step A-1):

B-1. Locate the proposed crossing on Figure B-1a, Figure B-1b, Figure B-1c, or Figure B-1d, and record its watershed as being in Zone I, II, III, or IV.

B-2. Locate the proposed crossing on Figure B-2a, Figure B-2b, Figure B-2c, or Figure B-2d, and record the value of P, to the nearest 0.1 inch, corresponding to that location.

Step C. Use of Figures C-1 and 1a-d

C-1. Enter Figure C-1a, Figure C-1b, Figure C-1c, or Figure C-1d (depending on the zone in which the watershed is located, from Step B-1) with the area of the watershed in 1,000 acres (Step A-2) and move vertically up the graph to the measured value of T (Step A-3d). Move horizontally across the graph to the selected value of P (Step B-2). Move vertically up the graph and read the estimated value of $Q_{10}(\hat{Q}_{10(ATP)})$ in 1,000 c.f.s. This is an estimate of the peak rate of runoff that may be expected to be equaled or exceeded on an average of once in 10 years. The accuracy of this estimate will depend on the degree to which the drainage characteristics of the watershed for the proposed crossing are similar to those of the watersheds used as a basis for the correlation graphs from which the estimate was derived. To determine this, proceed as described in Step D.

Step D. Use of Figures D-1a, b

D-1. Four graphs are shown in Figures D-1a and Figure D-1b. Select the graph for the zone in which the watershed of the proposed crossing is located (Step B-1). Enter this graph with the area of the watershed in 1,000 acres (Step A-2). Move vertically across the graph to the selected value of P (Step B-2). Move horizontally across the graph and record $\hat{T}_{AP}$, which is the estimated value of T.

Express the difference between this estimated value of T and the measured value (Step A-3d) as a percentage of the estimated value; that is,

$$(\hat{T}_{AP} - T) \div \hat{T}_{AP} \times 100 \cdot$$

D-2. If the percentage value obtained in Step D-1, that is, the difference between estimated and measured value of T, is *less* than $\pm$30 percent, it is an indication that the drainage characteristics of the watershed for the proposed crossing are similar to those of the watersheds on which the correlation graphs were based. In such cases, the value of $\hat{Q}_{10(ATP)}$, obtained from the correlation graphs (Step C-1), needs no modification and is the final estimate of Q_{10}.

D-3. If the value of ($\hat{T}_{AP}$ -T) ÷ $\hat{T}_{AP}$ X 100, is *equal to or greater* than $\pm$30 percent, it is an indication of significant differences between the drainage characteristics of the watershed for the proposed crossing and those for the correlation graph watersheds. In such cases, the value of $\hat{Q}_{10(ATP)}$ obtained from the correlation graphs (Step C-1) must be modified to compensate for these differences. This can be done by multiplying the value of $\hat{Q}_{10(ATP)}$ by a coefficient C, which is determined as described in Step E.

Step E. Use of Figures E-1 and E-3

E-1. Divide the measured value of T (Step A-3d) by the estimated value $\hat{T}_{AP}$ (Step D-1). Enter the graph in Figure E-1 with this ratio and move vertically up the graph to intercept the curve for the zone in which the watershed is located (Step B-1). Move horizontally across the graph and read the value of coefficient C.

E-2. In cases where the value of ($\hat{T}_{AP}$ -T) ÷ $\hat{T}_{AP}$ X 100 is equal to or greater than $\pm$30 percent (Step D-3), multiply the estimate $\hat{Q}_{10(ATP)}$ (Step C-1) by coefficient C (Step E-1) to obtain $\hat{Q}_{10(C)}$ as the final estimate of Q_{10}.

E-3. Enter the graph in Figure E-3 with the final estimate of Q_{10} (Steps D-2 or E-2) and move vertically down the graph to intercept the curve. Move horizontally across the graph and read $\hat{Q}_{50}$ (the estimated value of Q_{50}) in 1,000 c.f.s.

Step F. Use of Estimated Frequency Curve

F-1. To obtain estimates of Q for average recurrence intervals other than 10 or 50 years, plot the estimated values of Q_{10} (Steps D-2 or E-2) and Q_{50} (Step E-3) on extremal probability paper and draw a straight line through the plotted points. This is the estimated frequency curve for average recurrence intervals of 10 years or greater. The estimated frequency curve may be extended upward to provide estimates for recurrence intervals greater than 50 years but should never be extended downward for recurrence intervals less than 10 years.

Precision of Estimate

For 68 percent of the ungaged watersheds for which estimates of Q may be desired, the difference between the estimated values, as obtained from the procedures in Part IV, and the true values of Q may be assumed to be less than $\pm$20 percent of the estimated values. Likewise for 95 percent of the ungaged watersheds, this difference may be assumed to be less than $\pm$40 percent of the estimated values.

The highway engineer may wish to compensate for these probable differencesC20 percent in the one case and 40 percent in the otherCby multiplying all points on his estimated frequency curve (Step F-1) by corresponding factors of safety of 1.2 or 1.4, depending on the damage that might result from flooding the highway or the importance of keeping it open to traffic.

