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RUNOFF ESTIMATES FOR SMALL RURAL WATERSHEDS AND DEVELOPMENT OF A SOUND DESIGN METHOD

Vol. II Recommendations for Preparing Design Manuals and Appendices B, C, D, E, F, G, and H

October 1977

Final Report

Prepared for

FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Washington, D. C. 20590

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FOREWORD

This report is composed of three volumes: Volume I is the Research Report; Volume II consists of recommendations for establishing design manuals and Appendices B, C, D, E, F, G, and H, which are the design aids required for establishing design manuals; Volume III consists of Appendix A, an accumulation of the data base used in the study. FHWA chose to arrange the report as described to facilitate distribution of the results. The methods reported herein and designated as the Federal Highway Administration Methods are designed to be applied to watersheds smaller than 50 square miles but may be used on areas up to 100 square miles in size.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Sufficient copies of Volumes I and II will be distributed to provide a minimum of one copy to each FHWA Regional office, FHWA Division office and State Highway Agency. Volume III will be distributed only upon special request since it will be of interest primarily to individuals wishing to verify equations or develop new equations. Direct distribution is being made to the Division offices.

Charles F. Scheffey

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16. Abstract
Frequency analyses of more than 1,000 small watersheds in the United States and Puerto Rico were used to develop the estimation method for design of peak flow for ungaged watersheds. This method, called the Federal Highway Administration (FHWA) method, is conceptually similar to the Bureau of Public Roads (BRP) method developed by W. D. Potter. The FHWA method relates the runoff peak to easily determined hydrophysiographic parameters and is intended for use on watersheds smaller than 50 square miles. The concept of risk is incorporated into the design procedure. The risk is the probability that one or more events will exceed a specified peak flow within the usable lifetime of the drainage structure. The return period of the design flood peak can then be modified according to the risk the designer is willing to take. Another concept dealing with the probable maximum runoff peak derived as a function of watershed area is included. The flow obtained from this relationship is considered to be the upper limit of the design flow that may realistically be expected to ever occur. As such it may be appropriate to use in situations where the consequences of failure are extremely great.

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LIST OF SYMBOLS

A	Area of watershed in square miles.
AMS	Army Map Service.
cfs	Cubic feet per second.
FHWA	Federal Highway Administration.
Mcfs	Thousands of cubic feet per second.
USGS	United States Geological Survey.
$Q_{p(max)}$	Probable maximum runoff peak in cfs.
Q_c	Carrying capacity of the minimum sized culvert specified by the design agency in cfs.
R	Iso-erodent factor defined as the mean annual rainfall kinetic energy times the maximum respective 30-minute annual maximum rainfall intensity.
E_t	Elevation of the main channel at its most distant point from the structure site on the watershed boundary in feet above a reference datum.
E_c	Elevation of the stream channel at the culvert or drainage structure site in feet above the reference datum.
DH	Difference in elevation between E_t and E_c in feet.
q_{10}/A	10-year peak flow depth in cfs per square mile.
L	Length of the principal drainage channel from the structure site to the upper boundary of the watershed in miles.
P_{60}	10-year, 60-minute rainfall at the centroid of the watershed in inches.
LL	Cumulative length of all stream channels shown as solid or broken blue lines on the USGS 1:24,000 series topographic maps in miles.
LL_{250}	Cumulative length of all stream channels shown as solid or broken blue lines on the AMS 1:250,000 series topographic maps in miles.

P_{10} — 10-year, 10-minute rainfall intensity at the centroid of the watershed in inches per hour.

Q_{10}, q_{10} — 10-year runoff peak in cfs. The subscript indicates the return period for the particular flow value.

$\hat{q}_{10}$ — Estimate of the 10-year runoff peak in cfs.

$\hat{q}_{10(3AZ)}$ — 10-year runoff peak estimated from the 3-parameter all zone equation in cfs.

$\hat{q}_{10(k)}$ — 10-year runoff peak estimated from 3-parameter all zone equation corrected for zonal bias in cfs.

S — Percent of watershed area covered by the lakes, ponds, swamps, playas, etc.

x — Independent variables in regression or graphical correlation.

y — Dependent variable in regression or graphical correlation.

PS_e — The standard error of a regression equation in its linear form as a percent of the mean value of the measured dependent variables in its linear form. For most of the regression equations derived in this report, the $\log_{10}$ transformation was used, therefore

$$PS_e = \frac{100}{\log_{10}\bar{y}} \sqrt{\frac{\Sigma(\log_{10}y - \log_{10}\hat{y})^2}{df}}$$

PS_{EE} — The standard error of a point estimate made from any estimating equation as a percentage of the mean value of the measured dependent variable in its original untransformed state. For the equations derived in this report

$$PS_{EE} = \frac{100}{\bar{y}} \sqrt{\frac{\Sigma(y - \hat{y})^2}{n - 2}}$$

r — Simple correlation coefficient between any two variables x and y.

df — Degrees of freedom for hypothesis testing, in general, df = n-k-1.

k — Is the number of independent variables used in an estimating equation.

T_D — Return period of the design flood flow in years.

T — Return period of the nominally specified design flood in years.

P_k — The probability that exactly k flood events exceed the T-year flood in n years.

n	The usable lifetime of the structure in years. Also used as the number of observations used in developing a regression equation.
k	The number of flood events that exceed the T-year flood event.
$\binom{n}{k}$	The bionomial coefficient, $\frac{n!}{k!(n-k)!}$
p	The probability of the nominally specified design flood ($p = 1/T$).
R_e	The exceedance risk defined as the probability that a T-year flood will be exceeded one or more times in n years.
$Q_{2.33}$	The mean annual flood in cfs.
Q_{50}	The 50-year flood peak in cfs.
Q_{100}	The 100-year flood peak in cfs.
Q_{T_D}	The design flood flow in cfs.
Q_U	The flood flow at the upper 95 percent confidence level about the design flood in cfs.
Q_L	The flood flow at the lower 95 percent confidence level about the design flood in cfs.
P	The probability of a flood flow being less or equal to the T-year flood flow.

CONVERSION FACTORS

English to International System

1 mile	=	1.609 kilometers (km)
1,000 cubic feet per second (cfs)	=	28.32 cubic meters/second (m^3/s)
1 foot	=	0.3048 meters (m)
1 acre (a)	=	0.4047 hectares (ha) or 4047 square meters (m^2)
1 square mile (mi^2)	=	640 acres = 2,590 square kilometers (km^2) = 259 ha
1 cubic foot	=	0.02832 cubic meters (m^3)
1 acre-foot	=	1,233 cubic meters = 0.01028 hectare meters (ha-m)
1 ton/acre/year	=	2.24 tonnes/hectare/year (tonnes (t)/ha/yr)
inches (in)	=	25.4 millimeters (mm) = 2.54 centimeters (cm)

INTRODUCTION

A basic consideration in the design of bridges and culverts is the estimation of the rate of runoff expected during peak flow periods. The most widely used methods for this purpose have been either a hydrograph synthesis approach using rainfall-runoff models or empirical equations relating hydroclimatic and physiographic properties to a peak flow of a selected return period. Since only the peak flow is required for the design of most minor highway drainage structures, only the latter type methods have been considered in this study.

A detailed examination and verification of the Bureau of Public Roads or Potter's method (ref. 1) for estimating peak flow of specified return periods was conducted. Updated equations were derived using extended flow records and the most recent maps to derive the most reliable flow frequency information and to insure the correctness of the basic physiographic parameter measurements. Potter's method was judged to be soundly conceived and the revised equations did significantly reduce the standard error of estimate when tested on 25 randomly selected watersheds not used in deriving the equations.

The work of Boch, Enger, Malhotra and Chisholm (ref. 2) conducted for the Federal Highway Administration was also reviewed as an aid in developing a modified form of Potter's method for the entire United States and Puerto Rico. Their work consisted primarily of applying multiple regression techniques relating the peak flow to combinations of up to 28 different hydroclimatic-physiographic parameters. Eighty-four different equations were derived and published for estimating the peak runoff rates from the contiguous United States but the inherent simplicity of Potter's original work in which only three predicting parameters are used was lost. The number of equations presented and the difficulty of obtaining some of the basic parameter values tends to overwhelm the average field engineer and he gains the impression that it is just too complicated to be useful to him. These factors were kept in mind as the research was conducted in extending a Potter type method to the entire United States and Puerto Rico. A multiple regression (MR) approach was used instead of the graphical correlation (GC) approach of Potter because the derived relationships from the MR approach are not scale dependent and because the MR approach fully exploits the interaction that may exist among the predictor variables in reducing the variance of the prediction estimates.

In addition to producing a method no more complex to use than Potter's the concept of risk was also incorporated into the design procedures. By risk is meant the probability that one or more events will exceed a given peak flow within a specified period of years. The return period of the design flood peak can be modified according to the risk that one is willing to take in conjunction with the usable lifetime of the project.

A final concept introduced into the design procedure is that of the probable maximum runoff peak derived as a function of watershed area. The flow obtained from this relationship is considered to be the upper limit that may be anticipated from the particular size watershed drainage area and may thus be considered the ultra-safe or most conservative design flow peak realistically expected.

All of the basic equations used in the design procedure are included in the manual or the appropriate appendix as well as many of the corresponding graphical solutions so that the field or design engineer may solve the equations on his pocket calculator if he so desires. This also facilitates the preparation or modification of the graphs into other forms that some may feel are more useful.

The authors emphasize that the method presented in this design manual is particularly intended for use on watersheds smaller than 50 square miles but may be used on areas up to 100 square miles. In addition, it is realized that as time goes on and the method is used, data for improvements will become available so that the exact procedures will be subject to further refinement. However, it is believed that the material that follows does present a greatly improved method for estimating runoff peaks more simply and reliably than previously existing methods.

DESIGN PROCEDURE--FEDERAL HIGHWAY ADMINISTRATION METHOD

The design procedure for estimating the runoff from small rural watersheds, herein designated as the Federal Highway Administration (FHWA) Method, is outlined schematically in Figure 1. There are nine basic steps involved in estimating the design runoff peak necessary for sizing culverts and other highway drainage structures. Each of the steps is described in detail as follows:

Step I. Delineate the Watershed

The watershed is delineated by first plotting the culvert or drainage structure site on a suitable topographic map. The United States Geological Service (USGS) 1:24,000 scale map is recommended if available. The 1:250,000 Army Map Service (AMS) maps distributed by the USGS may be used if the drainage area of the watershed is large enough to insure its accurate determination. After locating the drainage site, carefully outline the watershed boundaries on the map and then measure the watershed drainage area, A, in square miles as accurately as feasible by use of a planimeter, dot grid or other suitable intergrating instrument.

Step II. Determine the Probable Maximum Runoff Peak, $Q_{p(max)}$

The probable maximum runoff peak is calculated as a function of the watershed drainage area from the equation

$$Q_{p(max)} = 10^{\{3.92 + 0.812 (\log A) - 0.0325 (\log A)^2\}} \quad . \; . \; . \; . \; . \quad (1)$$

in which

$Q_{p(max)}$ = the probable maximum runoff in cfs
$\log A$ = the base 10 logarithm of the watershed drainage area measured in square miles.

Alternatively, $Q_{p(max)}$ may be obtained graphically by entering Figure 2 on the horizontal axis with the area, A, moving vertically to the curve and then horizontally to the left where $Q_{p(max)}$ is read from the vertical scale.

At this point in the design process, two decisions must be made. First, if the design requirement specifies that the drainage structure be designed for the probable maximum runoff peak because of the serious consequences resulting from a failure and if it is feasible to install or construct a structure that will safely handle such a large flow, the design flow becomes $Q_{p(max)}$ and the design procedure is complete.

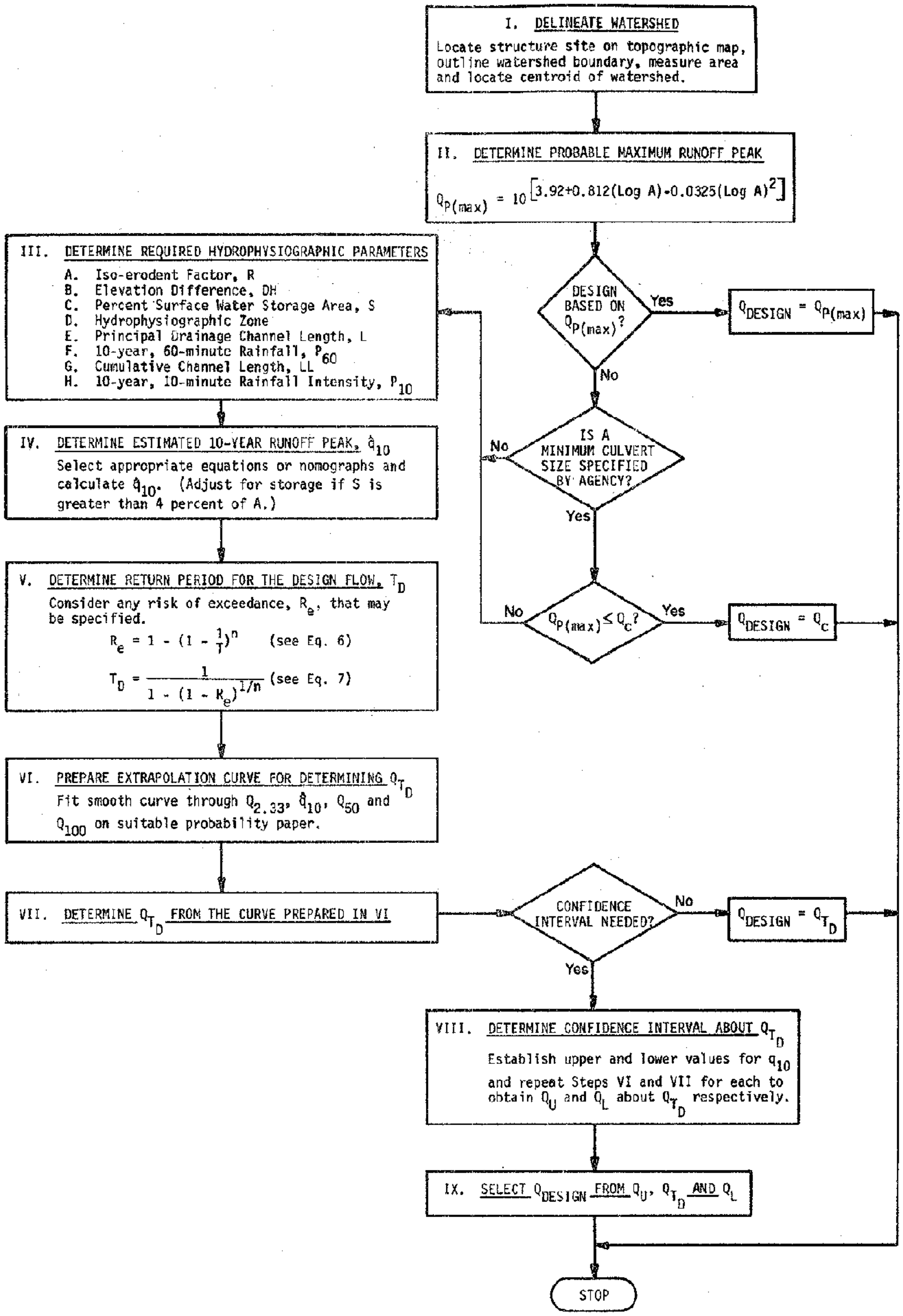


Figure 1. Schematic diagram of the design procedure for estimating peak runoff from small ungaged watersheds by the FHWA method.

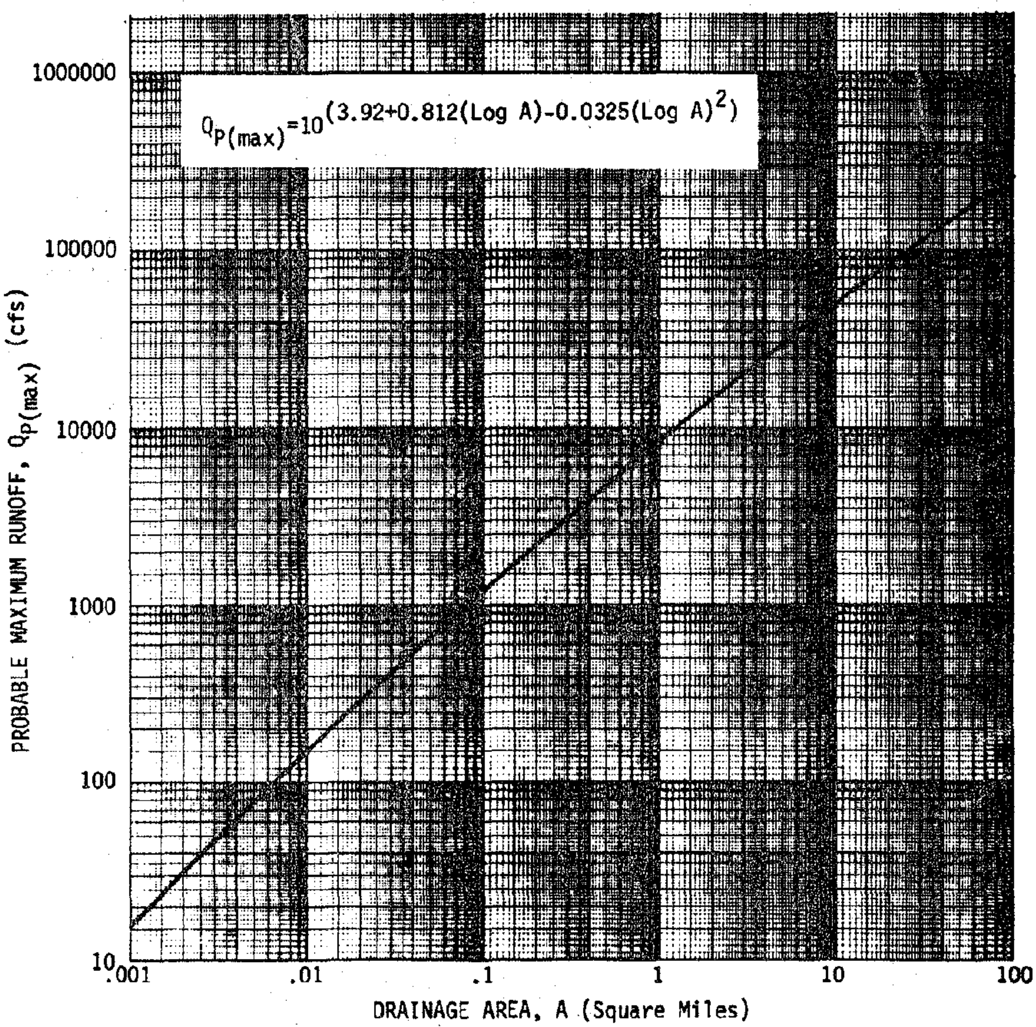


Figure 2. The probable maximum runoff peak curve for small watersheds in the United States and Puerto Rico. (See also Figure 31 of Volume I, Research Report.)

Second, if the agency has a policy that specifies that no culvert smaller than a minimum size will be used, the carrying capacity of that minimum size culvert must be calculated for the particular site delineated in Step I. This flow, designated as Q_c, is then compared with $Q_{p(max)}$ and if $Q_{p(max)}$ is less than Q_c the design flow is taken as Q_c and the minimum sized culvert specified by policy is adequate to carry the ultra-safe or virtually no-risk flow, $Q_{p(max)}$. However, the more usual cases of estimating the design flow, Q_{T_D}, will require completing the remaining steps.

Step III. Determine the Required Hydrophysiographic Parameters

The parameters that must be determined will depend on the particular equation or nomograph that is selected for use. Four different sets of equations have been derived and are tabulated in Tables H-1 through H-4. The estimation errors, etc. associated with the different equations are summarized in Table H-5. In addition to the drainage area, A, which has already been discussed in Steps I and II, the remaining parameters that enter into the equations are now described in their order of importance.

a. Iso-erodent factor, R. The iso-erodent factor is a precipitation parameter defined as the mean annual rainfall kinetic energy times the annual maximum 30 minute rainfall intensity. In order to determine the R value, the centroid of the watershed delineated in Step I must be located by eye and its latitude and longitude recorded to the nearest minute. Then, read R for the latitude and longitude from the proper iso-erodent state map given in Appendix C. This parameter is used in all of the equations.

b. Elevation difference, DH. The elevation difference is determined from a topographic map by taking the difference between the elevation of the main channel at its most distant boundary as measured along the channel and the elevation at the culvert or drainage structure site. DH is used in nearly all of the equations and must be measured in feet.

c. Percent surface water storage area, S. Storage is defined as the percent of the watershed area covered by lakes, ponds, swamps, playas, etc. It is determined from a topographic map by planimetering or otherwise measuring the surface water storage area within the watershed delineated in Step I, then dividing by the watershed area, A, and multiplying by 100.

d. Hydrophysiographic zone. In general a less biased and more precise estimate of a dependent variable may be obtained from equations derived from homogeneously grouped data. Consequently, the contiguous United States were divided into 22 hydrophysiographic zones by grouping the physiographic sections from the Fenneman and Johnson map (ref. 3) according to whether the gaging stations within the section had nonsignificantly different 10-year peak flow depths (q_{10}/A). The hydrophysiographic zones for the contiguous United States are shown in Figure 3 and are given in Appendix B on a state-by-state basis. The particular hydrophysiographic zone for a watershed is determined by entering the proper state map in Appendix B and reading the zone in which the centroid of the watershed delineated in Step I lies. Alaska was treated as a separate zone, zone 23, and Hawaii and Puerto Rico were combined to form zone 24. The hydrophysiographic zone is necessary only if a zonal equation is used or if an adjustment to the all zone equation value is desired.

e. Principal drainage channel length, L. This parameter is defined as the length in miles of the principal drainage channel from the structure site to the upper boundary of the watershed. It is needed only if the 5 or 7 parameter equations are used.

Table 1-A. The 3-parameter all zone regression equation and correction equations for each of the 24 hydrophysiographic zones of the United States and Puerto Rico. (See also Appendix H, Tables H-1 and H-4.)

All Zone Equation $\hat{q}_{10} = 1.28015\ A^{0.56172}\ R^{0.94356}\ DH^{0.16887}$

Zone	Correction Equation
01	$\hat{q}_{10(K)} = 0.16166\ \hat{q}_{10(3AZ)}^{1.21261}$
02	$\hat{q}_{10(K)} = 2.10583\ \hat{q}_{10(3AZ)}^{0.89466}$
03	$\hat{q}_{10(K)} = 3.01000\ \hat{q}_{10(3AZ)}^{0.86834}$
04	$\hat{q}_{10(K)} = 0.94719\ \hat{q}_{10(3AZ)}^{0.99893}$
05	$\hat{q}_{10(K)} = 0.02681\ \hat{q}_{10(3AZ)}^{1.48804}$
06	$\hat{q}_{10(K)} = 1.16675\ \hat{q}_{10(3AZ)}^{0.98518}$
07	$\hat{q}_{10(K)} = 0.10677\ \hat{q}_{10(3AZ)}^{1.38890}$
08	$\hat{q}_{10(K)} = 0.74039\ \hat{q}_{10(3AZ)}^{1.06262}$
09	$\hat{q}_{10(K)} = 0.17280\ \hat{q}_{10(3AZ)}^{1.26937}$
10	$\hat{q}_{10(K)} = 0.01207\ \hat{q}_{10(3AZ)}^{1.59770}$
11	$\hat{q}_{10(K)} = 0.24744\ \hat{q}_{10(3AZ)}^{1.25355}$
12	$\hat{q}_{10(K)} = 0.64332\ \hat{q}_{10(3AZ)}^{1.05533}$
13	$\hat{q}_{10(K)} = 0.98668\ \hat{q}_{10(3AZ)}^{1.10579}$
14	$\hat{q}_{10(K)} = 0.34563\ \hat{q}_{10(3AZ)}^{1.25915}$
15	$\hat{q}_{10(K)} = 0.98994\ \hat{q}_{10(3AZ)}^{0.94859}$
16	$\hat{q}_{10(K)} = 0.60069\ \hat{q}_{10(3AZ)}^{1.13479}$
17	$\hat{q}_{10(K)} = 0.57246\ \hat{q}_{10(3AZ)}^{1.04580}$
18	$\hat{q}_{10(K)} = 23.5251\ \hat{q}_{10(3AZ)}^{0.64862}$
19	$\hat{q}_{10(K)} = 2.44605\ \hat{q}_{10(3AZ)}^{1.02879}$
20	$\hat{q}_{10(K)} = 0.17546\ \hat{q}_{10(3AZ)}^{1.31670}$
21	$\hat{q}_{10(K)} = 0.16894\ \hat{q}_{10(3AZ)}^{1.32661}$
22	$\hat{q}_{10(K)} = 0.15938\ \hat{q}_{10(3AZ)}^{1.30941}$
23	$\hat{q}_{10(K)} = 0.30461\ \hat{q}_{10(3AZ)}^{1.190085}$
24	$\hat{q}_{10(K)} = 0.87269\ \hat{q}_{10(3AZ)}^{1.06360}$

Table 1-B. The 3-parameter regression equation for each of the 24 hydrophysiographic zones of the United States and Puerto Rico. (See also Appendix H, Table H-1.)

Zone		Equation
All Zone		$\hat{q}_{10} = 1.28015\ A^{0.56172}\ R^{0.94356}\ DH^{0.16887}$
1		$\hat{q}_{10} = 0.02137\ A^{0.43975}\ R^{1.16383}\ DH^{0.78453}$
2		$\hat{q}_{10} = 11.8893\ A^{0.57269}\ R^{0.44271}\ DH^{0.29510}$
3		$\hat{q}_{10} = 10410.4\ A^{0.54499}\ R^{-0.69141}\ DH^{0.32389}$
4		$\hat{q}_{10} = 76.7226\ A^{0.64795}\ R^{0.24744}\ DH^{0.03546}$
5		$\hat{q}_{10} = 1.14069\ A^{0.81060}\ R^{0.81127}\ DH^{0.16225}$
6		$\hat{q}_{10} = 10^{5.03658}\ A^{0.22735}\ R^{-2.07865}\ DH^{0.71475}$
7		$\hat{q}_{10} = 141.135\ A^{0.88572}\ R^{-0.13043}\ DH^{0.13981}$
8		$\hat{q}_{10} = 95.0775\ A^{0.58571}\ R^{0.07355}\ DH^{0.18493}$
9		$\hat{q}_{10} = 0.50051\ A^{0.69229}\ R^{0.74166}\ DH^{0.39729}$
10		$\hat{q}_{10} = 0.000613\ A^{1.30515}\ R^{3.28114}\ DH^{-0.54172}$
11		$\hat{q}_{10} = 1111.47\ A^{0.67899}\ R^{-0.76204}\ DH^{0.58914}$
12		$\hat{q}_{10} = 0.01961\ A^{0.47391}\ R^{1.68758}\ DH^{0.30700}$
13		$\hat{q}_{10} = 6.18115\ A^{0.66694}\ R^{0.87434}\ DH^{0.01023}$
	or	$\hat{q}_{10} = 6.6082\ A^{0.67054}\ R^{0.87120}$
14		$\hat{q}_{10} = 0.00353\ A^{0.42562}\ R^{1.64552}\ DH^{0.82680}$
15		$\hat{q}_{10} = 412.131\ A^{1.00832}\ R^{-0.43497}\ DH^{-0.18943}$
16		$\hat{q}_{10} = 5.99340\ A^{0.69400}\ R^{0.81381}\ DH^{-0.02694}$
17		$\hat{q}_{10} = 41.2165\ A^{0.95643}\ R^{0.90116}\ DH^{-0.49291}$
18		$\hat{q}_{10} = 5399.80\ A^{0.61776}\ R^{-0.20988}\ DH^{-0.28469}$
19		$\hat{q}_{10} = 0.67503\ A^{0.44020}\ R^{1.26786}\ DH^{0.24140}$
20		$\hat{q}_{10} = 0.88267\ A^{0.94684}\ R^{1.01373}\ DH^{0.06857}$
21		$\hat{q}_{10} = 8.80096\ A^{0.90473}\ R^{0.44704}\ DH^{0.13937}$
22		$\hat{q}_{10} = 0.76272\ A^{0.69452}\ R^{0.85611}\ DH^{0.23777}$
23		$\hat{q}_{10} = 9687.77\ A^{0.99975}\ R^{0.16025}\ DH^{-0.58516}$
24		$\hat{q}_{10} = 12.8566\ A^{0.86854}\ R^{1.17343}\ DH^{-0.37794}$

Table 1-C. The 5-parameter regression equations for each of the 24 hydrophysiographic zones of the United States and Puerto Rico. (See also Appendix H, Table H-2.)

Zone	Equation
All Zone	$\hat{q}_{10} = 1.5102\ A^{0.4707}\ R^{0.8386}\ DH^{0.1718}\ L^{0.1764}\ P_{60}^{0.3476}$
1	$\hat{q}_{10} = 0.31006\ A^{-0.1672}\ R^{0.1278}\ DH^{0.6261}\ L^{1.1489}\ P_{60}^{3.3884}$
2	$\hat{q}_{10} = 22.5512\ A^{0.8067}\ R^{0.5364}\ DH^{0.2743}\ L^{-0.4967}\ P_{60}^{-0.7727}$
3	$\hat{q}_{10} = 13954\ A^{0.9374}\ R^{-0.5560}\ DH^{0.5672}\ L^{-0.7957}\ P_{60}^{-1.6664}$
4	$\hat{q}_{10} = 43.1724\ A^{0.6940}\ R^{0.1581}\ DH^{0.0566}\ L^{-0.1062}\ P_{60}^{1.1102}$
5	$\hat{q}_{10} = 1.6364\ A^{1.0337}\ R^{0.6437}\ DH^{0.1830}\ L^{-0.4034}\ P_{60}^{0.2926}$
6	$\hat{q}_{10} = 10^{-6.2116}\ A^{1.0853}\ R^{5.0977}\ DH^{0.7256}\ L^{-1.2867}\ P_{60}^{-12.5327}$
7	$\hat{q}_{10} = 324.432\ A^{0.9306}\ R^{-0.3690}\ DH^{0.1133}\ L^{-0.0603}\ P_{60}^{0.7463}$
8	$\hat{q}_{10} = 53.0874\ A^{0.2186}\ R^{0.1945}\ DH^{0.1319}\ L^{0.6958}\ P_{60}^{0.2225}$
9	$\hat{q}_{10} = 7.7165\ A^{0.5814}\ R^{0.0547}\ DH^{0.3865}\ L^{0.0990}\ P_{60}^{0.8217}$
10	$\hat{q}_{10} = 35.8044\ A^{1.6863}\ R^{0.4101}\ DH^{-0.6609}\ L^{-0.6123}\ P_{60}^{5.6323}$
11	$\hat{q}_{10} = 5518.33\ A^{0.8668}\ R^{-1.4337}\ DH^{0.7315}\ L^{-0.6144}\ P_{60}^{2.3245}$
12	$\hat{q}_{10} = 0.00404\ A^{-0.1357}\ R^{2.0116}\ DH^{0.2913}\ L^{1.0946}\ P_{60}^{-0.2881}$
13	$\hat{q}_{10} = 19.0892\ A^{0.7919}\ R^{0.5162}\ DH^{0.0065}\ L^{-0.2461}\ P_{60}^{0.9859}$
14	$\hat{q}_{10} = 10^{-3.0471}\ A^{0.9278}\ R^{1.9168}\ DH^{1.0534}\ L^{-1.1568}\ P_{60}^{-0.2637}$
15	$\hat{q}_{10} = 227.5250\ A^{1.0024}\ R^{-0.2697}\ DH^{-0.1703}\ L^{-0.0099}\ P_{60}^{-0.4591}$
16	$\hat{q}_{10} = 53.9760\ A^{0.2406}\ R^{0.7042}\ DH^{-0.3647}\ L^{0.9690}\ P_{60}^{1.4407}$
17	$\hat{q}_{10} = 18.0037\ A^{0.8562}\ R^{1.1895}\ DH^{-0.5077}\ L^{0.1432}\ P_{60}^{-1.5285}$
18	$\hat{q}_{10} = 713.6839\ A^{0.4249}\ R^{0.7032}\ DH^{-0.4949}\ L^{0.6922}\ P_{60}^{-2.8743}$
19	$\hat{q}_{10} = 0.7227\ A^{0.4635}\ R^{1.2180}\ DH^{0.2569}\ L^{-0.0658}\ P_{60}^{0.2060}$
20	$\hat{q}_{10} = 1.9367\ A^{0.9351}\ R^{0.8322}\ DH^{0.0042}\ L^{0.00042}\ P_{60}^{1.1826}$
21	$\hat{q}_{10} = 15.8713\ A^{0.7602}\ R^{0.3027}\ DH^{0.0516}\ L^{0.3632}\ P_{60}^{0.6450}$
22	$\hat{q}_{10} = 2.3789\ A^{0.5215}\ R^{0.7453}\ DH^{0.0614}\ L^{0.4754}\ P_{60}^{0.4184}$
23	Insufficient observations for deriving a 5-parameter equation
24	$\hat{q}_{10} = 1.4209\ A^{0.6925}\ R^{2.0837}\ DH^{-0.6376}\ L^{0.5060}\ P_{60}^{-1.7726}$

Table 1-D. The 7-parameter regression equations for each of the 24 hydrophysiographic zones of the United States and Puerto Rico. (See also Appendix H, Table H-3.)

Zone	Equation
All Zone	$\hat{q}_{10} = 1.8816\ A^{0.3977}\ R^{0.8322}\ DH^{0.1461}\ L^{-0.0236}\ LL^{0.2613}\ P_{10}^{-0.1891}\ P_{60}^{0.4668}$
1	$\hat{q}_{10} = 10^{-9.9593}\ A^{-0.2759}\ R^{0.7417}\ DH^{0.5174}\ L^{0.2372}\ LL^{0.7087}\ P_{10}^{17.7125}\ P_{60}^{-16.1845}$
2	$\hat{q}_{10} = 10^{-7.1187}\ A^{0.8277}\ R^{0.3514}\ DH^{0.2154}\ L^{-0.9658}\ LL^{0.3287}\ P_{10}^{17.2401}\ P_{60}^{-17.2234}$
3	$\hat{q}_{10} = 10^{-16.2047}\ A^{0.9416}\ R^{0.1385}\ DH^{0.3787}\ L^{-0.5201}\ LL^{-0.1639}\ P_{10}^{34.1291}\ P_{60}^{-31.9517}$
4	$\hat{q}_{10} = 21.8893\ A^{0.6964}\ R^{0.1096}\ DH^{0.0598}\ L^{-0.1066}\ LL^{-0.0016}\ P_{10}^{0.5004}\ P_{60}^{1.0049}$
5	$\hat{q}_{10} = 2.9109\ A^{1.0119}\ R^{-0.3553}\ DH^{0.2164}\ L^{-0.1787}\ LL^{-0.1748}\ P_{10}^{2.5203}\ P_{60}^{-0.0776}$
6	$\hat{q}_{10} = 10^{-5.1795}\ A^{1.1351}\ R^{5.4283}\ DH^{0.7420}\ L^{-1.3539}\ LL^{-0.0742}\ P_{10}^{-2.6780}\ P_{60}^{-10.9168}$
7	$\hat{q}_{10} = 10^{6.6029}\ A^{0.7048}\ R^{-0.2011}\ DH^{0.1907}\ L^{-0.0621}\ LL^{0.1642}\ P_{10}^{-9.2707}\ P_{60}^{10.1924}$
8	$\hat{q}_{10} = 24.1002\ A^{0.0912}\ R^{-0.2570}\ DH^{0.0988}\ L^{0.5322}\ LL^{0.3114}\ P_{10}^{1.5265}\ P_{60}^{0.3177}$
9	$\hat{q}_{10} = 50.8080\ A^{0.3799}\ R^{-0.1432}\ DH^{0.3401}\ L^{0.0917}\ LL^{0.2879}\ P_{10}^{-0.9655}\ P_{60}^{1.8748}$
10	$\hat{q}_{10} = 10^{-5.0890}\ A^{0.9409}\ R^{4.1273}\ DH^{-1.0786}\ L^{-0.4183}\ LL^{0.8884}\ P_{10}^{0.7275}\ P_{60}^{4.2278}$
11	$\hat{q}_{10} = 5.97844\ A^{0.8616}\ R^{-1.3797}\ DH^{0.6271}\ L^{-0.7835}\ LL^{0.1630}\ P_{10}^{5.9753}\ P_{60}^{-3.6368}$
12	$\hat{q}_{10} = 807.3722\ A^{-0.5358}\ R^{1.3781}\ DH^{0.1457}\ L^{0.7667}\ LL^{0.9198}\ P_{10}^{-8.7780}\ P_{60}^{9.3897}$
13	$\hat{q}_{10} = 6.4357\ A^{0.7761}\ R^{0.4431}\ DH^{0.0095}\ L^{-0.4107}\ LL^{0.1424}\ P_{10}^{1.1422}\ P_{60}^{-0.1525}$
14	$\hat{q}_{10} = 10^{-6.3129}\ A^{1.1471}\ R^{2.3578}\ DH^{1.2258}\ L^{-0.9411}\ LL^{-0.5105}\ P_{10}^{4.8292}\ P_{60}^{-5.6504}$
15	$\hat{q}_{10} = 55.3750\ A^{0.8433}\ R^{-0.2586}\ DH^{-0.1705}\ L^{-0.1117}\ LL^{0.2228}\ P_{10}^{1.1934}\ P_{60}^{-1.6825}$
16	$\hat{q}_{10} = 57.4029\ A^{0.3052}\ R^{0.7323}\ DH^{-0.3973}\ L^{1.0963}\ LL^{-0.1118}\ P_{10}^{0.0259}\ P_{60}^{1.4146}$
17	$\hat{q}_{10} = 157.4954\ A^{0.5615}\ R^{1.2801}\ DH^{-0.6249}\ L^{-0.0429}\ LL^{0.4032}\ P_{10}^{-1.5484}\ P_{60}^{-0.5034}$
18	$\hat{q}_{10} = 10^{16.0040}\ A^{-0.1026}\ R^{2.0758}\ DH^{0.3202}\ L^{1.3339}\ LL^{-0.0842}\ P_{10}^{-35.7861}\ P_{60}^{16.6781}$
19	$\hat{q}_{10} = 48.8575\ A^{0.4962}\ R^{1.2266}\ DH^{0.2391}\ L^{0.0945}\ LL^{-0.0867}\ P_{10}^{-3.7389}\ P_{60}^{3.2559}$
20	$\hat{q}_{10} = 7.8890\ A^{0.8760}\ R^{0.8465}\ DH^{-0.0200}\ L^{-0.1091}\ LL^{0.1515}\ P_{10}^{-1.1600}\ P_{60}^{1.9548}$
21	$\hat{q}_{10} = 26.7400\ A^{0.7867}\ R^{0.2960}\ DH^{0.0539}\ L^{0.3939}\ LL^{-0.0486}\ P_{10}^{-0.4260}\ P_{60}^{0.9483}$
22	$\hat{q}_{10} = 0.00184\ A^{0.1791}\ R^{0.7746}\ DH^{0.0885}\ L^{0.4975}\ LL^{0.2660}\ P_{10}^{6.0977}\ P_{60}^{-4.2623}$
23	Insufficient observations for deriving a 7-parameter equation
24	$\hat{q}_{10} = 101.2426\ A^{0.6478}\ R^{1.7080}\ DH^{-0.7366}\ L^{0.5271}\ LL^{0.1474}\ P_{10}^{-1.6416}\ P_{60}^{0.0956}$

Table 2. Summary of the prediction errors associated with estimating 10-year peak runoff from the various regression equations given in Table 1.

Zone	$\bar{q}_{10}$ cfs	n	3-Parameter Equations PS_{EE} %	3-Parameter Equations PS_e %	3-Parameter Equations r	5-Parameter Equations PS_{EE} %	5-Parameter Equations PS_c %	5-Parameter Equations r	7-Parameter Equations PS_{EE} %	7-Parameter Equations PS_e %	7-Parameter Equations r	Un-corrected PS_{EE} %	3-Parameter All Zone Eq. Corrected by Zone PS_{EE} %	3-Parameter All Zone Eq. Corrected by Zone PS_e %	3-Parameter All Zone Eq. Corrected by Zone r
All Zone	1922	898	119	13	0.854	116	13	0.856	116	12	0.860	119	119	13	0.854
1	1058	42	84	13	0.774	76	11	0.844	67	11	0.876	97	92	16	0.595
2	4747	28	60	7	0.798	59	7	0.818	59	7	0.831	68	67	8	0.754
3	2295	14	108	9	0.925	110	10	0.930	97	11	0.934	105	105	9	0.912
4	1979	62	56	9	0.795	54	9	0.809	53	9	0.809	63	60	9	0.770
5	1472	35	44	8	0.927	51	8	0.931	45	8	0.942	58	75	8	0.912
6	2014	12	88	7	0.840	32	4	0.970	33	5	0.971	92	92	10	0.622
7	2306	33	76	7	0.918	76	7	0.919	79	7	0.929	103	88	7	0.893
8	2079	39	51	7	0.952	47	6	0.964	44	6	0.968	57	62	7	0.944
9	1170	37	85	8	0.850	87	8	0.865	83	8	0.879	88	88	9	0.800
10	1986	10	67	12	0.882	68	13	0.905	47	17	0.914	76	83	14	0.745
11	4320	32	43	7	0.902	42	6	0.921	39	6	0.923	81	61	9	0.764
12	461	34	115	21	0.672	115	20	0.749	89	19	0.793	106	107	23	0.587
13	2260	166	83	12	0.897	82	12	0.899	85	12	0.901	108	91	13	0.887
14	1304	30	132	17	0.762	134	17	0.789	133	18	0.796	133	121	18	0.704
15	356	37	91	14	0.795	91	14	0.800	97	14	0.808	118	101	21	0.375
16	624	21	95	8	0.897	73	7	0.940	72	7	0.941	88	73	8	0.893
17	368	56	89	15	0.784	71	14	0.809	76	14	0.825	107	98	18	0.622
18	1311	14	107	23	0.643	88	24	0.708	117	20	0.857	143	124	23	0.520
19	1586	40	83	13	0.833	82	13	0.833	82	13	0.838	125	84	13	0.807
20	759	42	103	10	0.926	104	9	0.936	106	10	0.937	103	131	12	0.883
21	1625	68	67	8	0.924	68	7	0.931	69	8	0.931	94	138	11	0.836
22	1013	22	36	5	0.974	34	4	0.979	30	4	0.986	45	38	5	0.966
23	2519	6	35	5	0.961	-	-	-	-	-	-	47	40	6	0.886
24	12277	18	56	5	0.882	42	4	0.917	34	4	0.924	92	72	6	0.772
Average error of estimate			77.3%			73.3%			71.2%			91.5%	87.1%		

Notes explaining the column headings:

$\bar{q}_{10}$ is the mean ten year peak flow calculated from the observed ten year peak flows for each zone.

n is the number of watersheds used in deriving the equation.

PS_{EE} is the standard error of estimate expressed as a percent of the zone $\bar{q}_{10}$. It is calculated by the equation:

$$PS_{EE} = \frac{100}{\bar{q}_{10}} \sqrt{\frac{\Sigma(q_{10} - \hat{q}_{10(K)})^2}{n - 2}}$$

PS_e is the standard error of the $\log_{10}$ linear equation expressed as a percent of $\log_{10}\bar{q}_{10}$. It is calculated by the equation:

$$PS_e = \frac{100}{\log_{10} \bar{q}_{10}} \sqrt{\frac{\Sigma(\log_{10}q_{10} - \log_{10}\hat{q}_{10(K)})^2}{df}}$$

r is the correlation coefficient between q_{10} and $\hat{q}_{10}$. It is calculated by the equation:

$$r = \frac{\Sigma(x - \bar{x})\ (y - \bar{y})}{\sqrt{\Sigma(x - \bar{x})^2\ (y - \bar{y})^2}}$$

where x and y are any two independent and dependent variables respectively.

df Degrees of freedom for hypothesis testing and variance computations, in general df = n - k - 1

k The number of independent variables used in an estimating equation.

f. 10-year, 60-minute rainfall, P_{60}. The value of P_{60} is the value in inches read from the proper state map given in Appendix D at the centroid of the watershed delineated in Step I. The values obtained should correspond closely with those given by USWB 4 or Atlas 2 computations. P_{60} is required only if a 5 or 7 parameter equation is used.

g. Cumulative channel lengths, LL. LL is the cumulative length in miles of all drainage channels shown as blue lines within the watershed on a USGS

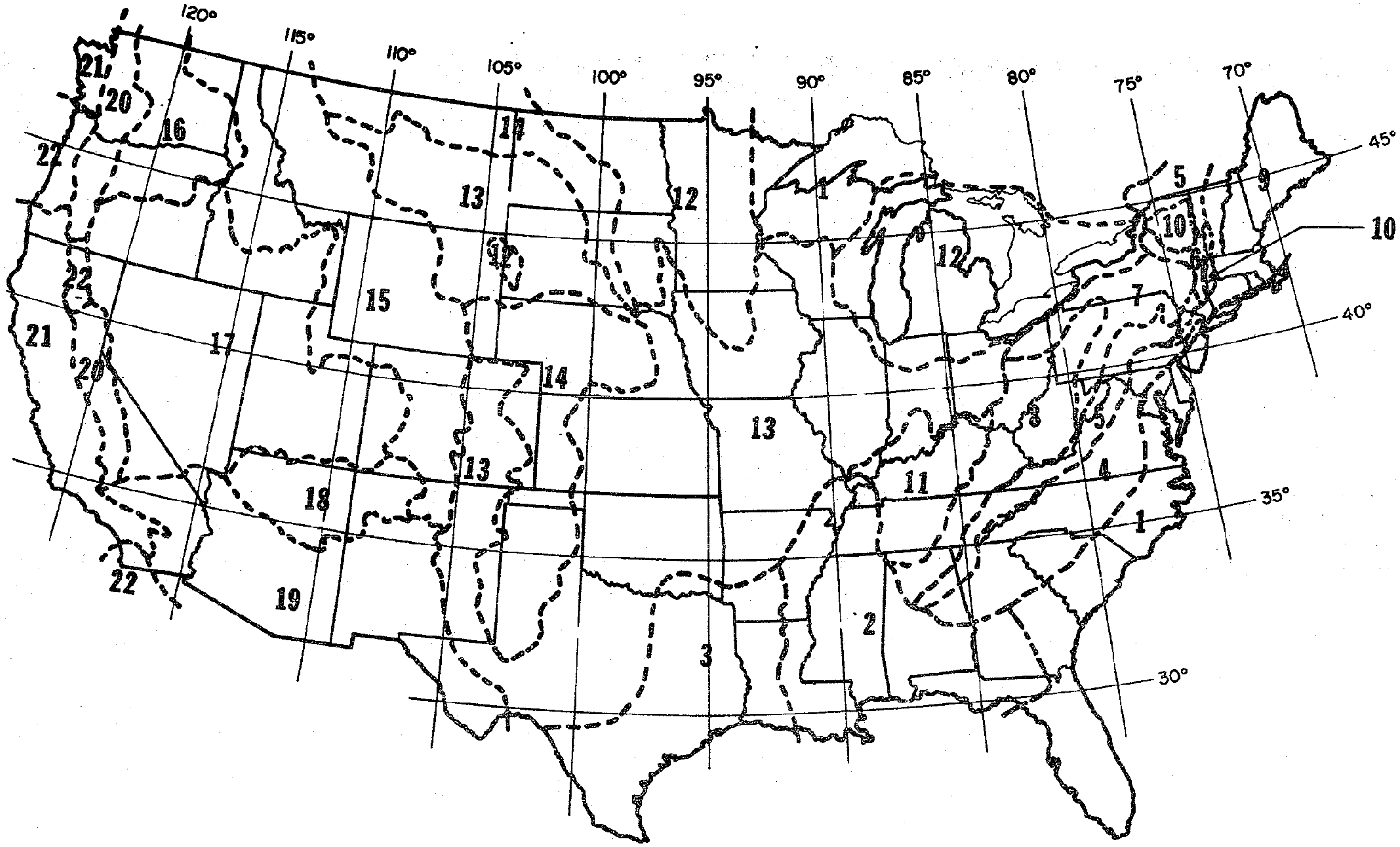


Figure 3. Hydrophysiographic zone map for the contiguous United States. Prepared from an analysis of the physiographic sections of the United States defined by Fenneman and Johnson (ref. 3). (See Figure 38 of Volume I, Research Report.)

7½ minute quadrangle (1:24,000 scale) map. If LL is measured from a 1:250,000 scale map it must be corrected by the equation

$$LL = 2.00\ (LL_{250})^{1.036} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Alternatively, the corrected LL value may be obtained graphically from Figure 4. This parameter is needed only if a 7-parameter equation is used.

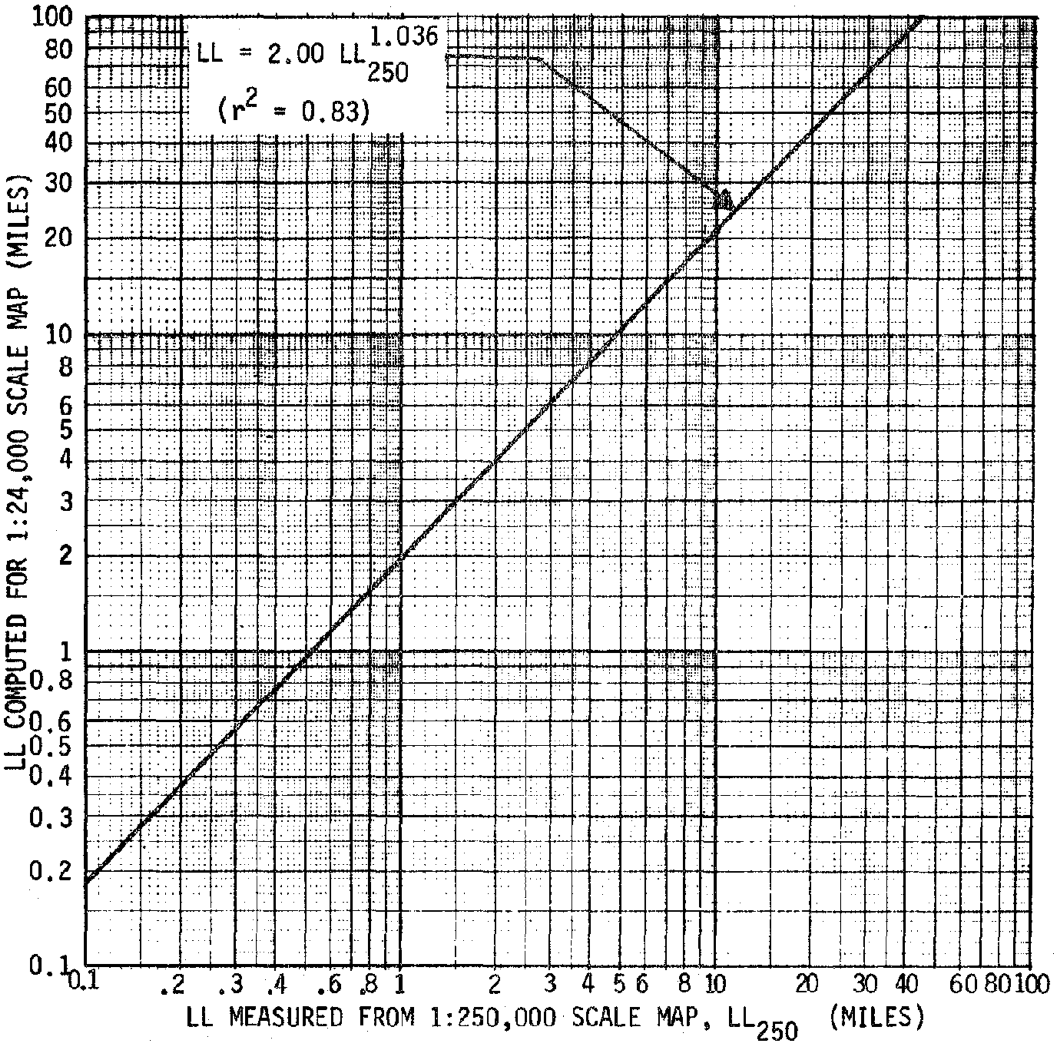


Figure 4. The relationship between LL measured on a 1:250,000 scale map to that measured on a 1:24,000 scale map. (See Figure 37 of Volume I, Research Report.)

h. 10-year, 10-minute rainfall intensity, P_{10}. The value of P_{10} is the value read from the proper state map given in Appendix E at the centroid of the watershed delineated in Step I in inches per hour. This parameter is only necessary if a 7-parameter equation is used.

Step IV. Determine the Estimated 10-year Runoff Peak, $\hat{q}_{10}$

The 10-year peak flow is estimated from one of the equations given in Table 1 which relate $\hat{q}_{10}$ to the hydrophysiographic data determined in Step III. For example, if the 3-parameter all zone equation is selected for this step, only information through Step III-d would be required and $\hat{q}_{10}$ would be determined from the equation

$$\hat{q}_{10(3AZ)} = 1.28015 \, A^{0.56172} \, R^{0.94356} \, DH^{0.16887} \quad . \; . \; . \; . \; . \; . \; . \; (3)$$

given in Table 1-A by using the value of A, R, and DH evaluated in Steps I, III-a and III-b above. If it is desired to adjust the all zone value for the particular hydrophysiographic zone then $q_{10(k)}$ may be obtained from the proper zone correction equation also tabulated in Table 1. For example, if the watershed delineated in Step I is in zone 22 then the correction equation from Table 1-A is

$$\hat{q}_{10(k)} = 0.15938 \, \hat{q}_{10(3AZ)}^{\;1.30941} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (4)$$

Alternatively, $\hat{q}_{10}$ may be evaluated graphically by using the nomograph for solving Equation 3 and the correction curve for zone 22 solving Equation 4 contained in Appendix H-00 and H-46 respectively.

After the 10-year peak flow has been determined from the desired equations or nomographs and curves, it must be adjusted if the area of surface water storage, S, determined in Step III-c is greater than 4 percent. The storage adjustment relationship is given in Figure 5. Simply enter Figure 5 with the percent storage and read the storage correction multiplier from the graph. The product of $\hat{q}_{10}$ and the storage correction multiplier is the estimated 10-year peak flow corrected for storage.

Step V. Determine the Return Period, T_D, for the Design Flow

Often the return period for the design flow is specified by agency policy as 50 or 100 or some other number of years. If this is the case proceed to Step VI with the T_D specified by policy. However, if the risk or probability must be considered that one or more flows will exceed the design flow within a specified number of years, usually taken as the usable lifetime of the structure, then the design flood peak must be modified to take this into account. The modified return period for the design flood is determined by use of the binomial probability distribution given by

$$P_R = \binom{n}{k} p^k (1-p)^{n-k} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (5)$$

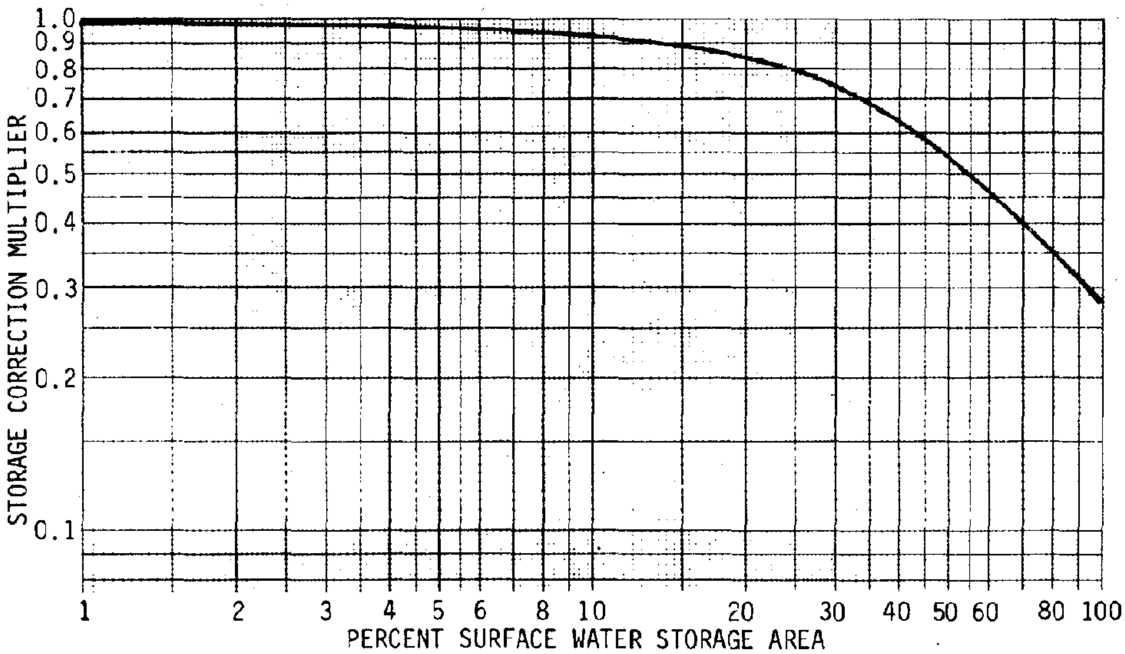


Figure 5. Storage correction curve. (Defines the relationship between the percentage of watershed area covered by lakes, ponds, swamps, playas, etc. and the multiplication factor required to correct a peak runoff estimate for storage.)

in which

n = the usable lifetime of the structure in years

k = the number of flood events that exceed the T year flood event

$\binom{n}{k}$ = the binomial coefficient, $\frac{n!}{k!\,(n-k)!}$

p = the probability of the nominally specified design flood ($p = 1/T$)

P_R = the probability that exactly k flood events exceed the T-year flood in n years

If we define the exceedence risk, R_e, as the probability that a T-year flood will be exceeded one or more times in n years,

$$R_e = 1 - P_0 = 1 - \left(1 - \frac{1}{T}\right)^n \quad (6)$$

in which

P_0 = the probability of no events exceeding the T-year flood and all other symbols are as previously defined

Equation 6 may be used directly to evaluate the risk of exceedance to ascertain its acceptability for the particular circumstances. If so, then the design return period is taken as T, the nominally specified design return period, and one may proceed directly to Step VI. However, if the risk is unacceptable or the risk has been specified as a design criteria, an adjusted return period, T_D, may be obtained by rewriting Equation 6 as follows:

$$T_D = \frac{1}{1 - (1-R_e)^{1/n}} \quad . . . . (7)$$

The solution to Equation 7 is tabulated for several commonly used values of R_e and n in Table 3 and a graphical solution is given in Figure 6.

Step VI. Prepare the Extrapolation Curve for Determining Q_{T_D}

The extrapolation curve is prepared by plotting the mean annual, $Q_{2.33}$, the 50-year, Q_{50}, and the 100-year, Q_{100}, floods estimated from their respective functional relationships to the adjusted $\hat{q}_{10}$ obtained in Step IV on any suitable probability paper and fitting a smooth curve to the above four points. The equations for this step are:

$$Q_{2.33} = 0.46921\ \hat{q}_{10}^{\ 1.00243} \quad . . . . (8)$$

$$Q_{50} = 1.45962\ \hat{q}_{10}^{\ 1.02342} \quad . . . . (9)$$

$$Q_{100} = 1.64380\ \hat{q}_{10}^{\ 1.02918} \quad . . . . (10)$$

Alternatively, the above flows may also be obtained graphically from Figure 7. If T_D is 50 or 100, this step and Step VII are not necessary as the design peak may be evaluated directly from Equation 9 or 10 or from Figure 7.

Step VII. Determine Q_{D_T} from the Curve Prepared in Step IV

Q_{T_D} is determined by entering the graph prepared in the previous step at the proper probability for the design return period, T_D, and reading the value of Q from the ordinate taking into account any scaling that may have been used in preparing the extrapolation curve in Step VI.

After completing Step VII, consideration must be given to the uncertainties that still exist in the design flow obtained in Step VI. This may be handled in a variety of ways such as by arbitrarily assigning a safety factor by which Q_{T_D} is multiplied or by determining an upper, Q_U, and lower, Q_L, value based on the confidence interval associated with the uncertainty of the estimate of q_{10}. If a confidence interval about the estimated design peak flow is not desired, then the design flow is based on Q_{T_D} after any safety factor adjustments have been made and this phase of the culvert sizing is complete. If the decision is made to calculate the confidence interval about Q_{T_D}, then proceed to Step VIII.

Table 3. Return period required for a specified risk of exceedance within the design lifetime of the project.

Acceptable Risk of Exceedance, R (Percent)	Design Lifetime of the Project, n Years							
	1	2	5	10	25	50	100	200
1	100	200	498	995	2488	4975	9950	19900
2	50	100	248	495	1238	2475	4950	9900
5	20	39	98	195	488	975	1950	3900
10	10	19	48	95	238	475	950	1899
25	4	7.5	18	35	87	174	348	696
50	2	3.4	8	15	37	73	145	289
75	1.33	2.0	4.2	7.7	19	37	73	145
90	1.11	1.46	2.7	4.9	11	22	44	87
95	1.05	1.29	2.2	3.9	8.9	17	34	67
98	1.02	1.16	1.8	3.1	6.9	13	26	52
99	1.01	1.11	1.7	2.7	5.9	11	22	44

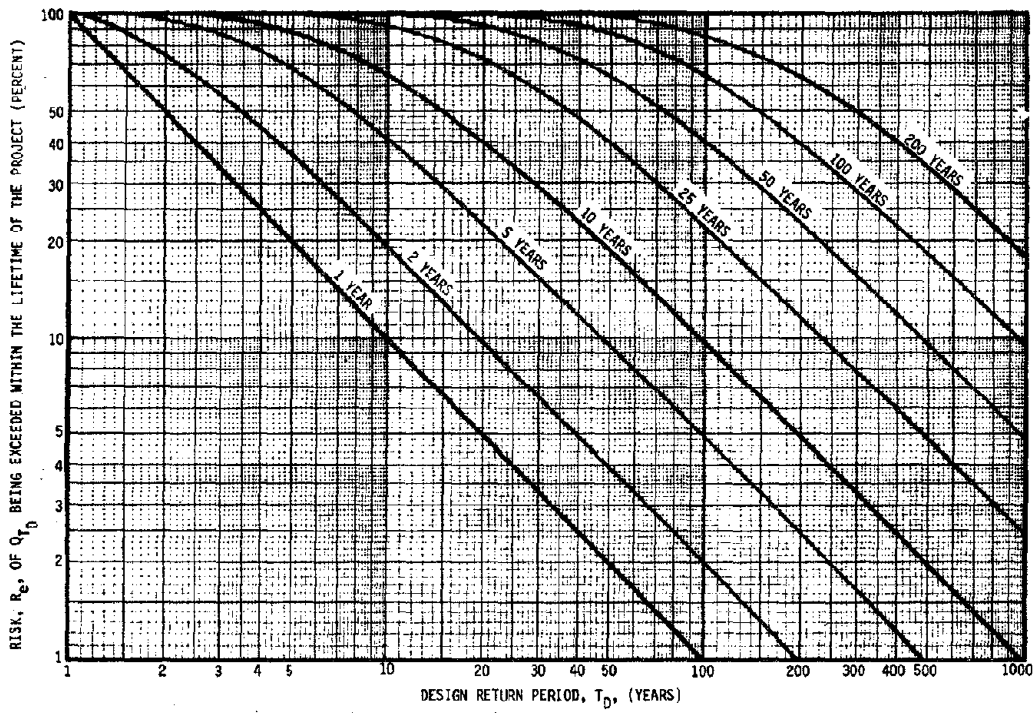


Figure 6. The risk or probability of exceeding a specified return period flood peak within a period of 1, 2, 5, 10, 25, 50, 100, and 200 years.

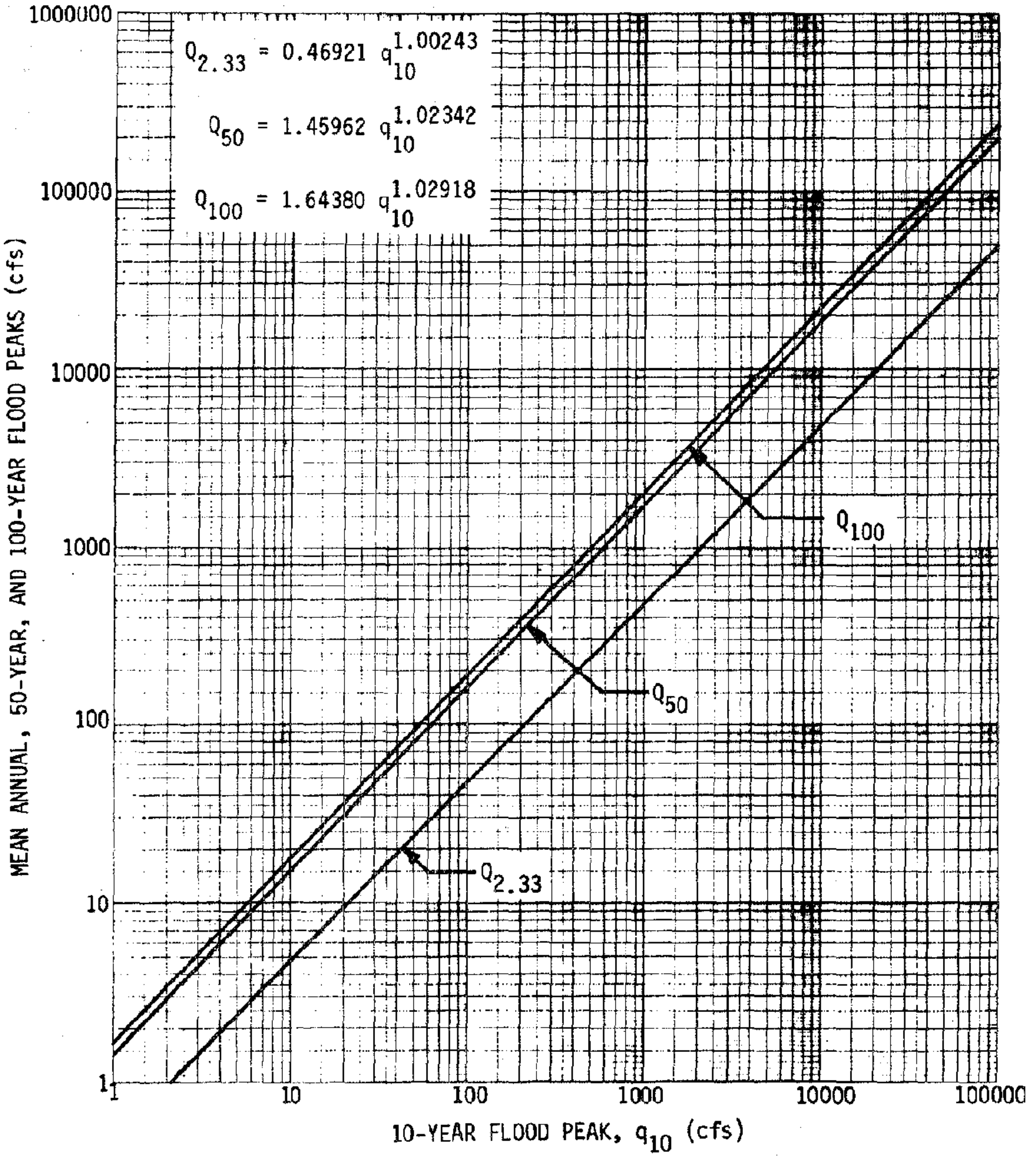


Figure 7. Relationships between the mean annual, the 50-year, the 100-year and the 10-year flood peak.

Step VIII. Determine the Confidence Interval About Q_{T_D}

This step is accomplished by reading the appropriate upper and lower values of $\hat{q}_{10}$ from the confidence interval curves given in Appendix G or H for the equation used in Step IV. Repeat Steps VI and VII for each of the values of $\hat{q}_{10}$ and obtain an upper, Q_U, and lower, Q_L, estimate for Q_{T_D}.

Step IX. Select Q_{Design} from Q_U, Q_{T_D} and Q_L

The design flow is then selected from among the three values, Q_U, Q_{T_D} and Q_L.

ILLUSTRATIVE EXAMPLES

Some detailed hypothetical examples are now given to illustrate the application of the FHWA method for different situations.

Example 1

Problem: Determine the design peak runoff for a culvert located at the site shown in Figure 9 on Small Creek. The expected lifetime of the culvert is 25 years and the allowable risk of exceeding the design peak within the project lifetime is 15 percent.

Solution: The FHWA method for determining the design peak may be illustrated by following the step by step procedure outlined in the preceding section and shown schematically in Figure 1.

1. Delineate the watershed. The structure site has already been located on the USGS 1:24,000 scale map shown in Figure 8. The watershed boundary has been drawn and the drainage area was measured by planimeter and found to be 0.61 square miles. The centroid of the watershed was located by eye and found to be at Latitude 41° 40' 20", Longitude 112° 02' 06".

2. Calculate $Q_{p(max)}$ from Equation 1 or obtain graphically from Figure 2.

   $Q_{p(max)}$ = 5,548.8 cfs

3. Since no minimum culvert size was specified and because the design criteria was given as the risk of exceedance during the lifetime of the project, it is necessary to select an appropriate equation from Table 1 (see also Appendix H) and determine the hydrophysiographic parameters required to apply the selected equation. The all zone 3-parameter equation was selected for this example and the parameters required in addition to the drainage area, A, already determined above are:

   a. The iso-erodent value, R. In accordance with the detailed instructions given under Step III, the appropriate iso-erodent map covering the centroid location of 41° 48' latitude and 112° 02' longitude is Appendix C-49, a portion of which is shown herein as Figure 9. From Figure 9 the R value is read as 17.

   b. The elevation difference, DH, is obtained from the topographic map on which the watershed boundaries have been outlined (Figure

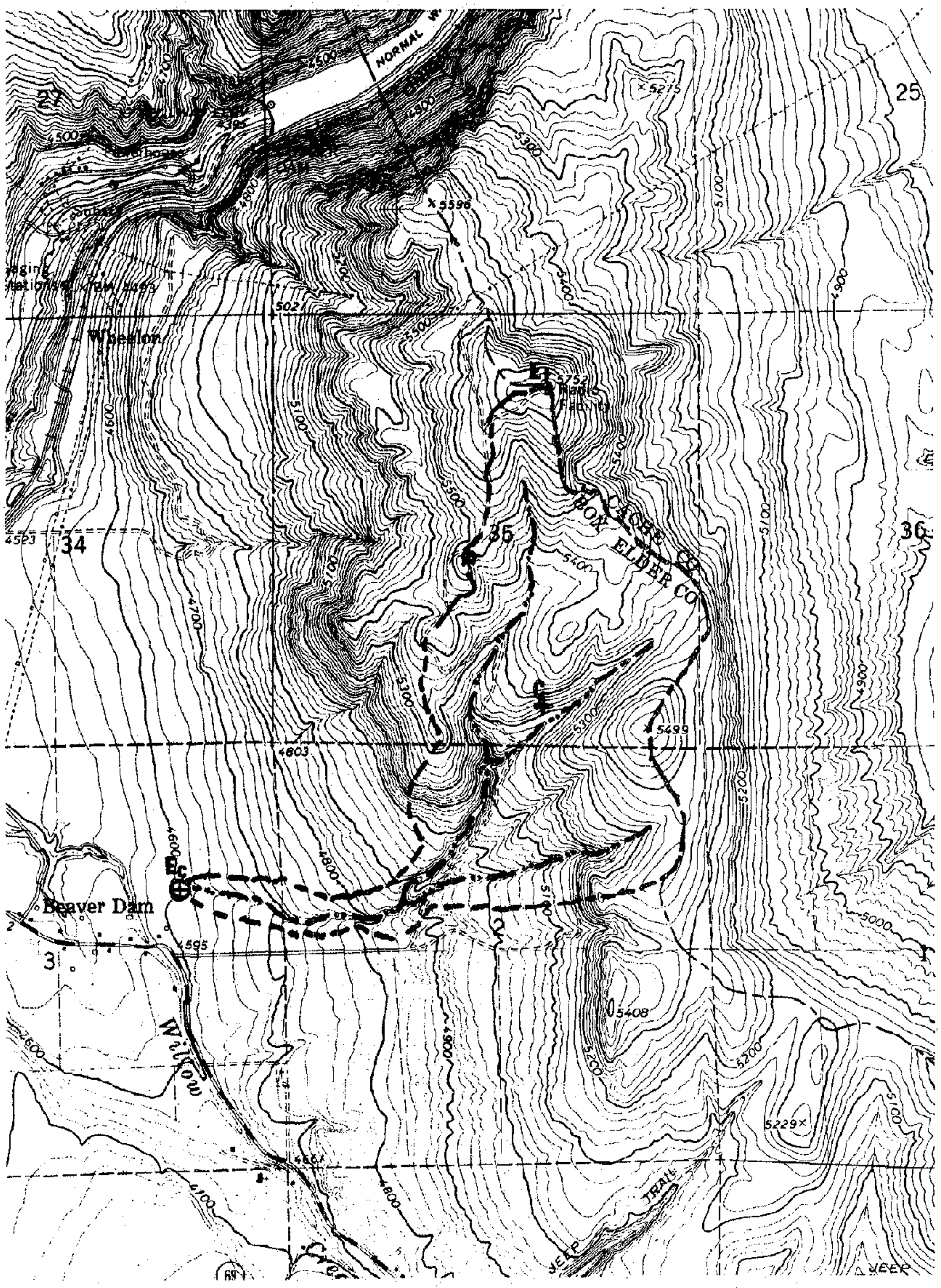


Figure 8. Topographic map illustrating the delineation of the watershed drainage area above the structure site on Small Creek.

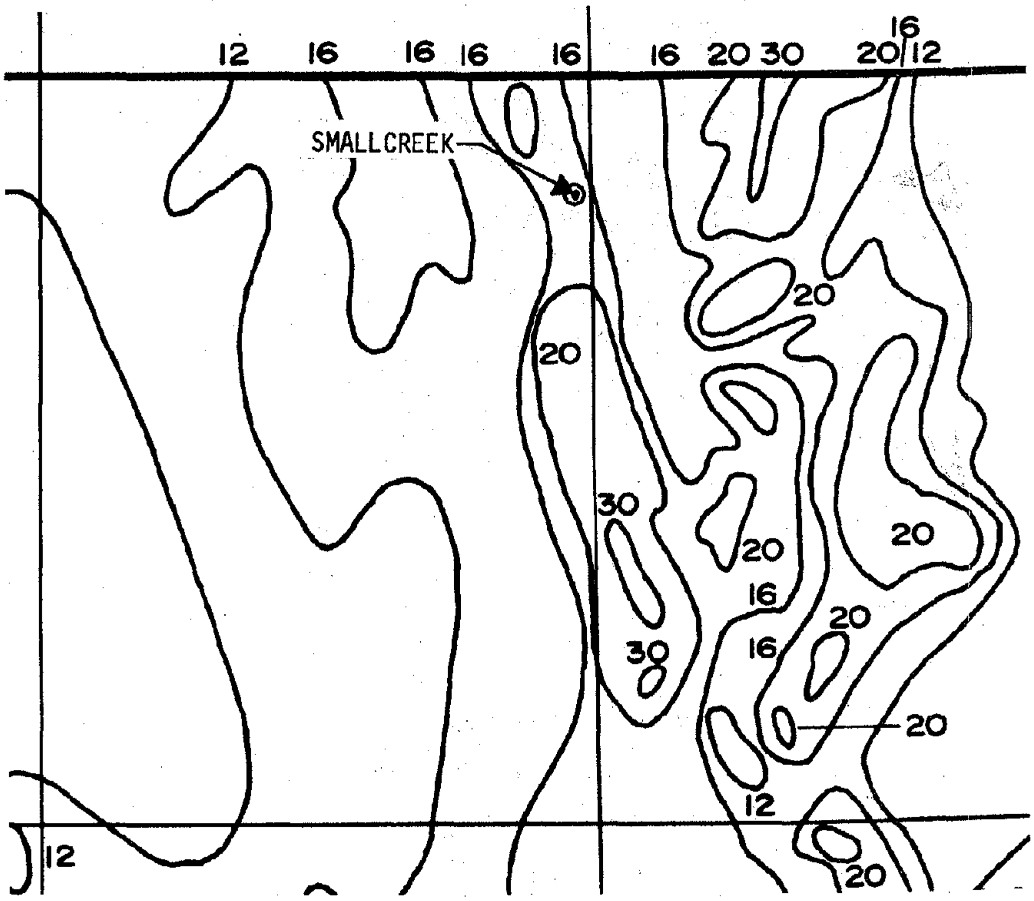


Figure 9. Iso-erodent map covering the Small Creek watershed.

8) by subtracting the elevation of the structure site, E_c, from the elevation of the main drainage channel at the top of the watershed, E_t. Accordingly, DH = 5752 - 4600 = 1152 ft.

c. The percent surface water storage is determined from the topographic map (Figure 8) and observed to be zero.

These are the only hydrophysiographic parameters required to apply the 3-parameter all zone equation. However, in order to illustrate the manner in which all of the other parameters may be obtained, they are given as follows:

d. The hydrophysiographic zone is determined by locating the watershed centroidal location on the hydrophysiographic zone map shown in Figure 3 (see also Figure 38 in Volume I). If Figure 3 is not of sufficient resolution to make the proper zonal determination, the zone may be read with greater resolution from the state hydrophysiographic zone maps contained in Appendix B. The zone for the example watershed is 17.

e. The principal drainage channel length, L, is measured on the topographic map as the distance from the structure site up the main channel to the watershed boundary. For this example L = 1.73 miles.

f. The 10-year, 60-minute rainfall, P_{60}, is taken from the isohyetal maps covering the watershed centroidal location given in Appendix D. A portion of the map covering the example watershed is shown in Figure 10. The P_{60} value for this watershed is read as 0.95 inches.

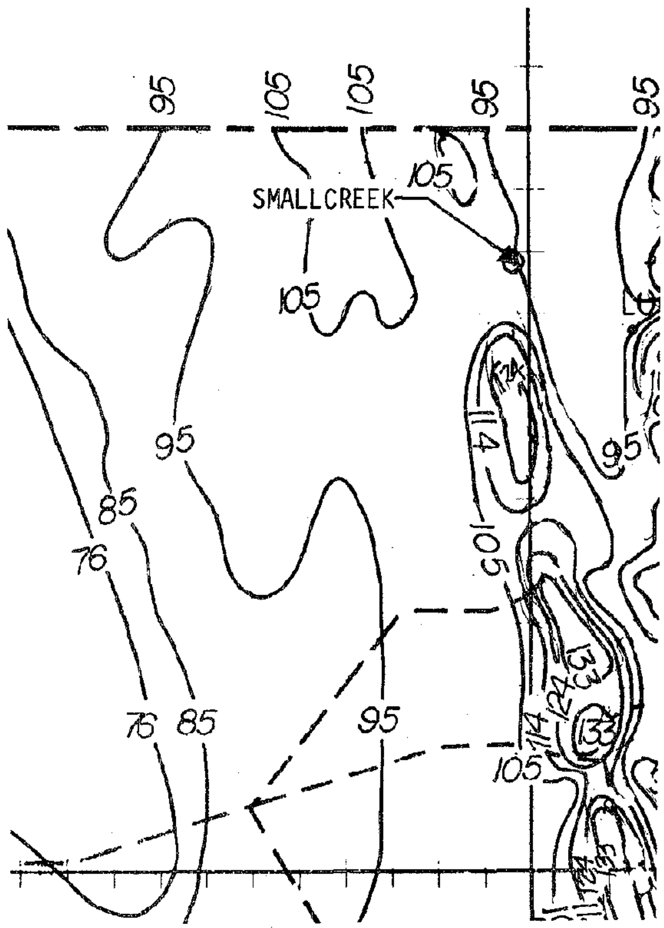


Figure 10. The 10-year, 60-minute rainfall, P_{60}, isohyetal map for the area covering the Small Creek watershed.

g. The cummulative channel length, LL, is measured in a manner similar to L except that it is the length in miles of all drainage channels that have some flow during the year indicated by the blue color code used on the USGS 1:24,000 scale maps. LL for the example watershed is 2.79 miles. (The blue lines on the map are shown as dash dotted lines in Figure 8.) If LL had been measured from a 1:250,000 scale map it should be adjusted by the use of Equation 2 or Figure 4.

h. The 10-year, 10-minute rainfall intensity, P_{10}, is determined in a manner similar to determining P_{60} except that the P_{10} isohyetal maps are given in Appendix E. The portion of the map covering the example watershed is also given as Figure 11. P_{10} is 3.01 inches/hour for this watershed.

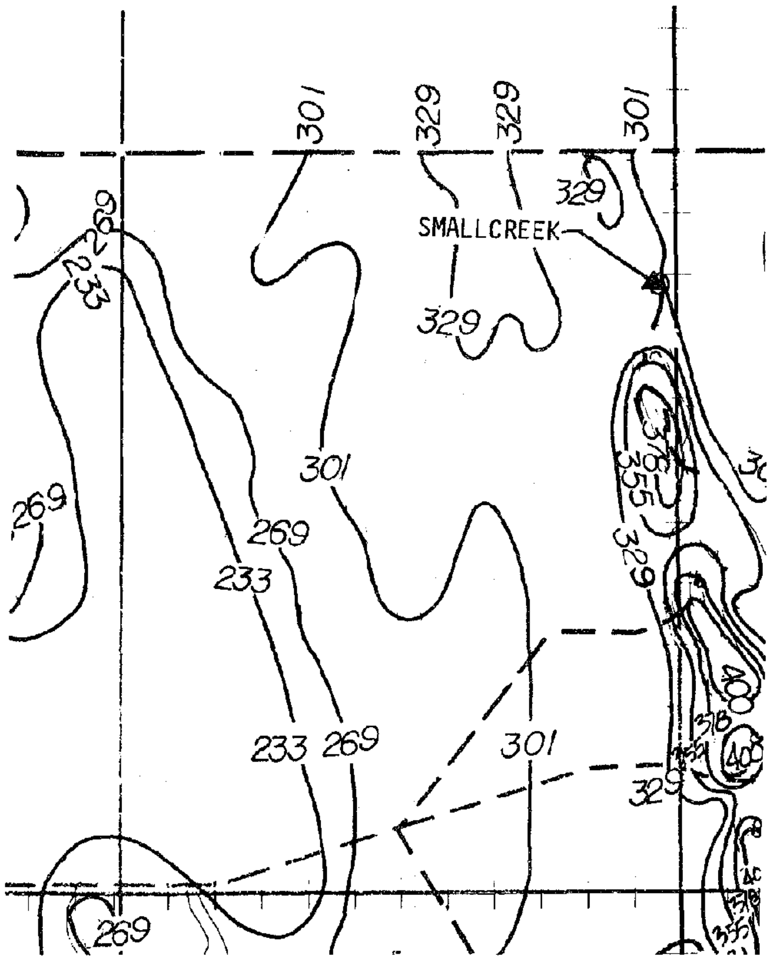


Figure 11. The 10-year, 10-minute rainfall intensity, P_{10}, isohyetal map for the area covering the Small Creek watershed.

4. The estimate of the 10-year peak, $\hat{q}_{10}$, is now calculated from the equation or nomograph deemed appropriate for the particular situation. For this example the 3-parameter, all zone equation was selected and consequently $\hat{q}_{10}$ is given by Equation 3 which yields a value of 46.2 cfs.

5. The design return period is now calculated from Equation 7 using the exceedance risk, R_e, of 15 percent and an estimated project lifetime of 25 years.

$$T_D = \frac{1}{1-(1-0.15)^{1/25}} = 154.33 \text{ years}$$

The same value within the resolution of the graphical plotting could have been read from Figure 6 by entering with an R_e of 15 percent on the risk axis, moving horizontally across to the 25 year curve and reading 150 from the T_D axis.

6. The extrapolation curve for determining Q_{T_D} is now prepared by plotting the $Q_{2.33}$, $\hat{q}_{10}$, Q_{50} and Q_{100} values on probability paper and fitting a smooth curve through the 4 points that extend beyond the T_D return period. The Q values as determined from Equations 8, 9, and 10 with a $\hat{q}_{10}$ of 46.2 cfs are:

$$Q_{2.33} = 21.9 \text{ cfs}$$

$$Q_{50} = 73.8 \text{ cfs}$$

$$Q_{100} = 84.9 \text{ cfs}$$

The extrapolation curve for this example is shown in Figure 12. It may be observed that the value for T_D is often more easily read by converting the return period to a probability by the following equation:

$$P = \left(1 - \frac{1}{T_D}\right) 100 \quad \ldots\ldots\ldots\ldots\ldots \quad (11)$$

For this example P = 99.35 percent. Entering with this value on the probability axis of the graph paper gives

$$Q_{T_D} = 92.4 \text{ cfs}$$

Since no confidence interval was specified the design peak flow Q_{150} is taken as 92.4 cfs. Note that the ordinate axis of Figure 12 illustrating the construction of the extrapolation curve is scaled by $\hat{q}_{10}$. Therefore the $Q_{150}/\hat{q}_{10}$ value read from the curve shown in the figure is 2.0 which when multiplied by 46.2, the estimate of q_{10}, gives Q_{T_D} = 92.4 cfs. Other scale factors could be chosen; however, the ratio of $Q/\hat{q}_{10}$ has proven to be generally satisfactory, particularly when used for evaluating the confidence interval about the design estimate as will be shown in the following examples.

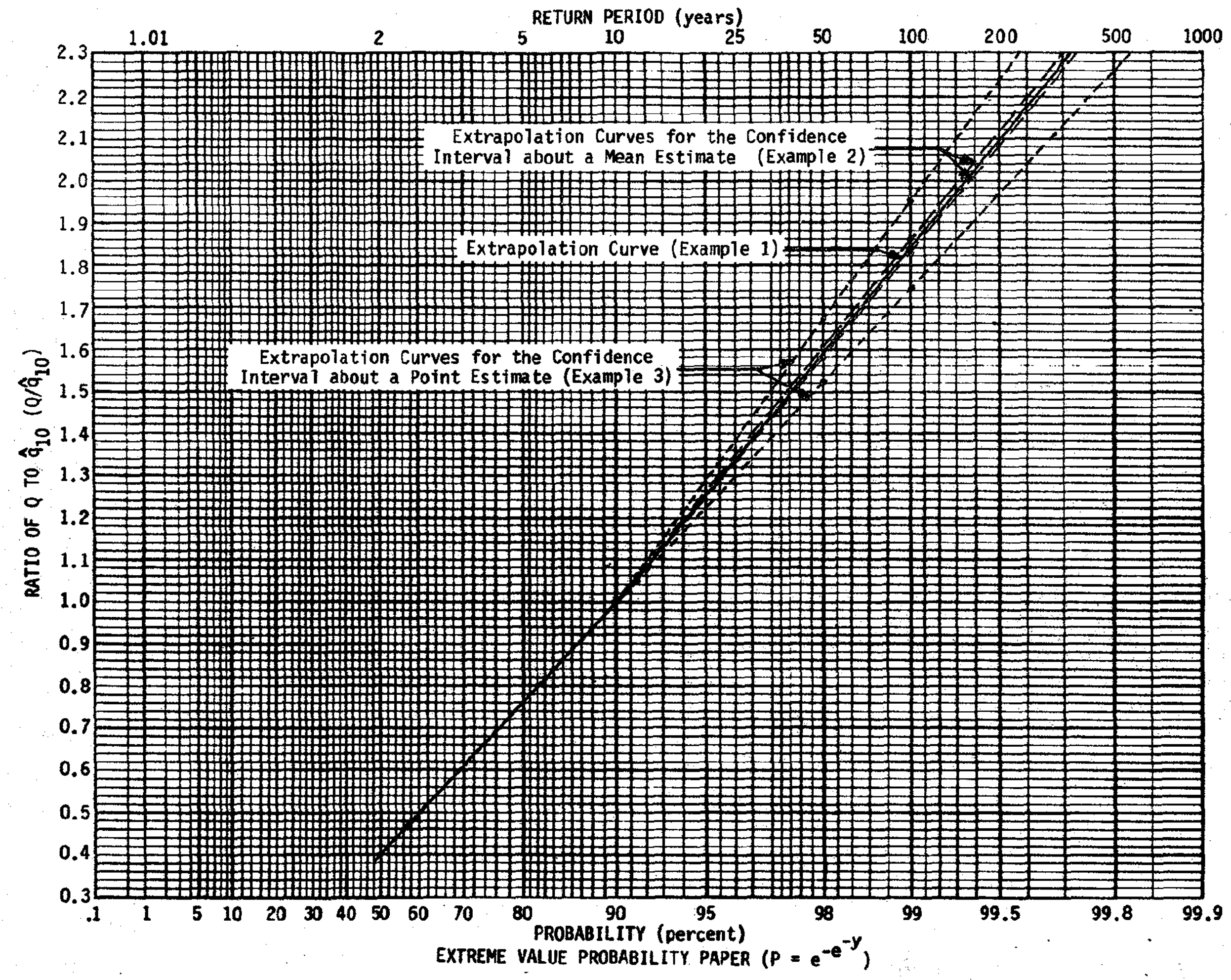


Figure 12. Extrapolation curves plotted on extreme value (Gumbel) probability paper for Examples 1, 2, and 3.

Example 2

Problem: Determine the 95 percent confidence interval about the mean for the design flow calculated in Example 1.

Solution: The 95 percent confidence interval is obtained by completing Step VIII of the design procedures. The confidence interval curves for the 3-parameter all zone equation are shown in Figure 13 taken from Appendix G. The upper and lower values for the 95 percent confidence about a mean q_{10} of 46.2 cfs are 56.0 and 40.0 cfs respectively. Applying Equations 8, 9, and 10

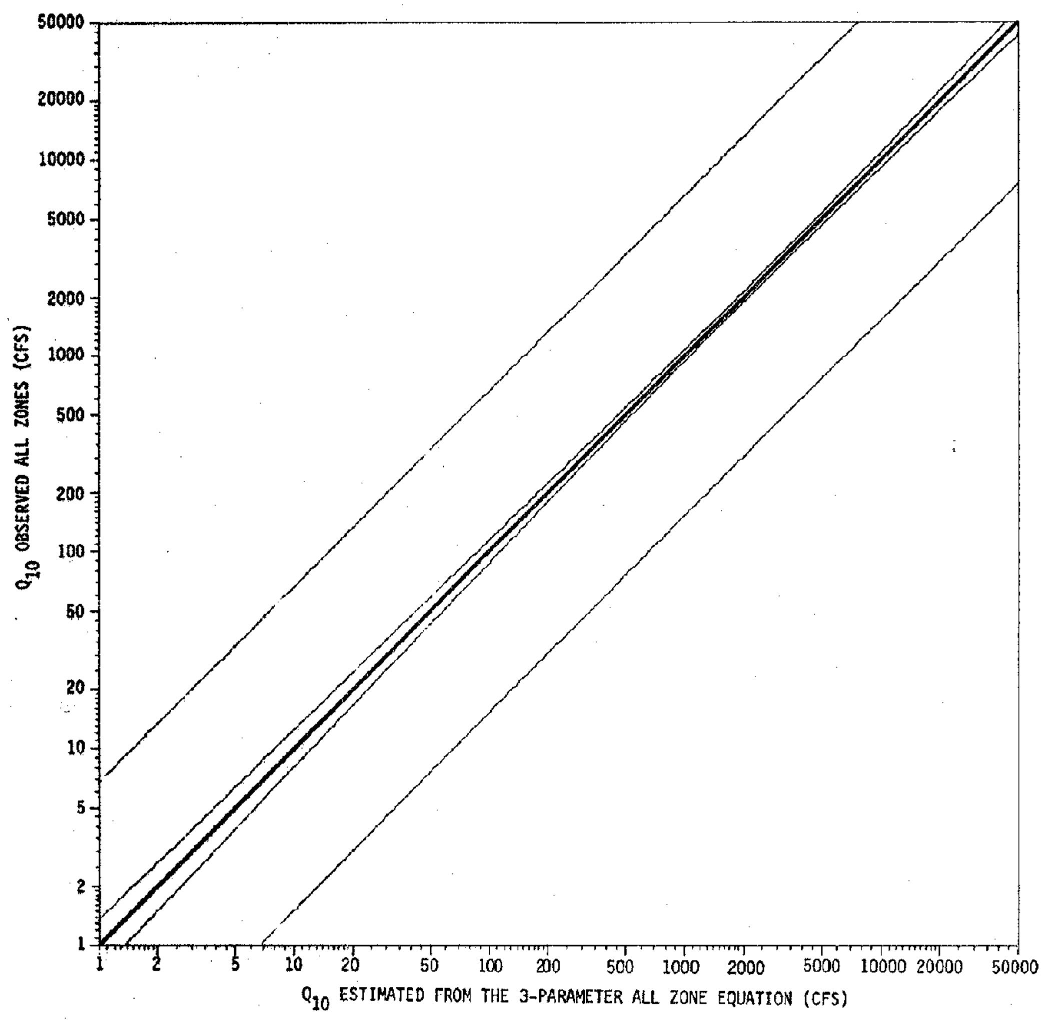


Figure 13. 95 percent confidence interval curves about the mean and a point estimate made from the 3-parameter all zone equation. (See also Appendix G-00.)

to these values yields 26.5, 89.8 and 103.5 cfs for $Q_{2.33}$, Q_{50} and Q_{100} respectively for the upper curve and 18.9, 63.6 and 73.2 cfs for the lower curve. The extrapolation curves for the upper and lower confidence interval are shown on Figure 12. Entering the extrapolation curve with the 150 year return period (99.35 percent probability) yields Q_U of 112.8 cfs and Q_L of 79.6 cfs.

The interpretation of these results is that there is a 95 percent probability that the mean of the true design flood is between 79.6 cfs and 112.8 cfs; i.e., 5 percent of the values obtained from this procedure will not encompass the mean design flow in the interval $[Q_L, Q_U]$.

The field engineer must now assess the risks associated with the design flow and select the particular value from within the interval that satisfies the needs of his particular situation.

Example 3

Problem: Determine the 95 percent confidence interval about the point estimate for the design flow determined in Example 1.

Solution: This problem is essentially the same as Example 2 except that the point estimate confidence interval curves shown in Figure 13 (also Appendix G-00) are used. The equations given for calculating $\hat{q}_{10}$ may be interpreted either as an estimate of the mean q_{10} or a point estimate of q_{10}. In both cases the estimate is the same but the variance of the point estimate is much larger than the variance of the mean causing a wider confidence interval as is apparent from examining Figure 13. The respective upper and lower confidence interval values about the point estimate of q_{10} of 46.2 cfs are 300 cfs and 7 cfs.

The upper and lower extrapolation curves for the point estimate confidence interval are constructed by following the same procedure outlined in Example 2 and are shown in Figure 12.

The values obtained for the upper and lower flows for a 150 year event are 637 cfs and 13 cfs respectively. Again it is up to the designer to assess his particular situation and select the design flow best suited to his needs.

Example 4

Problem: Determine the design flow for the problem given in Example 1 using the 3-parameter all zone equation corrected for bias when applied to sites located in hydrophysiographic zone 17.