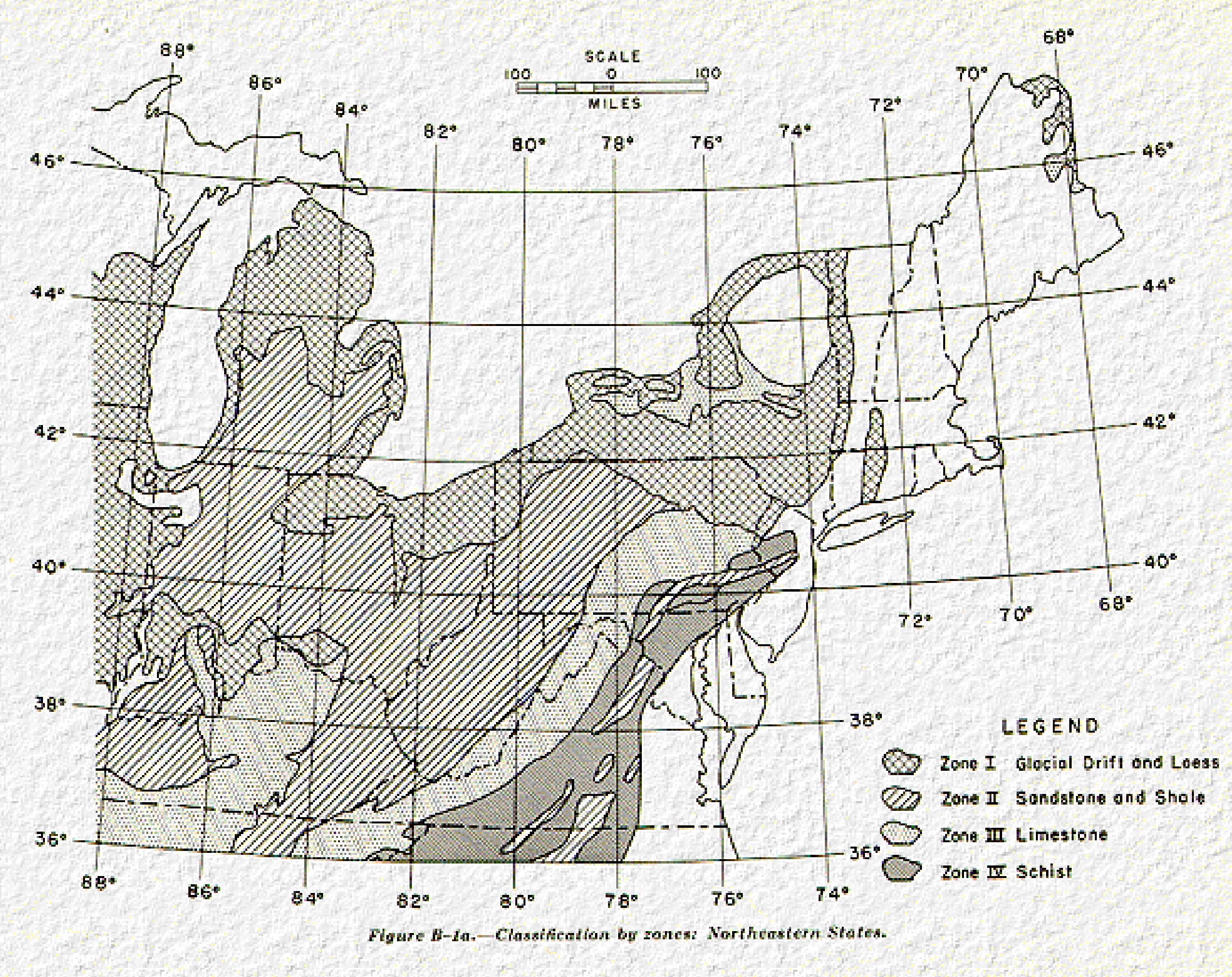


Figure B-1a. Classification by Zones: Northern States

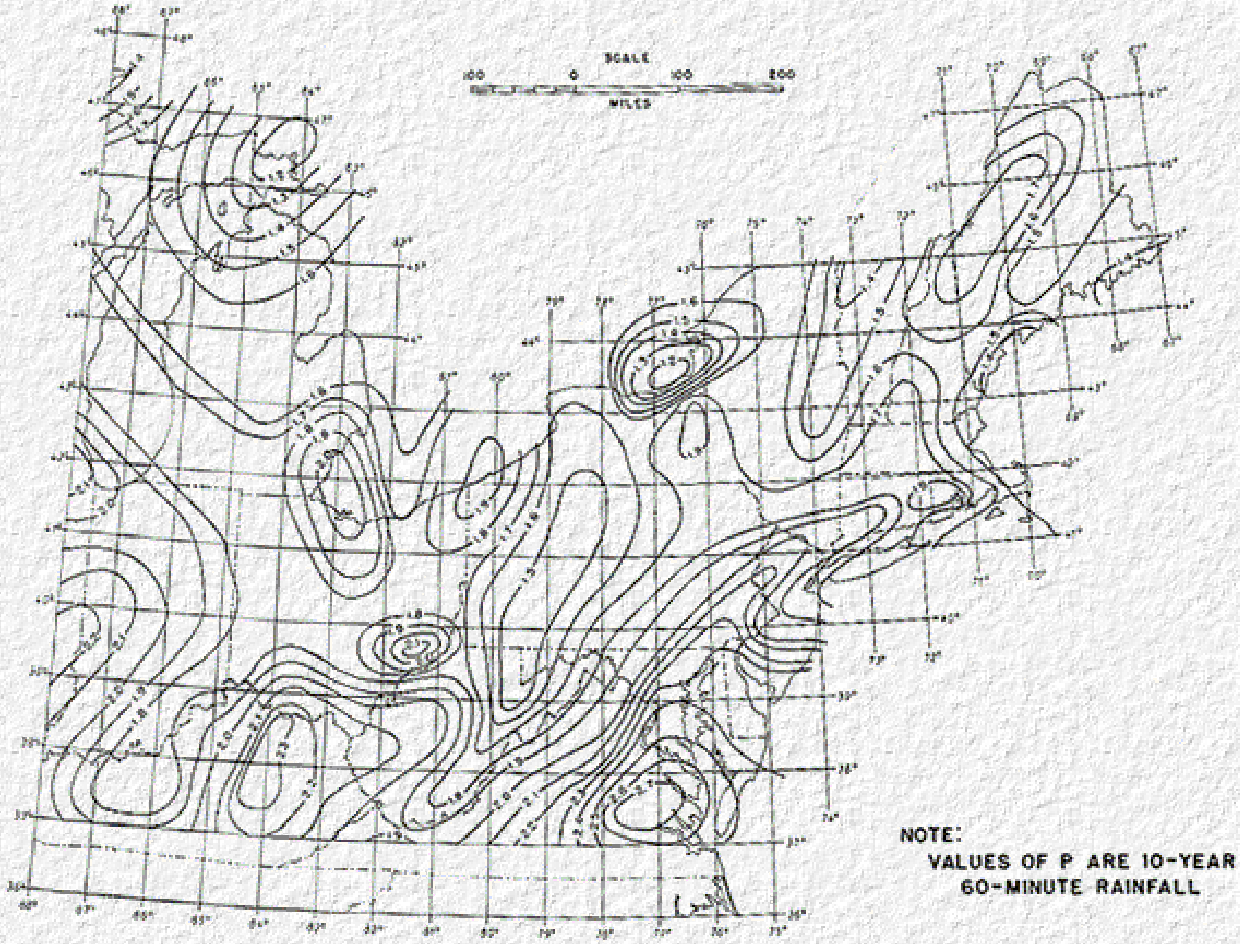


Figure B-2a. Rainfall Index P: Northeastern States

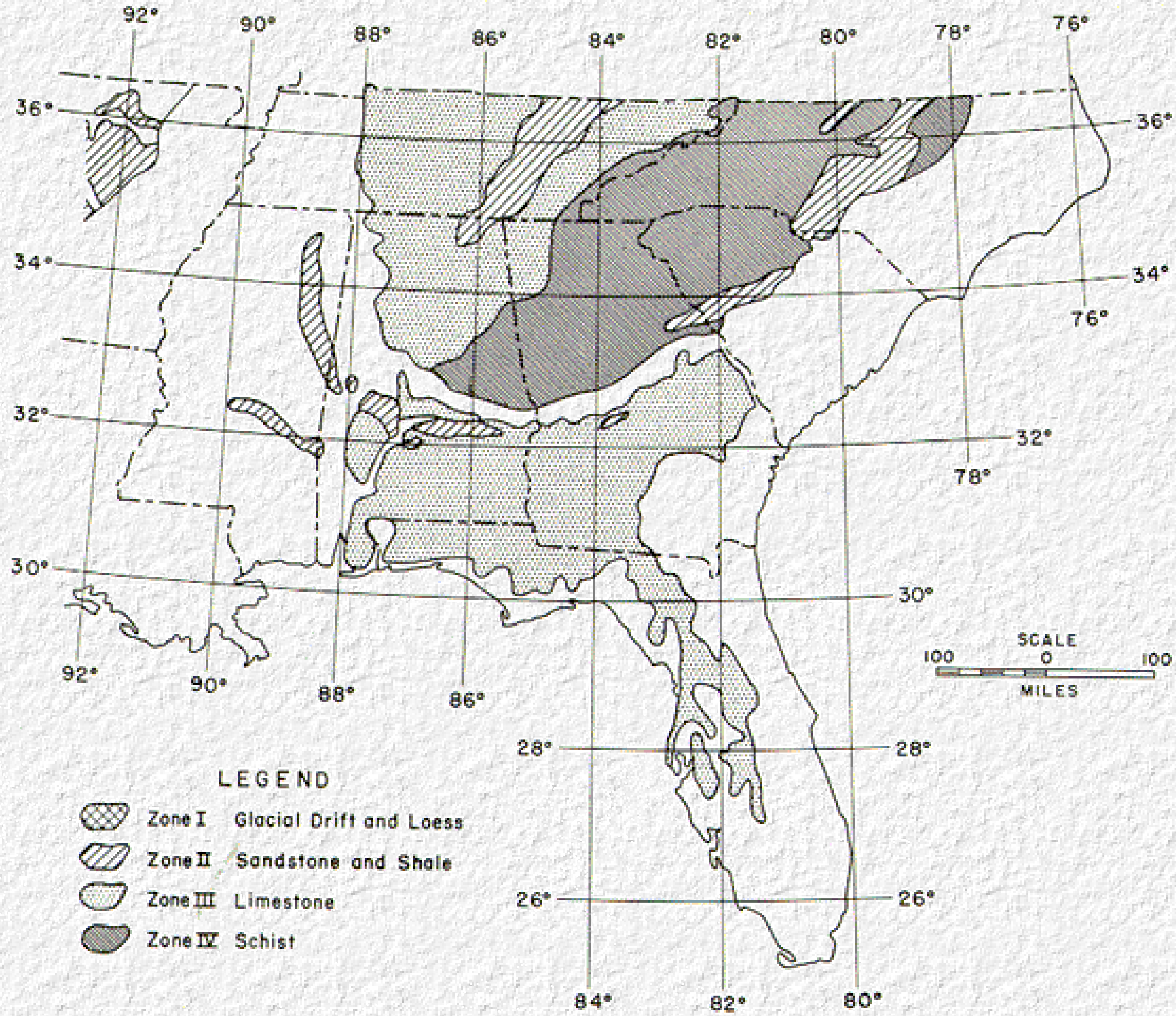


Figure B-1b. Classification by Zones: Southeastern States

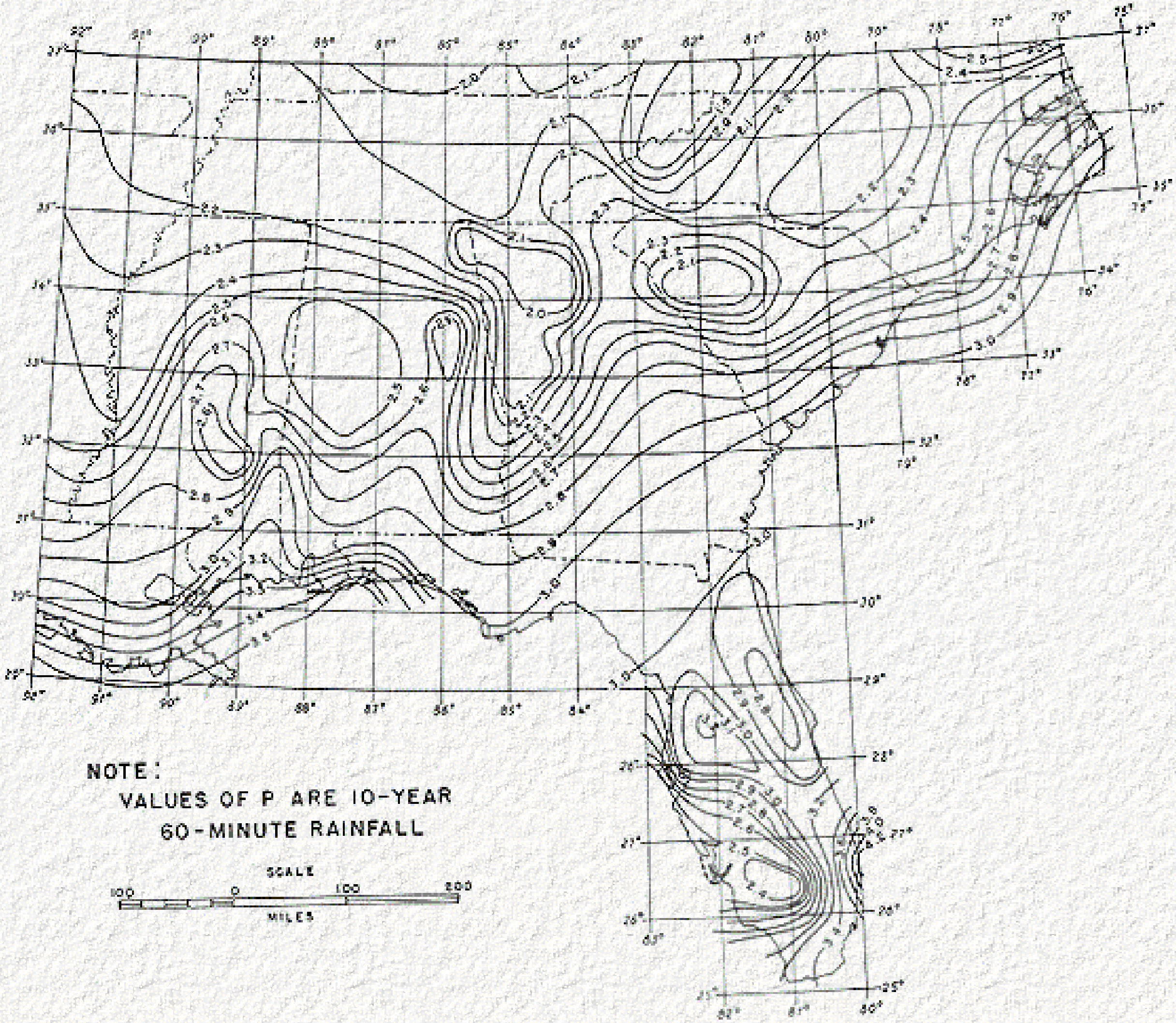


Figure B-2b. Rainfall Index P: Southeastern States

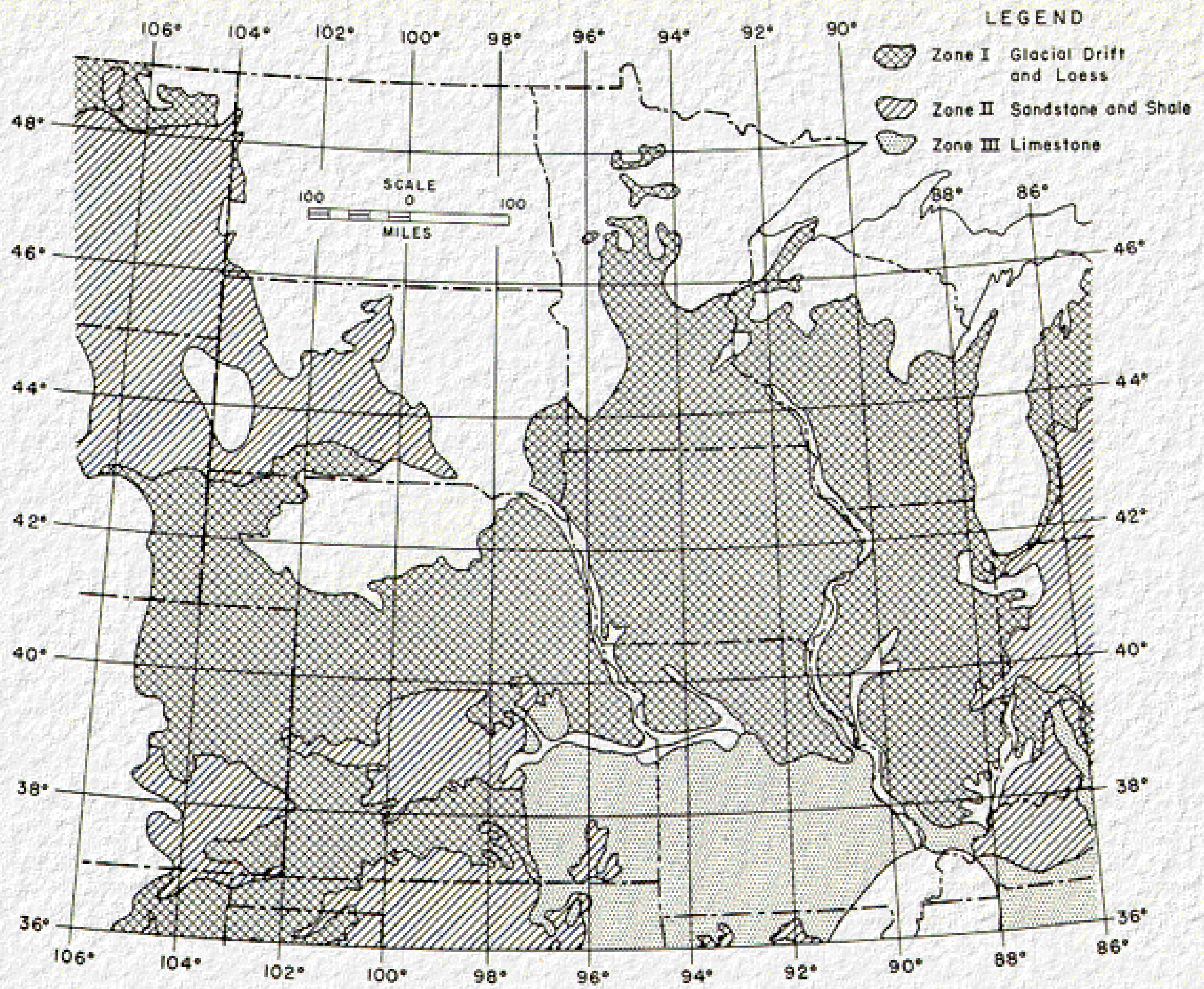
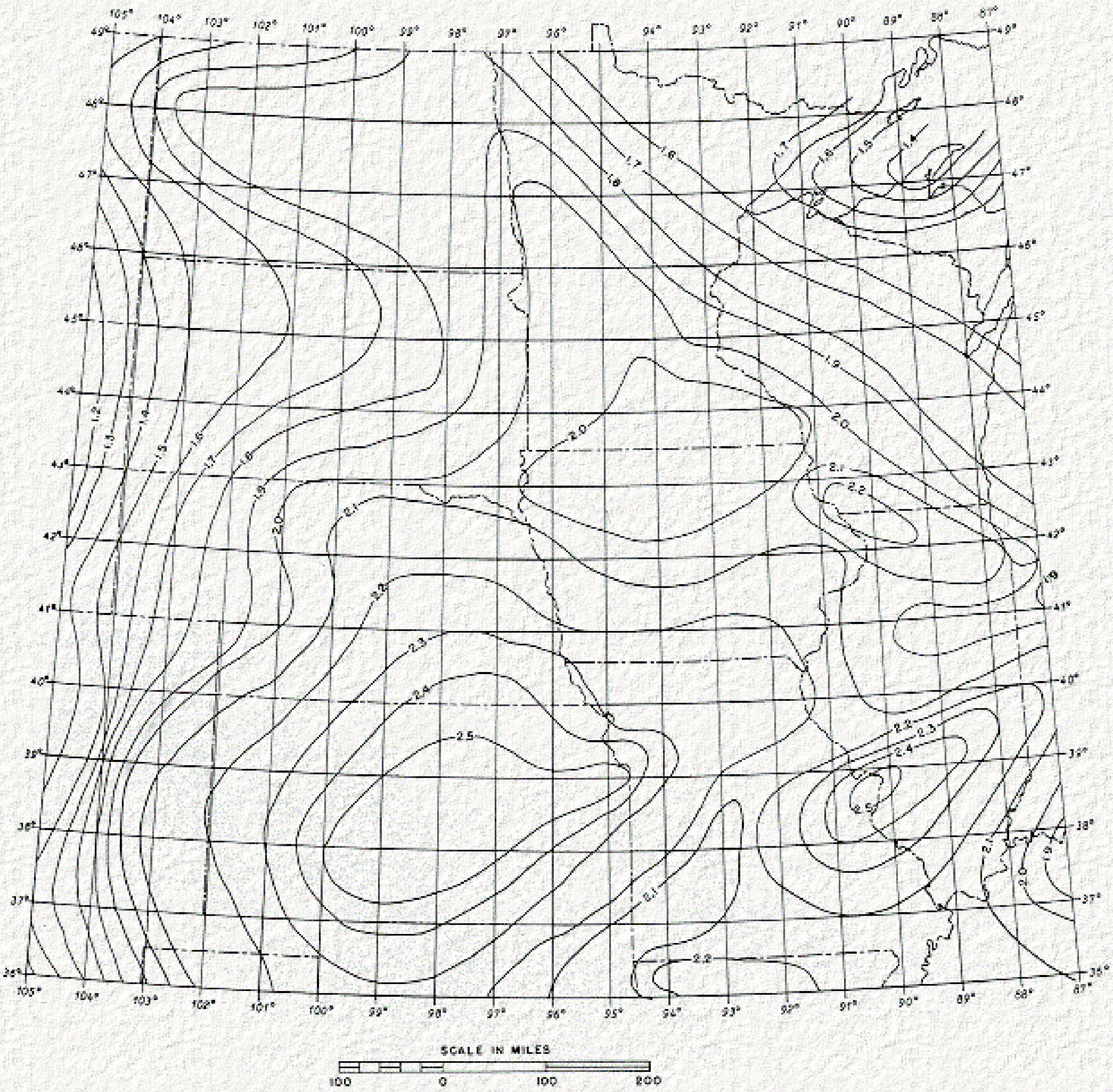