Solution: This problem is solved by simply applying the appropriate correction equation given in Table 1-A to aid in removing any zonal bias inherent in the 3-parameter all zone equation. The equation from Table 1-A (also Appendix H, Table 4, and Appendix H-41) is:

$$\hat{q}_{10(k)} = 0.57246\ \hat{q}_{10(3AZ)}^{1.04580} \quad (12)$$

When applied to 46.2 cfs, the original 10-year flood estimate, the corrected $\hat{q}_{10}$ becomes 31.5 cfs. The design flow is now obtained by following the same procedure described in Example 1 except that 31.5 cfs is used for $\hat{q}_{10}$ rather than 46.2 cfs. This gives a design flow estimate for Q_{150} of 62.4 cfs. Confidence intervals about this value as a mean or point estimate may be obtained by applying the procedures described in solving Examples 2 and 3 except that the confidence interval curves given in Appendix H-41 (for zone 17) are used rather than the general curves given in Appendix G.

Summary of Examples

Many other examples could be given, but they would only differ from the four given above in the particular equations selected, the hydrophysiographic parameters required for their solution and the confidence interval curves selected from Appendices G and H. One situation that is not covered in the examples is that of the design according to the probable maximum flood. In situations where the consequences of failure are extremely great, this design may be appropriate. When this is the case, only Steps I and II of the design procedure are required and $Q_{p(max)}$ is calculated from Equation 1. For Example 1, this value was 5,549 cfs compared to a 150 year event of 92.4 cfs given by the 3-parameter all zone equation or 62.4 cfs given by applying the zone 17 correction to the 3-parameter all zone estimate. Situations where $Q_{p(max)}$ might be appropriate would be the design inflow for determining the spillway capacity of a dam where failure would cause great loss of life. It probably would not be used on the bulk of the design work involving minor highway drainage structures.

INSTRUCTIONS FOR PREPARING A DESIGN MANUAL FOR A PARTICULAR AREA

The instructions for preparing a design manual for any desired area may be summarized as follows:

1. Take the material from this manual starting with the Design Procedure Section through the illustrative examples and include as the first section of the specific design manual.

2. Select the appropriate materials from the appendices that apply to the particular area for which the manual is being prepared. The appendices cover the following materials:

   A. Annual Flood Frequency Curves and Data for the Contiguous United States, Alaska, Hawaii and Puerto Rico.

   B. Hydrophysiographic Zones by States for the Contiguous United States, Alaska, Hawaii and Puerto Rico.

   C. Iso-erodent Maps for the Contiguous United States, Alaska, Hawaii and Puerto Rico.

   D. 10-year, 1-hour Precipitation, P_{60}, for Each of the Contiguous States of the United States, Alaska, Hawaii and Puerto Rico.

   E. 10-year, 10-minute Rainfall Intensity for the Contiguous United States, Alaska, Hawaii and Puerto Rico.

   F. 10-year Snow Water Equivalent of the Western United States and Alaska.

   G. Scatter Diagrams for the Relationship Between the Measured and Estimated 10-year Peak Flow and the 95 Percent Confidence Intervals for the Mean and Point Estimates for All the United States (Lumped) and for Each of the 24 Hydrophysiographic Zones.

   H. Equations, Nomographs and Correction Curves for Each of the Hydrophysiographic Zones of the United States and Puerto Rico.

This material would probably be placed at the end of the manual or as an associated appendix.

3. Provide a collection of the appropriate equations, graphs and plotting paper that would facilitate the rapid and easy utilization of the materials assembled in 2 above. This may include an abstraction from Table 1 of only the equations pertinent to the particular area or the selection of a particular recommended equation for the area. This could take the form of a short table of equations, including:

   a. The equation for calculating $Q_{p(max)}$

   b. The 3-parameter all zone equation

   c. The correction equation for the particular hydrophysiographic zone or zones

   d. The appropriate hydrophysiographic zone equations

   e. Equations 8, 9, and 10 relating $Q_{2.33}$, Q_{50}, and Q_{100} to $\hat{q}_{10}$.

The figures that should be included in this section are as follows and clear copies suitable for reproduction are appended hereto:

Figure 2. The probable maximum runoff peak curve for small watersheds in the United States and Puerto Rico.

Figure 3. Hydrophysiographic zone map for the contiguous United States.

Figure 5. Storage correction curves.

Figure 6. The risk or probability of exceeding a specified return period flood peak with a period of 1, 2, 5, 10, 25, 50, 100 and 200 years.

Figure 7. Relationship between the mean annual, the 50-year, the 100-year and the 10-year flood peak.

Figure 14. Extreme value (Gumbel) probability paper.

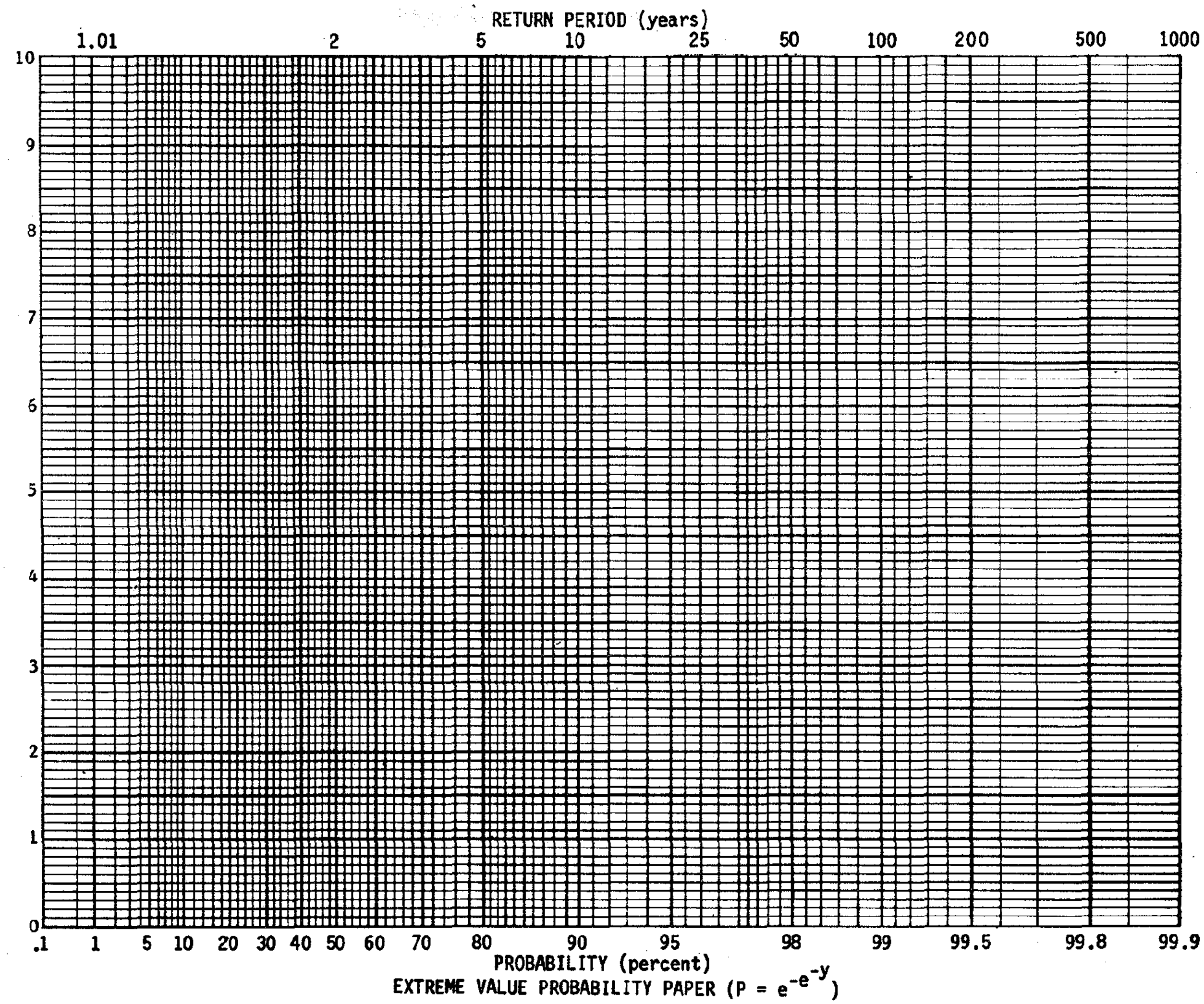


Figure 14. Extreme value (Gumbel) probability paper. (Used for preparing extrapolation curves for the FHWA method of determining runoff peaks from small ungaged watersheds.)

REFERENCES CITED

1. Potter, William D. 1961. Peak rates of runoff from small watersheds. USDC BPR Hydraulic Design Series No. 2. 35 p.

2. Bock, P., I. Enger, G. P. Malhotra and D. A. Chisholm. 1972. Estimating runoff rates from ungaged small rural watersheds. NCHRP Program Report 136. 85 p.

3. Fenneman, N. M., and Douglas W. Johnson. 1964. Physical divisions of the United States. (Map) USGS 1:7,000,000.

APPENDIX B

Hydrophysiographic Zones by States for the Contiguous

United States, Alaska, Hawaii, and Puerto Rico.

State Numbers are Those Assigned by U.S.

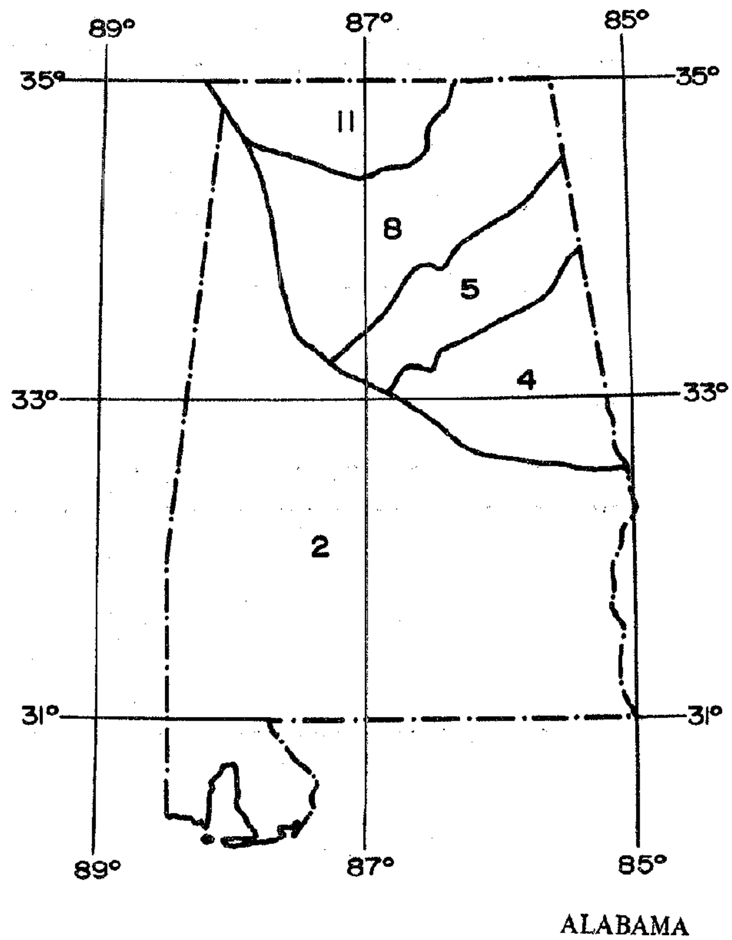
Geological Survey.

The hydrophysiographic zones in this appendix were delineated from the physiographic sections of Fenneman and Johnson by combining all areas whose values of q_{10}/A were not significantly different as shown by the t test.

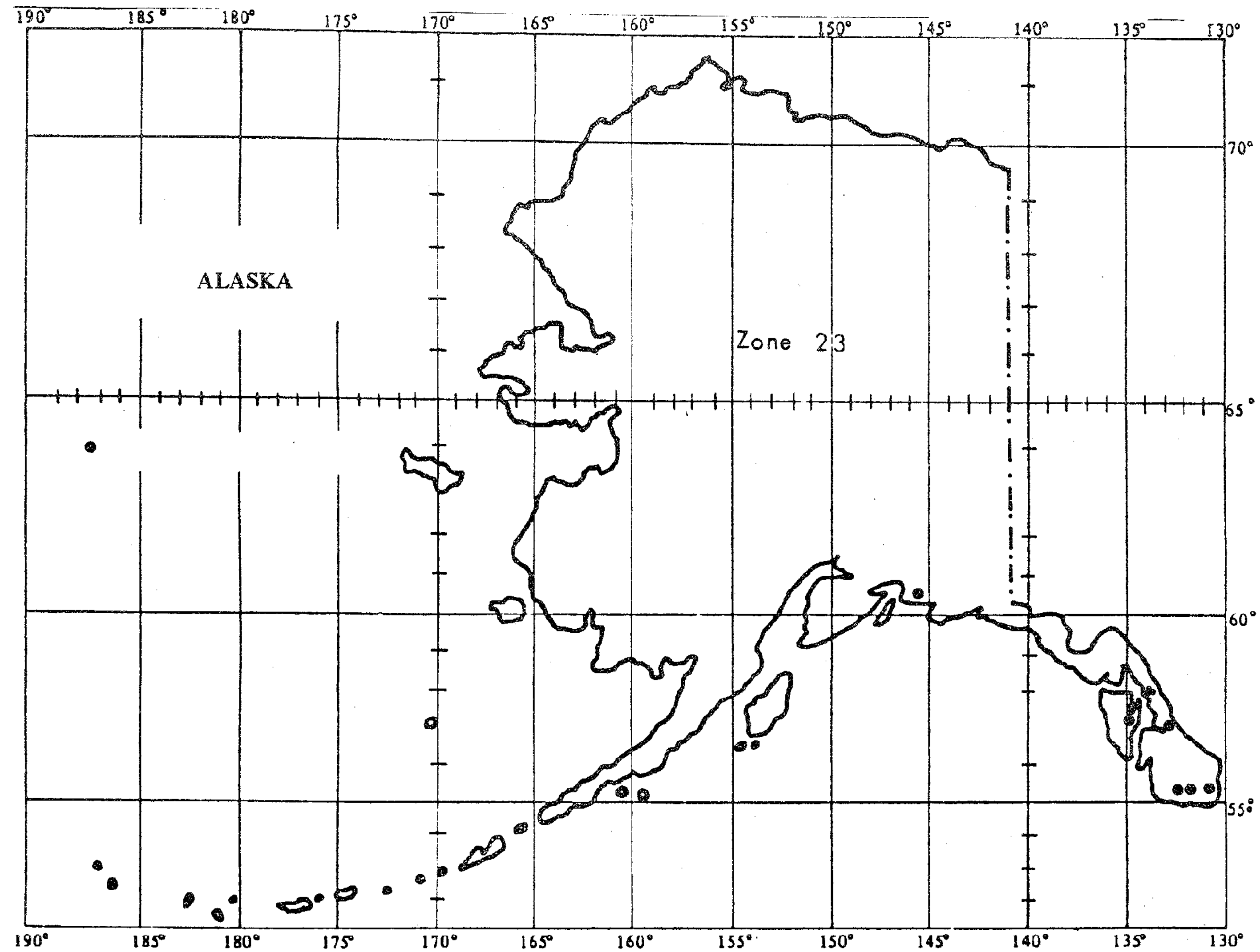
No separations were made in Alaska, Hawaii, or Puerto Rico. The balance of the states are arranged alphabetically.

NOTE:

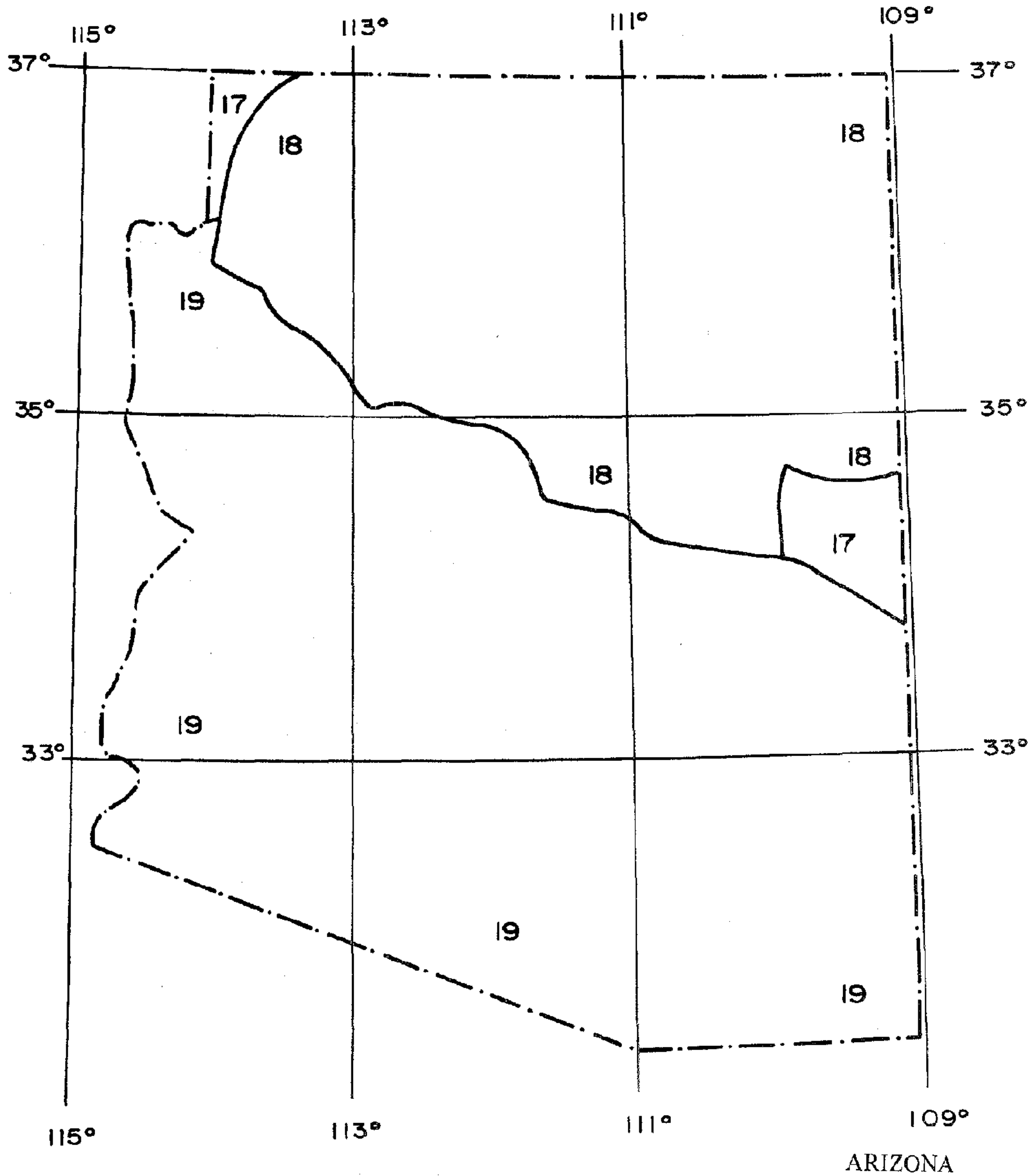
Scales of maps are different because some maps were not available in a proper scale or it would be impractical to show for example Texas in the same scale as Rhode Island.



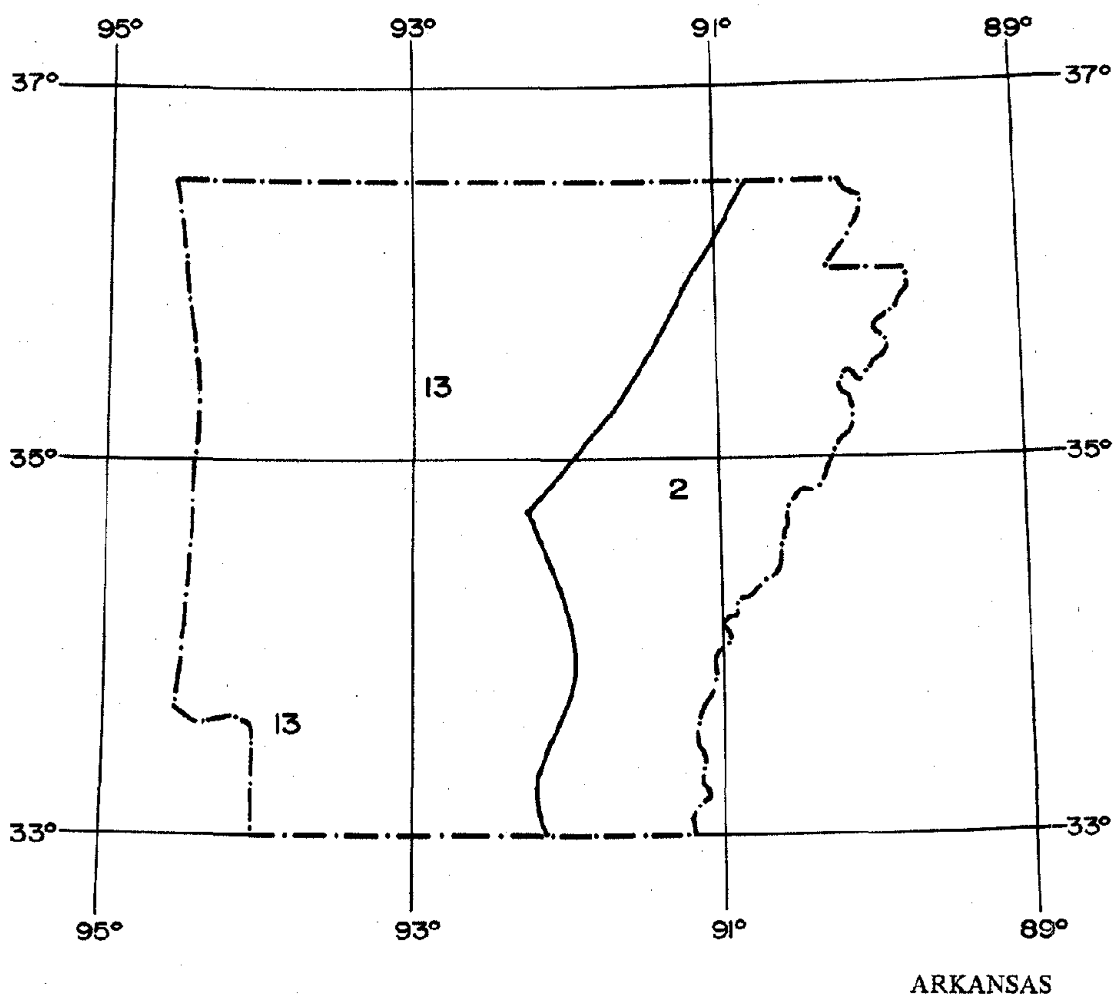
Appendix B-01. Hydrophysiographic zones of Alabama.



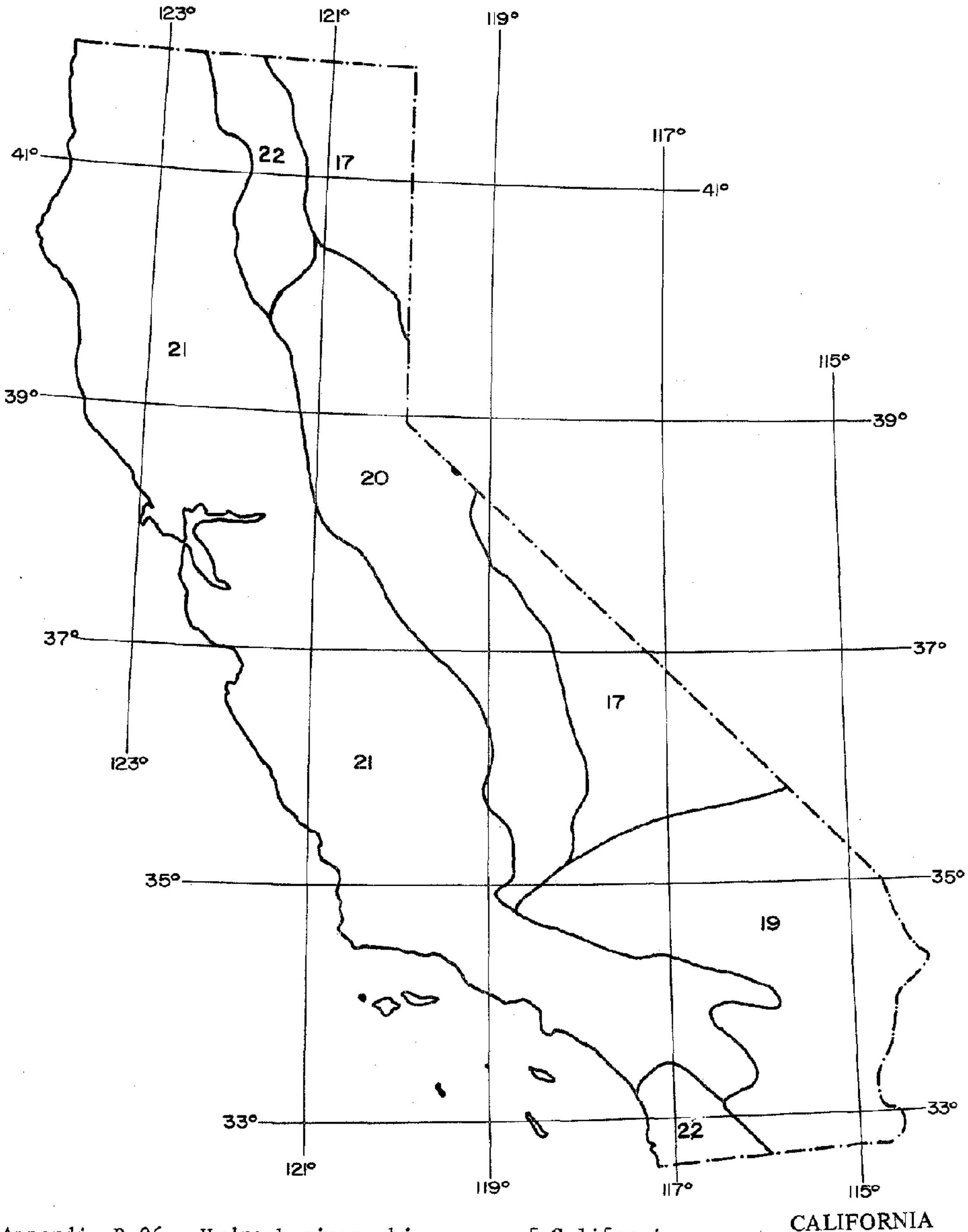
Appendix B-02. Hydrophysiographic zones of Alaska.



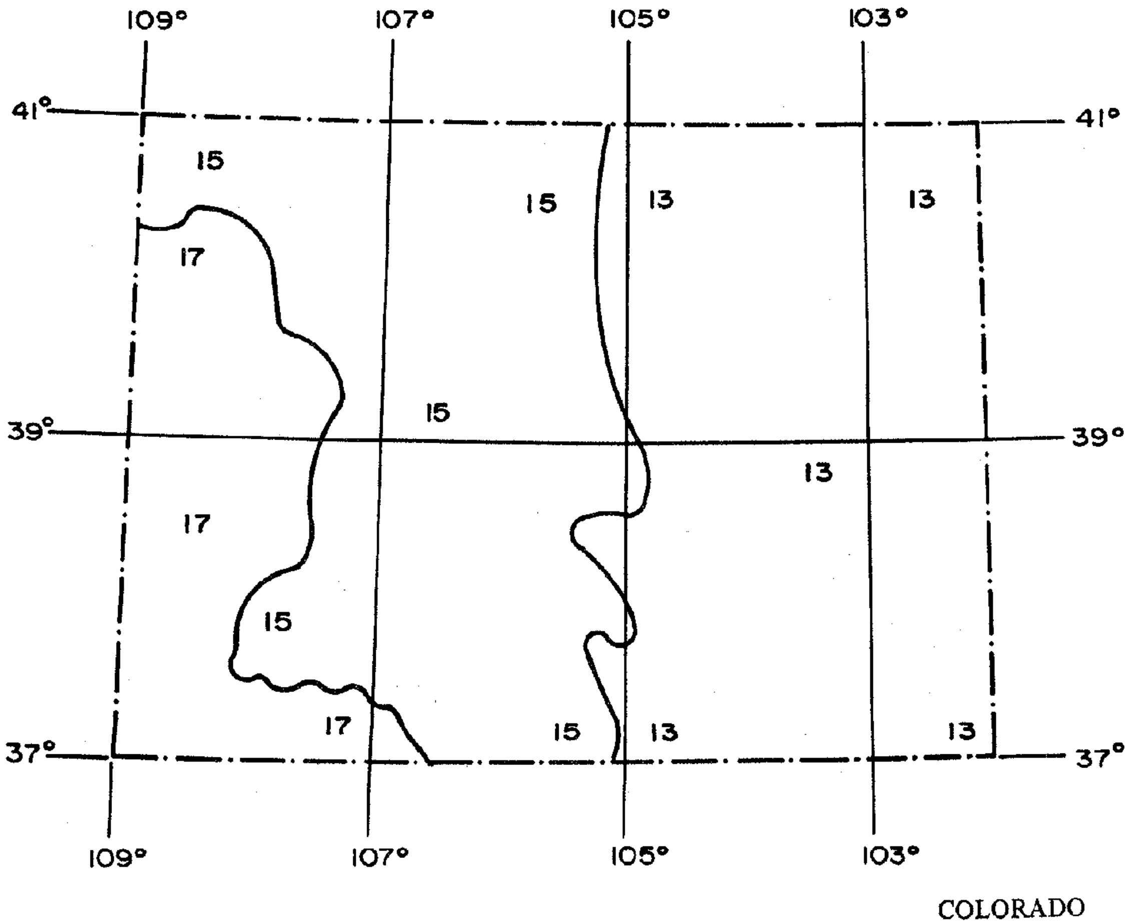
Appendix B-04. Hydrophysiographic zones of Arizona.



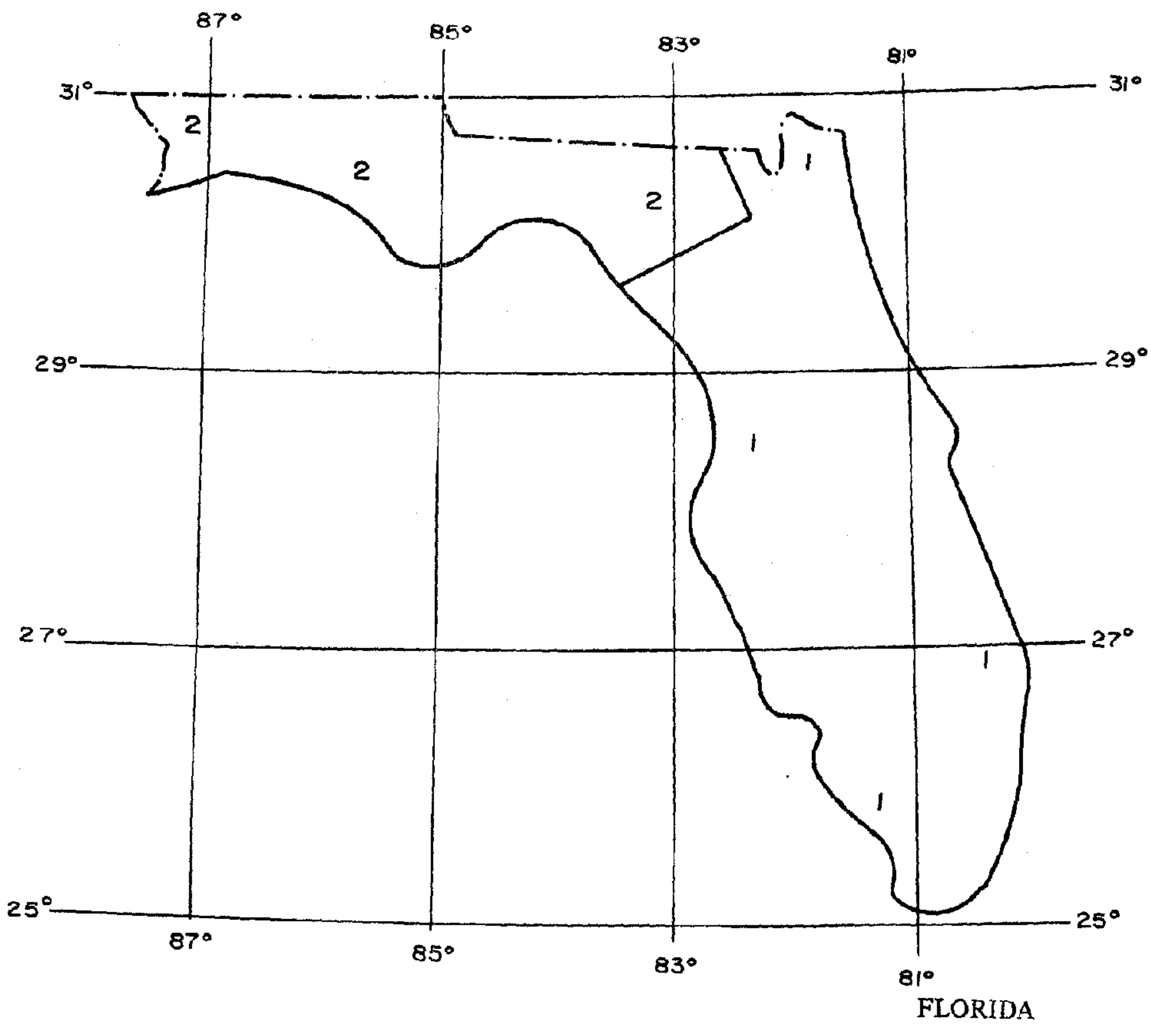
Appendix B-05. Hydrophysiographic zones of Arkansas.



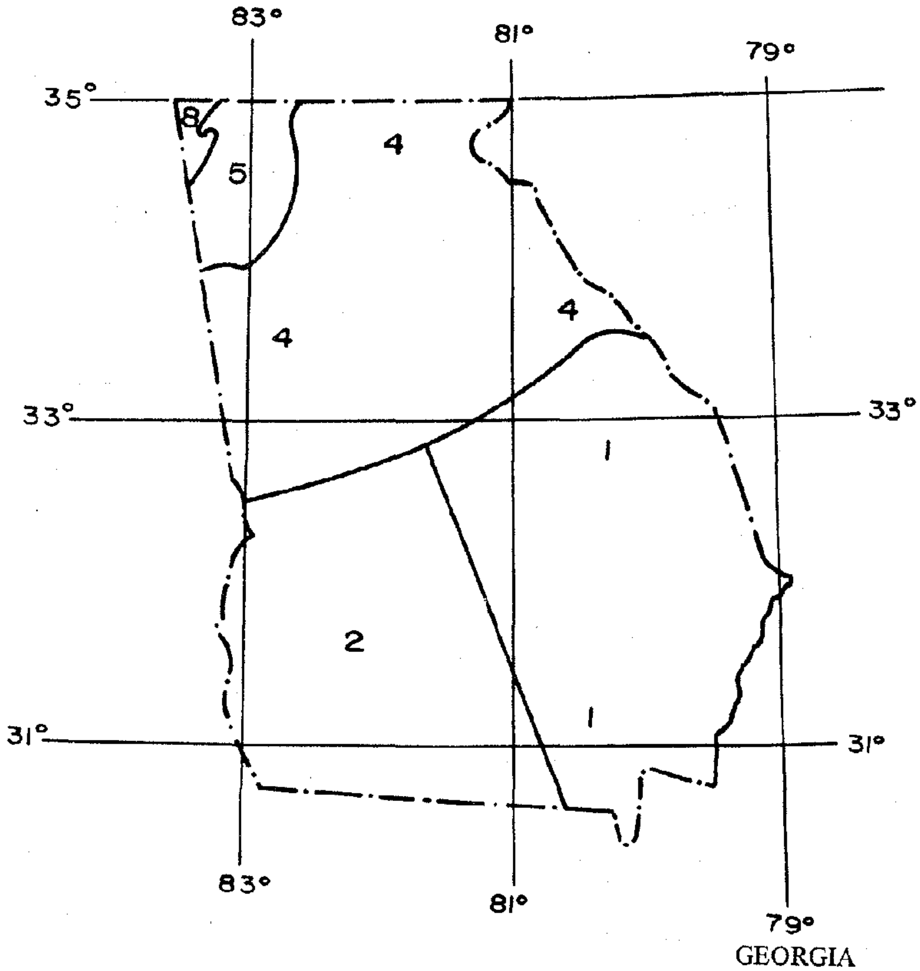
Appendix B-06. Hydrophysiographic zones of California.



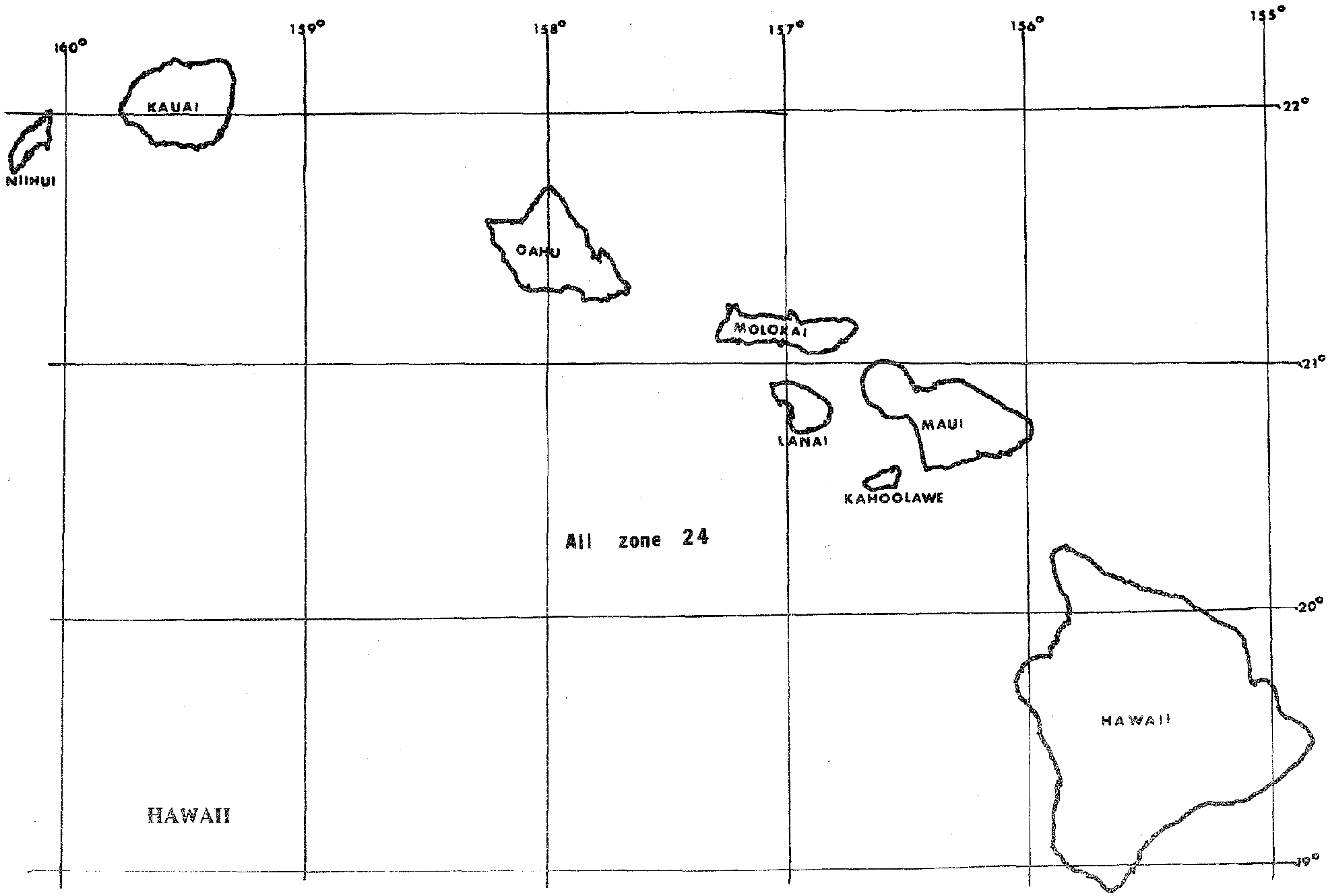
Appendix B-08. Hydrophysiographic zones of Colorado.



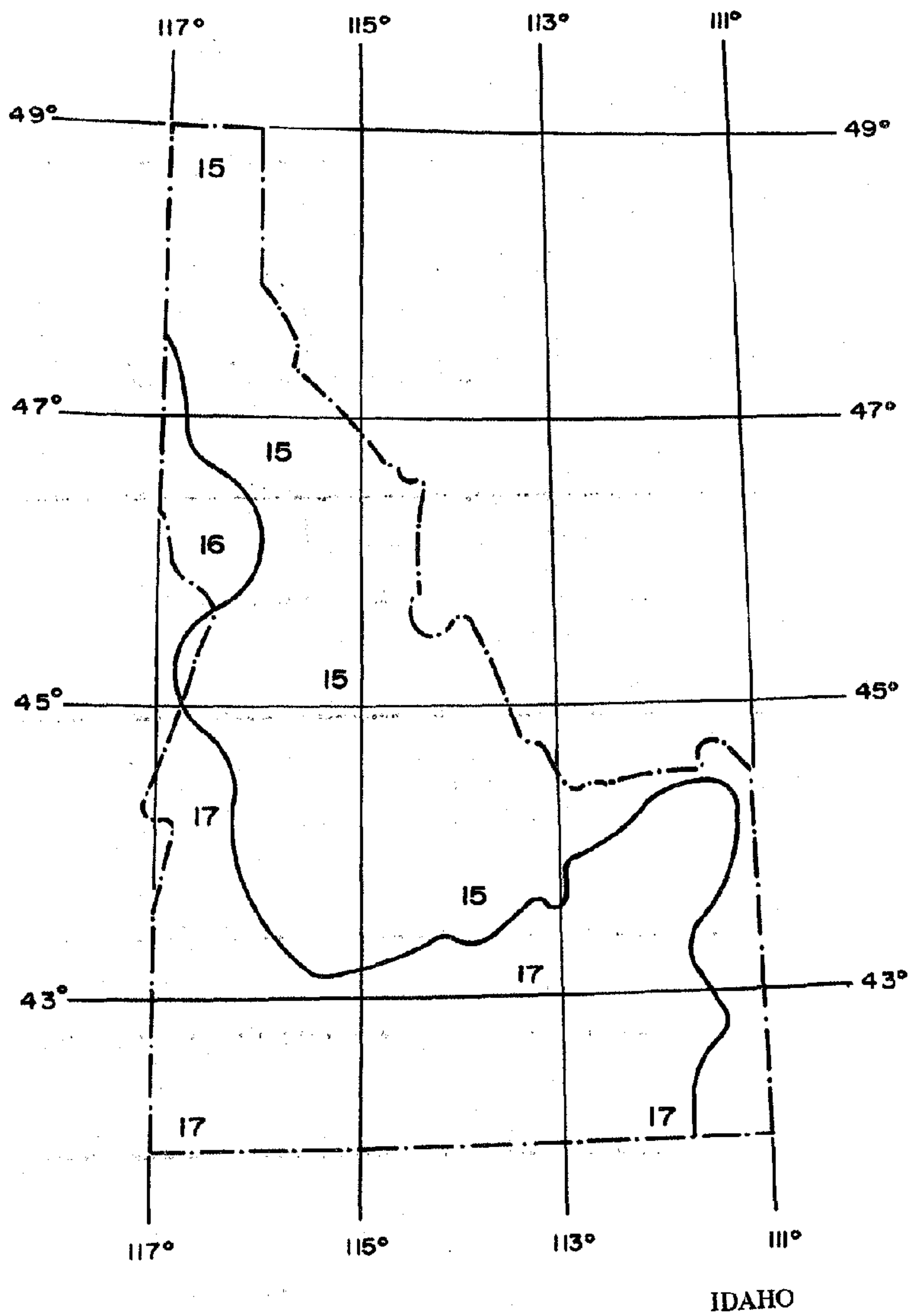
Appendix B-12. Hydrophysiographic zones of Florida.



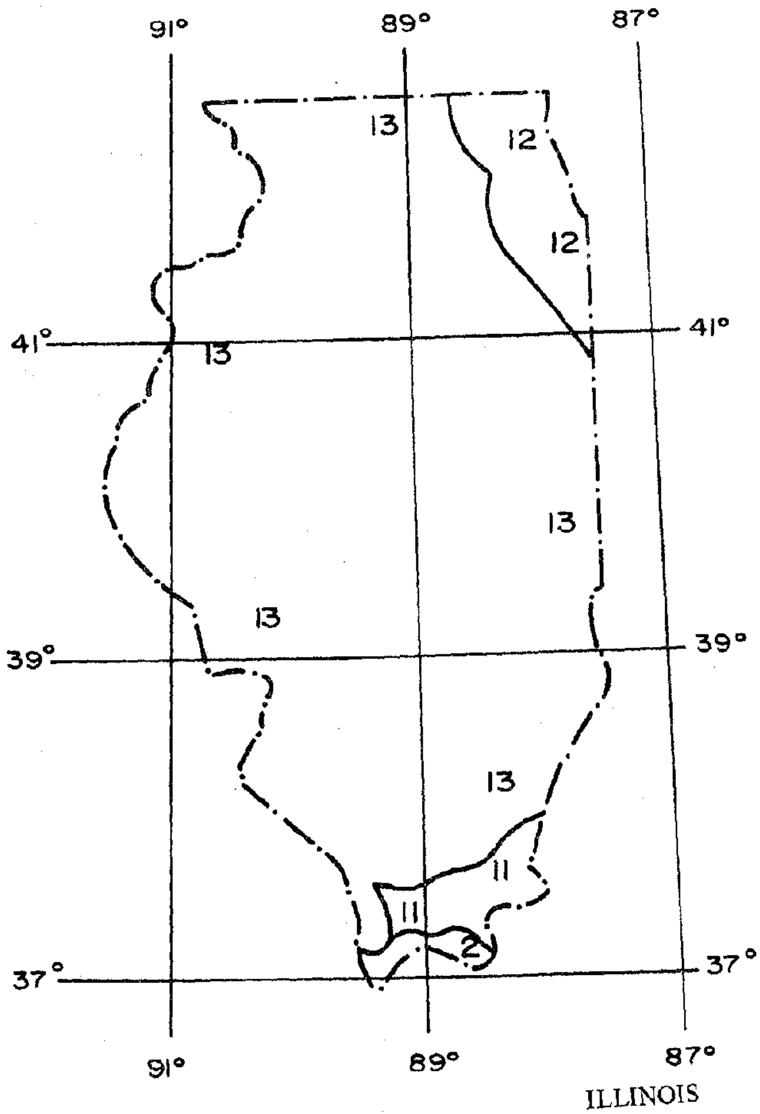
Appendix B-13. Hydrophysiographic zones of Georgia.



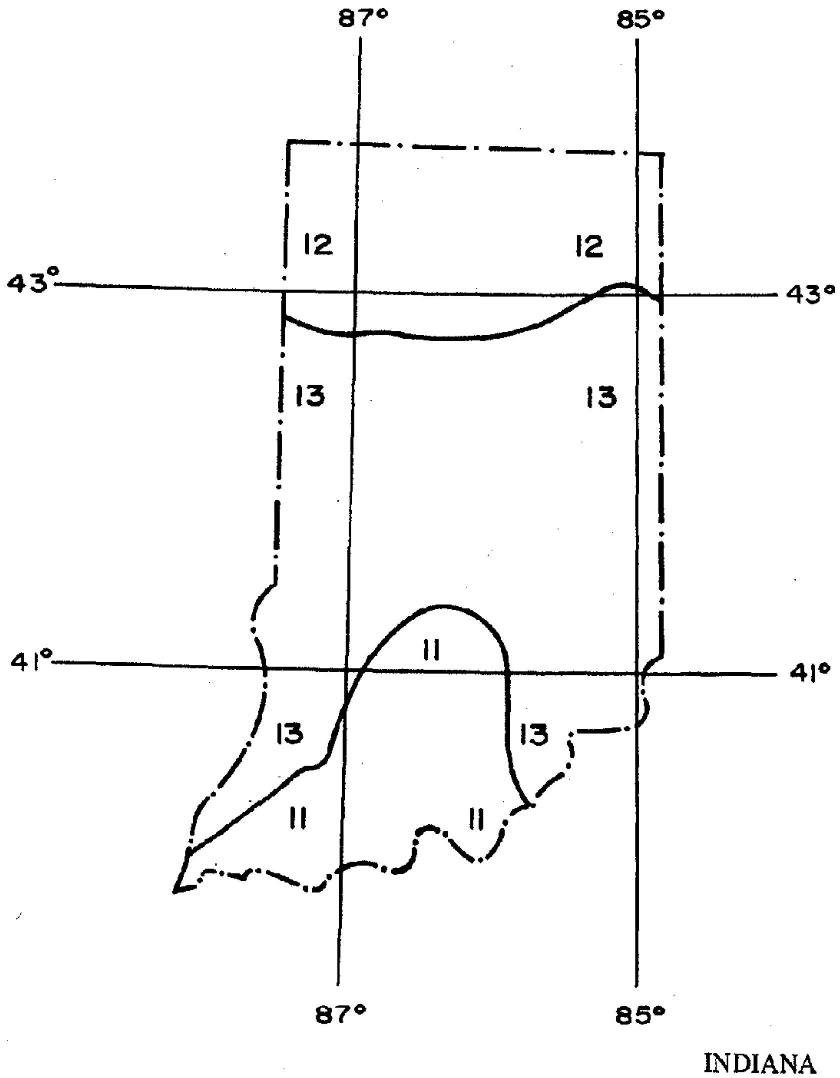
Appendix B-15. Hydrophysiographic zones of Hawaii.



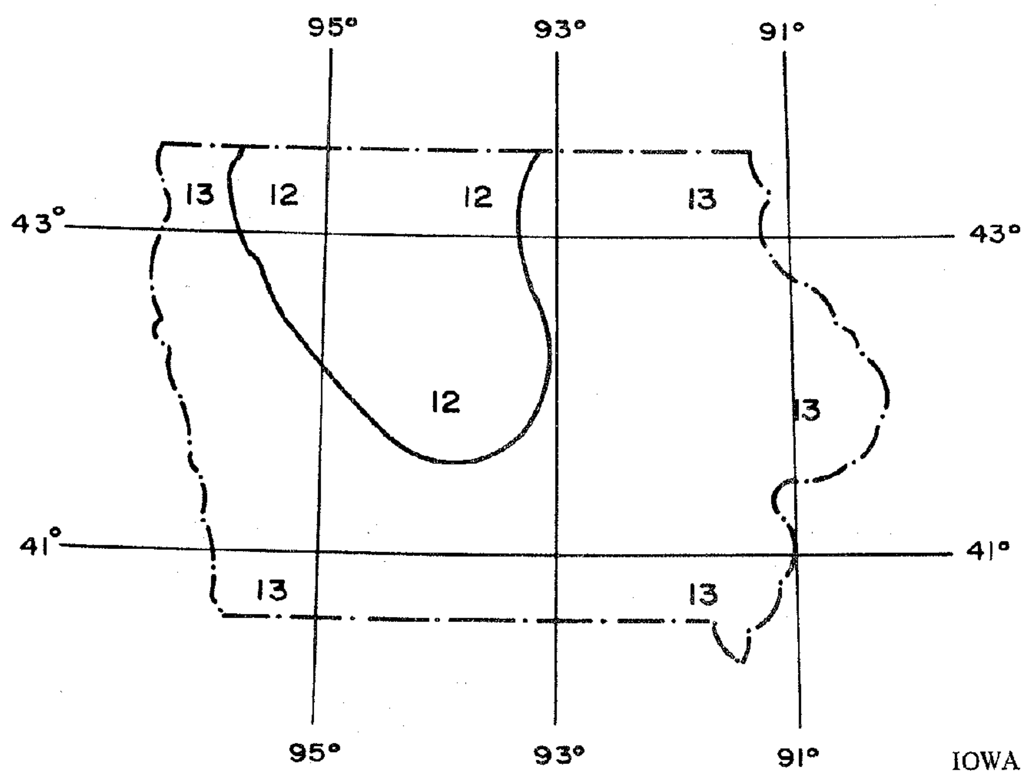
Appendix B-16. Hydrophysiographic zones of Idaho.



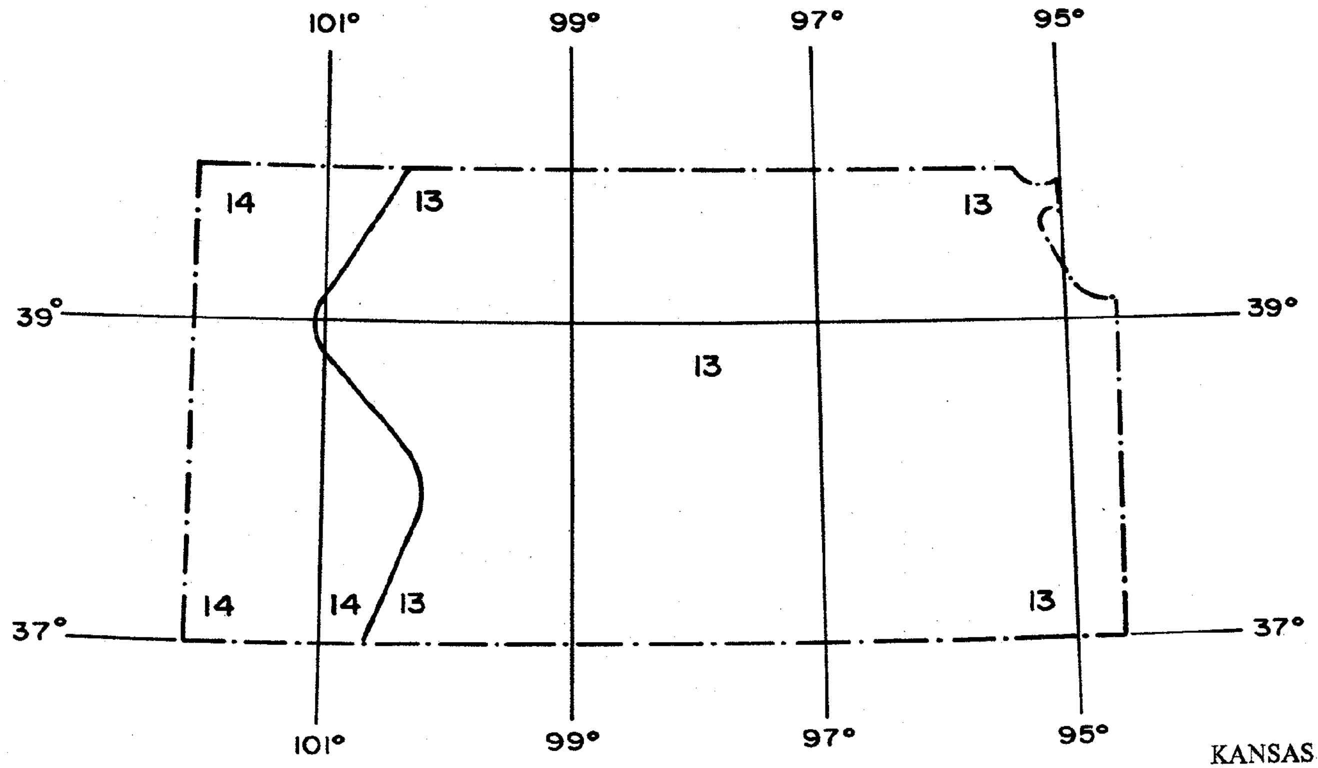
Appendix B-17. Hydrophysiographic zones of Illinois.



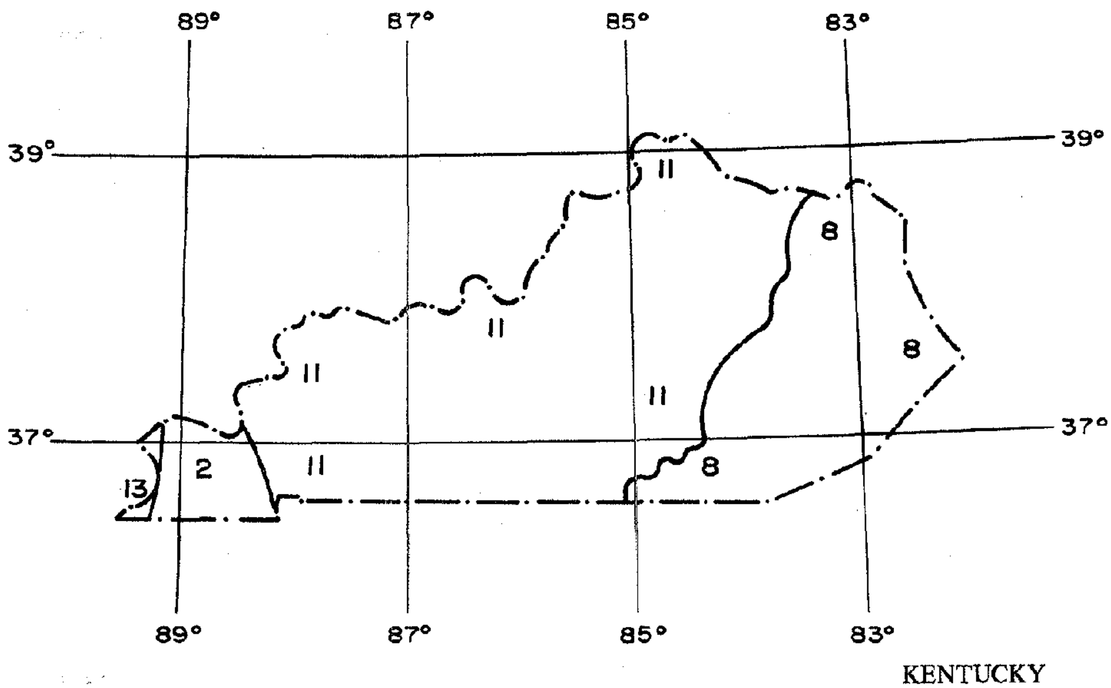
Appendix B-18. Hydrophysiographic zones of Indiana.



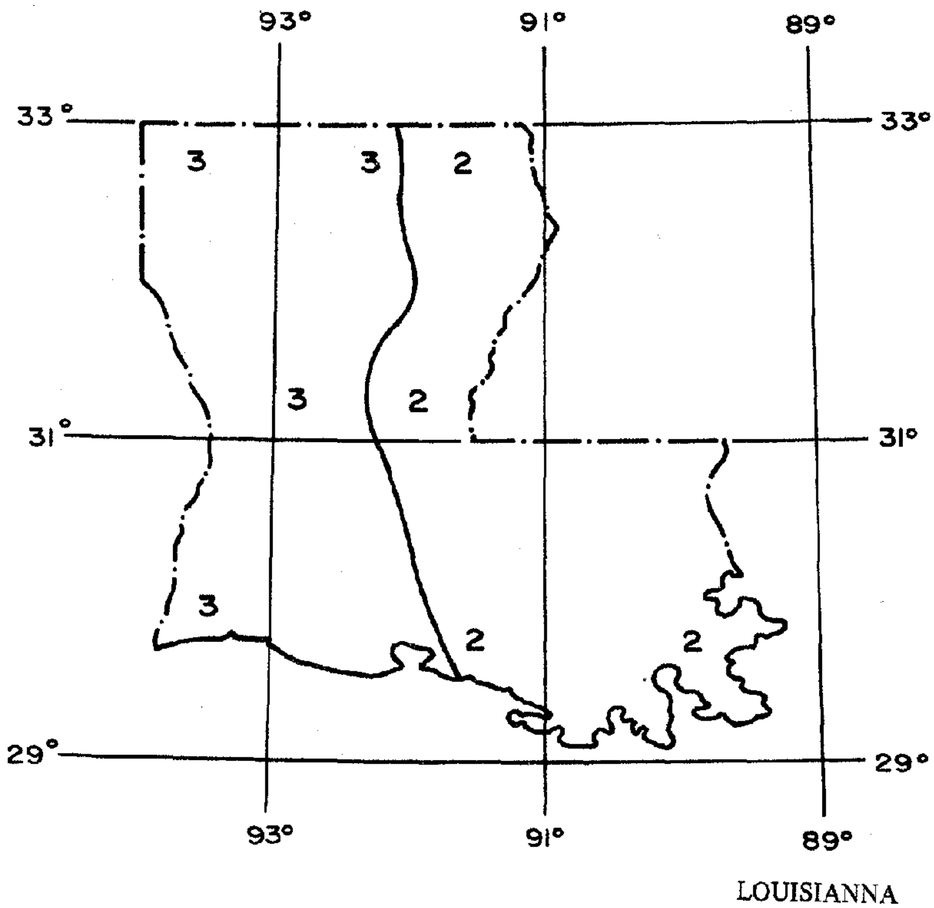
Appendix B-19. Hydrophysiographic zones of Iowa.



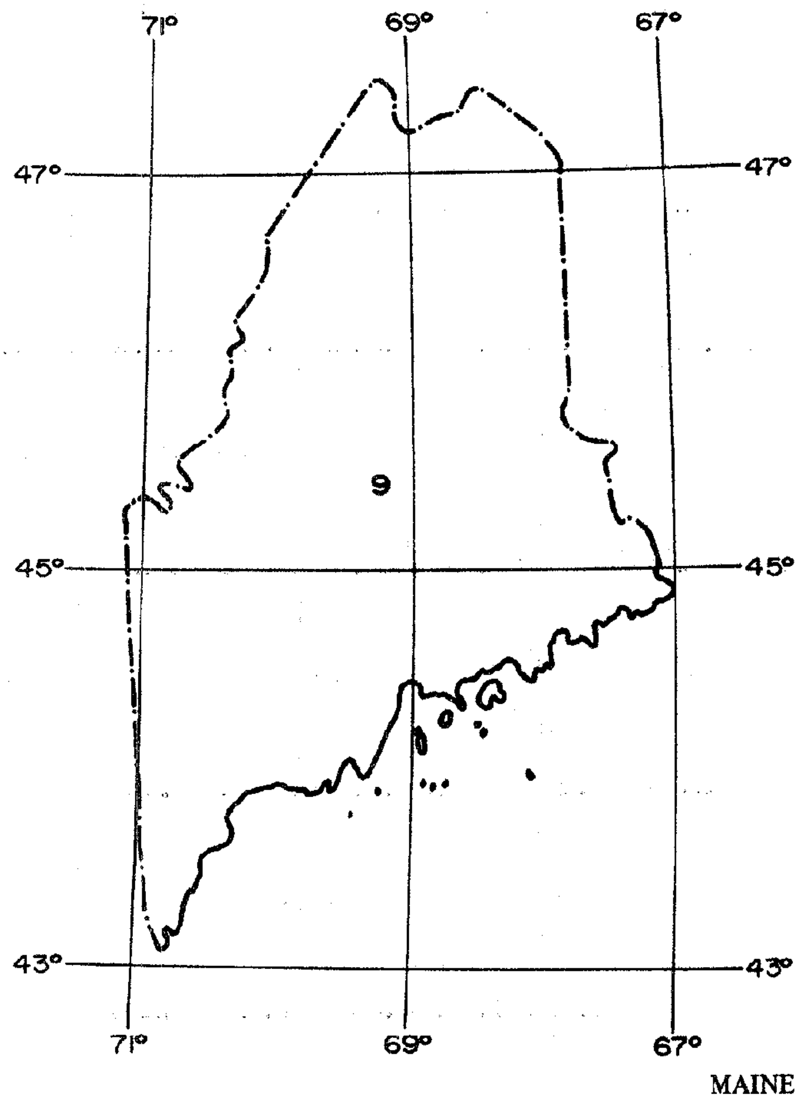
Appendix B-20. Hydrophysiographic zones of Kansas.



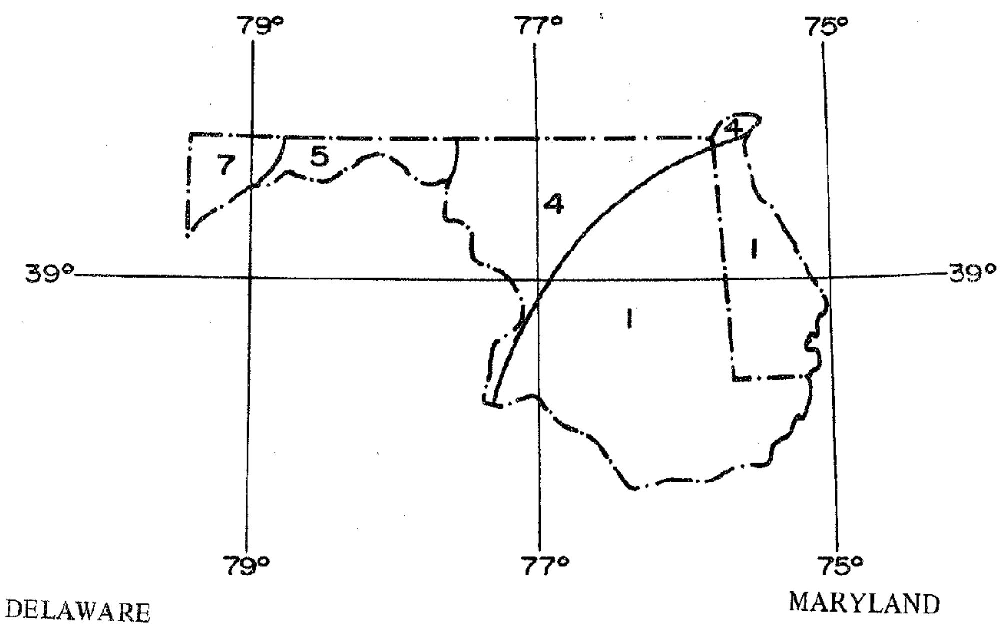
Appendix B-21. Hydrophysiographic zones of Kentucky.



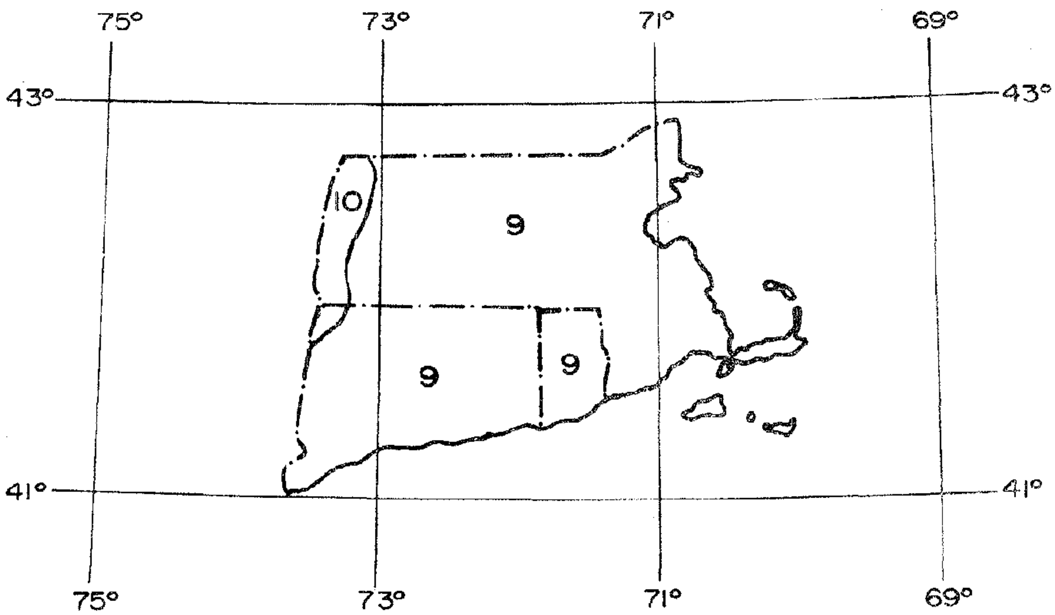
Appendix B-22. Hydrophysiographic zones of Louisianna.



Appendix B-23. Hydrophysiographic zones of Maine.

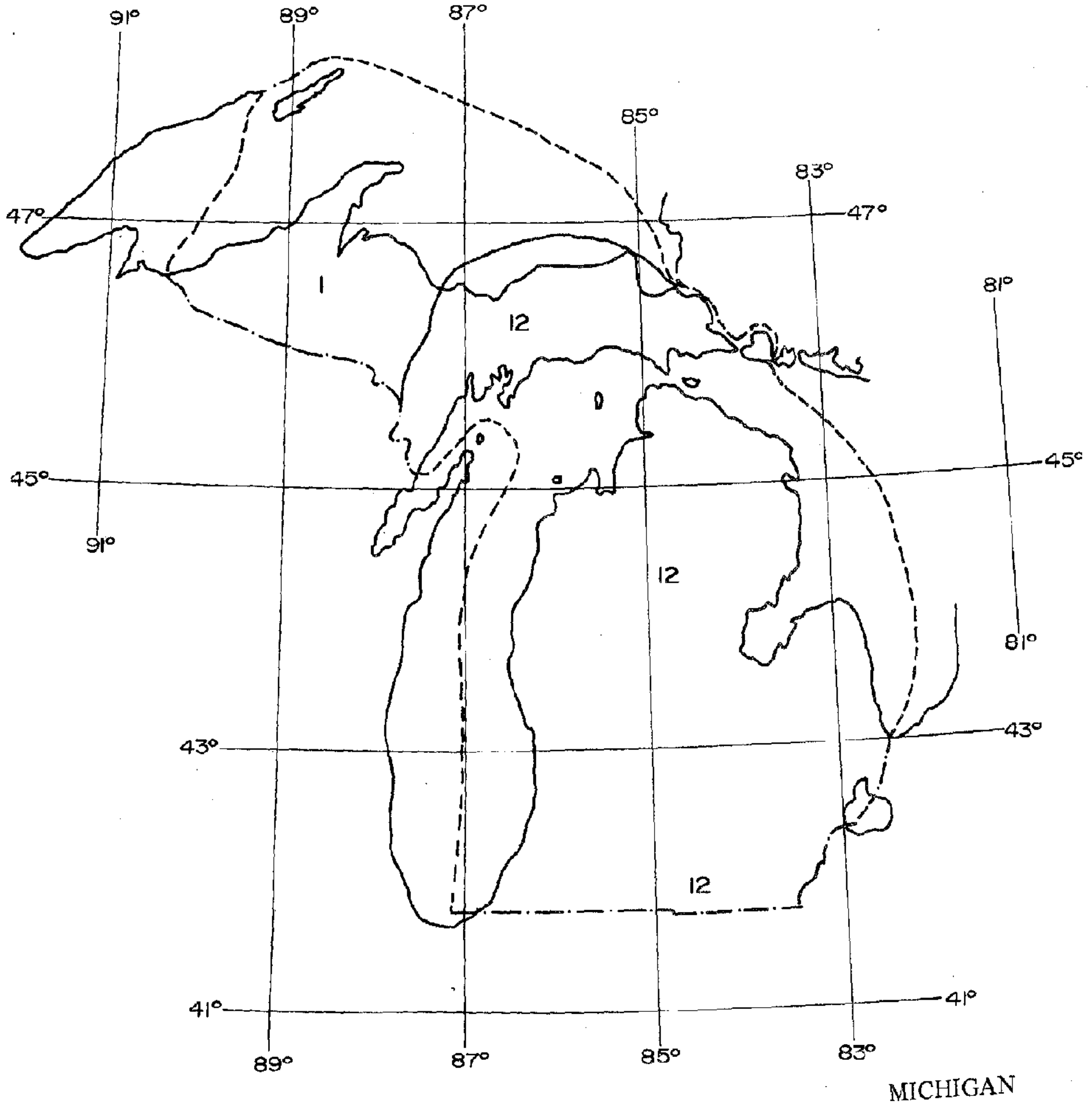


Appendix B-10. Hydrophysiographic zones of Delaware.
Appendix B-24. Hydrophysiographic zones of Maryland.

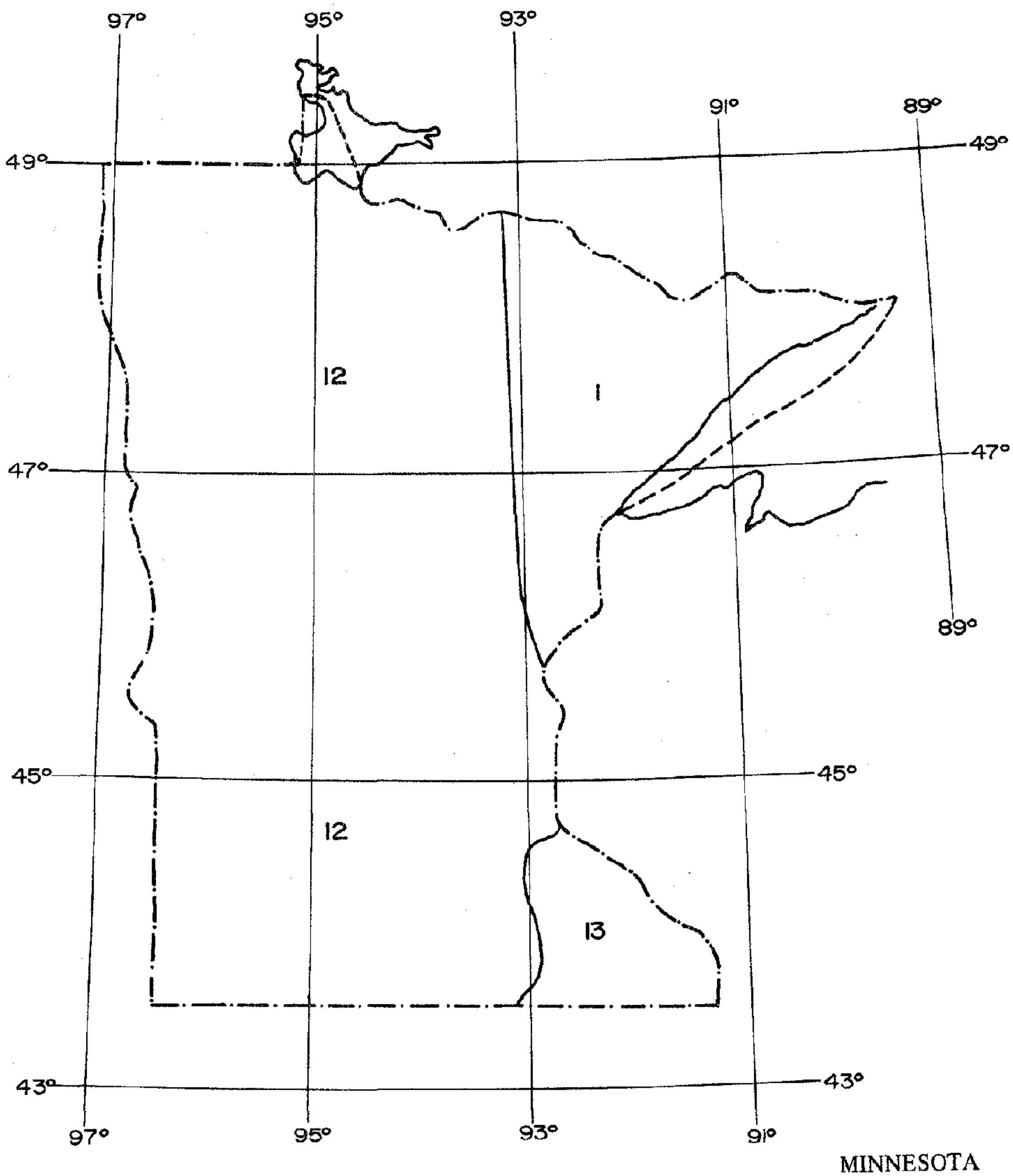


CONNECTICUT MASSACHUSETTS RHODE ISLAND

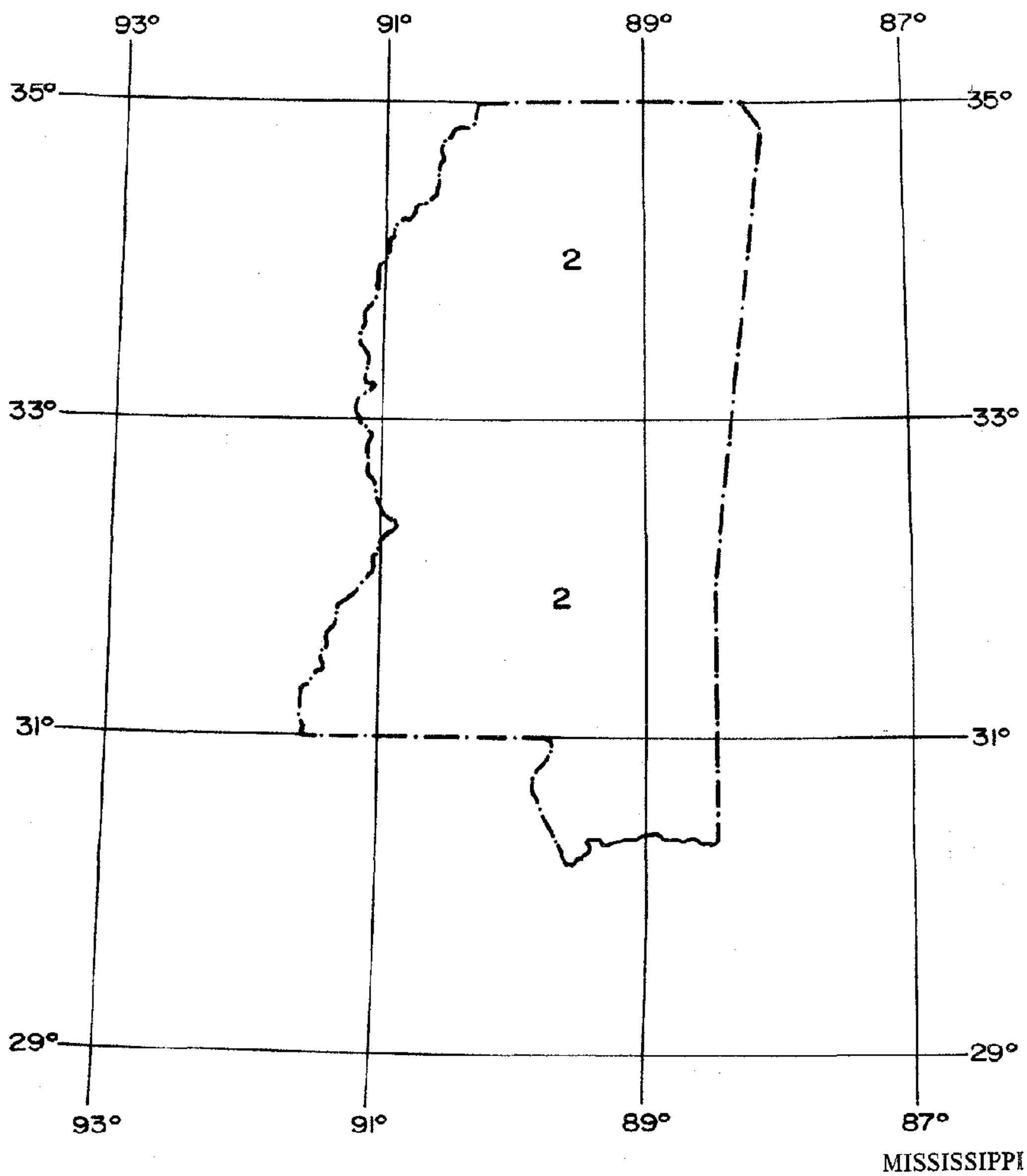
Appendix B-09. Hydrophysiographic zones of Connecticut.
Appendix B-25. Hydrophysiographic zones of Massachusetts.
Appendix B-44. Hydrophysiographic zones of Rhode Island.



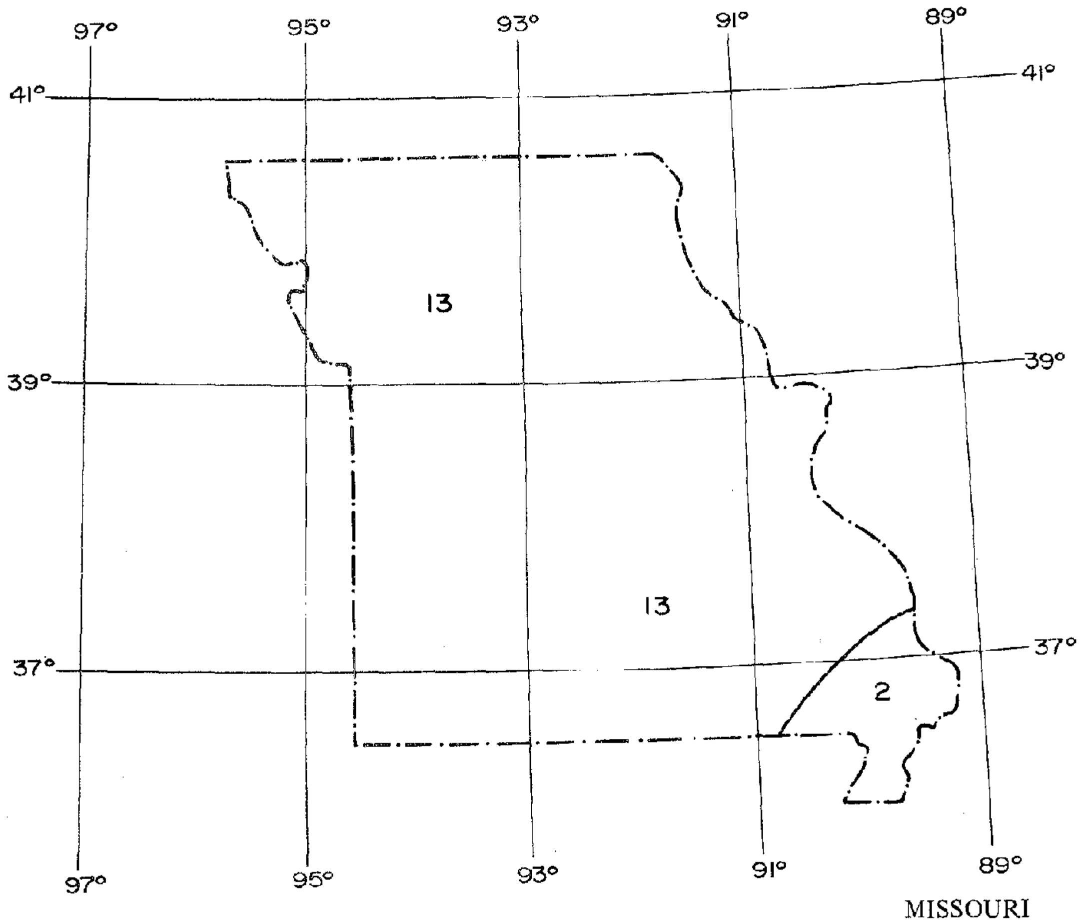
Appendix B-26. Hydrophysiographic zones of Michigan.



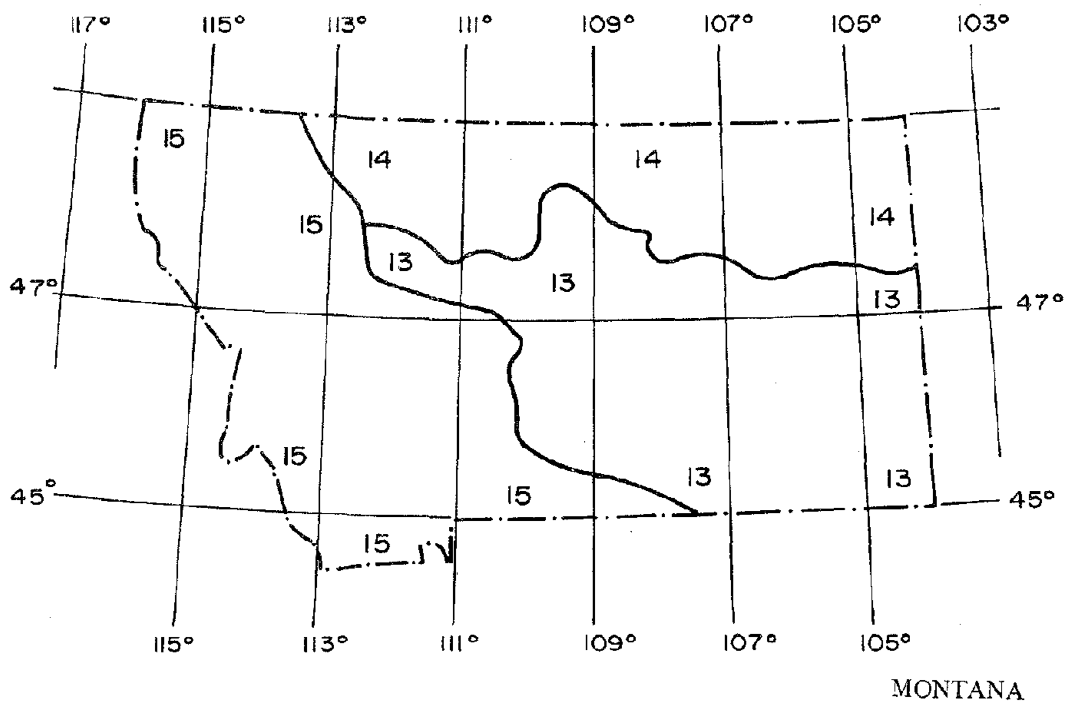
Appendix B-27. Hydrophysiographic zones of Minnesota.



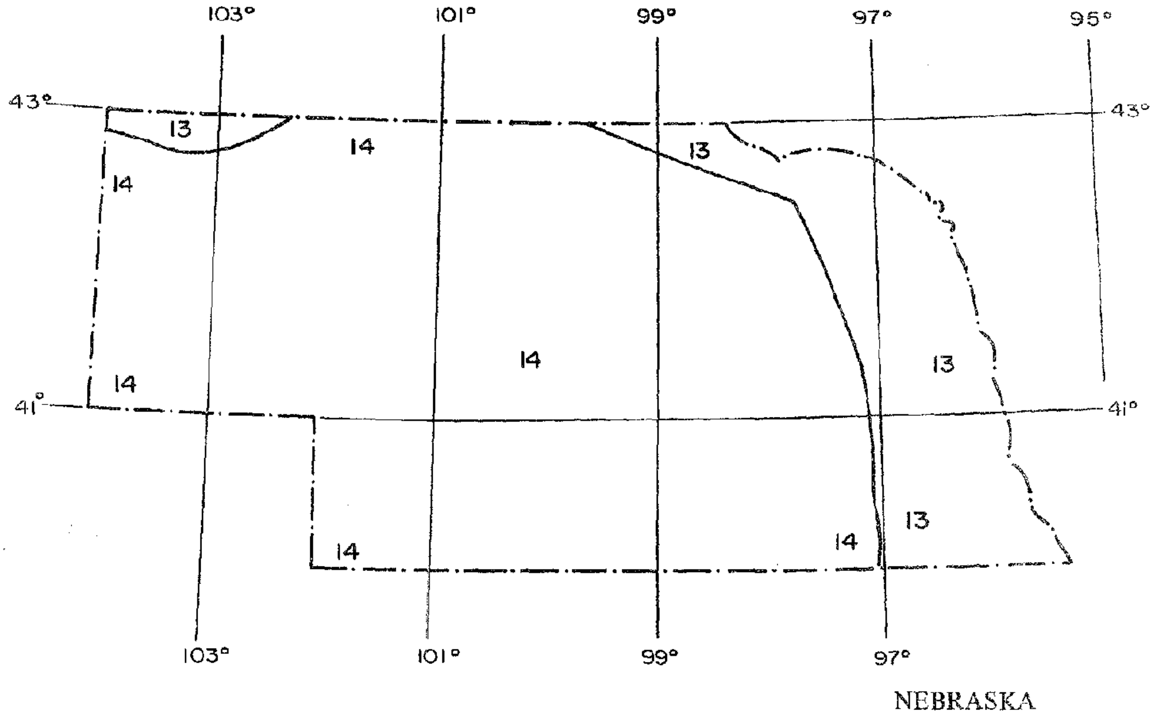
Appendix B-28. Hydrophysiographic zones of Mississippi.



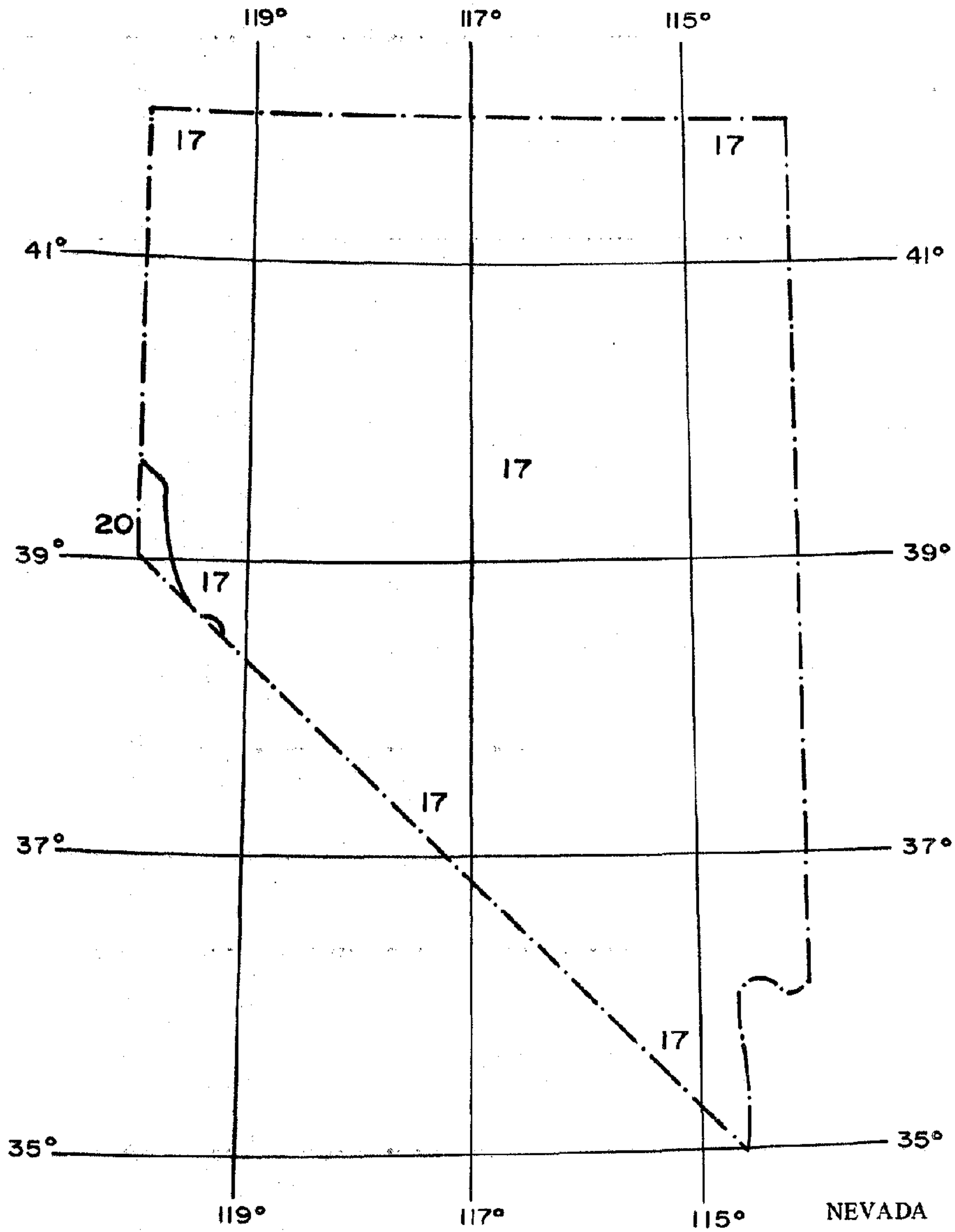
Appendix B-29. Hydrophysiographic zones of Missouri.



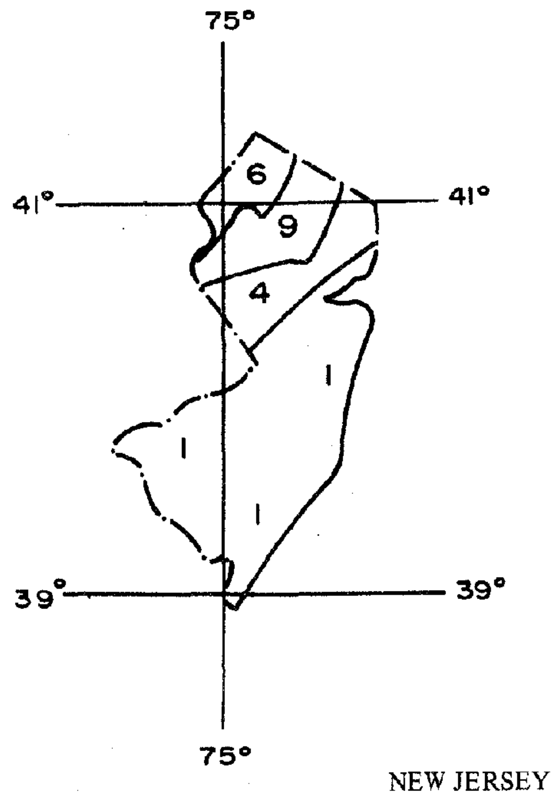
Appendix B-30. Hydrophysiographic zones of Montana.