Figure B-1c. Classification by Zones: North Central States



NOTE: VALUES OF P ARE 10-YEAR 60-MINUTE RAINFALL

Figure B-2c. Rainfall Index P: North Central States

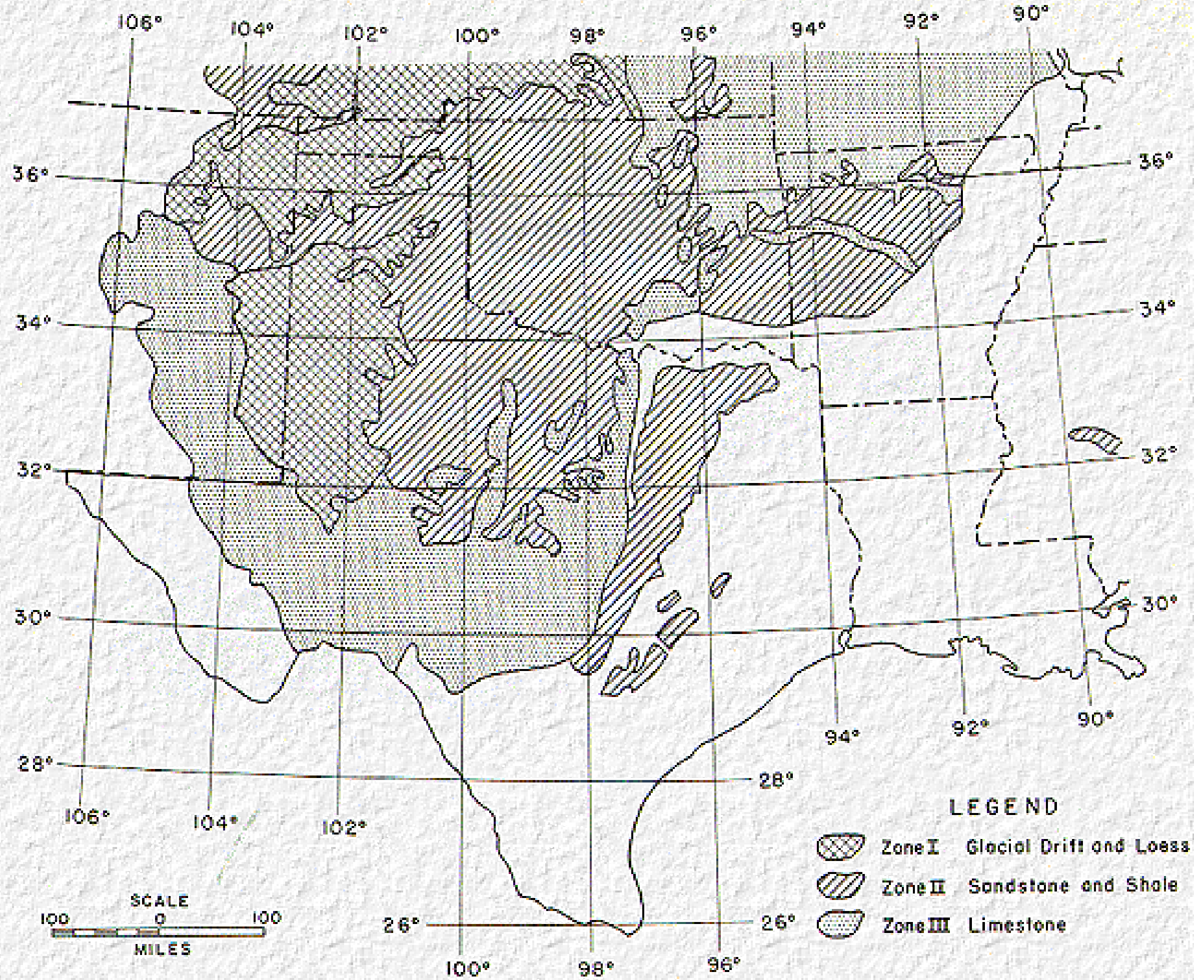


Figure B-1d. Classification by Zones: South Central States

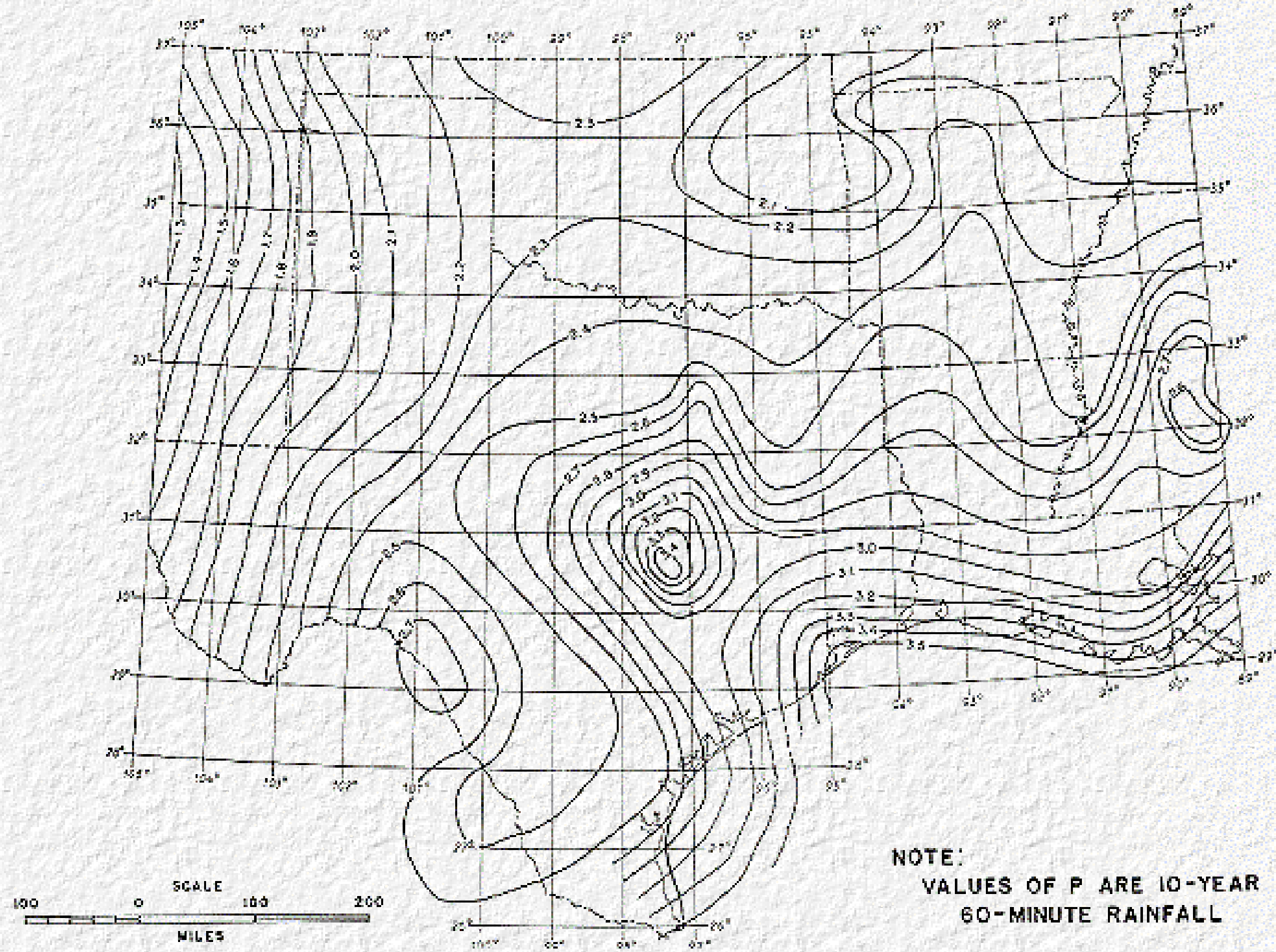


Figure B-2d. Rainfall Index P: South Central States

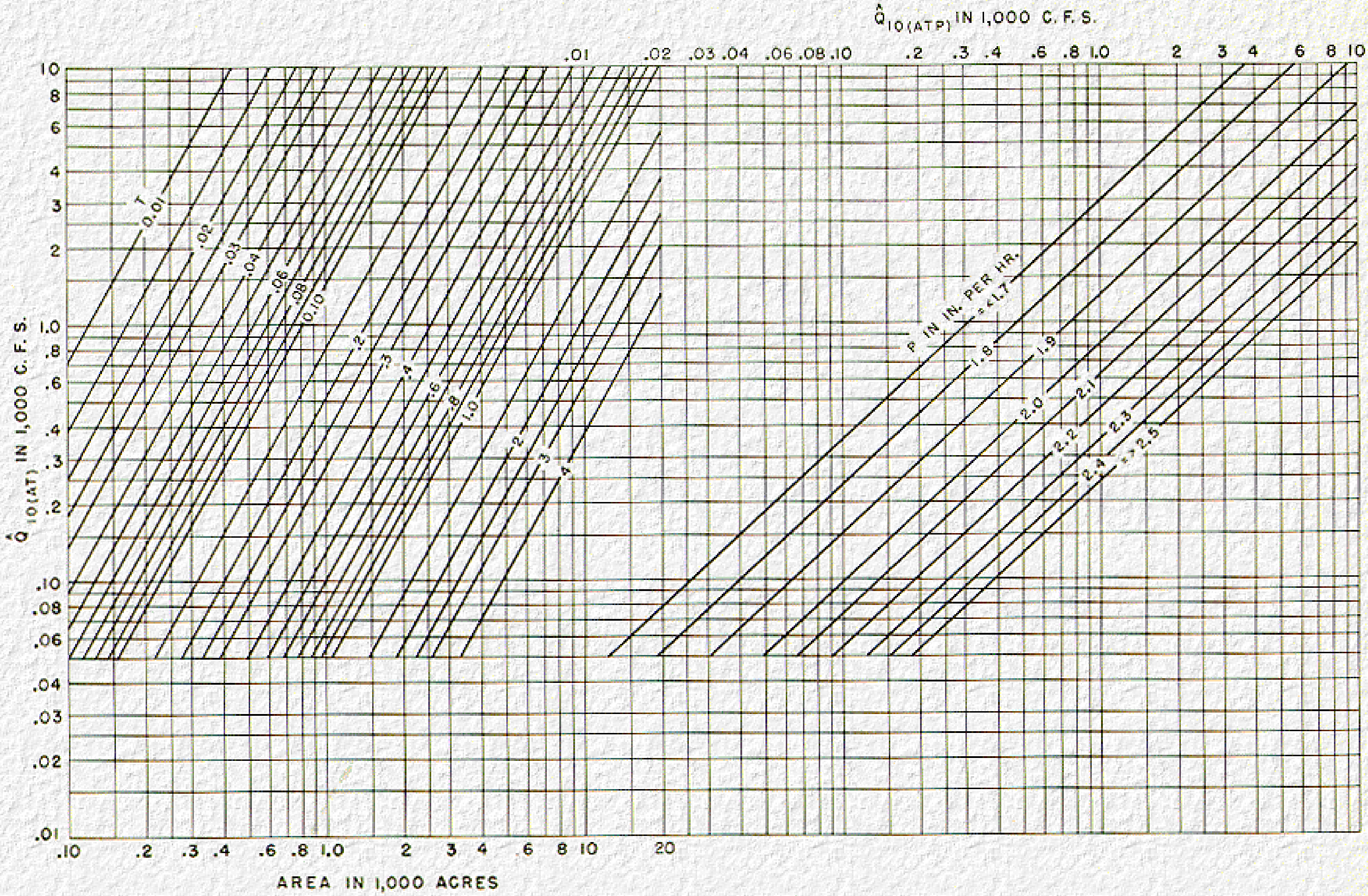


Figure C-1a. Relations between Q_{10}, A, T, and P: Zone I

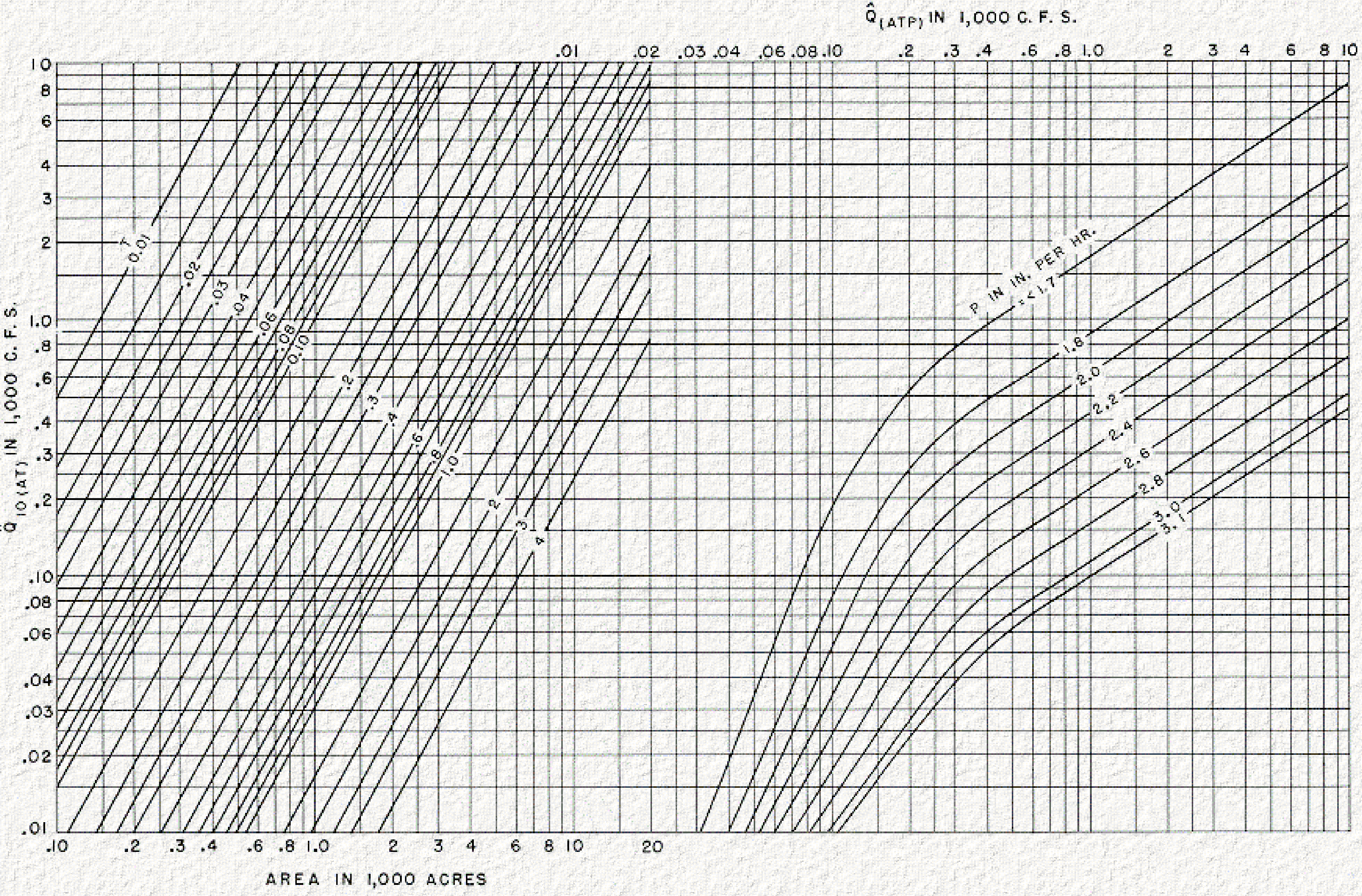


Figure C-1b. Relations between Q_{10}, A, T, and P: Zone II

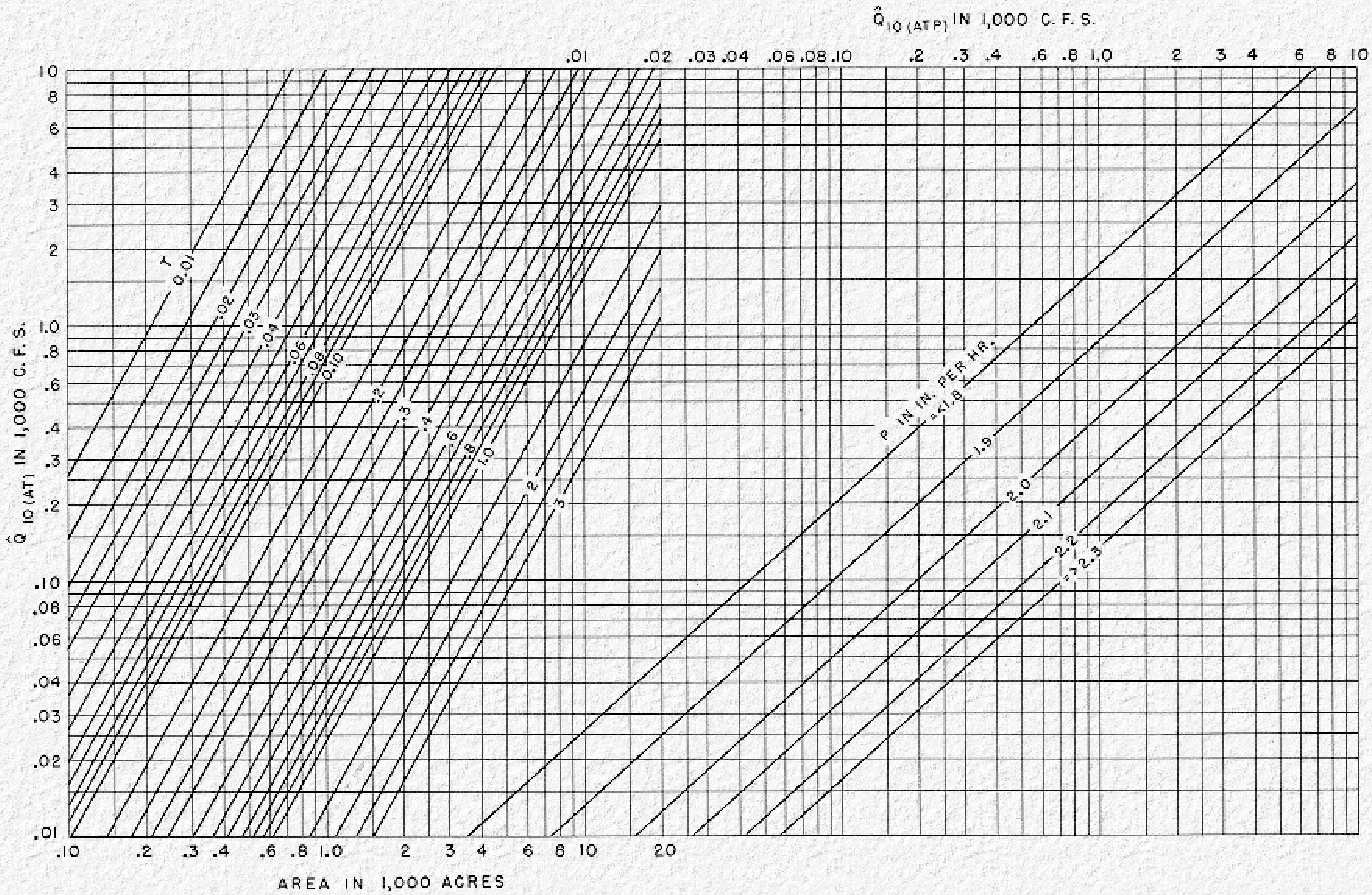


Figure C-1c. Relations between Q_{10}, A, T, and P: Zone III

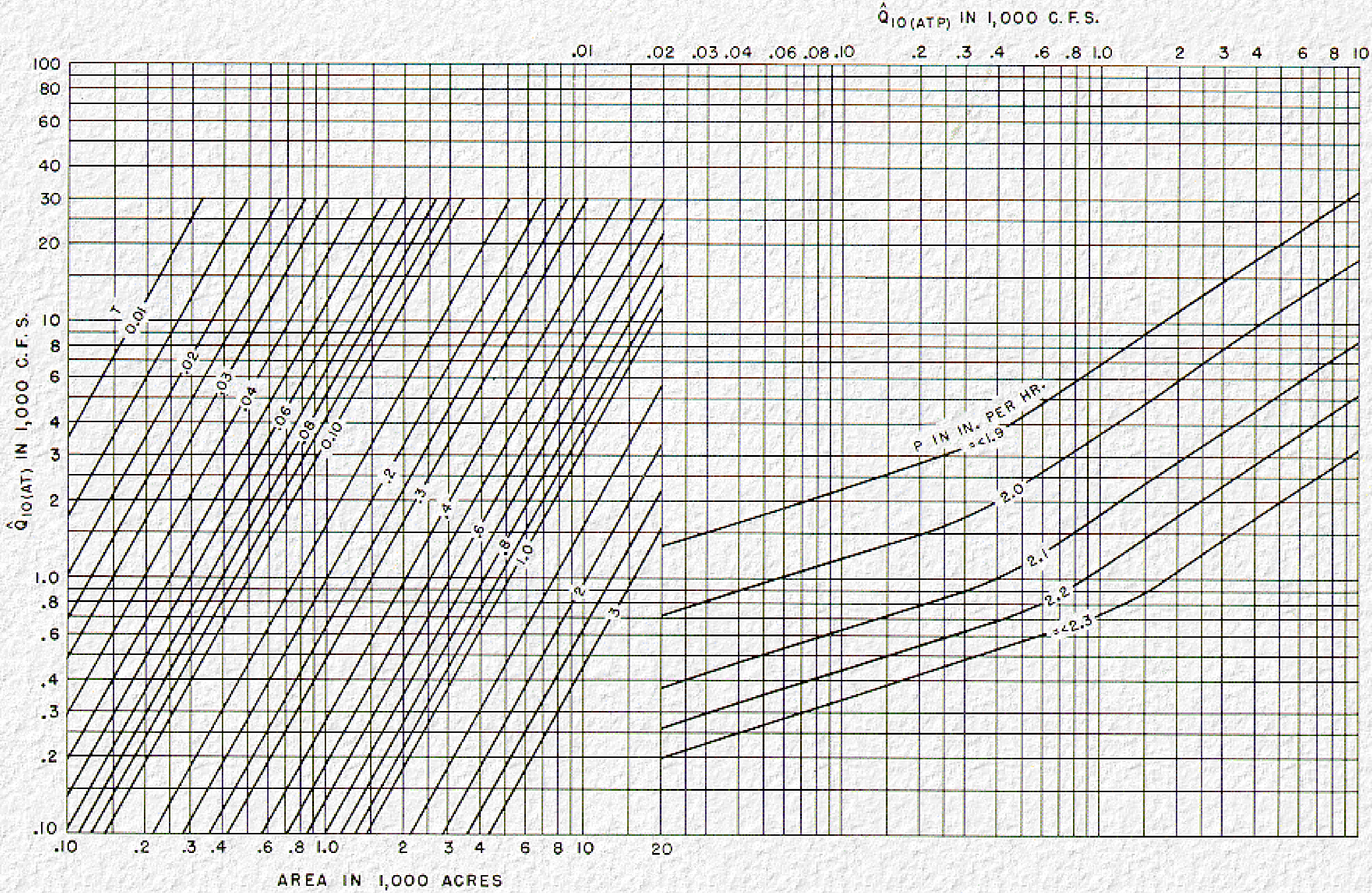


Figure C-1d. Relations Between Q_{10}, A,T, and P: Zone IV

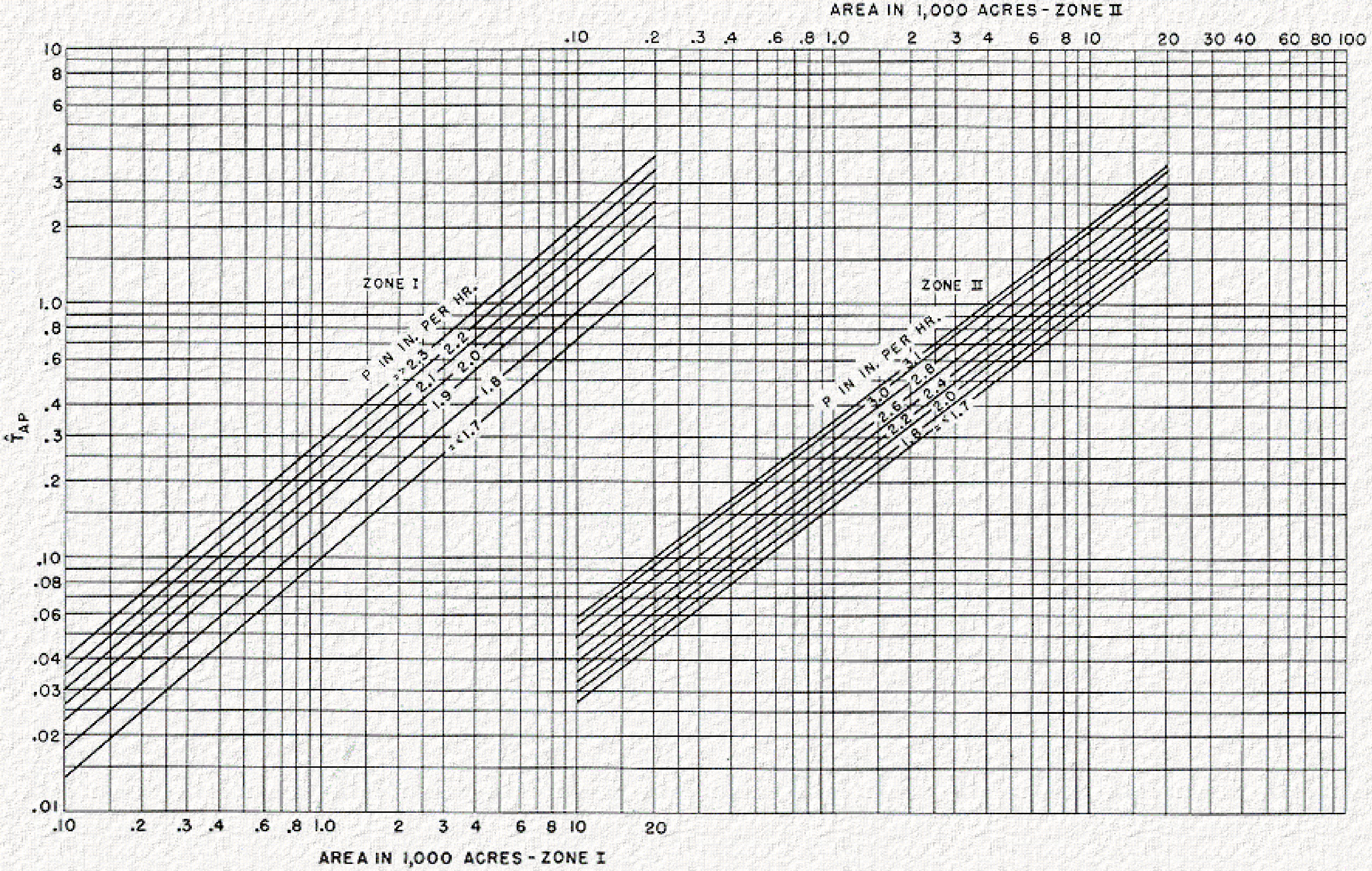


Figure D-1a. Relations Between T, A, and P: Zones I and II

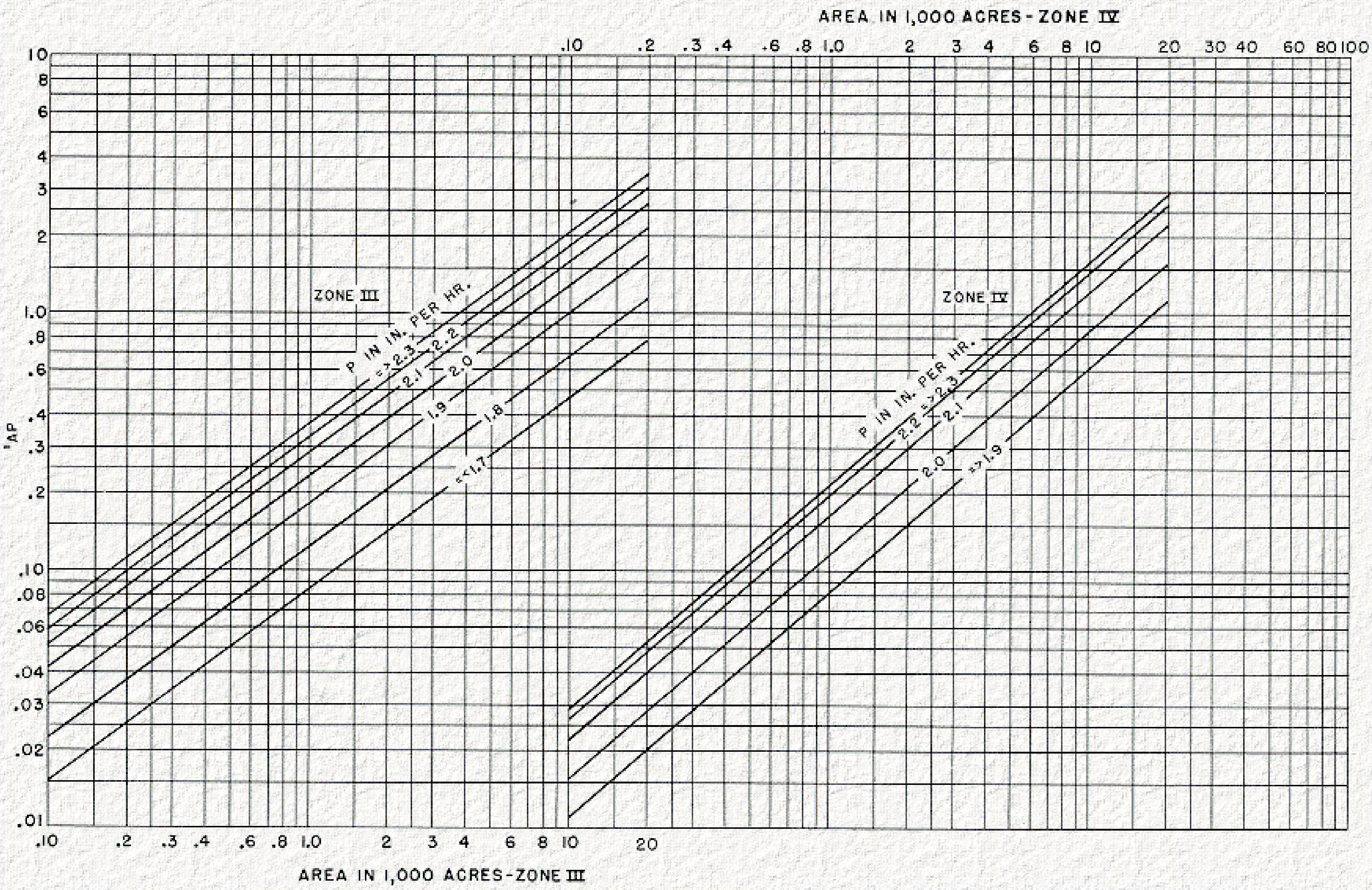


Figure D-1b. Relations between T, A, and P: Zones III and IV

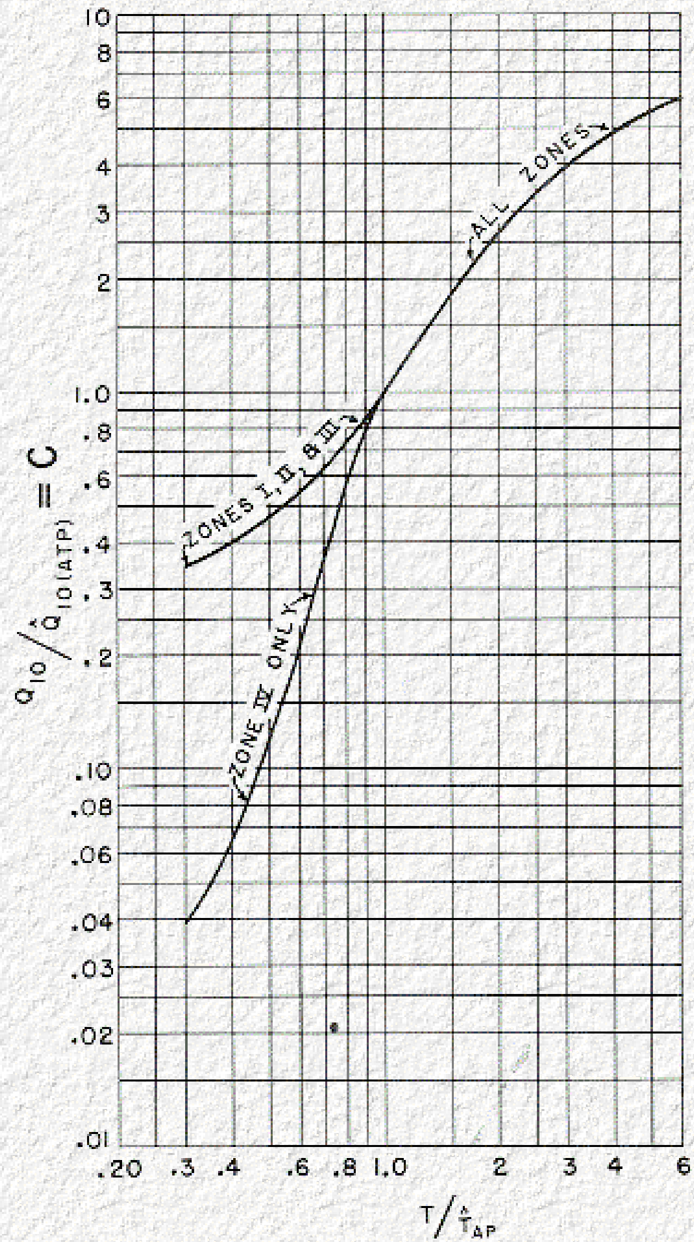


Figure E-1. Coefficient C as a function of T/ $\hat{T}_{AP}$

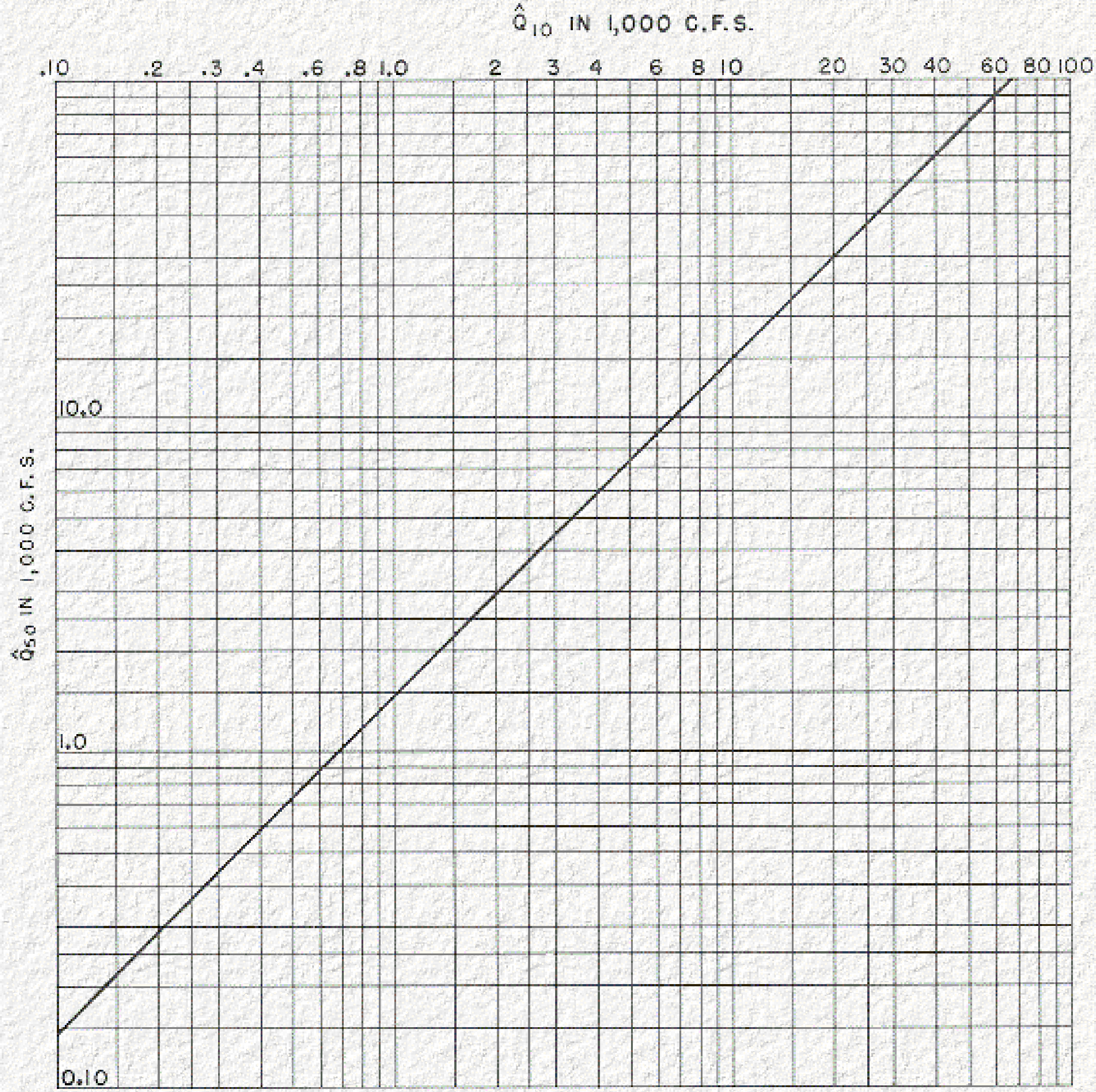


Figure E-3. Relation Between Q_{10} and Q_{50} for All Zones

SUGGESTED WORK SHEET FOR ESTIMATING PEAK RATE OF RUNOFF OF SMALL WATERSHEDS

STEP A Identification of watershed ______________________________

Location: Topographic map quadrangle ______________ Principal stream ______________

A-1 Location of crossing: Latitude _____ Longitude _____

A-2 Area of watershed, A (planimetered) = _____ 1,000 acres.

A-3 Principal stream length: L = _____ miles; 0.3L = _____ miles; 0.7L = _____ miles.

Elevations on principal stream:

a, at headwater _____ ft.; b, at 0.7L above crossing _____ ft.; c, at crossing _____ ft.

S_1 = (el. a - el. b) ÷ 0.3L = (_____ - _____) ÷ _____ = _____ ÷ _____ = _____ ft./mi.; $\sqrt{S_1}$ = _____

S_2 = (el. b - el. c) ÷ 0.7L = (_____ - _____) ÷ _____ = _____ ÷ _____ = _____ ft./mi.; $\sqrt{S_2}$ = _____

$T = (0.3L \div \sqrt{S_1}) + (0.7L \div \sqrt{S_2})$ = (_____ ÷ _____) + (_____ ÷ _____) = _____ + _____ = _____

STEP B From step A-1: Lat. _____ Long. _____

B-1 From figure B-1a, b, c, or d: Zone _____ B-2 From figure B-2a, b, c, or d: P = _____ in.

STEP C From steps A & B: Zone _____ A = _____ P = _____ T = _____

From figure C-1a, b, c, or d: $\hat{Q}_{10(ATP)}$ = _____ 1,000 c.f.s.

STEP D From steps A & B: Zone _____ A = _____ P = _____ T = _____

From figure D-1a or b: $\hat{T}_{AP}$ = _____

Error = $(\hat{T}_{AP} - T) \div \hat{T}_{AP} \times 100$ = (_____ - _____) ÷ _____ x 100 = _____ ÷ _____ = _____ %

STEP E From step D: Error = _____ %.

E-1 & 2 Use only if error is equal to or greater than 30%.

From steps A, B, C, & D: Zone _____ T = _____ $\hat{T}_{AP}$ = _____ $\hat{Q}_{10(ATP)}$ = _____

$T \div \hat{T}_{AP}$ = _____ ÷ _____ = _____ From figure E-1: Coefficient C = _____

$\hat{Q}_{10(C)} = \hat{Q}_{10(ATP)} \times C$ = _____ x _____ = _____ 1,000 c.f.s.

E-3 From steps C, D, & E-2: $\hat{Q}_{10(ATP)}$ = _____ $\hat{Q}_{10(C)}$ = _____ Error = _____ %

When error is less than 30% . . . . $\hat{Q}_{10} = \hat{Q}_{10(ATP)}$ = _____

When error is equal to or greater than 30%, $\hat{Q}_{10} = \hat{Q}_{10(C)}$ = _____

From figure E-3, $\hat{Q}_{50}$ = _____

STEP F From step E-3: $\hat{Q}$ = _____ $\hat{Q}$ = _____

STEP F   From step E-3: Q_{10} = _____ Q_{50} = _____

Plot $\hat{Q}_{10}$ and $\hat{Q}_{50}$ on extremal probability paper; connect points;

read from extended curve: $\hat{Q}_{25}$ = _____ $\hat{Q}_{100}$ = _____ $\hat{Q}_{200}$ = _____ $\hat{Q}_{500}$ = _____

Suggested Worksheet for Estimating Peak Rate Runoff of Small Watersheds

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Table 2. Gaged Watershed Sample: Location, Area, and Period of Record