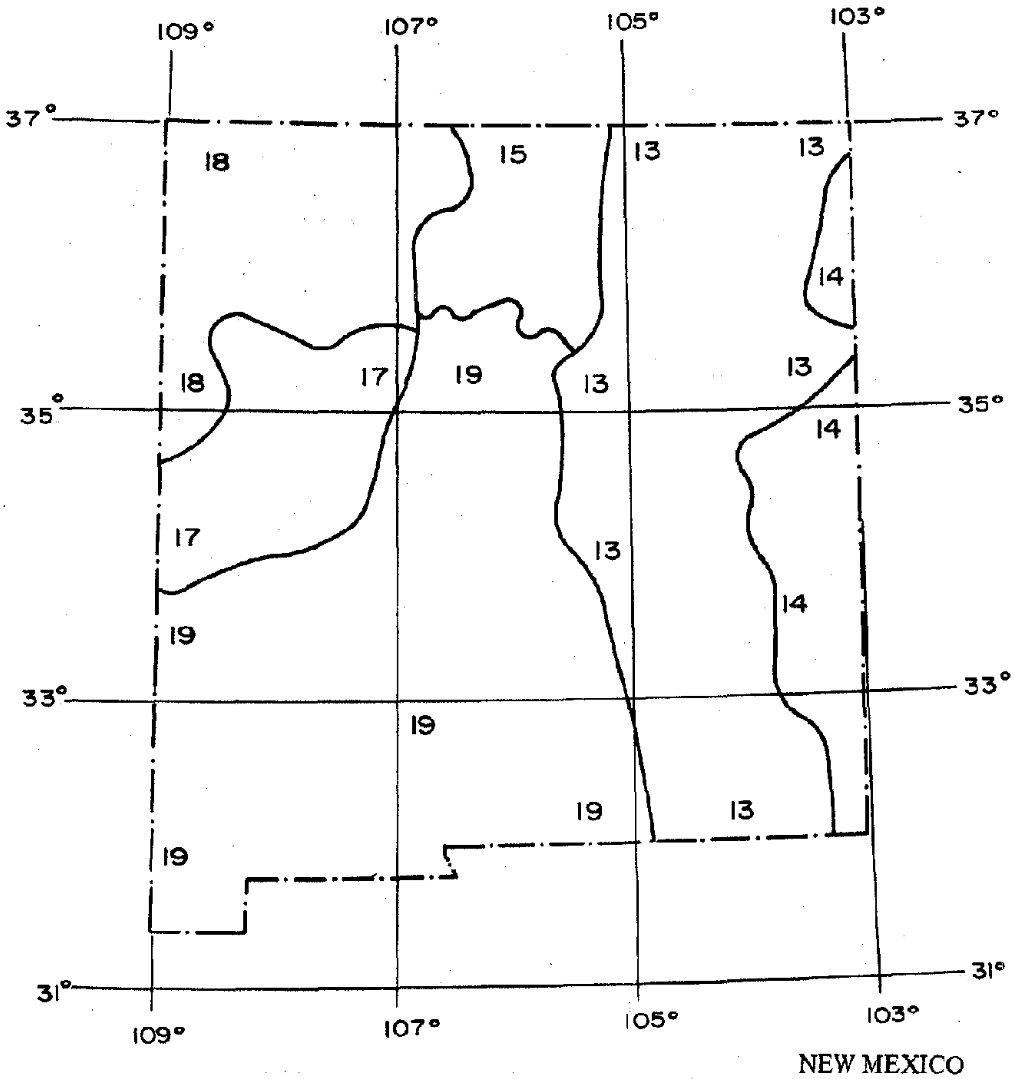
Appendix B-31. Hydrophysiographic zones of Nebraska.



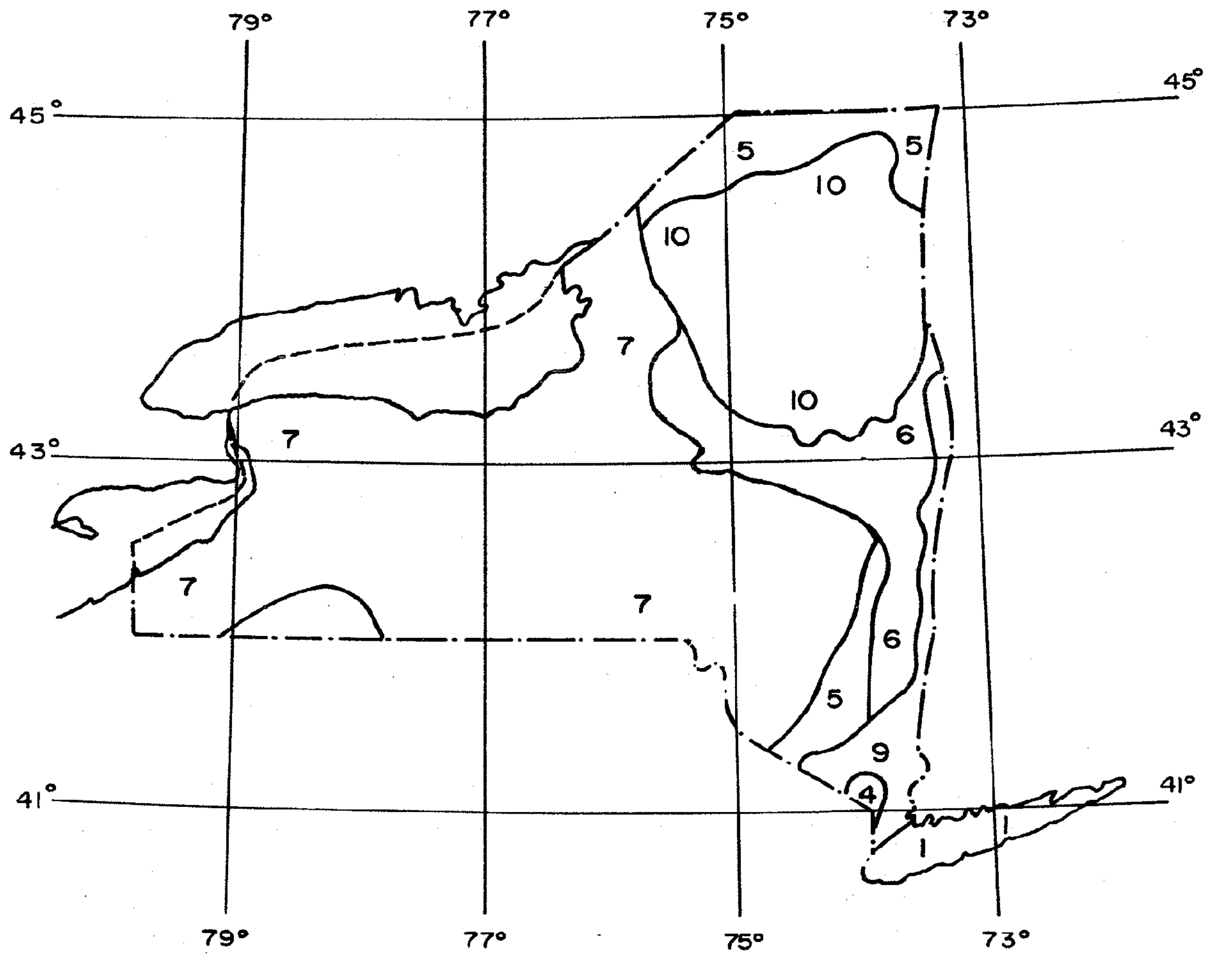
Appendix B-32. Hydrophysiographic zones of Nevada.



Appendix B-34. Hydrophysiographic zones of New Jersey.

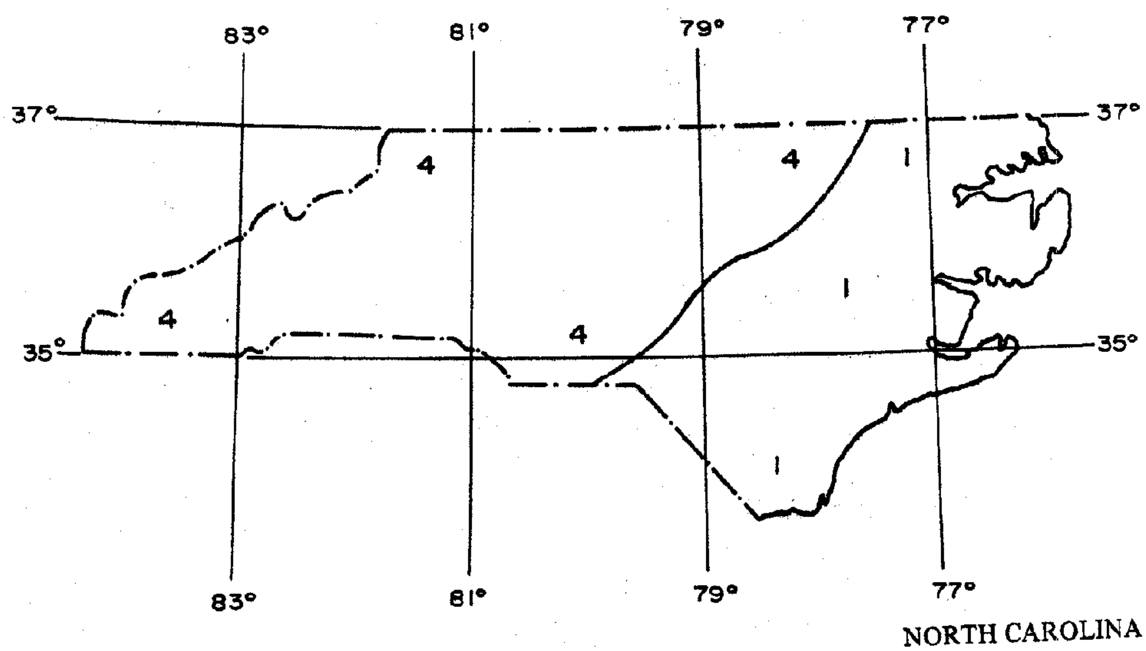


Appendix B-35. Hydrophysiographic zones of New Mexico.

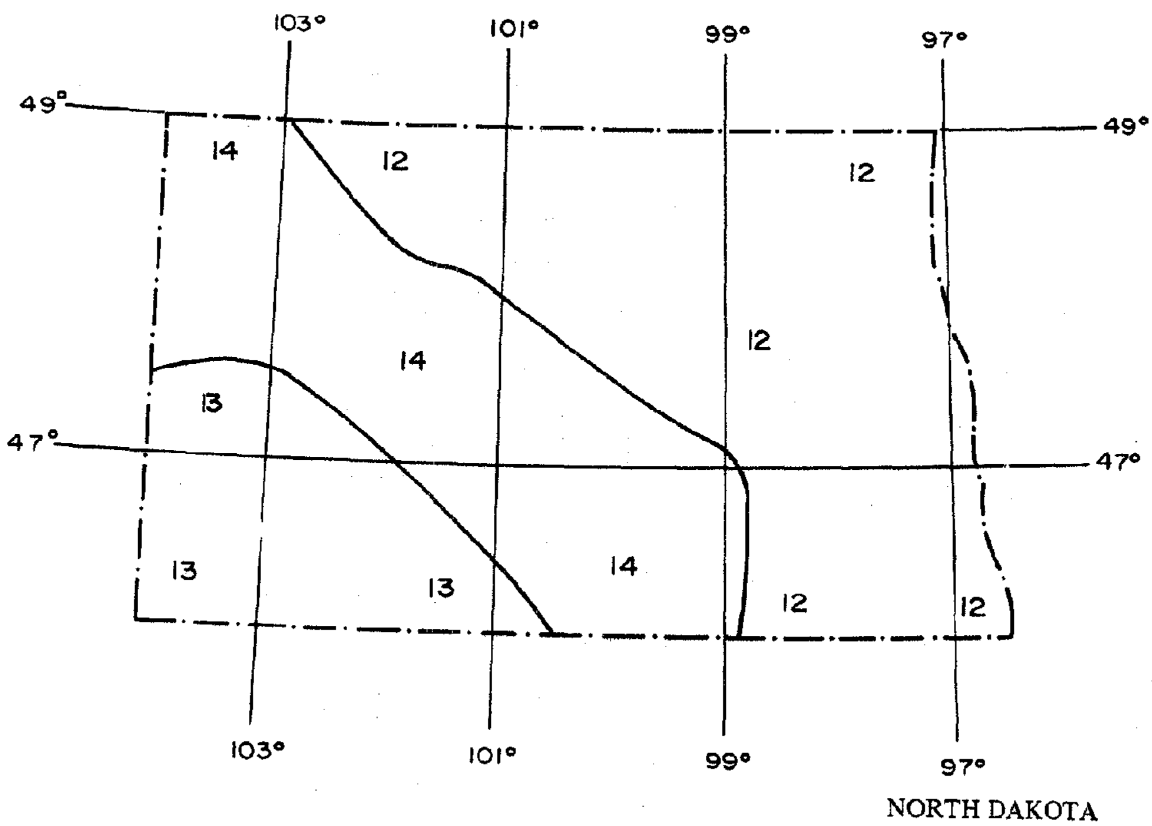


NEW YORK

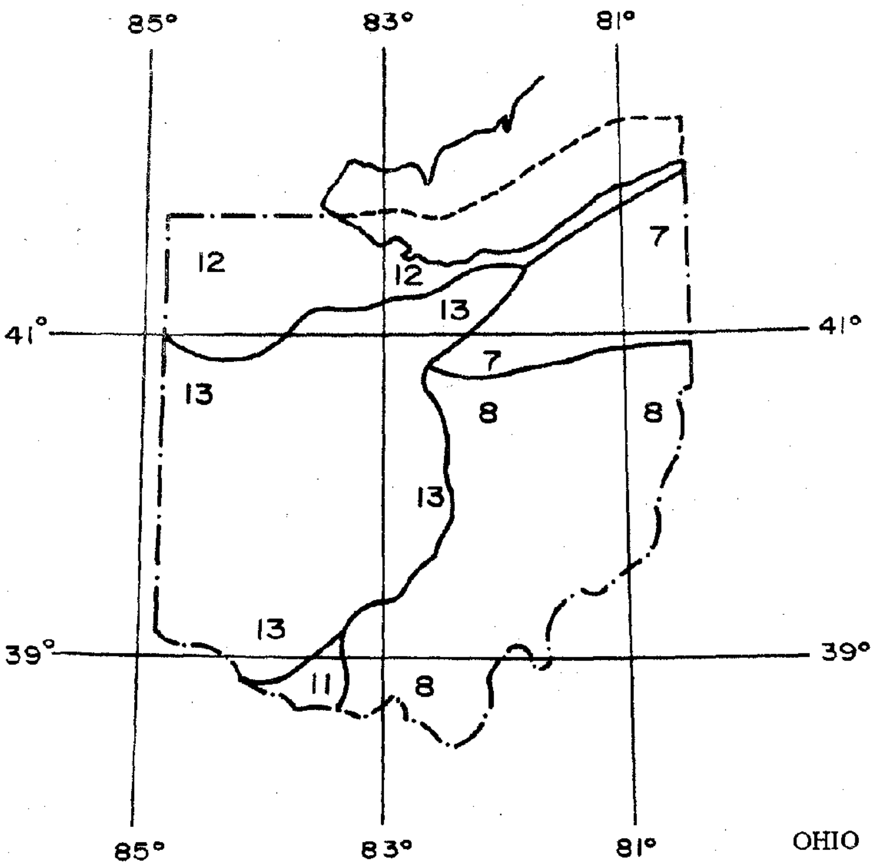
Appendix B-36. Hydrophysiographic zones of New York.



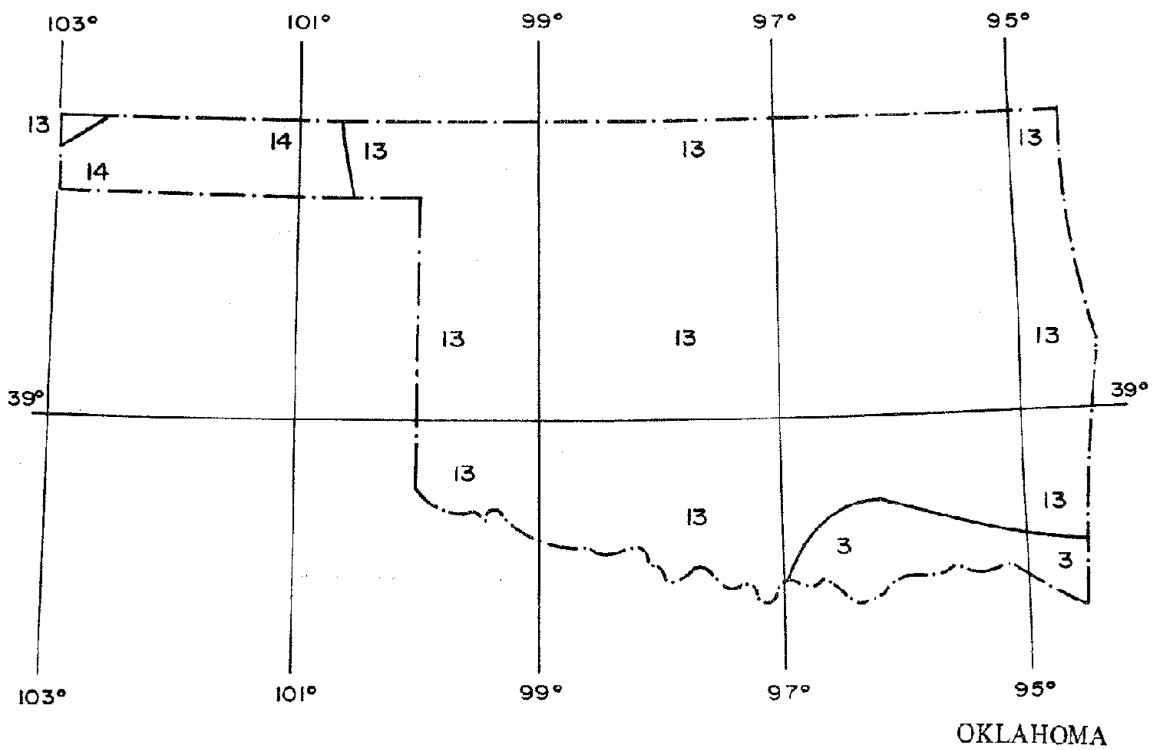
Appendix B-37. Hydrophysiographic zones of North Carolina.



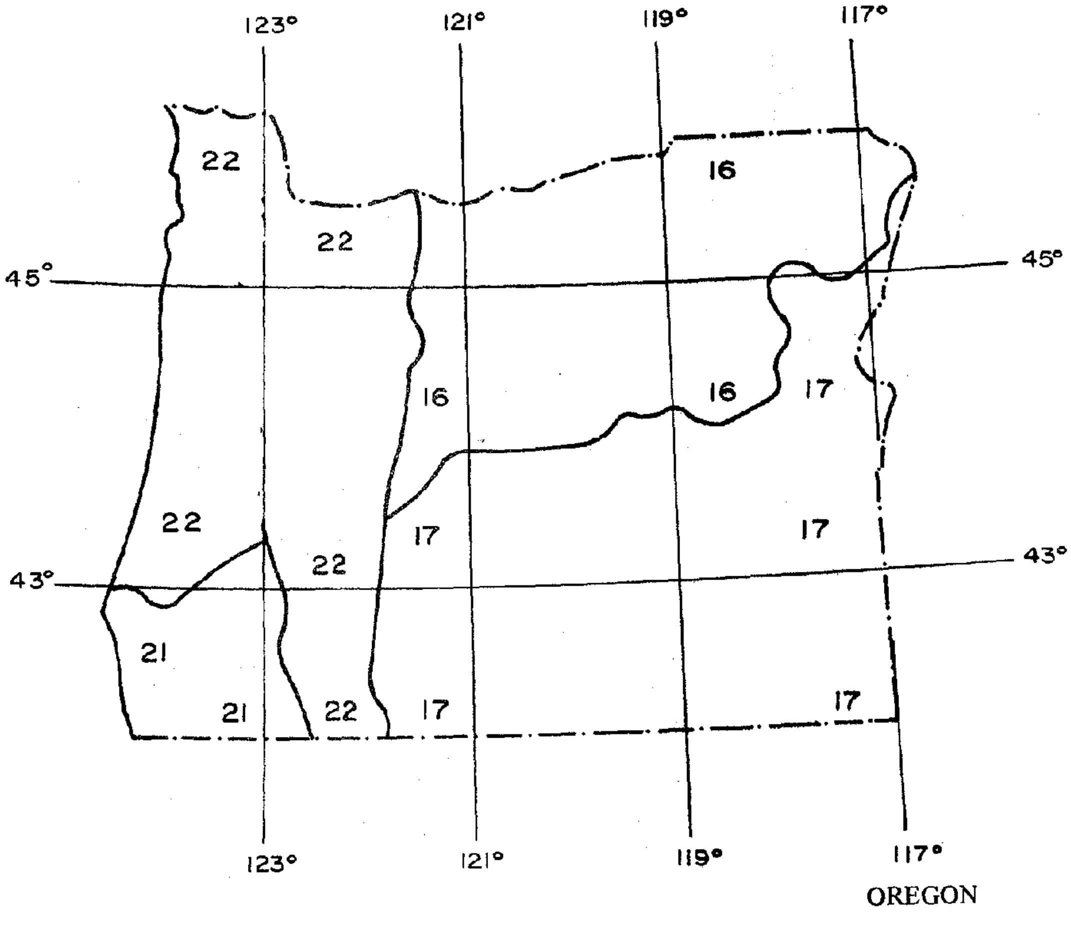
Appendix B-38. Hydrophysiographic zones of North Dakota.



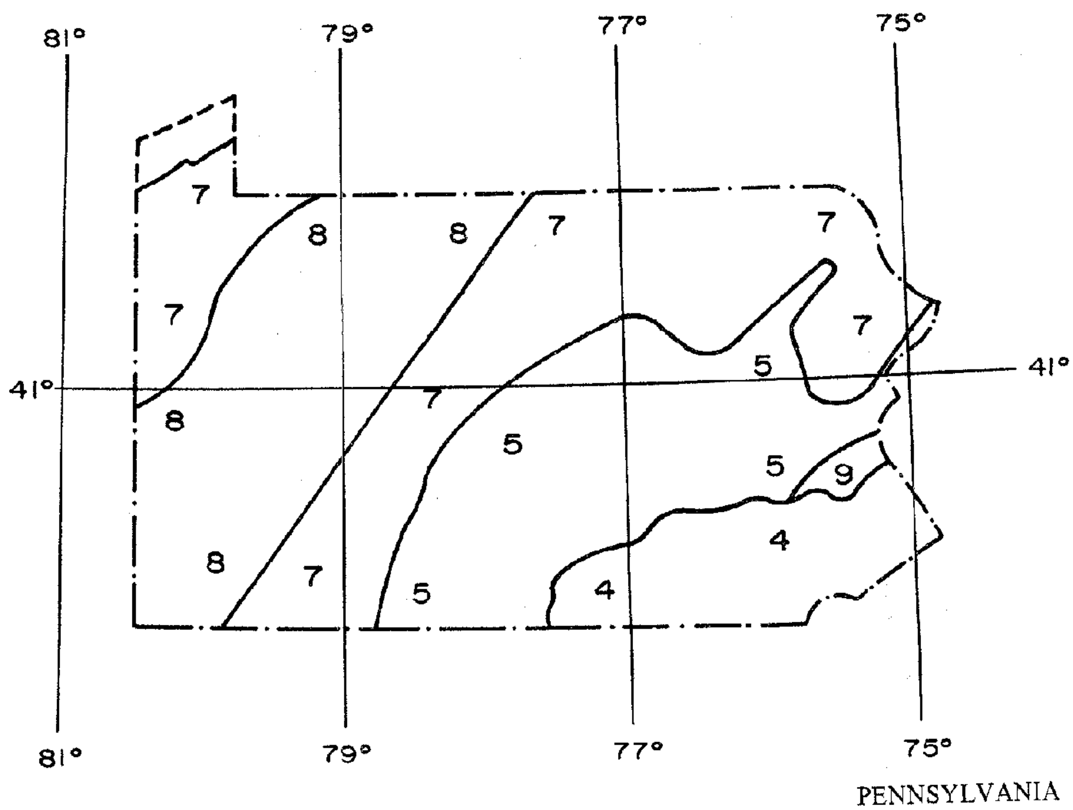
Appendix B-39. Hydrophysiographic zones of Ohio.



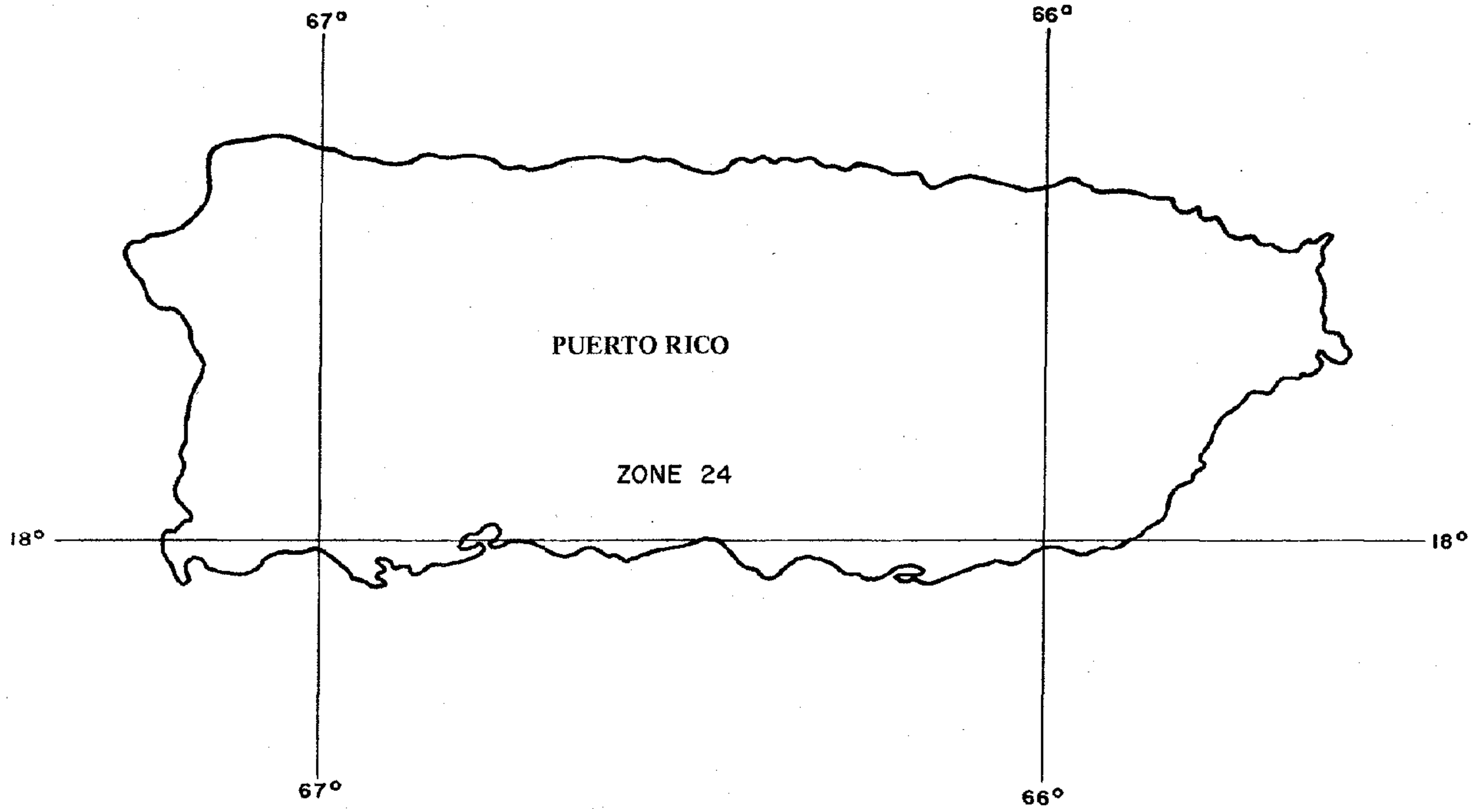
Appendix B-40. Hydrophysiographic zones of Oklahoma.



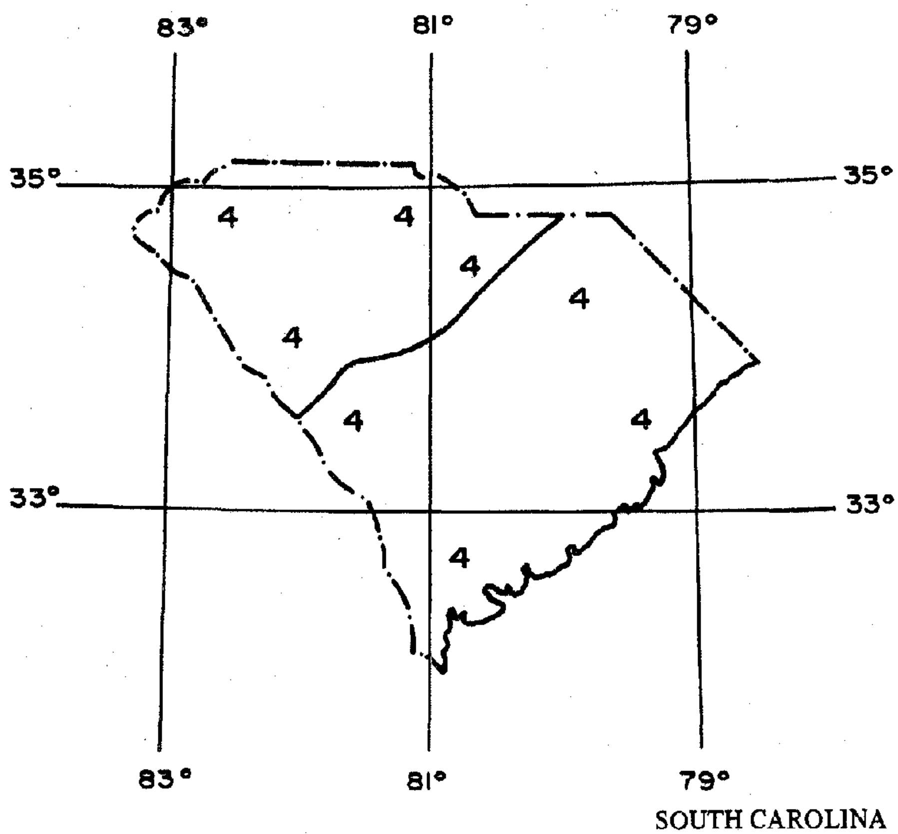
Appendix B-41. Hydrophysiographic zones of Oregon.



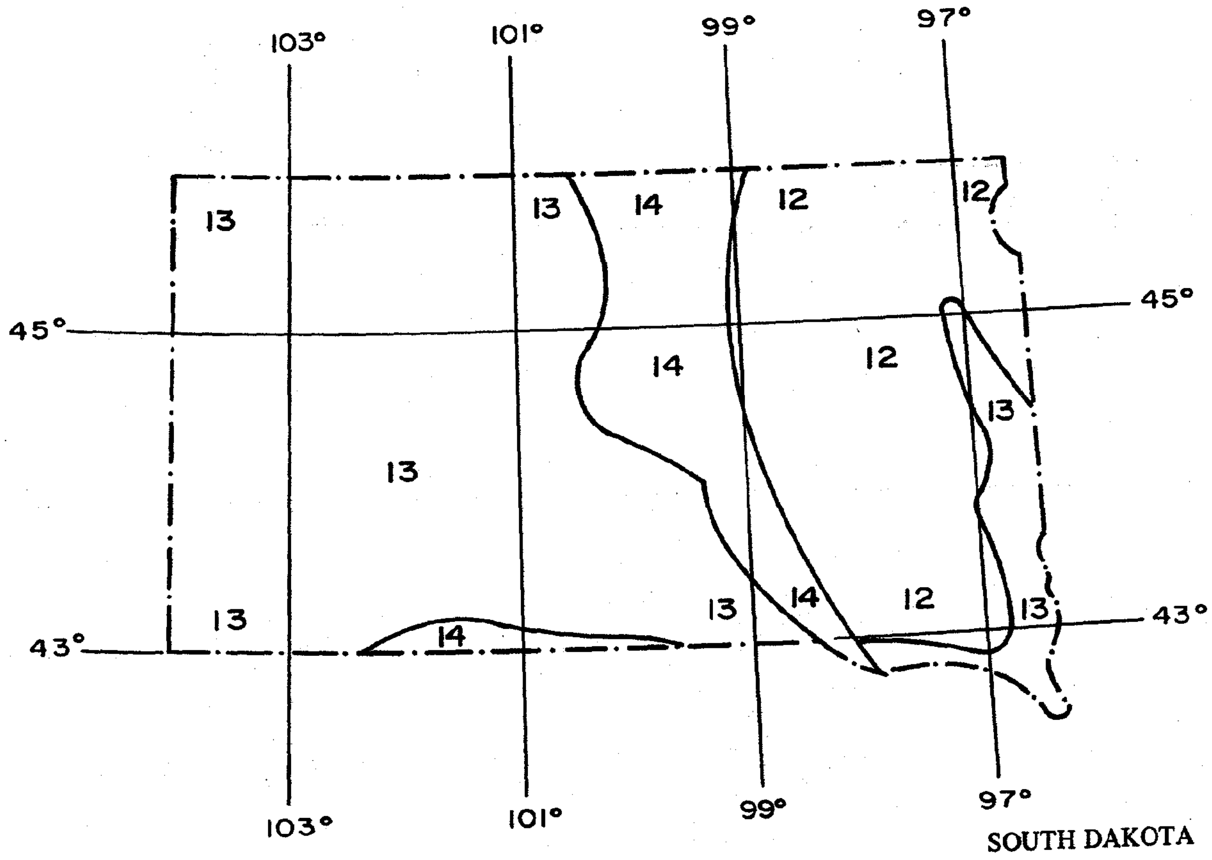
Appendix B-42. Hydrophysiographic zones of Pennsylvania.



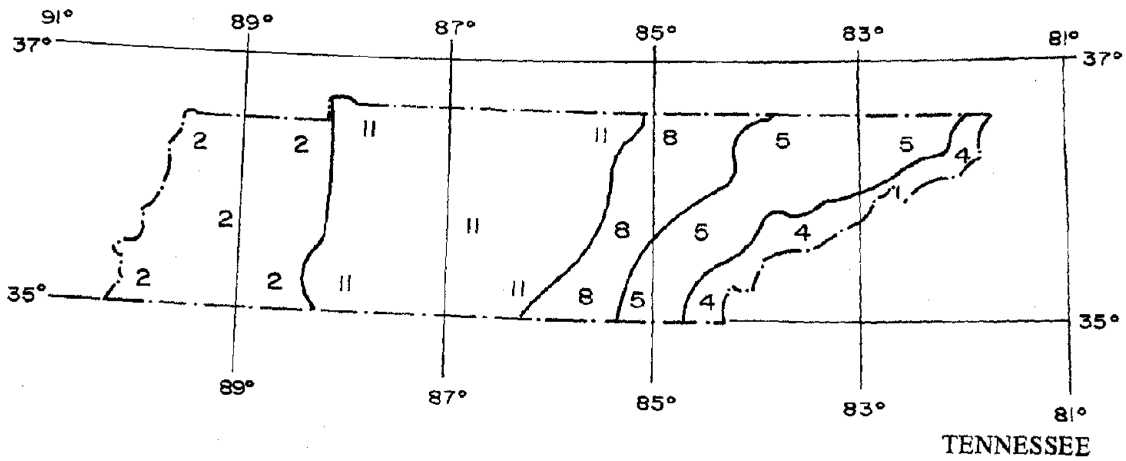
Appendix B-43. Hydrophysiographic Zones of Puerto Rico.



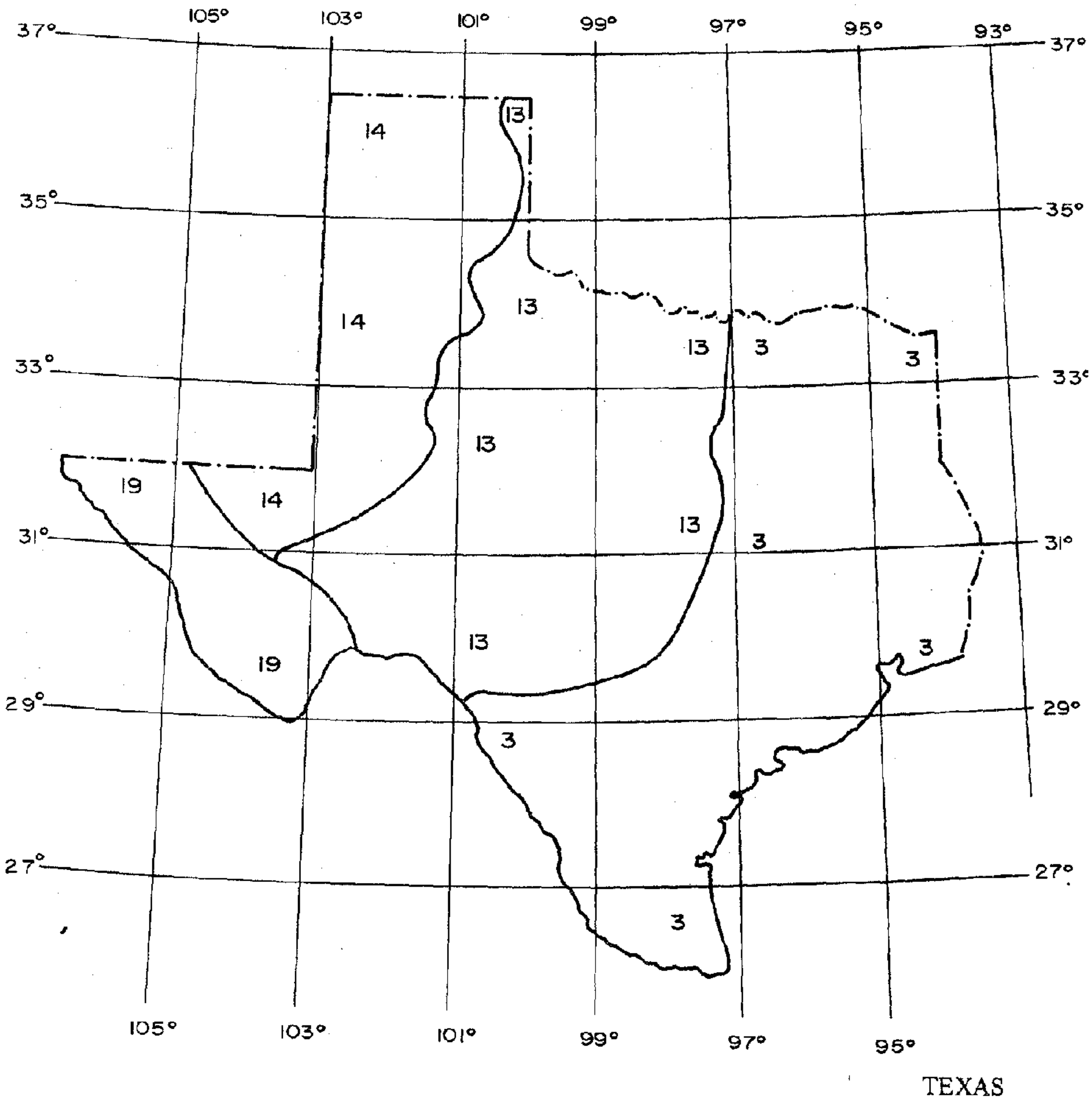
Appendix B-45. Hydrophysiographic zones of South Carolina.



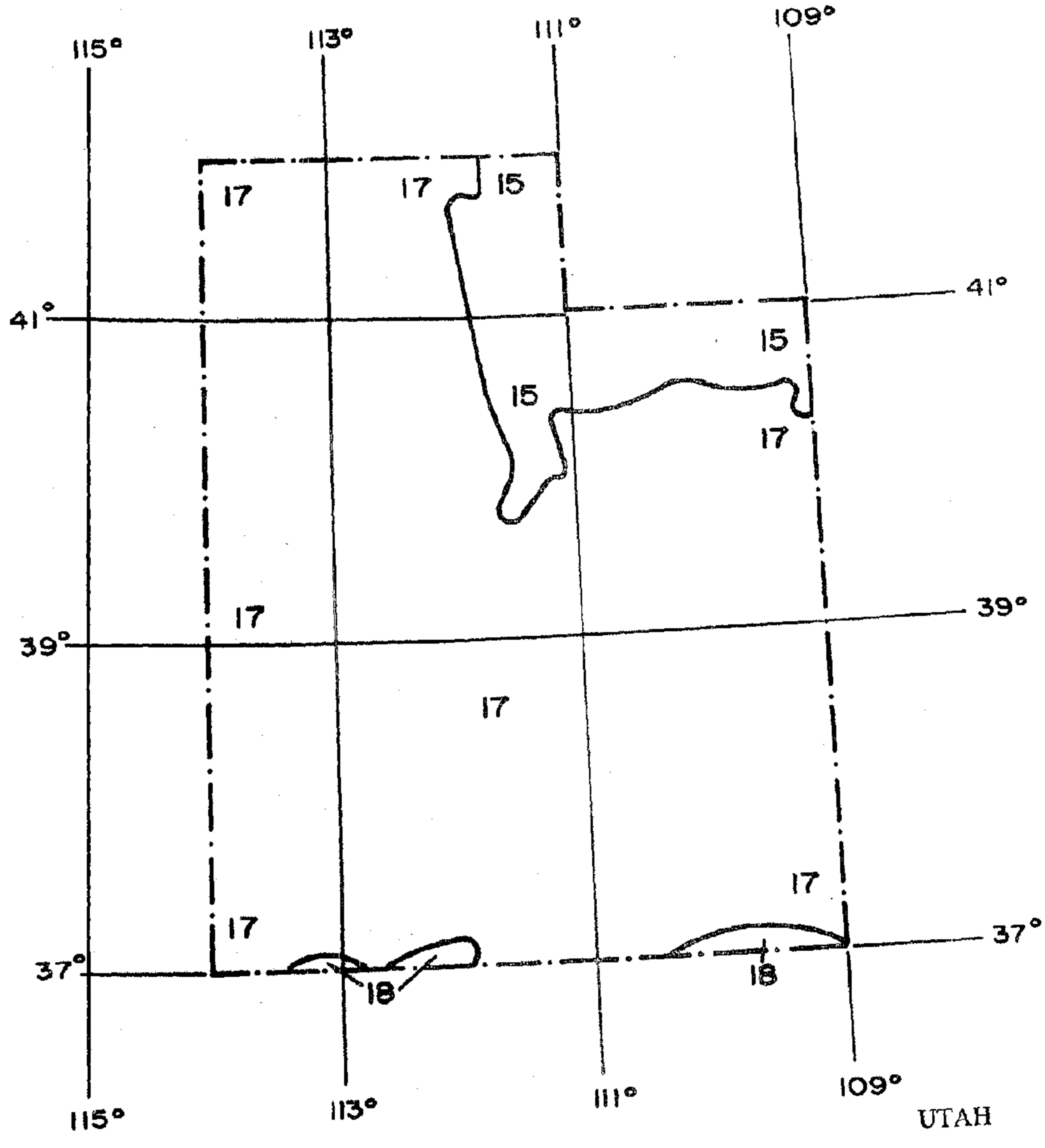
Appendix B-46. Hydrophysiographic zones of South Dakota.



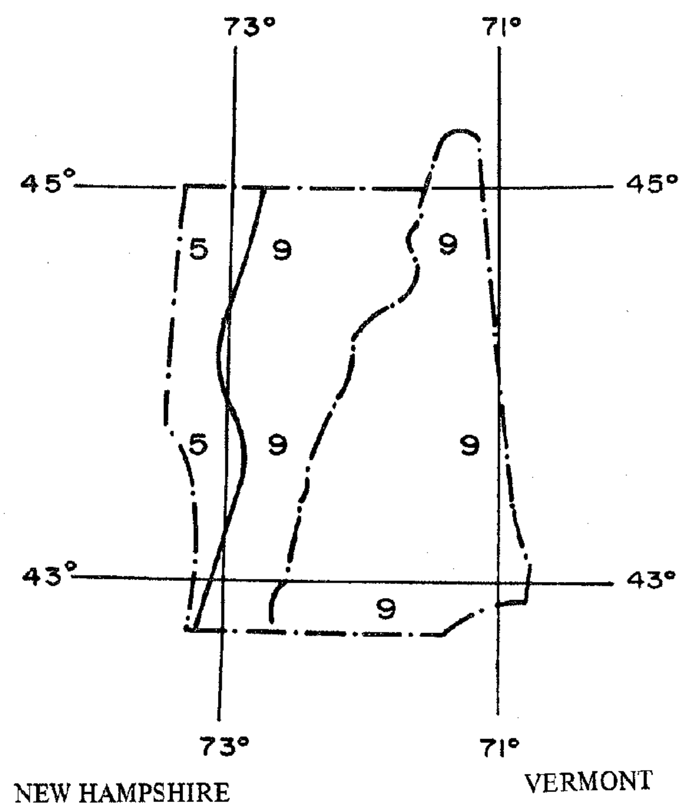
Appendix B-47. Hydrophysiographic zones of Tennessee.



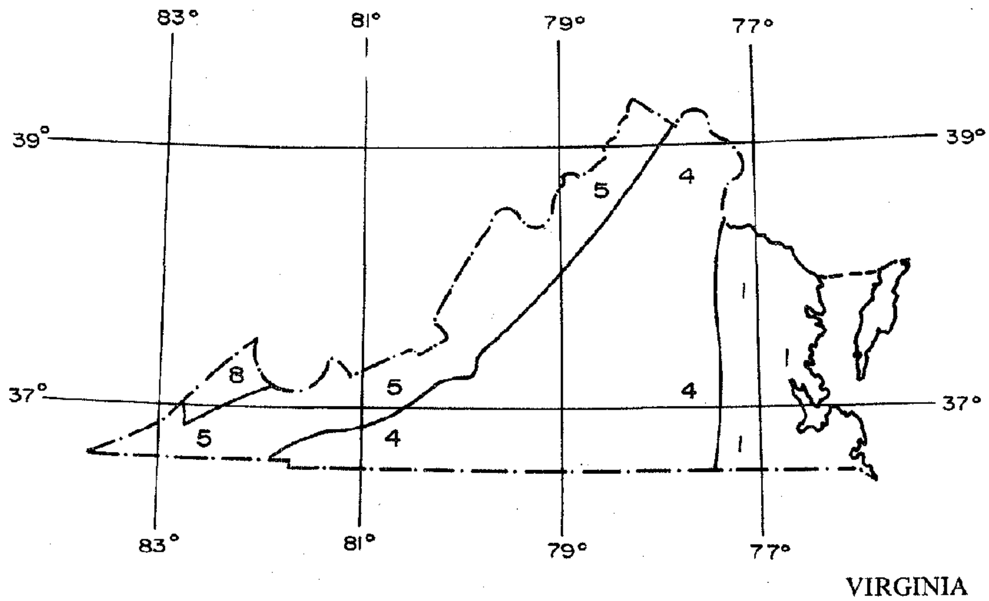
Appendix B-48. Hydrophysiographic zones of Texas.



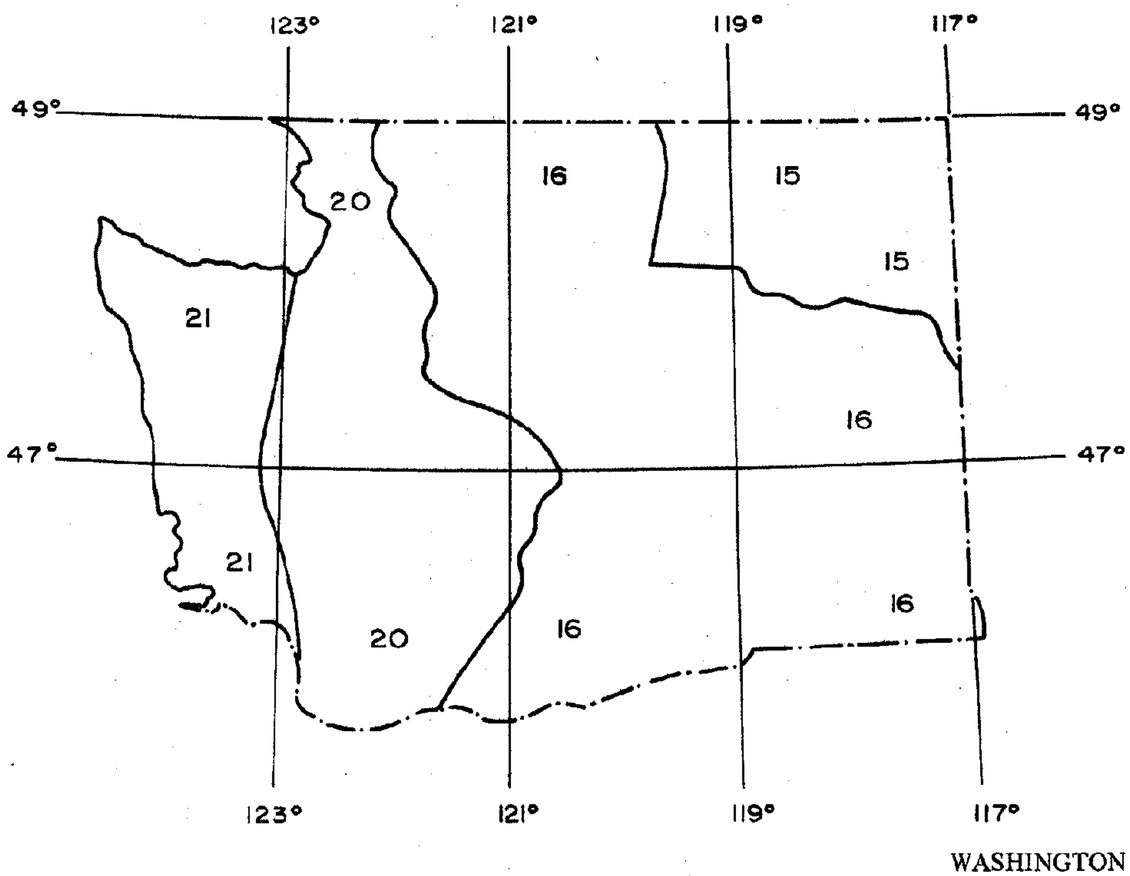
Appendix B-49. Hydrophysiographic zones of Utah.



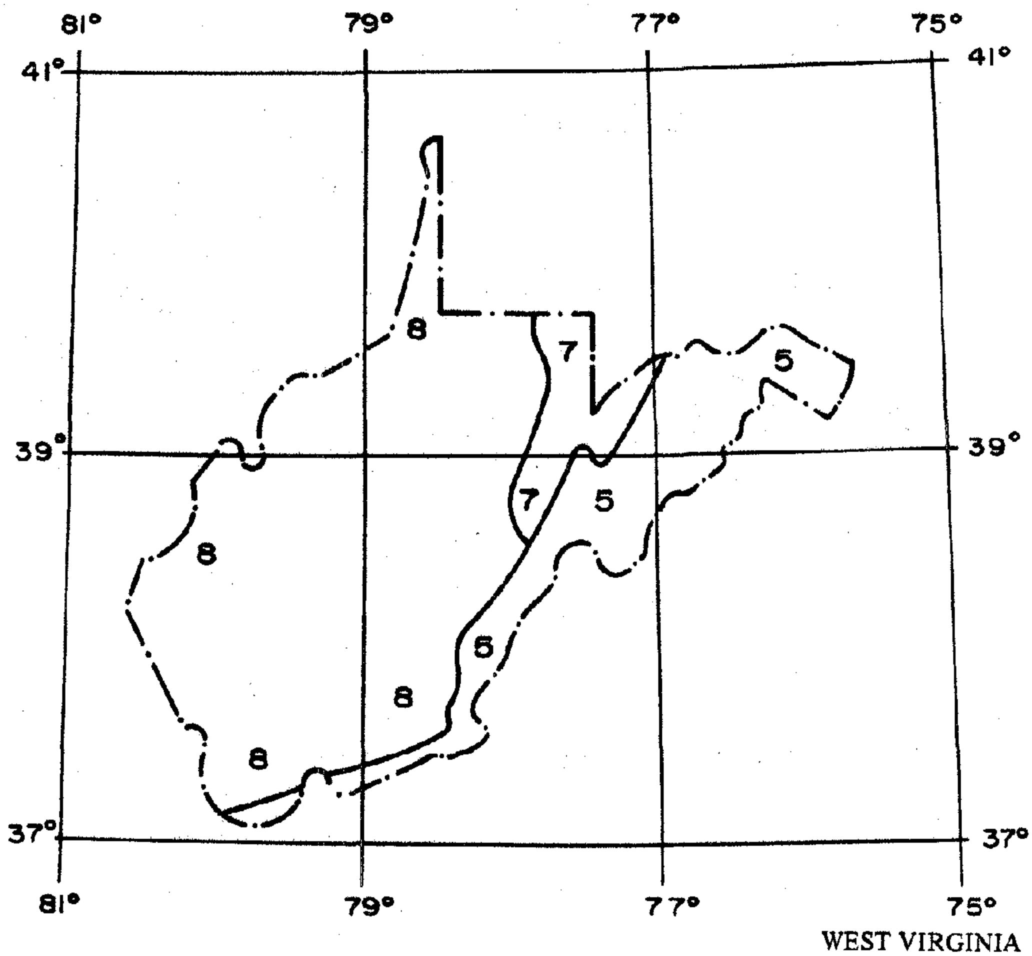
Appendix B-33. Hydrophysiographic zones of New Hampshire.
Appendix B-50. Hydrophysiographic zones of Vermont.



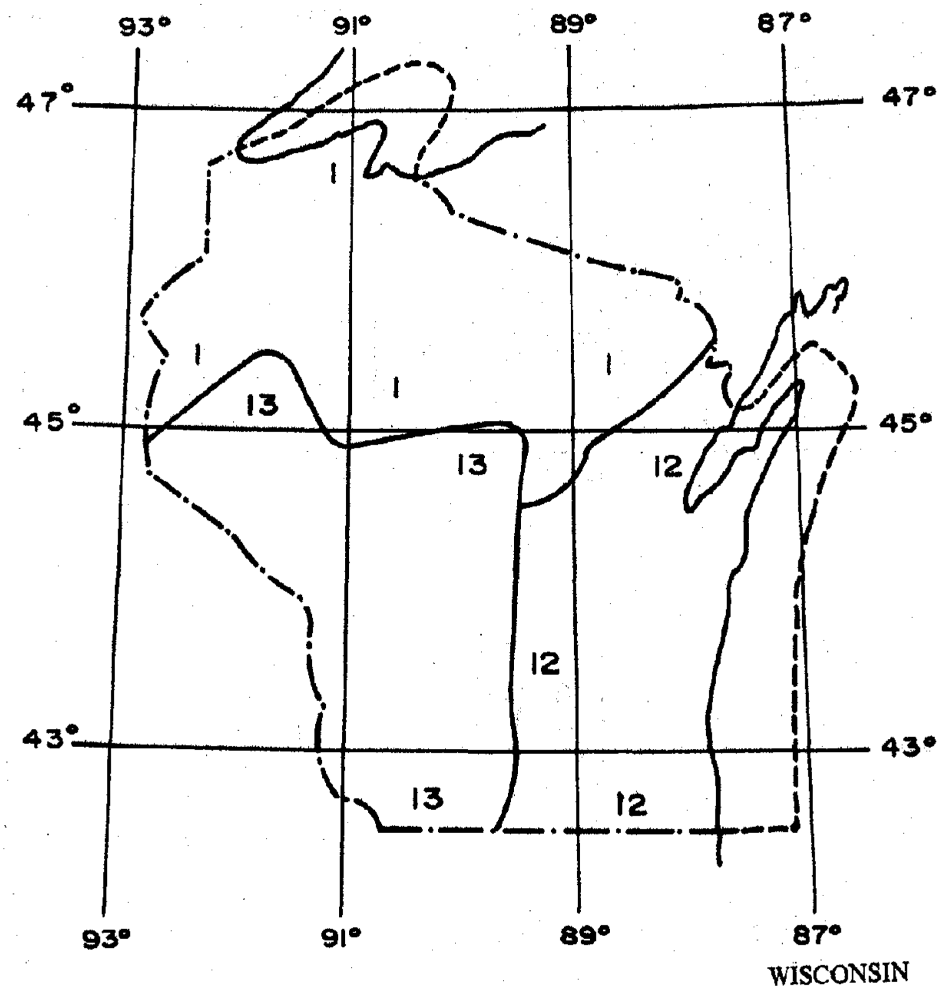
Appendix B-51. Hydrophysiographic zones of Virginia.



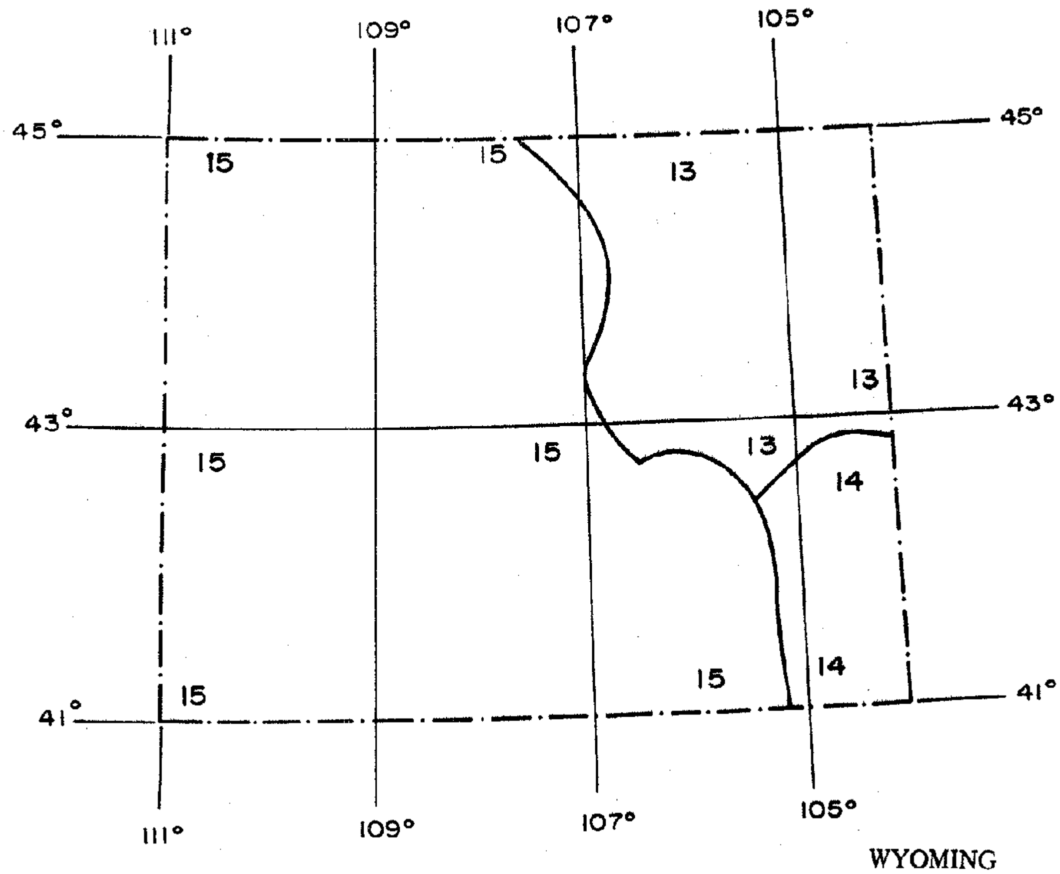
Appendix B-53. Hydrophysiographic zones of Washington.



Appendix B-54. Hydrophysiographic zones of West Virginia.



Appendix B-55. Hydrophysiographic zones of Wisconsin.



Appendix B-56. Hydrophysiographic zones of Wyoming.

APPENDIX C

Isoerodent Maps of Each of the Contiguous United States Alaska, Hawaii, and Puerto Rico. The R Values are the Mean Annual Rainfall Kinetic Energy Times the 30-Minute Rainfall Intensity Divided by 100 as Proposed by the Agricultural Research Service. State Numbers are Those Assigned by U.S. Geological Survey.

The mean annual isoerodent of R value maps for each state are shown in this appendix. The annual isoerodent value for each year is calculated by the equation

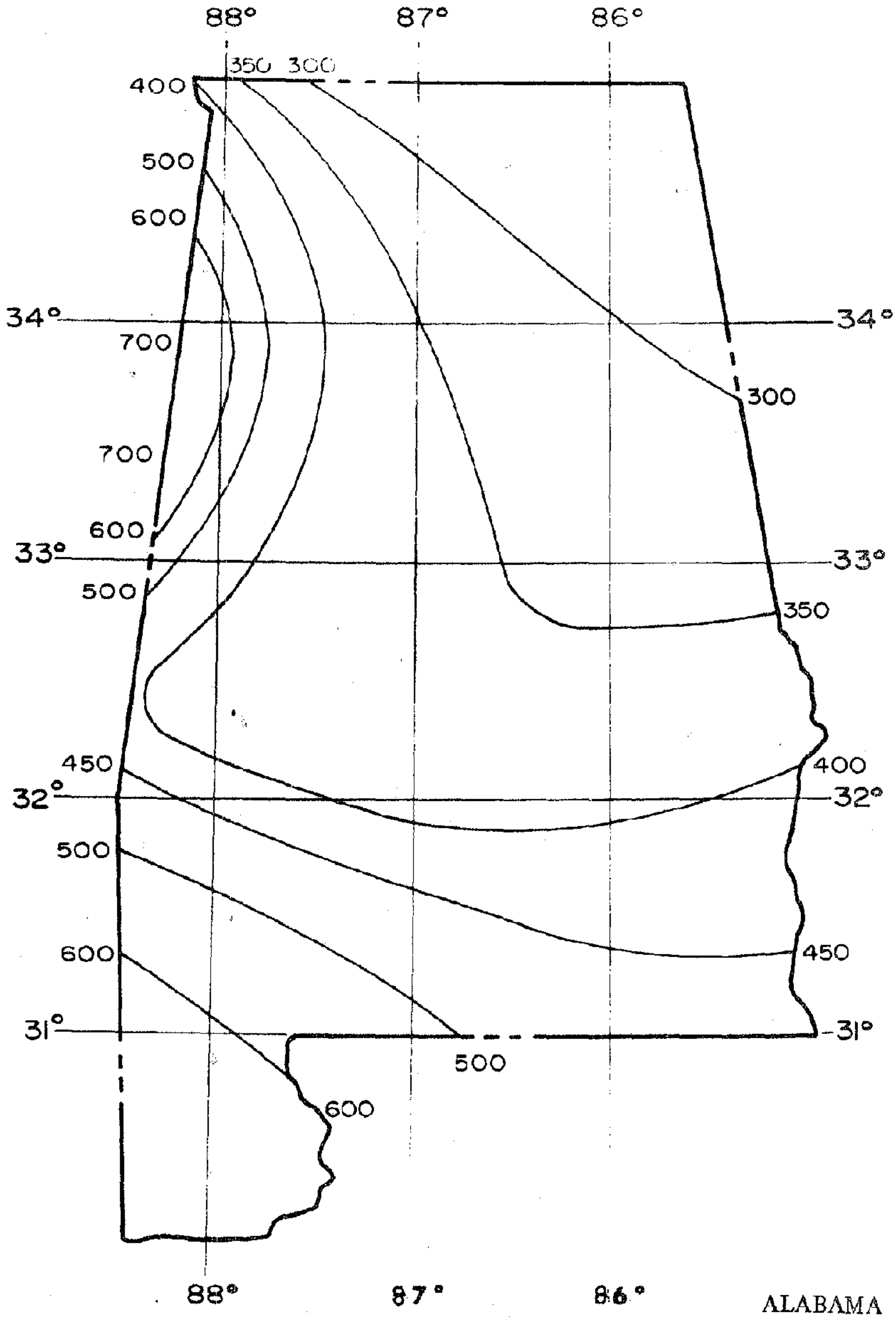
$$EI = \frac{\sum_{0}^{12\ \text{months}} (916 + 331 \log I)\ (I_{30}\ \text{max})}{100}$$

wherein I is the intensity of each constant intensity period of time times its volume in inches and I_{30} is the maximum 30 minute intensity for the period of record.

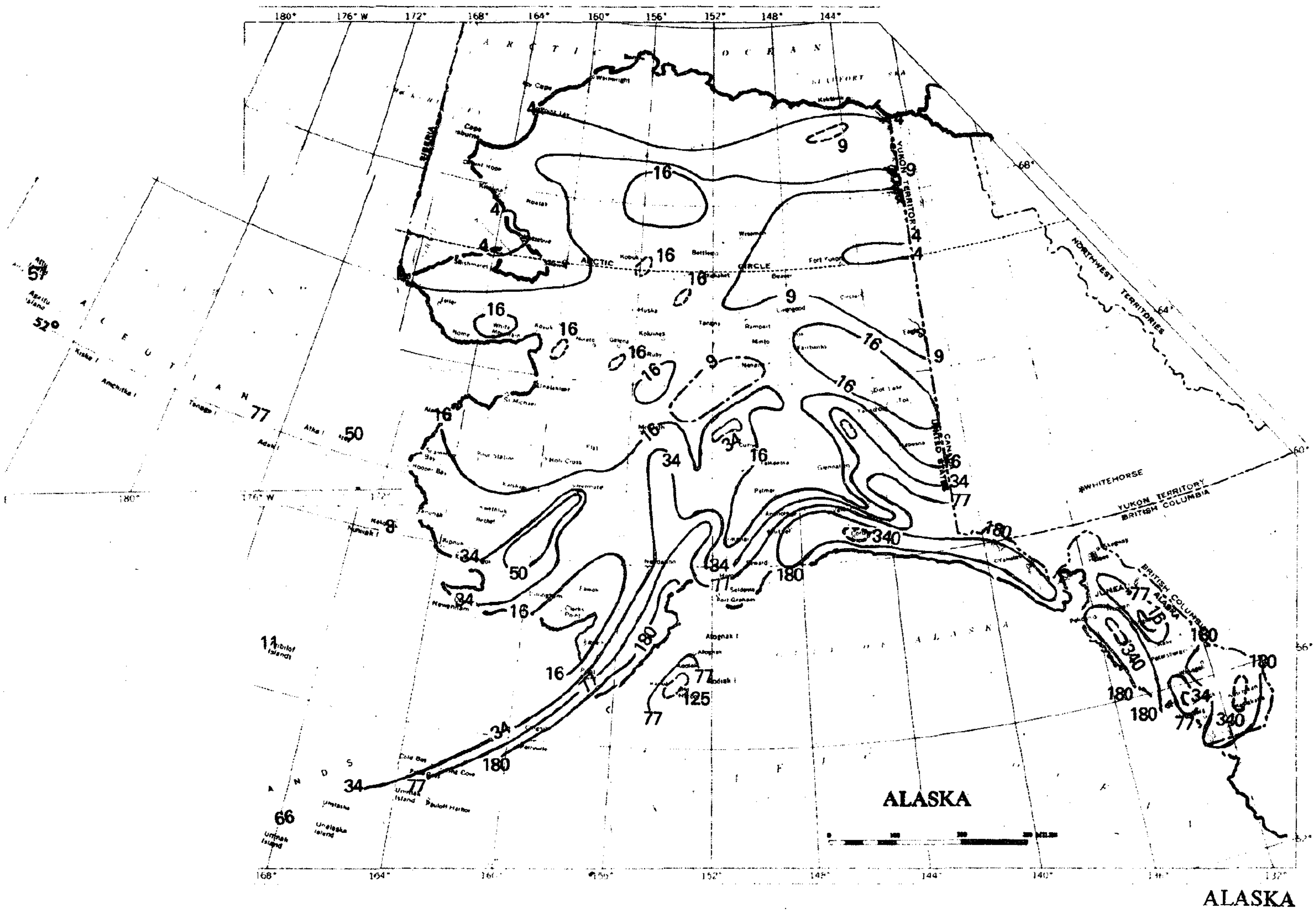
In those areas where the EI values are unknown, they were computed from regressions of the 2-year 6-hour rainfall volume and R. Note, however, that a different regression is needed for Type 1 and Type 2 storms.

NOTE:

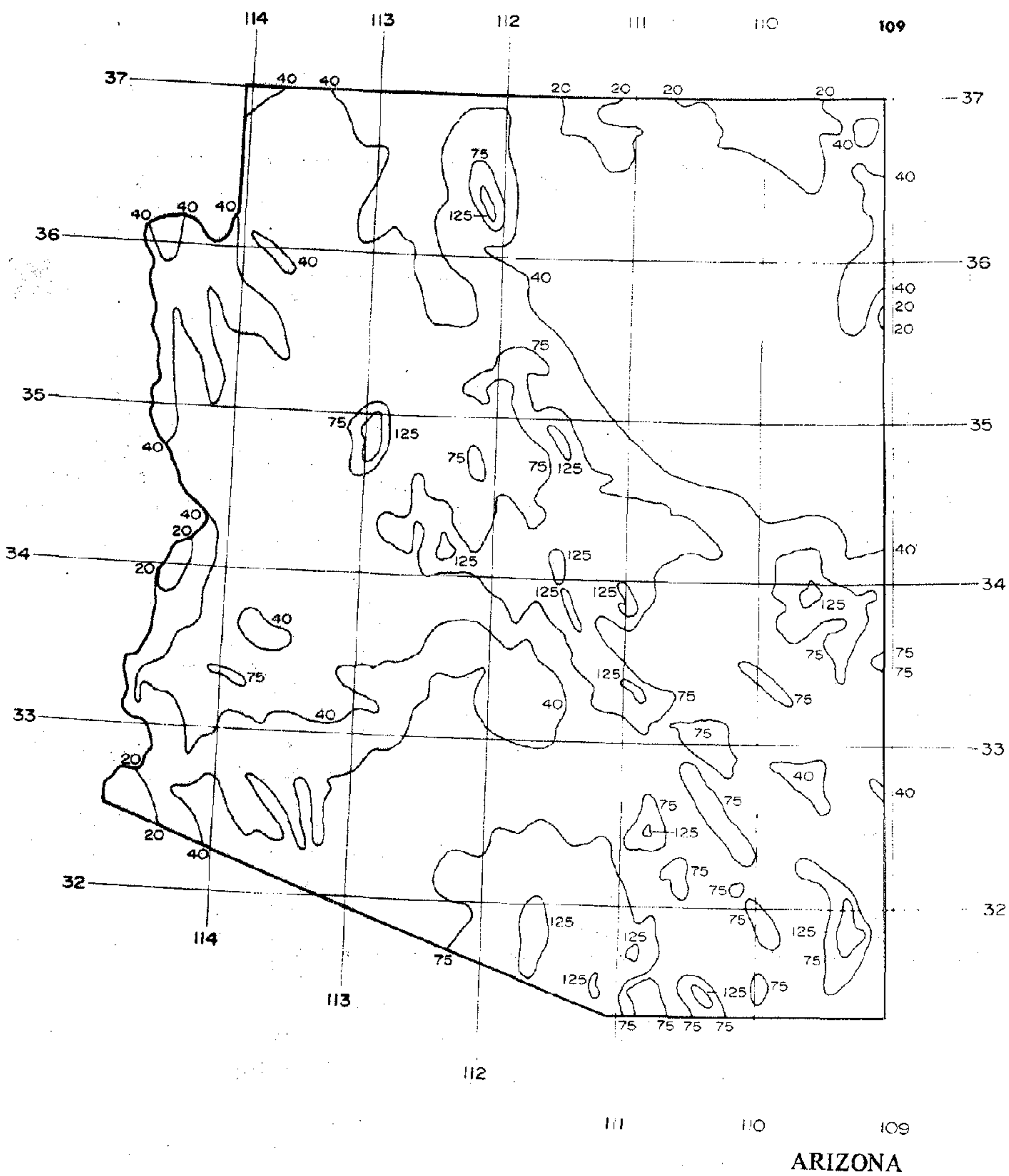
Scales of maps are different because some maps were not available in a proper scale or it would be impractical to show for example Texas in the same scale as Rhode Island.



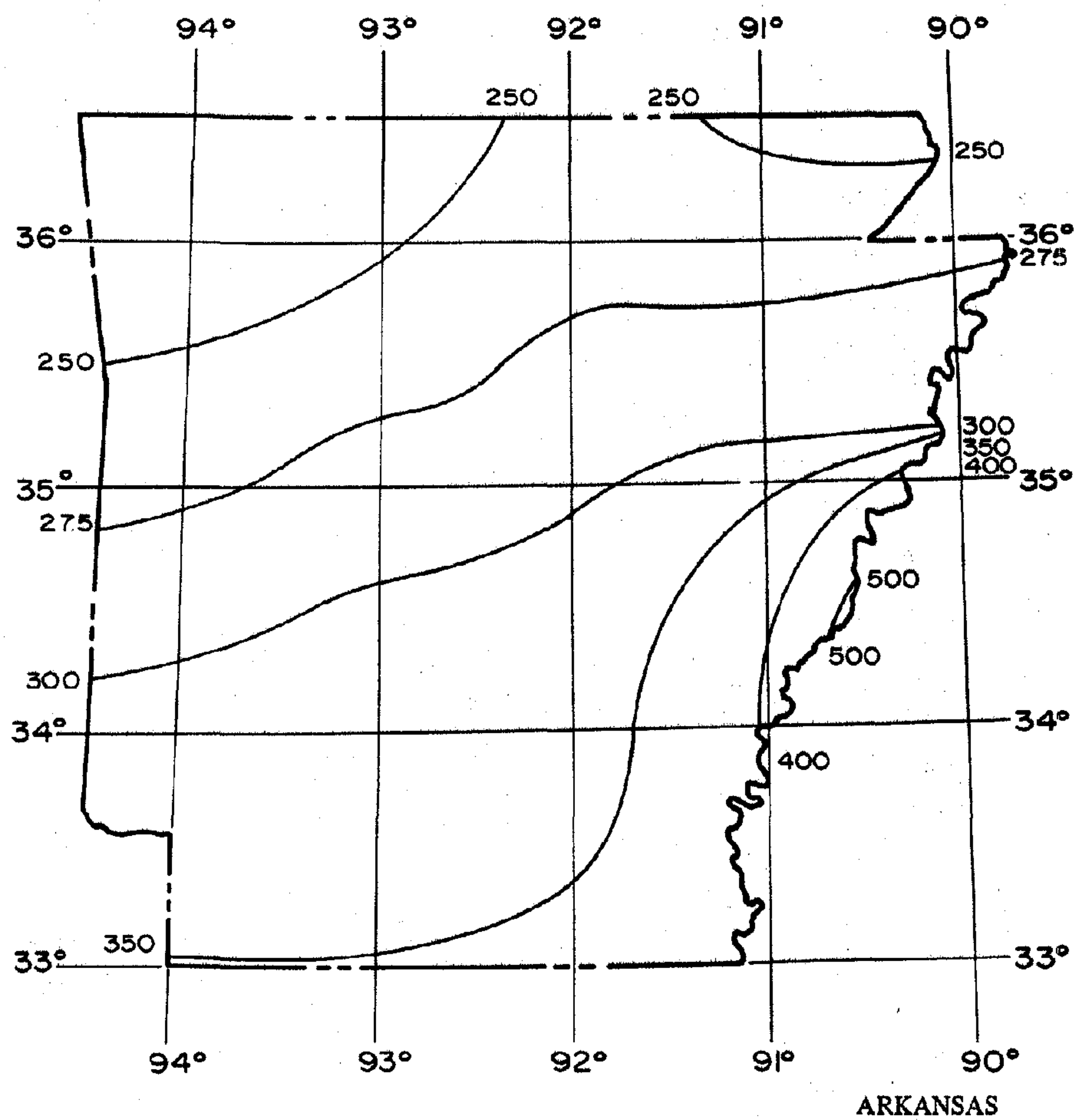
Appendix C-01. Isoerodent, R, map of Alabama.



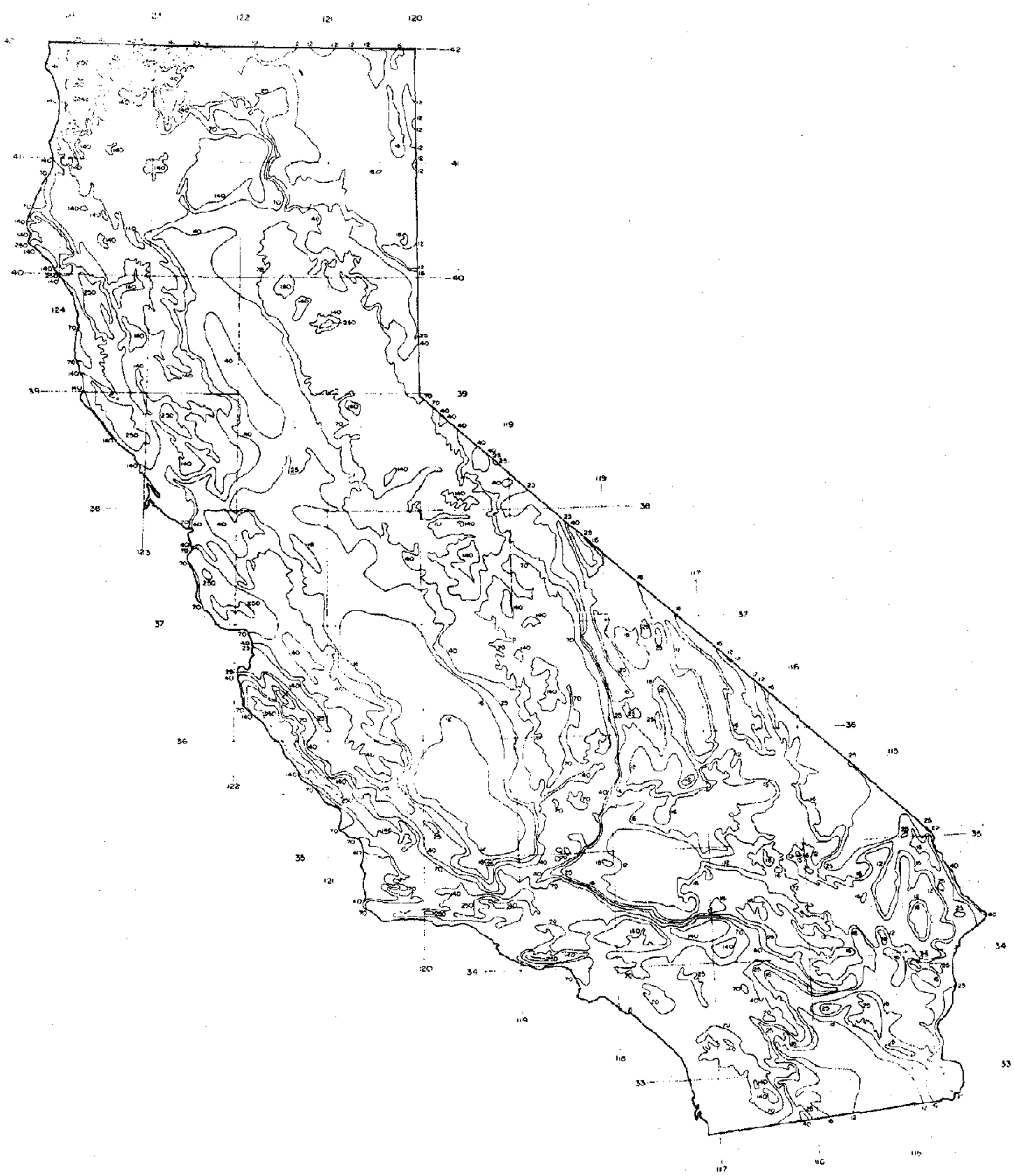
Appendix C-02. Isoerodent, R, map of Alaska.



Appendix C-04. Isoerodent, R, map of Arizona.

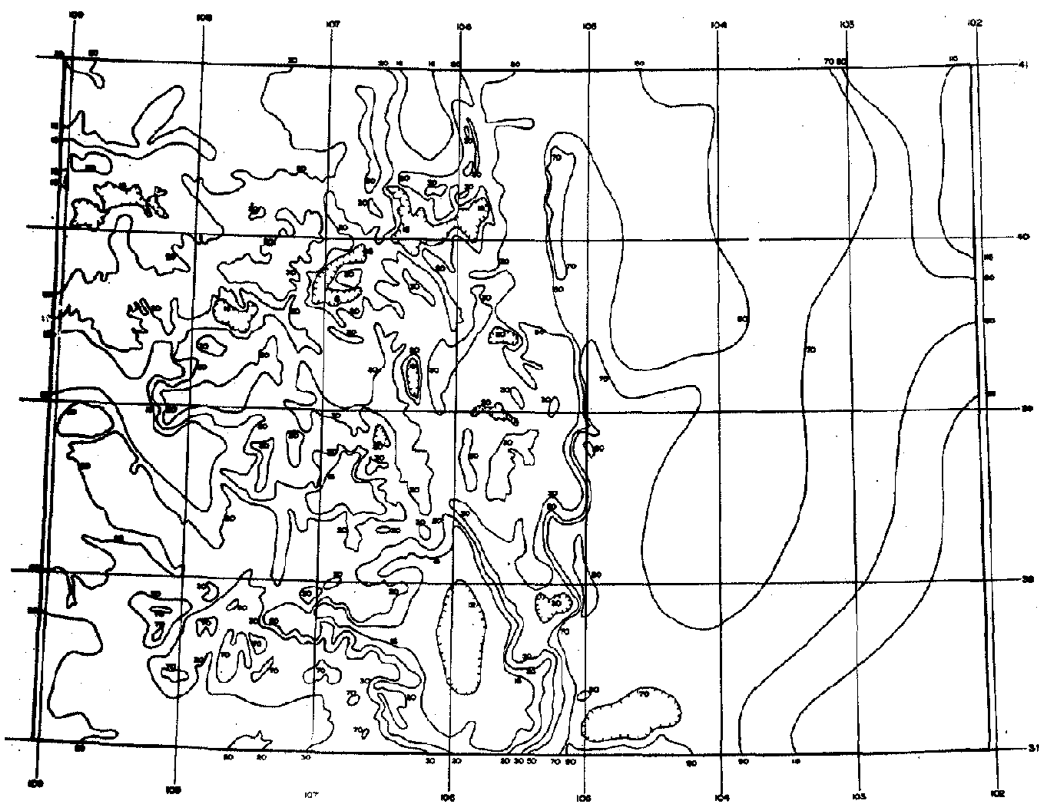


Appendix C-05. Isoerodent, R, map of Arkansas.

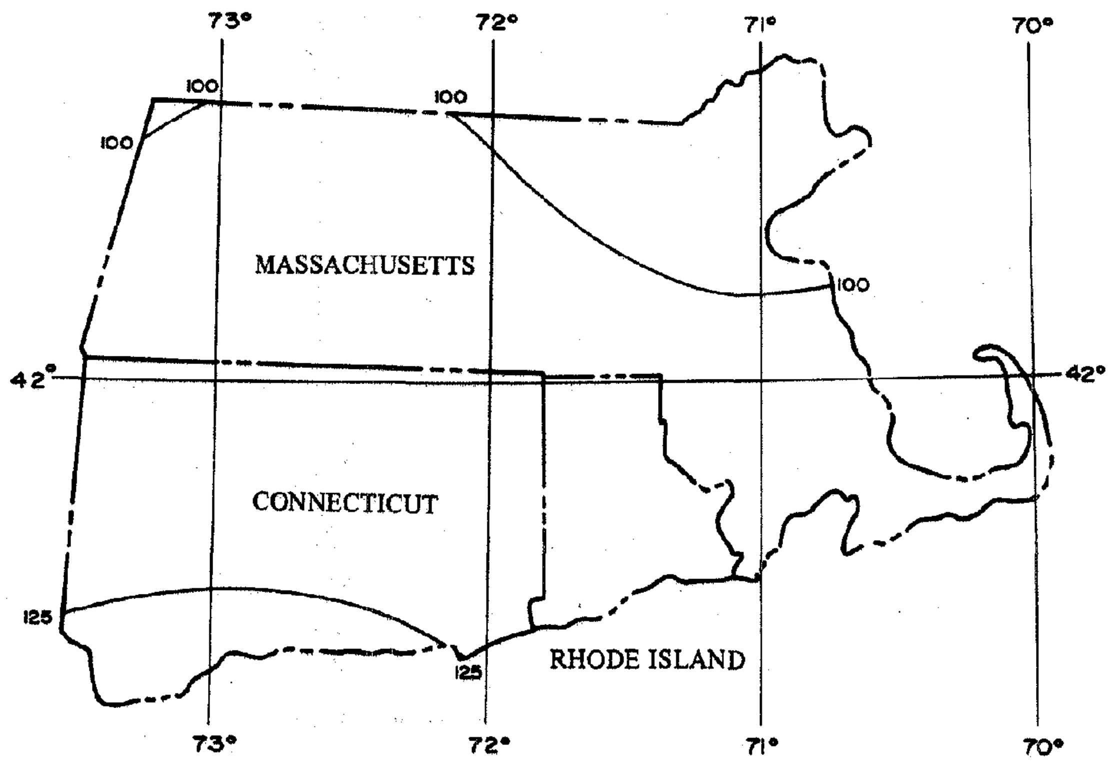


CALIFORNIA

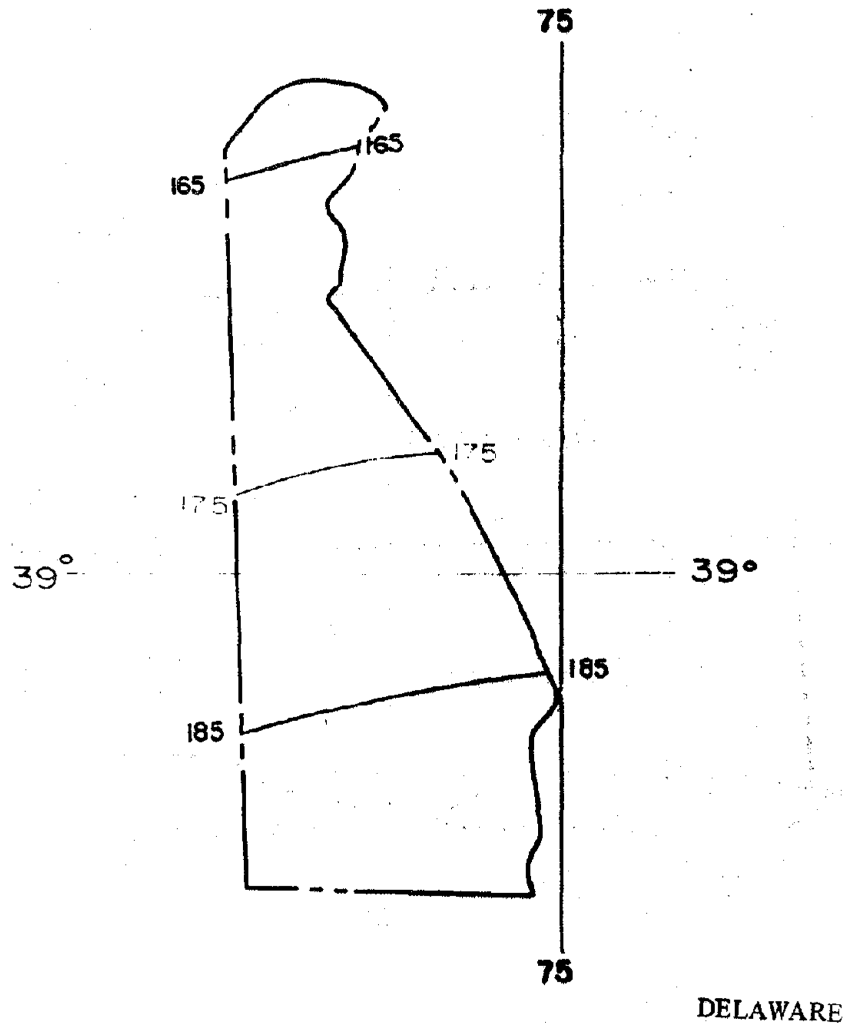
Appendix C-06. Isoerodent, R, map of California.



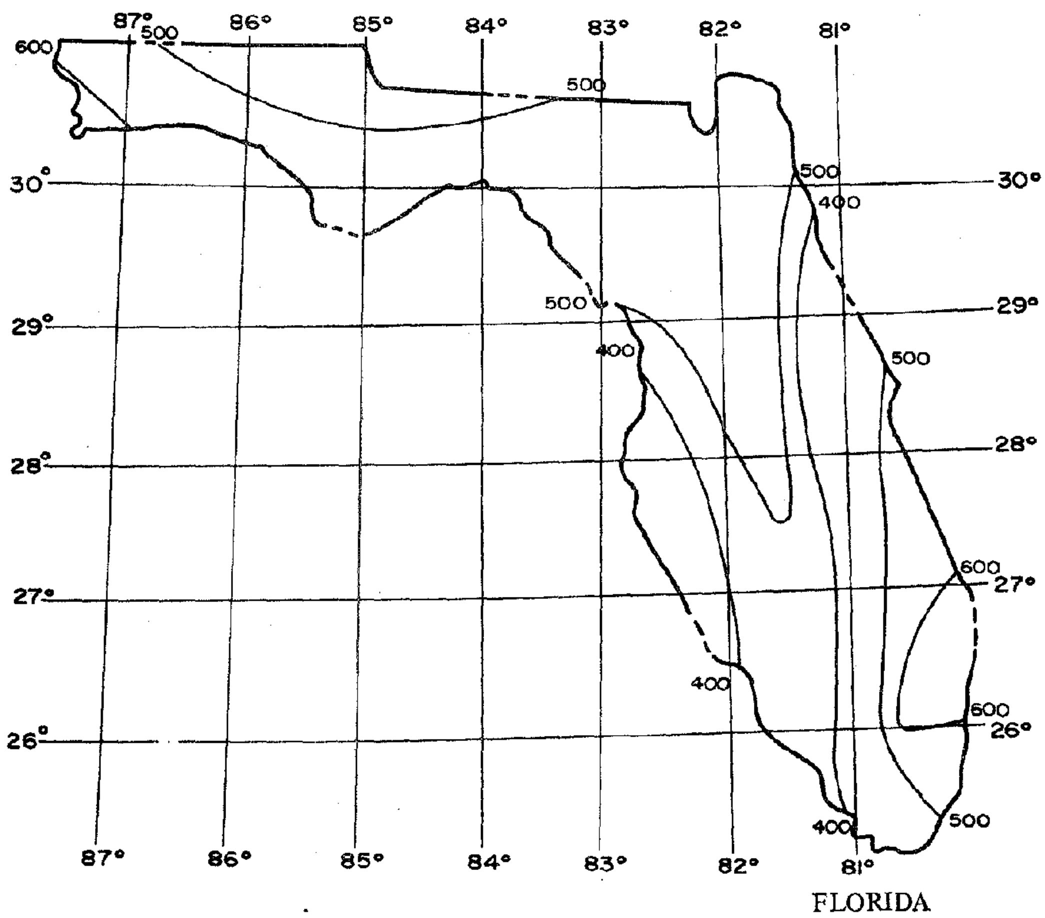
Appendix C-08. Isoerodent, R, map of Colorado.



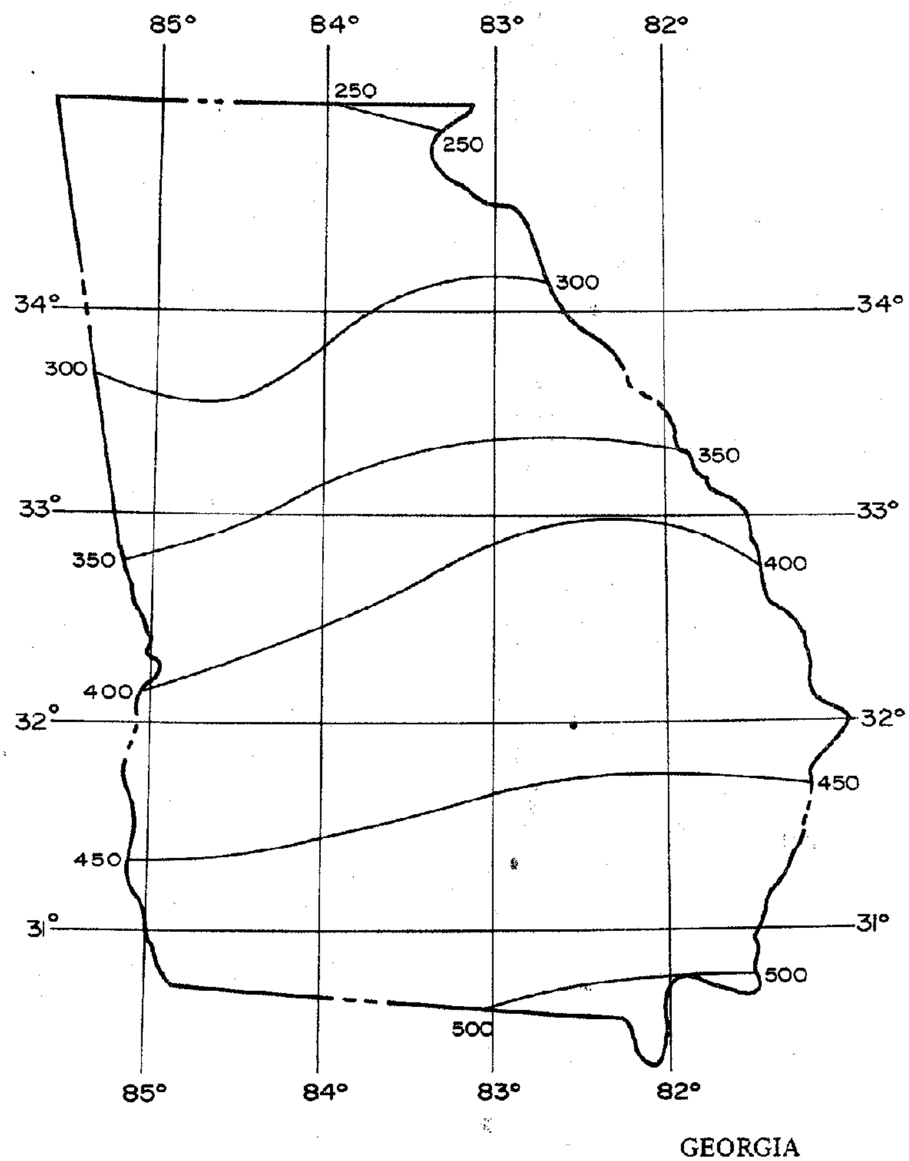
Appendix C-44. Isoerodent, R, map of Rhode Island.
Appendix C-25. Isoerodent, R, map of Massachusetts.
Appendix C-09. Isoerodent, R, map of Connecticut.



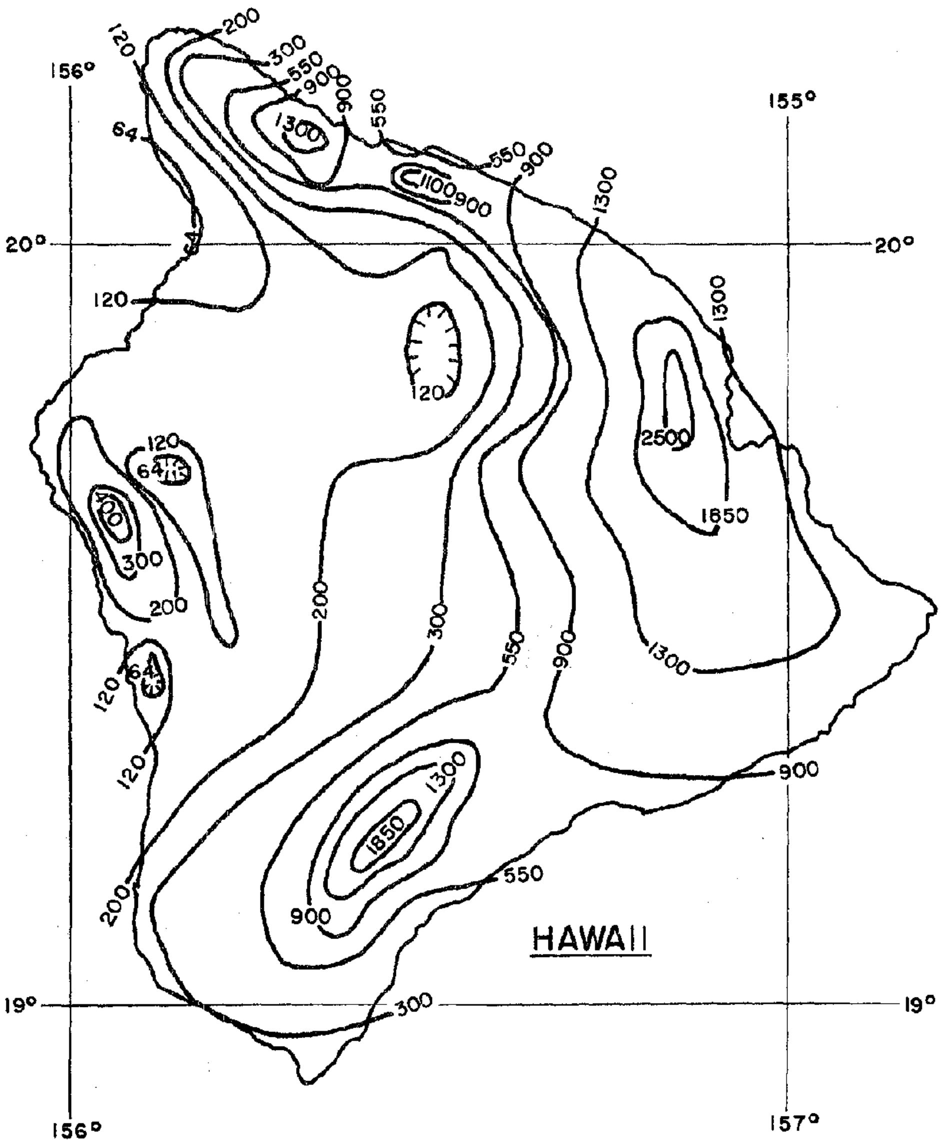
Appendix C-10. Isoerodent, R, map of Delaware.



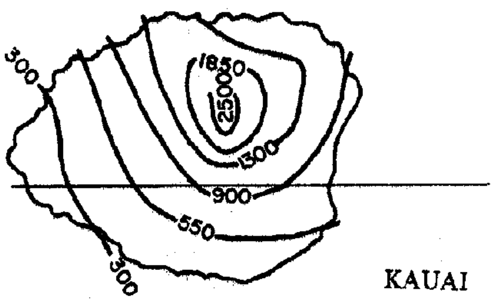
Appendix C-12. Isoerodent, R, map of Florida.

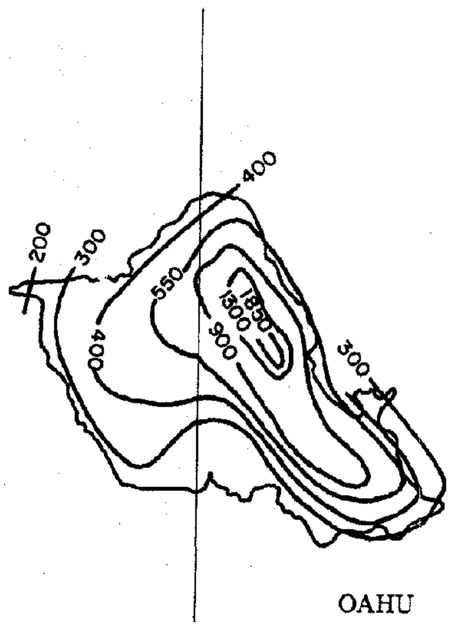


Appendix C-13. Isoerodent, R, map of Georgia.

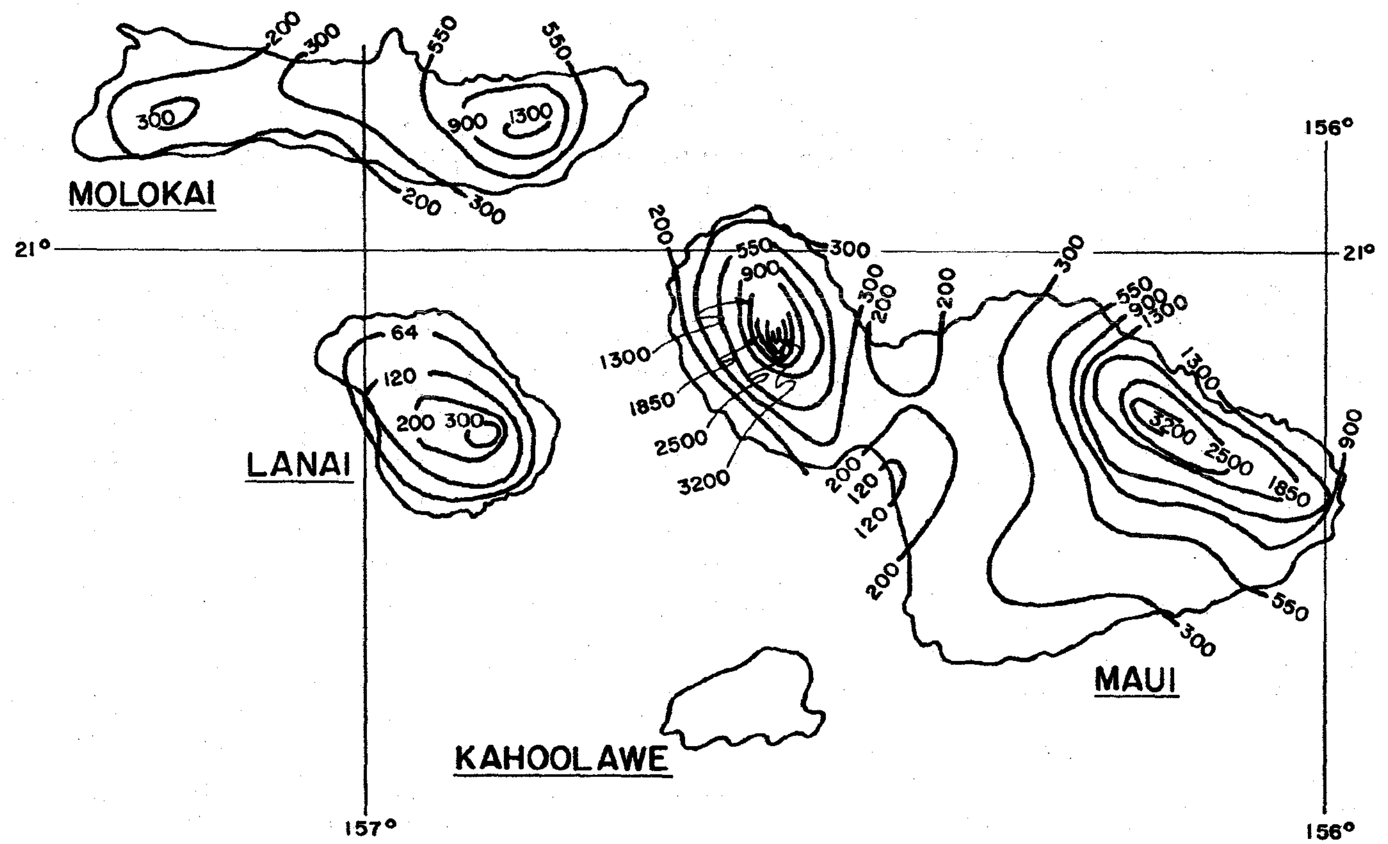


Appendix C-15a. Isoerodent, R, map of Hawaii , Hawaii.

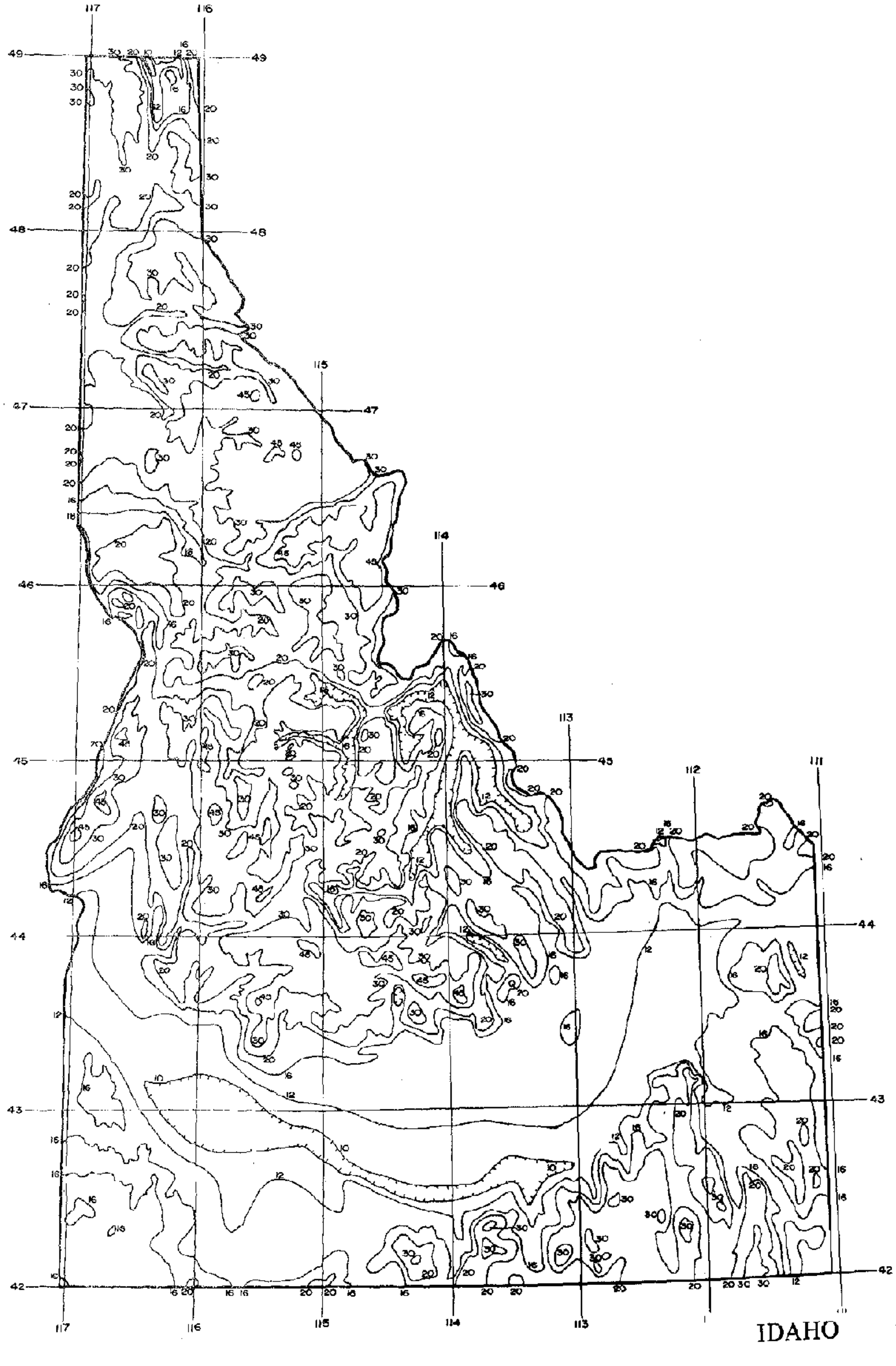




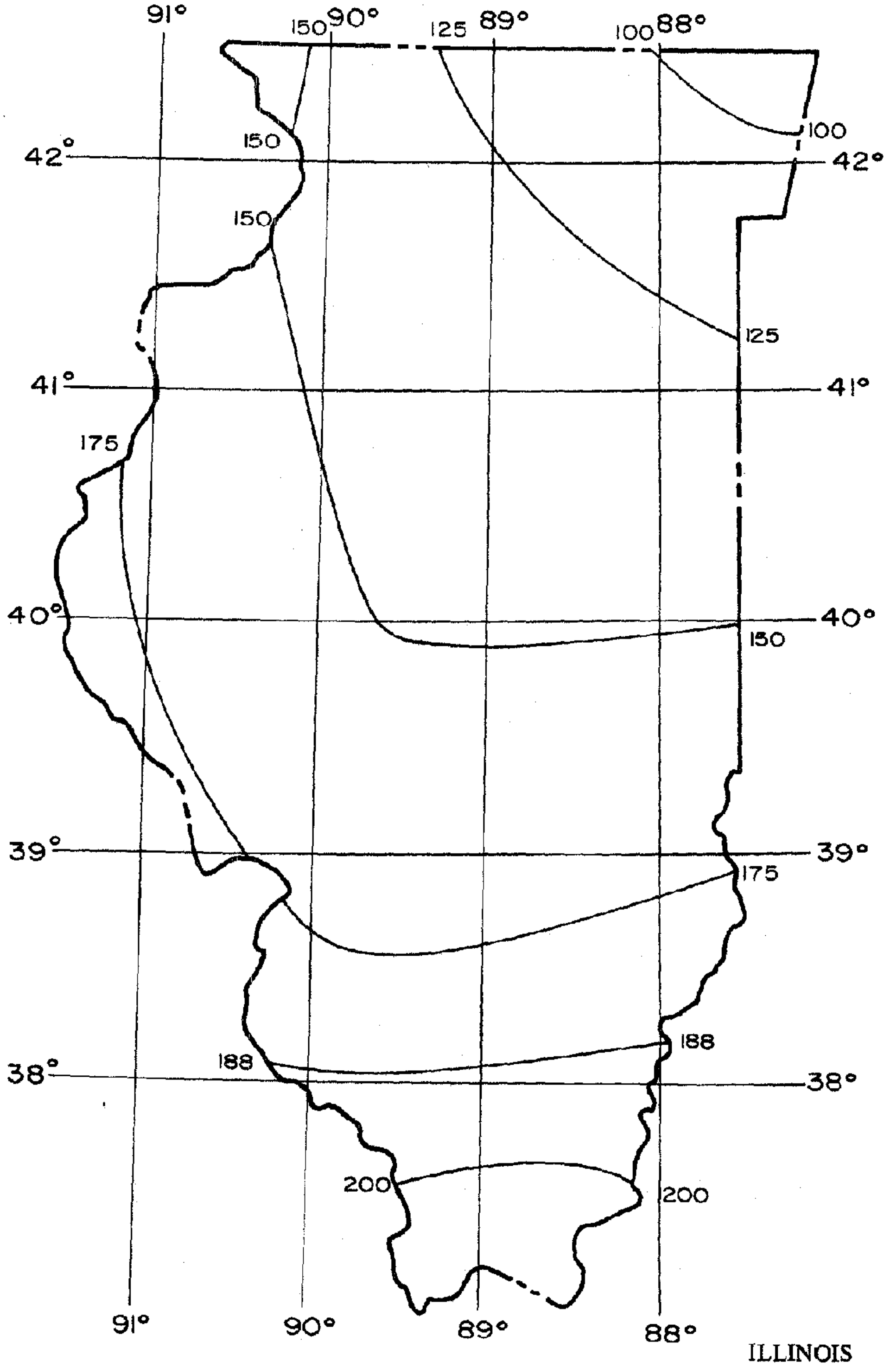
Appendix C-15b. Isoerodent, R, map of Kauai and Oahu, Hawaii.



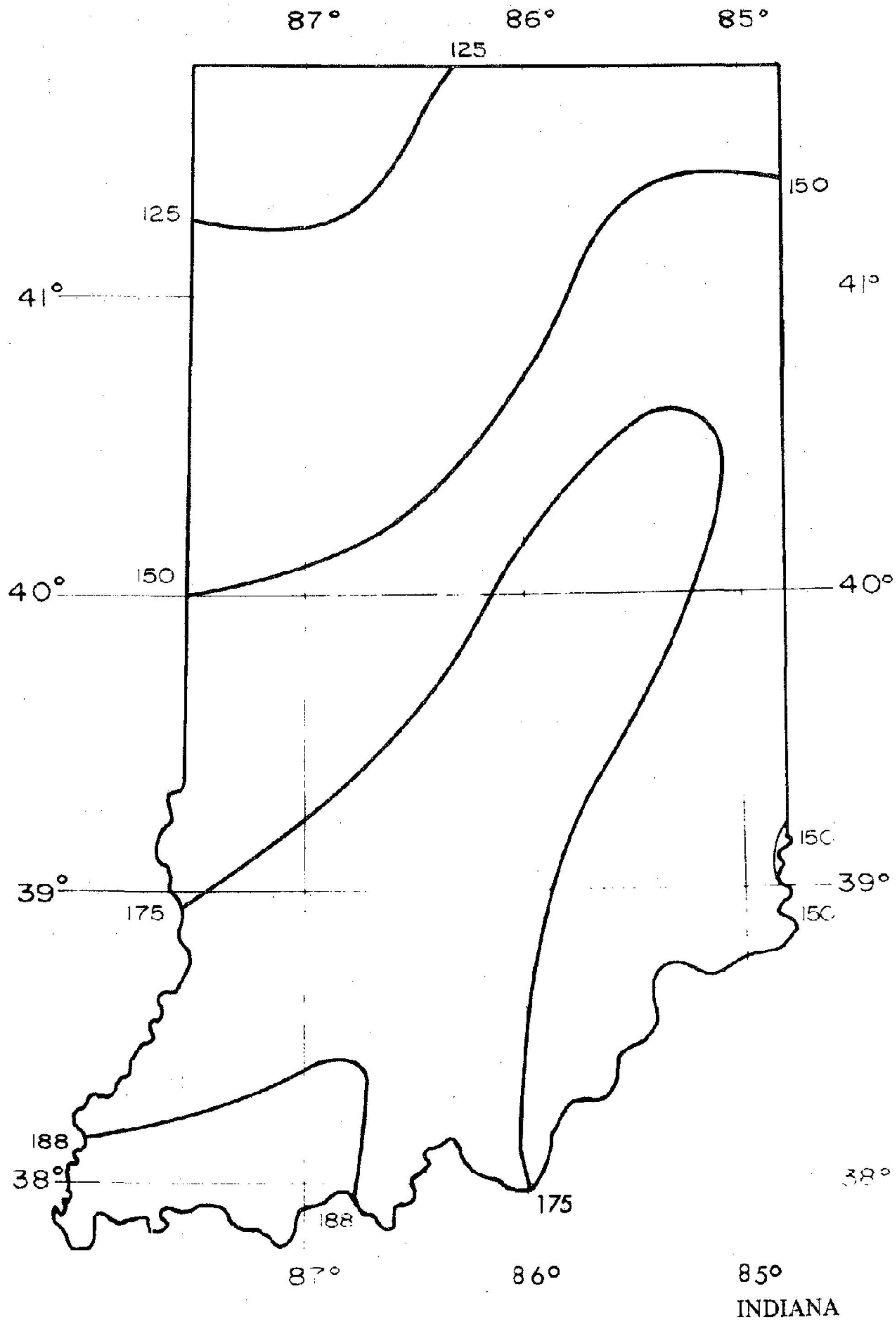
Appendix C-15c. Isoerodent, R, map of Molokai, Lanai, and Maui, Hawaii.



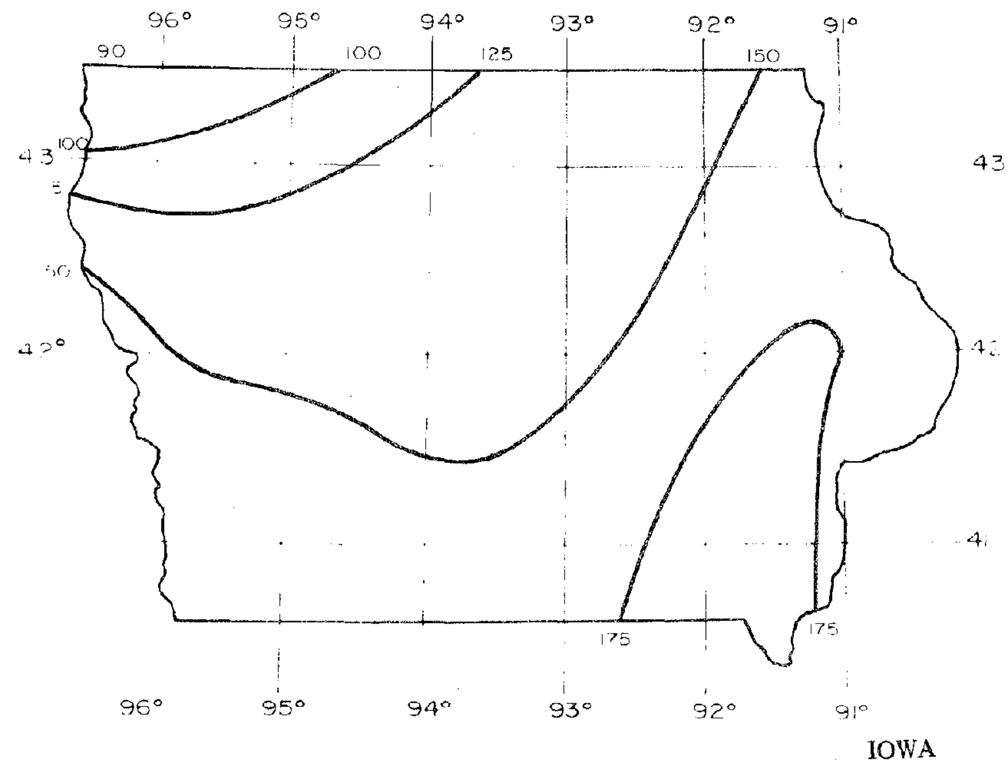
Appendix C-16. Isoerodent, R, map of Idaho.



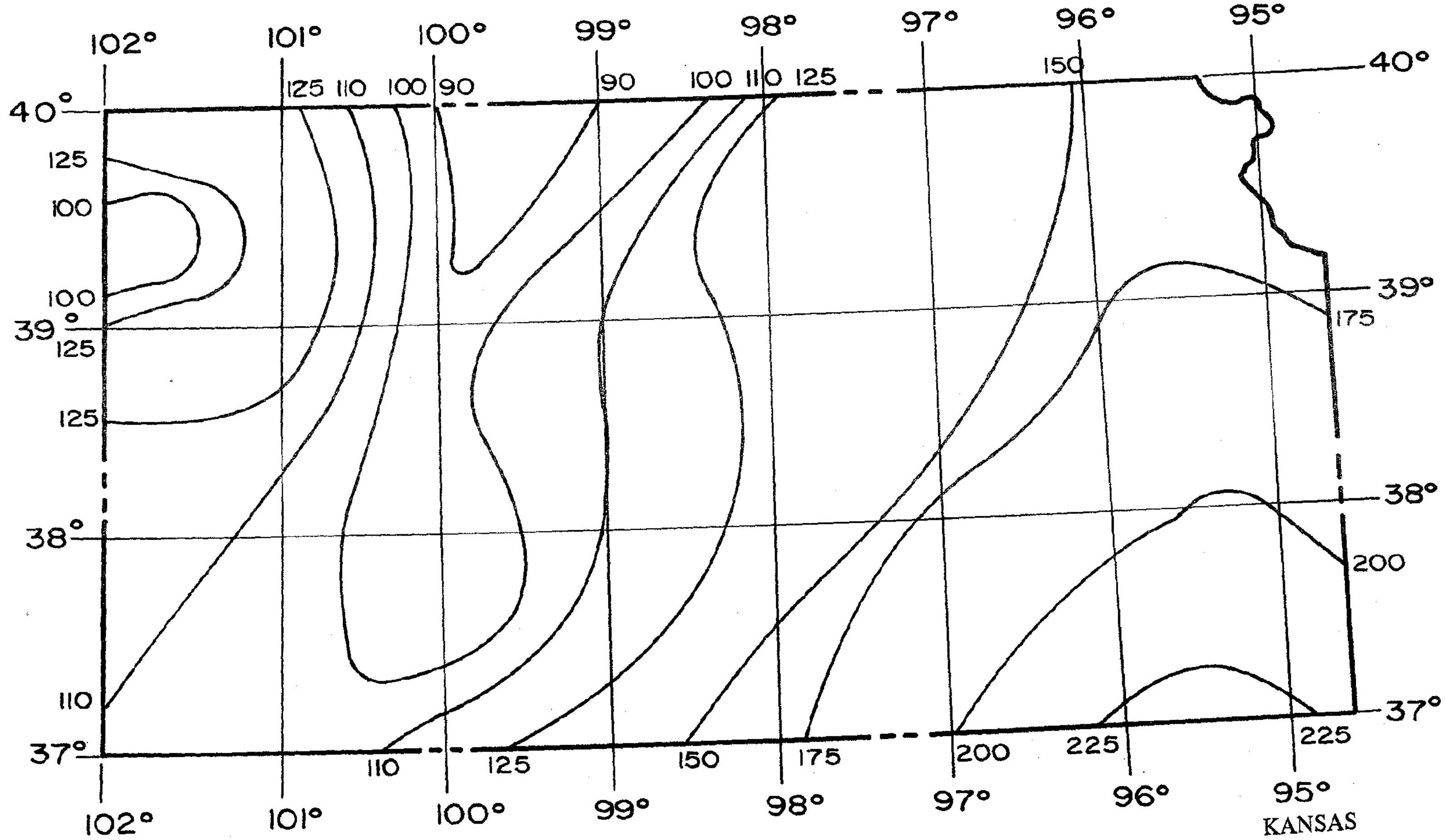
Appendix C-17. Isoerodent, R, map of Illinois.



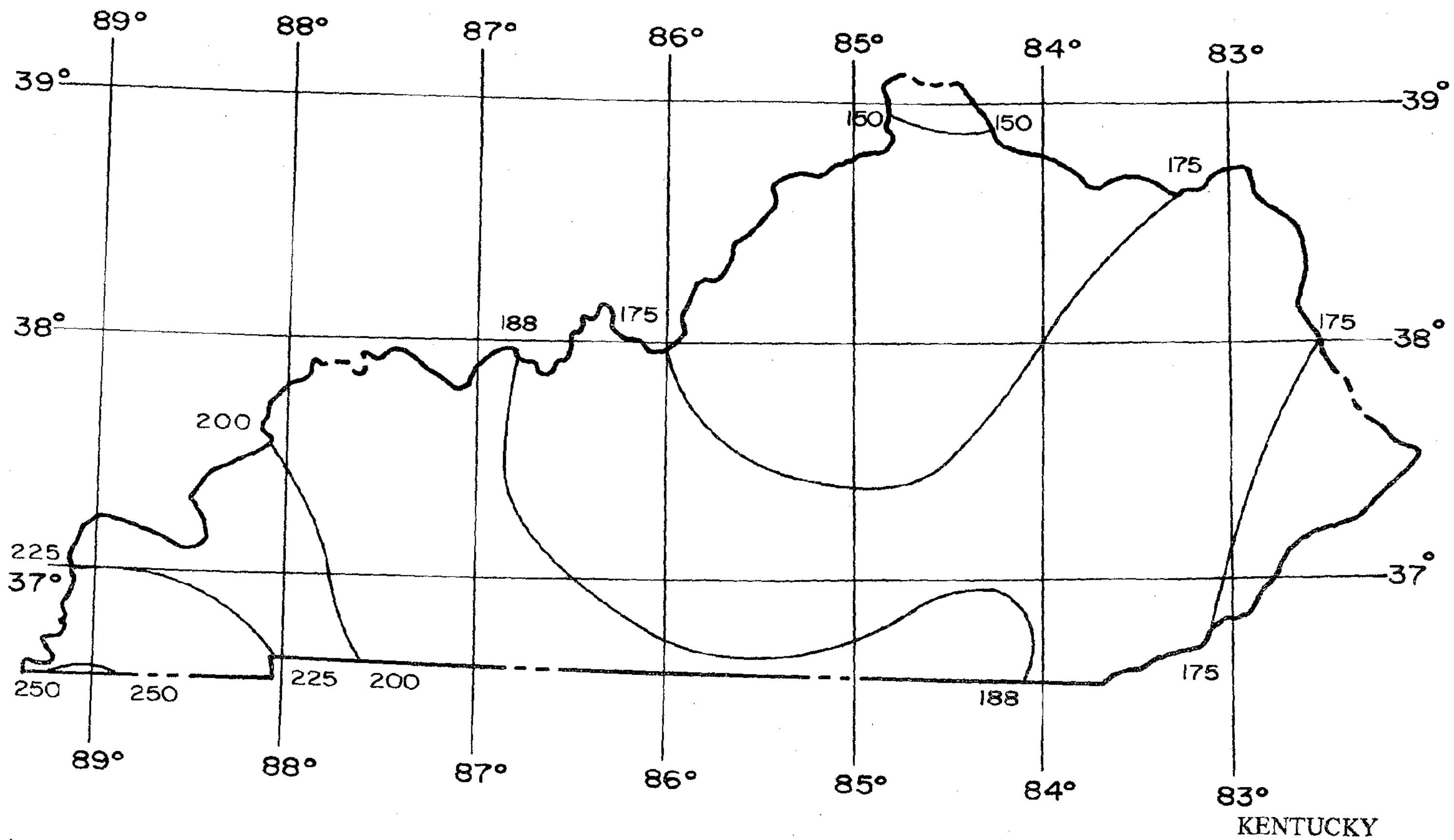
Appendix C-18. Isoerodent, R, map of Indiana.



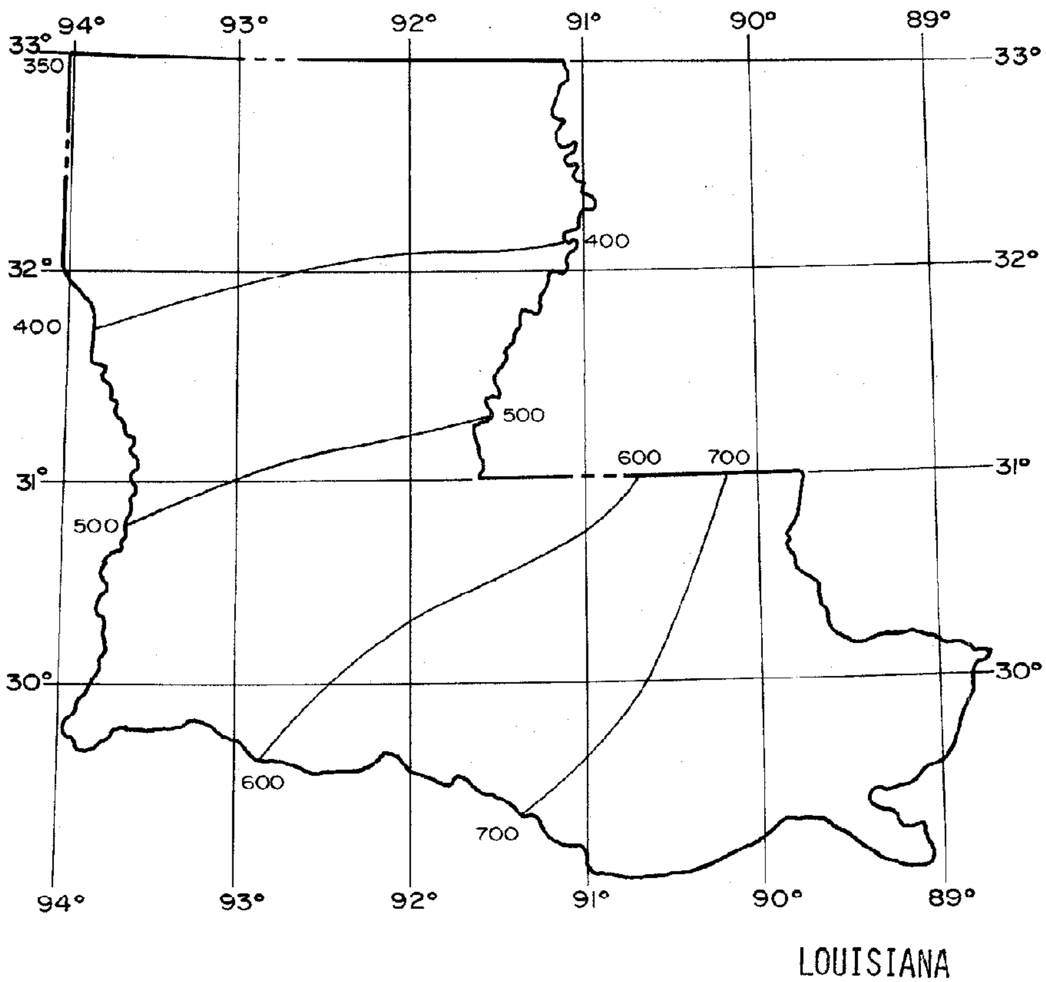
Appendix C-19. Isoerodent, R, map of Iowa.



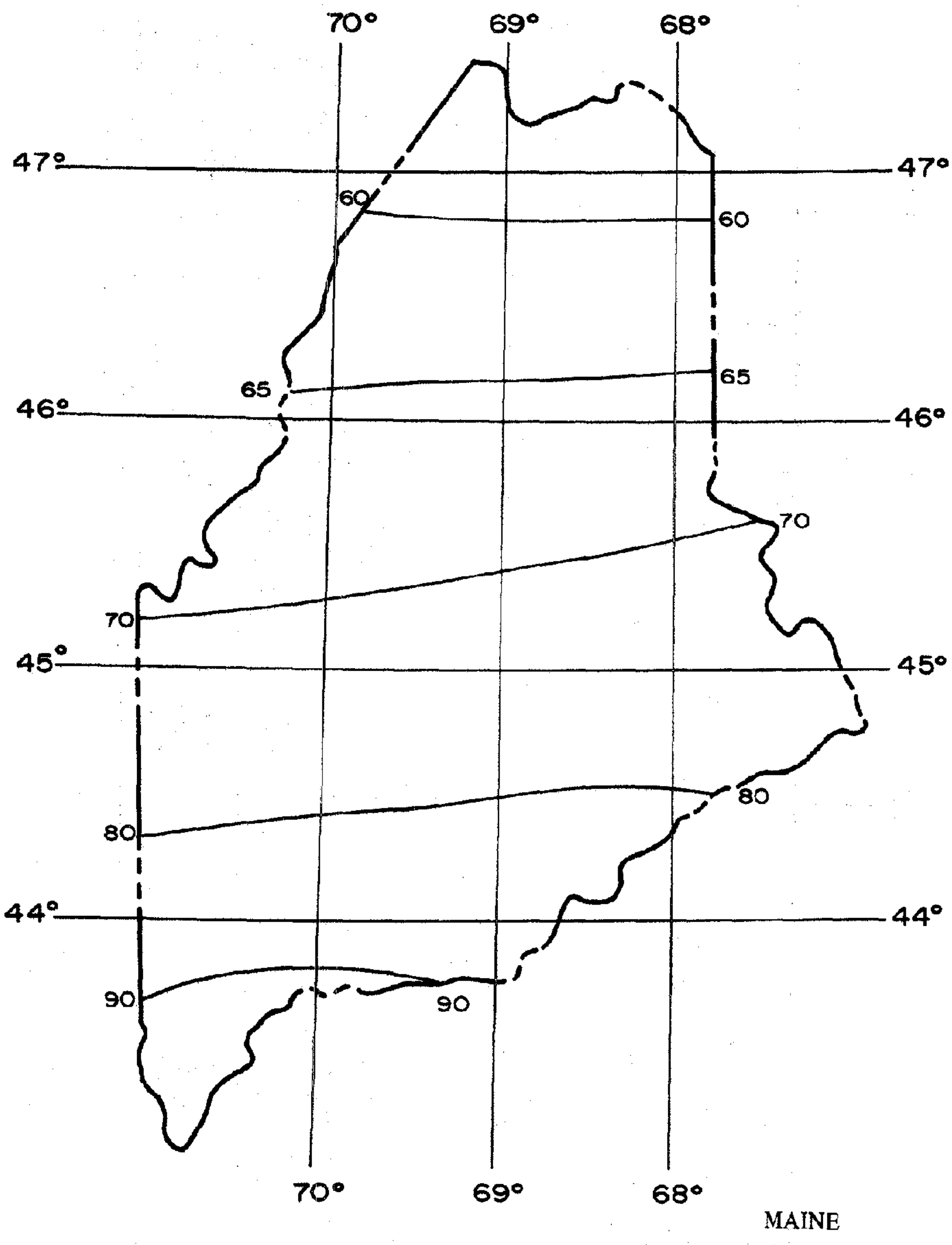
Appendix C-20. Isoerodent, R, map of Kansas.



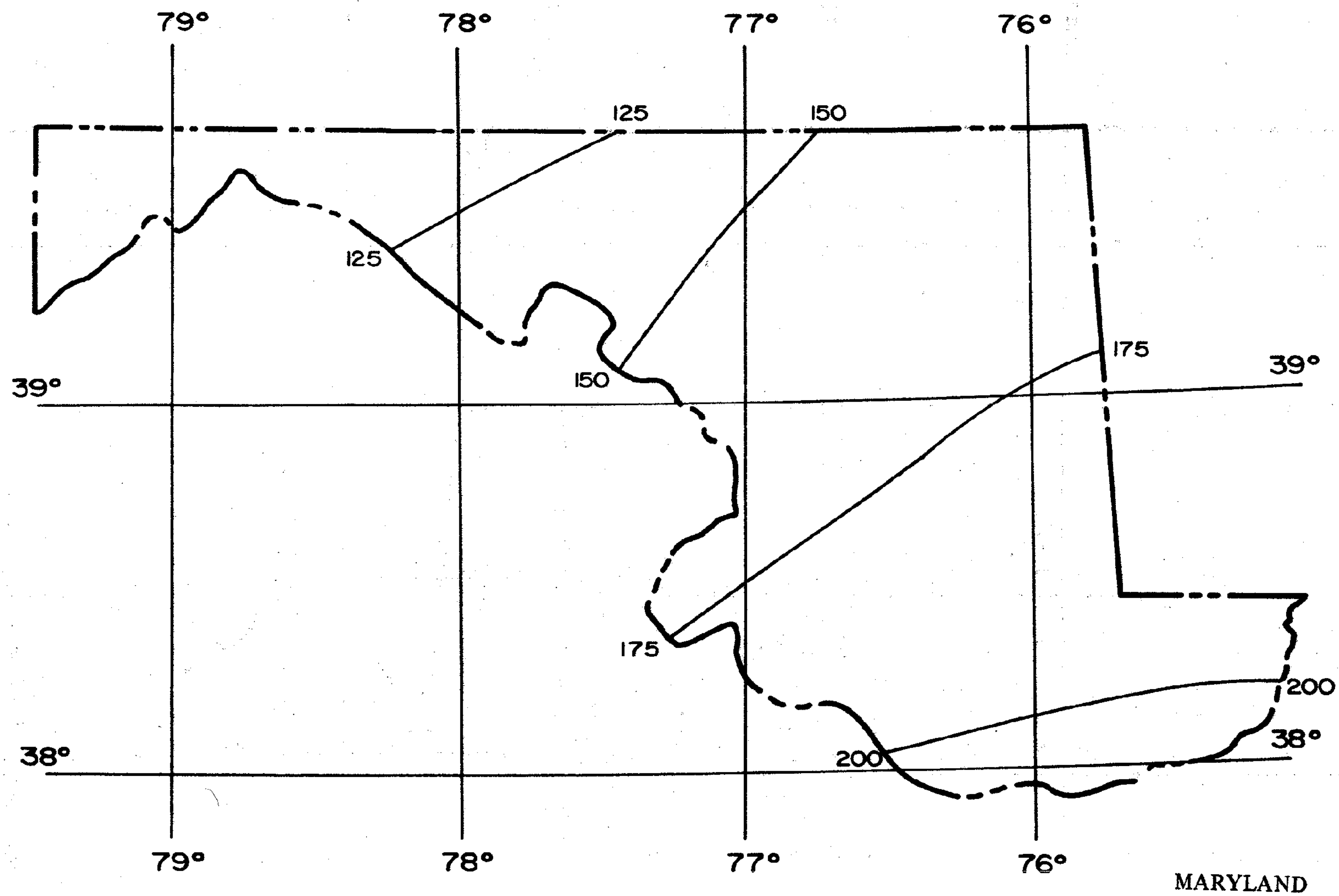
Appendix C-21. Isoerodent, R, map of Kentucky.



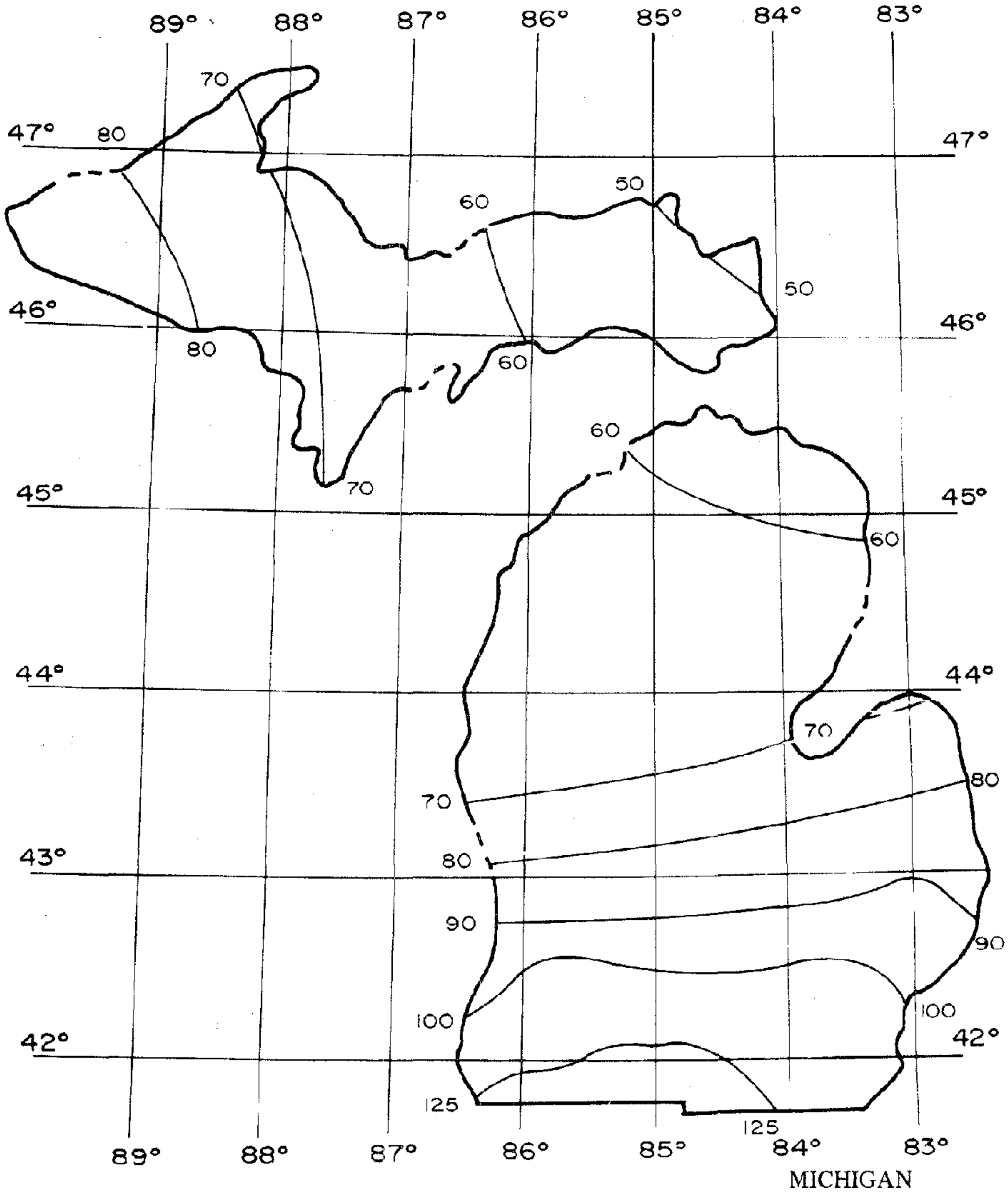
Appendix C-22. Isoerodent, R, map of Louisiana



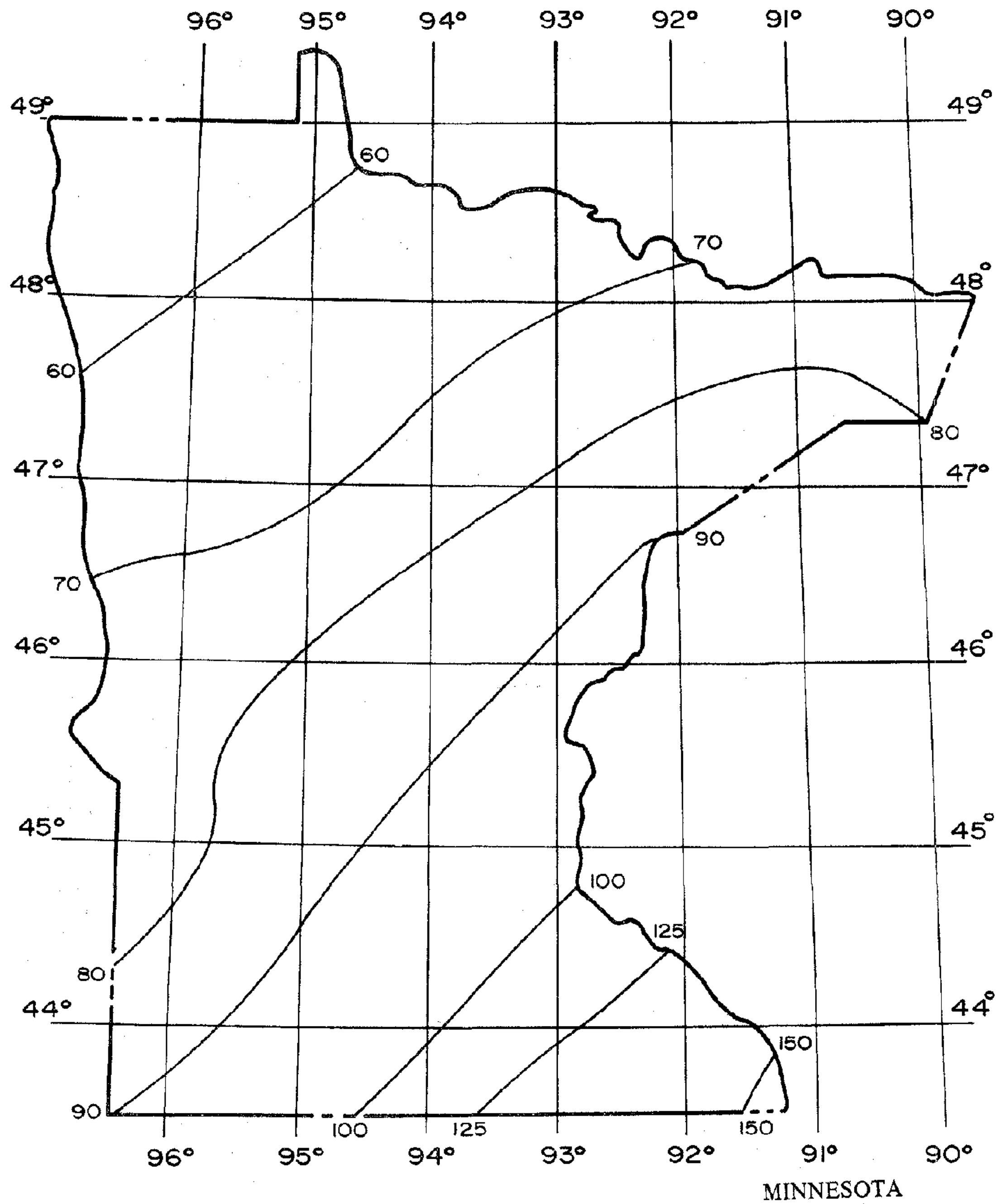
Appendix C-23. Isoerodent, R, map of Maine.



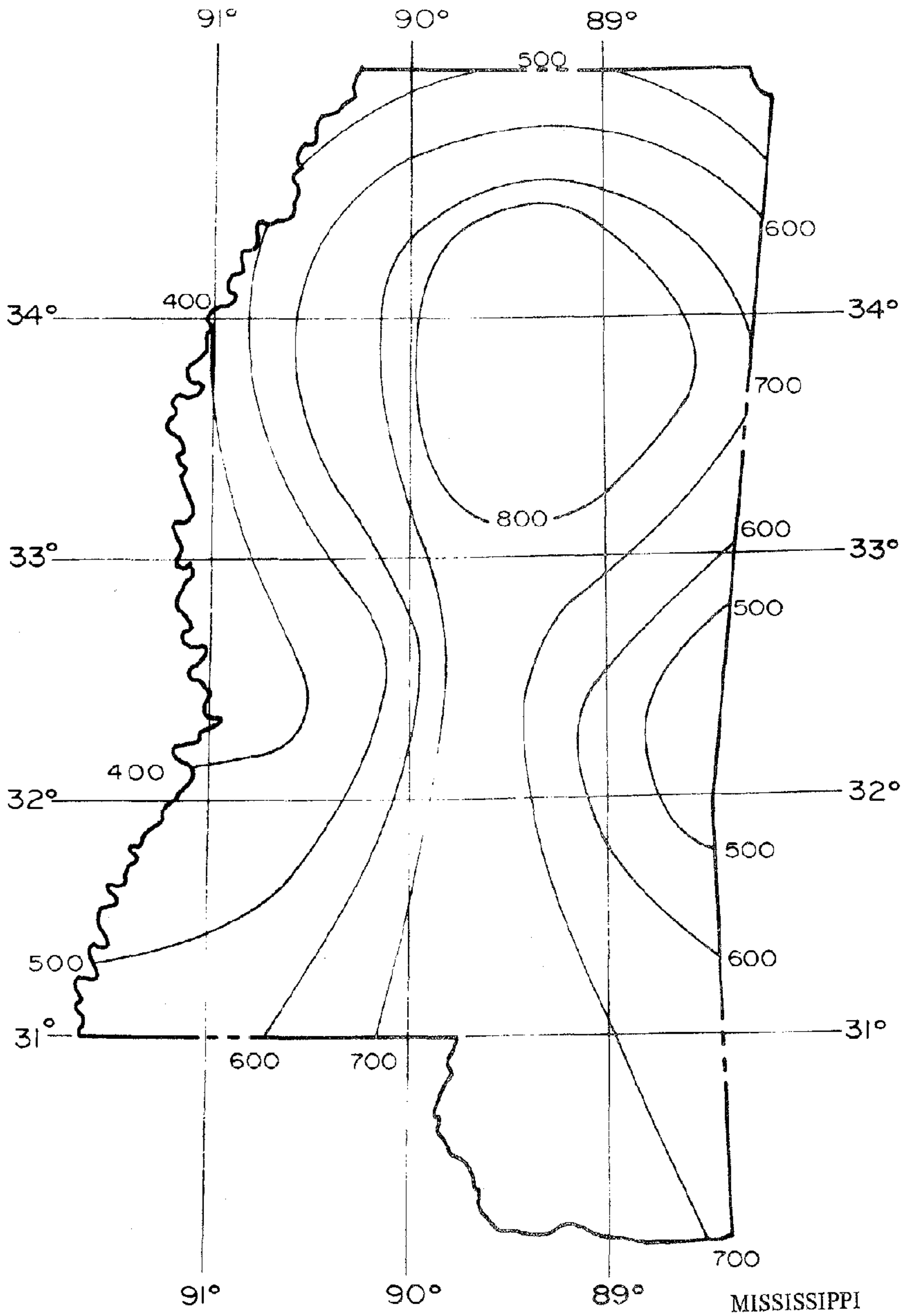
Appendix C-24. Isoerodent, R, map of Maryland.



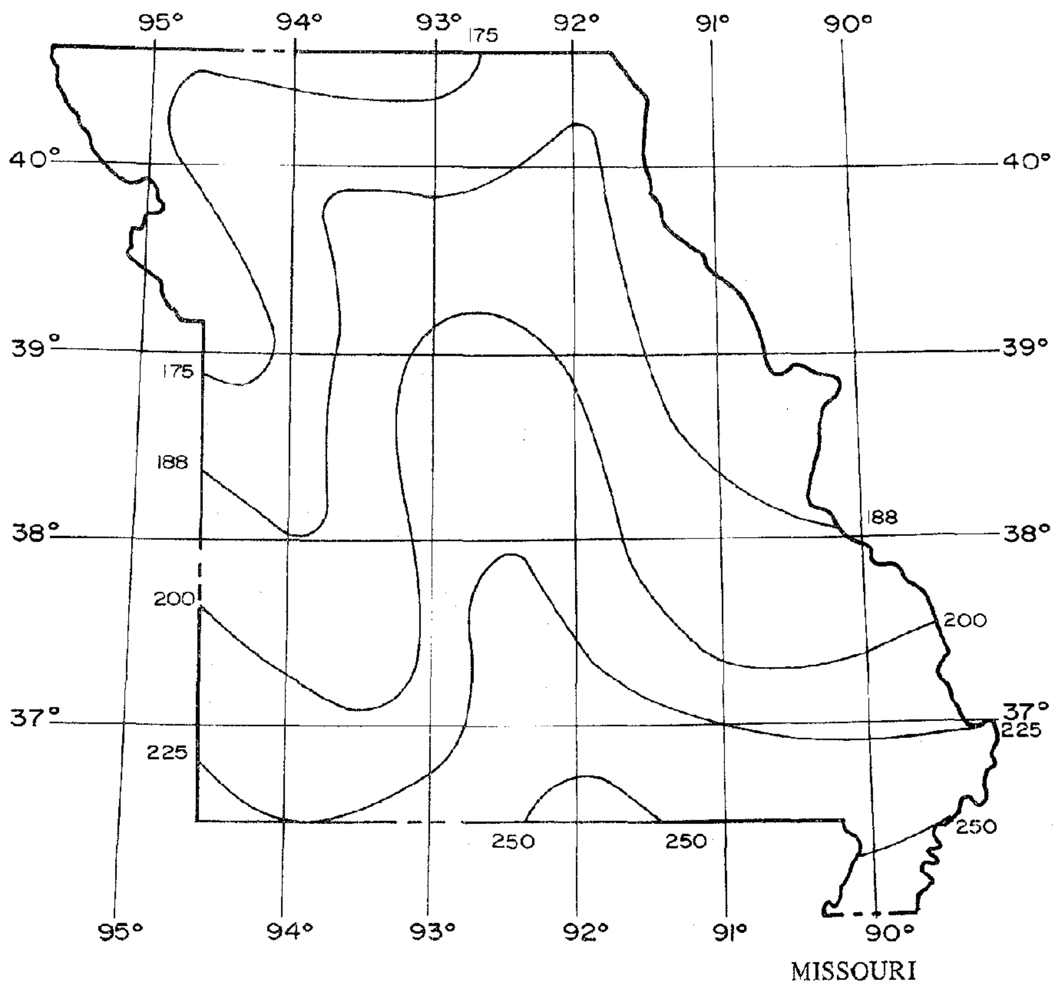
Appendix C-26. Isoerodent, R, map of Michigan.



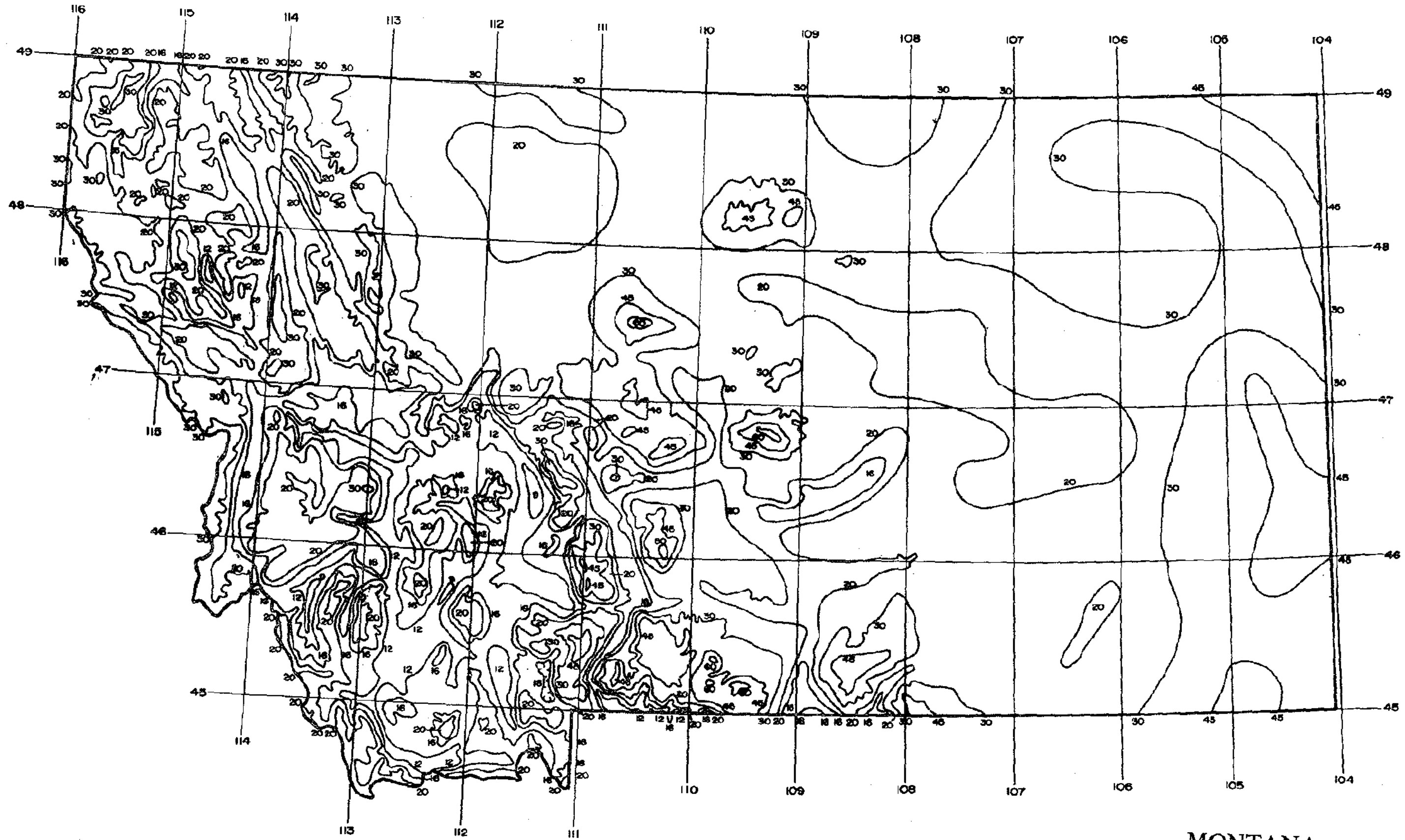
Appendix C-27. Isoerodent, R, map of Minnesota.



Appendix C-28. Isoerodent, R, map of Mississippi.

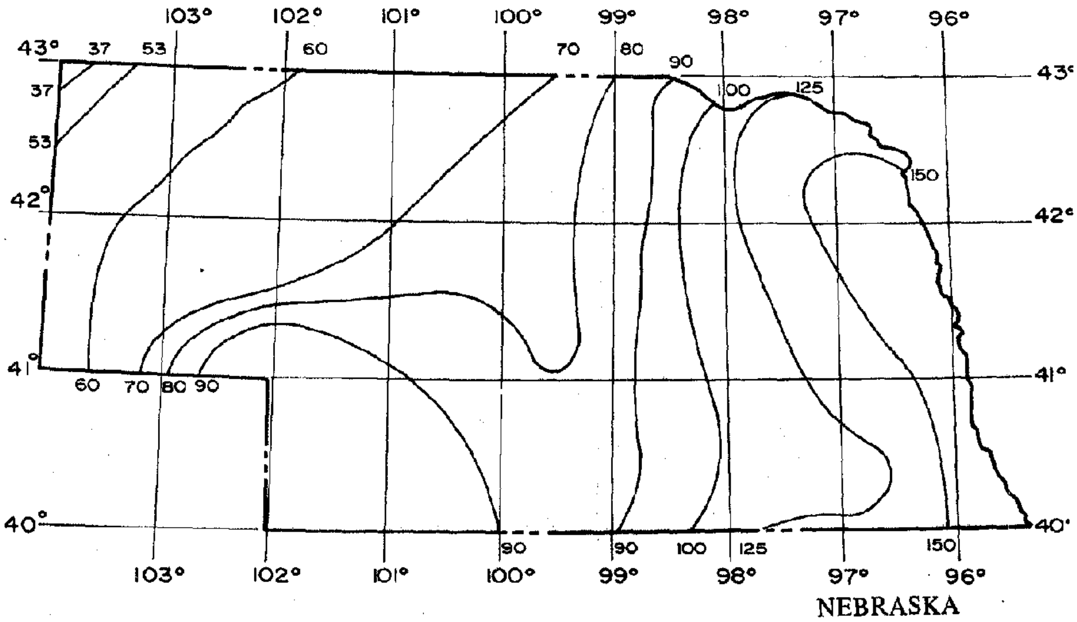


Appendix C-29. Isoerodent, R, map of Missouri.

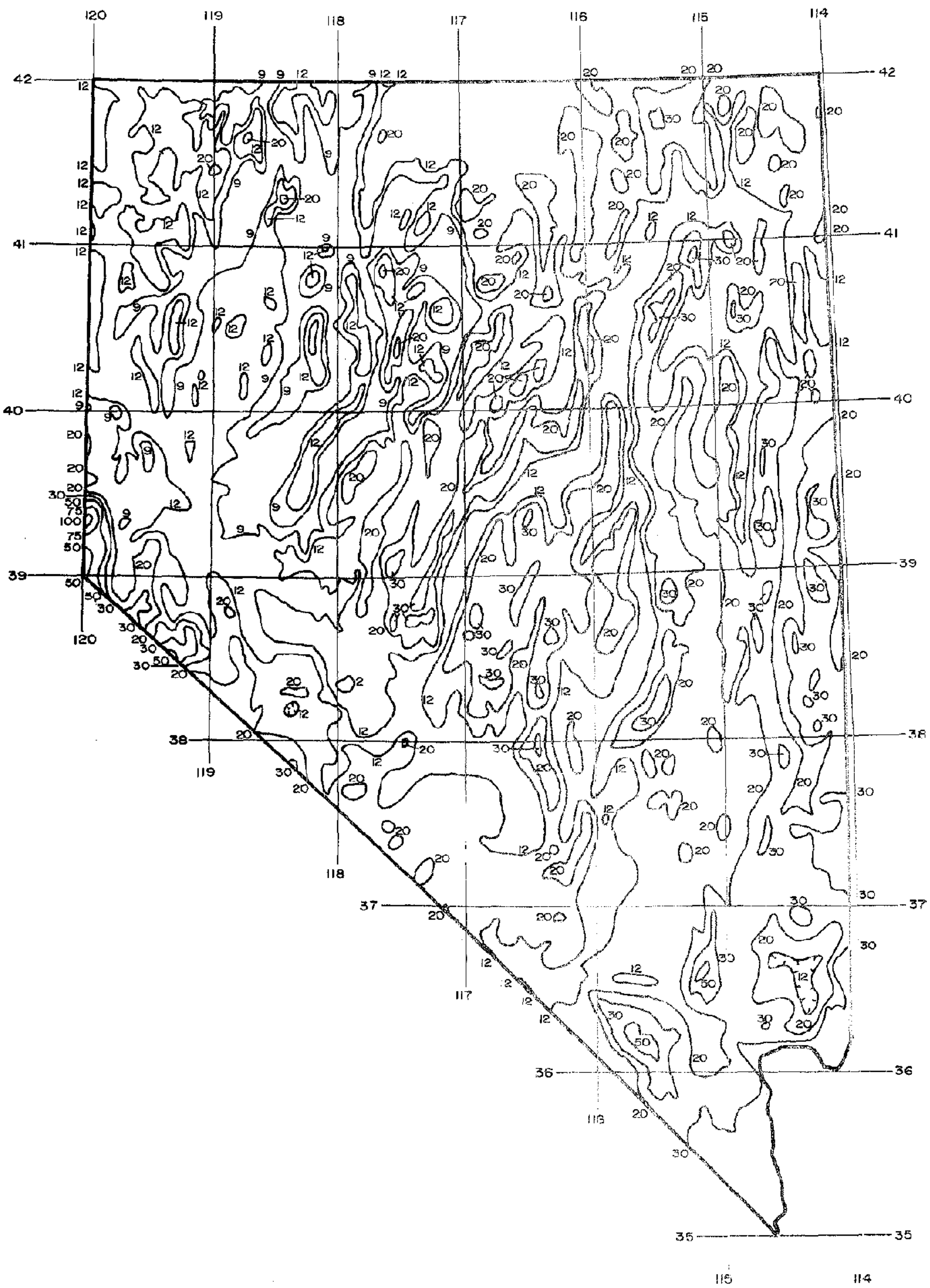


MONTANA

Appendix C-30. Isoerodent, R, map of Montana.

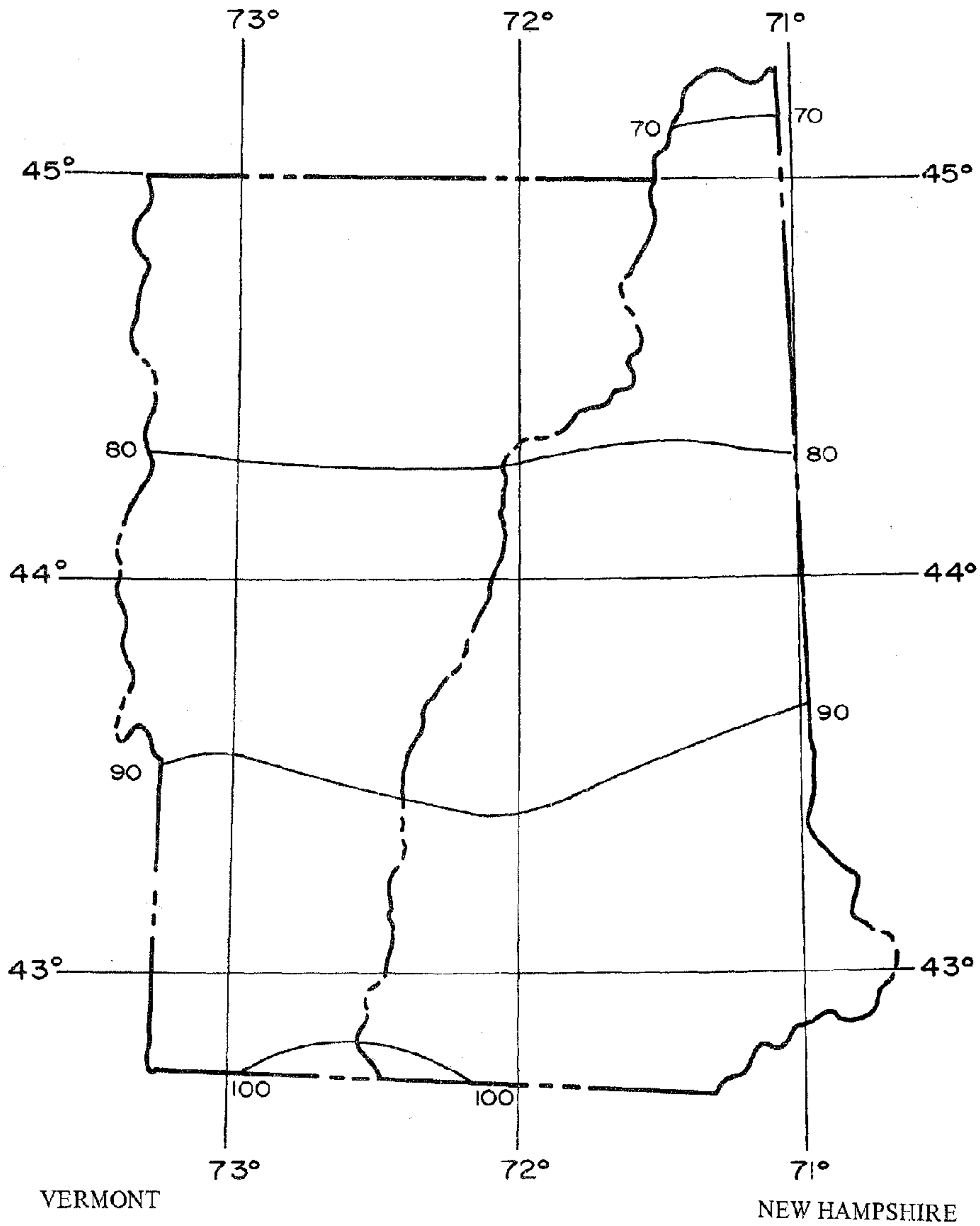


Appendix C-31. Isoerodent, R, map of Nebraska.

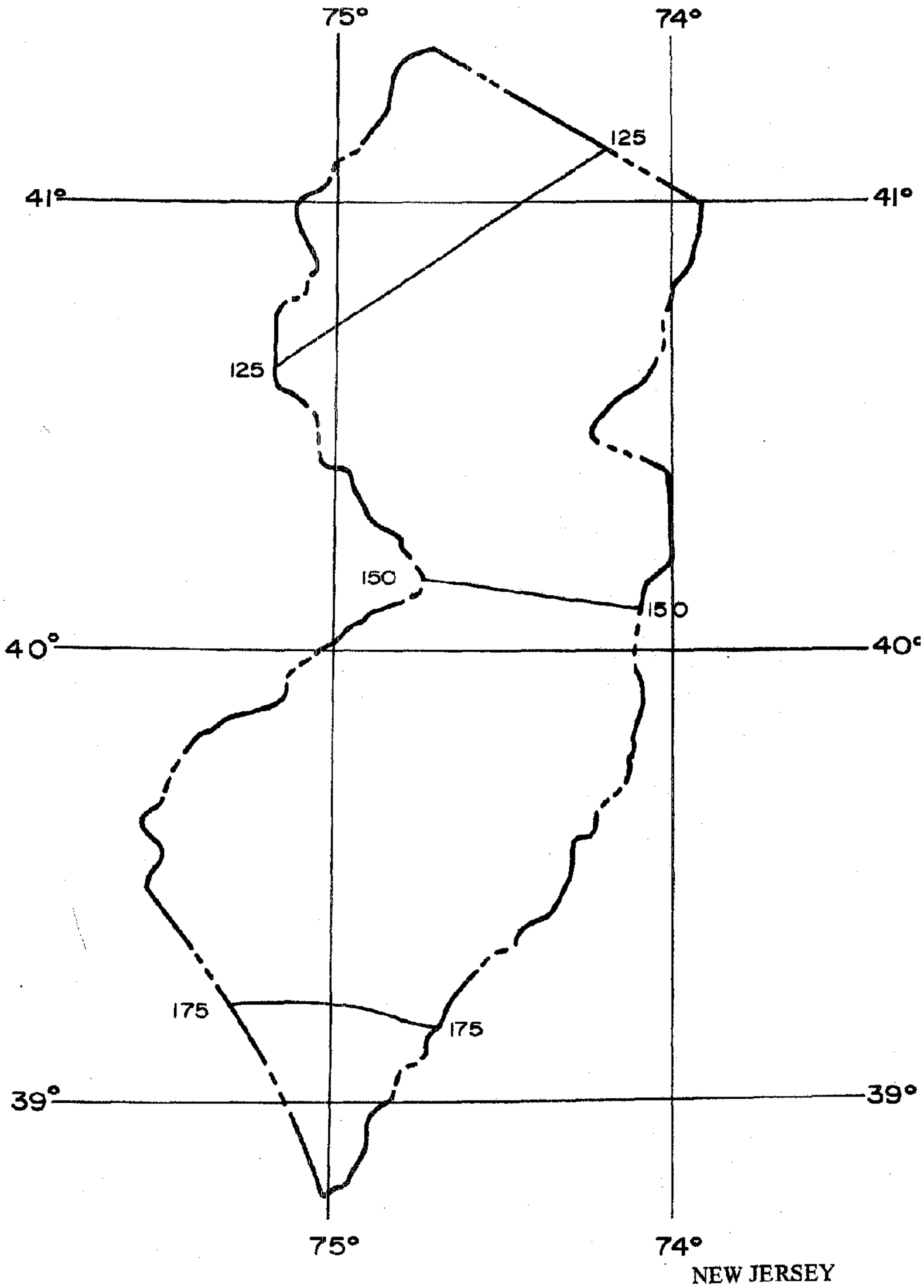


Appendix C-32. Isoerodent, R, map of Nevada.

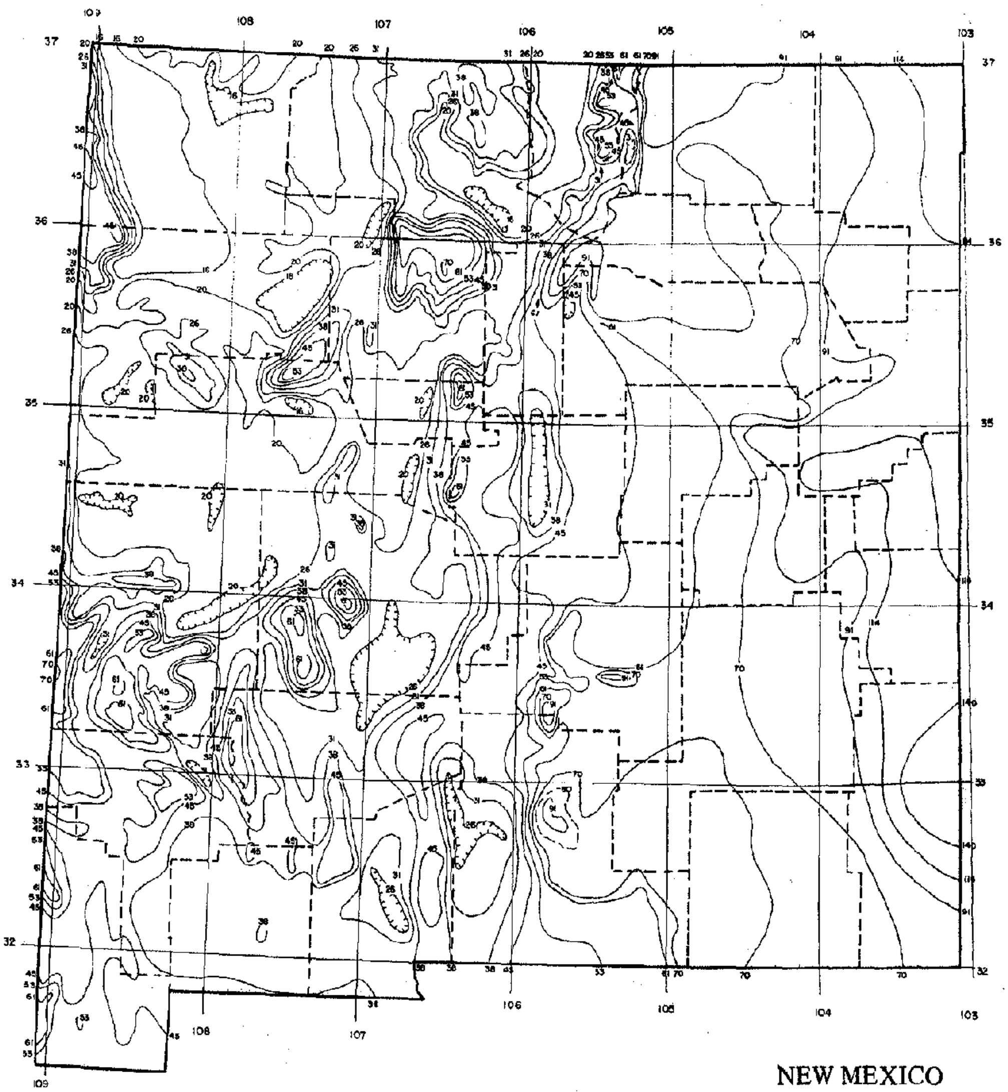
NEVADA



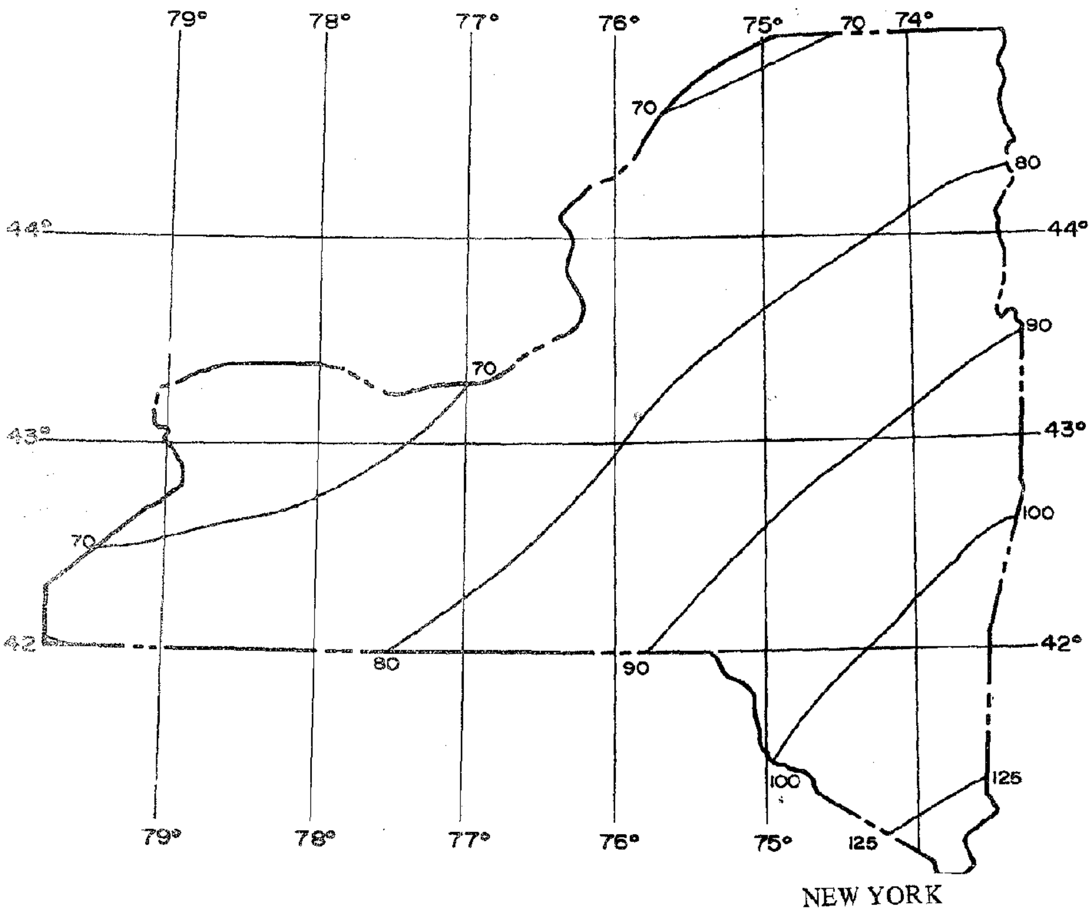
Appendix C-33. Isoerodent, R, map of New Hampshire.
Appendix C-50. Isoerodent, R, map of Vermont.



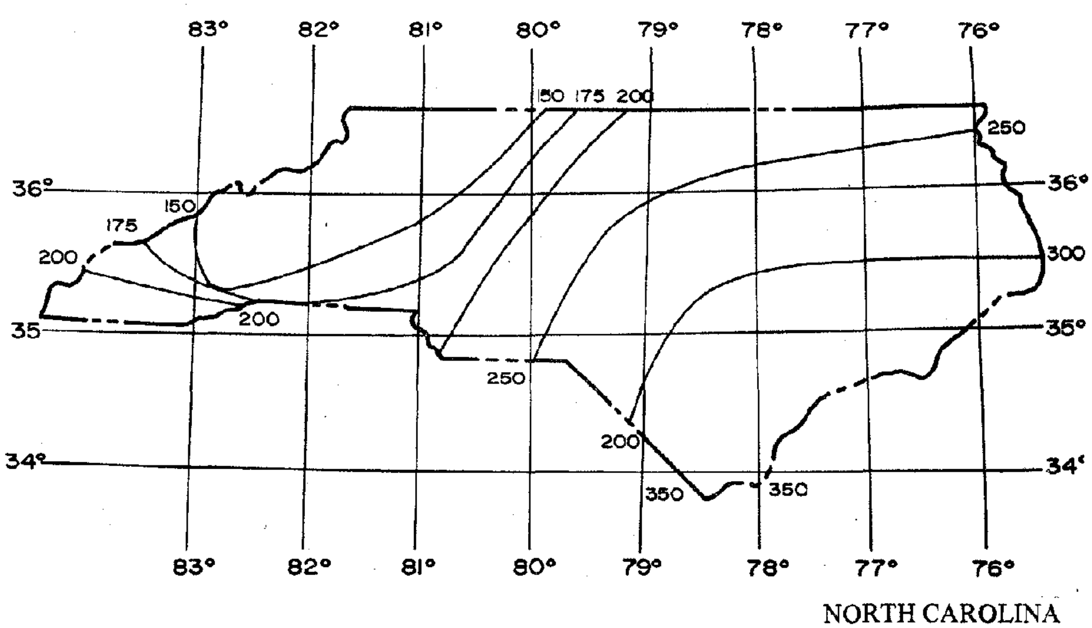
Appendix C-34. Isoerodent, R, map of New Jersey.



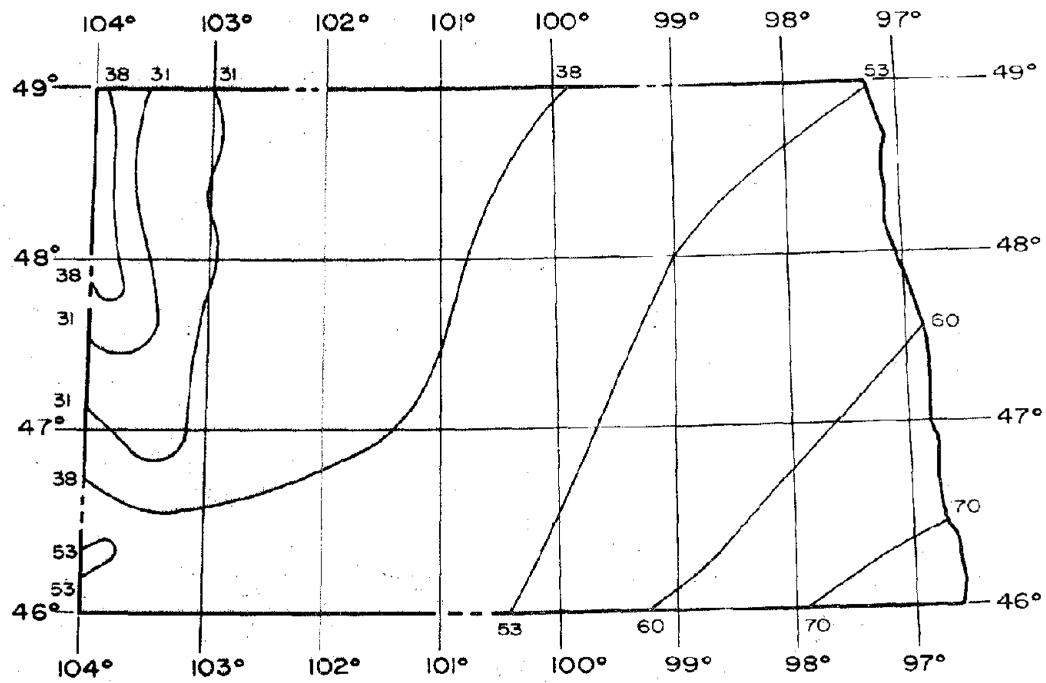
Appendix C-35. Isoerodent, R, map of New Mexico.



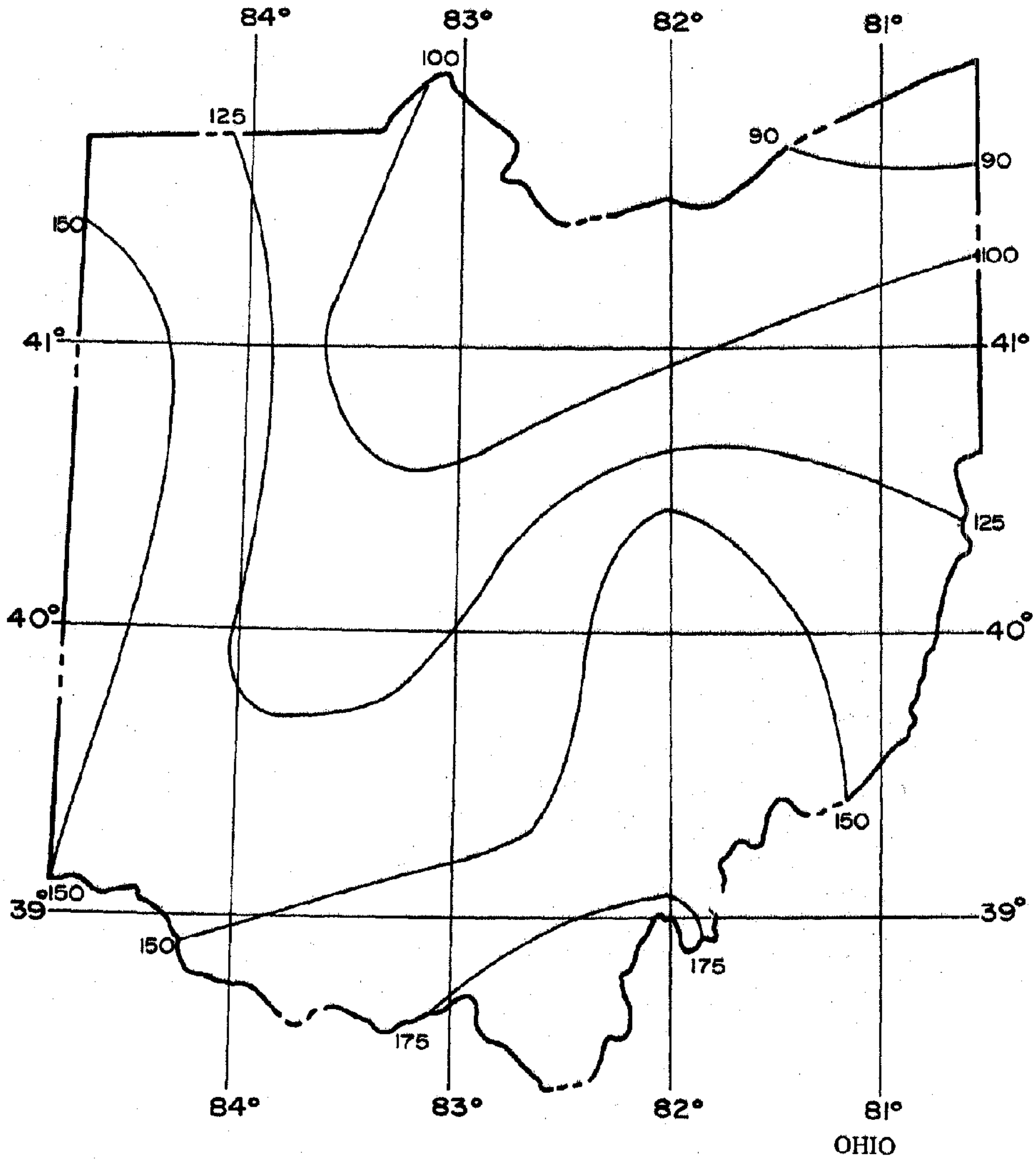
Appendix C-36. Isoerodent, R, map of New York.



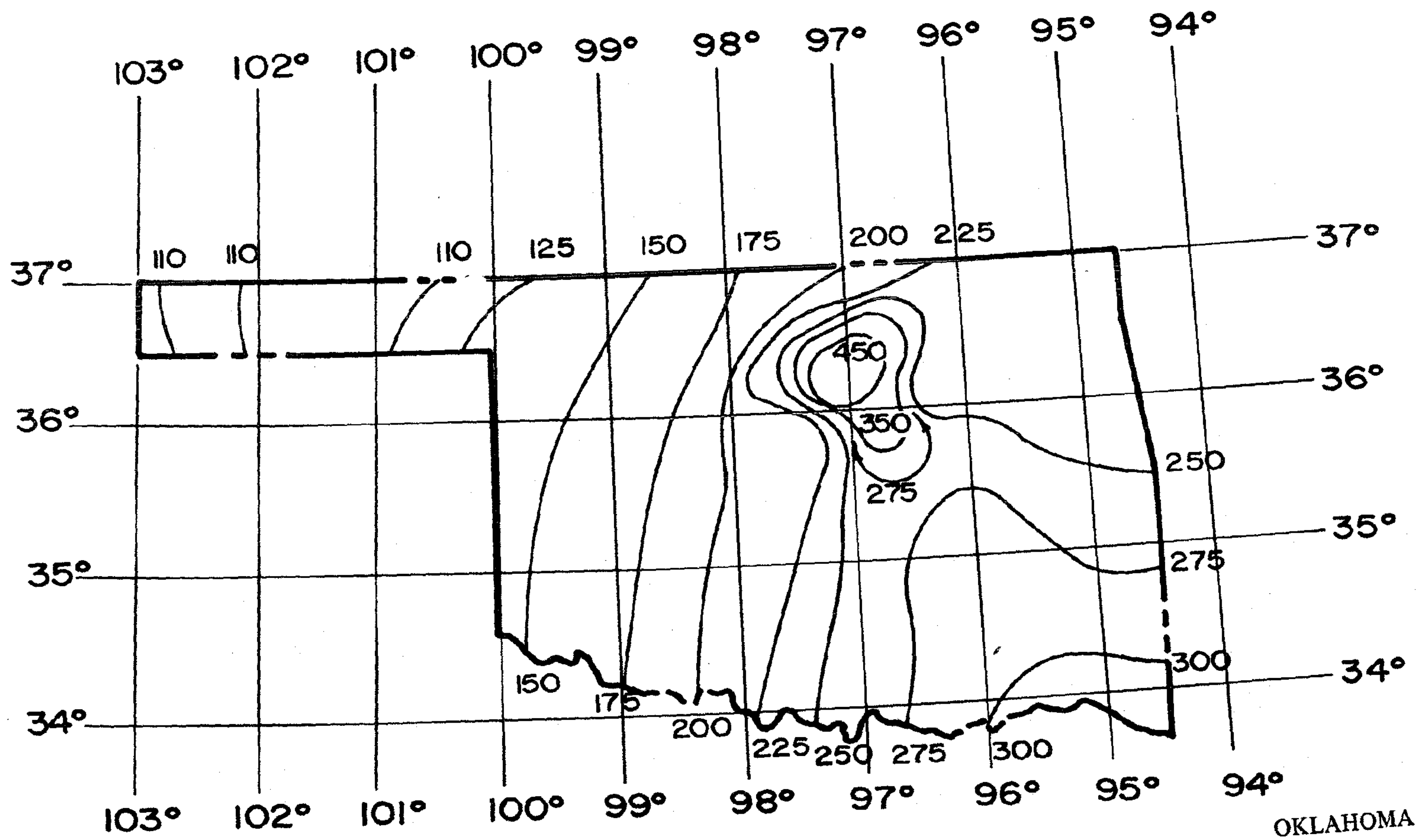
Appendix C-37. Isoerodent, R, map of North Carolina.



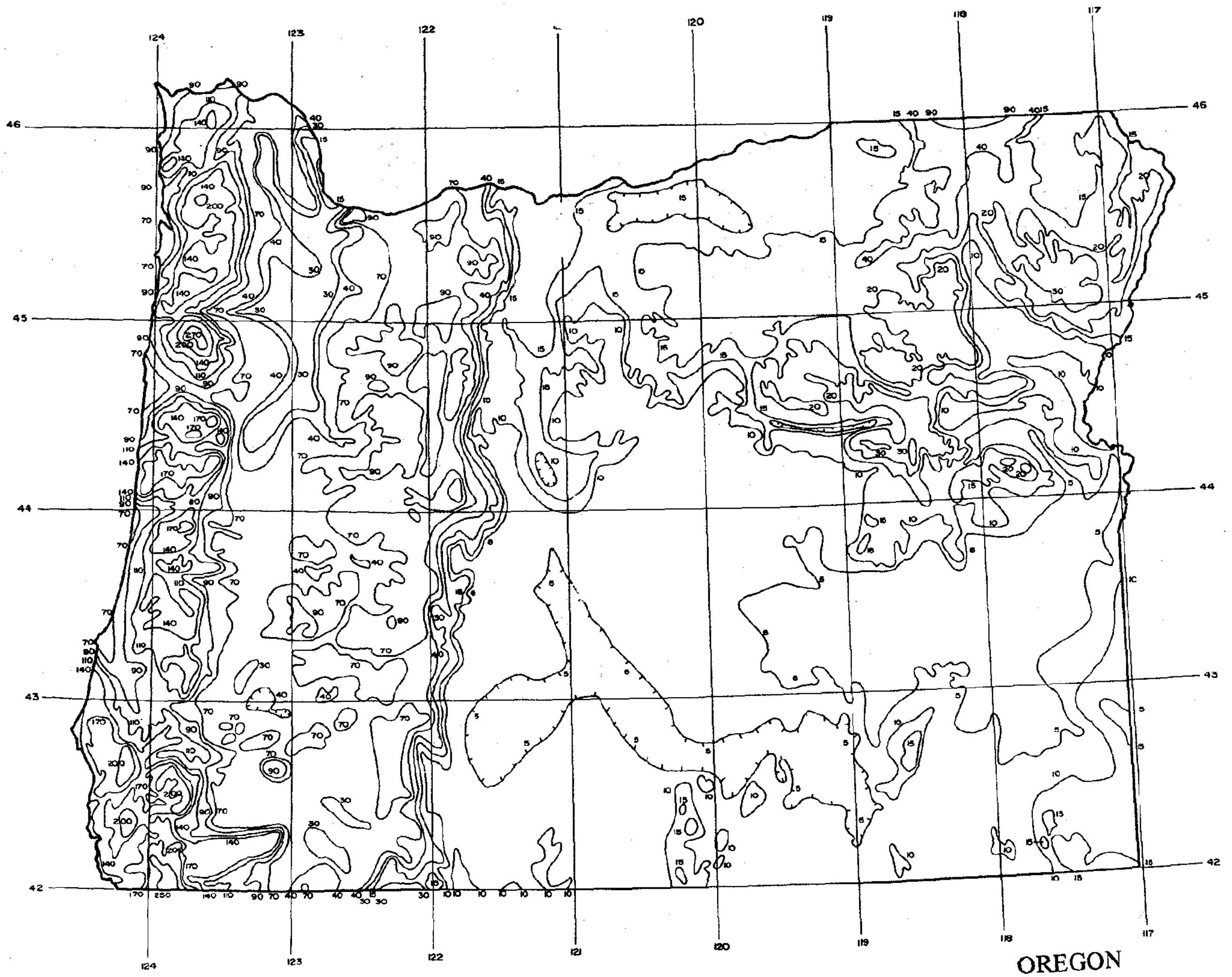
Appendix C-38. Isoerodent, R, map of North Dakota.