No.	Name and Location	Area	Period of Record	No.	Name and Location	Area	Period of Record
ZONE I				ZONE II - Continued			
		1,000 acres	Years			1,000 acres	Years
1	W-III (Horton), Fennimore, Wis.[1]	0.052	18	31	Tiderishi Creek near Jenera, Ohio	2.89	10
2	W-IV (Horton), Fennimore, Wis.[1]	.171	18	32	Roller Creek at Ohio City, Ohio	3.16	10
3	W-IV (Love), Edwardsville, Ill.[1]	.290	18				
4	W-I (Horton), Fennimore, Wis.[1]	.330	18	33	Touby Run at Mansfield, Ohio	3.31	10
5	W-3 Hastings, Nebr.[1]	.481	18	34	Bridge Creek near Greenville, Ohio	3.51	10
				35	Lisbon Creek at Lisbon, Ohio	3.89	10
6	Ralston Creek at Iowa City, Iowa	1.93	31	36	Hominy Creek at Circleville, Ohio	4.02	8
8	Patterson Run near Owensville, Ohio	2.14	10	37	Mad River at Zanesfield, Ohio	4.10	10
9	Norwalk Creek near Norwalk, Ohio	2.68	10				
10	Plum Creek at Oberlin, Ohio	3.12	10	40	No. 97, Coshocton, Ohio[1]	4.58	19
19	Hickory Creek above Lake Bloomington, Ill	6.46	16	43	Indian Creek at Massieville, Ohio	6.22	10
				45	Salt Creek at Tarlton, Ohio	6.78	10
20	Bond Creek at Dunham Basin, N.Y.	9.41	8	46	Timber Run near Zanesville, Ohio	6.79	10
22	East Fork, Galena River at Council Hill, Ill	12.9	15	48	Scioto Big Run at Briggsdale, Ohio	7.04	10
12a	Sage Brook near South New Berlin, N.Y.	.448	21				
13a	Clear Creek at Dilworth, Ohio	.582	10	51	Connotton Creek at Jewett, Ohio	9.02	10
18b	Cold Spring Brook at China, N.Y.	.966	19	57	Muncy Creek near Sonestown, Pa	15.2	15
				59	Council Creek near Stillwater, Okla.	19.8	22
38	Hoskins Creek at Hartsgrove, Ohio	4.44	10	ZONE III			
39	Albright Creek at East Homer, N.Y.	4.53	16	1	W-III, Blacksburg, Va.1	0.019	13
41	Walnut Creek at Cortland, Ohio	5.83	10	2	Behmke Branch near Rolla, Mo.	.672	9
42	Sugar Run at Pymatuning Dam, Pa	5.98	20	3	Dilltown Creek near Long Pond, Pa	1.53	8
44	Quaker Creek at Florida, N.Y.	6.23	17	4	Shackham Brook near Truxton, N.Y.	2.00	20