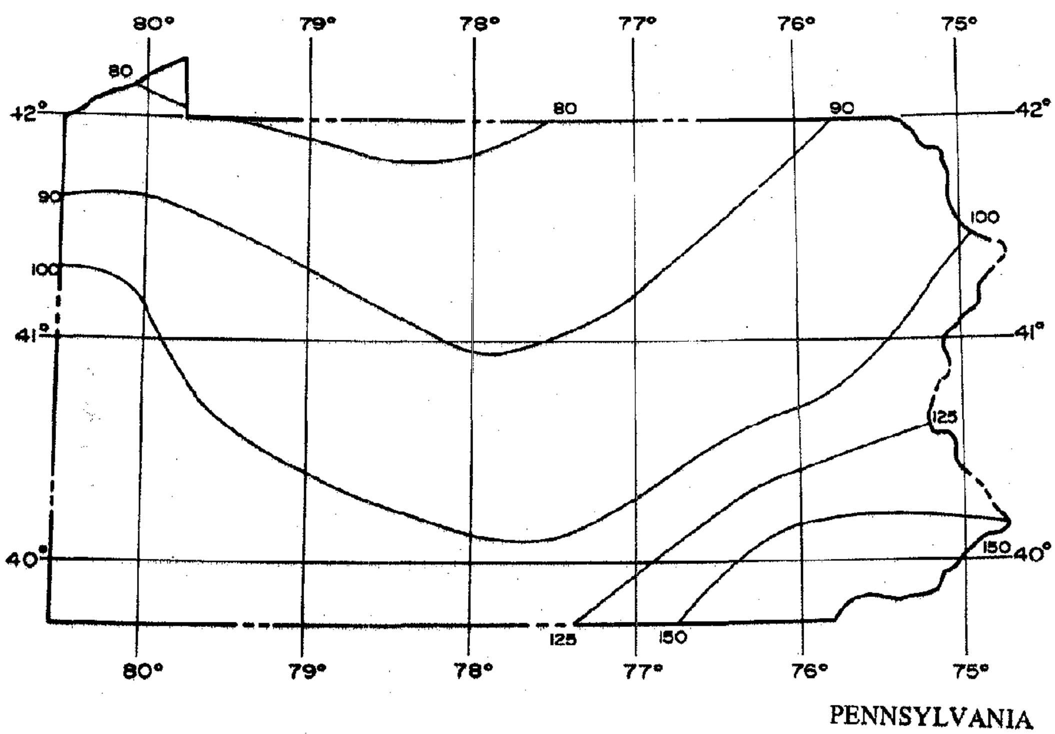
Appendix C-39. Isoerodent, R, map of Ohio.



Appendix C-40. Isoerodent, R, map of Oklahoma.

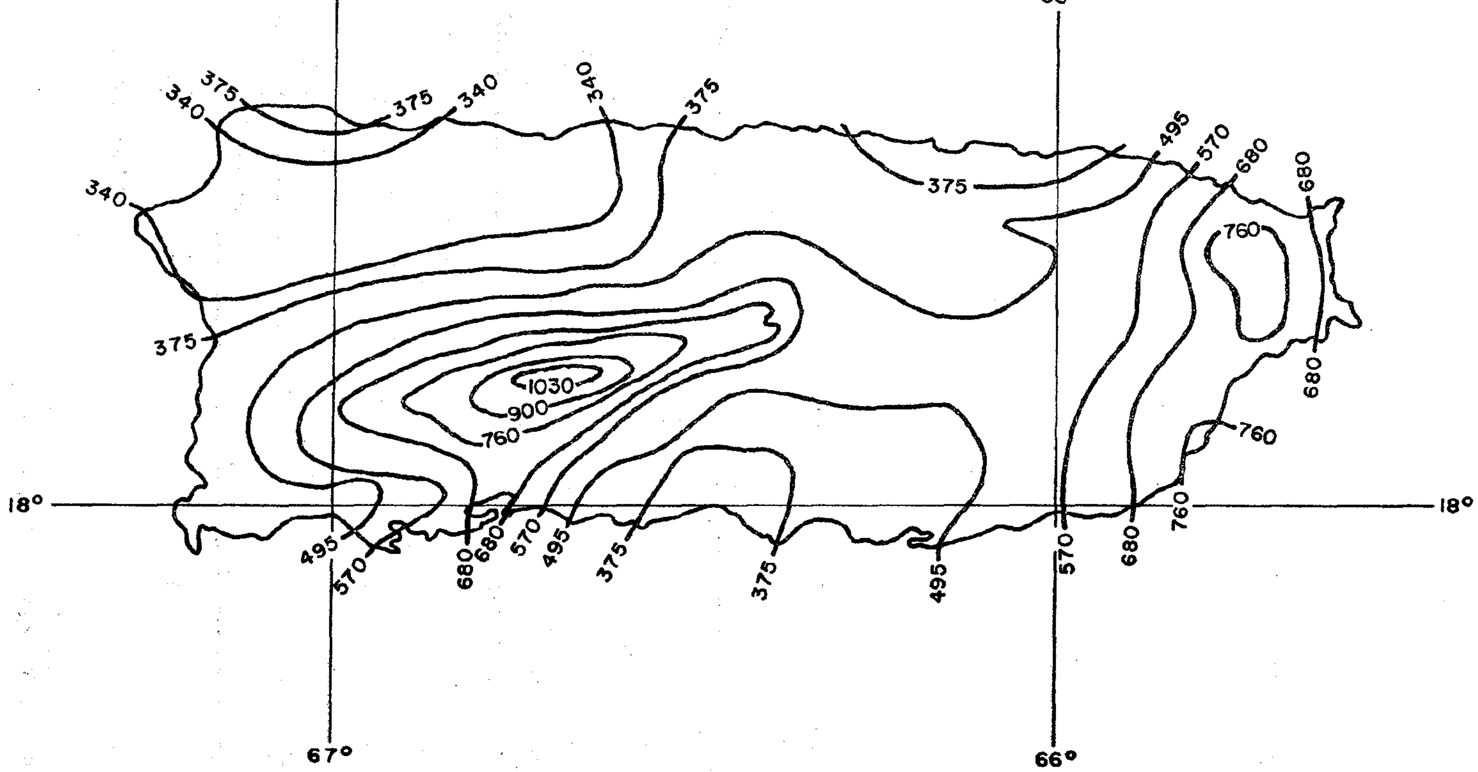


Appendix C-41. Isoerodent, R, map of Oregon.

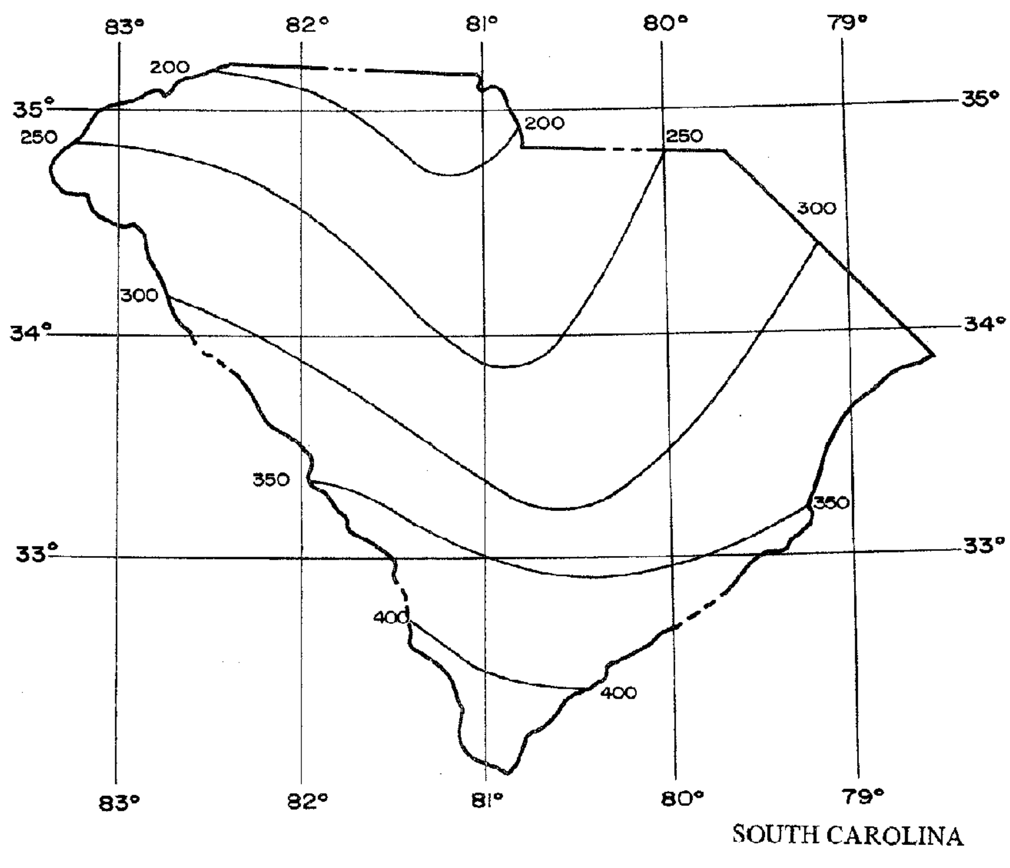


Appendix C-42. Isoerodent, R, map of Pennsylvania.

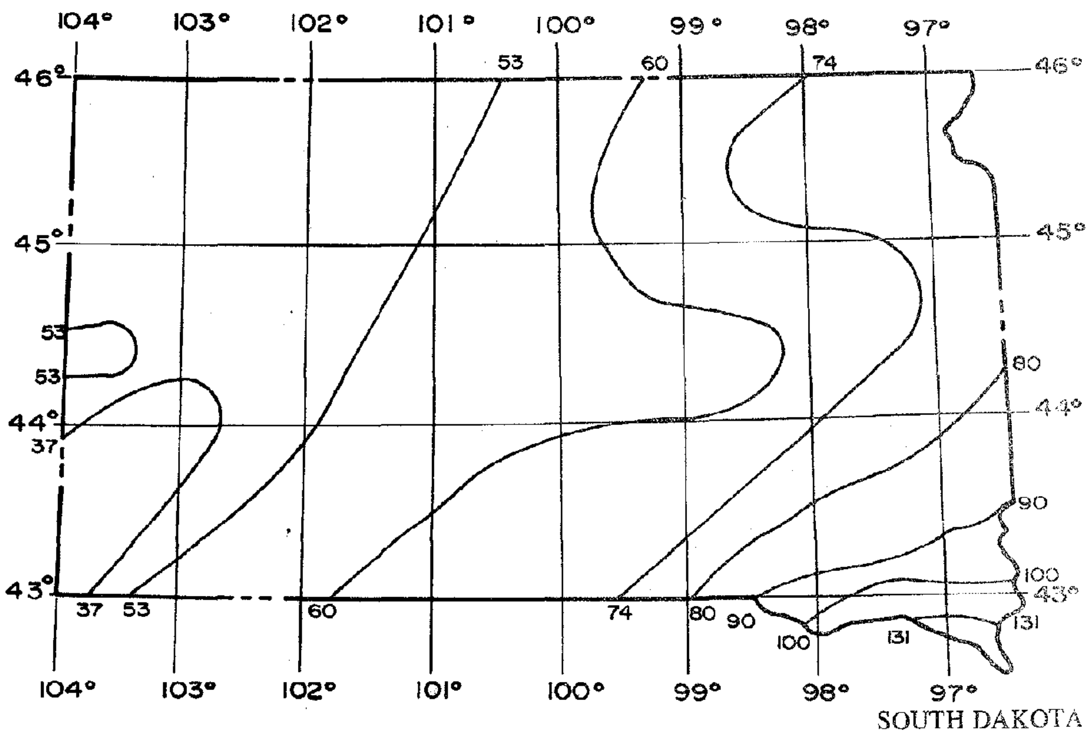
PUERTO RICO



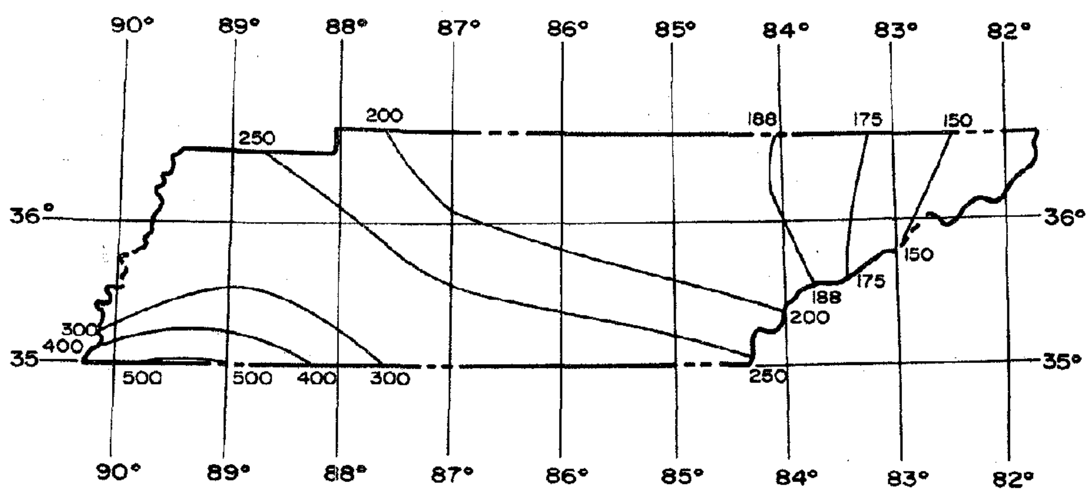
Appendix C-43 Isoerodent, R, map of Puerto Rico.



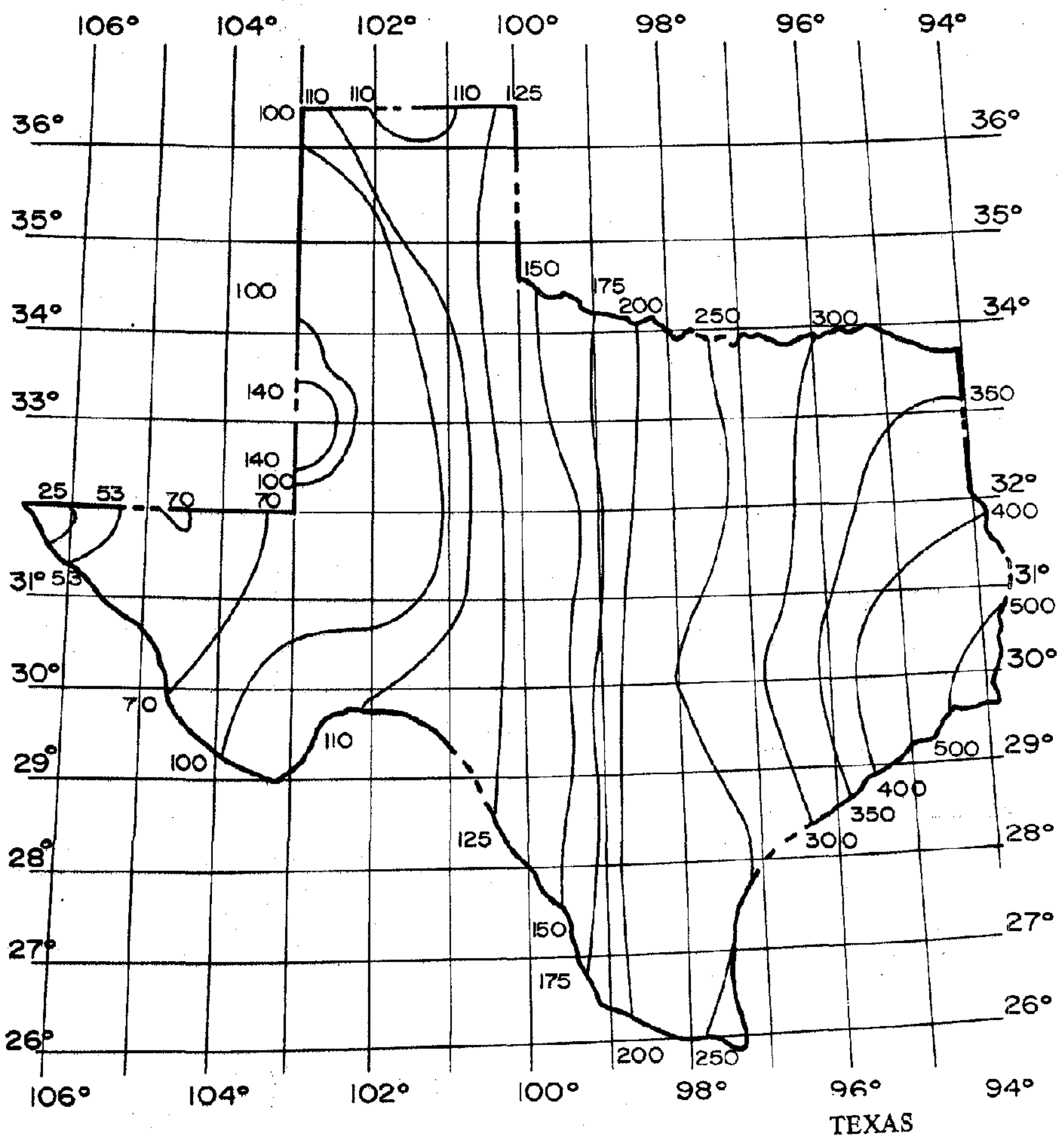
Appendix C-45. Isoerodent, R, map of South Carolina.



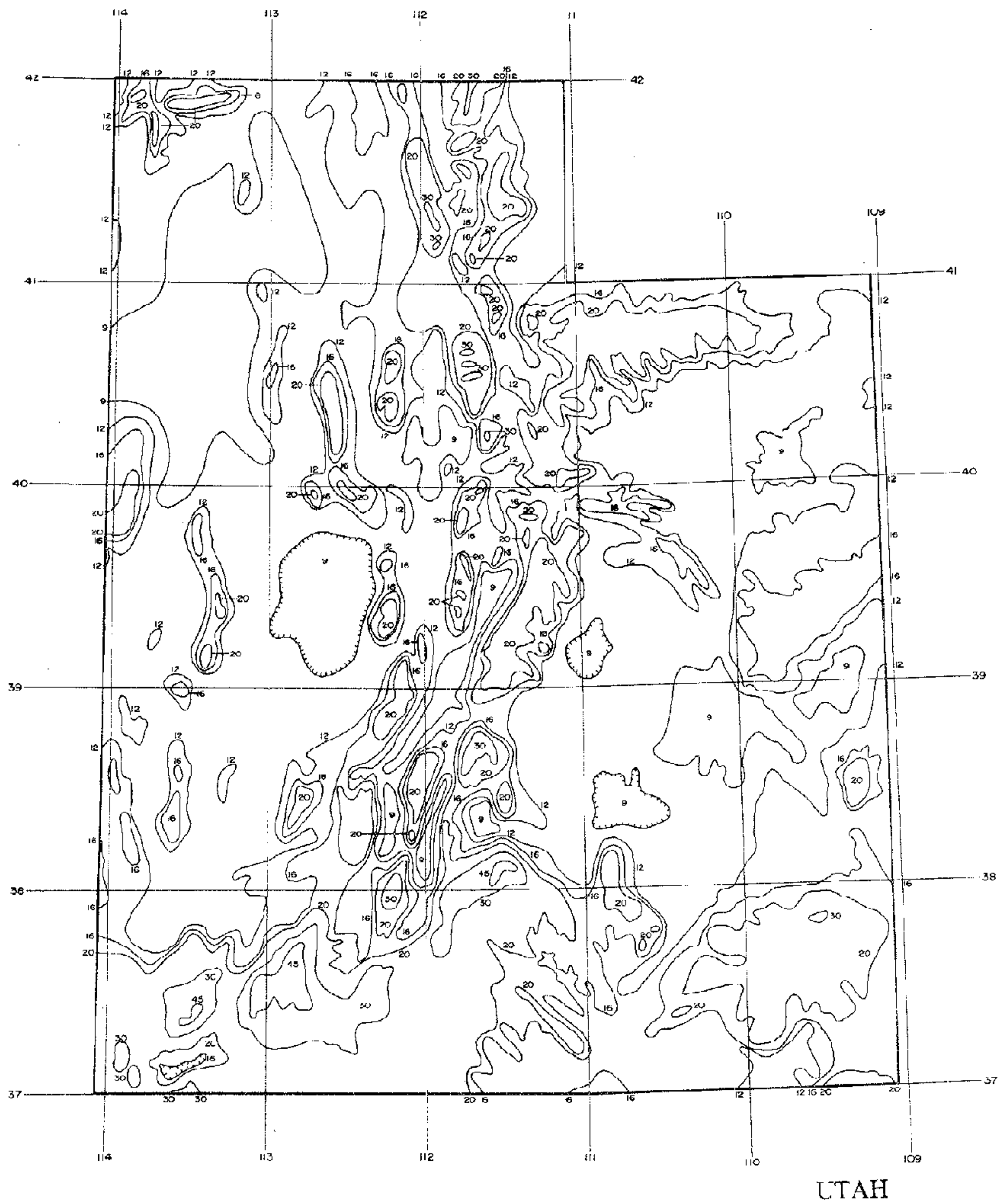
Appendix C-46. Isoerodent, R, map of South Dakota.



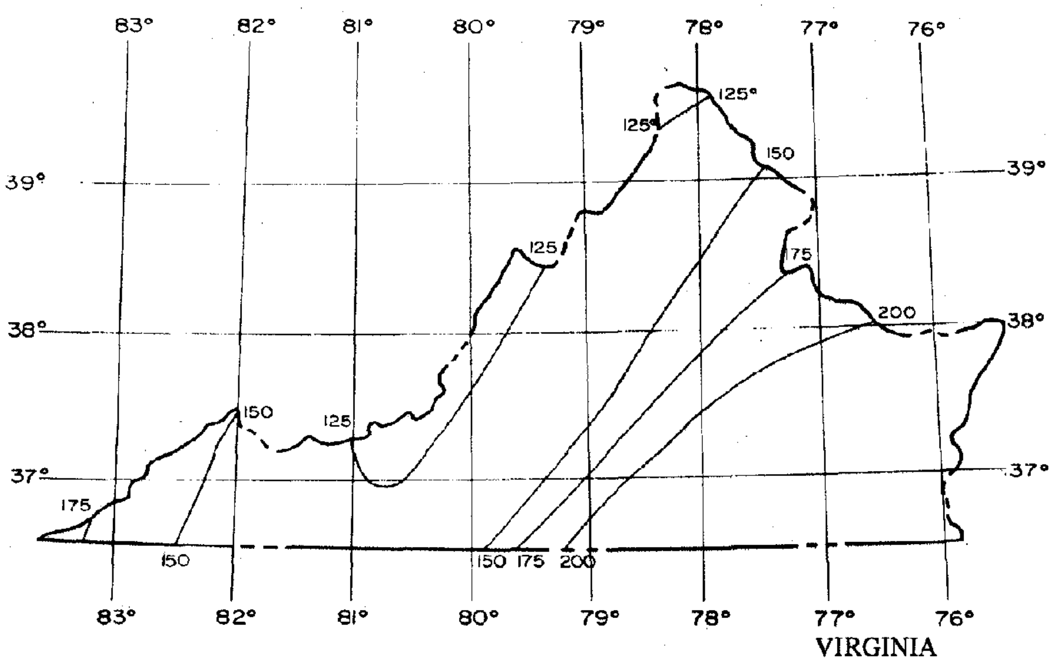
Appendix C-47. Isoerodent, R, map of Tennessee.



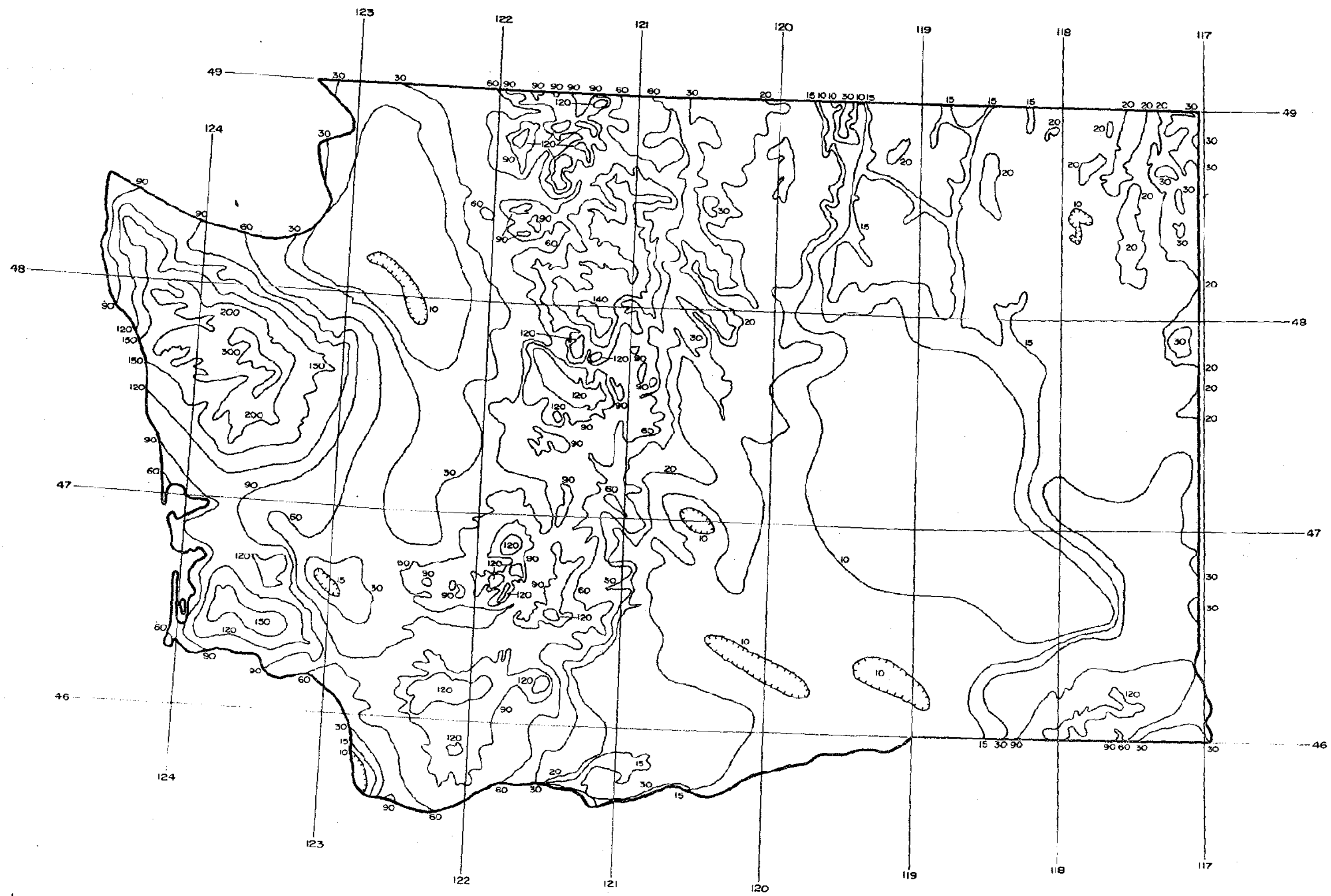
Appendix C-48. Isoerodent, R, map of Texas.



Appendix C-49. Isoerodent, R, map of Utah.

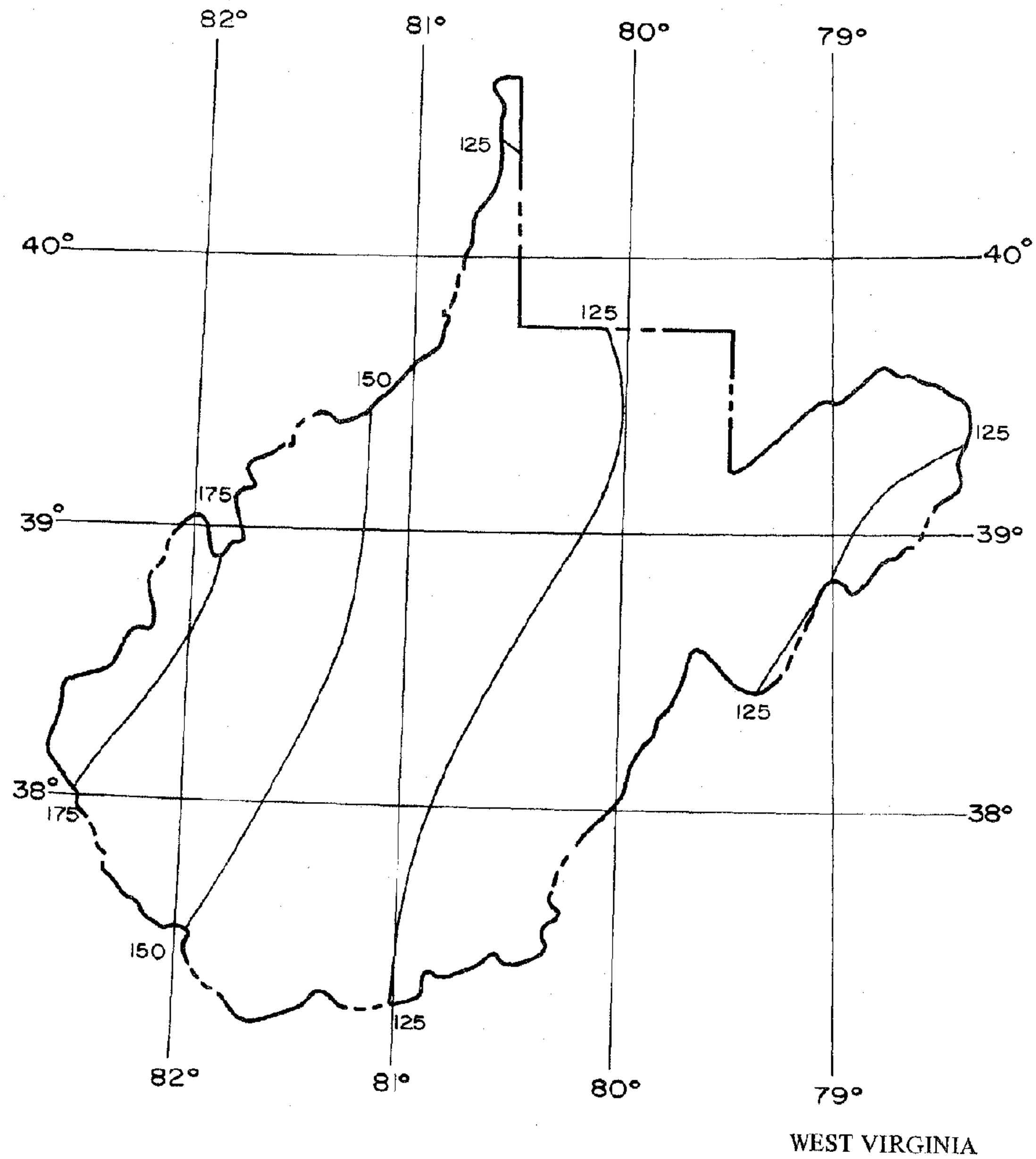


Appendix C-51. Isoerodent, R, map of Virginia.

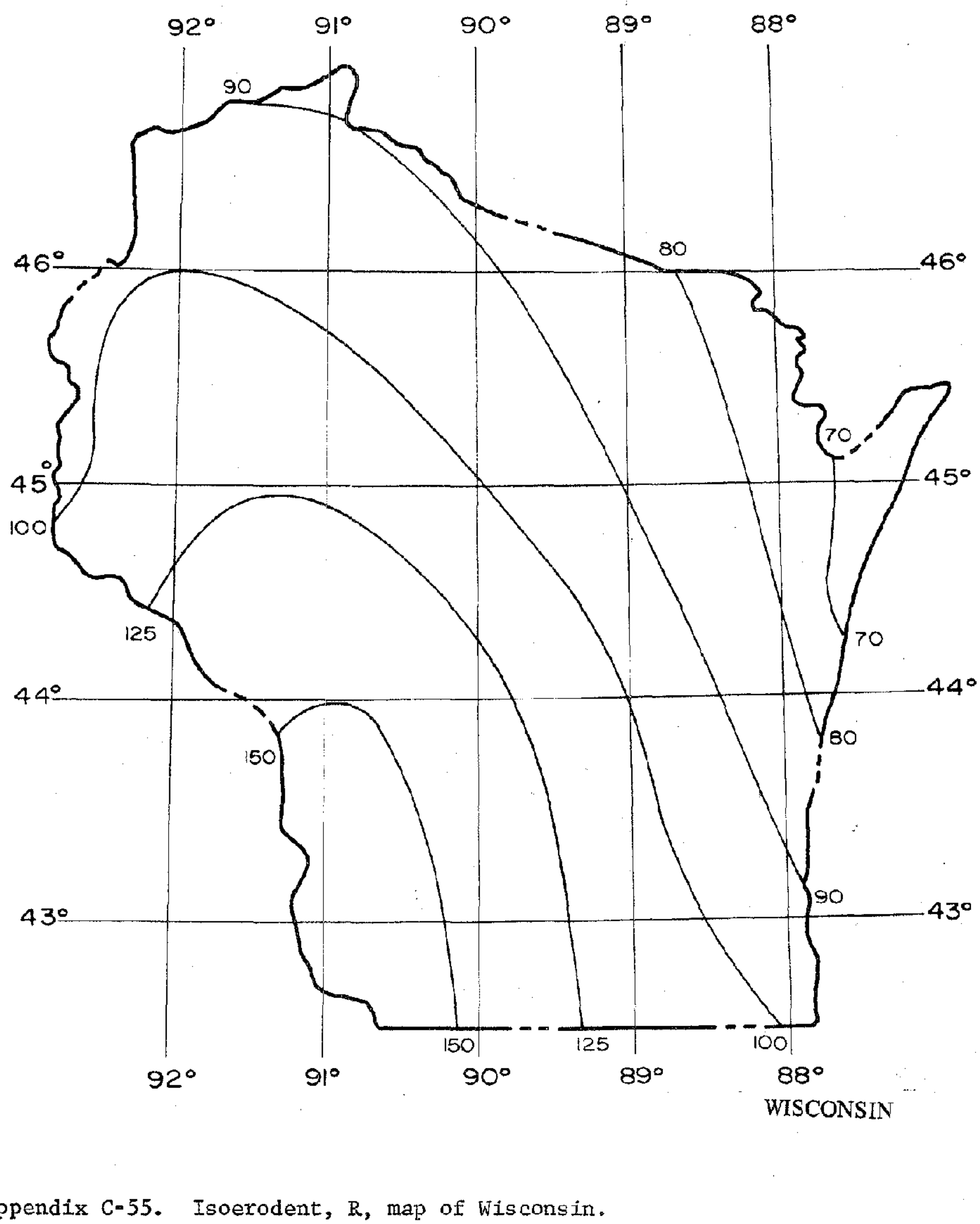


Appendix C-53. Isoerodent, R, map of Washington.

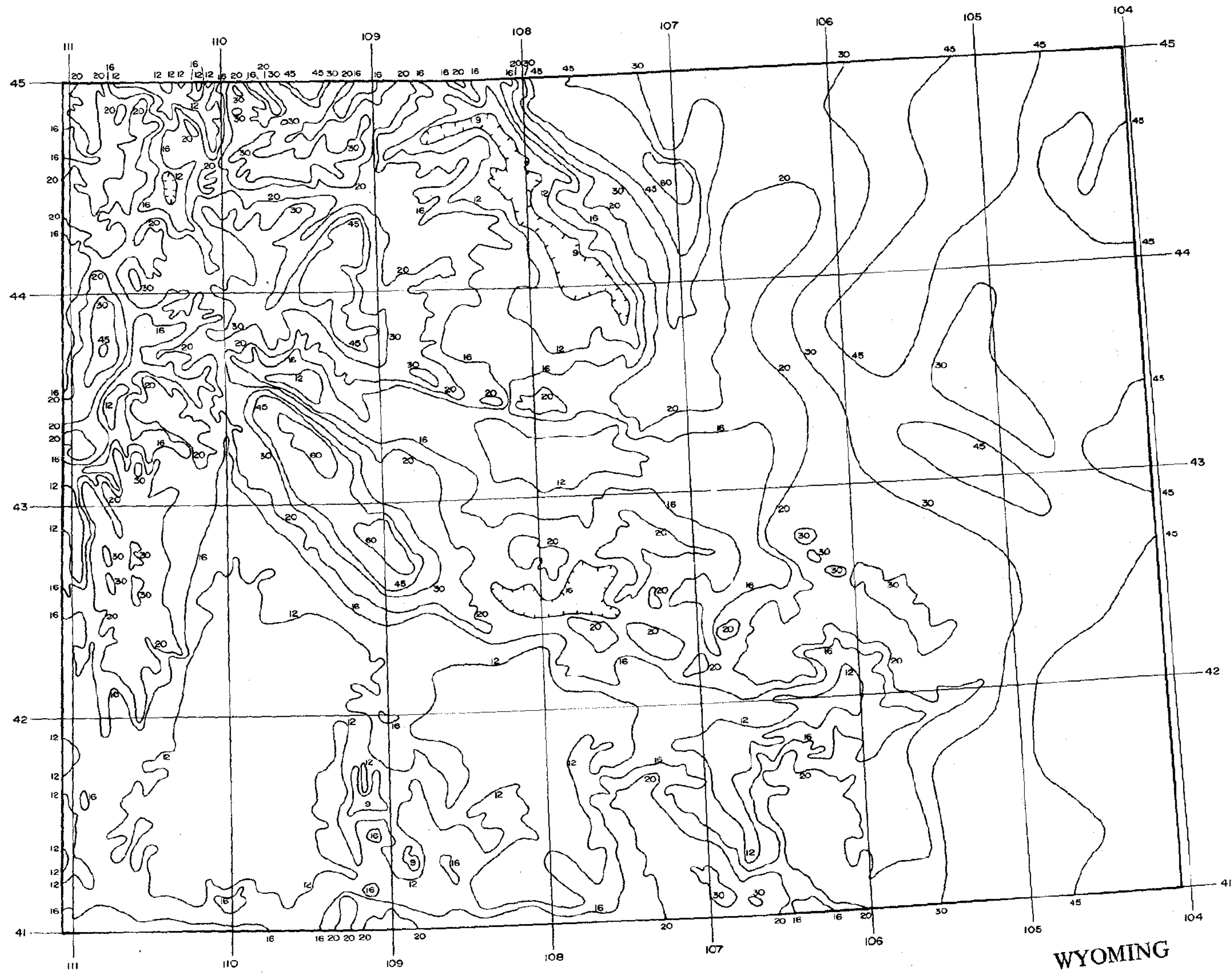
WASHINGTON



Appendix C-54. Isoerodent, R, map of West Virginia.



Appendix C-55. Isoerodent, R, map of Wisconsin.



Appendix C-56. Isoerodent, R, map of Wyoming.

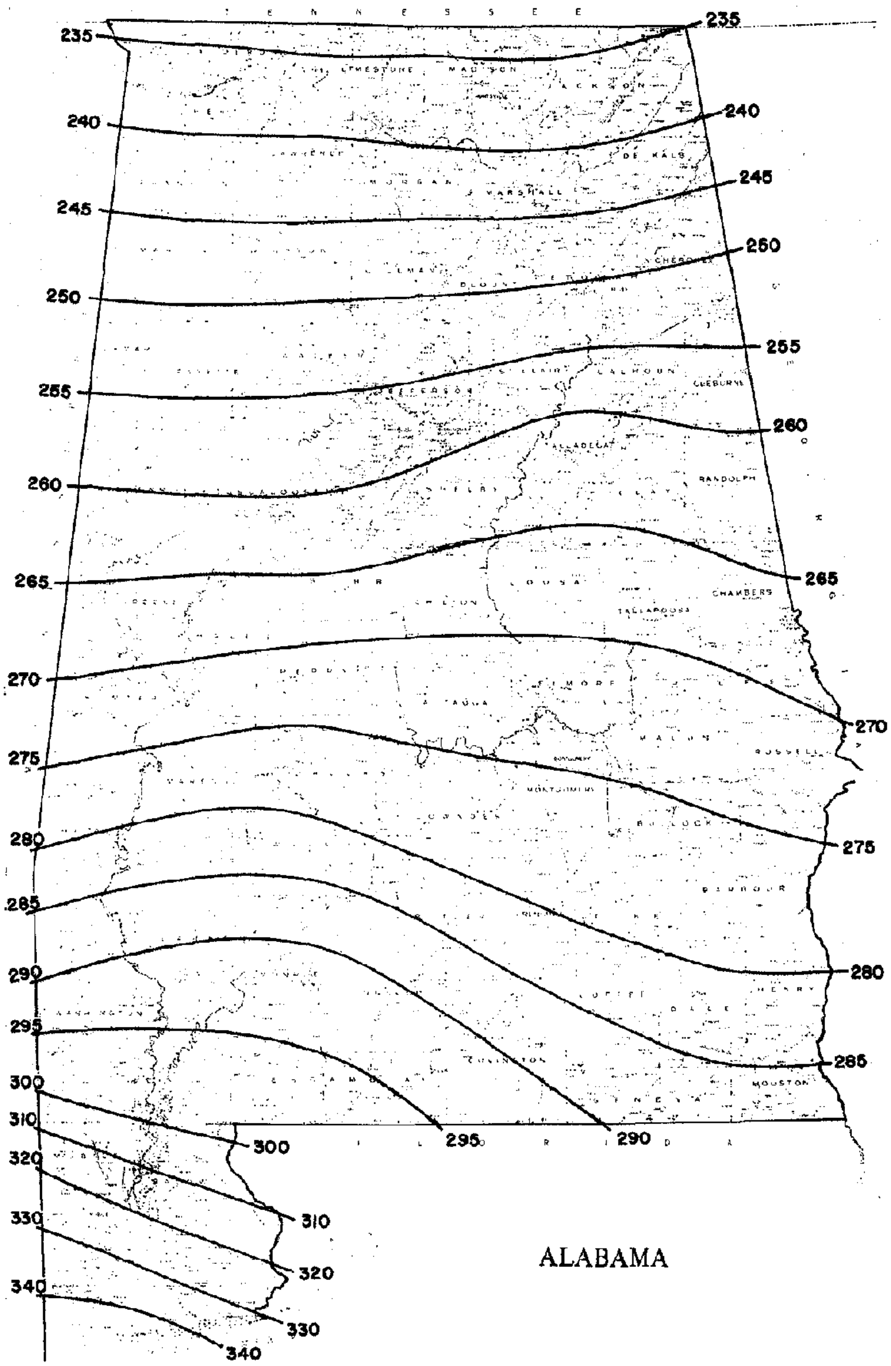
APPENDIX D

10-Year, 1-Hour Precipitation, P_{60} for Each of the Contiguous States of the United States, Alaska, Hawaii, and Puerto Rico. The Numbers are Those Assigned by the U.S. Geological Survey.

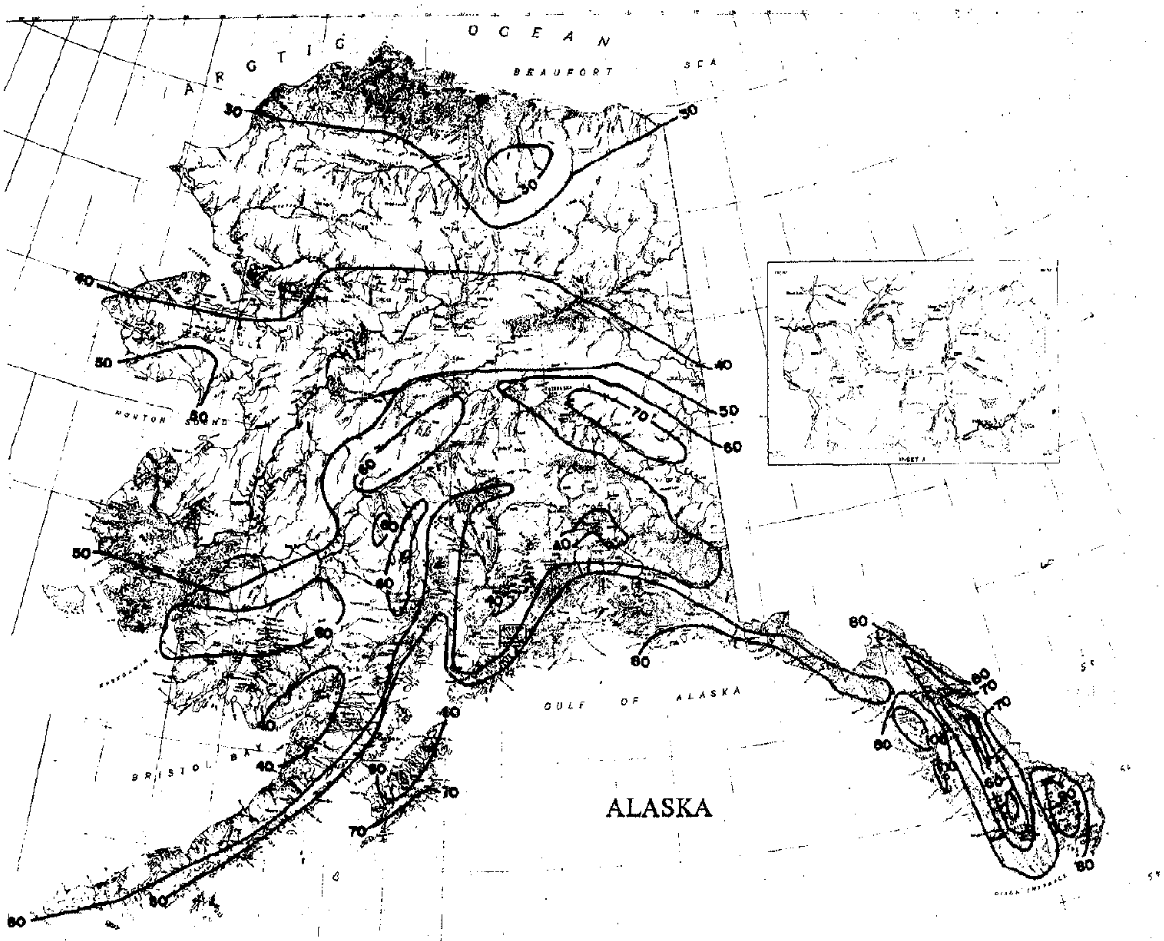
Appendix D contains state maps of the 10-year 1-hour precipitation for each of the states and Puerto Rico. The values were computed from WB-40 and NOAA ATLAS 2, W.B. Technical Papers 42 and 47 by the regressions given in each publication. Isohyetal values are plotted in hundredths of an inch.

NOTE:

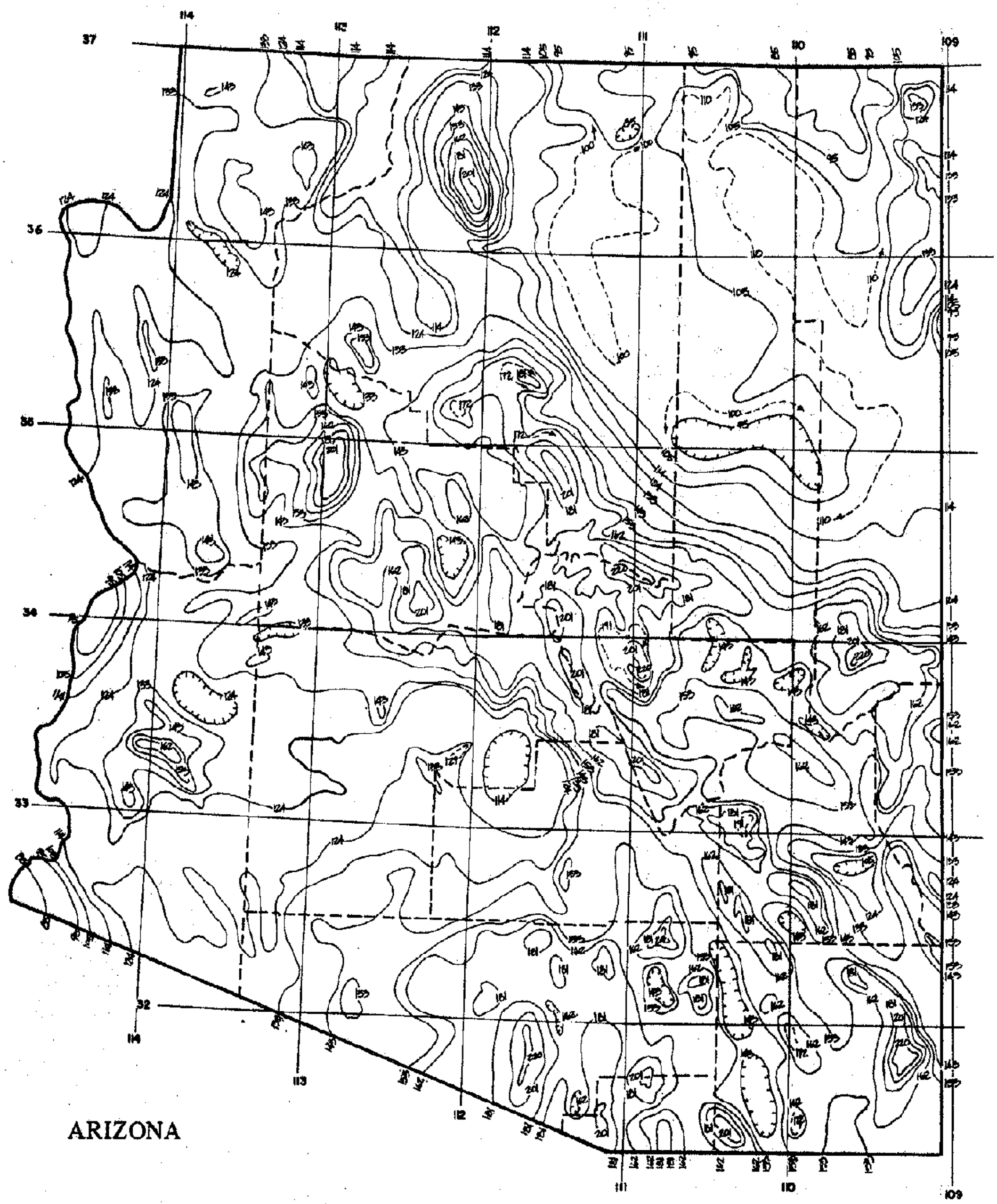
Scales of maps are different because some maps were not available in a proper scale or it would be impractical to show for example Texas in the same scale as Rhode Island.



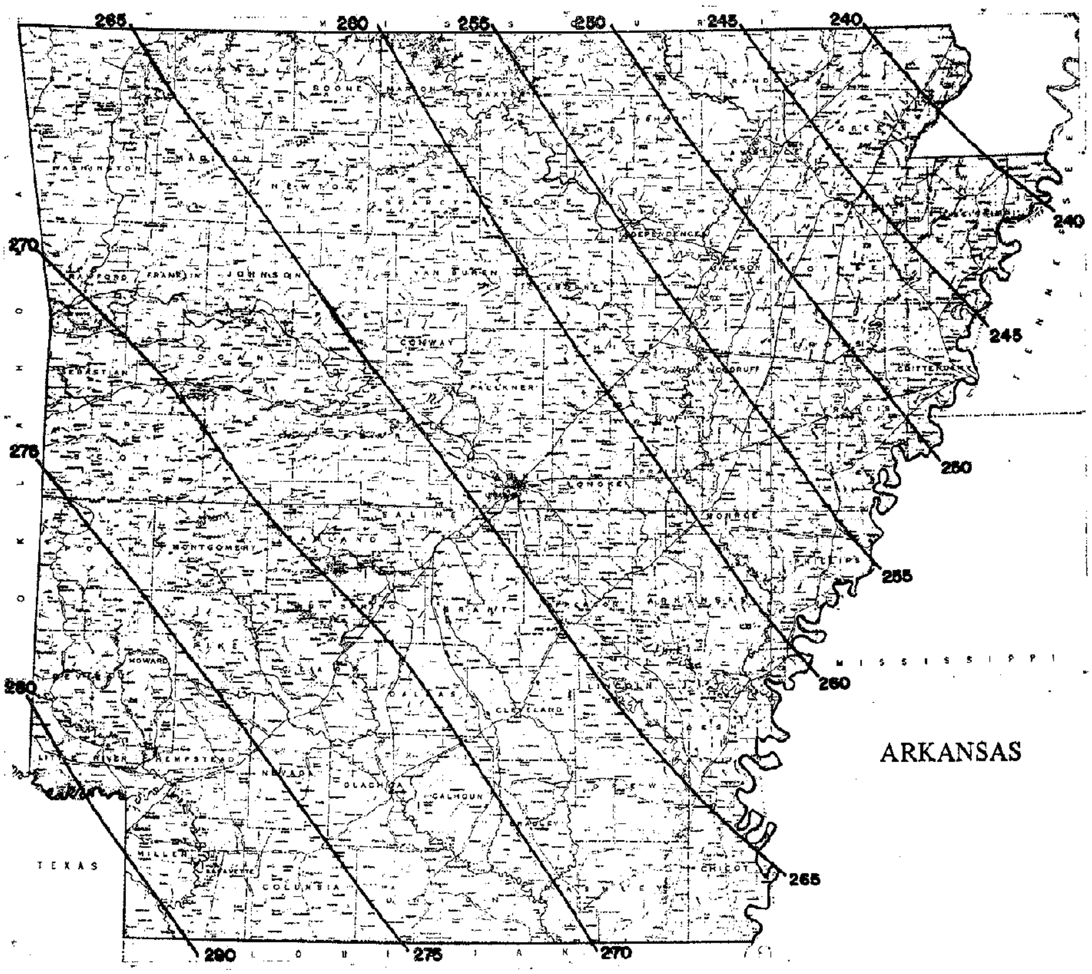
Appendix D-01. Isohyetal map of 10-year 1-hour rainfall for Alabama.



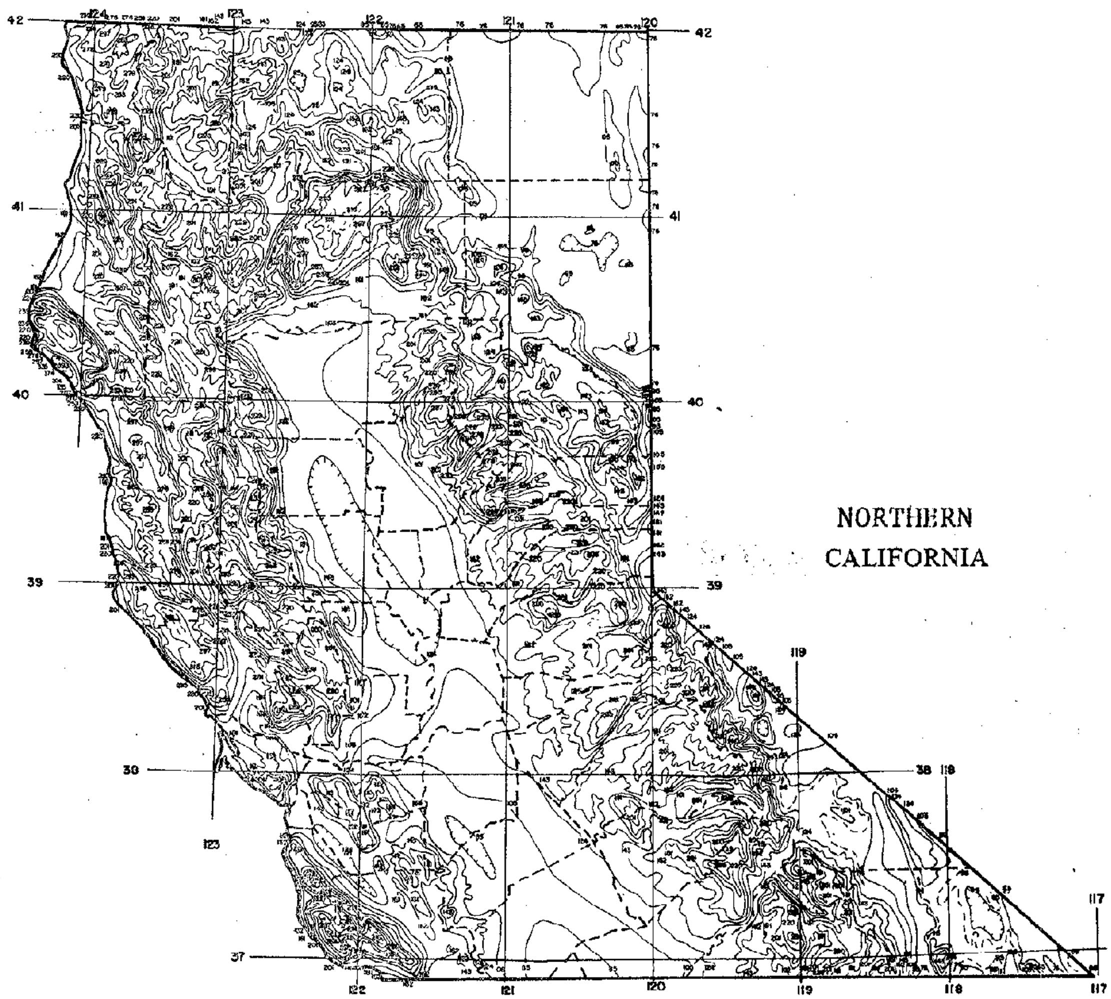
Appendix D-02. Isohyetal map of 10-year 1-hour rainfall for Alaska.



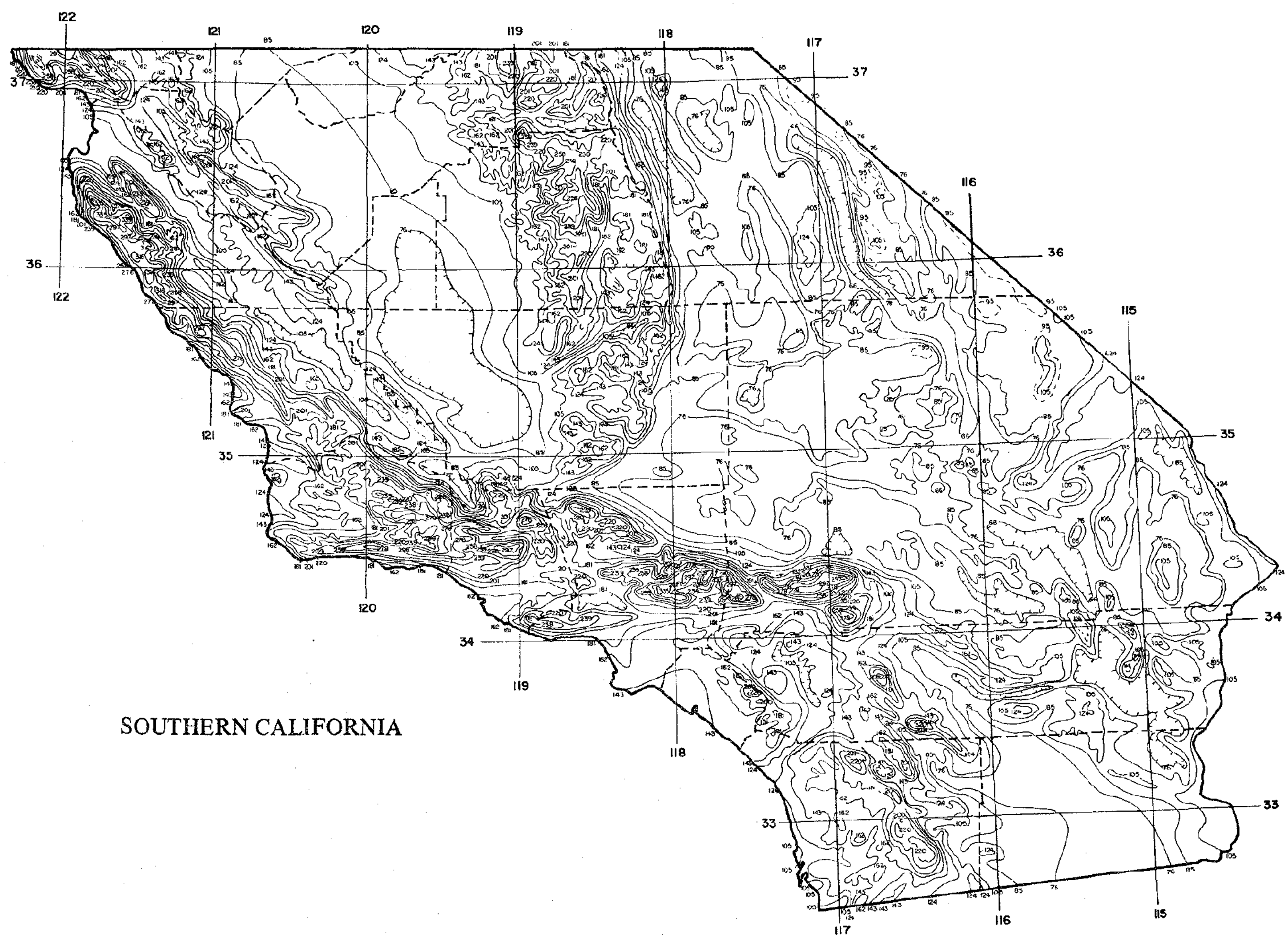
Appendix D-04. Isohyetal map of 10-year 1-hour rainfall for Arizona.



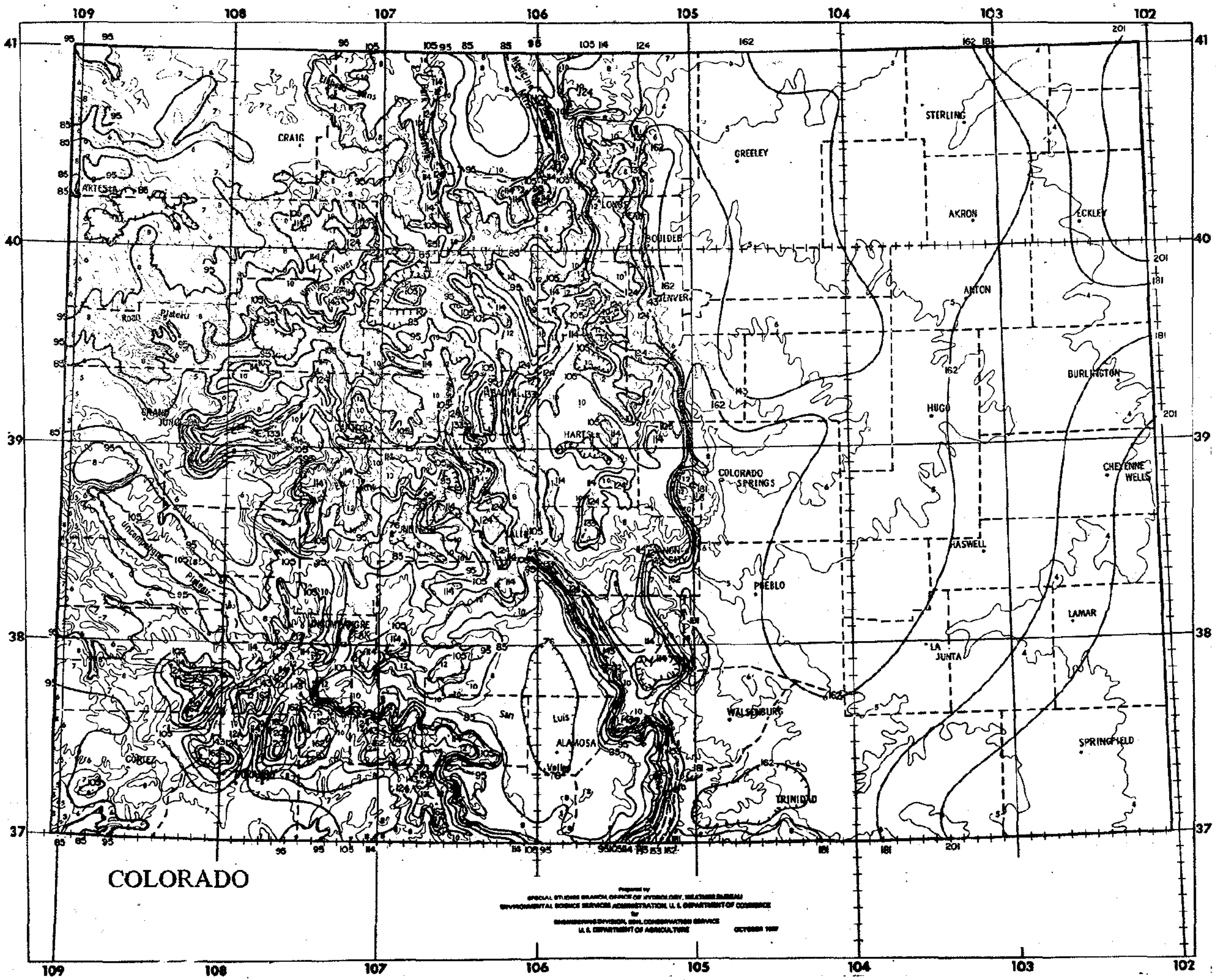
Appendix D-05. Isohyetal map of 10-year 1-hour rainfall for Arkansas.



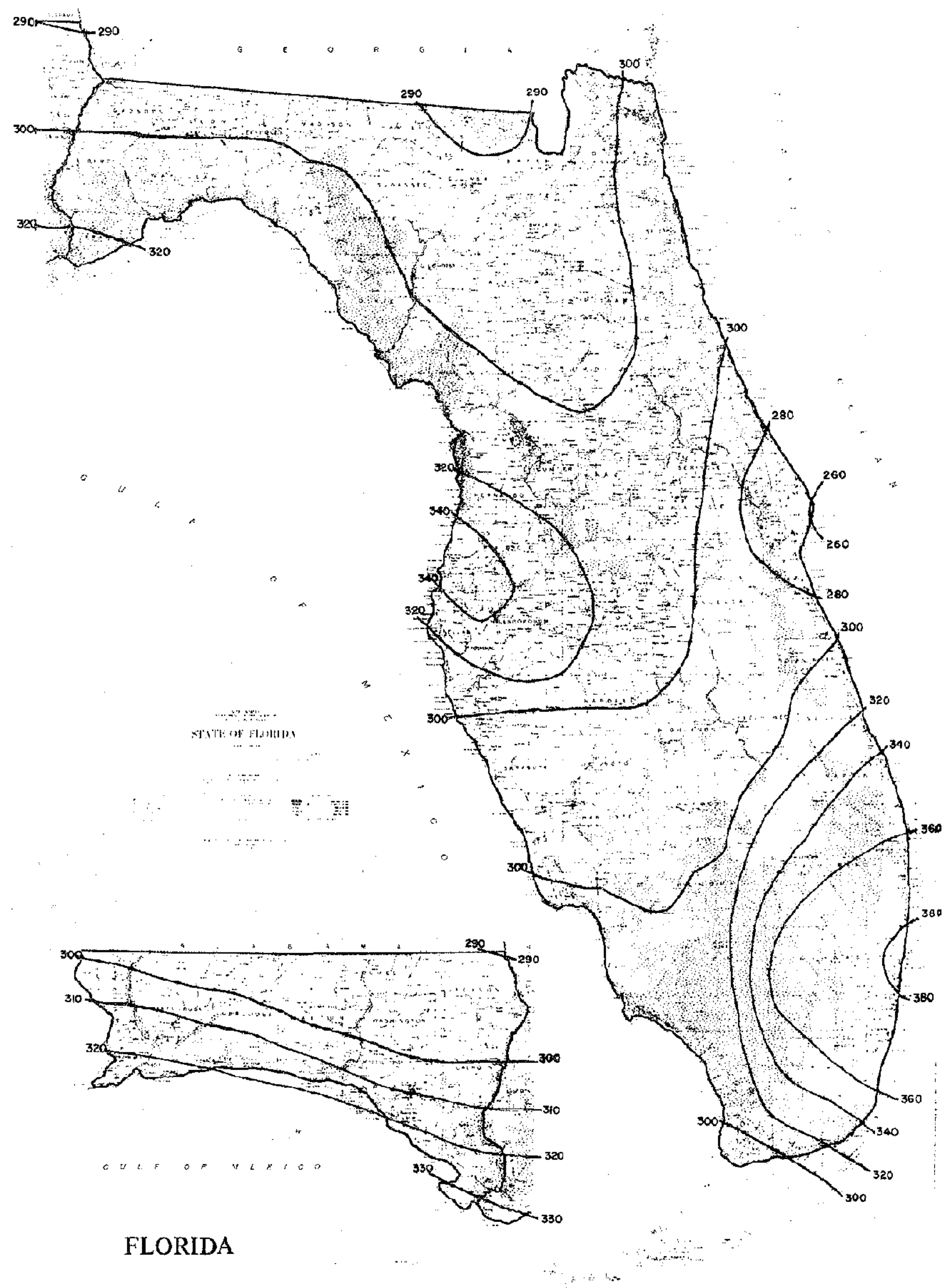
Appendix D-06a. Isohyetal map of 10-year 1-hour rainfall for N. California.



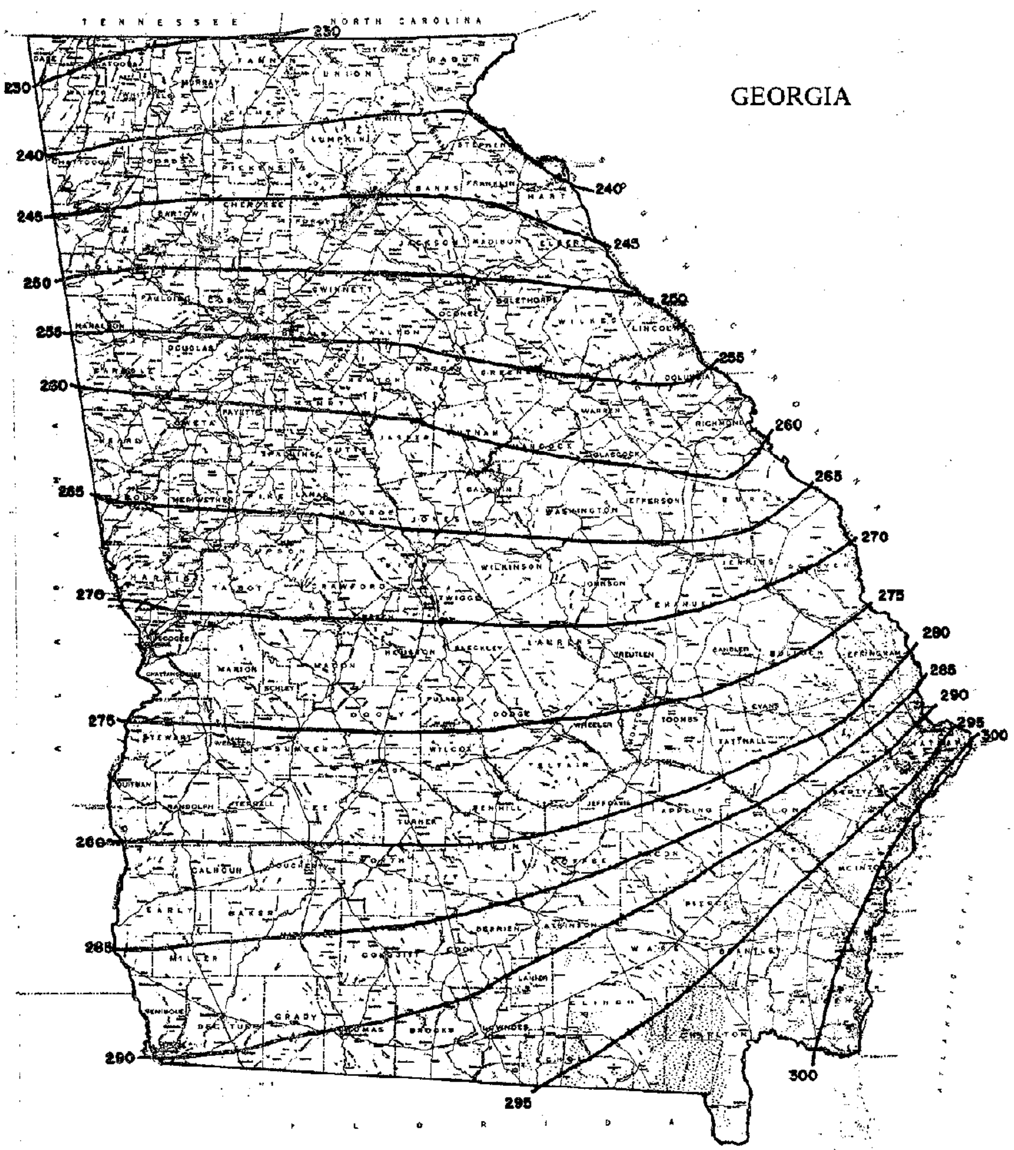
Appendix D-06b. Isohyetal map of 10-year 1-hour rainfall for S. California.



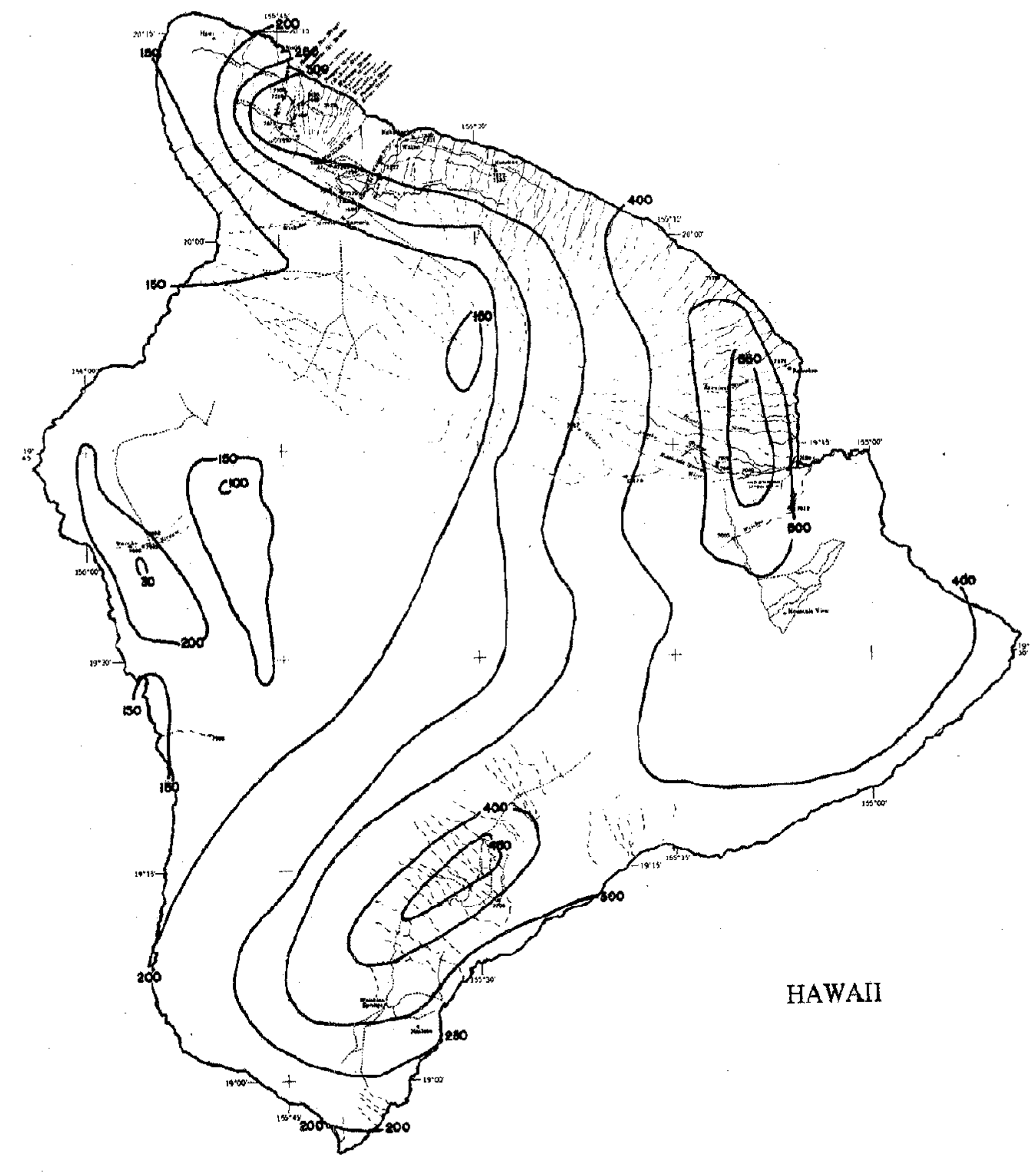
Appendix D-08. Isohyetal map of 10-year 1-hour rainfall for Colorado.



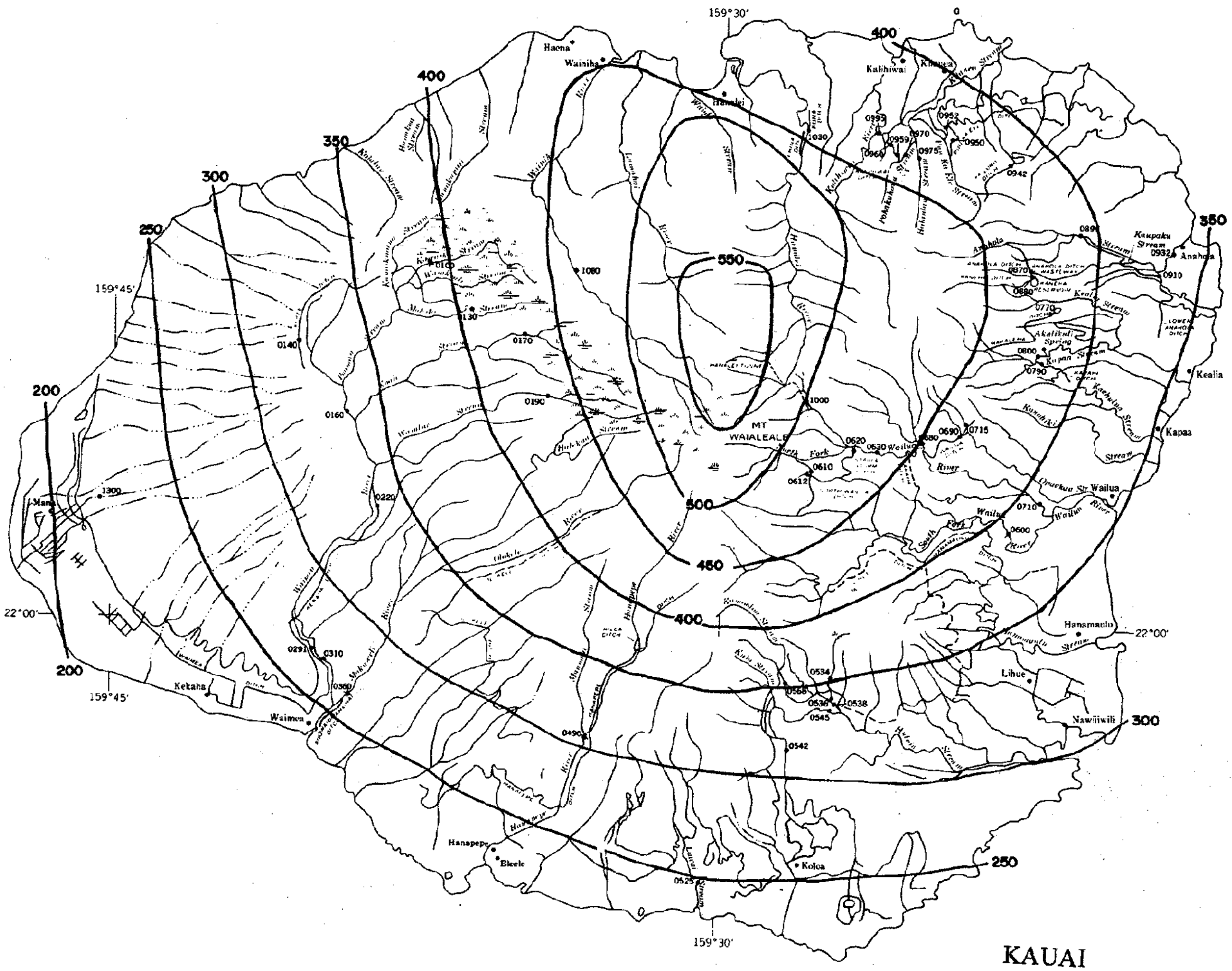
Appendix D-12. Isohyetal map of 10-year 1-hour rainfall for Florida.



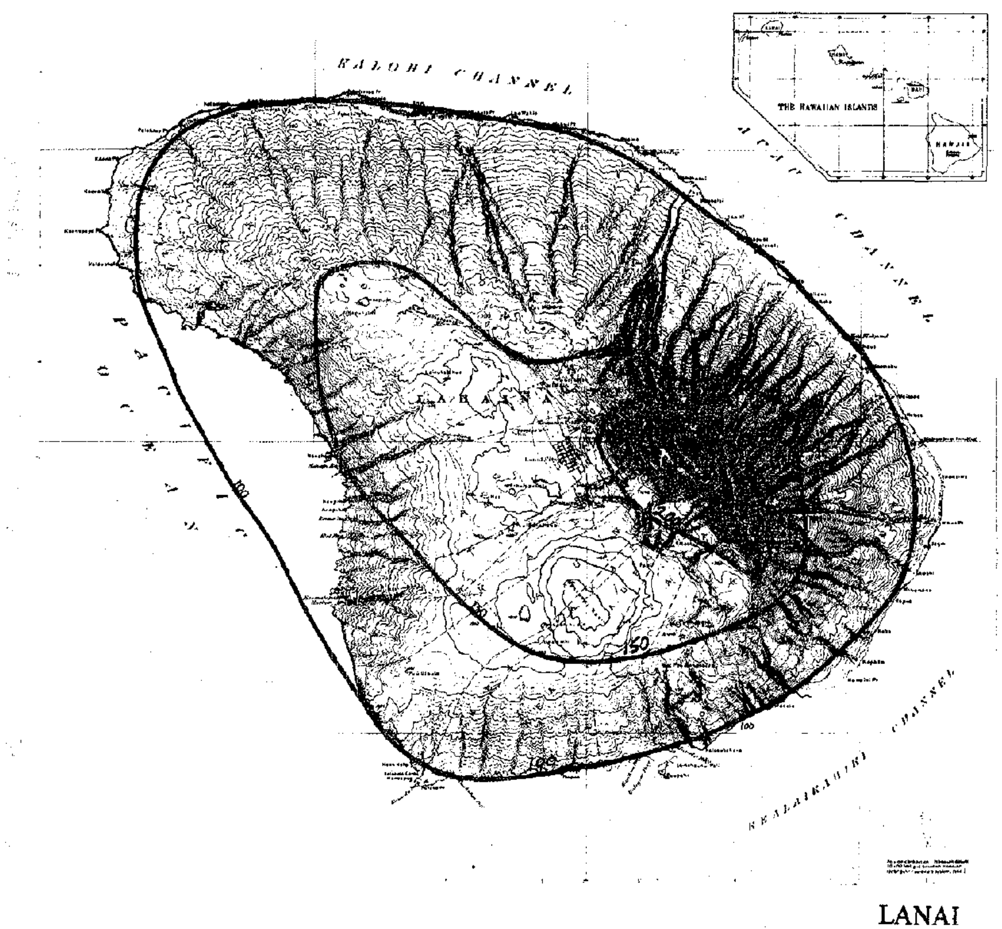
Appendix D-13. Isohyetal map of 10-year 1-hour rainfall for Georgia.



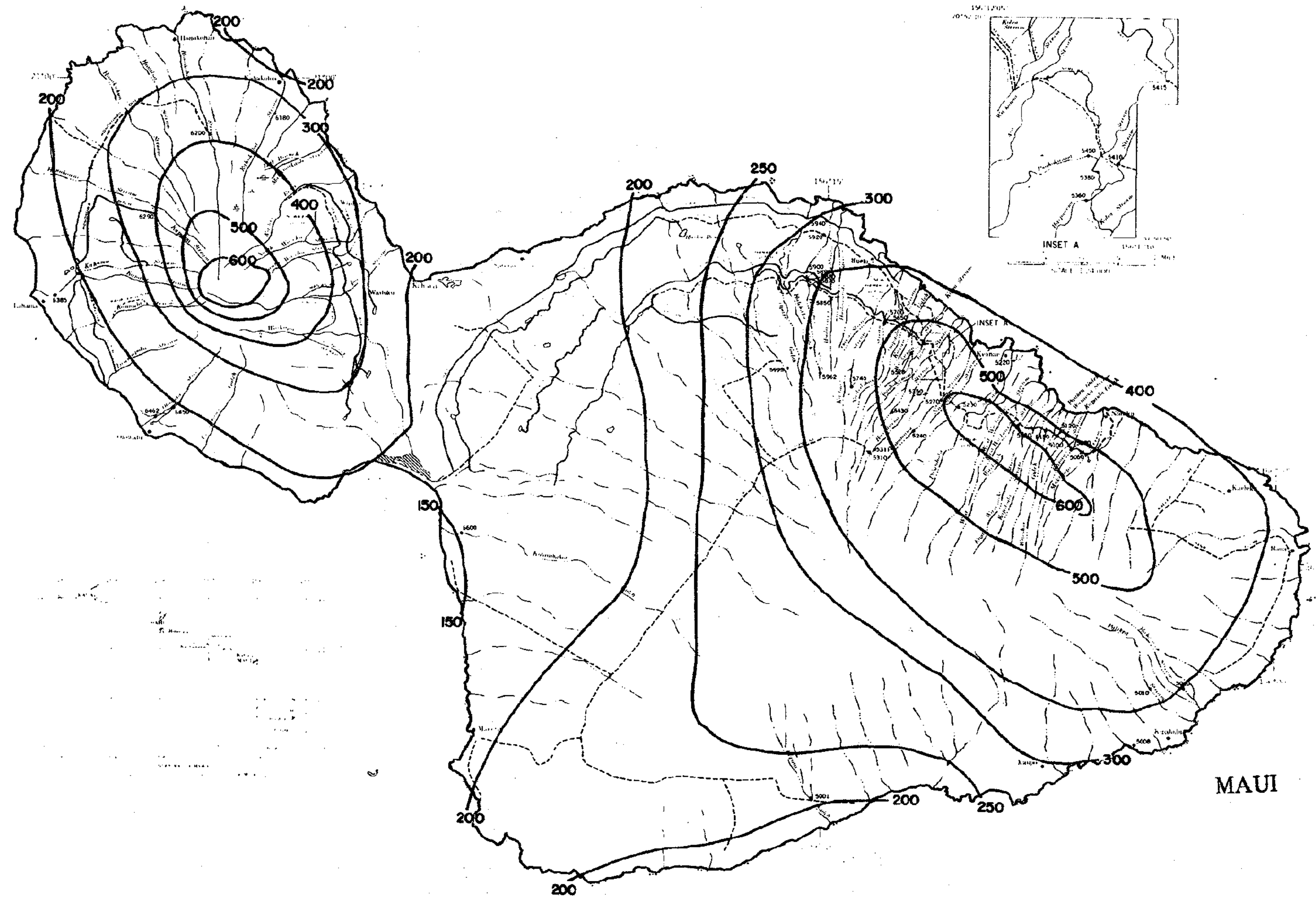
Appendix D-15a. Isohyetal map of 10-year 1-year rainfall for Hawaii.



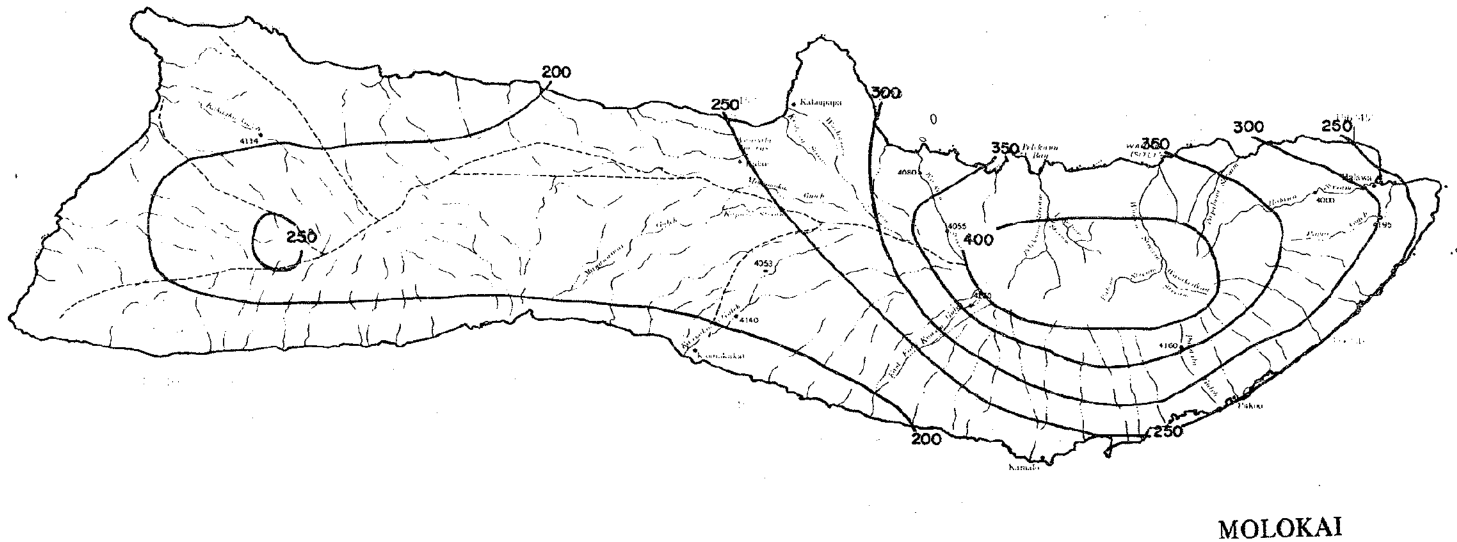
Appendix D-15b. Isohyetal map of 10-year 1-hour rainfall for Kauai, Hawaii.



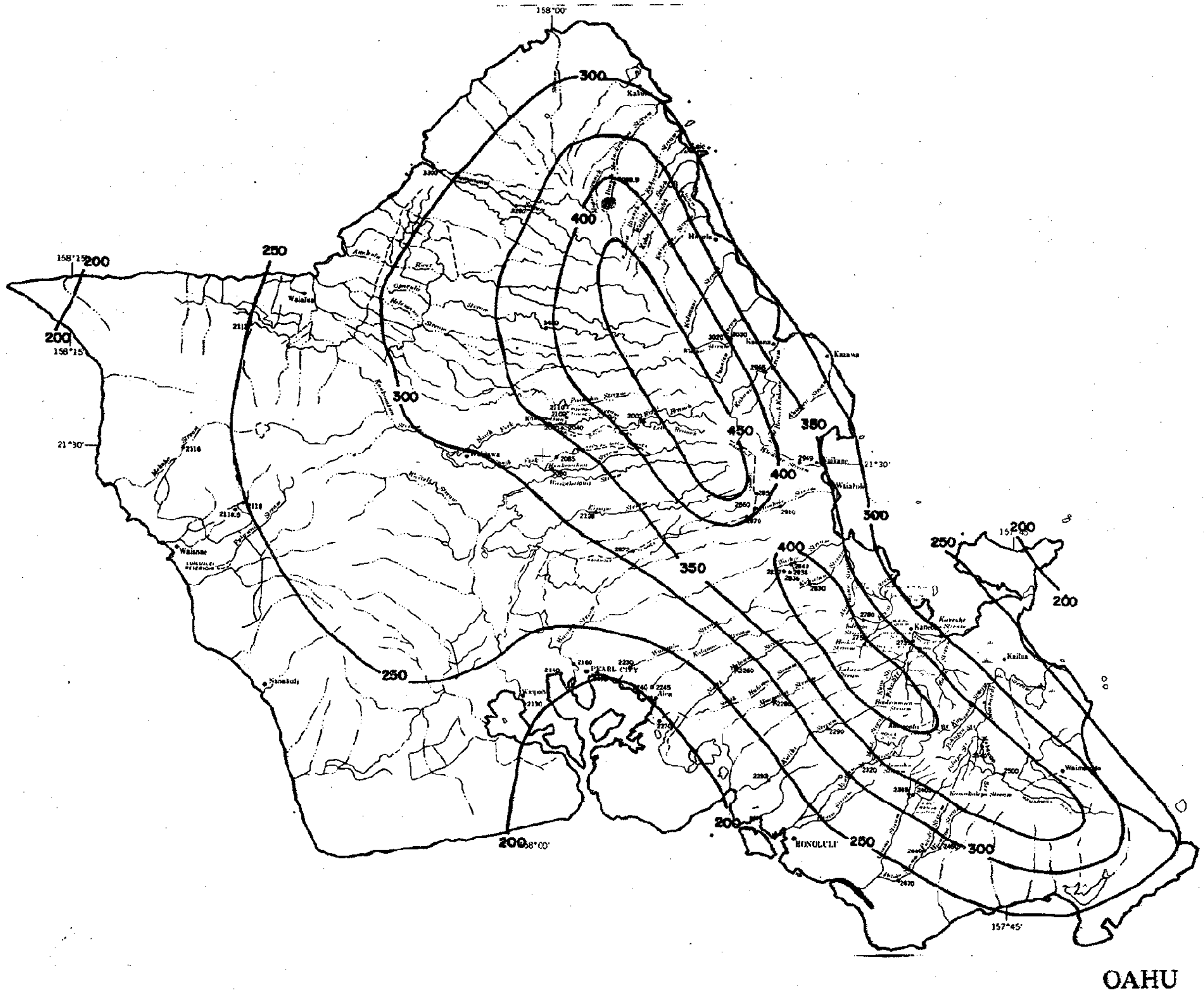
Appendix D-15c. Isohyetal map of 10-year 1-hour rainfall for Lanai, Hawaii.



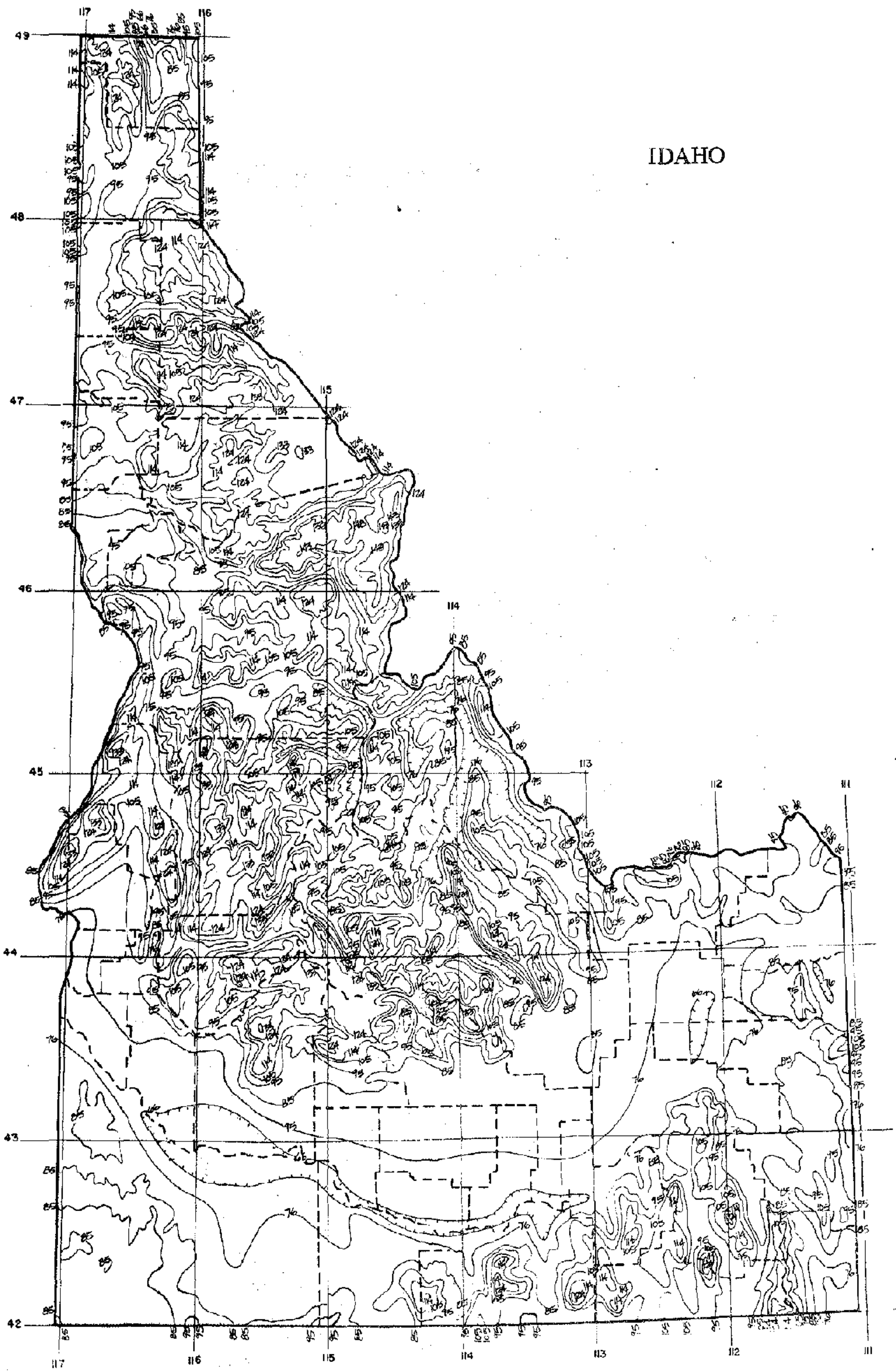
Appendix D-15d. Isohyetal map of 10-year 1-hour rainfall for Maui, Hawaii.



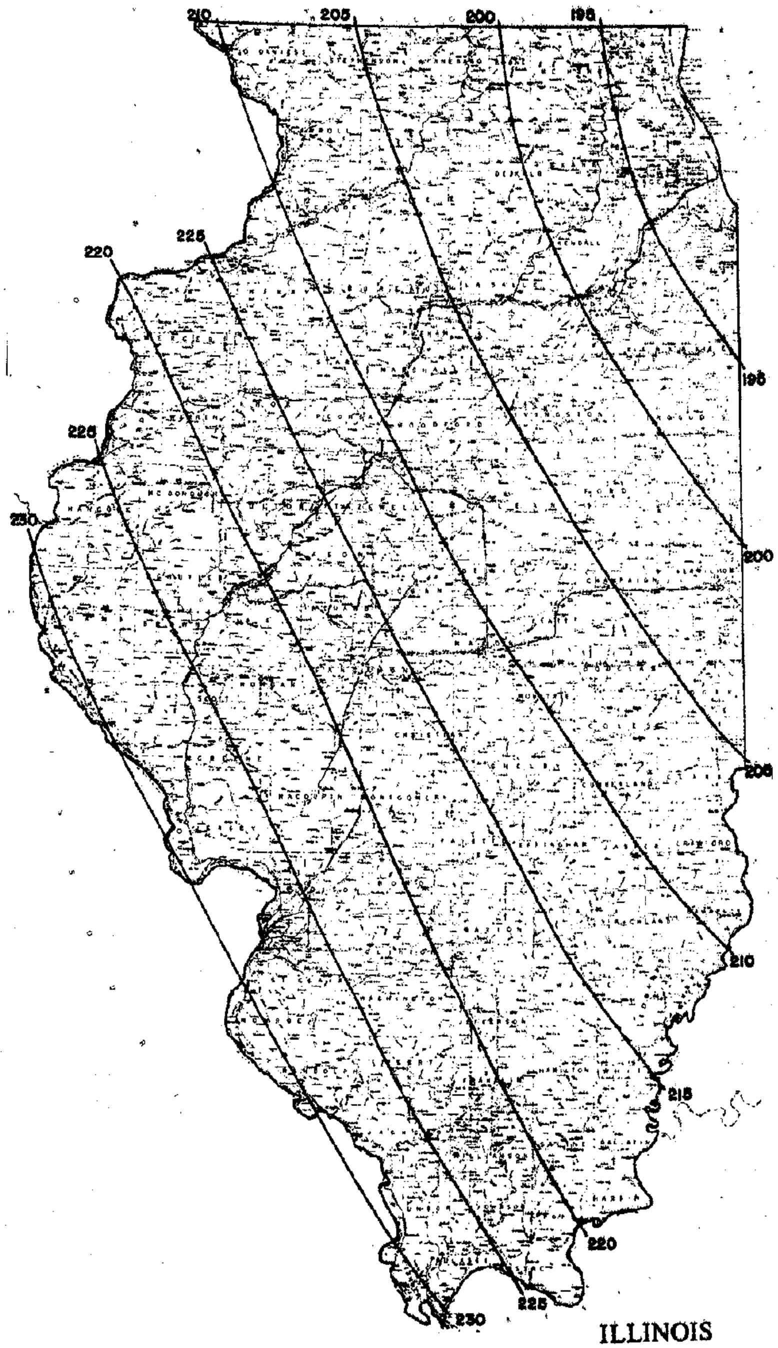
Appendix D-15e. Isohyetal map of 10-year 1-hour rainfall for Molokai, Hawaii.



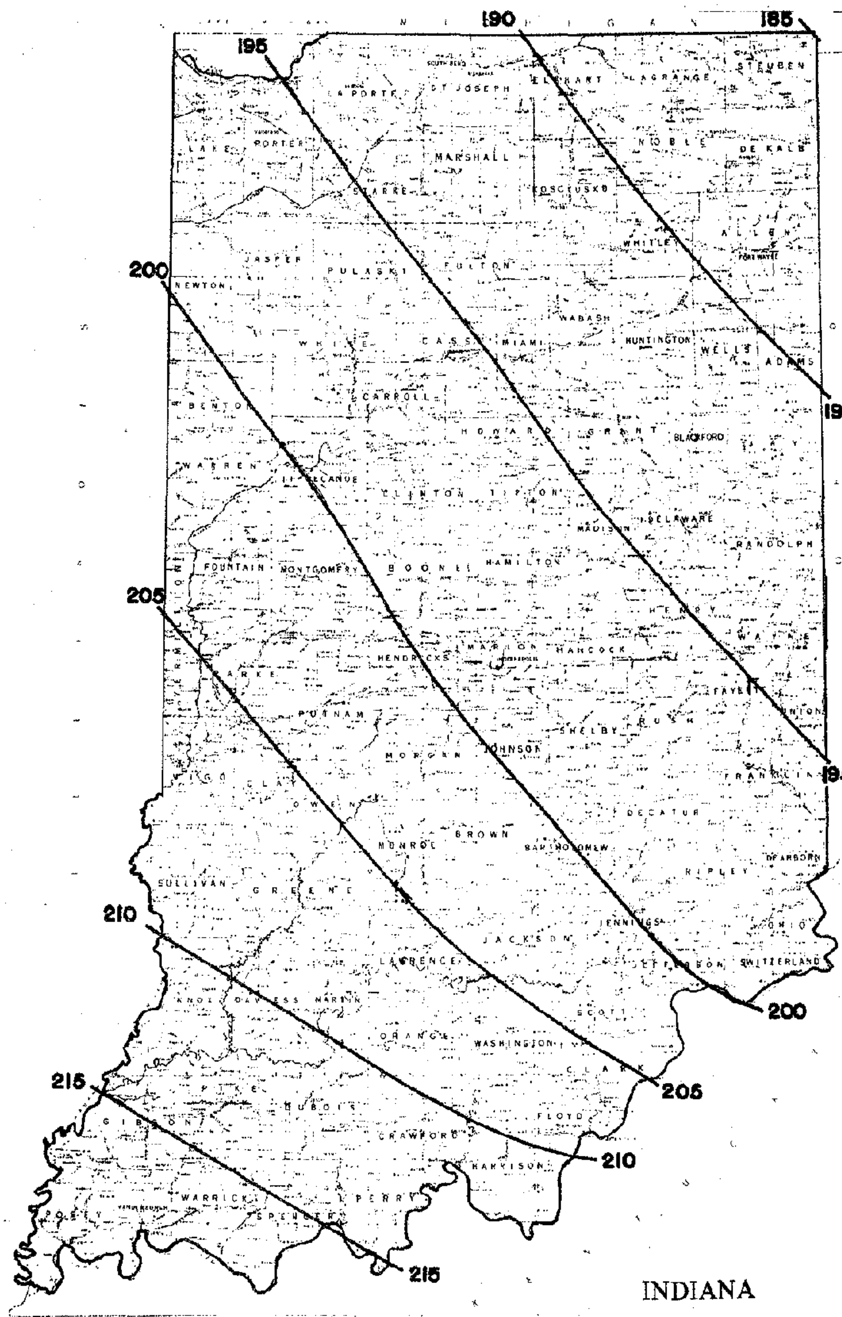
Appendix D-15f. Isohyetal map of 10-year 1-hour rainfall for Oahu, Hawaii.



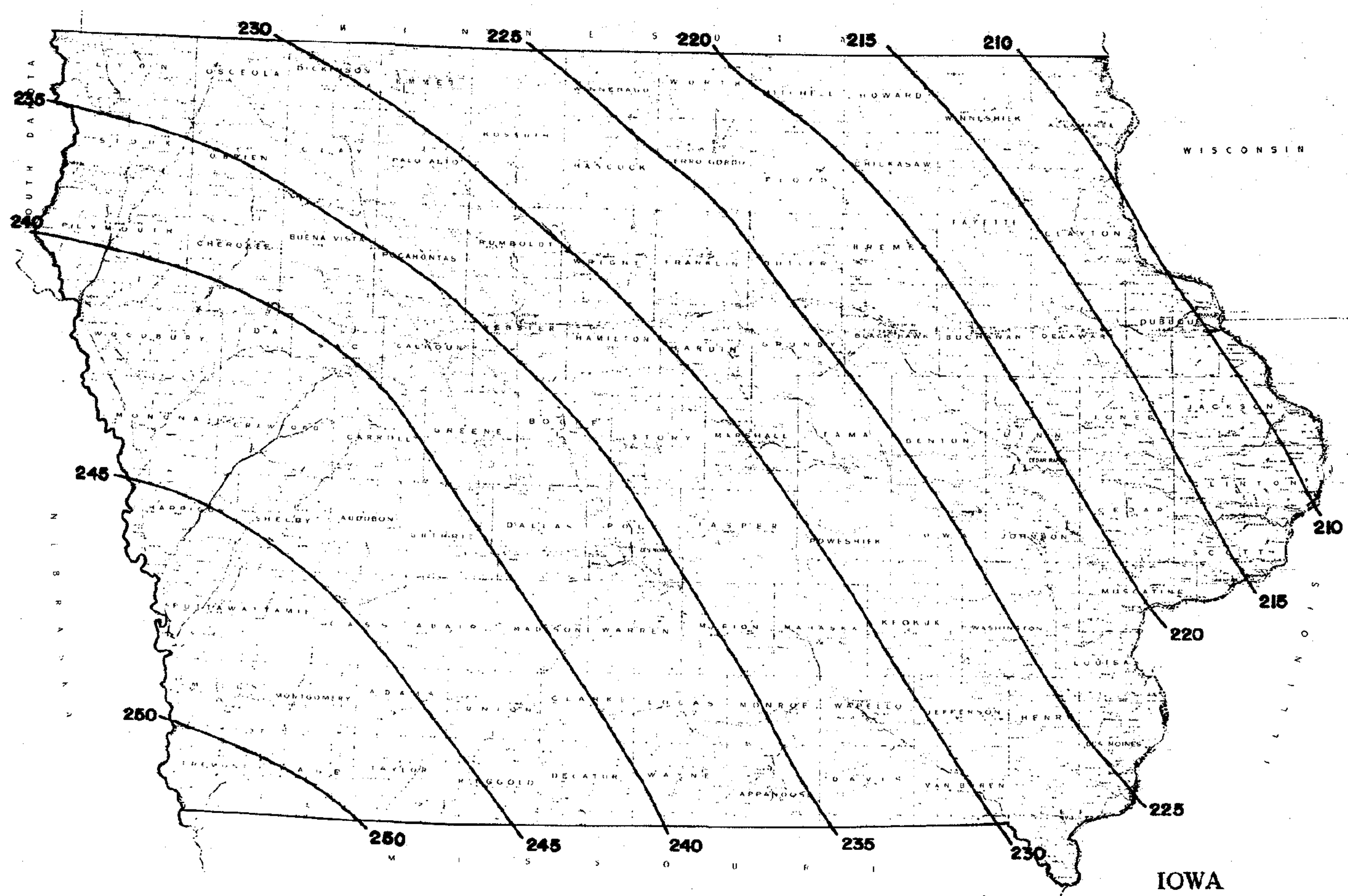
Appendix D-16. Isohyetal map of 10-year 1-hour rainfall for Idaho.



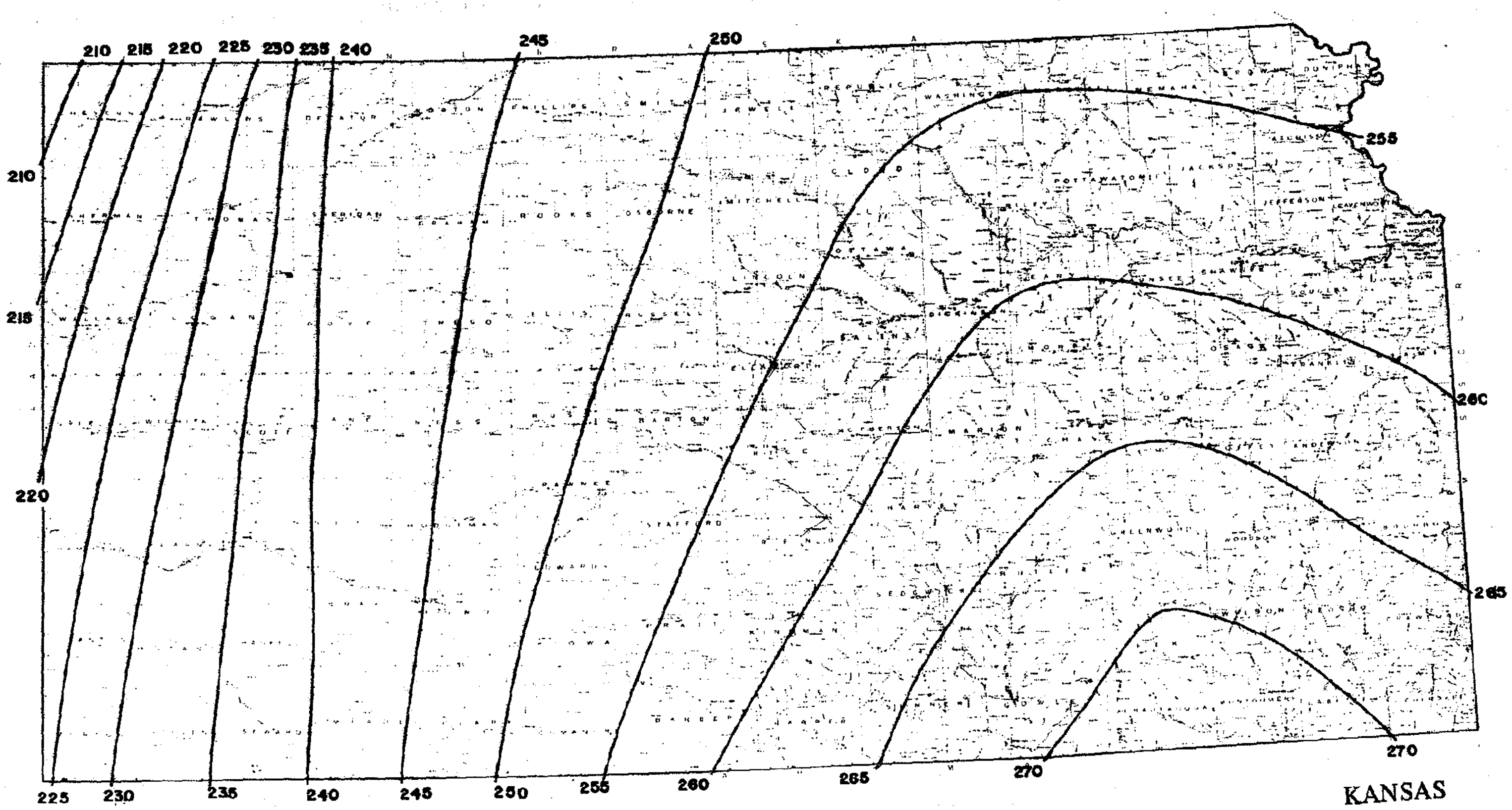
Appendix D-17. Isohyetal map of 10-year 1-hour rainfall for Illinois.



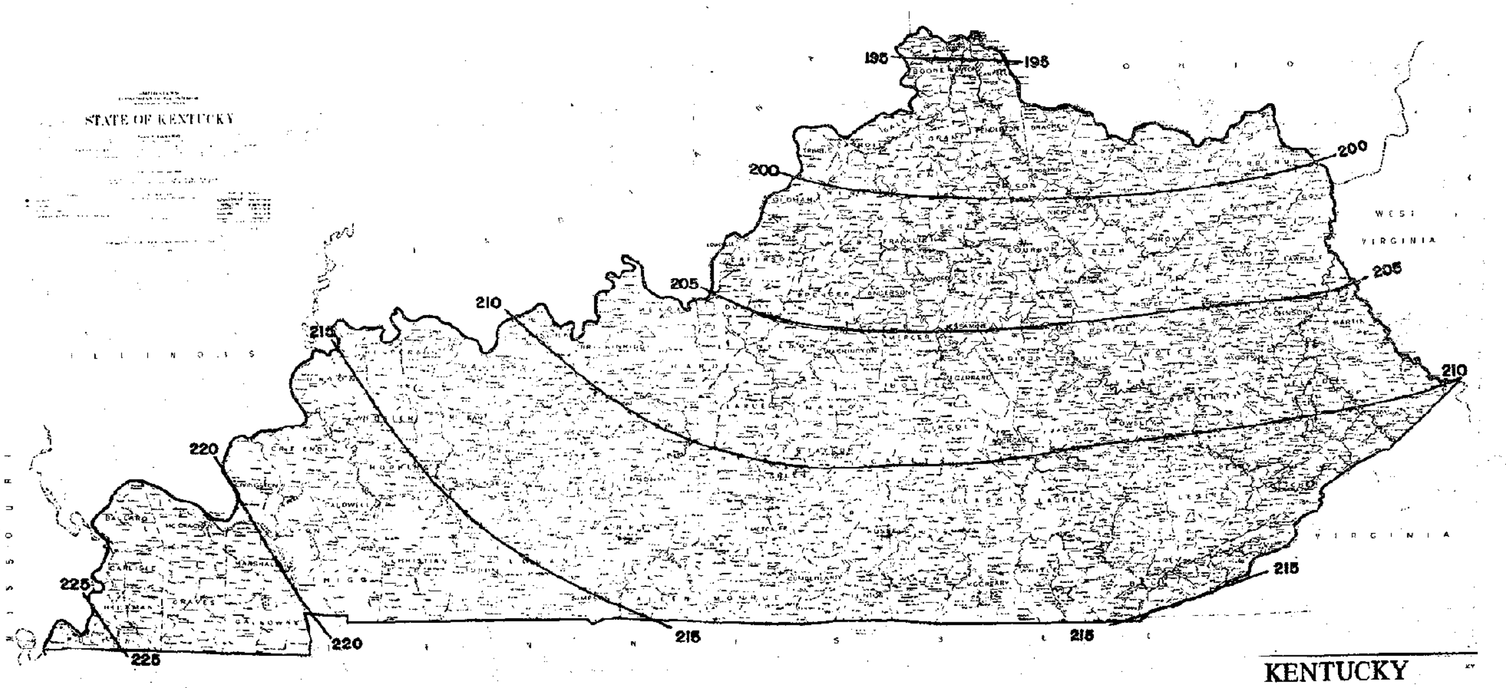
Appendix D-18. Isohyetal map of 10-year 1-hour rainfall for Indiana.



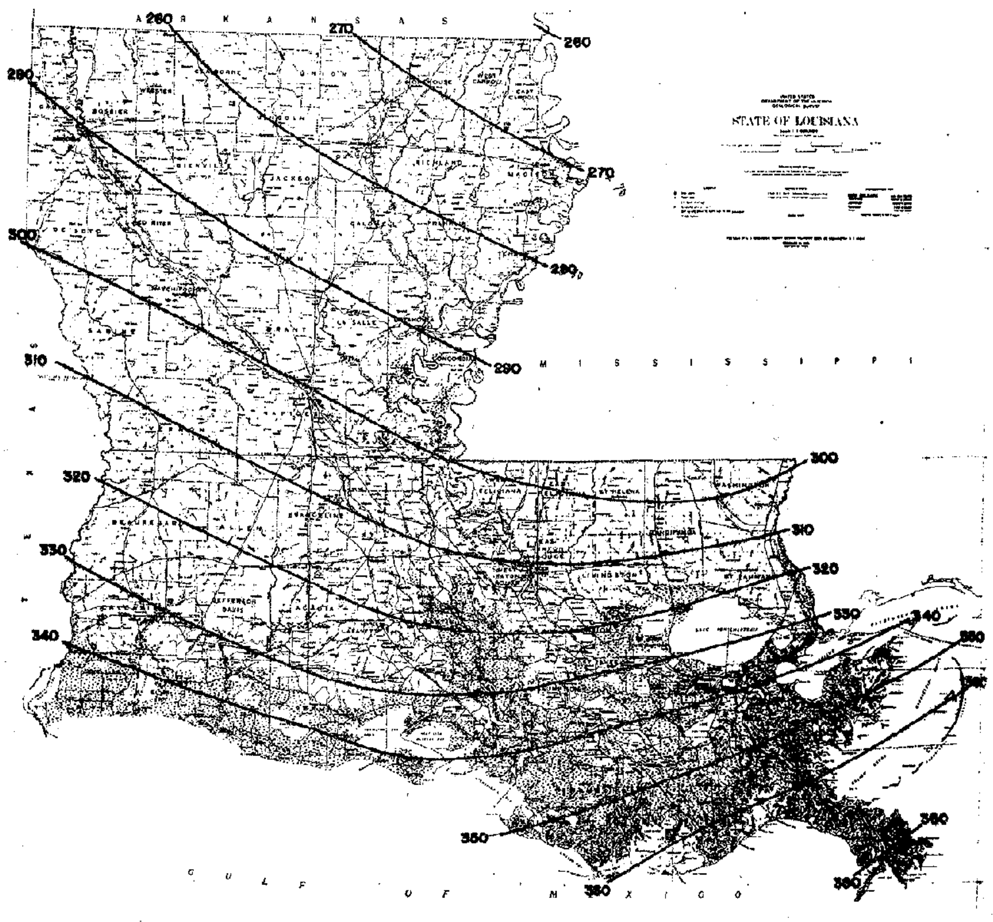
Appendix D-19. Isohyetal map of 10-year 1-hour rainfall for Iowa.



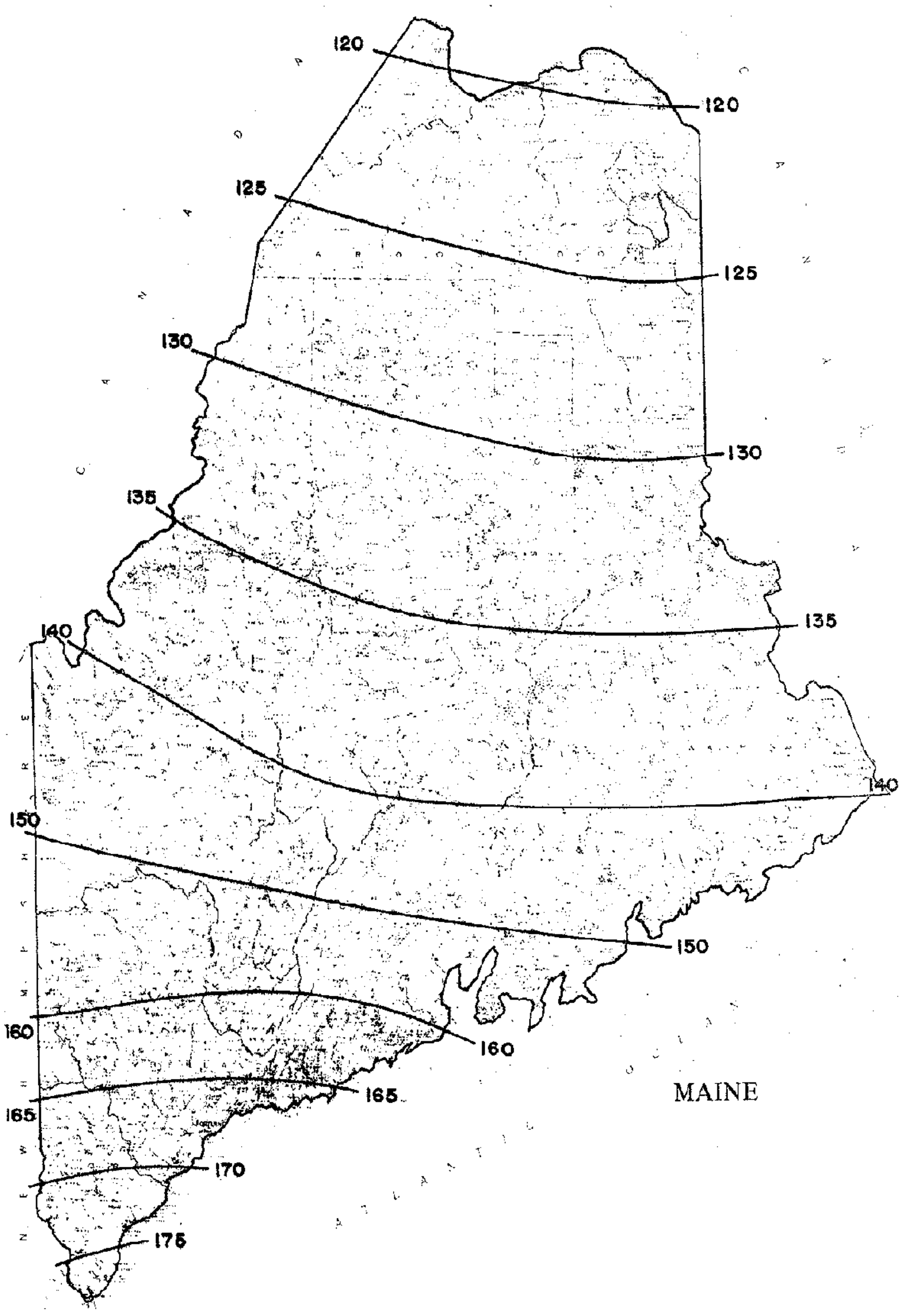
Appendix D-20. Isohyetal map of 10-year 1-hour rainfall for Kansas.



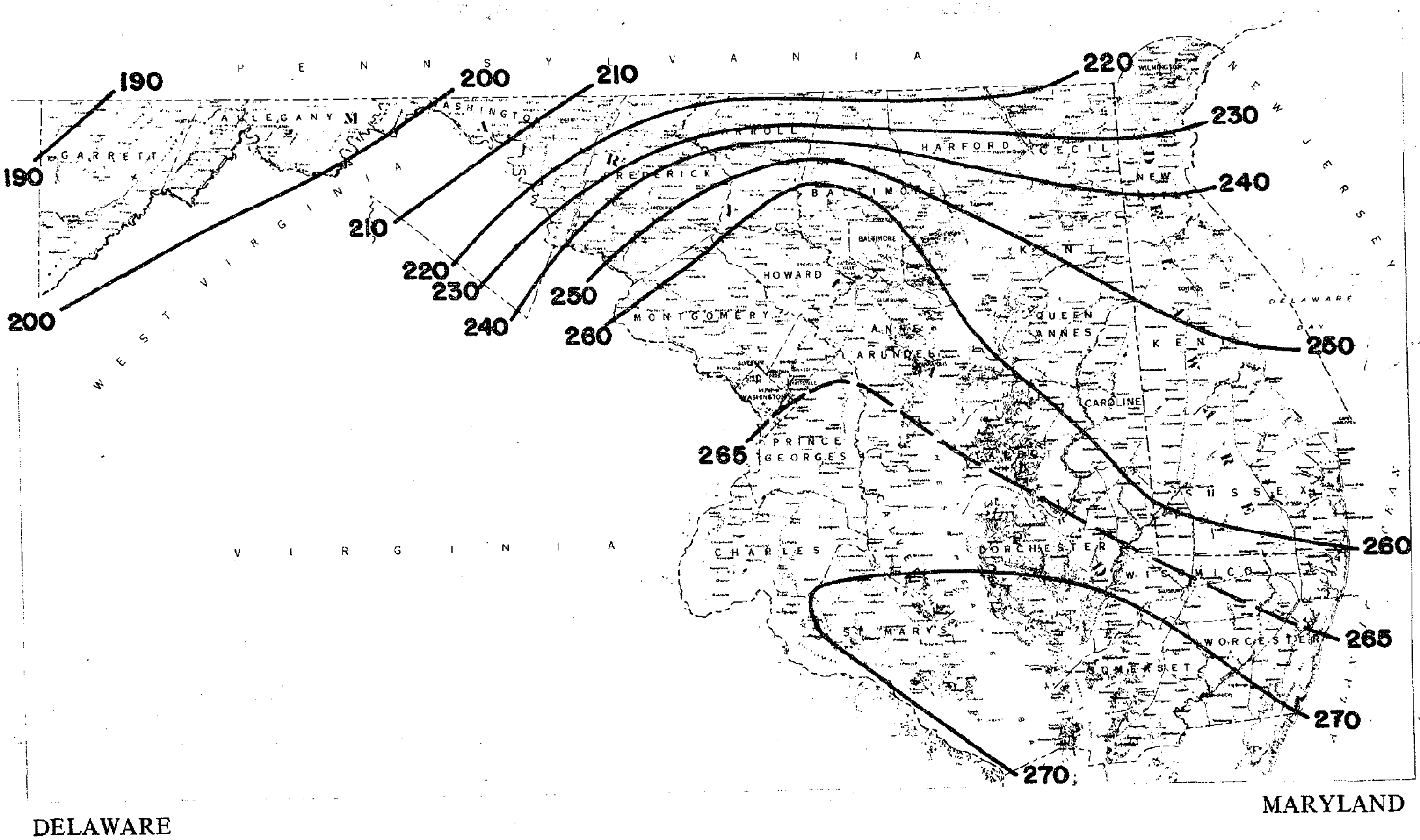
Appendix D-21. Isohyetal map of 10-year 1-hour rainfall for Kentucky.



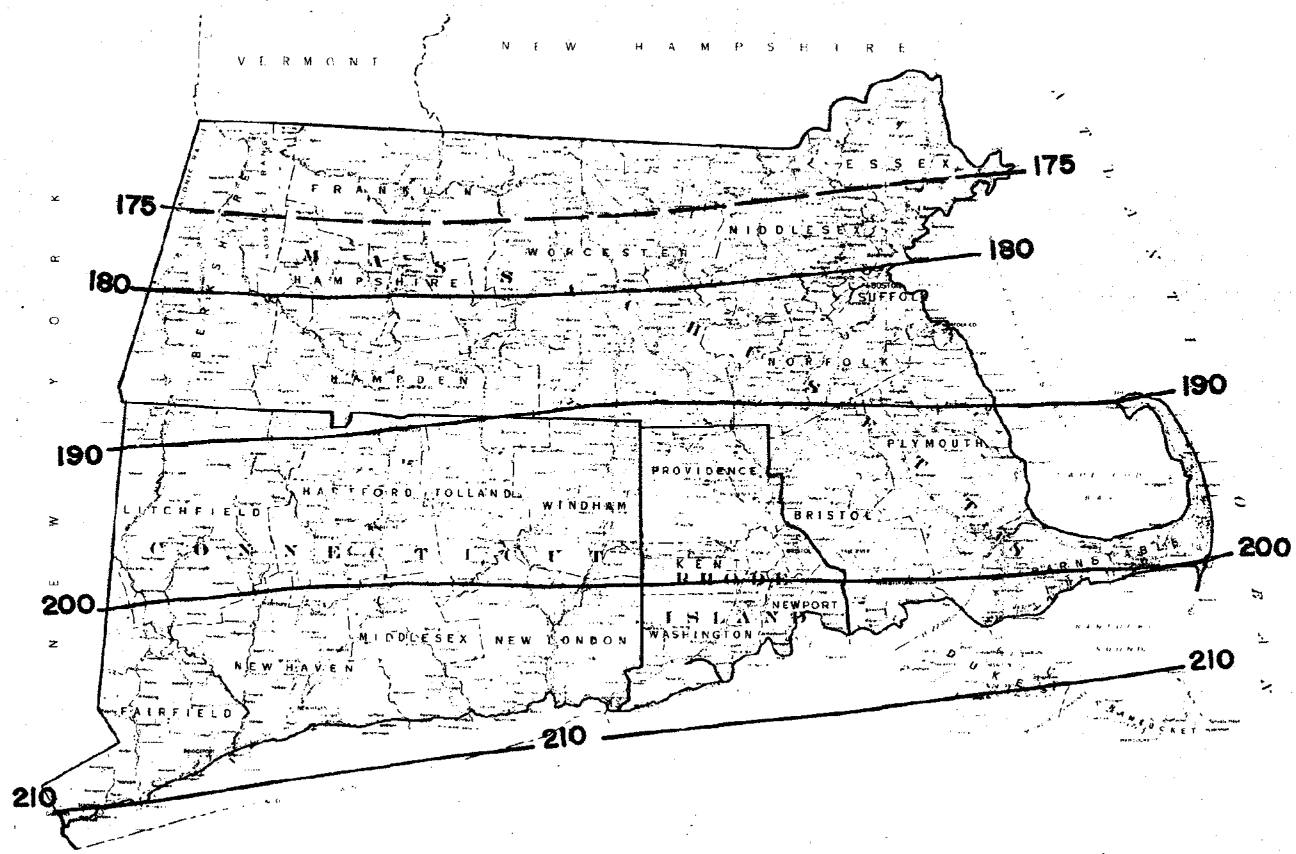
Appendix D-22. Isohyetal map of 10-year 1-hour rainfall for Louisiana.



Appendix D-23. Isohyetal map of 10-year 1-hour rainfall for Maine.

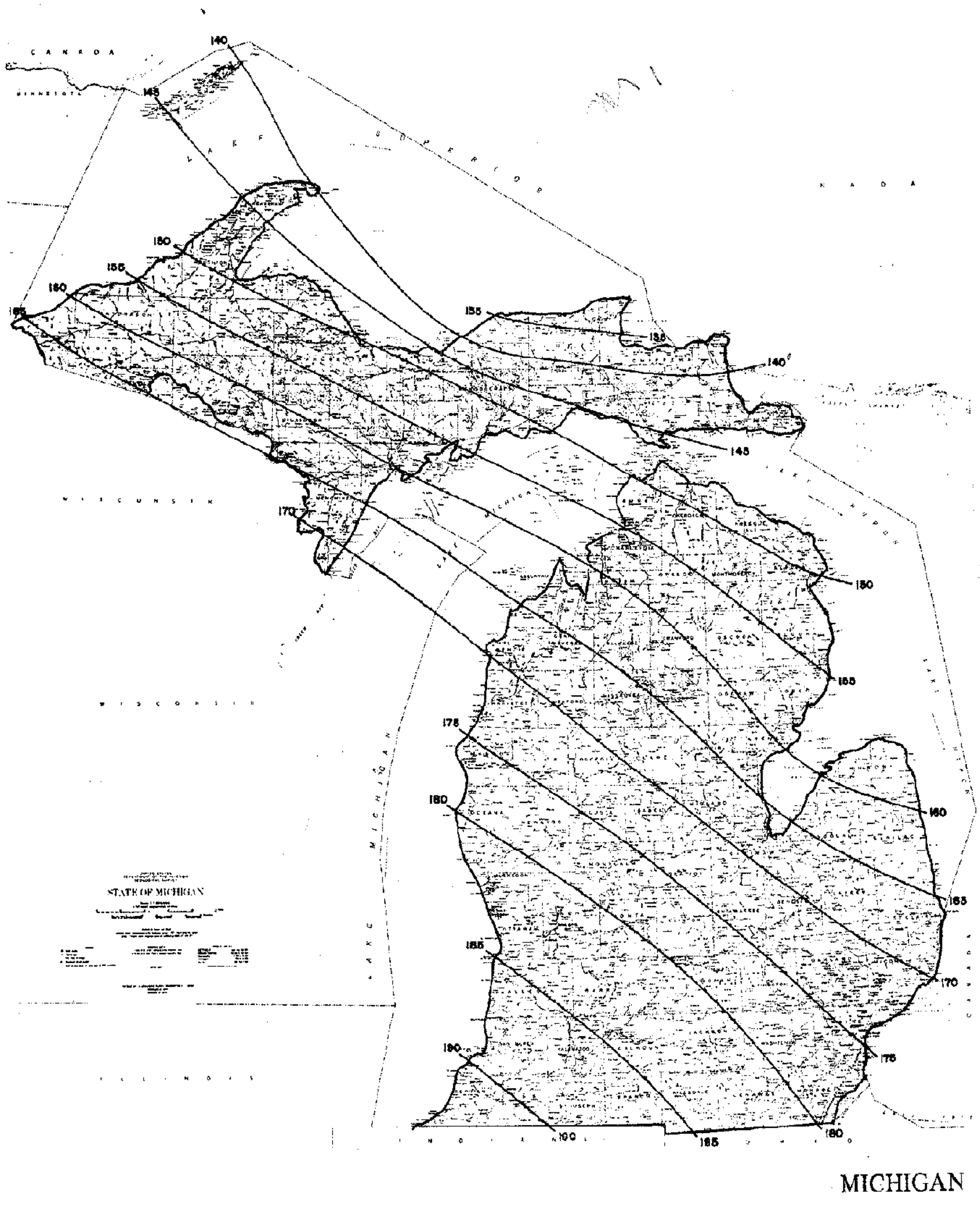


Appendix D-10. Isohyetal map of 10-year 1-hour rainfall for Delaware.
Appendix D-24. Isohyetal map of 10-year 1-hour rainfall for Maryland.



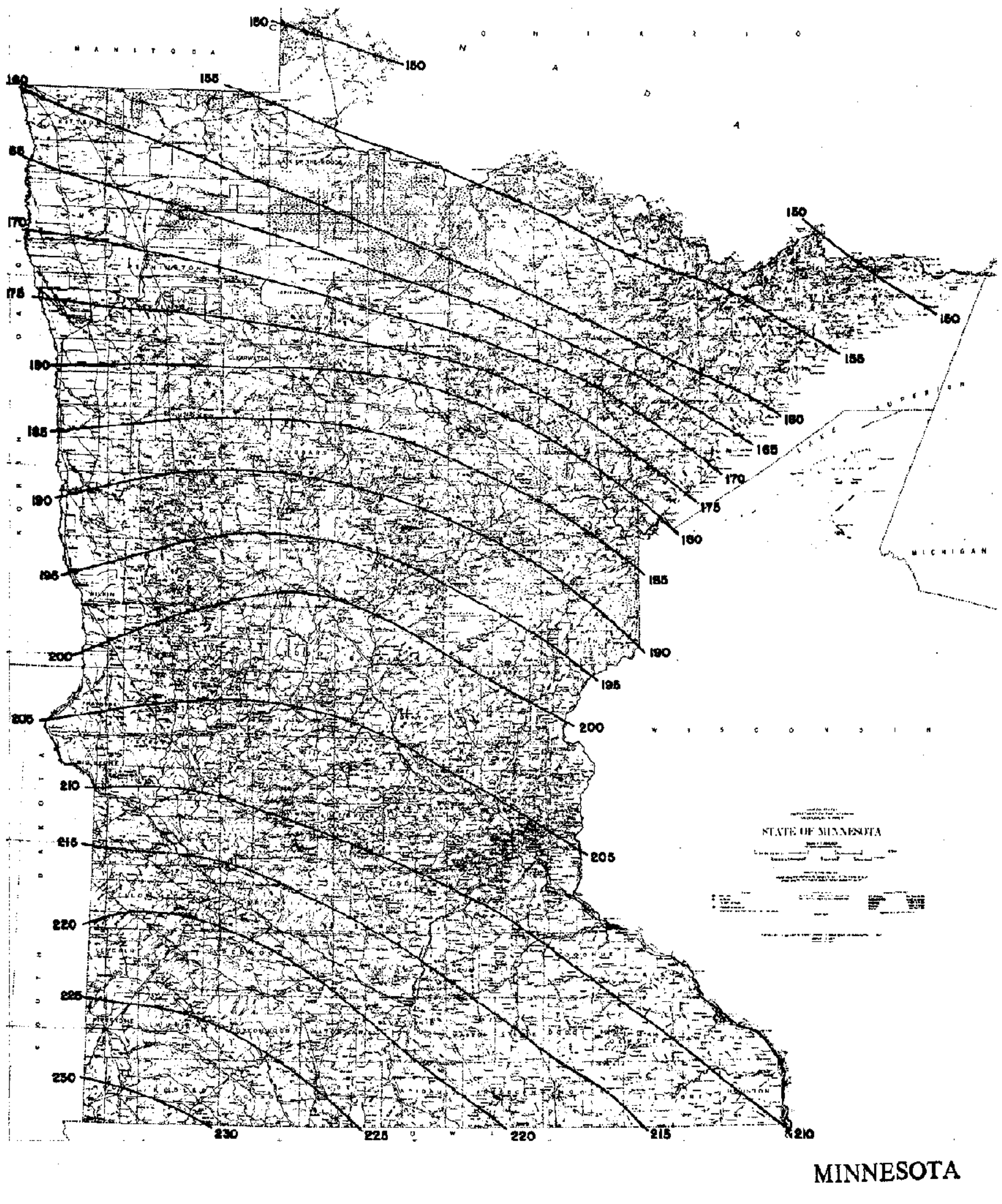
CONNECTICUT MASSACHUSETTS RHODE ISLAND

Appendix D-09. Isohyetal map of 10-year 1-hour rainfall for Connecticut.
Appendix D-25. Isohyetal map of 10-year 1-hour rainfall for Massachusetts.
Appendix D-44. Isohyetal map of 10-year 1-hour rainfall for Rhode Island.

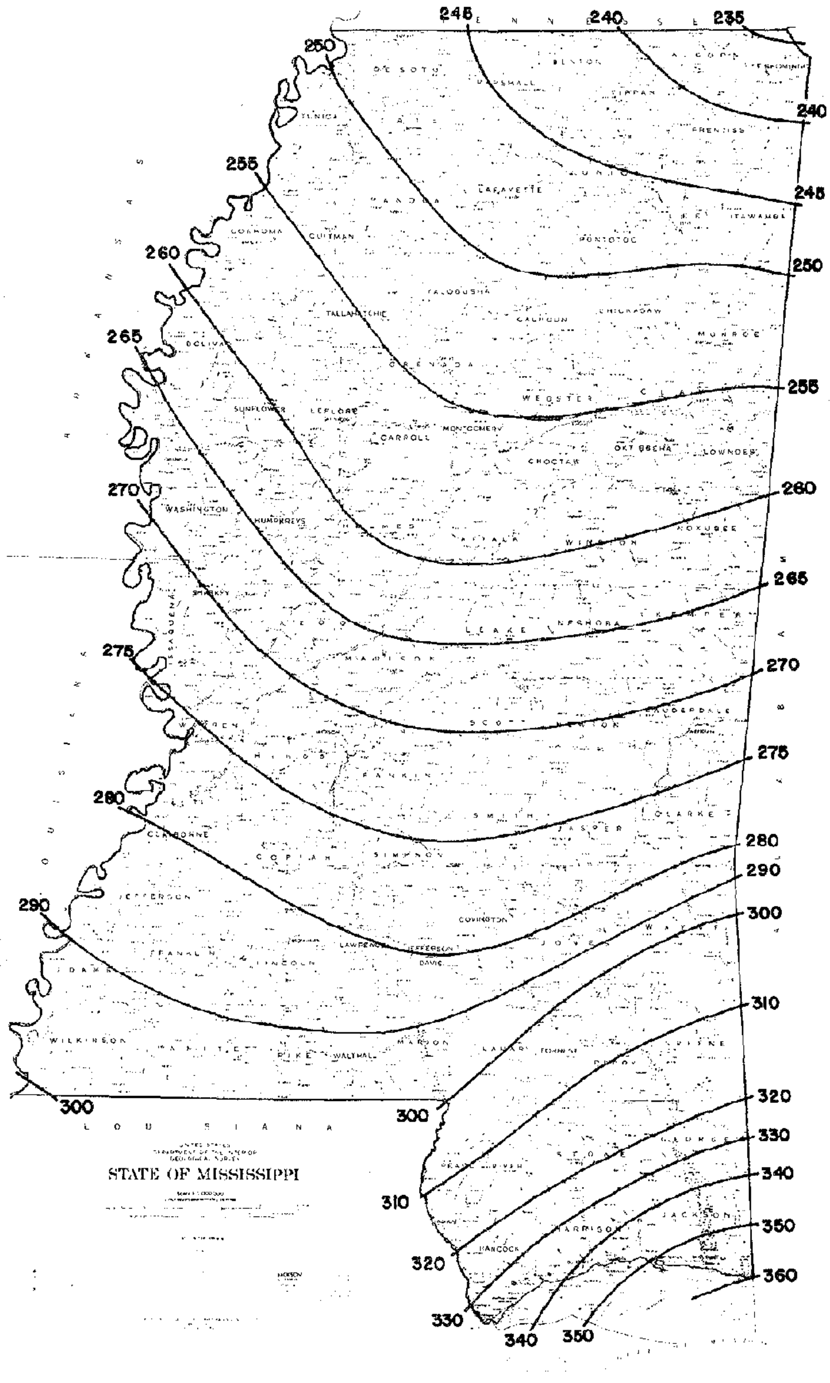


MICHIGAN

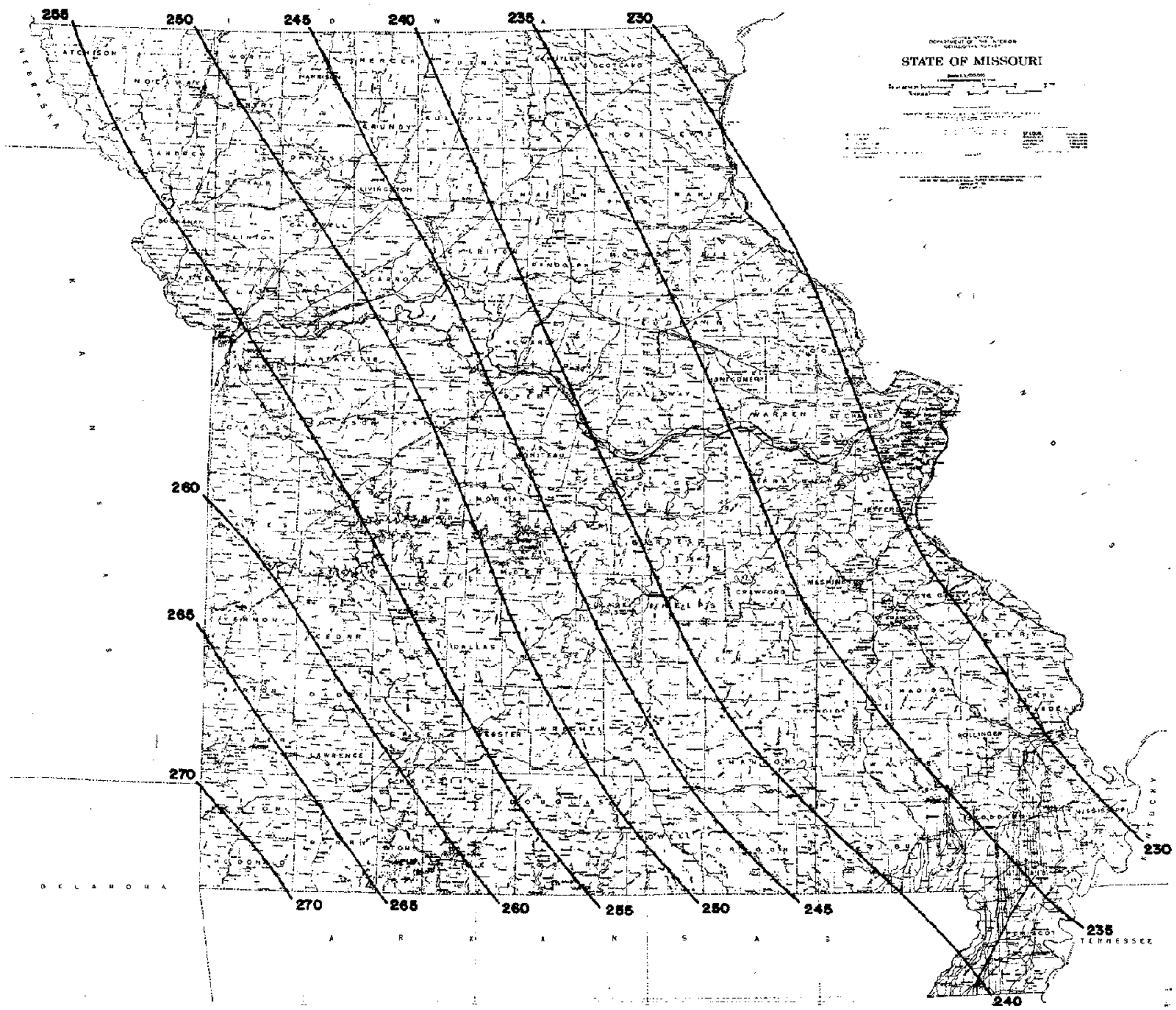
Appendix D-26. Isohyetal map of 10-year 1-hour rainfall for Michigan.



Appendix D-27. Isohyetal map of 10-year 1-hour rainfall for Minnesota.

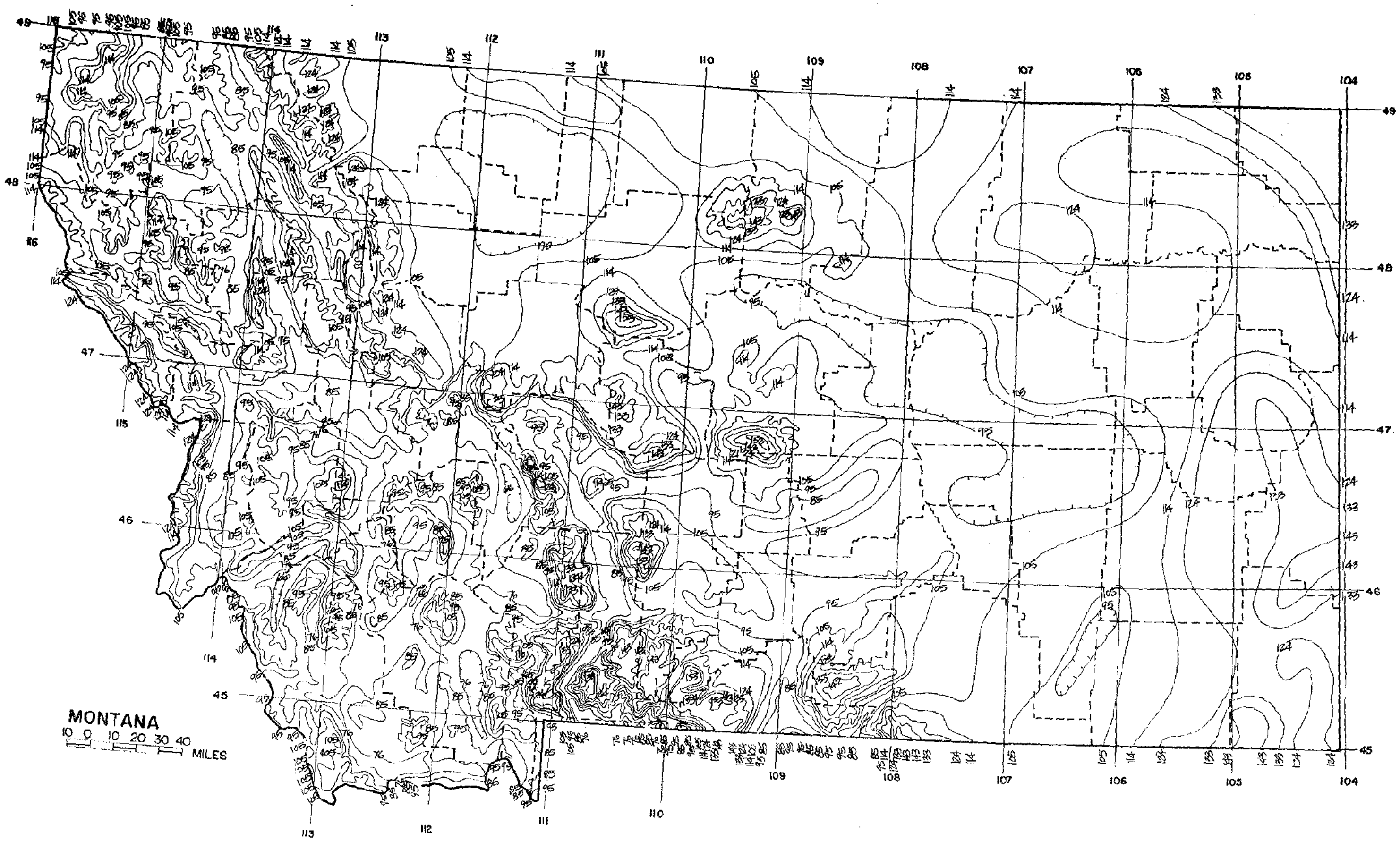


Appendix D-28. Isohyetal map of 10-year 1-hour rainfall for Mississippi.



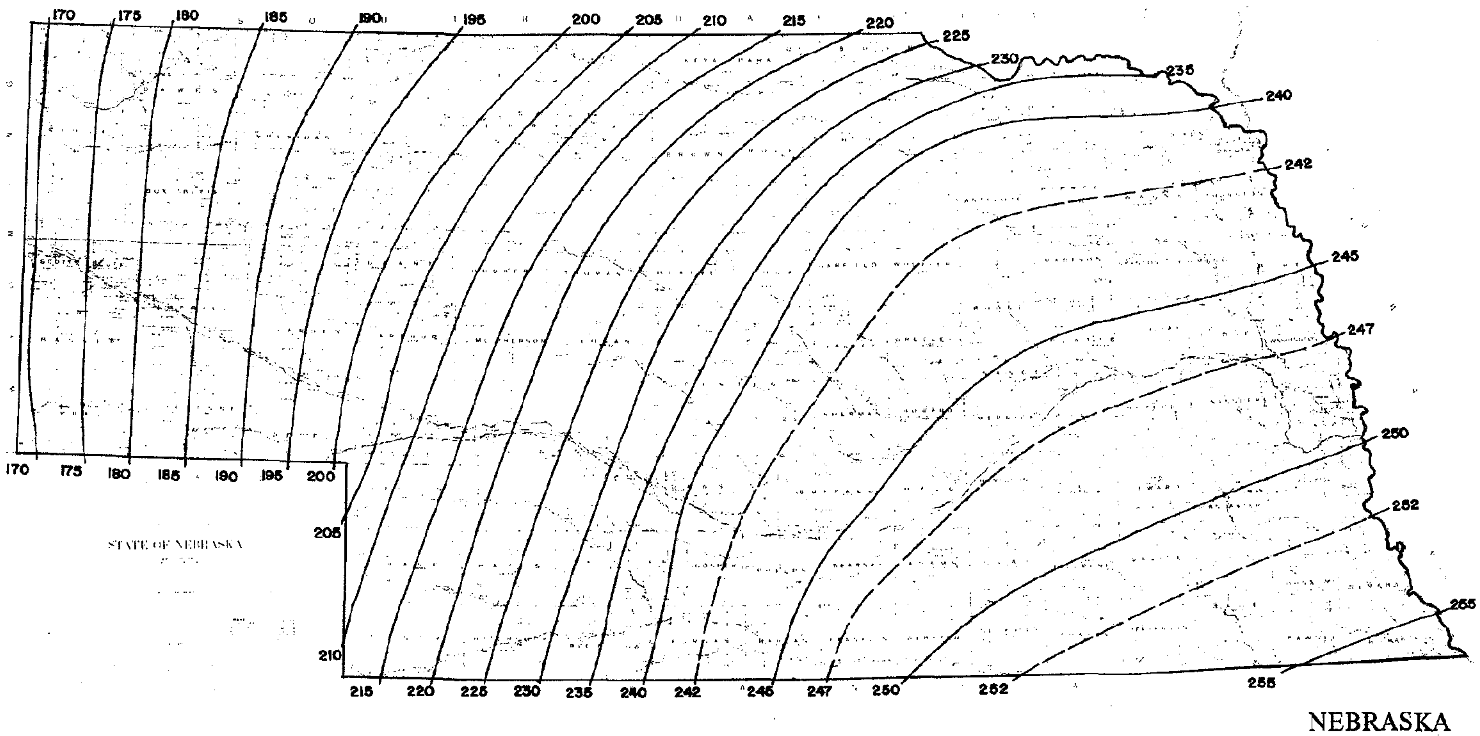
MISSOURI

Appendix D-29. Isohyetal map of 10-year 1-hour rainfall for Missouri.

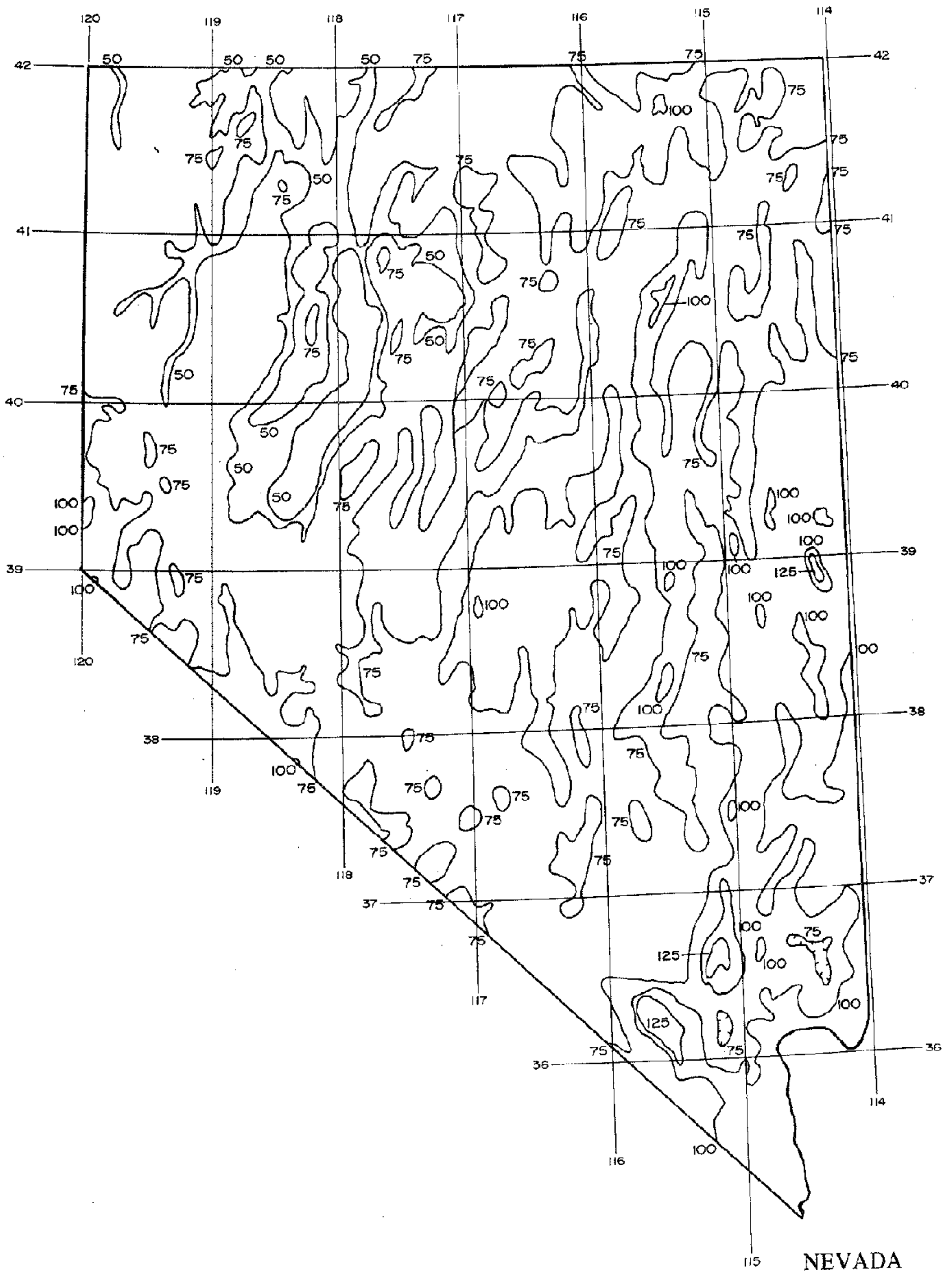


MONTANA

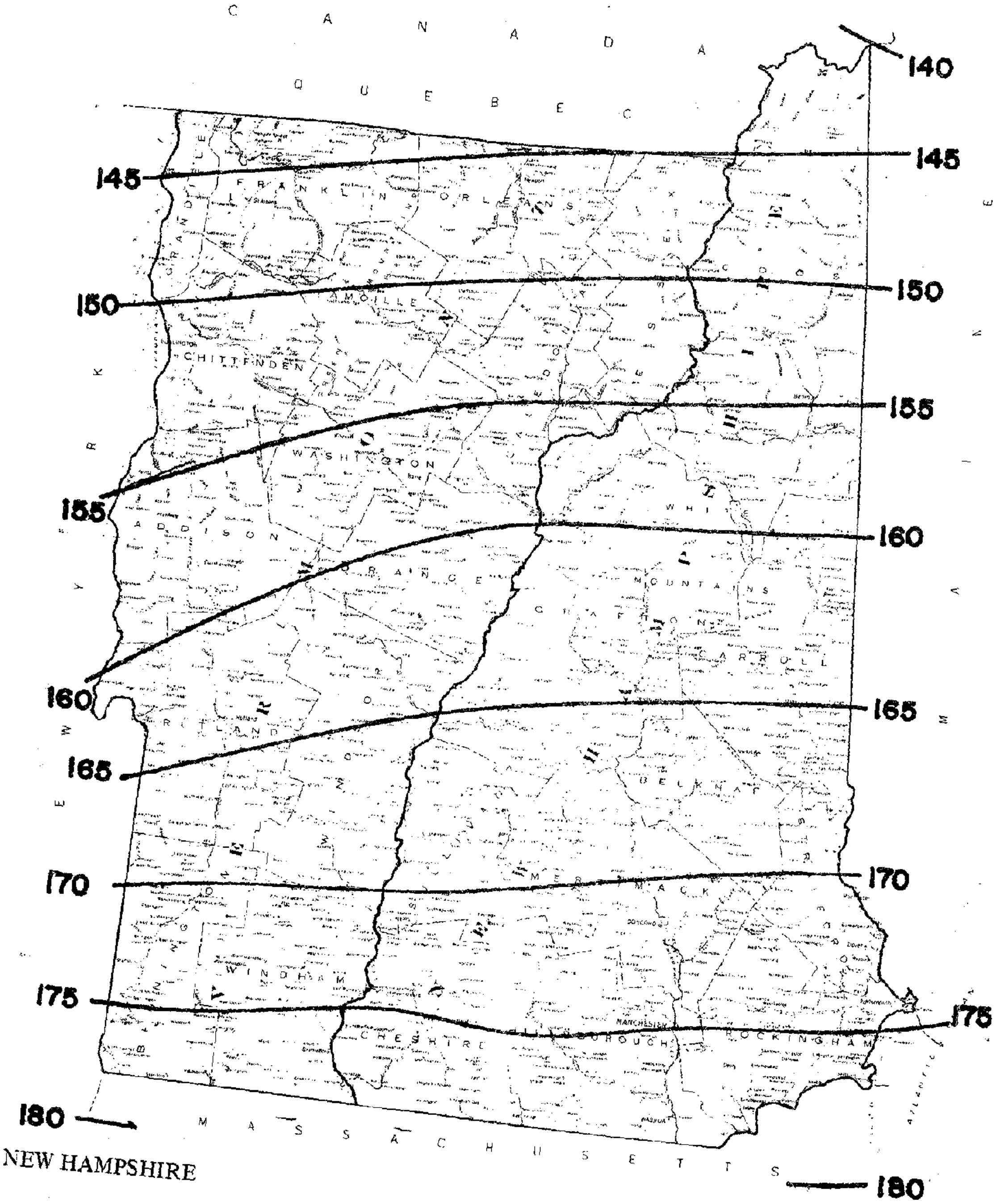
Appendix D-30. Isohyetal map of 10-year 1-hour rainfall for Montana.



Appendix D-31. Isohyetal map of 10-year 1-hour rainfall for Nebraska.



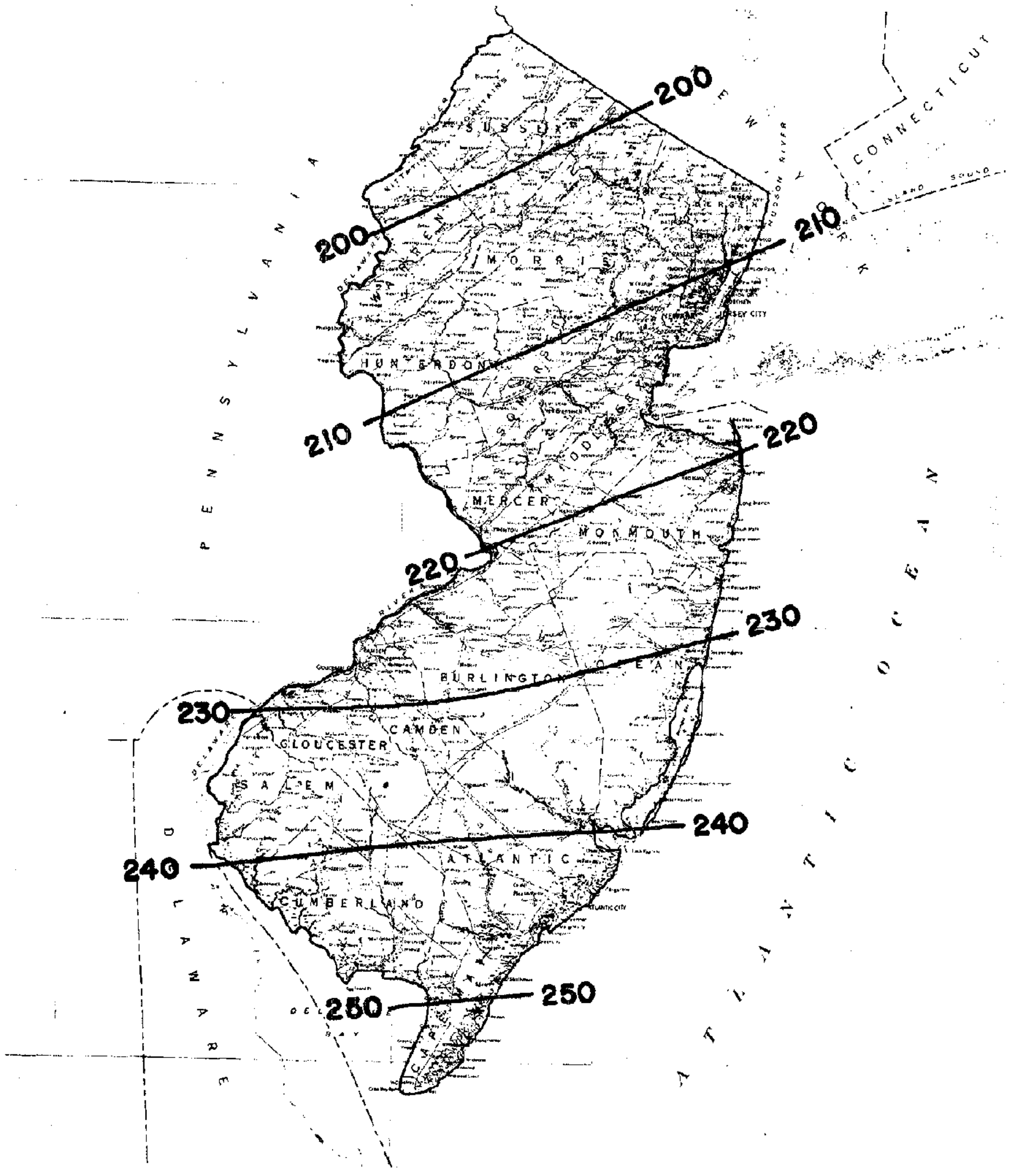
Apprndix D-32. Isohyetal map of 10-year 1-hour rainfall for Nevada.



NEW HAMPSHIRE

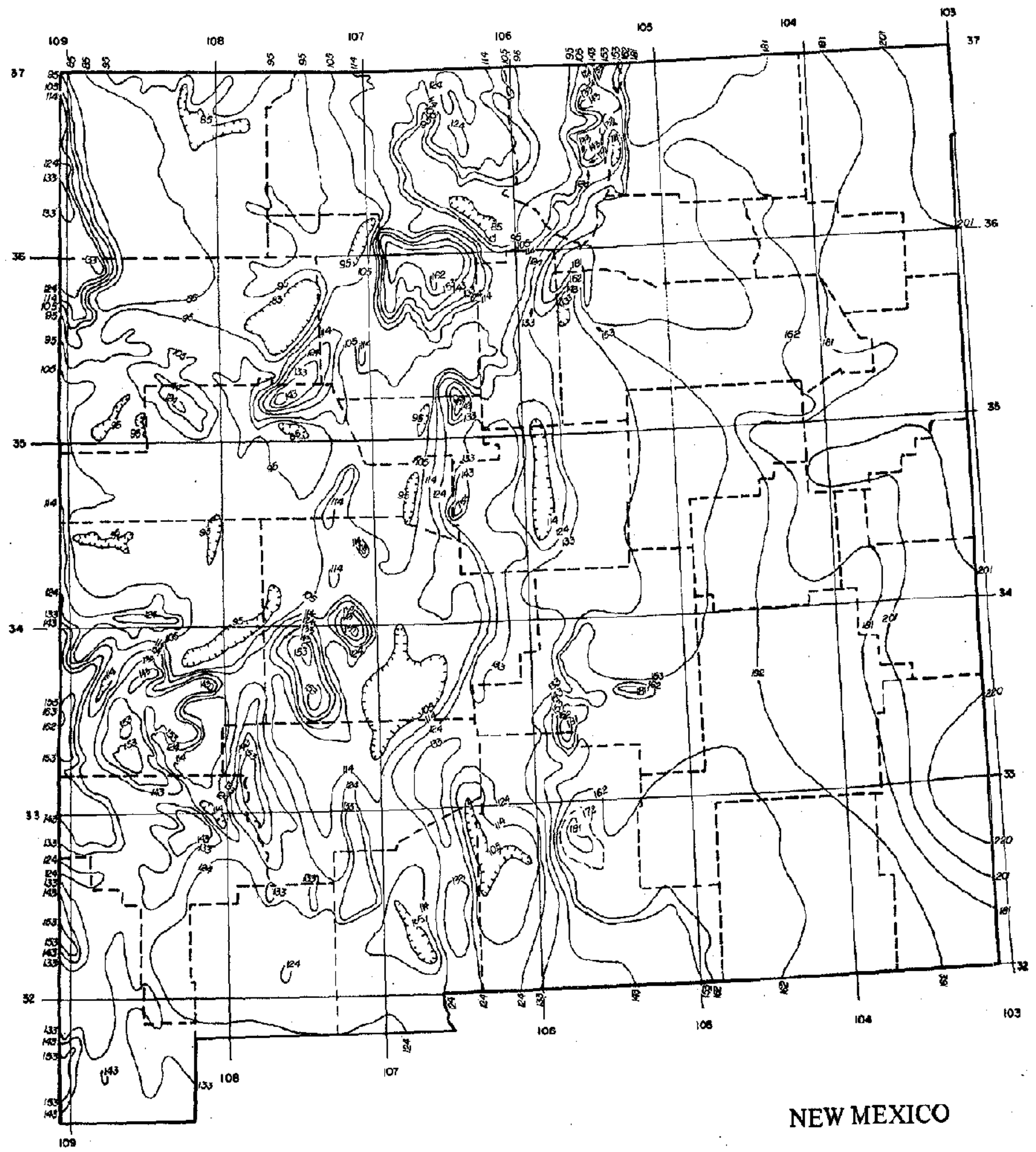
VERMONT

Appendix D-33. Isohyetal map of 10-year 1-hour rainfall for New Hampshire.
Appendix D-50. Isohyetal map of 10-year 1-hour rainfall for Vermont.

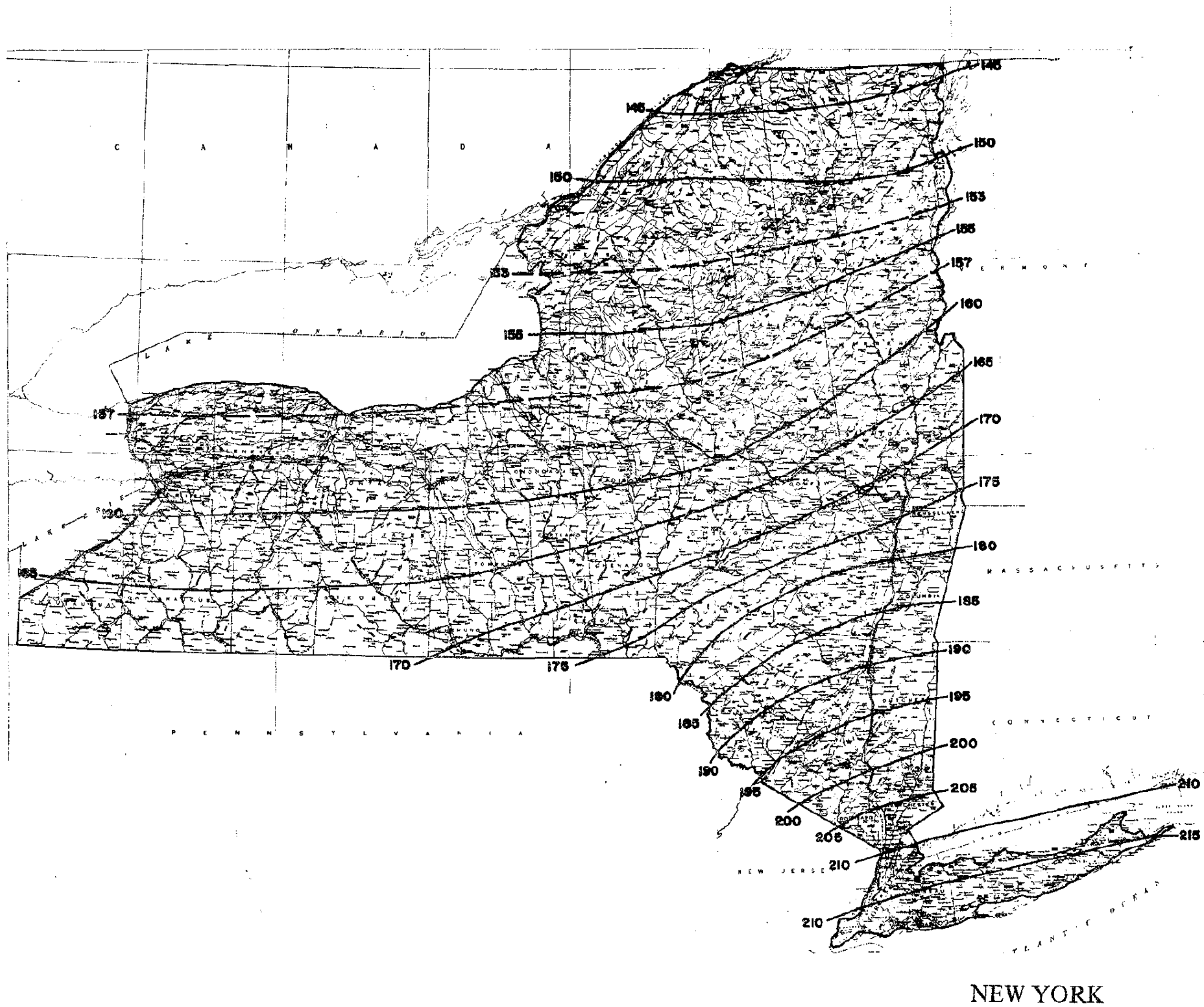


NEW JERSEY

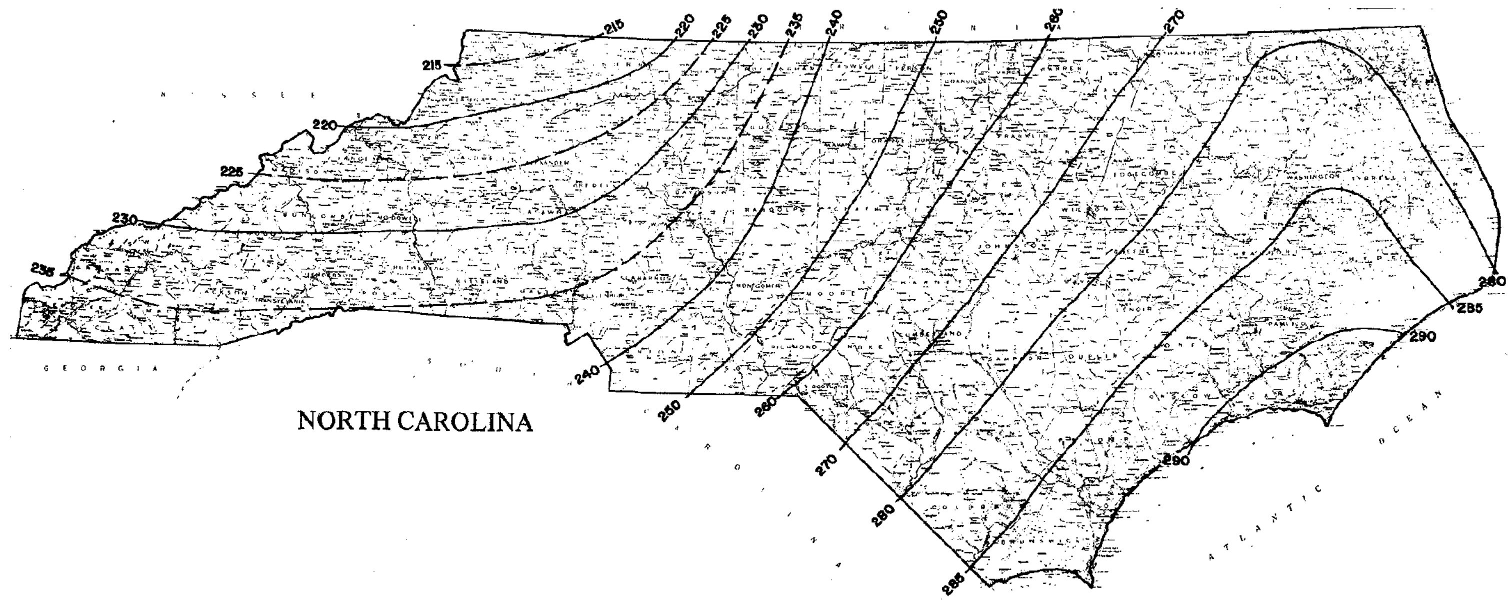
Appendix D-34. Isohyetal map of 10-year 1-hour rainfall for New Jersey.



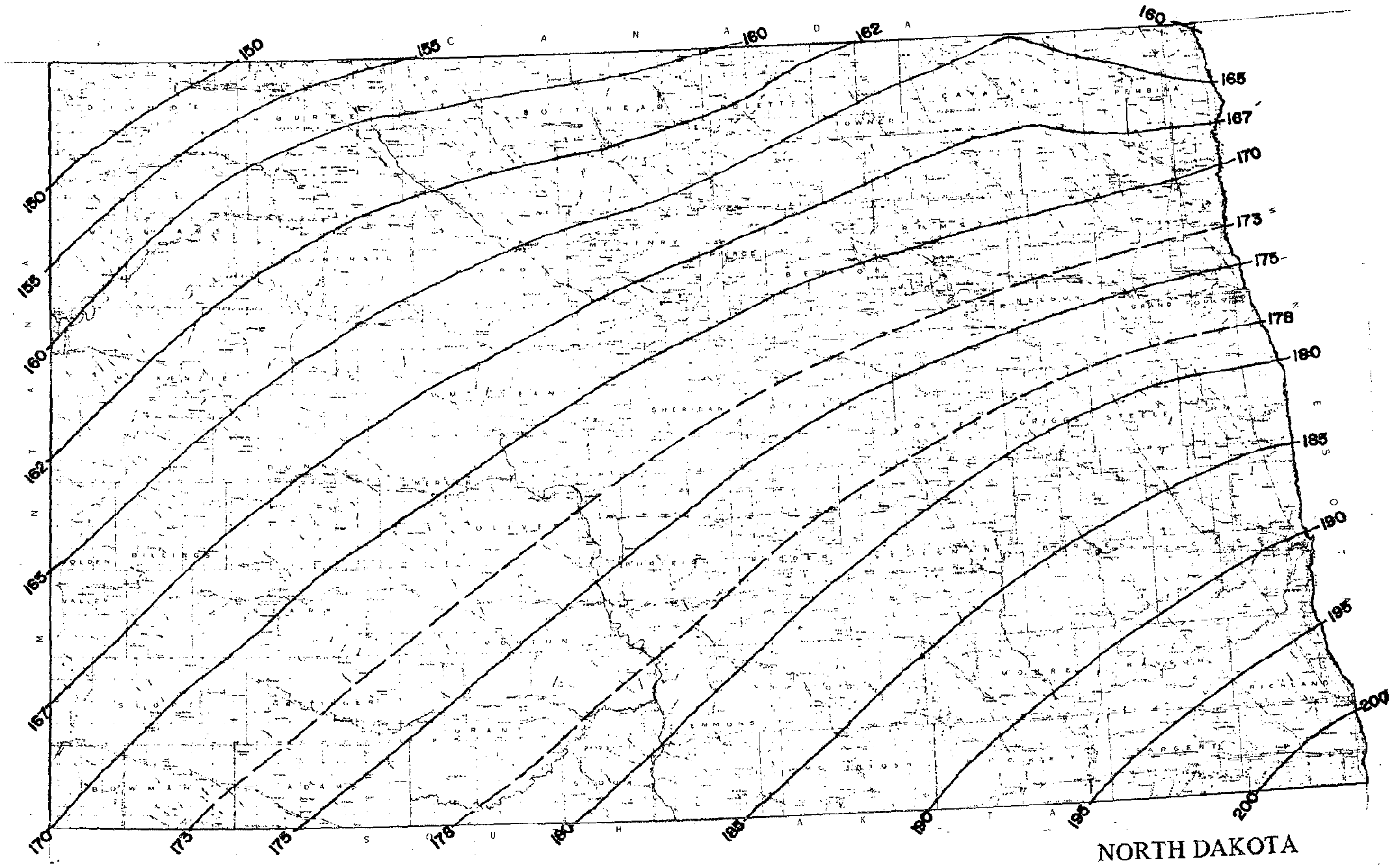
Appendix D-35. Isohyetal map of 10-year 1-hour rainfall for New Mexico.



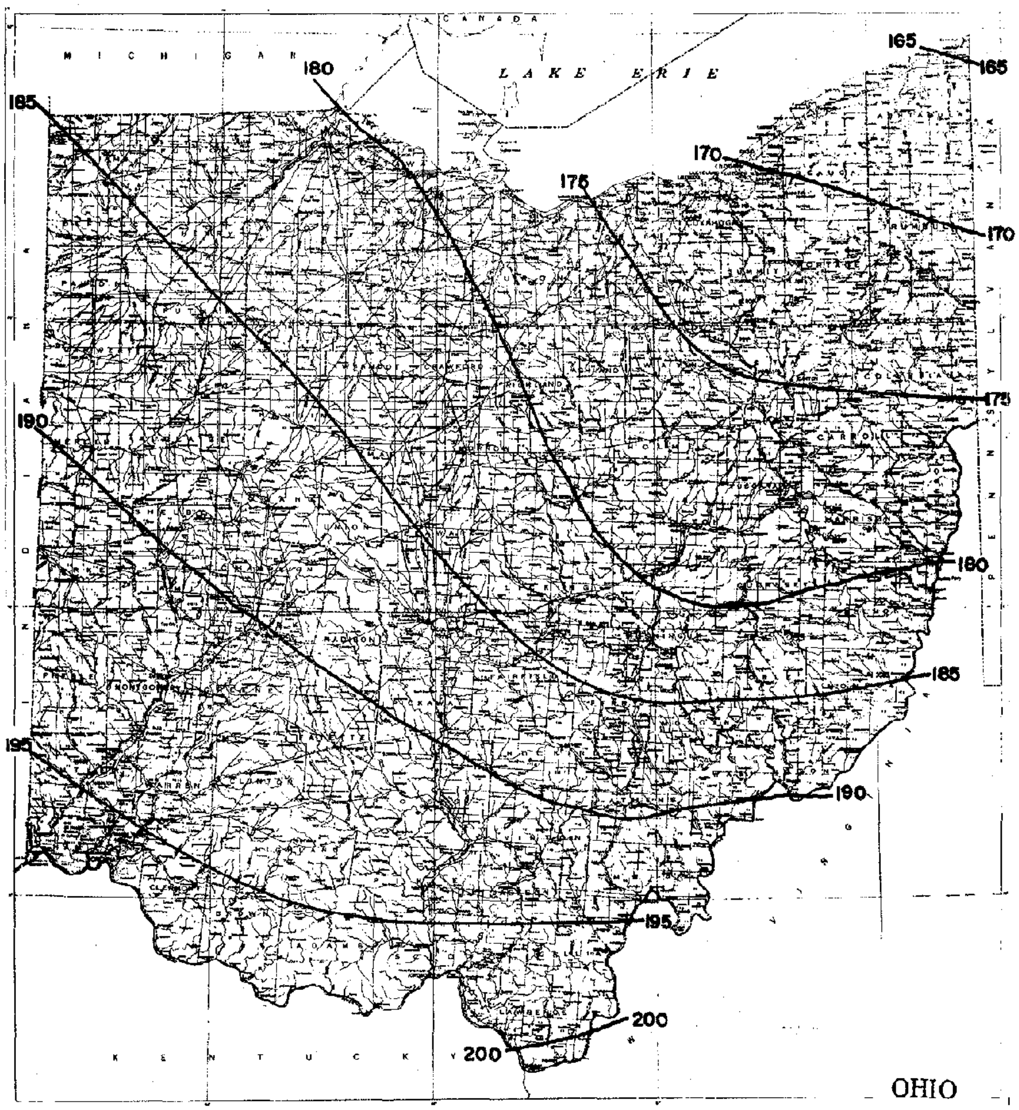
Appendix D-36. Isohyetal map of 10-year 1-hour rainfall for New York.



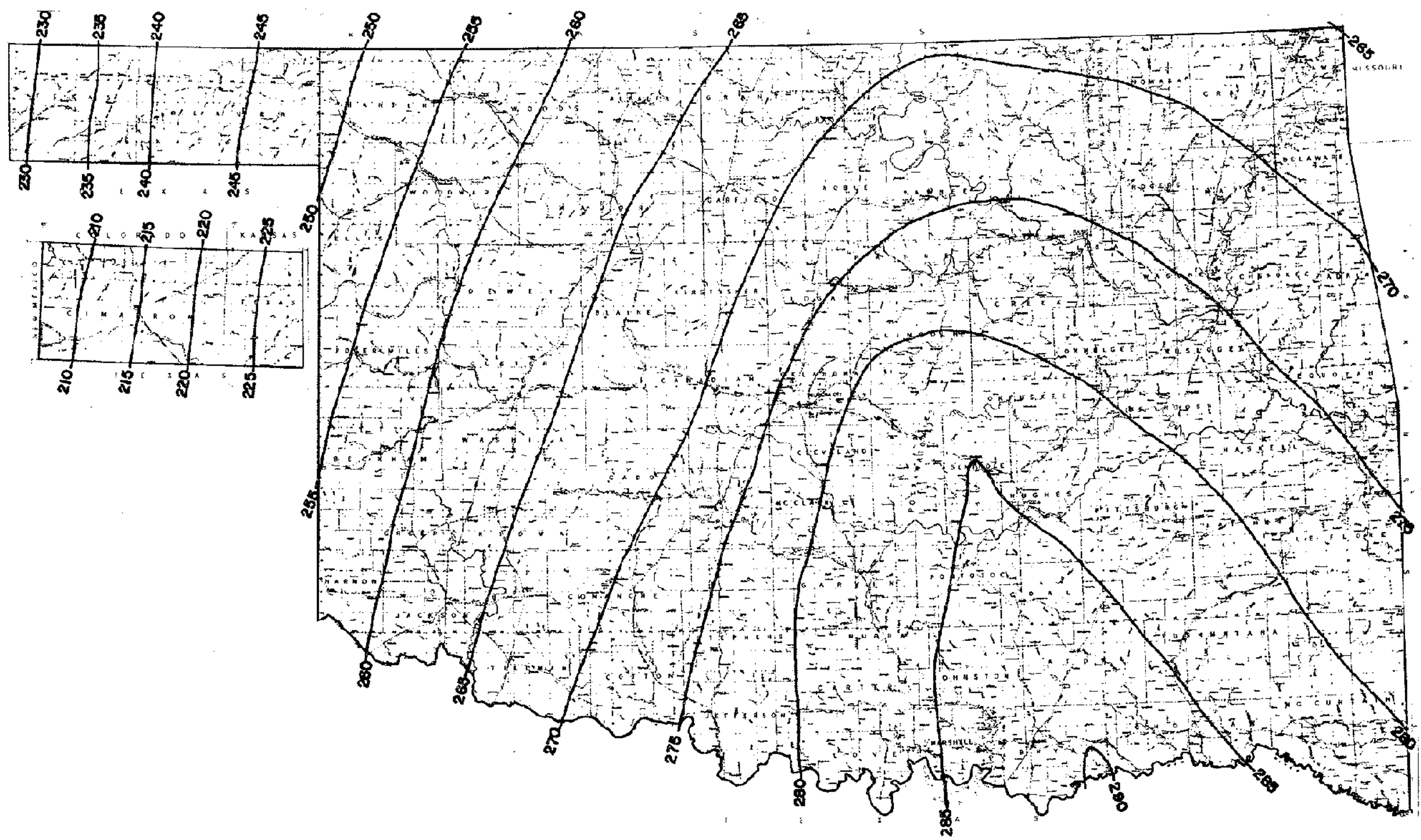
Appendix D-37. Isohyetal map of 10-year 1-hour rainfall for North Carolina.



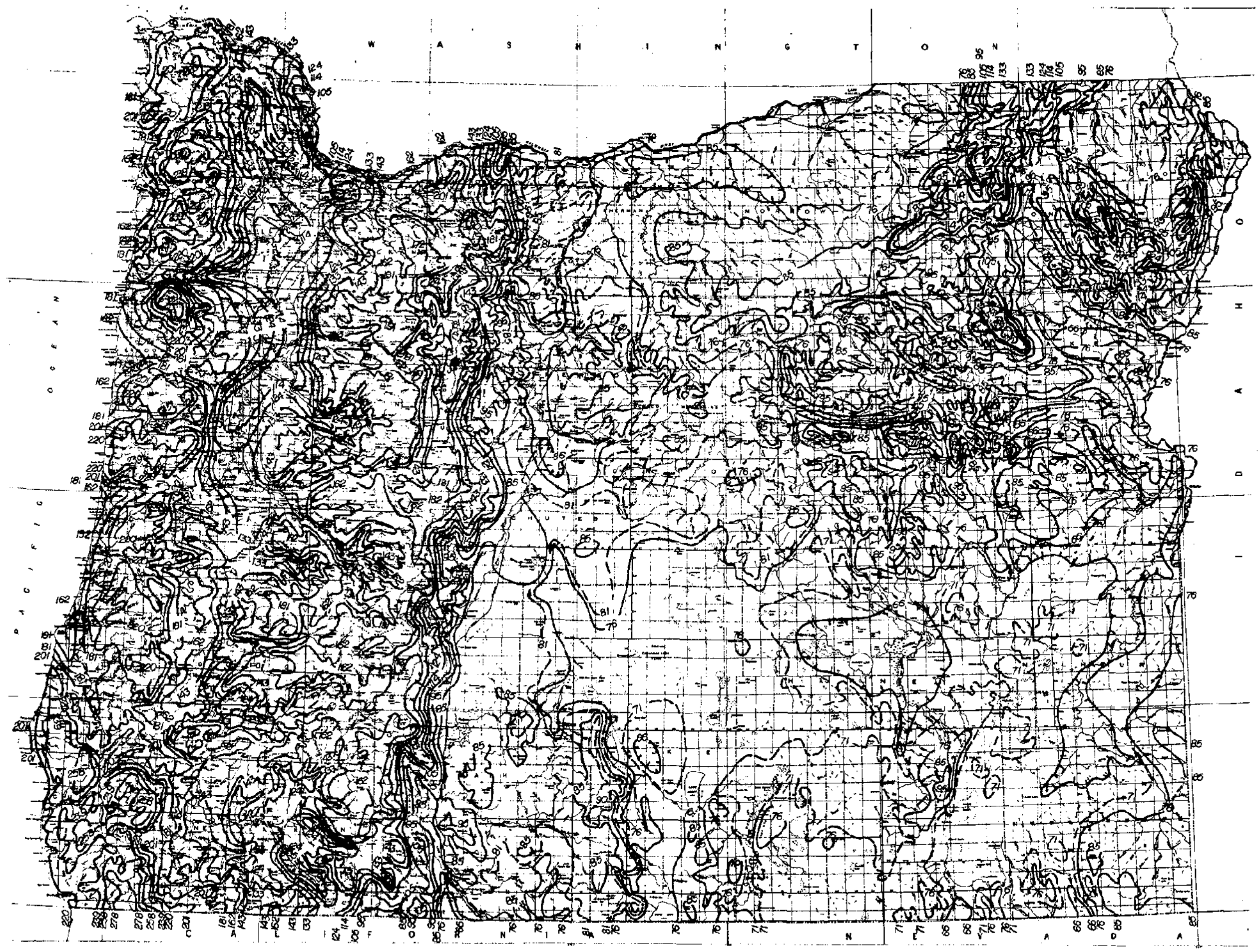
Appendix D-38. Isohyetal map of 10-year 1-hour rainfall for North Dakota.