				6	Sawpit Run near Oldtown, Md	3.20	8
47	Hinkley Creek near Charlestown, Ohio	6.92	10				
49	Little Chippewa Creek near Smithville, Ohio	8.90	10	7	Little Beaver Creek near Rolla, Mo	4.10	11
50	Terry Clove Kill near Pepacton, N.Y.	8.96	14	9	Bell Creek at Frank Mill, Staunton, Va	6.14	8
53	Mill Creek near Berlin, Ohio	12.6	14	10	Paxton Creek near Penbrook. Pa	7.17	11
55	Kale Creek near Pricetown, Ohio	13.4	15	12	Manada Creek at Manada Gap, PA	9.02	18
				13	Beaver Creek near Rolla, Mo.	8.96	7
56	Little Tonawanda Creek at Linden, N.Y.	14.1	38				
58	Mill Brook at Arena, N.Y.	16.0	15	14	Beaver Creek near Wallace, Va	8.77	10
ZONE II				17	Little Tonoloway Creek near Hancock, Md	10.8	8
1	W-10, near Waco, Tex.[1]	0.020	17	18	South Fork Little Barren River at Edmonton, Ky	11.6	14
2	No. 169, Coshocton, Ohio[1]	0.029	16	19	Middle Fork Beargrass Creek at Louisville, Ky	11.8	11
3	W-6, near Waco, Tex.[1]	0.42	16	20	South Fork Beargrass Creek at Louisville, Ky	12.0	10
4	No. 183, Coshocton, Ohio[1]	0.74	18				
5	No. 177, Coshocton, Ohio[1]	0.76	16	21	Bourbeuse River near St. James, Mo.	13.6	9
				22	North River near Stokesville, Va	15.0	9
6	No. 10, Coshocton, Ohio[1]	.122	19	ZONE IV			
7	W-2, near Waco, Tex.[1]	.130	18	2	Walnut Brook near Flemington, N.J.	1.43	21
8	W-1, near Waco, Tex.[1]	.176	18	3	Little Falls Branch near Bethesda, Md.	2.62	12
9	Blake Run near Reily, Ohio	.186	10	5	Dial Creek near Bahama, N.C.	3.14	26
10	No. 196, Coshocton, Ohio[1]	.301	19	6	Basin Run at Liberty Grove, Md	3.40	9
				7	Shellpot Creek at Wilmington, Del.	4.77	12
11	No. 5, Coshocton, Ohio[1]	.349	17				
14	"C", near Waco, Tex.[1]	.597	6	8	South Fork Mills River at The Pink Beds, N.C.	6.39	23
15	Bell creek at McConnelsville, Ohio	.621	9	9	Crab Creek near Penrose, N.C.	6.98	13
16	No. 92, Coshocton, Ohio[1]	.920	19	10	Piney Run near Skyesville, Md	7.30	26
20	"D", near Waco, Tex.[1]	1.11	6	11	Noland Creek near Byson City, N.C.	8.83	20

				12	East Fork Deep River near High Point, N.C.	9.40	30
21	No. 94, Coshocton, Ohio[1]	1.52	19				
22	Jefferson Creek near Jewett, Ohio	1.59	10	13	Boylston Creek near Horseshoe, N.C.	9.47	13
23	Otter Fork near Centerburg, Ohio	1.90	10	15	Christina River at Coochs Bridge, Del.	13.1	14
26	Barnes Run near Summerfield, Ohio	2.26	10	16	Forbush Creek near Yadkinville, N.C.	13.9	18
27	South Branch Little Salt Creek at Jackson, Ohio	2.50	10	17	Accotink Creek near Annadale, Va.	15.1	11
28	No. 95, Coshocton, Ohio	2.57	17				
29	East Fork Paint Creek near Sedalia, Ohio	2.71	10				
30	Shawnee Creek at Xenia, Ohio	2.77	9				

[1]Experimental watershed, Agricultural Research Service, USDA.

Table 3. Basic data and values of $\hat{T}_{AP}$ and $\hat{Q}_{10(ATP)}$ for Group 1 watersheds

No.	A	P	T	$\hat{T}_{AP}$	Error[1] in $\hat{T}_{AP}$	Q_{10}	$\hat{Q}_{10(AT)}$	$\hat{Q}_{10(ATP)}$	Error[2] in $\hat{Q}_{10(ATP)}$
ZONE I									
	1,000 acres	*in./hr.*			*Percent*	*1,000 c.f.s*	*1,000 c.f.s*	*1,000 c.f.s*	*Percent*
1	0.052	2.2	0.027	0.021	-29	0.096	0.056	0.102	6
2	.171	2.2	.044	.056	21	.270	.210	.420	36
3	.290	2.5	.121	.100	-21	.440	.120	.480	8
4	.330	2.2	.099	.098	-1	.400	.200	.400	0
6	1.93	2.2	.470	.450	-4	1.06	.500	1.08	2
12a	.448	1.7	.045	.050	10	.110	1.10	.335	67
39	4.53	1.8	.490	.470	-4	.830	2.10	1.05	21
42	5.98	1.9	.935	.800	-17	1.05	1.32	1.05	0
44	6.23	1.9	.797	.820	2	.860	1.40	1.40	39
50	8.96	1.7	.552	.660	17	1.55	5.70	2.00	22
58	16.0	1.7	.894	1.08	18	3.90	8.40	3.15	-24
ZONE II									
1	0.020	3.1	0.021	0.017	-24	0.107	0.009	0.096	-10
2	.029	1.8	.014	.012	-17	.061	.031	.065	6
3	.042	3.1	.030	.030	0	.155	.019	.165	6
4	.074	1.8	.032	.025	-28	.092	.052	.082	-12
5	.076	1.8	.027	.024	-12	.096	.068	.092	-4
6	.122	1.8	.041	.035	-17	.092	.088	.103	11
7	.130	3.1	.055	.073	25	.420	.064	.510	18
8	.176	3.1	.068	.090	25	.620	.080	.720	14
9	.186	1.8	.050	.048	-4	.160	.135	.130	-23
10	.301	1.8	.051	.070	27	.295	.320	.245	-20
11	.349	1.7	.061	.072	15	.150	.310	.138	-9
14	.597	3.1	.291	.240	-21	.900	.082	.760	-18
15	.621	2.0	.124	.135	8	.630	.350	.440	-43
16	.920	1.8	.142	.162	12	.320	.490	.400	20
21	1.52	1.8	.256	.242	-6	.630	.560	.510	-24
26	2.22	2.1	.391	.380	-3	1.40	.560	1.15	-22
28	2.57	1.8	.400	.350	-14	.660	.660	.660	0
33	3.31	2.0	.566	.500	-13	.940	.660	1.10	15
37	4.10	1.8	.577	.510	-11	1.30	.960	1.15	-13
43	6.22	1.9	.646	.750	14	2.30	1.62	3.30	30
46	6.79	1.8	.927	.760	-22	1.90	1.19	1.62	-17
51	9.02	1.7	.862	.880	2	1.42	2.20	1.40	-1
57	15.2	1.7	.964	1.31	26	3.95	4.50	4.00	1
59	19.8	2.2	2.18	2.10	-4	5.60	2.10	11.0	49
ZONE III									

2	0.672	2.3	0.212	0.275	23	0.635	0.102	0.740	14
3	1.53	1.9	.219	.250	12	.370	.400	.430	14
4	2.00	1.8	.170	.205	17	.490	1.08	.600	18
9	6.14	1.9	.746	.695	-7	1.15	.940	1.10	-5
10	7.17	1.9	.844	.790	-7	2.00	1.10	1.32	-52
12	9.02	1.9	.878	.930	6	1.50	1.50	1.85	19
14	8.77	1.9	1.15	.900	-28	.580	.920	1.08	46
17	10.8	1.8	.673	.720	7	1.72	3.00	1.90	9
22	15.0	1.8	.785	.920	15	2.50	4.40	2.85	12
ZONE IV									
2	1.43	2.0	0.172	0.160	-8	0.490	2.40	0.510	4
6	3.40	2.2	.533	.580	8	1.27	1.45	1.50	15
7	4.77	2.2	.667	.770	13	2.90	1.90	2.25	-29
10	7.30	2.2	1.15	1.12	-3	2.20	1.50	1.60	-38
12	9.40	2.2	1.31	1.40	6	2.90	2.00	2.45	-18
15	13.1	2.3	2.49	2.05	-22	2.28	1.10	2.10	-9
16	13.9	2.2	1.62	1.95	17	2.13	2.30	2.90	27
17	15.1	2.3	2.32	2.30	-1	3.70	1.55	3.45	-7

1 $(\hat{T}_{AP} - T) \div \hat{T}_{AP} \times 100$ 2 $(\hat{Q}_{10(ATP)} - Q_{10}) \div \hat{Q}_{10(ATP)} \times 100$.

Table 4. Basic Data and Values of $\hat{T}_{AP}$ and $\hat{Q}_{10(ATP)}$ for Group 2 Watersheds

No.	A	P	T	$\hat{T}_{AP}$	Error[1] in $\hat{T}_{AP}$	Q_{10}	$\hat{Q}_{10(AT)}$	$\hat{Q}_{10(ATP)}$	Error[2] in $\hat{Q}_{10(ATP)}$
ZONE I									
	1,000 acres	*in./hr.*			*Percent*	*1,000 c.f.s*	*1,000 c.f.s*	*1,000 c.f.s*	*Percent*
5	0.481	2.4	0.288	0.155	-86	0.690	0.080	0.250	-176
8	2.14	2.0	.772	.375	-106	.860	.280	.315	-173
9	2.68	2.0	.949	.460	-106	.860	.300	.335	-156
10	3.12	1.9	1.04	.450	-134	.910	.350	.250	-264
19	6.46	2.0	1.79	.950	-88	1.75	.550	.650	-169
20	9.41	1.5	.980	.680	-44	1.80	2.80	.920	-96
22	12.9	2.2	1.22	2.30	46	5.60	3.60	9.20	39
13a	.582	1.9	.191	.105	-82	.142	.200	.135	-5
18b	.966	1.7	.130	.095	-37	.179	.850	.255	30
38	4.44	1.8	1.39	.470	-196	.660	.420	.190	-247
41	5.83	1.8	1.31	.600	-118	1.30	.800	.380	-242
47	6.92	1.8	1.81	.690	-163	.820	.610	.285	-188
49	8.90	1.8	1.75	.860	-103	1.15	1.05	.510	-126
53	12.6	1.8	2.30	1.20	-92	1.87	1.30	.640	-192
55	13.4	1.8	2.69	1.25	-115	2.05	1.15	.560	-266
56	14.1	1.6	1.56	.970	-61	2.05	2.95	.990	-107
ZONE II									
20	1.11	3.1	0.510	0.385	-33	1.42	0.102	1.05	-35
22	1.59	1.8	.377	.250	-51	.260	.300	.225	-14
23	1.90	1.8	.509	.290	-76	.385	.280	.210	-84
27	2.50	2.0	.754	.400	-88	.910	.250	.275	-231
29	2.71	1.8	1.73	.380	-355	.530	.080	.100	-430
30	2.77	1.8	.875	.380	-130	.830	.440	.350	-138
31	2.89	1.8	1.49	.400	-273	.590	.115	.120	-392
32	3.16	1.8	1.25	.430	-190	.520	.180	.155	-236
34	3.51	1.8	1.12	.470	-138	.920	.260	.200	-360
35	3.89	1.8	.696	.500	-39	1.14	.640	.620	-84
36	4.02	1.8	.705	.510	-38	1.25	.670	.670	-86
40	4.58	1.8	.802	.570	-41	1.10	.700	.710	-55
45	6.78	1.8	1.22	.760	-60	2.10	.760	.980	-114
48	7.04	1.8	.998	.760	-31	2.35	1.10	1.45	-62
ZONE III									
1	0.019	2.0	0.018	0.013	-38	0.014	0.0057	0.0083	-69
6	3.20	1.7	.693	.200	-246	.710	.340	.170	-318
7	4.10	2.2	.379	.950	60	3.60	1.22	8.20	56
13	8.96	2.2	.913	1.70	46	3.90	1.40	9.40	58
18	11.6	2.0	2.15	1.42	-51	2.38	.660	1.58	-51
19	11.8	1.8	1.71	.770	-122	1.85	1.05	.600	-208
20	12.0	1.8	2.25	.780	-189	1.55	.660	.360	-331
21	13.6	2.3	1.09	2.60	58	8.70	2.20	22.0	61

ZONE IV									
3	2.62	2.4	0.296	0.500	41	1.70	2.60	7.50	77
5	3.14	2.2	.800	.540	-48	.740	.600	.400	-85
8	6.39	2.1	.534	.820	35	1.06	4.50	3.95	73
9	6.98	2.1	.505	.900	44	1.15	6.20	6.40	82
11	8.83	2.2	.430	1.32	68	1.60	12.0	34.0	95
13	9.47	2.1	2.05	1.18	-74	.750	.900	.360	-108

[1] $(\hat{T}_{AP} - T) \div \hat{T}_{AP} \times 100$ [2] $(\hat{Q}_{10(ATP)} - Q_{10}) \div \hat{Q}_{10(ATP)} \times 100$.

Table 5. Values of T/ $\hat{T}_{AP}$, $\hat{Q}_{10}$ / $Q_{10(ATP)}$, C, and $Q_{10(C)}$ for Group 2 Watersheds.