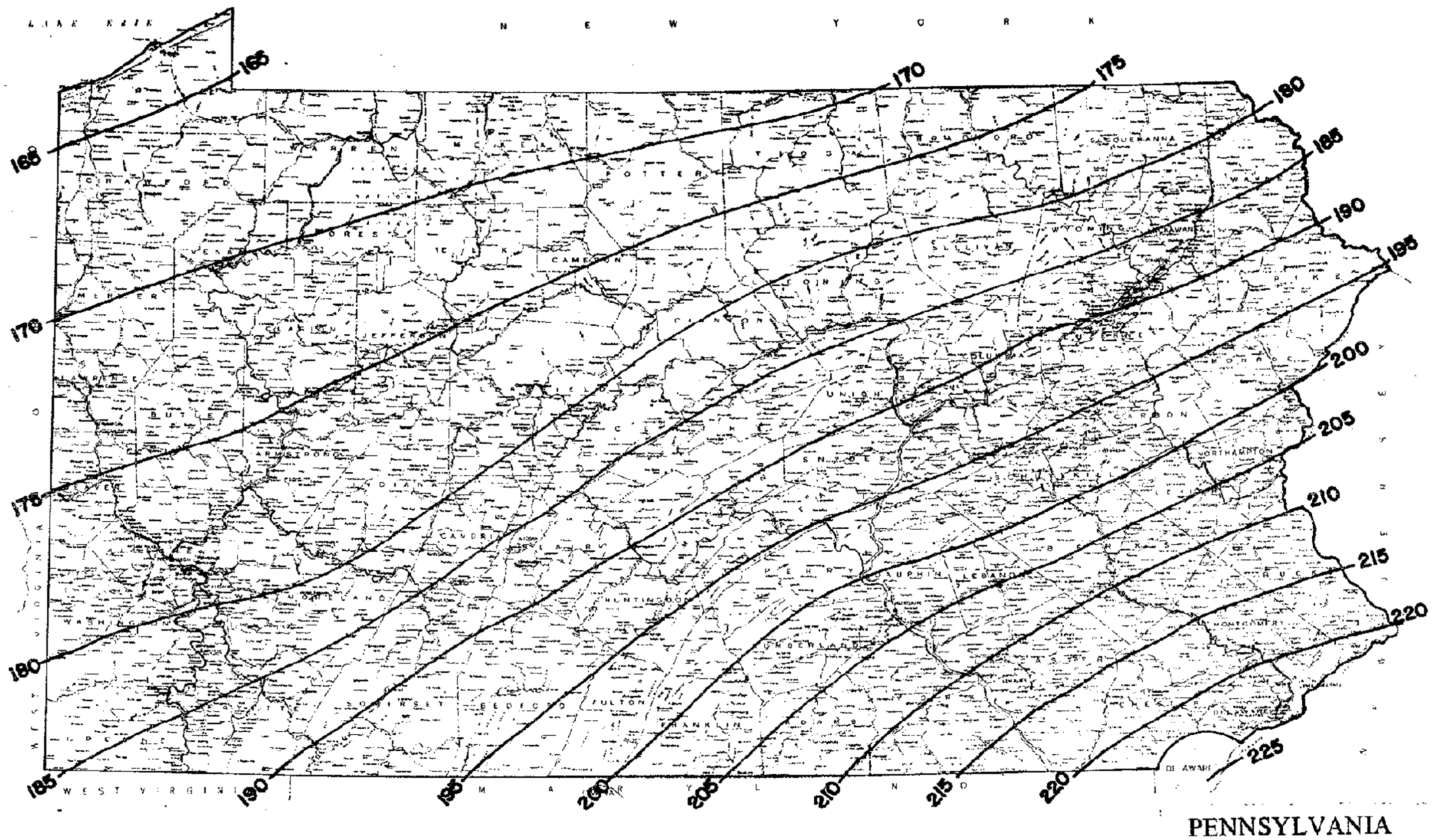
Appendix D-39. Isohyetal map of 10-year 1-hour rainfall for Ohio.



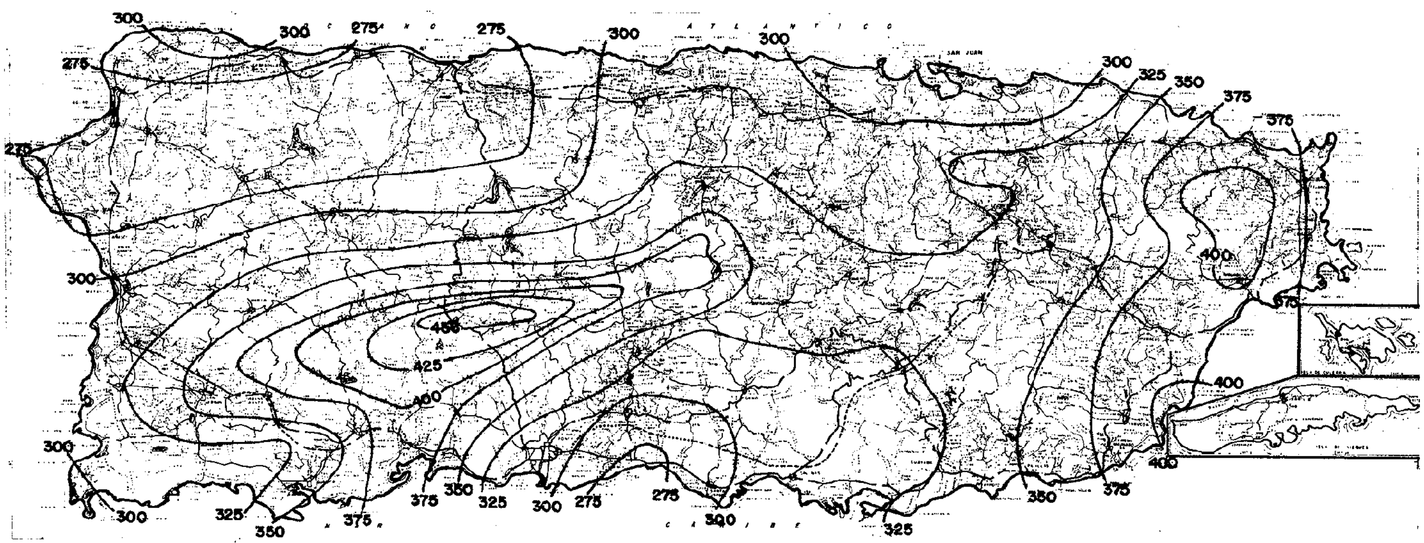
Appendix D-40. Isohyetal map of 10-year 1-hour rainfall for Oklahoma.



Appendix D-41. Isohyetal map of 10-year 1-hour rainfall for Oregon.

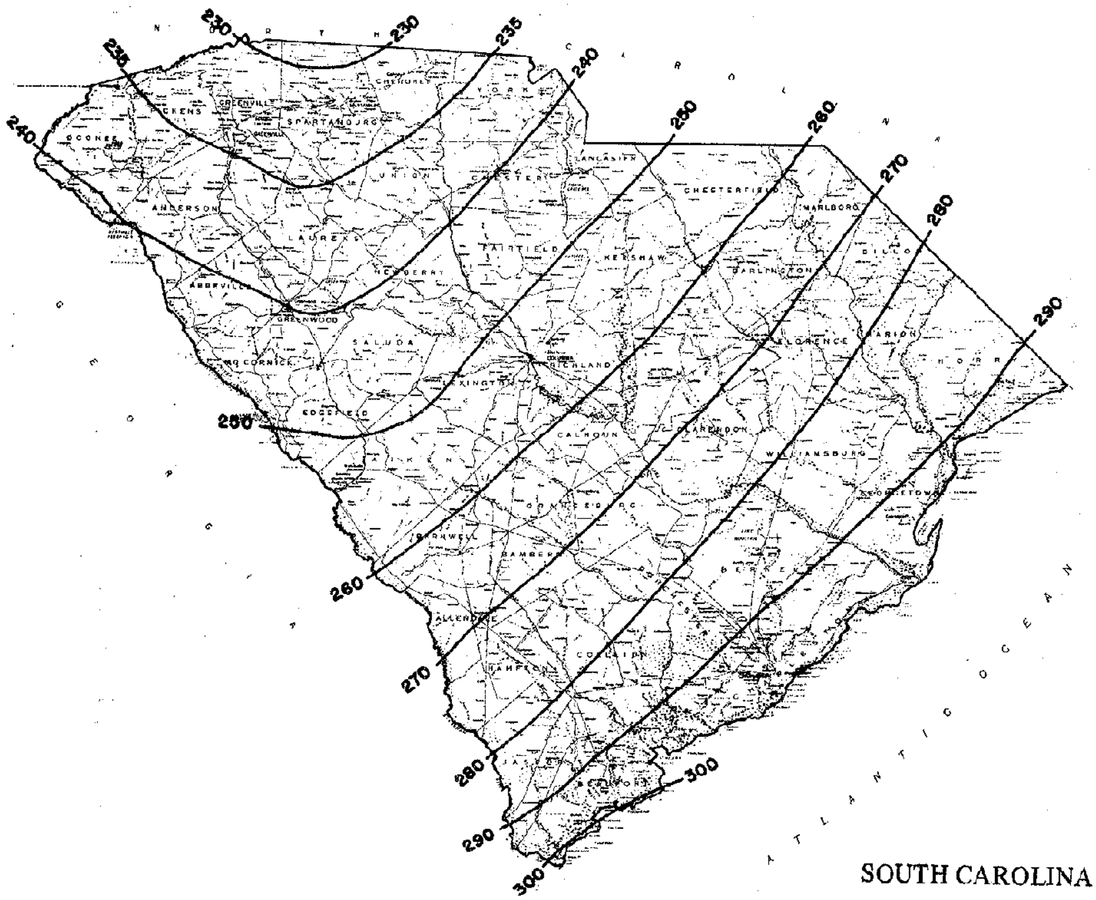


Appendix D-42. Isohyetal map of 10-year 1-hour rainfall for Pennsylvania.

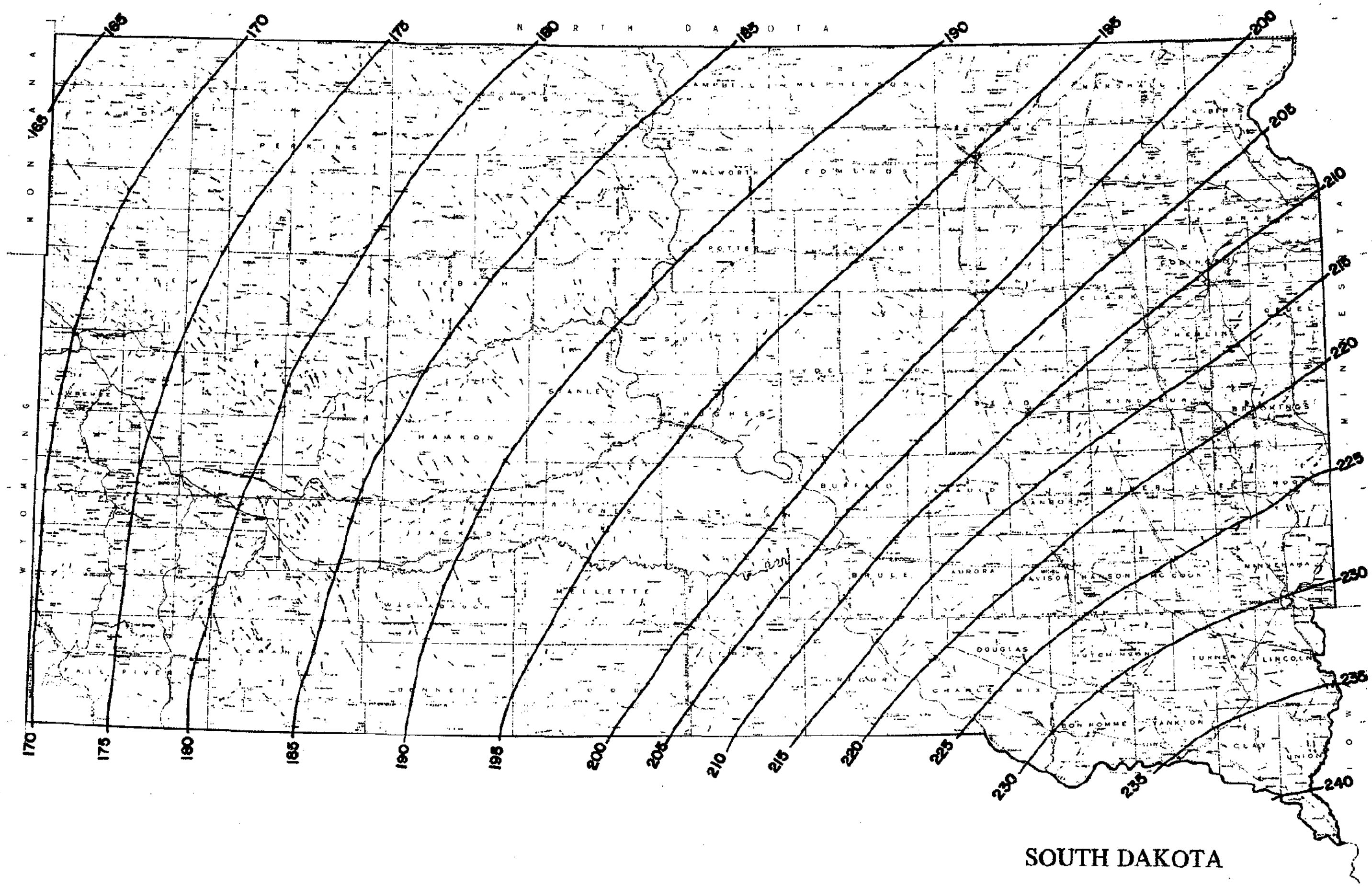


PUERTO RICO

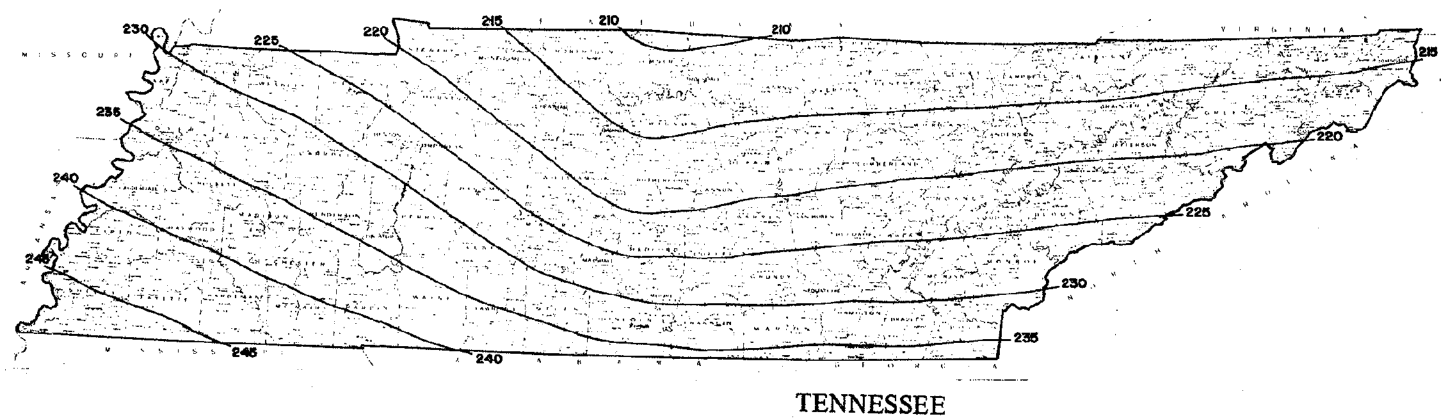
Appendix D-43. Isohyetal map of 10-year 1-hour rainfall for Puerto Rico.



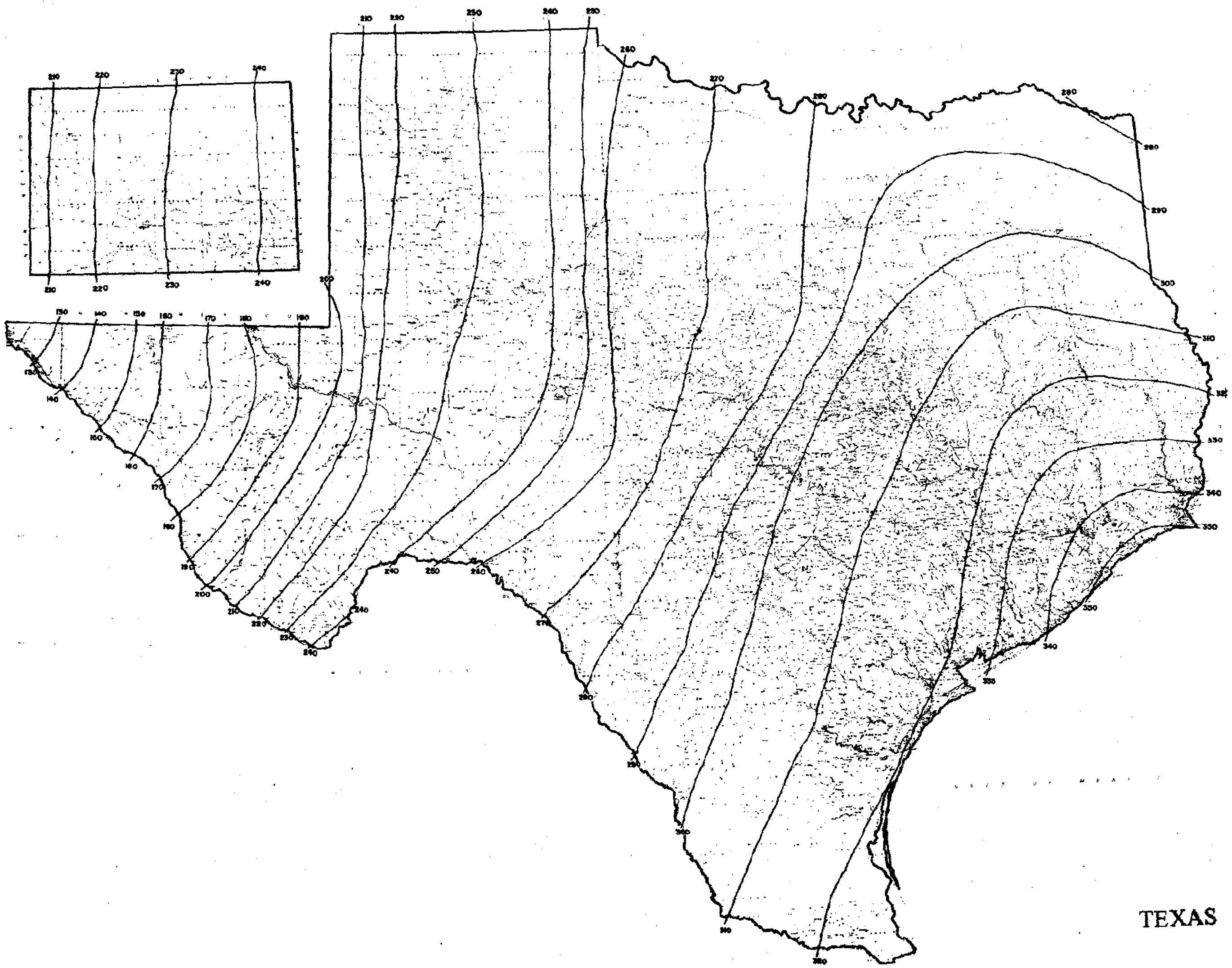
Appendix D-45. Isohyetal map of 10-year 1-hour rainfall for South Carolina.



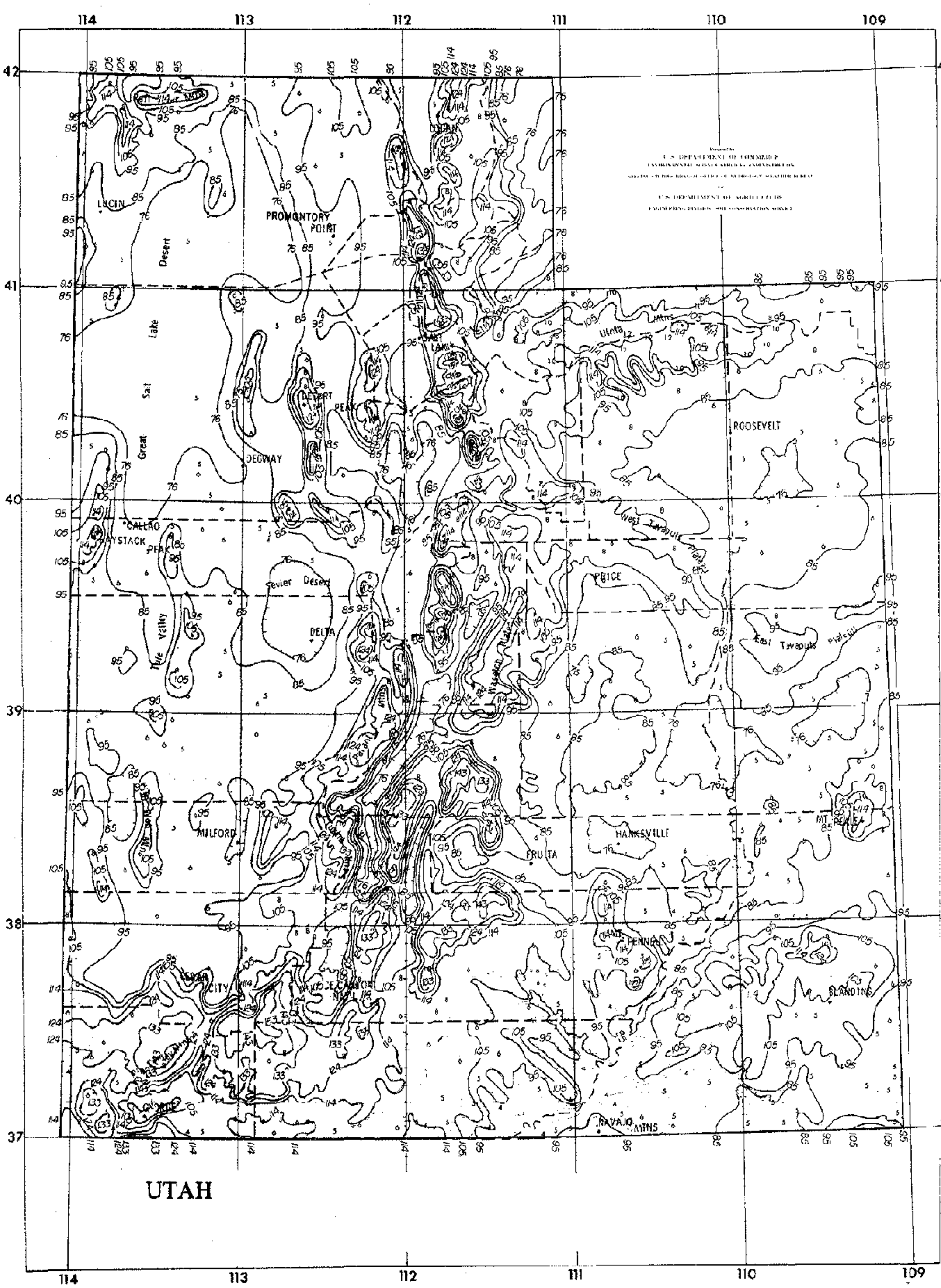
Appendix D-46. Isohyetal map of 10-year 1-hour rainfall for South Dakota.



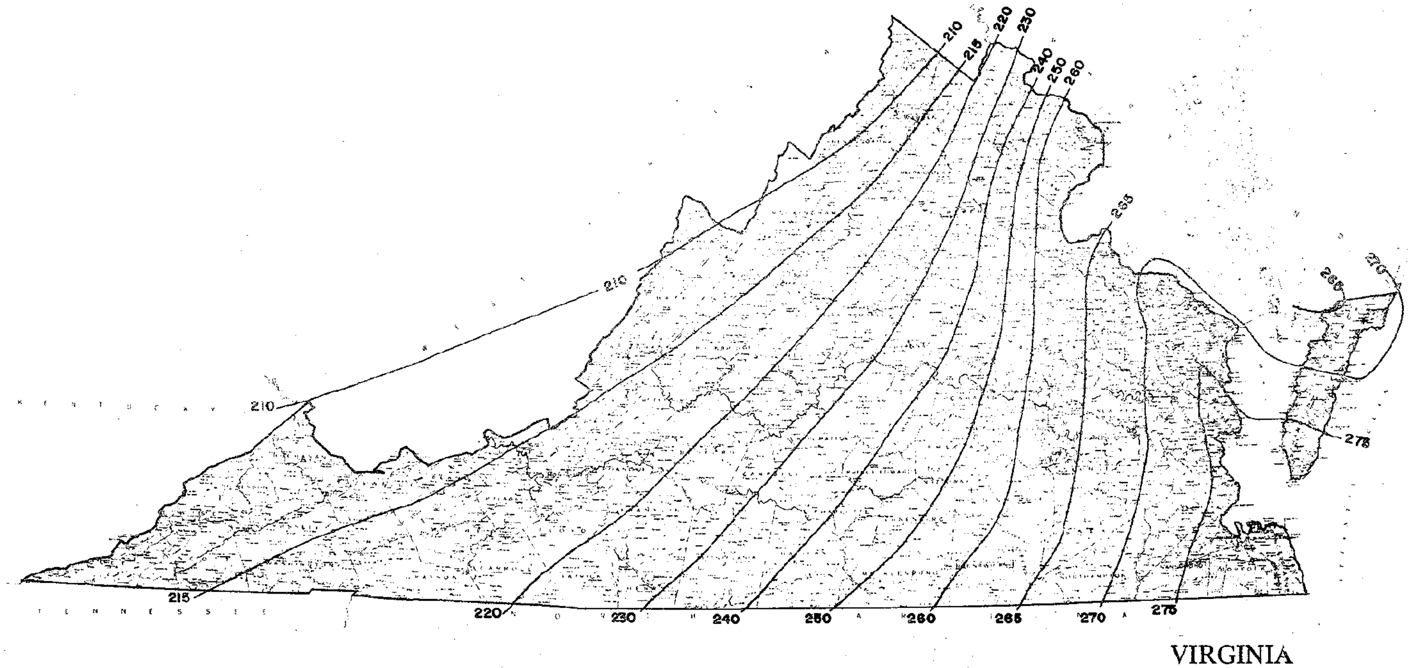
Appendix D-47. Isohyetal map of 10-year 1-hour rainfall for Tennessee.



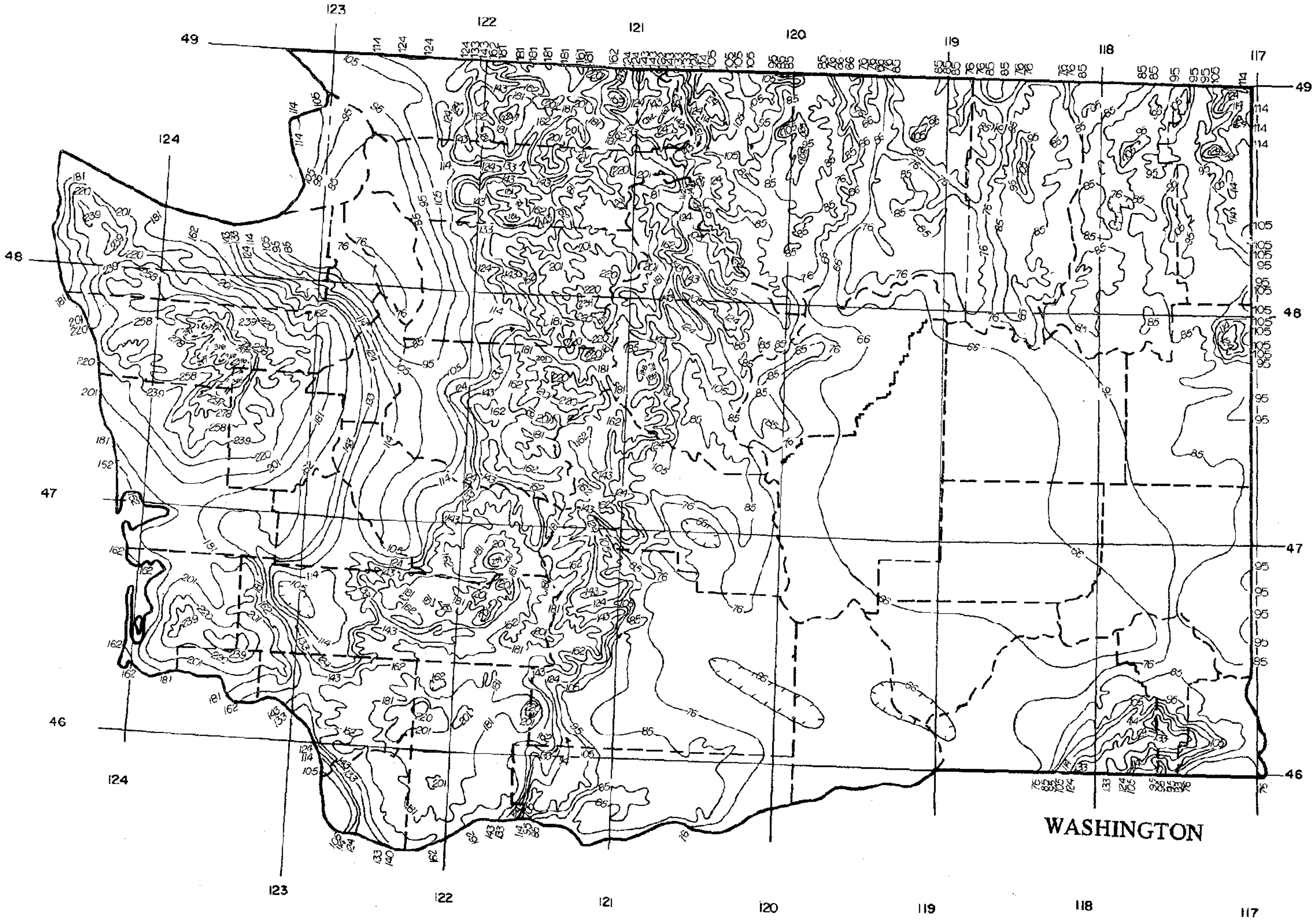
Appendix D-48. Isohyetal map of 10-year 1-hour rainfall for Texas.



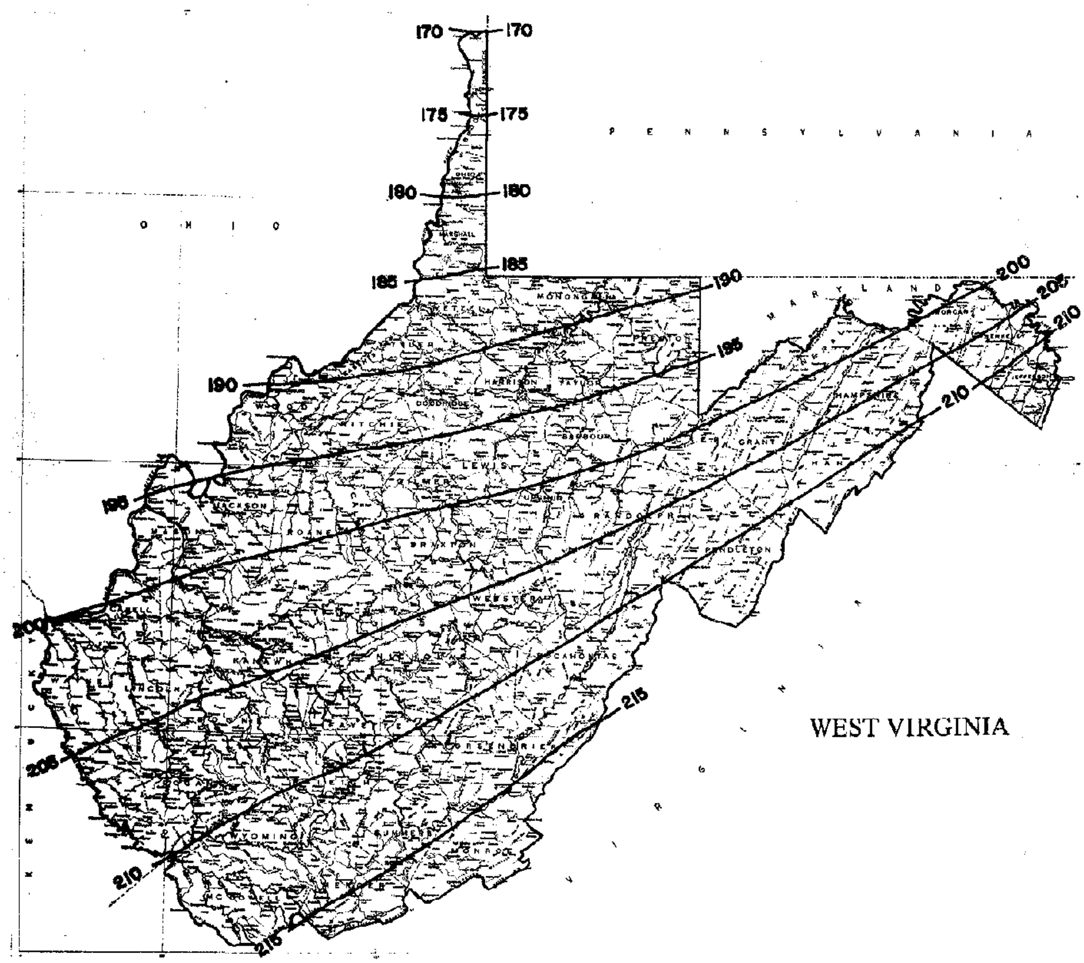
Appendix D-49. Isohyetal map of 10-year 1-hour rainfall for Utah.



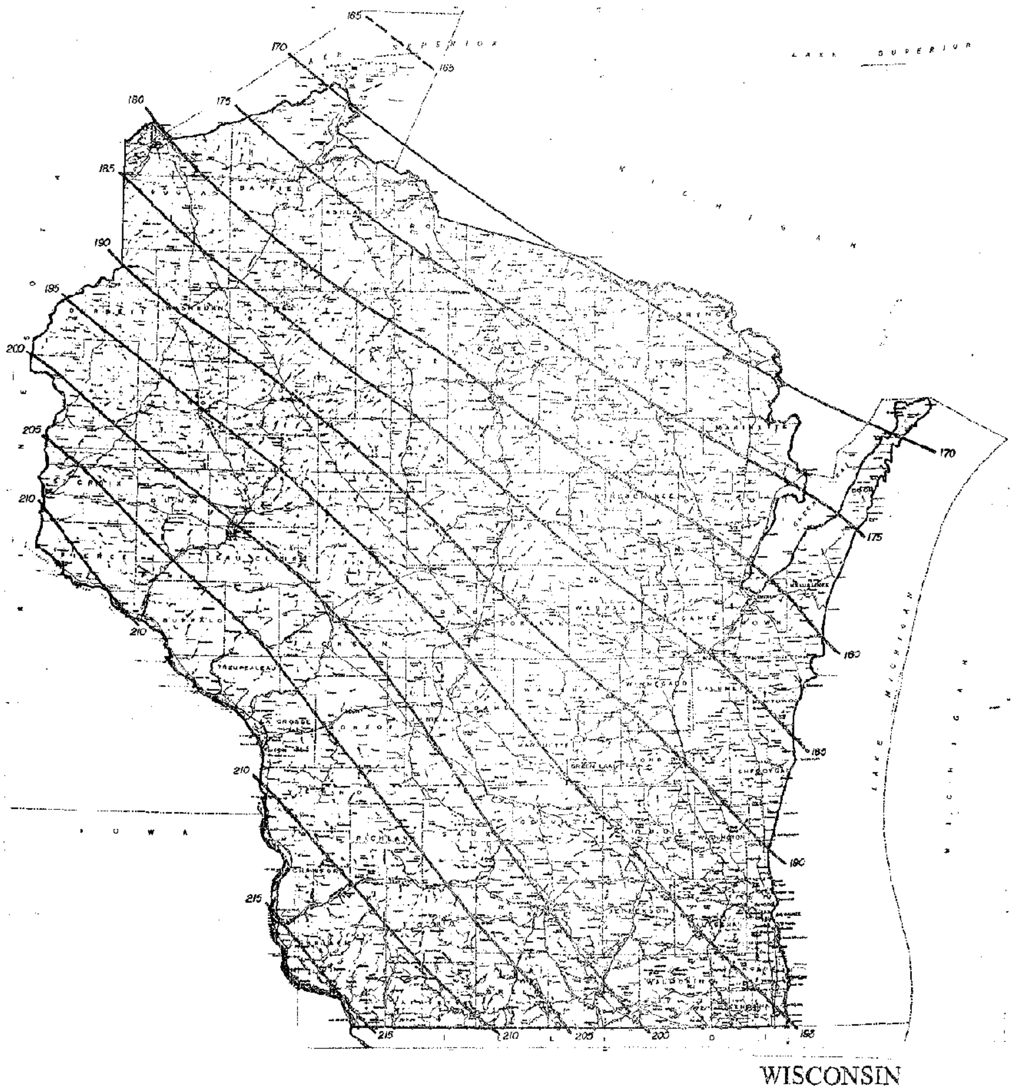
Appendix D-51. Isohyetal map of 10-year 1-hour rainfall for Virginia.



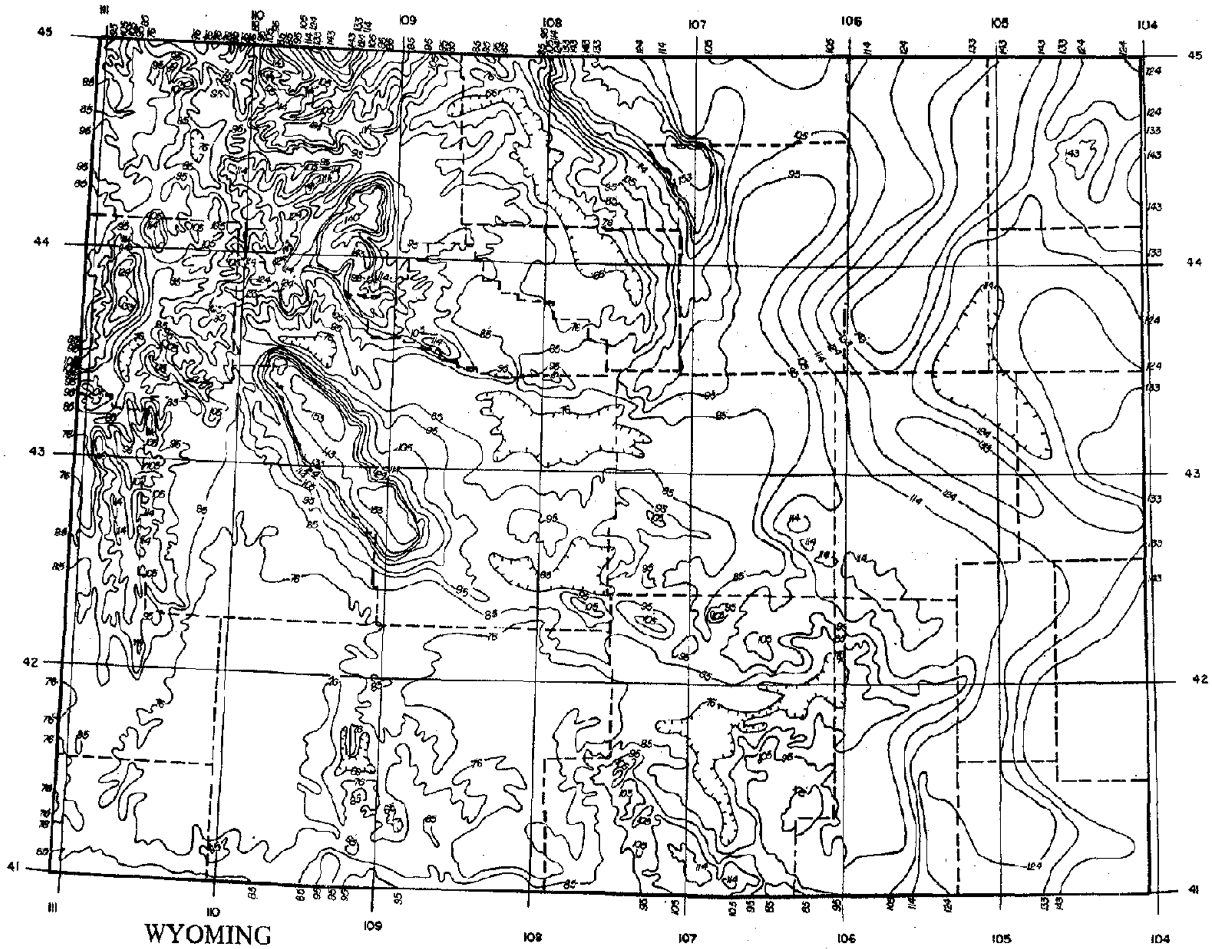
Appendix D-53. Isohyetal map of 10-year 1-hour rainfall for Washington.



Appendix D-54. Isohyetal map of 10-year 1-hour rainfall for West Virginia.



Appendix D-55. Isohyetal map of 10-year 1-hour rainfall for Wisconsin.



Appendix D-56. Isohyetal map of 10-year 1-hour rainfall for Wyoming.

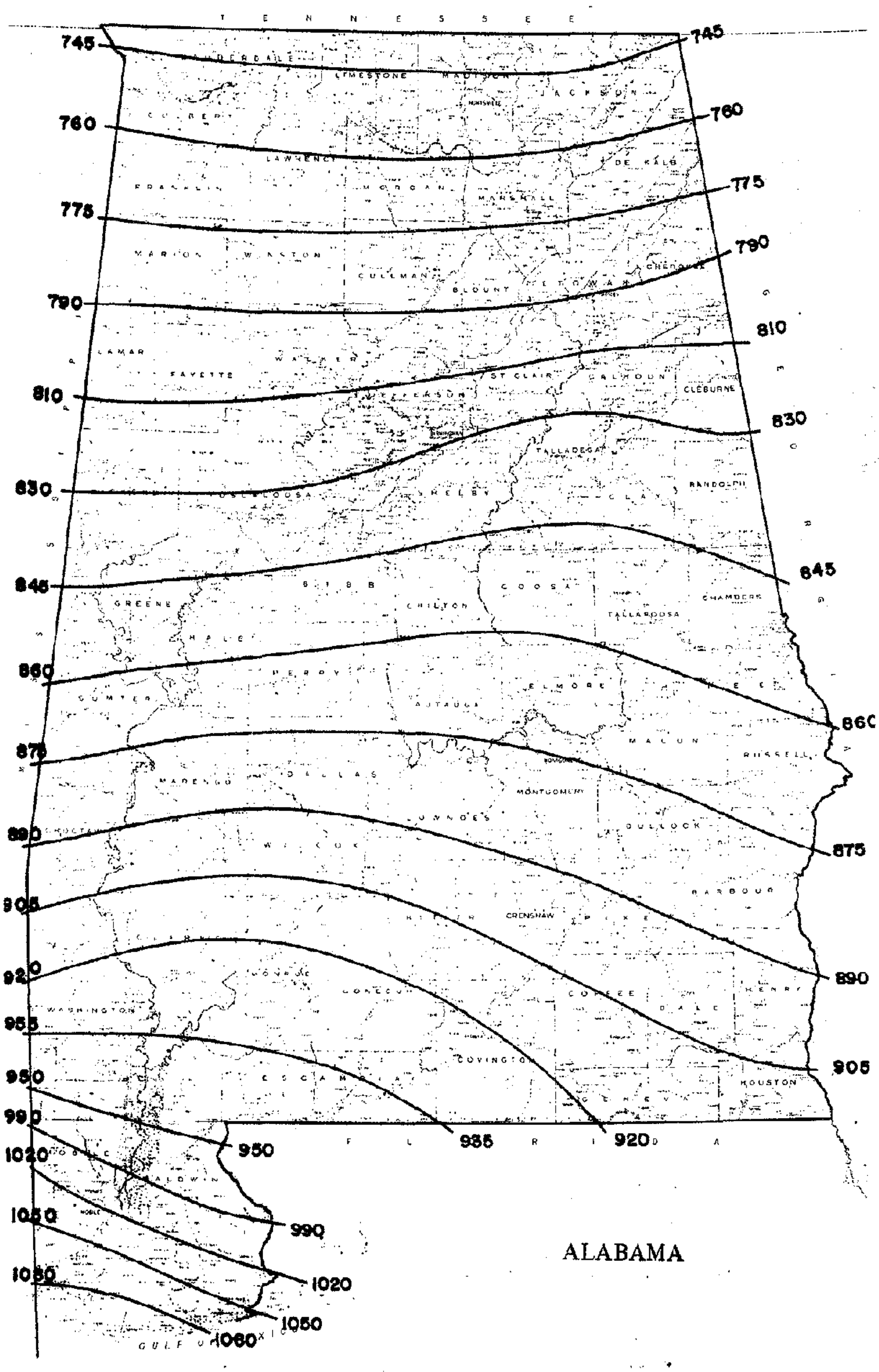
APPENDIX E

10-Year, 10-Minute Rainfall Intensity of the Contiguous United States, Alaska, Hawaii, and Puerto Rico. State Numbers are Those Given by the U.S. Geological Survey.

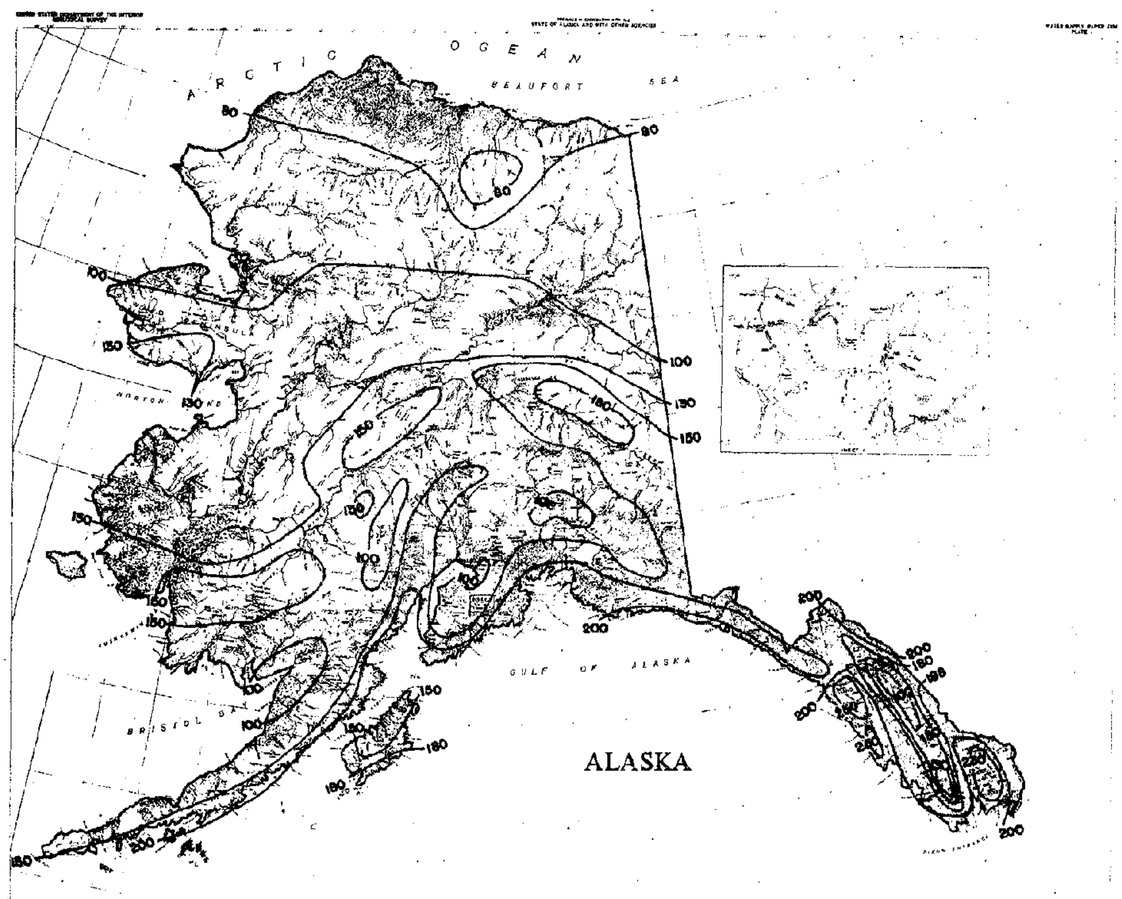
Appendix E contains maps of each of the states and Puerto Rico as computed from WB-40, NOAA ATLAS 2, W. B. Technical Papers 42 and 47 with the regressions given in them with proper attention being given to the different storm types in the same states in the Western United States. The intensity values plotted are in hundredths of an inch per hour.

NOTE:

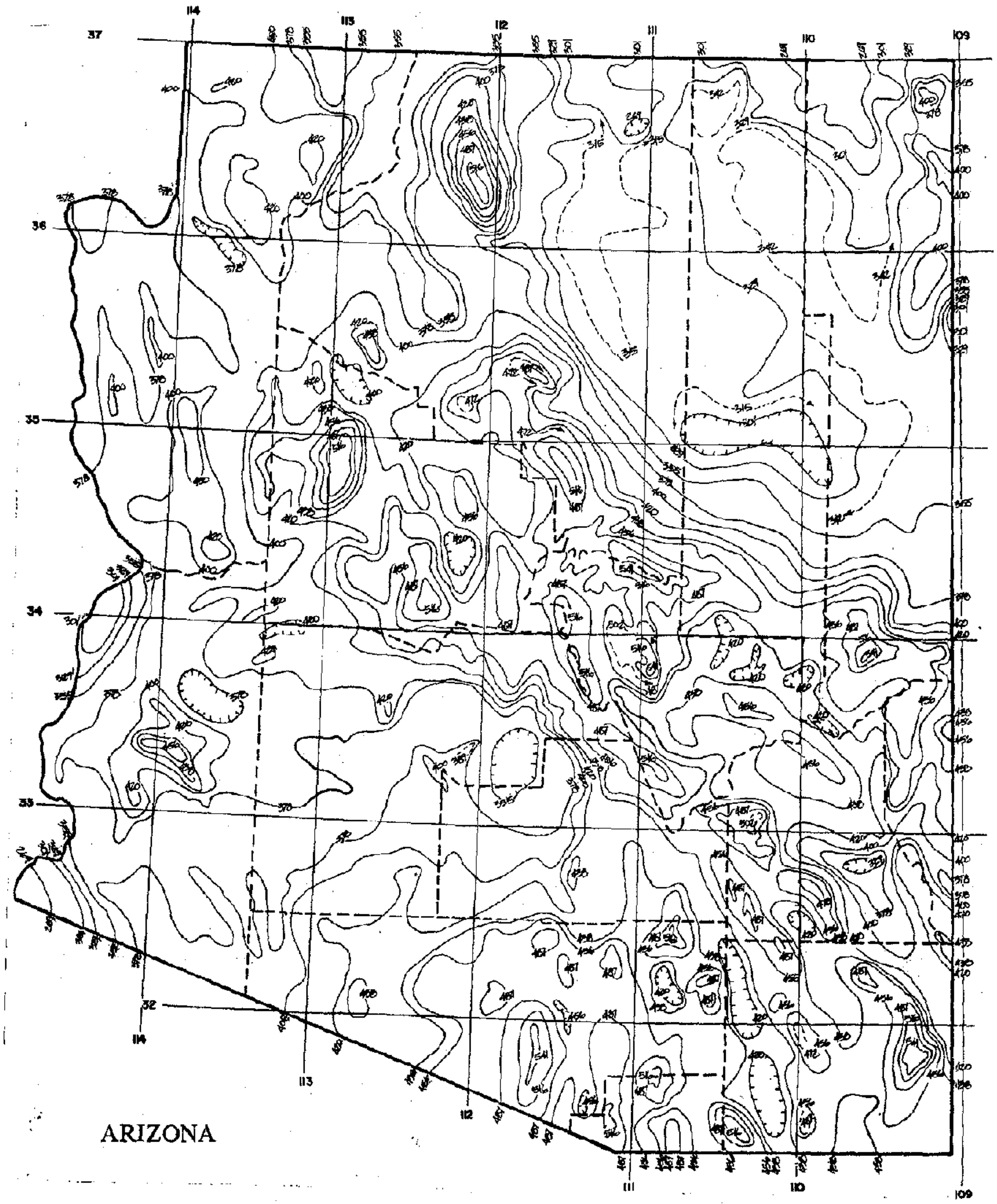
Scales of maps are different because some maps were not available in a proper scale or it would be impractical to show for example Texas in the same scale as Rhode Island.



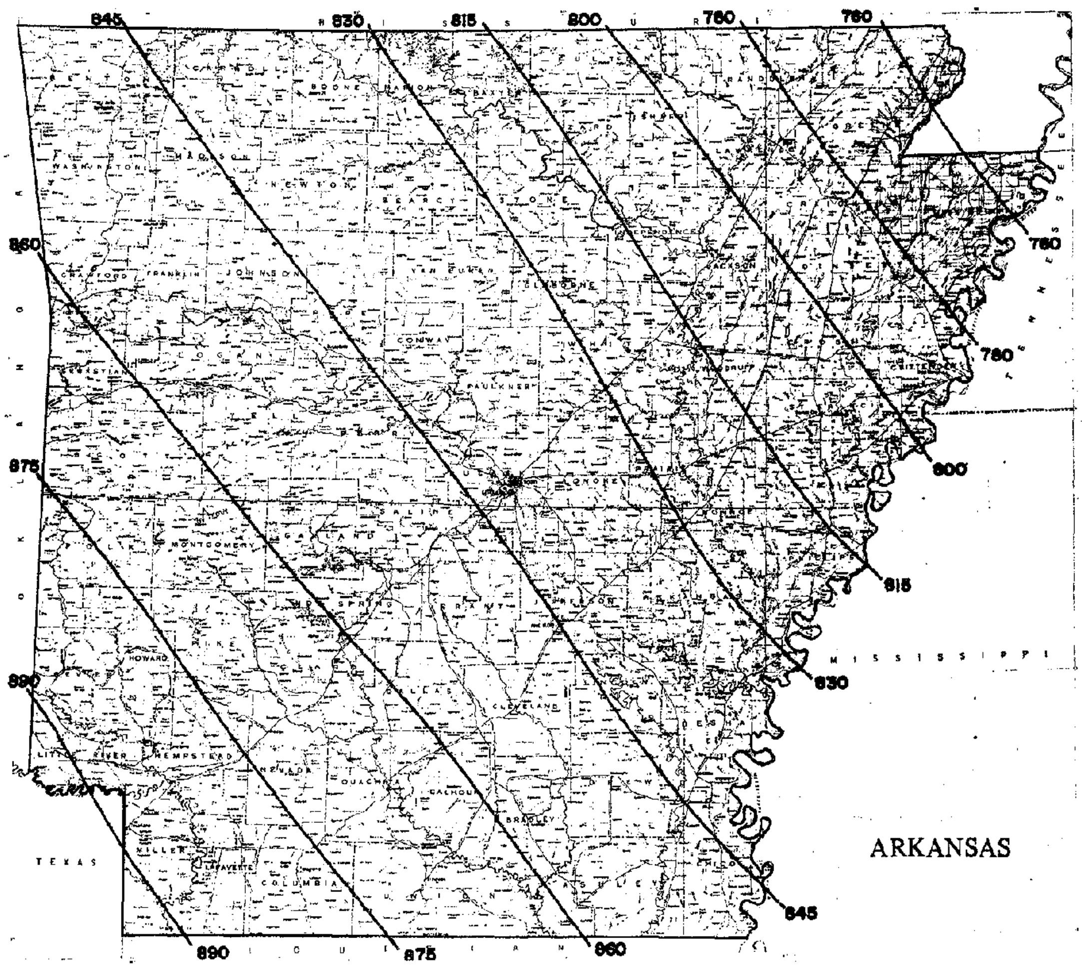
Appendix E-01. Isohyetal map of 10-year, 10-minute rainfall intensity for Alabama.



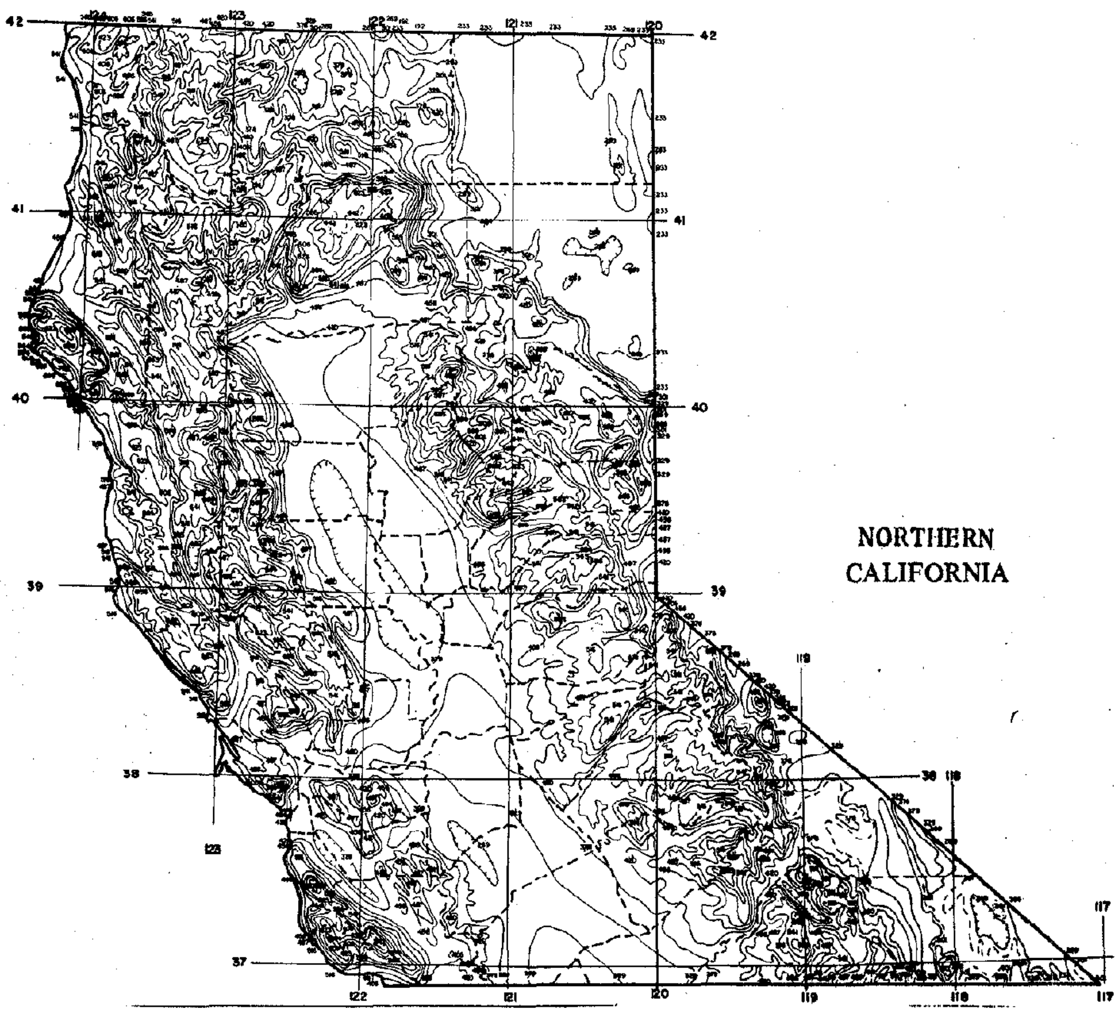
Appendix E-02. Isohyetal map of 10-year, 10-minute rainfall intensity for Alaska.



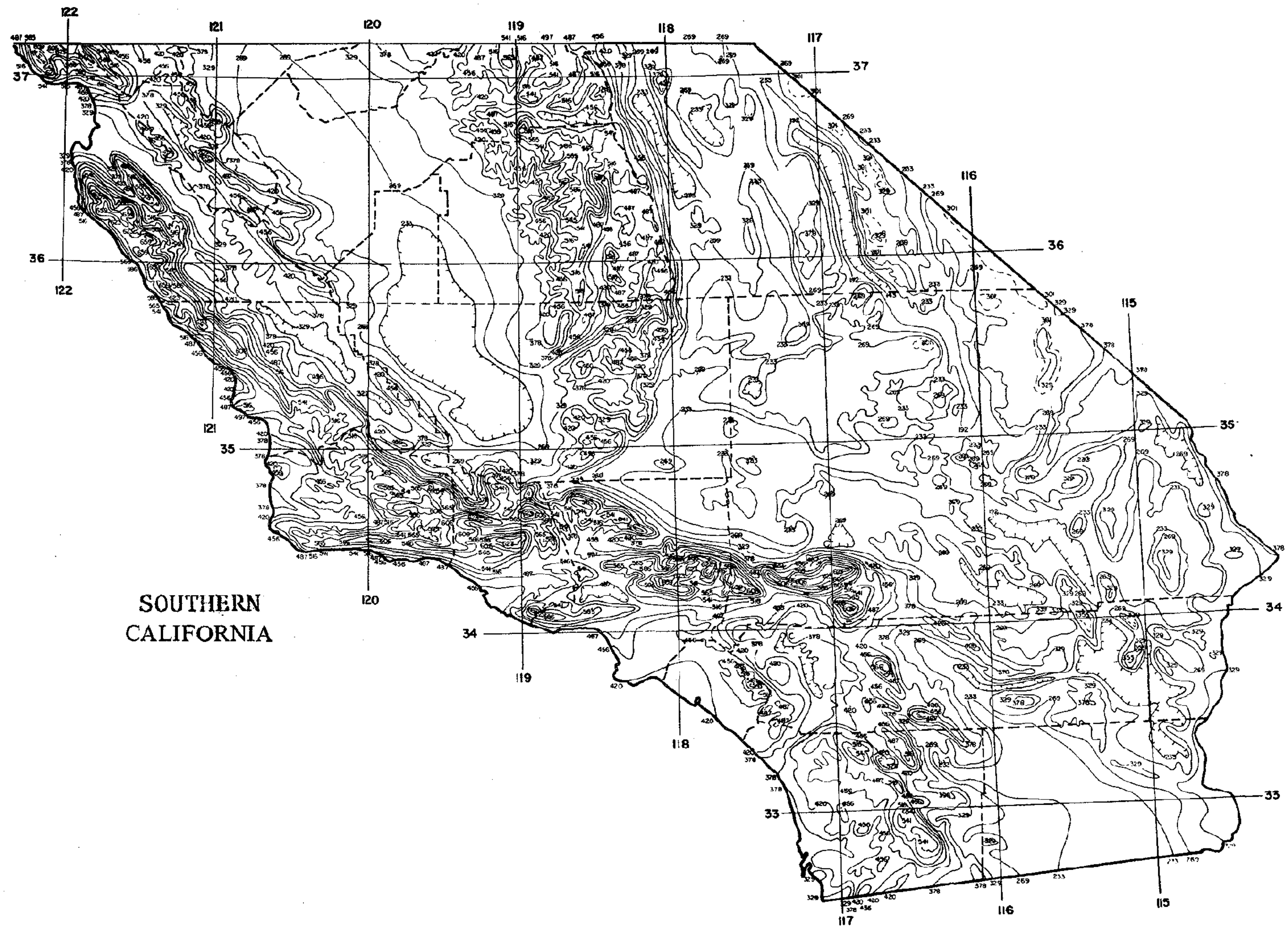
Appendix E-04. Isohyetal map of 10-year, 10-minute rainfall intensity for Arizona.



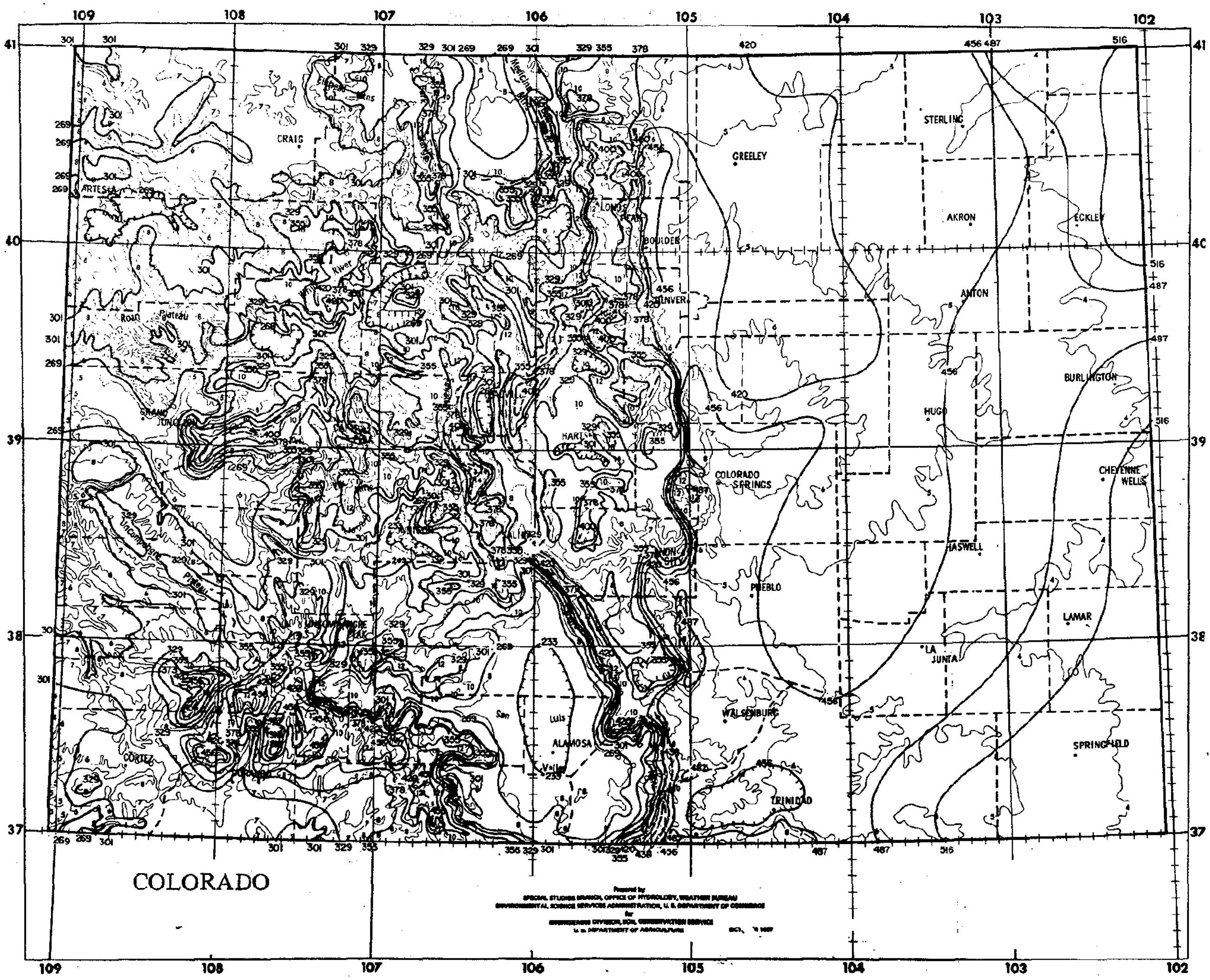
Appendix E-05. Isohyetal map of 10-year, 10-minute rainfall intensity for Arkansas.



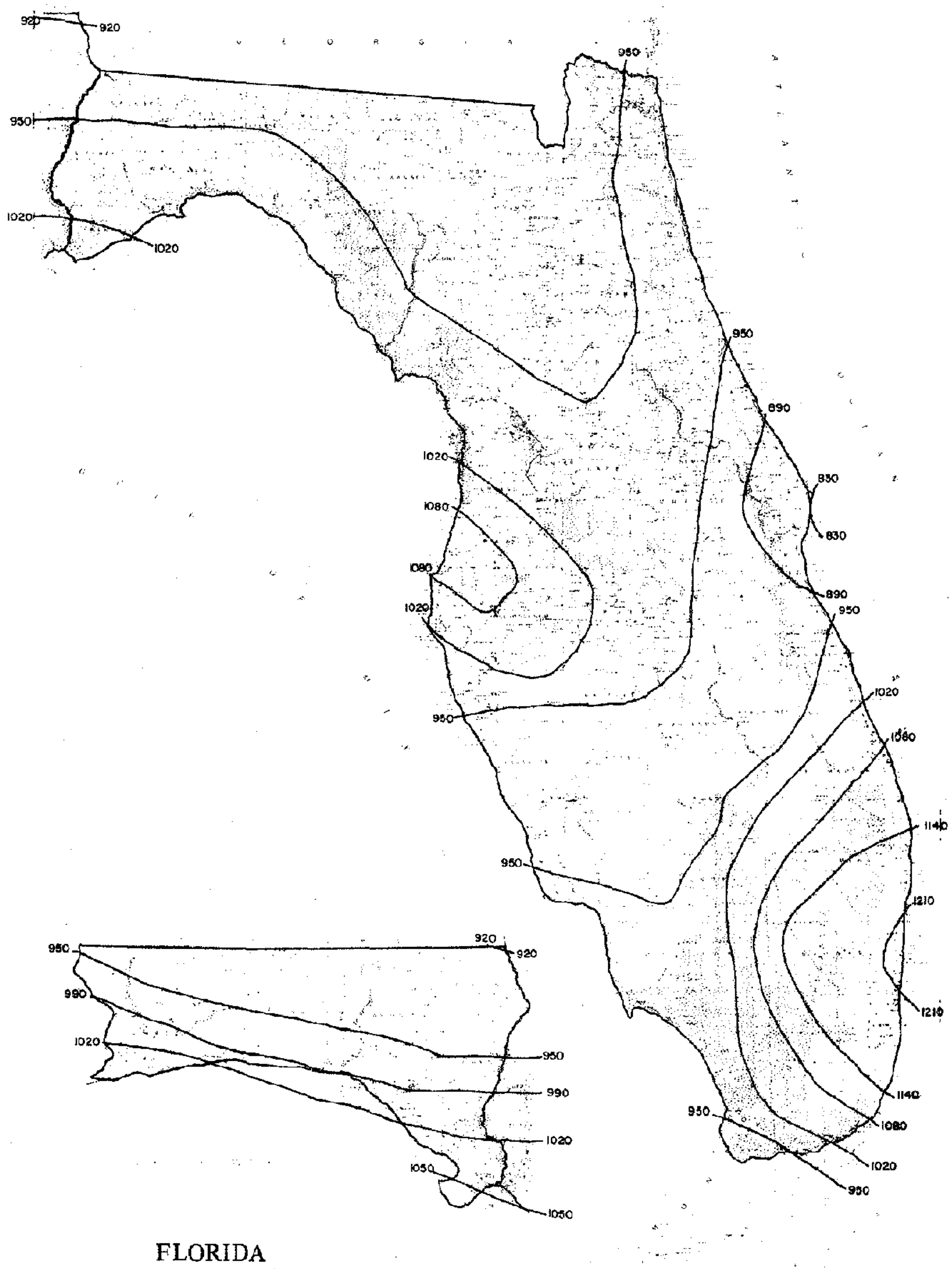
Appendix E-06a. Isohyetal map of 10-year, 10-minute rainfall intensity for N. California.



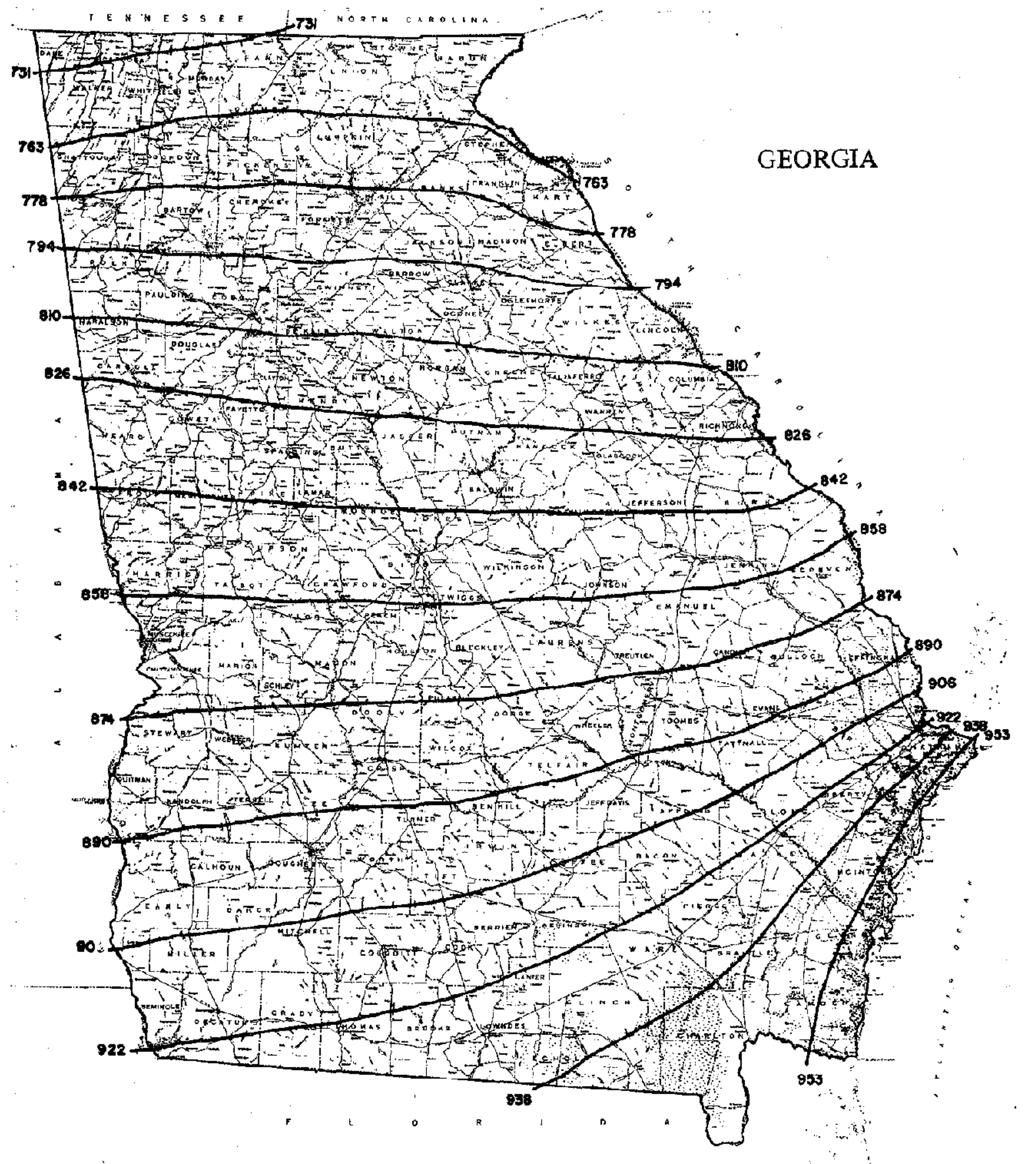
Appendix E-06b. Isohyetal map of 10-year, 10-minute rainfall intensity for S. California.



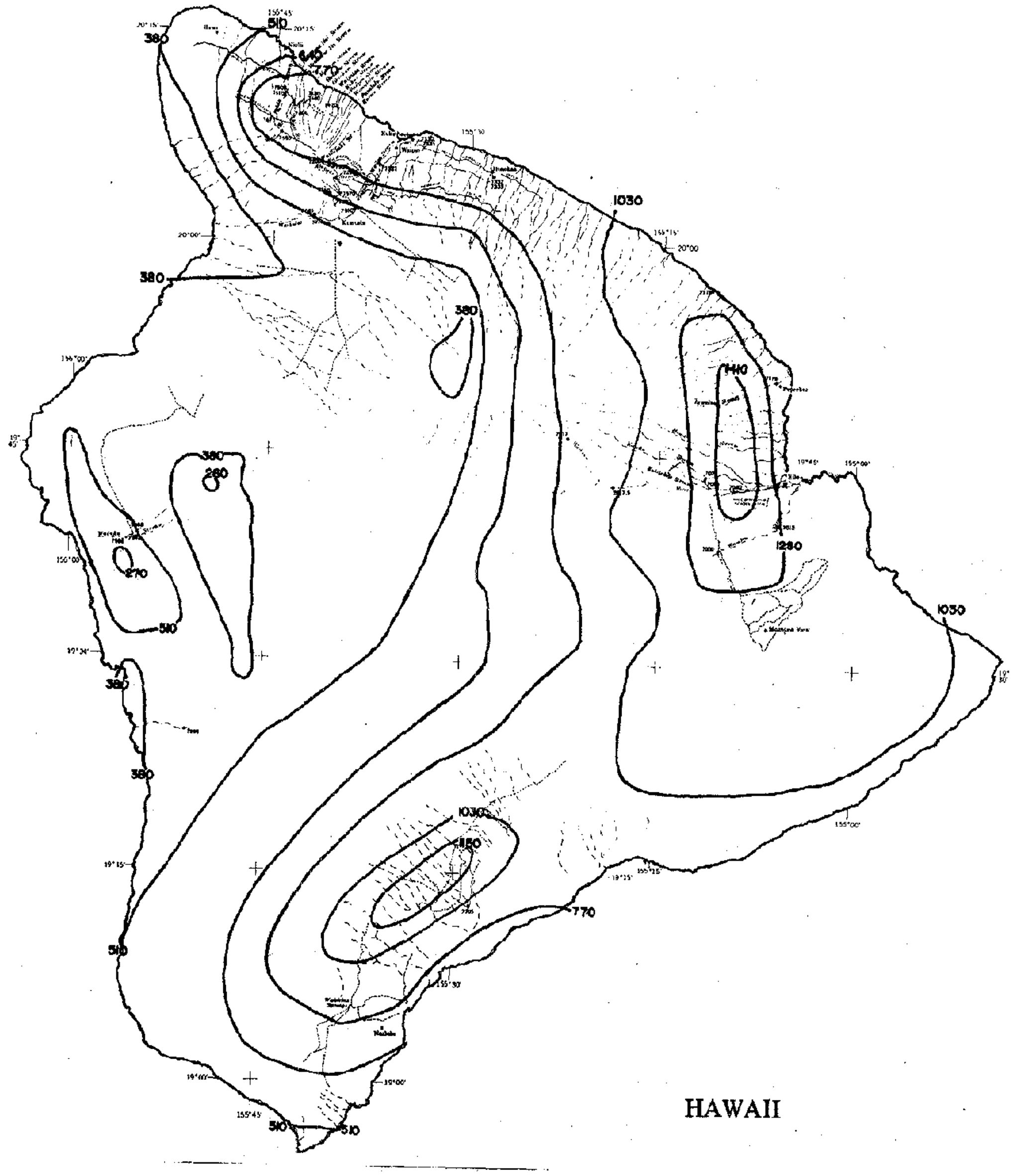
Appendix E-08. Isohyetal map of 10-year, 10-minute rainfall intensity for Colorado.



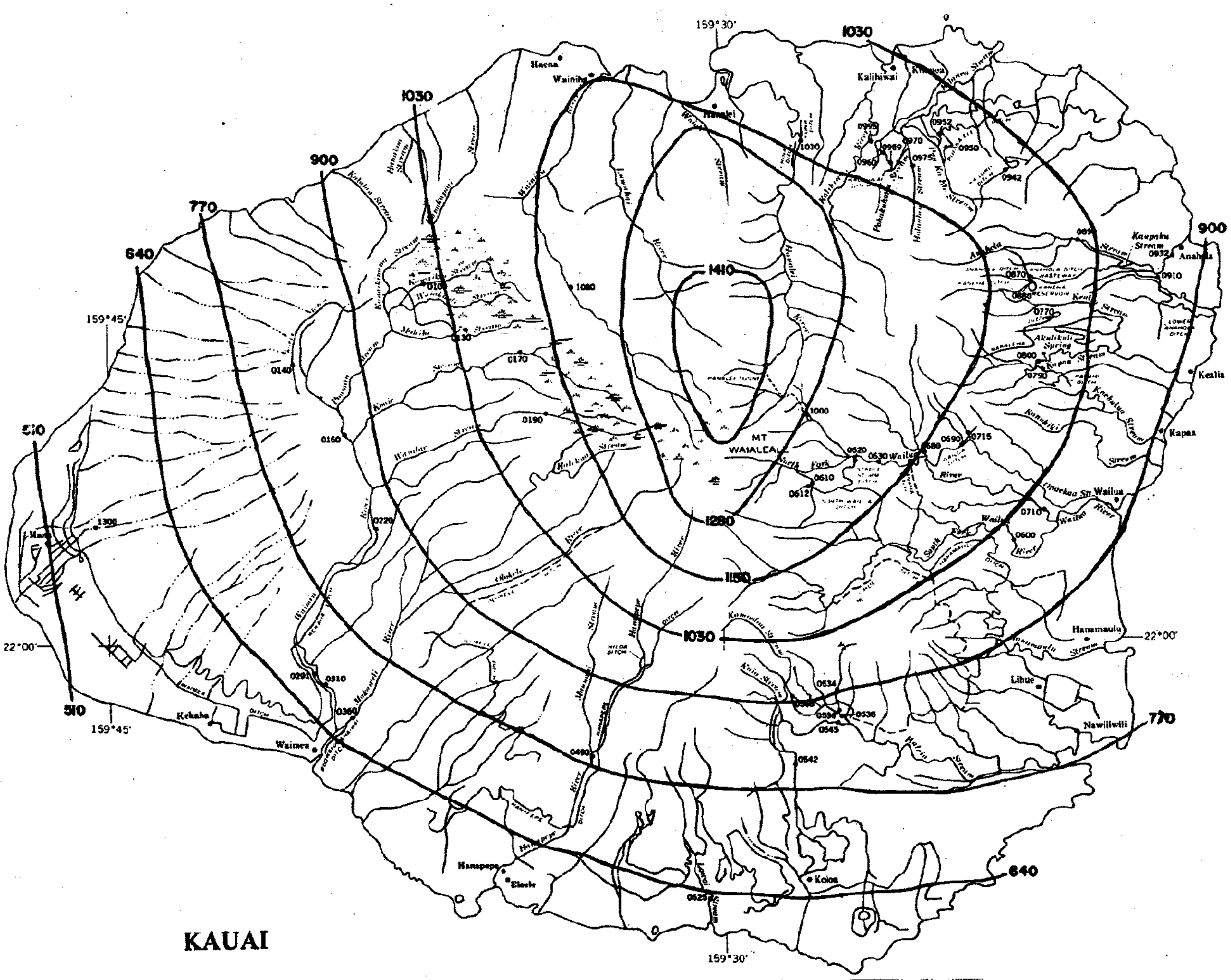
Appendix E-12. Isohyetal map of 10-year, 10-minute rainfall intensity for Florida.



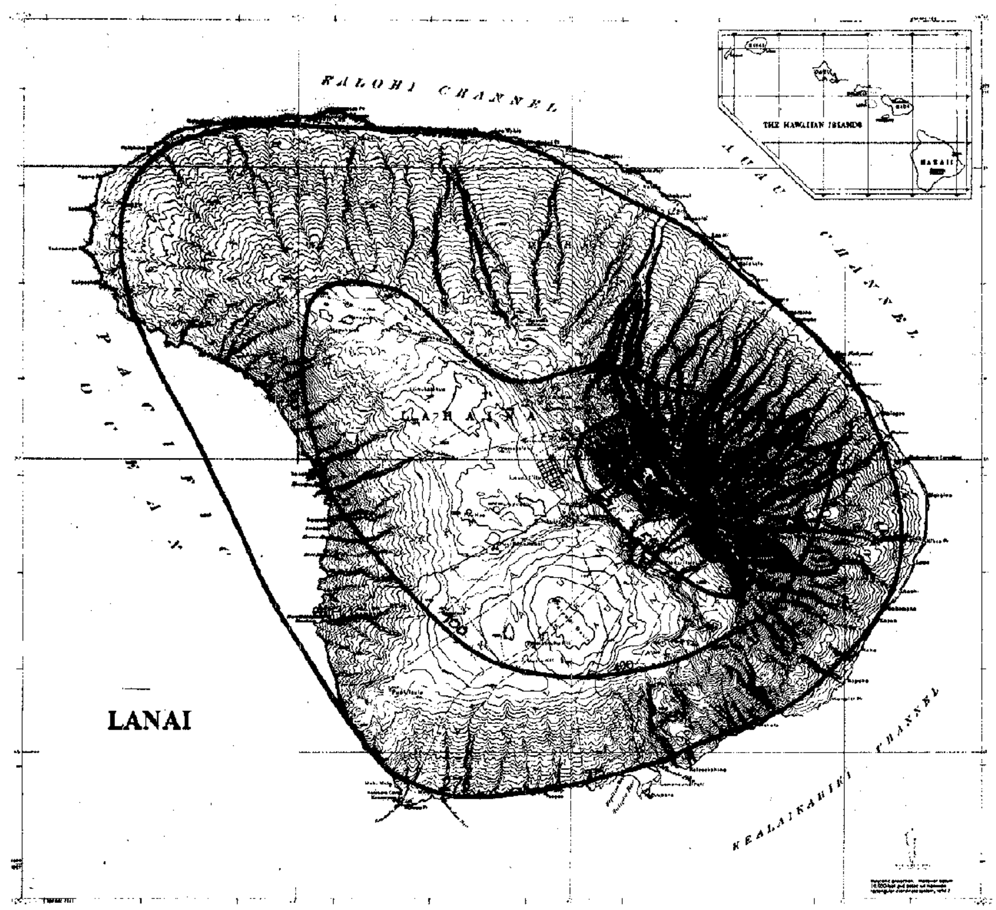
Appendix E-13. Isohyetal map of 10-year, 10-minute rainfall intensity for Georgia.



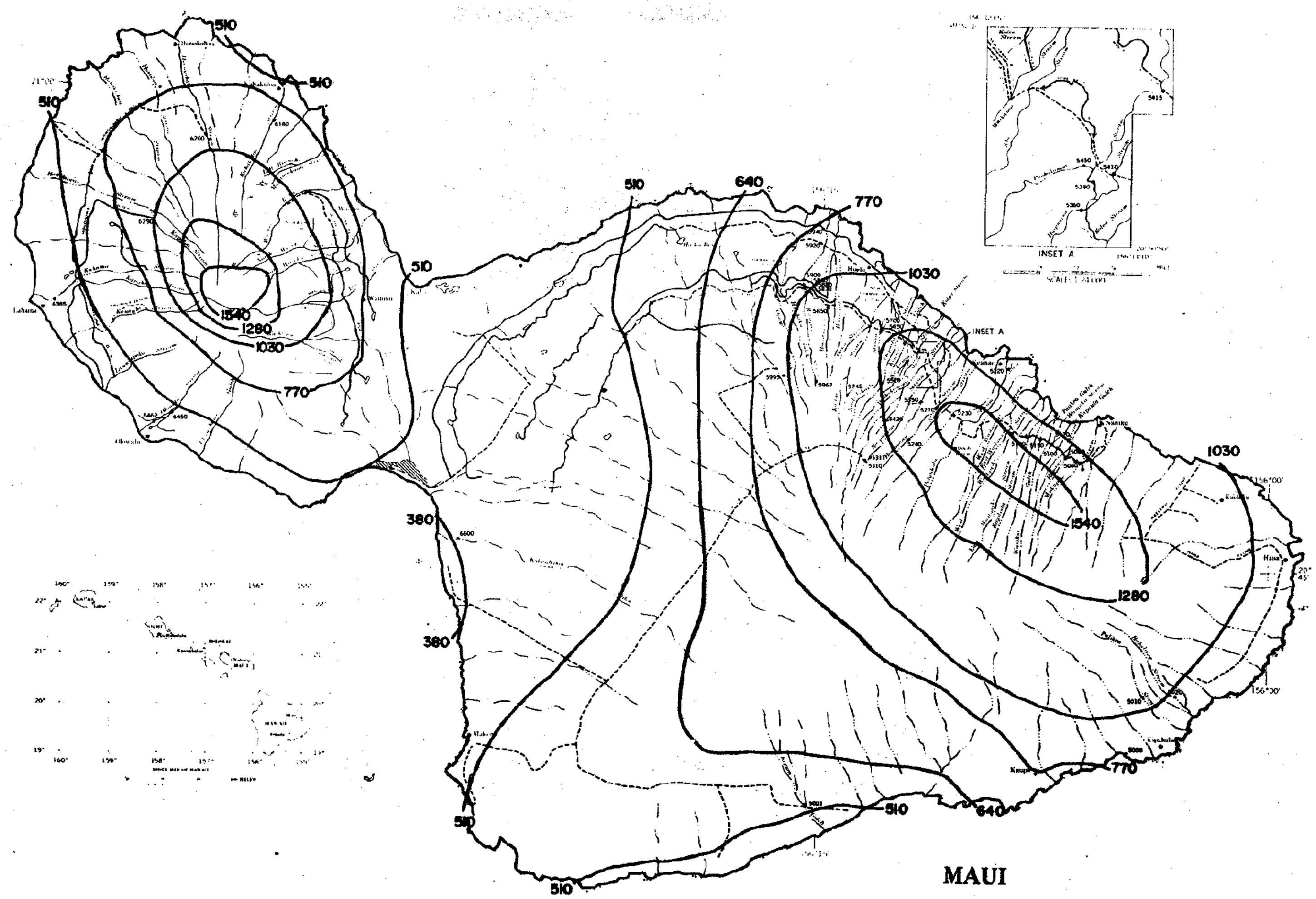
Appendix E-15a. Isohyetal map of 10-year, 10-minute rainfall intensity for Hawaii, Hawaii.



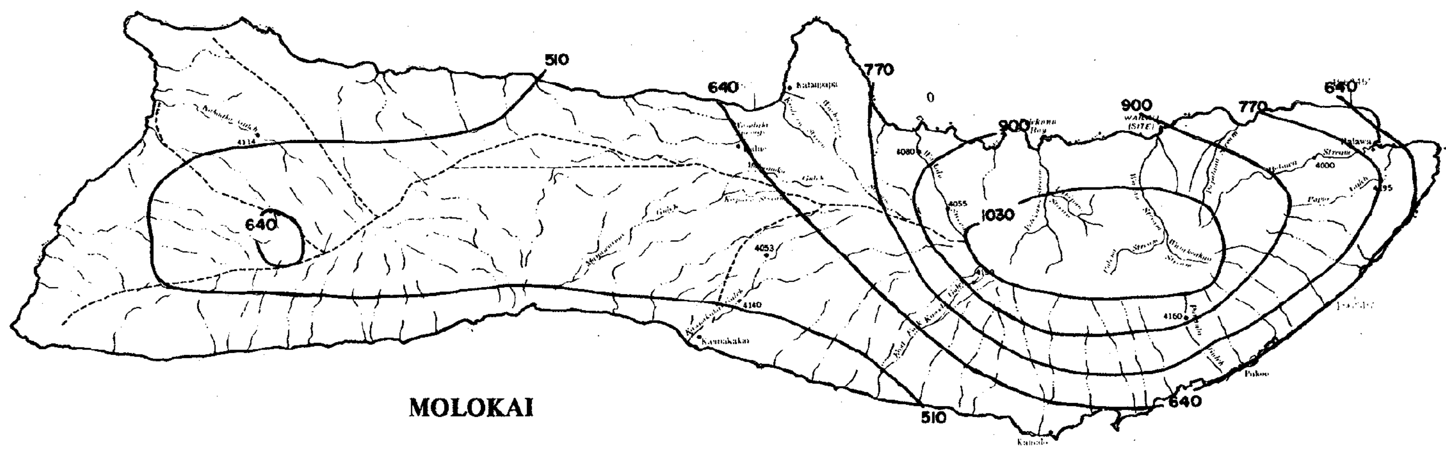
Appendix E-15b. Isohyetal map of 10-year, 10-minute rainfall intensity for Kauai, Hawaii.



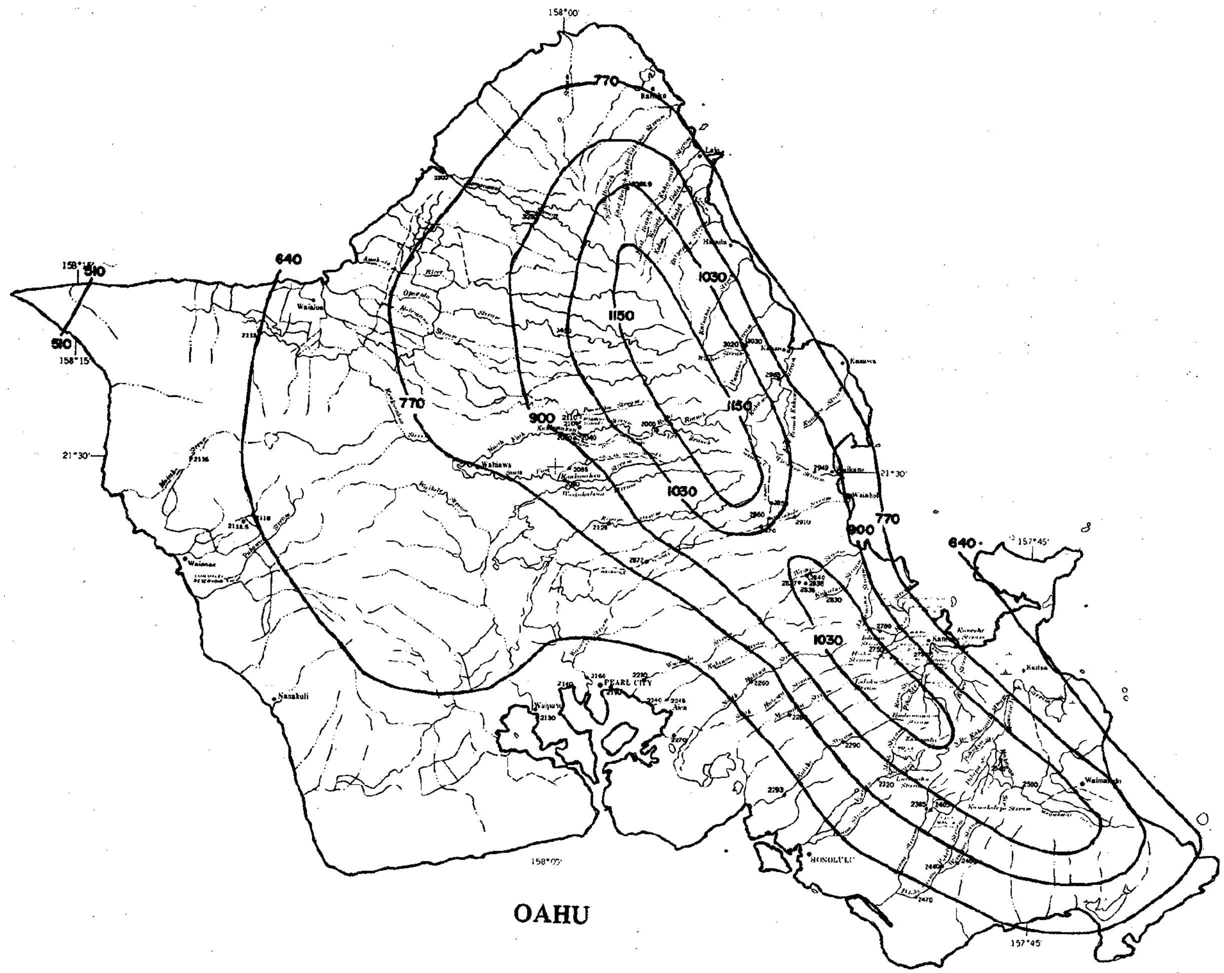
Appendix E-15c. Isohyetal map of 10-year, 10-minute rainfall intensity for Lanai, Hawaii.