No.	T	$\hat{T}_{AP}$	T/ $\hat{T}_{AP}$	Q_{10}	$\hat{Q}_{10(ATP)}$	$Q_{10} \div \hat{Q}_{10(ATP)}$	C	$\hat{Q}_{10(C)}$	Error[1] in $\hat{Q}_{10(C)}$
ZONE I									
				1,000 c.f.s	*1,000 c.f.s*			*1,000 c.f.s*	*Percent*
5	0.288	0.155	1.86	0.690	0.250	2.76	2.35	0.590	-17
8	.772	.375	2.06	.860	.315	2.73	2.70	.850	-1
9	.949	.460	2.06	.860	.335	2.57	2.70	.905	5
10	1.04	.450	2.31	.910	.250	3.64	3.10	.775	-17
19	1.79	.950	1.89	1.75	.650	2.69	2.45	1.60	-9
20	.980	.680	1.44	1.80	.920	1.96	1.69	1.56	-15
22	1.22	2.30	0.530	5.60	9.20	0.610	0.495	4.56	-23
13a	.191	.105	1.82	.142	.135	1.05	2.30	.301	54
18b	.130	.095	1.37	.179	.255	0.70	1.55	.395	55
38	1.39	.470	2.96	.660	.190	3.48	3.80	.721	8
41	1.31	.600	2.19	1.30	.380	3.42	2.89	1.10	-18
47	1.81	.690	2.62	.820	.285	2.87	3.45	.985	17
49	1.75	.860	2.04	1.15	.510	2.26	2.65	1.35	15
53	2.30	1.20	1.92	1.87	.640	2.92	2.50	1.60	-17
55	2.69	1.25	2.15	2.05	.560	3.66	2.80	1.57	-30
56	1.56	.970	1.61	2.05	.990	2.07	1.98	1.96	-5
ZONE II									
20	0.510	0.385	1.32	1.42	1.05	1.36	1.50	1.58	10
22	.377	.250	1.50	.260	.222	1.16	1.80	.405	36
23	.509	.290	1.76	.385	.210	1.83	2.20	.462	17
27	.754	.400	1.88	.910	.275	3.31	2.40	.660	-38
29	1.73	.380	4.55	.530	.100	5.30	5.30	.530	0
30	.875	.380	2.30	.830	.350	2.38	3.00	1.05	21
31	1.49	.400	3.72	.590	.120	4.90	4.60	.553	-7
32	1.25	.430	2.90	.520	.155	3.36	3.75	.582	11
34	1.12	.470	2.39	.920	.200	4.60	3.15	.630	-46
35	.696	.500	1.39	1.14	.620	1.84	1.62	1.00	-14
36	.705	.510	1.38	1.25	.670	1.88	1.60	1.07	-17
40	.802	.570	1.41	1.10	.710	1.55	1.65	1.17	6
45	1.22	.760	1.60	2.10	.980	2.14	1.98	1.94	-8
48	.998	.760	1.30	2.35	1.45	1.62	1.50	2.18	-8
ZONE III									
1	0.018	0.013	1.39	0.014	0.0083	1.69	1.62	0.014	0
6	.693	.200	3.46	.710	.170	4.18	4.30	.730	3
7	.379	.950	.400	3.60	8.20	.440	.405	3.32	-8
13	.913	1.70	.538	3.90	9.40	.415	.500	4.70	17
18	2.15	1.42	1.50	2.38	1.58	1.50	1.80	2.84	16
19	1.71	.770	2.22	1.85	.600	3.08	2.90	1.74	-6
20	2.25	.780	2.89	1.55	.360	4.31	3.75	1.35	-15
21	1.09	2.60	.420	8.70	22.0	.395	.420	9.25	6

ZONE IV									
3	0.296	0.500	0.592	1.70	7.50	0.226	0.200	1.65	-3
5	.800	.540	1.48	.740	.400	1.85	1.78	.712	-4
8	.534	.820	.651	1.06	3.95	.269	.270	1.06	0
9	.505	.900	.560	1.15	6.40	.180	.170	1.09	-6
11	.430	1.32	.326	1.60	34.0	.047	.045	1.53	-5
13	2.05	1.18	1.74	.750	.360	2.08	2.20	.792	5

[1] $(\hat{Q}_{10(C)} - Q_{10}) \div \hat{Q}_{10(C)} \times 100$.

Table 6. Comparison of Estimated Values of Q_{10} and Q_{50} with Maximum Q of Record, for Gaged Watershed Sample.

No.	$\hat{Q}_{10(ATP)}$	$\hat{Q}_{10(C)}$	$\hat{Q}_{50}$	Maximum Q of Record	No.	$\hat{Q}_{10(ATP)}$	$\hat{Q}_{10(C)}$	$\hat{Q}_{50}$	Maximum Q of Record	No.	$\hat{Q}_{10(ATP)}$	$\hat{Q}_{10(C)}$	$\hat{Q}_{50}$	Maximum Q of Record
ZONE I														
	1,000 c.f.s	*1,000 c.f.s*	*1,000 c.f.s*	*1,000 c.f.s*		*1,000 c.f.s*	*1,000 c.f.s*	*1,000 c.f.s*	*1,000 c.f.s*		*1,000 c.f.s*	*1,000 c.f.s*	*1,000 c.f.s*	*1,000 c.f.s*
1	0.102	----------	0.152	0.086	20	----------	1.56	2.30	1.37		----------	0.985	1.43	0.584
2	.420	----------	.620	.304	22	----------	4.56	6.60	16.6	47	----------	1.35	1.98	1.45
3	.480	----------	.710	.810	12a	0.335	----------	.490	.287	49	2.00	----------	2.95	4.01
4	.400	----------	.590	.565	13a	----------	.310	.460	.095	50	----------	1.60	2.35	1.90
5	----------	0.590	.870	.845	18b	----------	.395	.580	.335	53	----------	1.57	2.30	3.63
										55				
6	1.08	----------	1.58	1.48	38	----------	.721	1.05	.543		----------	1.96	2.85	2.13
8	----------	.850	1.25	.810	39	1.05	----------	1.50	.787	56	3.15	----------	4.60	3.82
9	----------	.905	1.32	1.06	41	----------	1.10	1.63	1.20	58				
10	----------	.775	1.13	.658	42	1.05	----------	1.50	1.46					
19	----------	1.60	2.35	1.69	44	1.40	----------	2.08	1.05					
ZONE II														
1	0.096	----------	0.140	0.132	16	0.400	----------	0.590	0.460	34	----------	0.630	.930	0.632
2	.065	----------	.094	.070	20	----------	1.58	2.30	.833	35	----------	1.00	1.48	1.13
3	.165	----------	.240	.211	21	.510	----------	.750	.667	36	----------	1.07	1.55	2.10
4	.082	----------	.118	.193	22	----------	.405	.600	.367	37	1.15	----------	1.70	1.38
5	.092	----------	.134	.156	23	----------	.462	.680	.368	40	----------	1.17	1.75	1.72
6	.103	----------	.150	.212	26	1.15	----------	1.70	2.05	43	3.30	----------	4.90	5.64
7	.510	----------	.765	.633	27	----------	.660	.980	1.05	45	----------	1.94	2.85	2.78
8	.720	----------	1.05	.800	28	.660	----------	.970	.944	46	1.62	----------	2.40	1.90
9	.130	----------	.190	.144	29	----------	.530	.780	----------	48	----------	2.18	3.20	2.79
10	.245	----------	.360	.580	30	----------	1.05	1.55	.790	51	1.40	----------	2.08	1.06
11	.138	----------	.205	.293	31	----------	.553	.810	.348	57	4.00	----------	5.90	7.31
14	.760	----------	1.13	.760	32	----------	.582	.850	.351	59	11.0	----------	16.0	18.0
15	.440	----------	.650	1.19	33	1.10	----------	1.60	.965					
ZONE III														
1	----------	0.014	0.020	0.019	9	1.10	----------	1.60	0.912	18	----------	2.84	4.15	2.14
2	0.740	----------	1.10	1.19	10	1.32	----------	1.95	1.90	19	----------	1.74	2.55	1.54
3	.430	----------	.630	.342	12	1.85	----------	2.70	2.65	20	----------	1.35	1.98	1.89
4	.600	----------	.880	.487	13	----------	4.70	6.90	3.80	21	----------	9.25	13.5	8.25
6	----------	.730	1.08	.770	14	1.08	----------	1.58	.383	22	2.85	----------	4.20	11.1
7	----------	3.32	4.90	7.42	17	1.90	----------	2.80	1.47					
ZONE IV														
2	0.510	----------	0.740	0.645	8	----------	1.06	1.55	2.22	13	----------	0.792	1.15	0.805
3	----------	1.65	2.45	2.34	9	----------	1.09	1.60	1.50	15	2.10	----------	3.10	2.62
5	----------	.712	1.06	1.05	10	1.60	----------	2.35	7.38	16	2.90	----------	4.20	2.45
6	1.50	----------	2.20	1.44	11	----------	1.53	2.25	1.53	17	3.45	----------	5.00	3.95
7	2.25	----------	3.30	4.08	12	2.45	----------	3.55	6.30					

Table 7. Distribution of Gaged Watershed Sample by Periods of Runoff Record and by States

Distribution by period of runoff record

Period of record, years	# of watersheds: Total #	# of watersheds: Maximum record[1] $Q \Rightarrow \hat{Q}_{50}$
6	2	0
7	1	0
8	6	1
9	6	3
10	26	3
11	4	1
12	2	1
13	3	0
14	4	1
15	4	3
16	5	1
17	4	1
18	10	2
19	6	2
20	3	0
21	2	0
22	1	1
23	1	1
26	2	1
30	1	1
31	1	0
38	1	0
Total	95	23

Distribution by state

State	# of watersheds
Delaware	2
Illinois	3
Iowa	1
Kentucky	3
Maryland	5
Missouri	4
Nebraska	1
New Jersey	1
New York	9
North Carolina	7
Ohio	39
Oklahoma	1
Pennsylvania	5
Texas	6
Virginia	5
Wisconsin	3
Total	95

[1]Number where maximum recorded peak equaled or exceeded the estimated 50-year peak.

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Preface : HDS 2

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This publication, second in the Bureau of Public Roads' series on hydraulic design, reports a research study of peak rates of runoff from small watersheds, and the practical application of the results of that research. Since the descriptions of both the study and the method of application are relatively short, both are combined in this one publication.

The research study was limited to watersheds with areas of 25 square miles or less, located east of the 105th meridian. It makes use of two independent watershed samples. The first of these, comprising a sample of 243 ungaged watersheds, was selected so as to give representation both to the location of the watersheds and as to their range in size. The second sample, consisting of 96 gaged watersheds, was screened from an inventory of available streamflow records.

Following the introduction, which states the problem, Part I of the report deals with an analysis of the drainage characteristics of the ungaged watershed sample. Correlations are established between a topographic index T, a precipitation index P, and the watershed area A. It is shown that errors in estimates of T, obtained from these correlations, can be explained by differences in the drainage characteristics of the watershed as measured by the watershed's drainage density index D. Thus the magnitude of the error in the estimated value of T can be used as an indication of the degree to which the drainage characteristics of a watershed differ from those of the watersheds on which the correlation was based.

The criteria developed in Part I are used in Part II of the report to divide the 96 gaged watersheds into two groups: Group 1 watersheds, with drainage characteristics similar to those on which the correlation was based; and Group 2 watersheds, in which these characteristics differed by varying degrees. Correlations are established, for Group 1 watersheds, between the peak rate of runoff for an average recurrence interval of 10 years, Q_{10}, and the indexes A, T, and P. These correlations are used to obtain estimated values of Q_{10} for the Group 2 watersheds. It is shown that the errors in these estimates bear a close relation to the corresponding errors in the estimated value of T. This relation is used to obtain a correction coefficient C which can be applied to the estimate of Q_{10} when the estimate of T indicates a difference in drainage characteristics.

The remainder of the publication is concerned with the practical procedure, developed from the research, for estimating peak rates of runoff from small watersheds. Part III presents some considerations that must be borne in mind in the use of the procedure, and Part IV describes, step by step, the procedure itself, which is based on the use of lithological zone and rainfall index maps and a series of correlation nomographs. As pointed out early in the text, the results obtained through the procedure must be considered as aids to engineering judgment rather than proven figures.

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