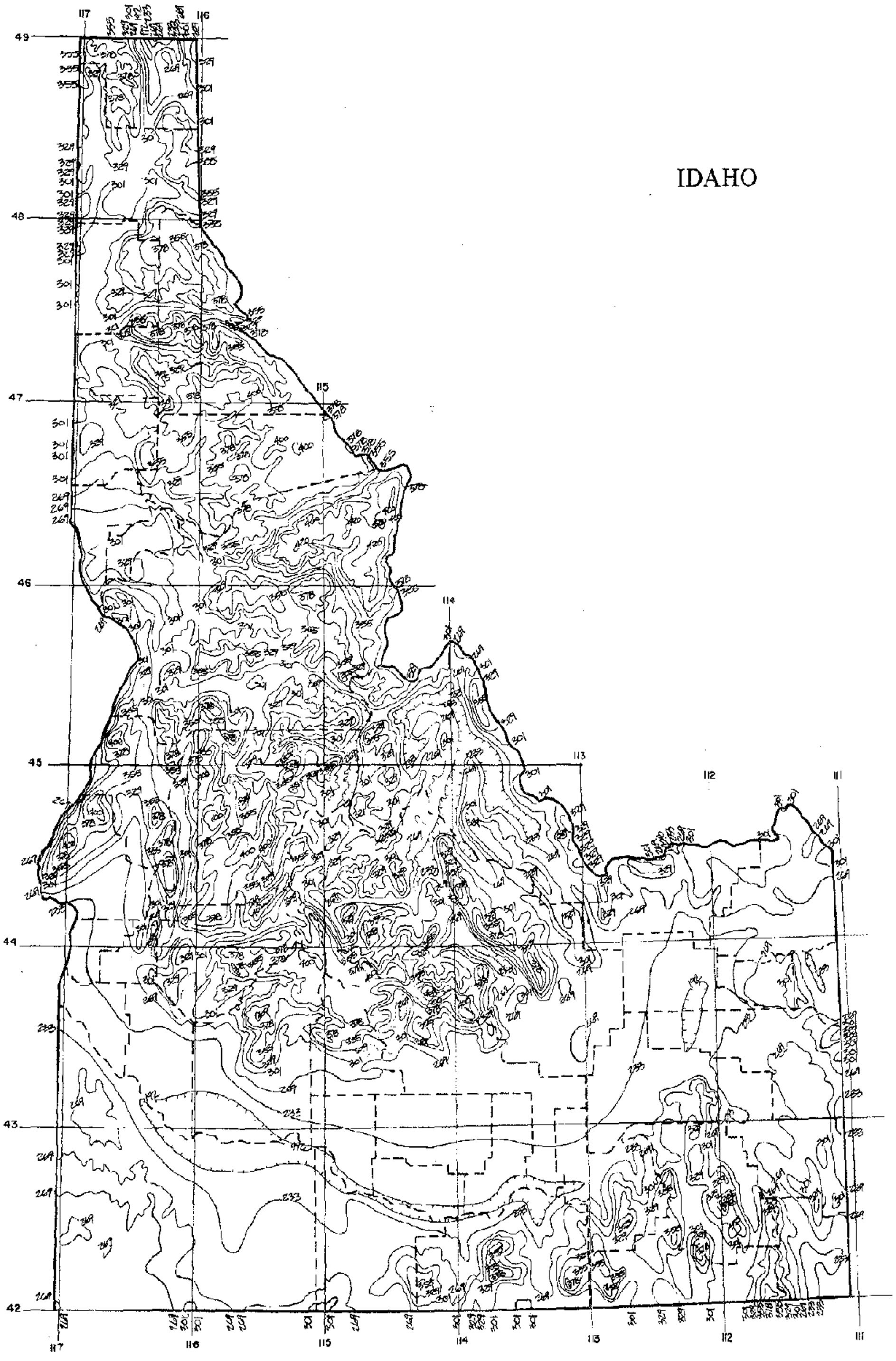
Appendix E-15d. Isohyetal map of 10-year, 10-minute rainfall intensity for Maui, Hawaii.



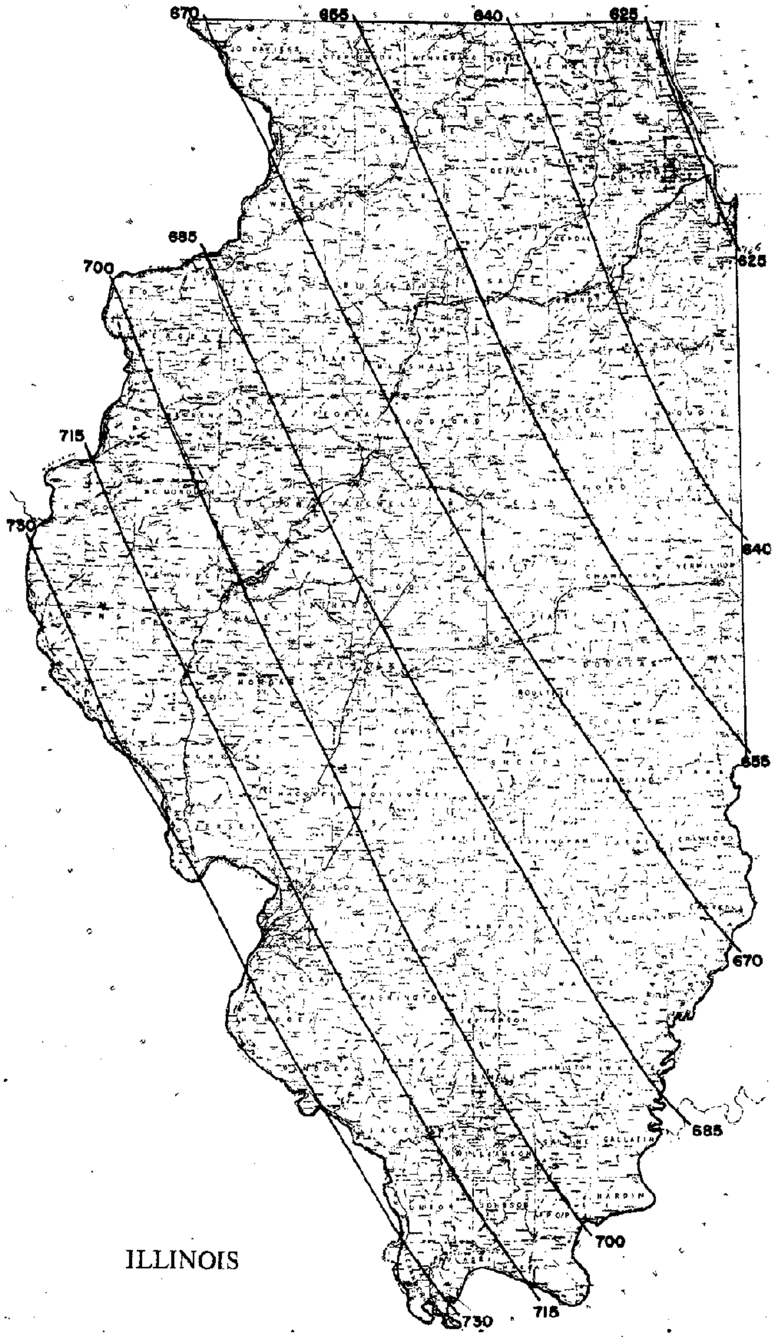
Appendix E-15e. Isohyetal map of 10-year, 10-minute rainfall intensity for Molokai, Hawaii.



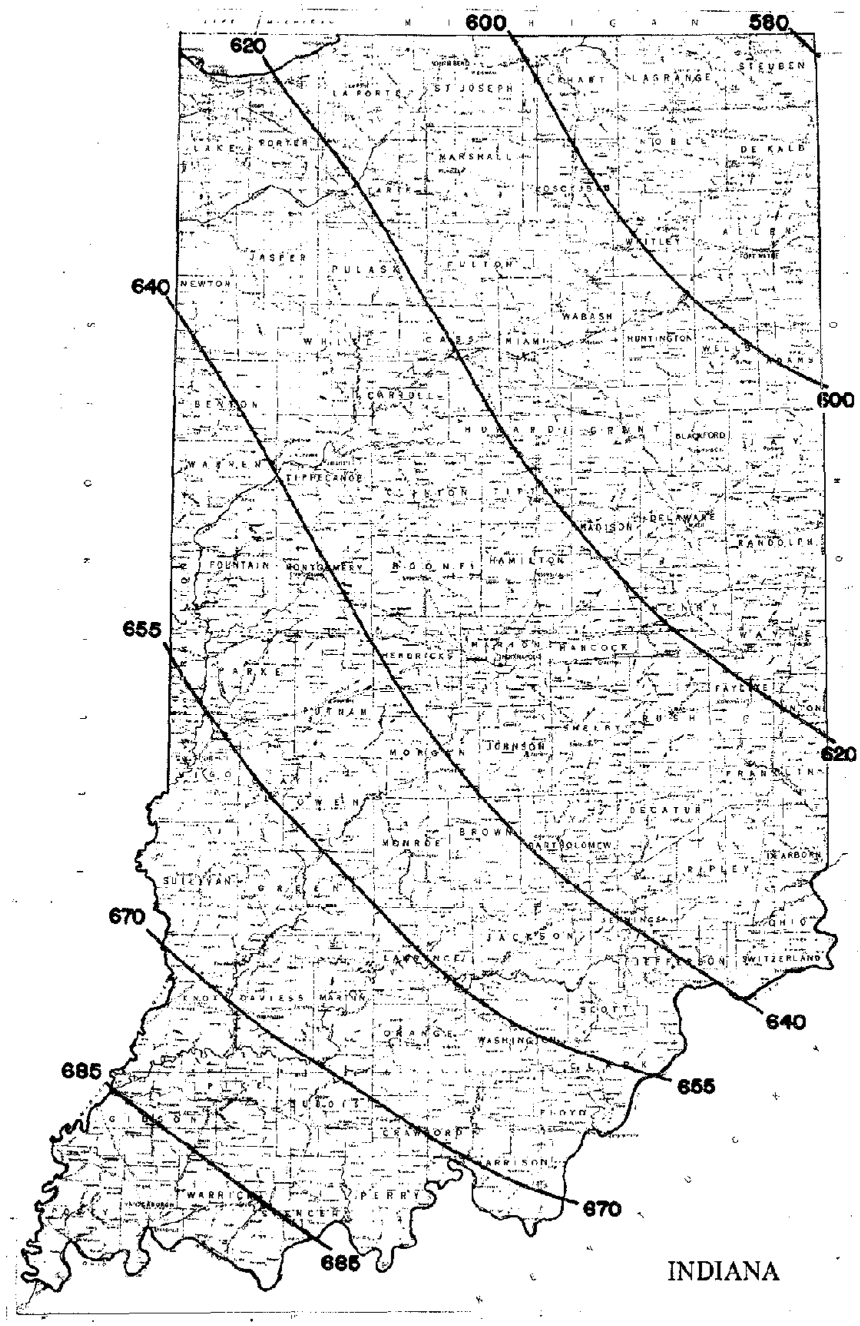
Appendix E-15f. Isohyetal map of 10-year, 10-minute rainfall intensity for Oahu, Hawaii.



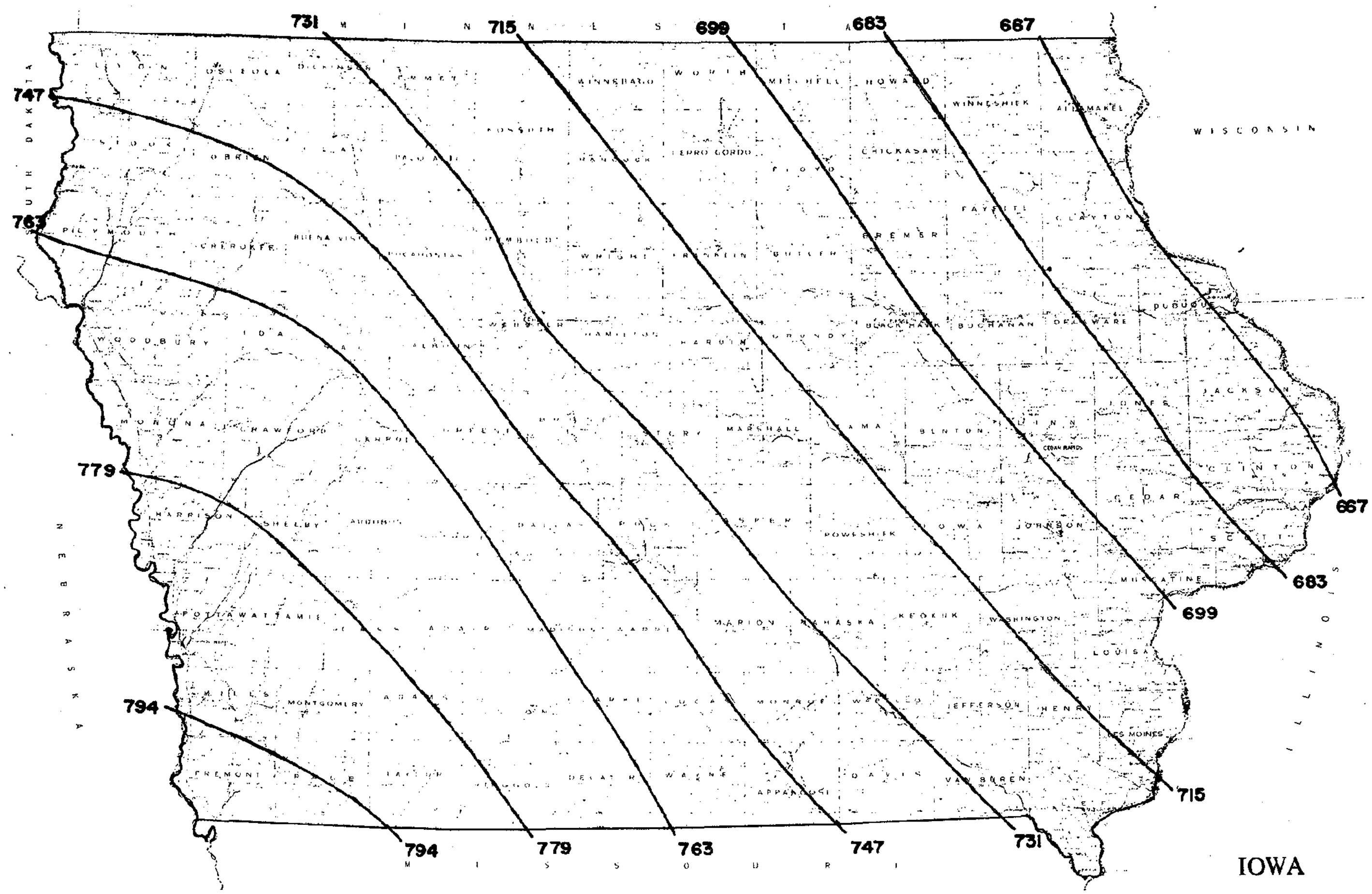
Appendix E-16. Isohyetal map of 10-year, 10-minute rainfall intensity for Idaho.



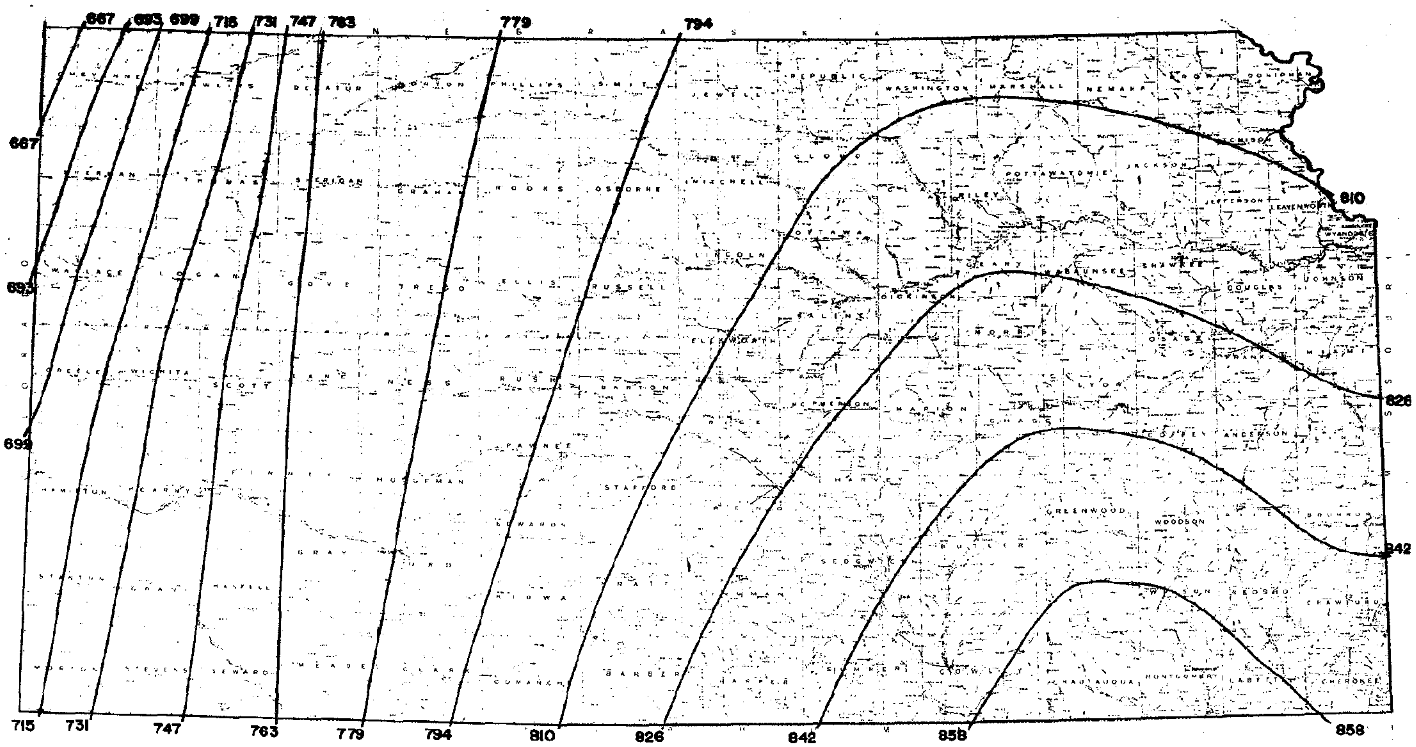
Appendix E-17. Isohyetal map of 10-year, 10-minute rainfall intensity for Illinois.



Appendix E-18. Isohyetal map of 10-year, 10-minute rainfall intensity for Indiana.

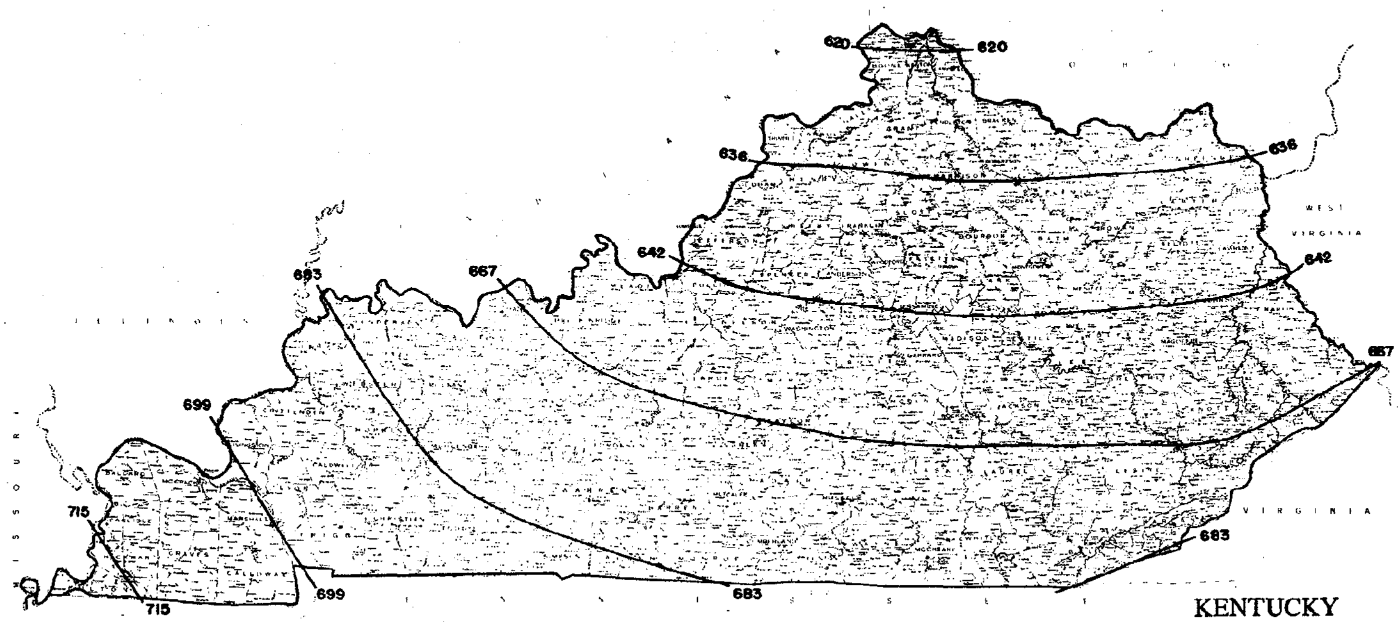


Appendix E-19. Isohyetal map of 10-year, 10-minute rainfall intensity for Iowa.

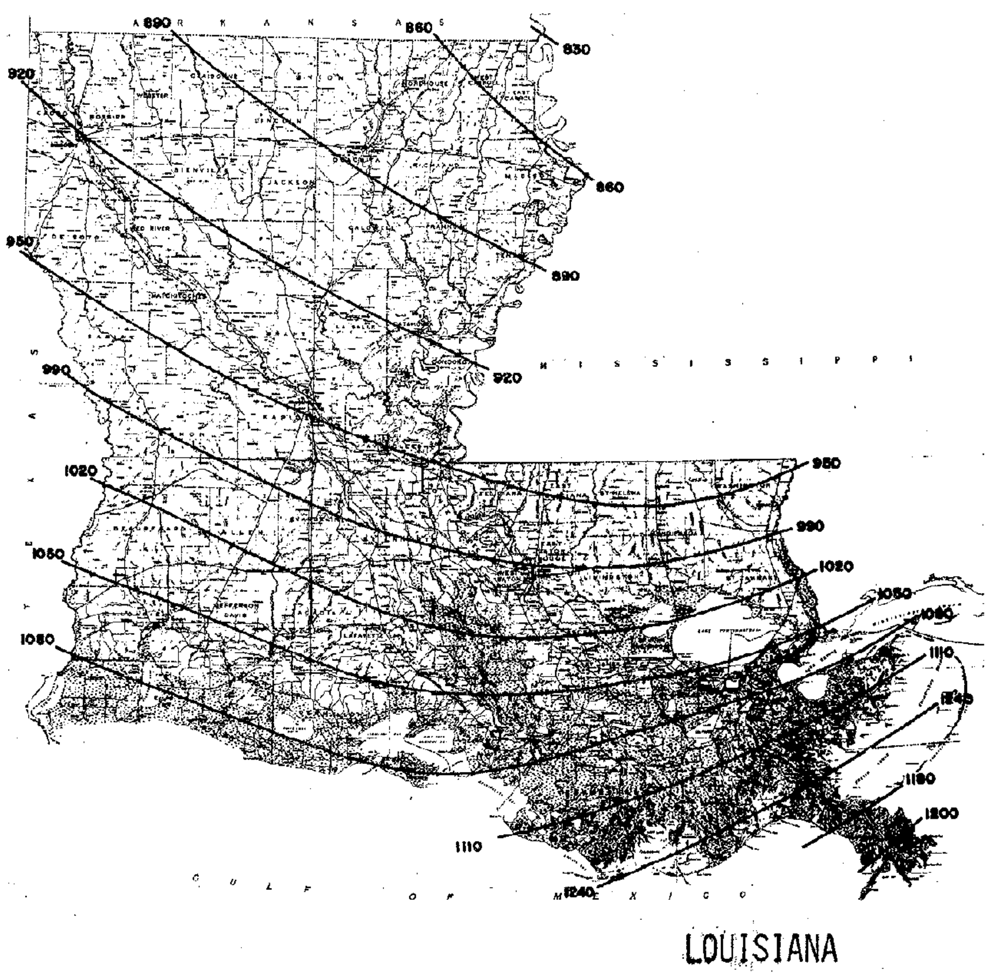


KANSAS

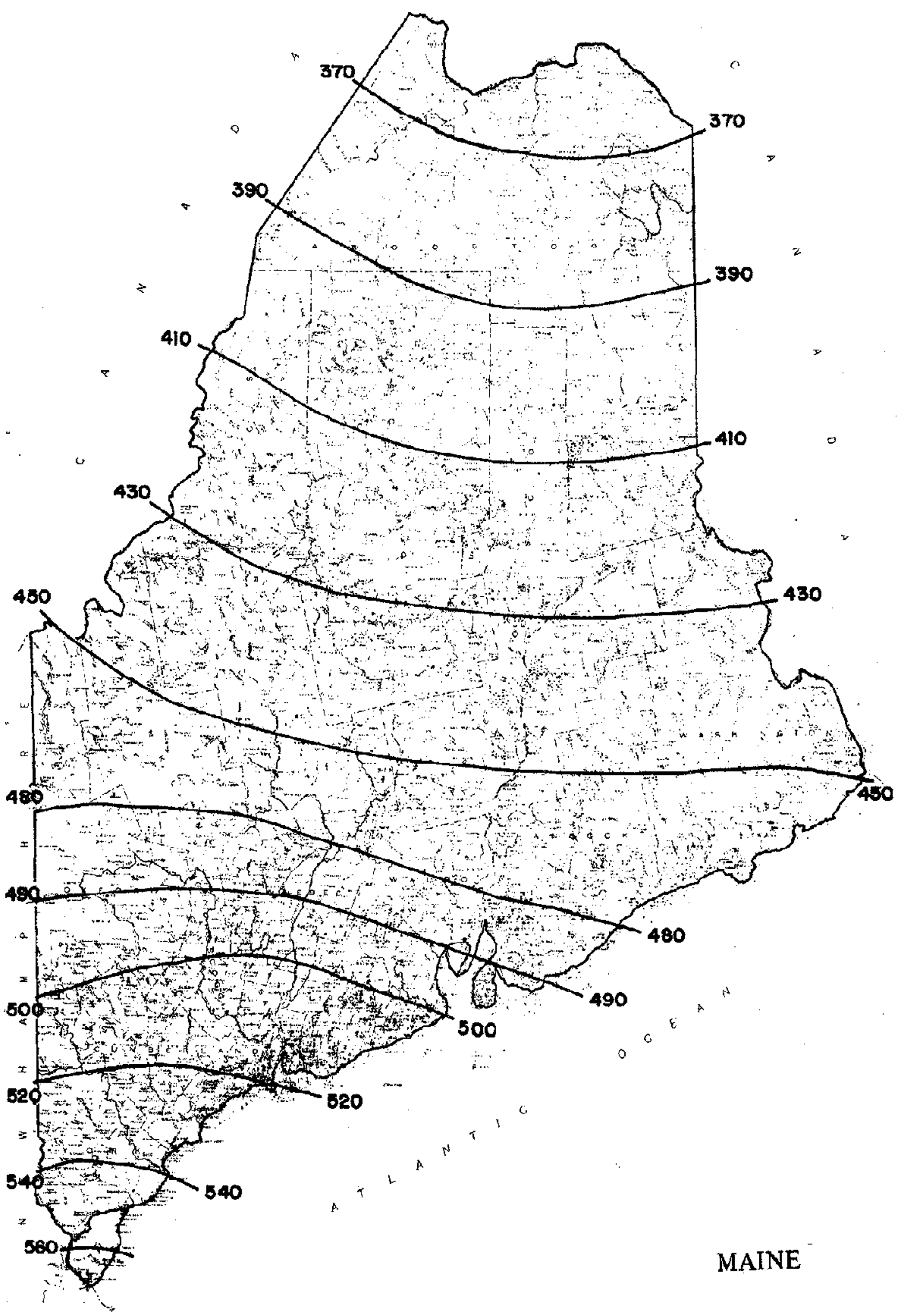
Appendix E-20. Isohyetal map of 10-year, 10-minute rainfall intensity for Kansas.



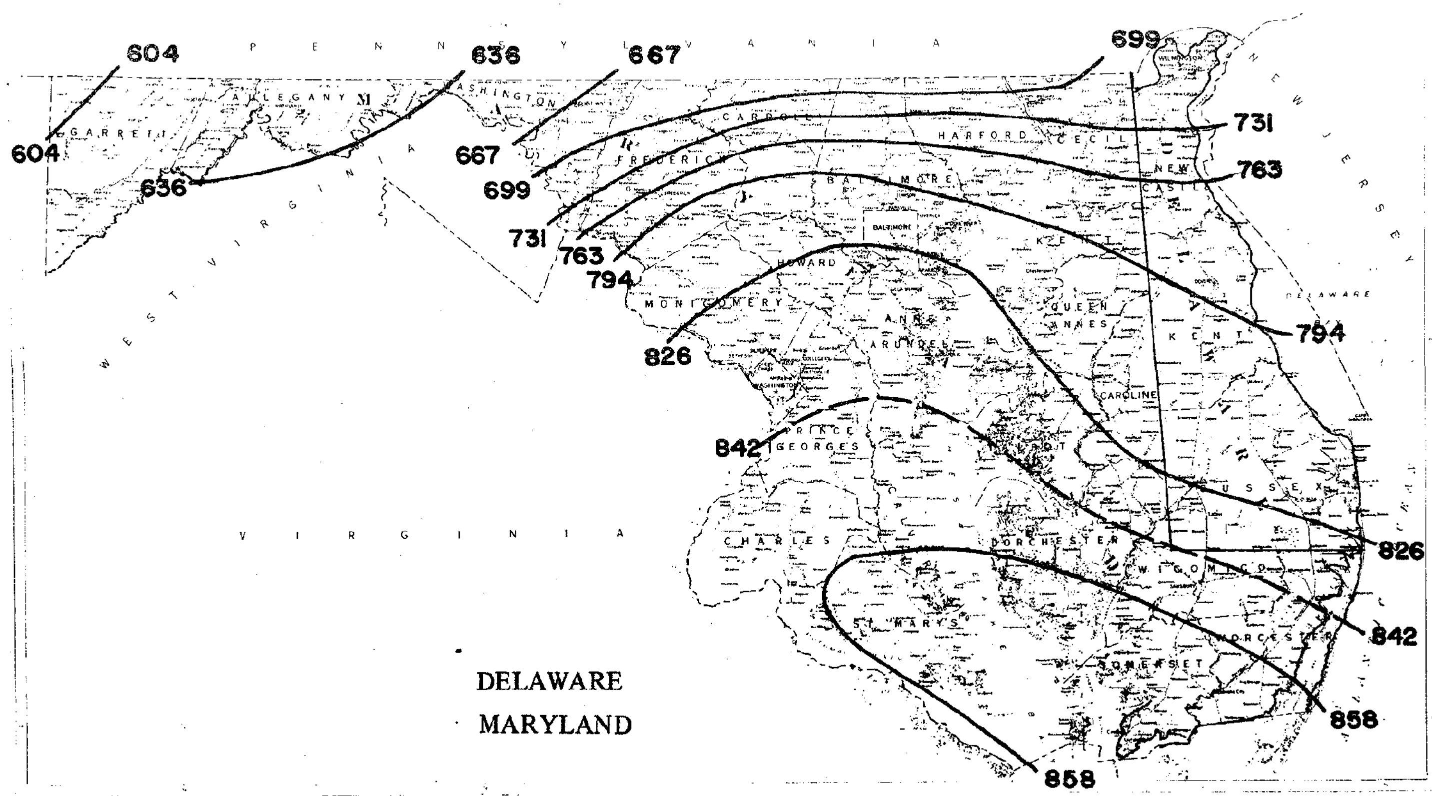
Appendix E-21. Isohyetal map of 10-year, 10-minute rainfall intensity for Kentucky.



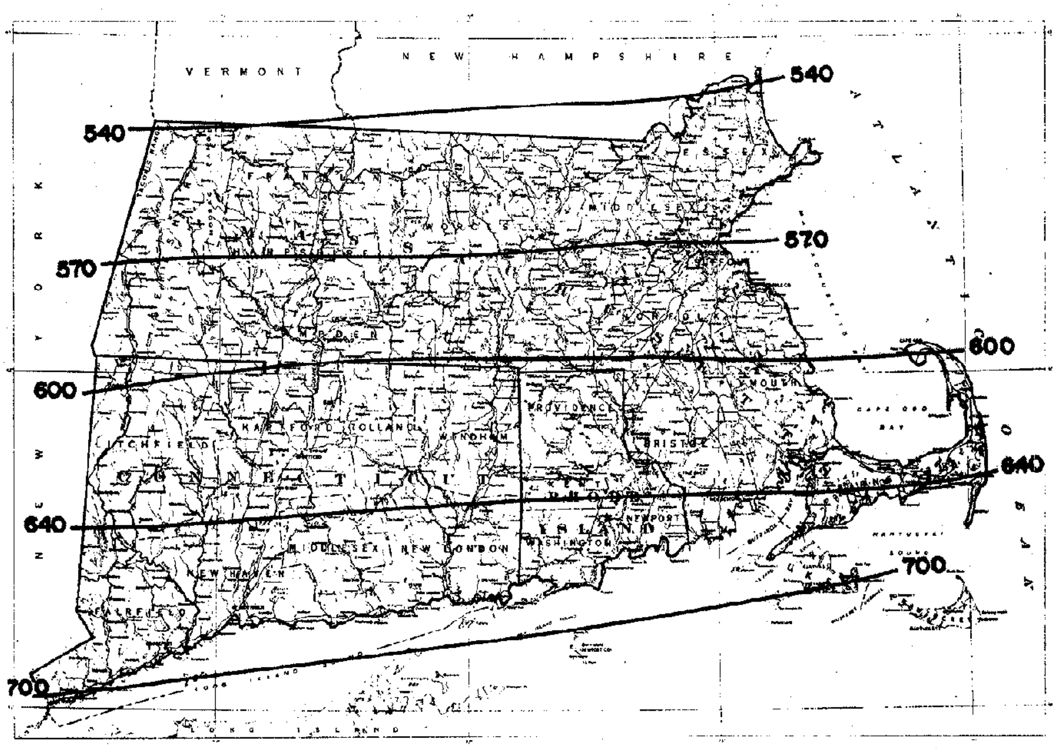
Appendix E-22. Isohyetal map of 10-year, 10-minute rainfall intensity for Louisiana.



Appendix E-23. Isohyetal map of 10-year, 10-minute rainfall intensity for Maine.

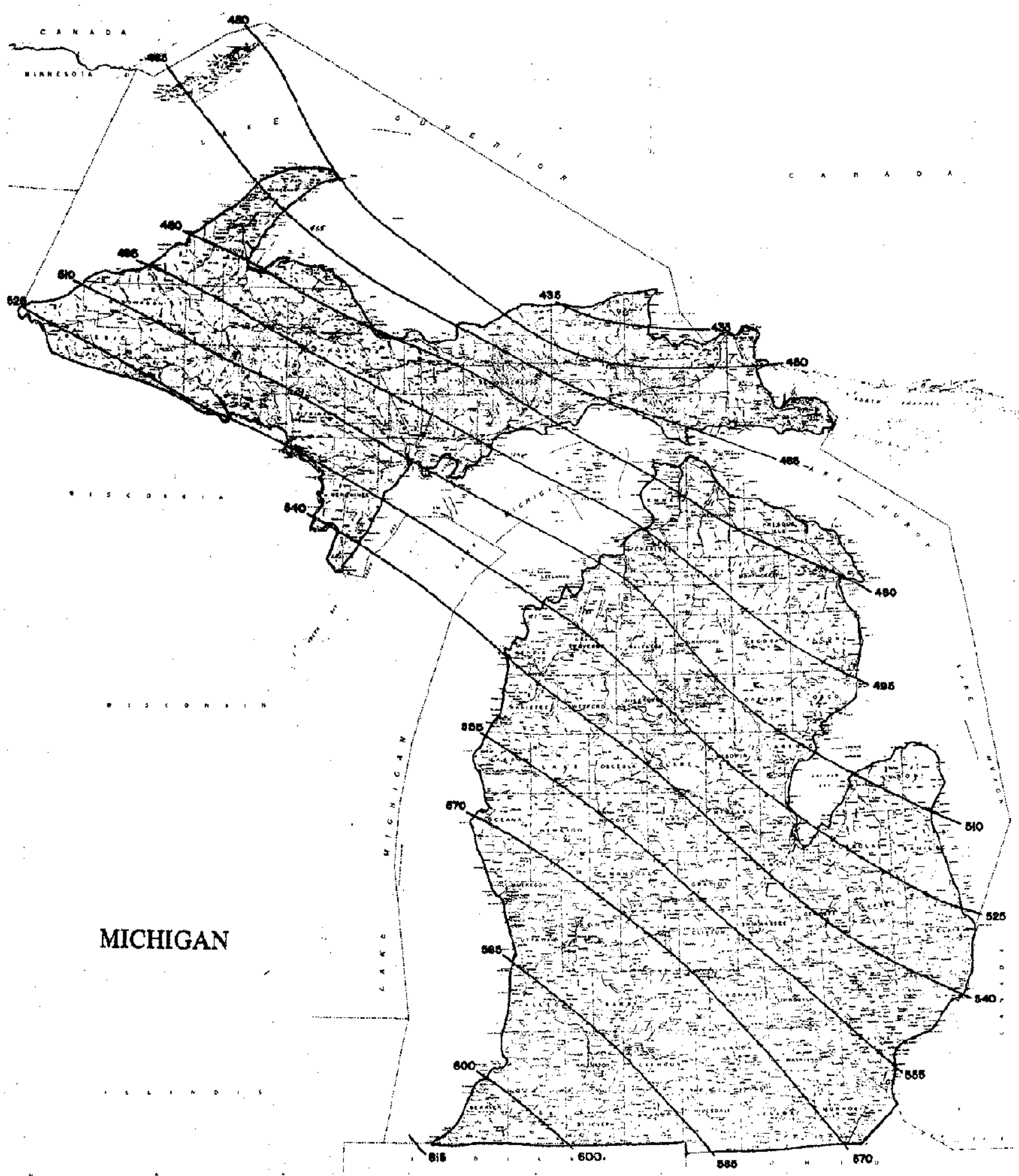


Appendix E-10. Isohyetal map of 10-year, 10-minute rainfall intensity for Delaware.
Appendix E-24. Isohyetal map of 10-year, 10-minute rainfall intensity for Maryland.

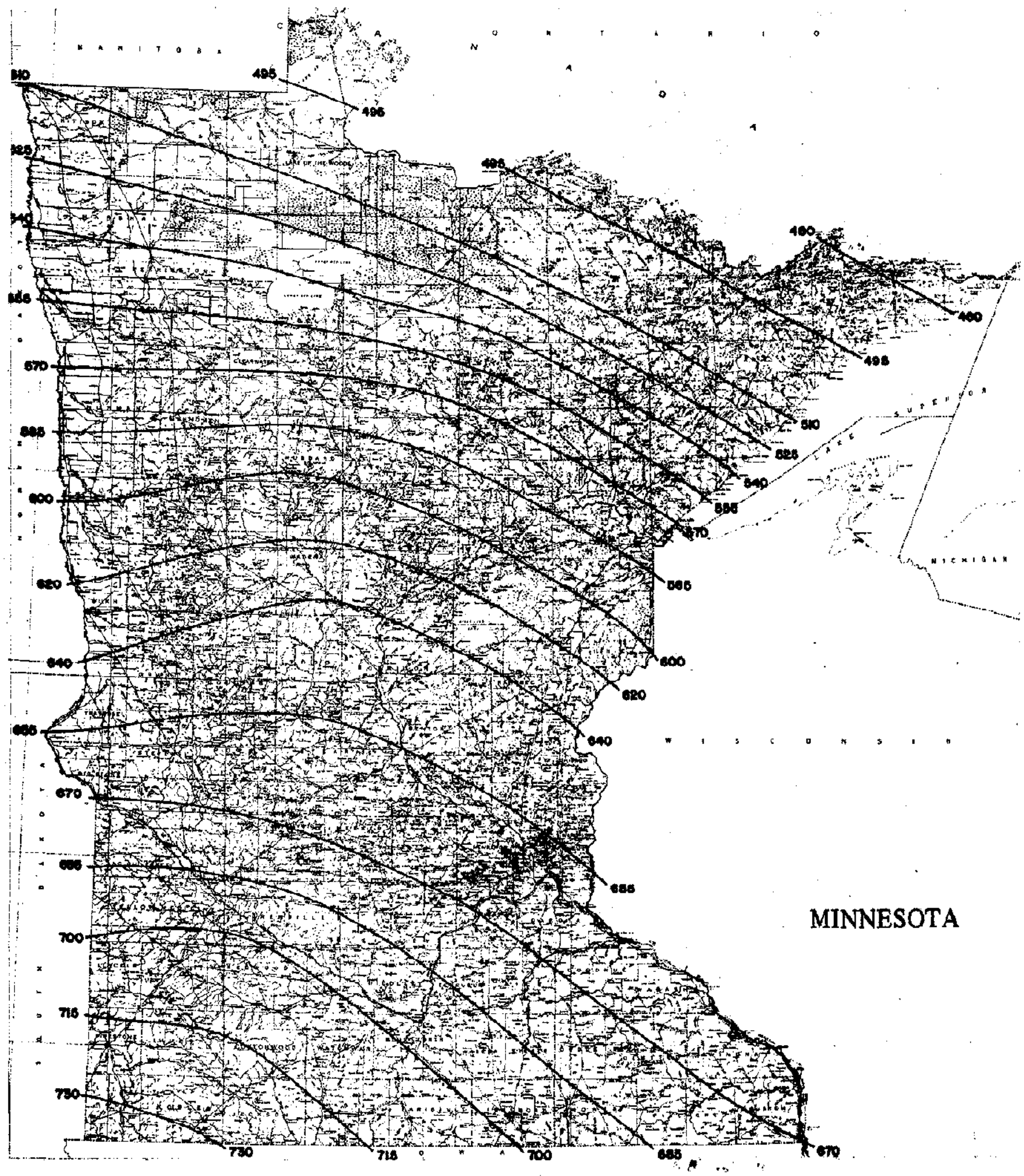


CONNECTICUT MASSACHUSETTS RHODE ISLAND

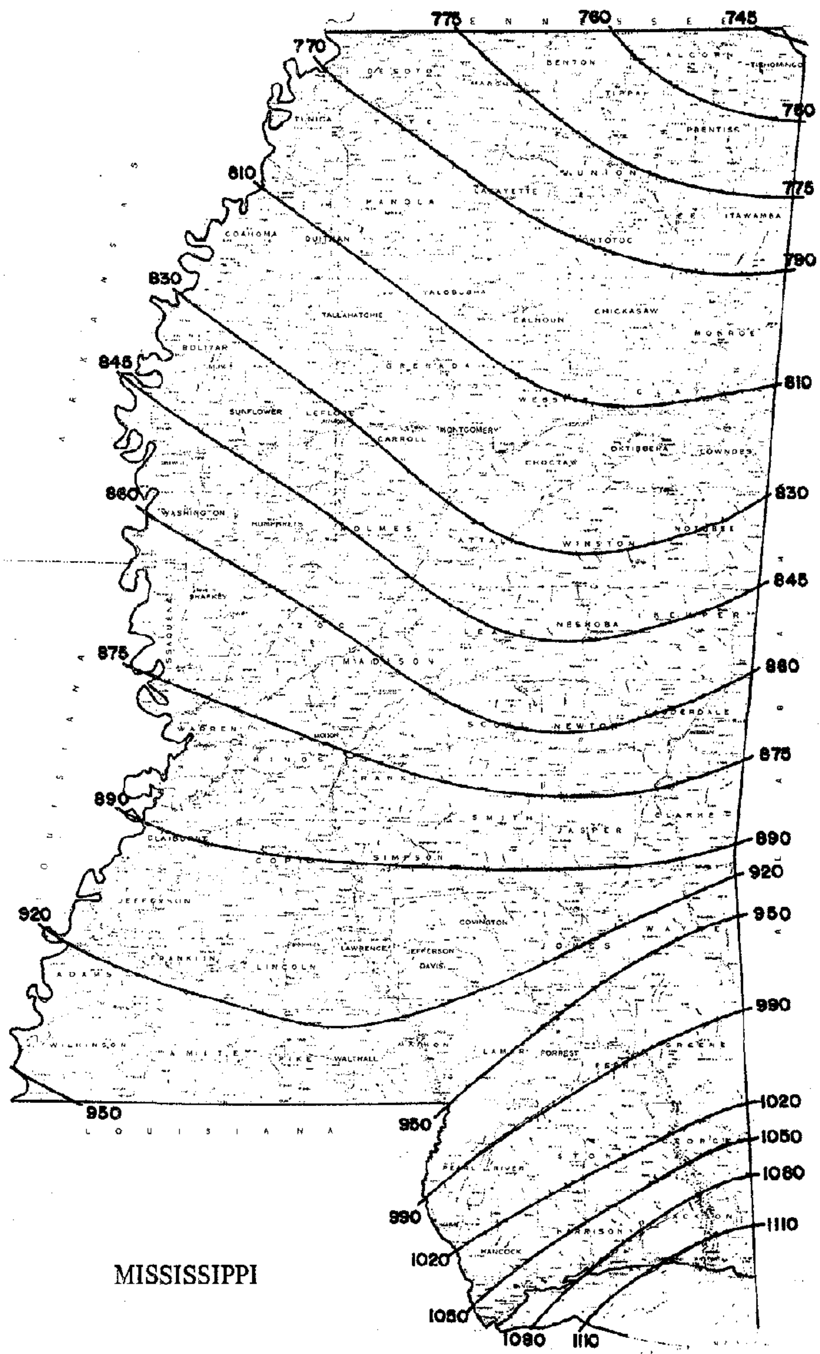
Appendix E-09. Isohyetal map of 10-year, 10-minute rainfall intensity for Connecticut.
Appendix E-25. Isohyetal map of 10-year, 10-minute rainfall intensity for Massachusetts.
Appendix E-44. Isohyetal map of 10-year, 10-minute rainfall intensity for Rhode Island.



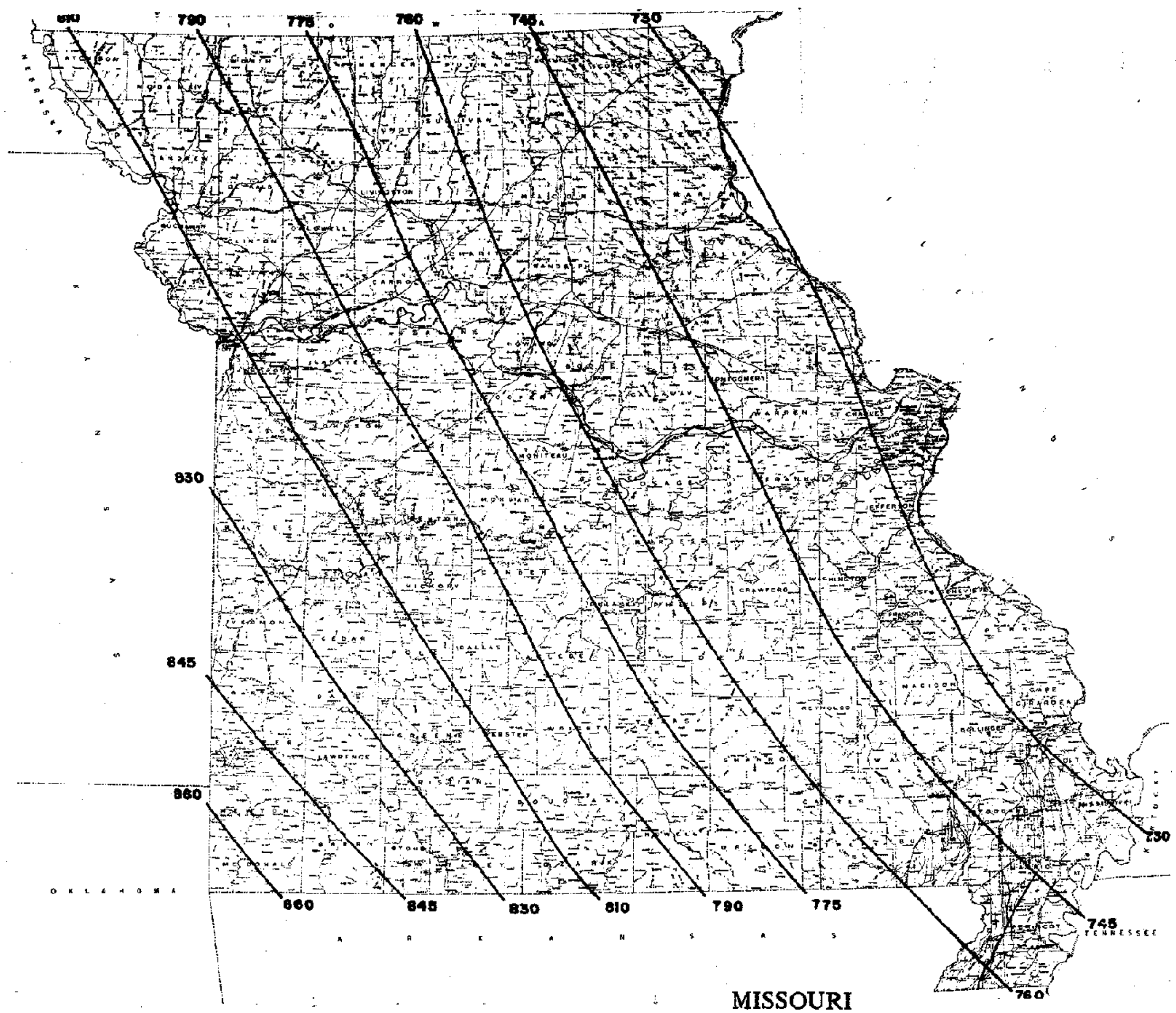
Appendix E-26. Isohyetal map of 10-year, 10-minute rainfall intensity for Michigan.



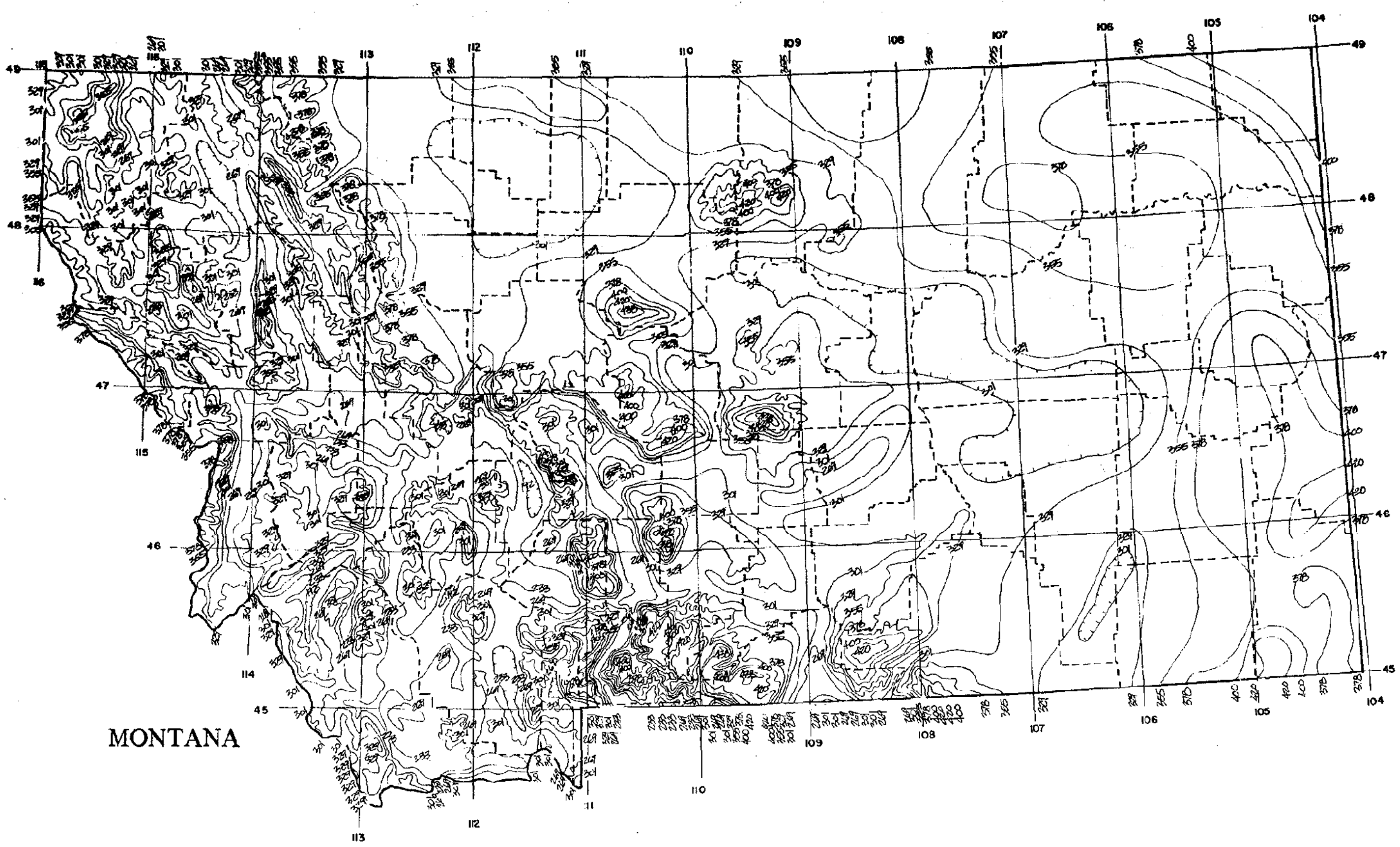
Appendix E-27. Isohyetal map of 10-year, 10-minute rainfall intensity for Minnesota.



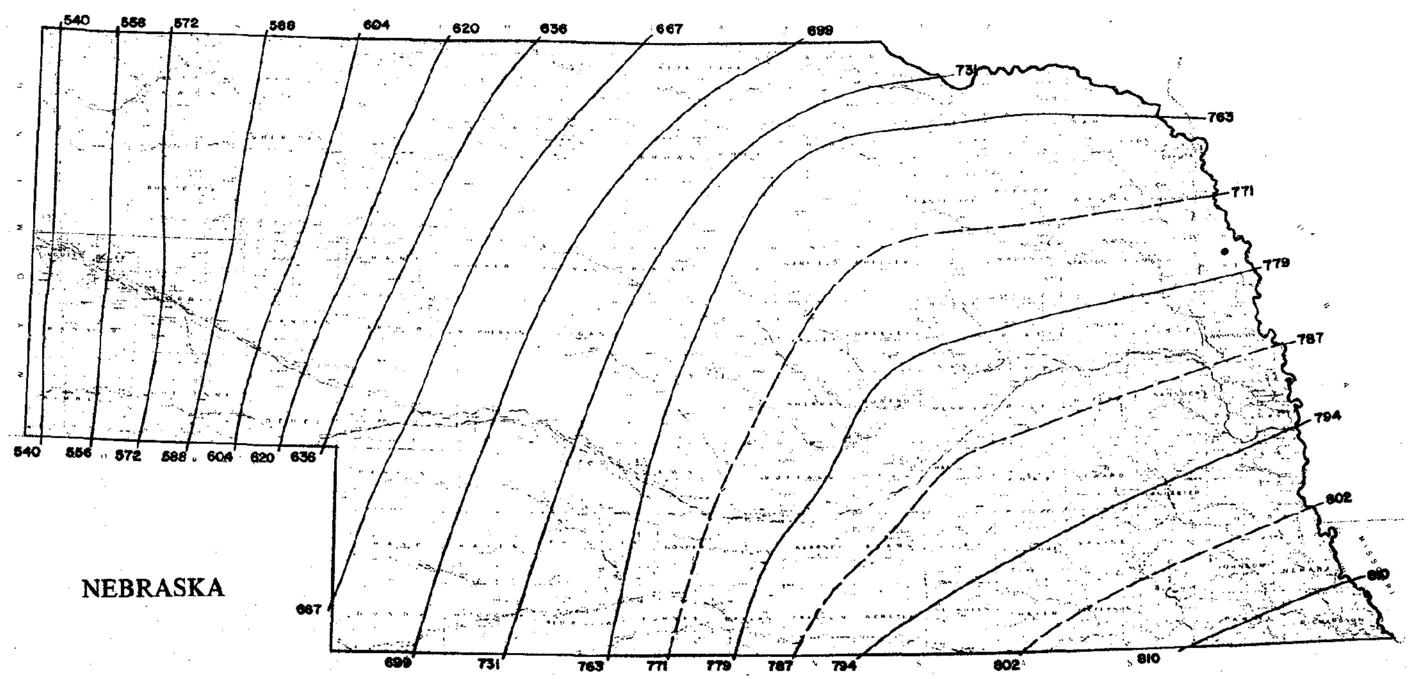
Appendix E-28. Isohyetal map of 10-year, 10-minute rainfall intensity for Mississippi.



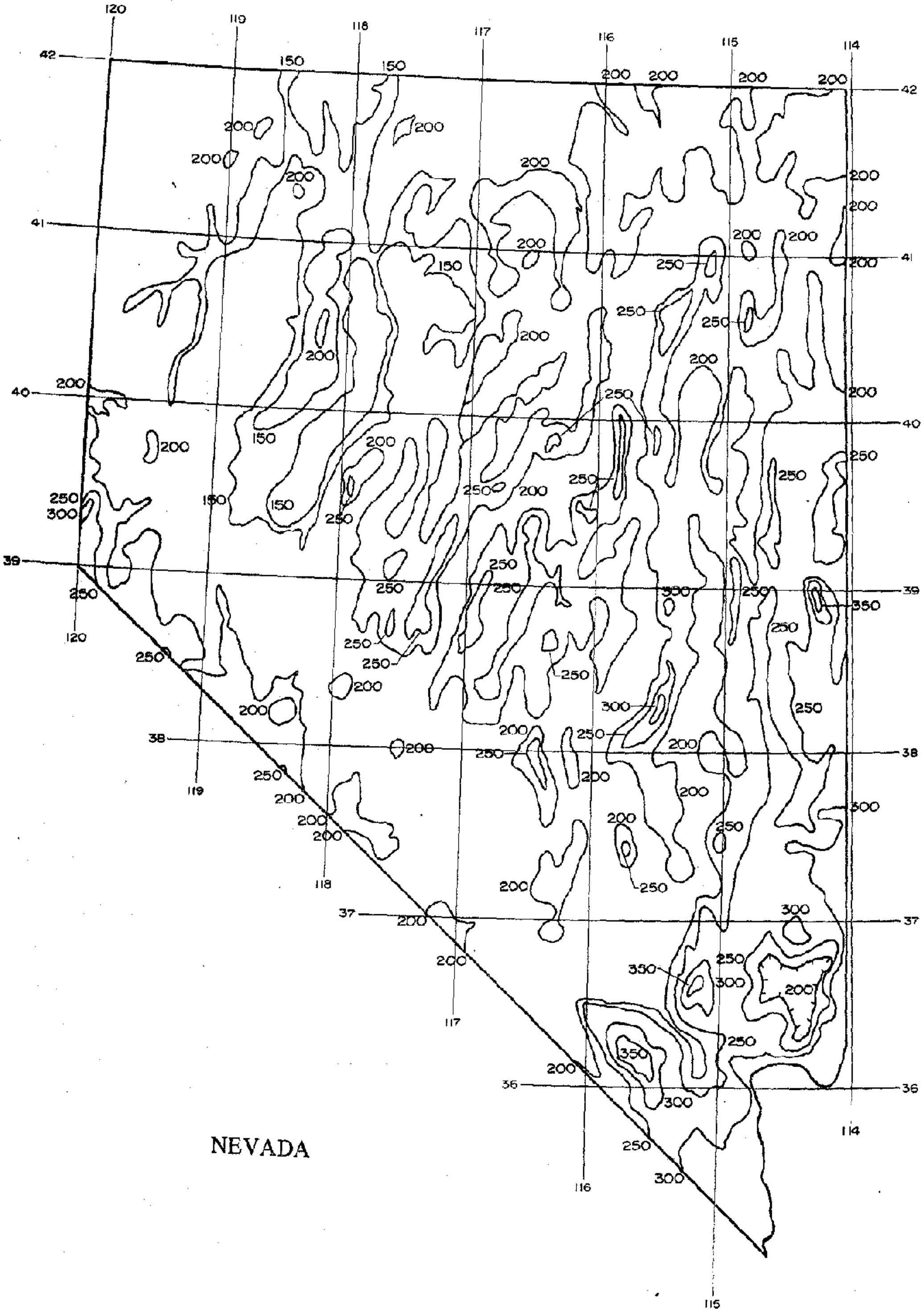
Appendix E-29. Isohyetal map of 10-year, 10-minute rainfall intensity for Missouri.



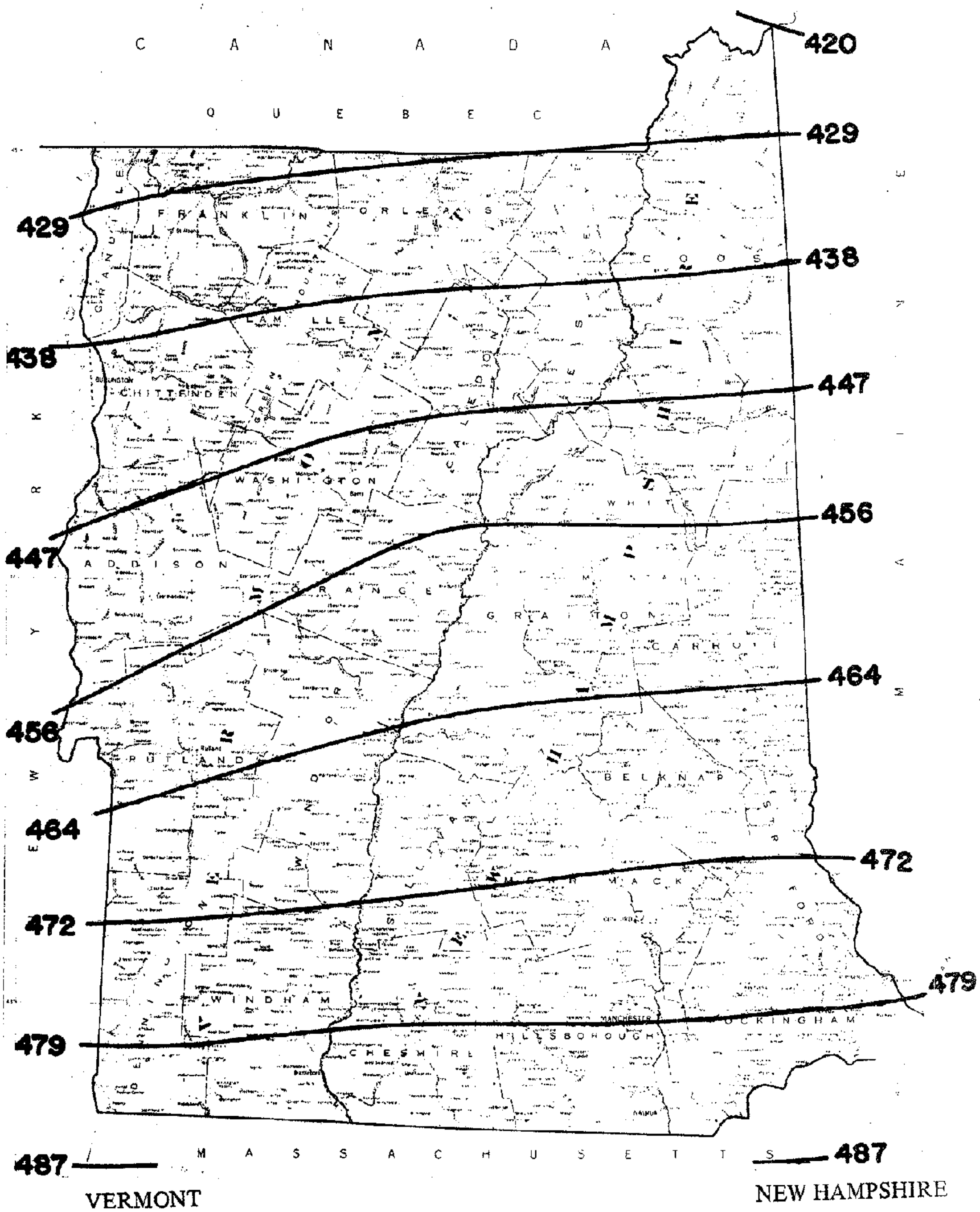
Appendix E-30. Isohyetal map of 10-year, 10-minute rainfall intensity for Montana.



Appendix E-31. Isohyetal map of 10-year, 10-minute rainfall intensity for Nebraska.

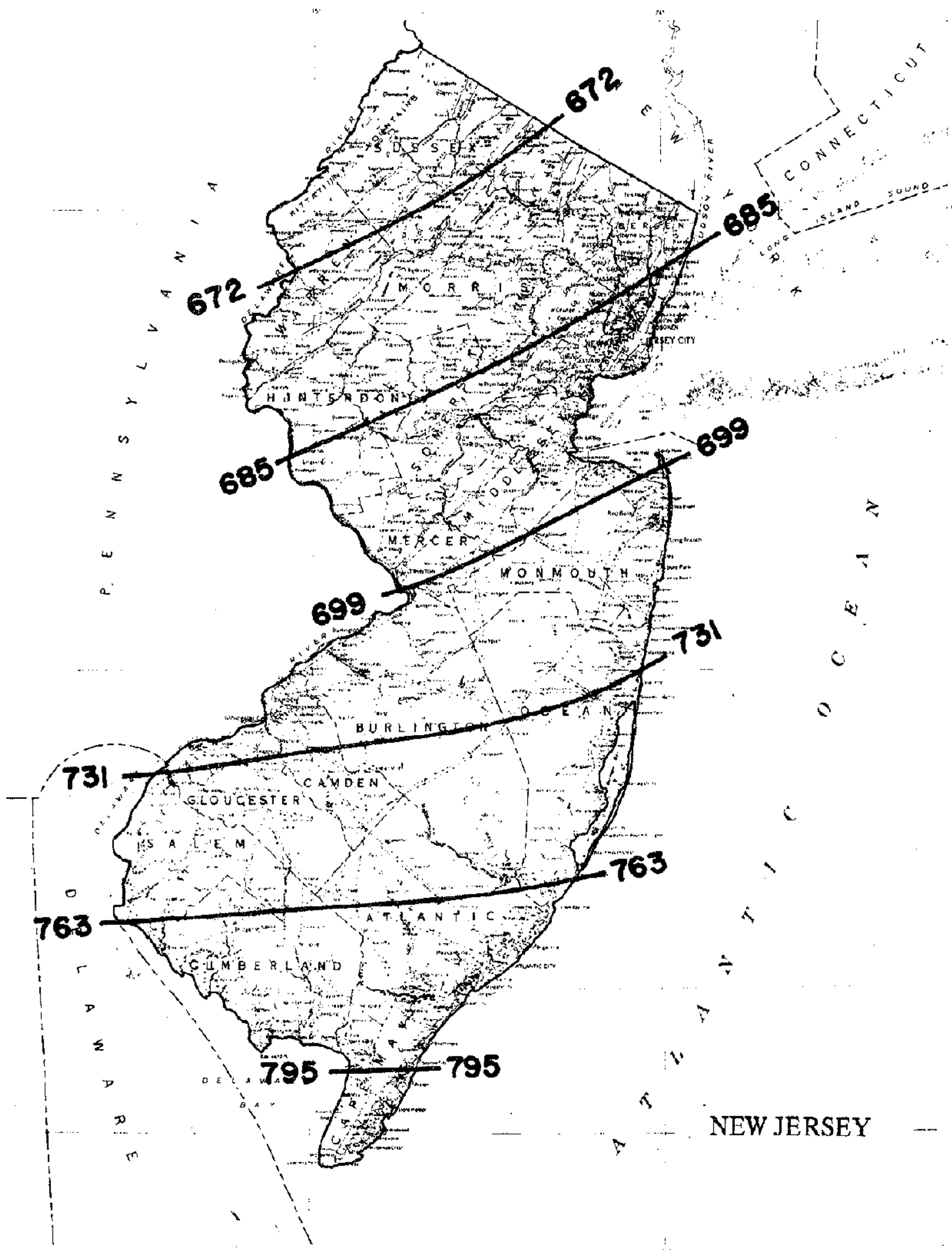


Appendix E-32. Isohyetal map of 10-year, 10-minute rainfall intensity for Nevada.

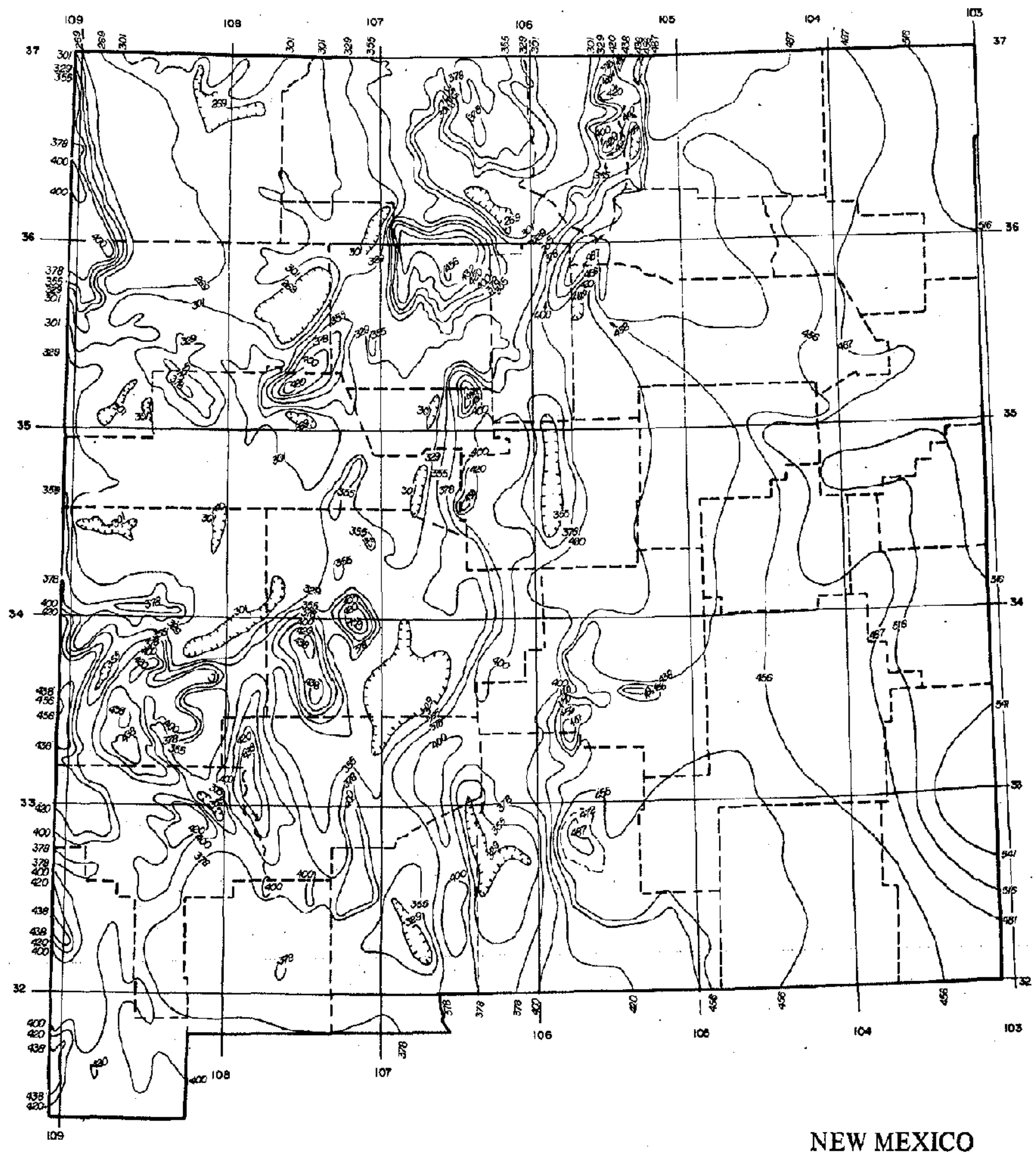


Appendix E-33. Isohyetal map of 10-year, 10-minute rainfall intensity for New Hampshire.

Appendix E-50. Isohyetal map of 10-year, 10-minute rainfall intensity for Vermont.

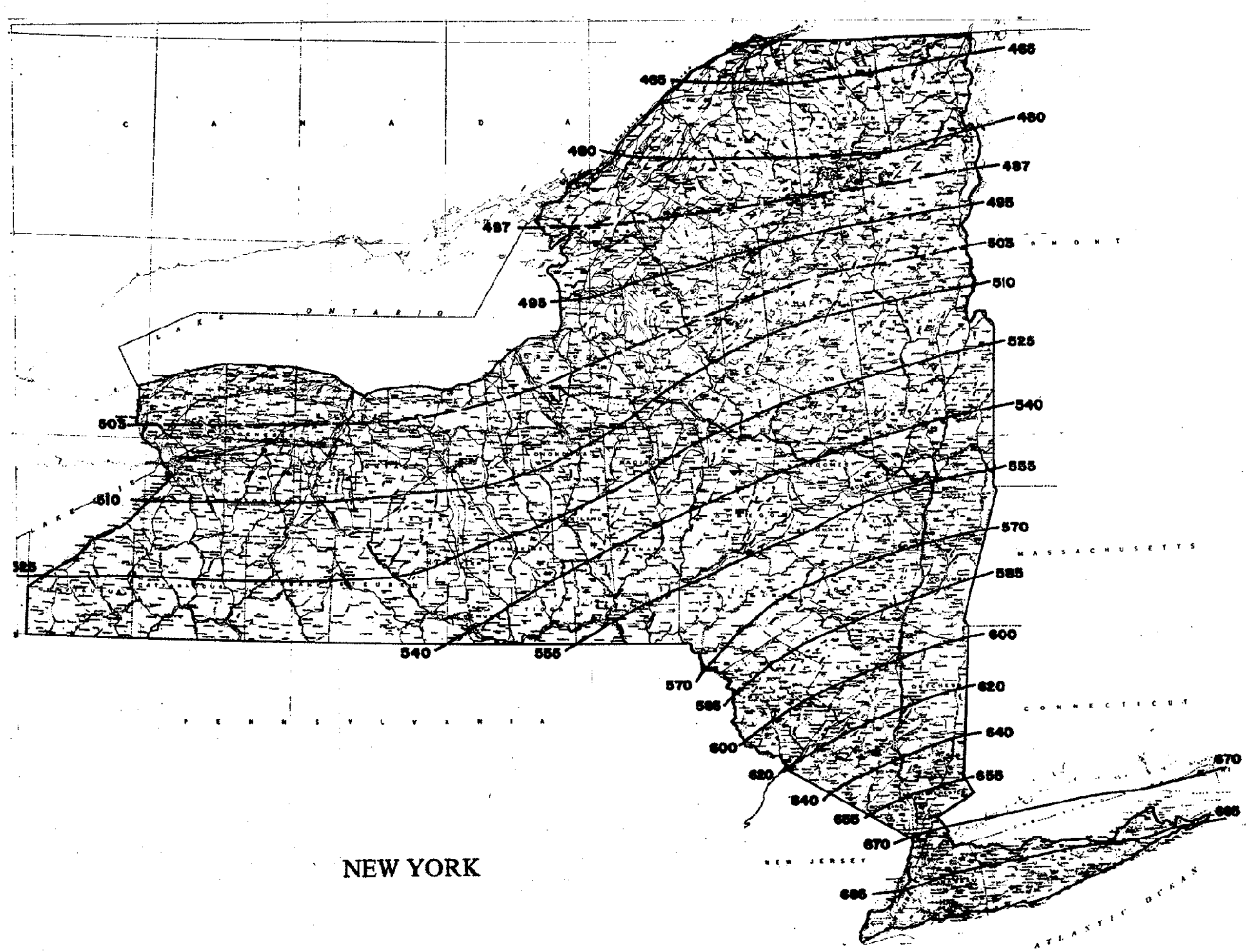


Appendix E-34. Isohyetal map of 10-year, 10-minute rainfall intensity for New Jersey.

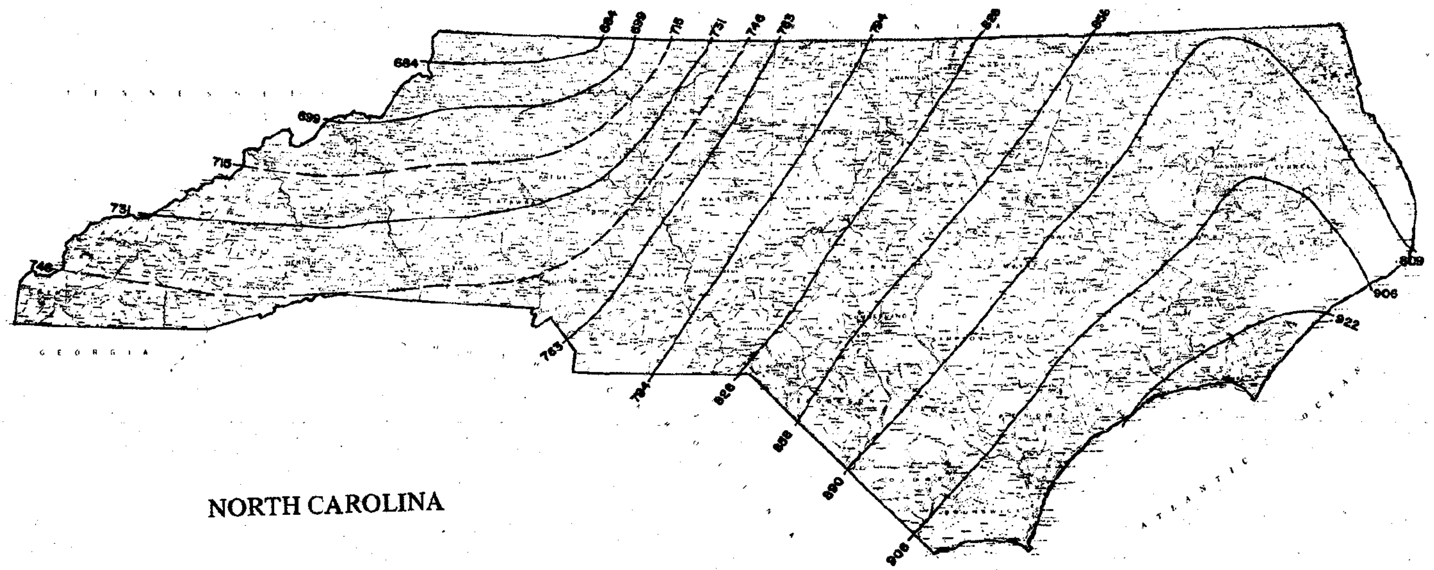


NEW MEXICO

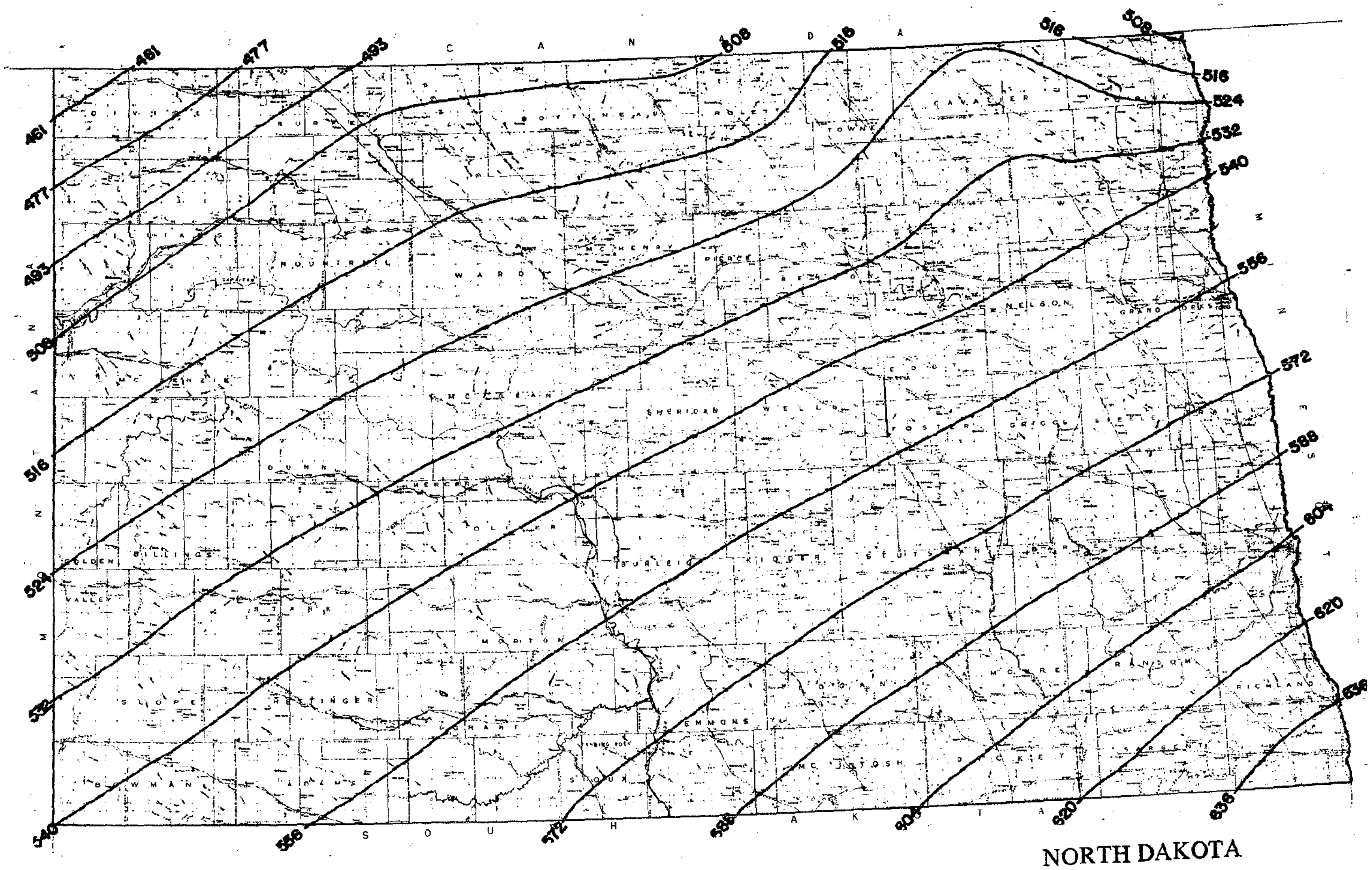
Appendix E-35. Isohyetal map of 10-year, 10-minute rainfall intensity for New Mexico.



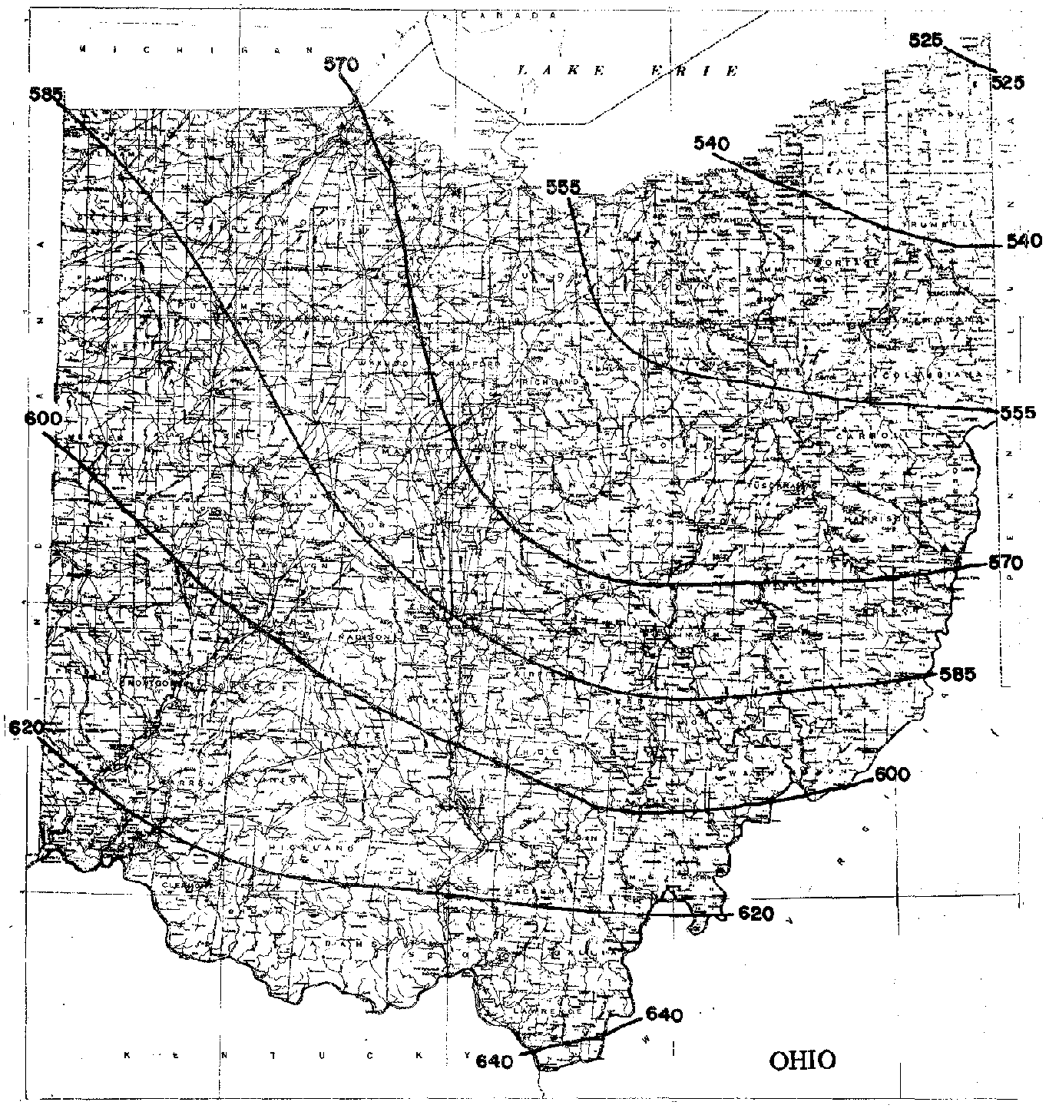
Appendix E-36. Isohyetal map of 10-year, 10-minute rainfall intensity for New York.



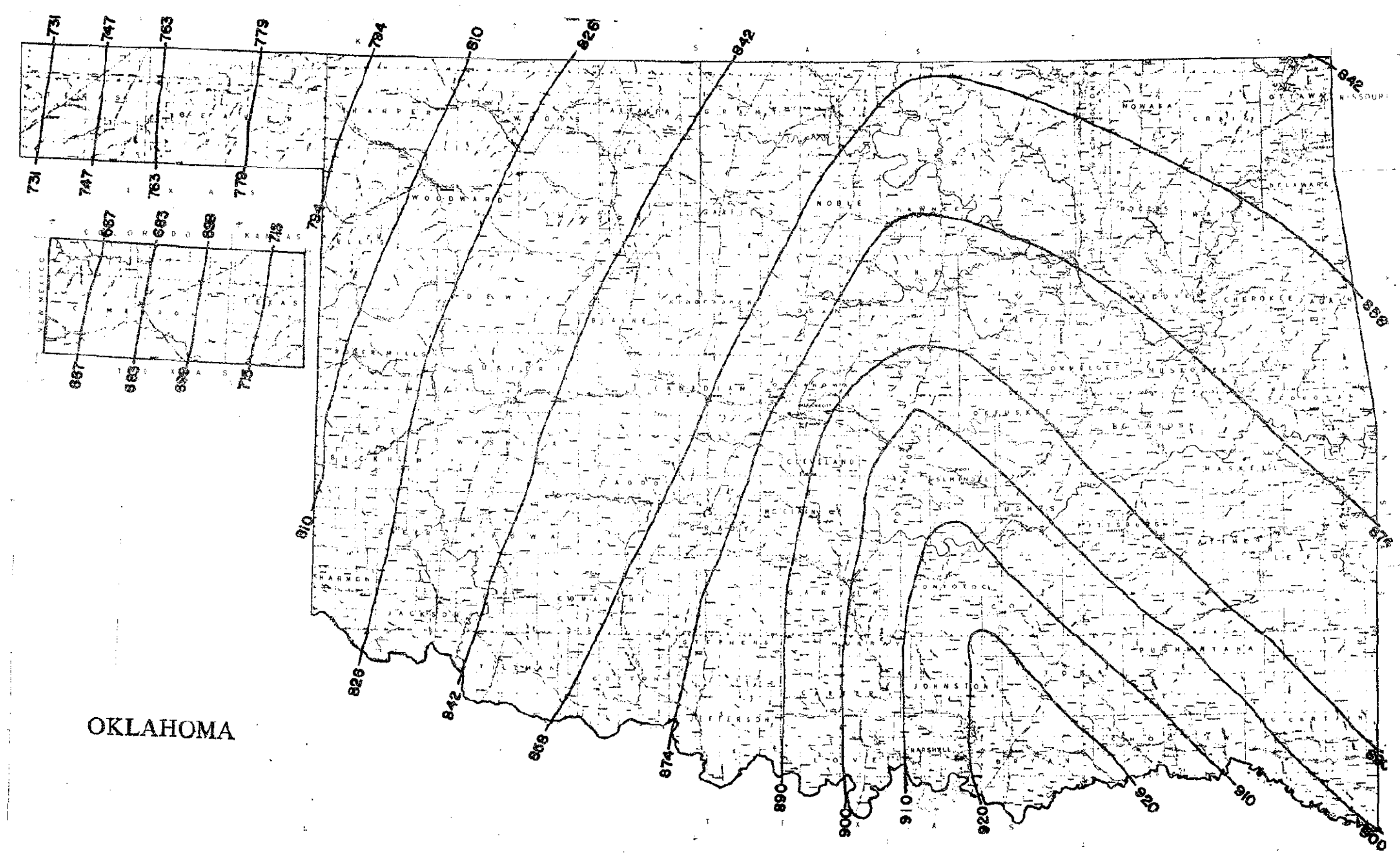
Appendix E-37. Isohyetal map of 10-year, 10-minute rainfall intensity for North Carolina.



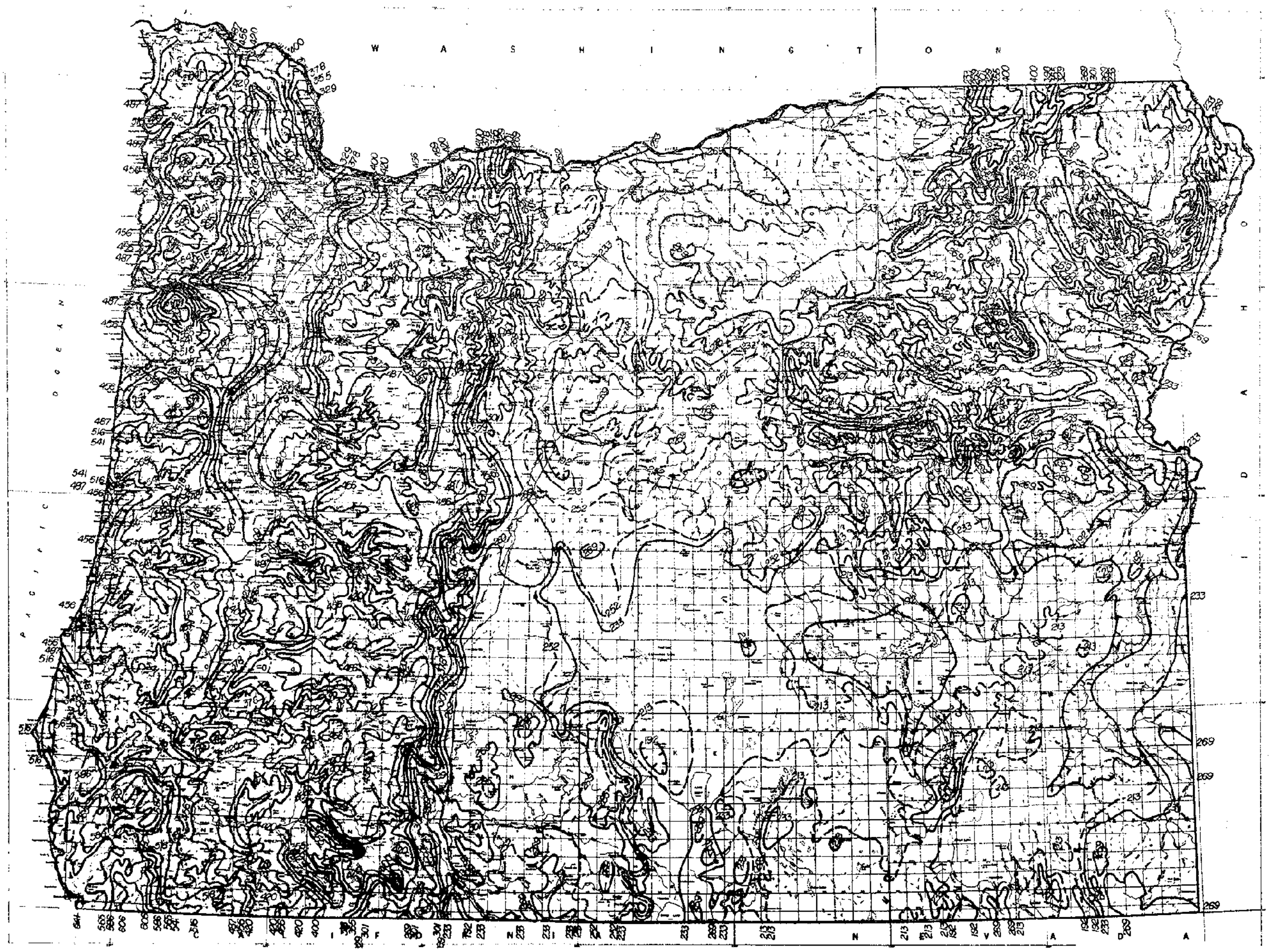
Appendix E-38. Isohyetal map of 10-year, 10-minute rainfall intensity for North Dakota.



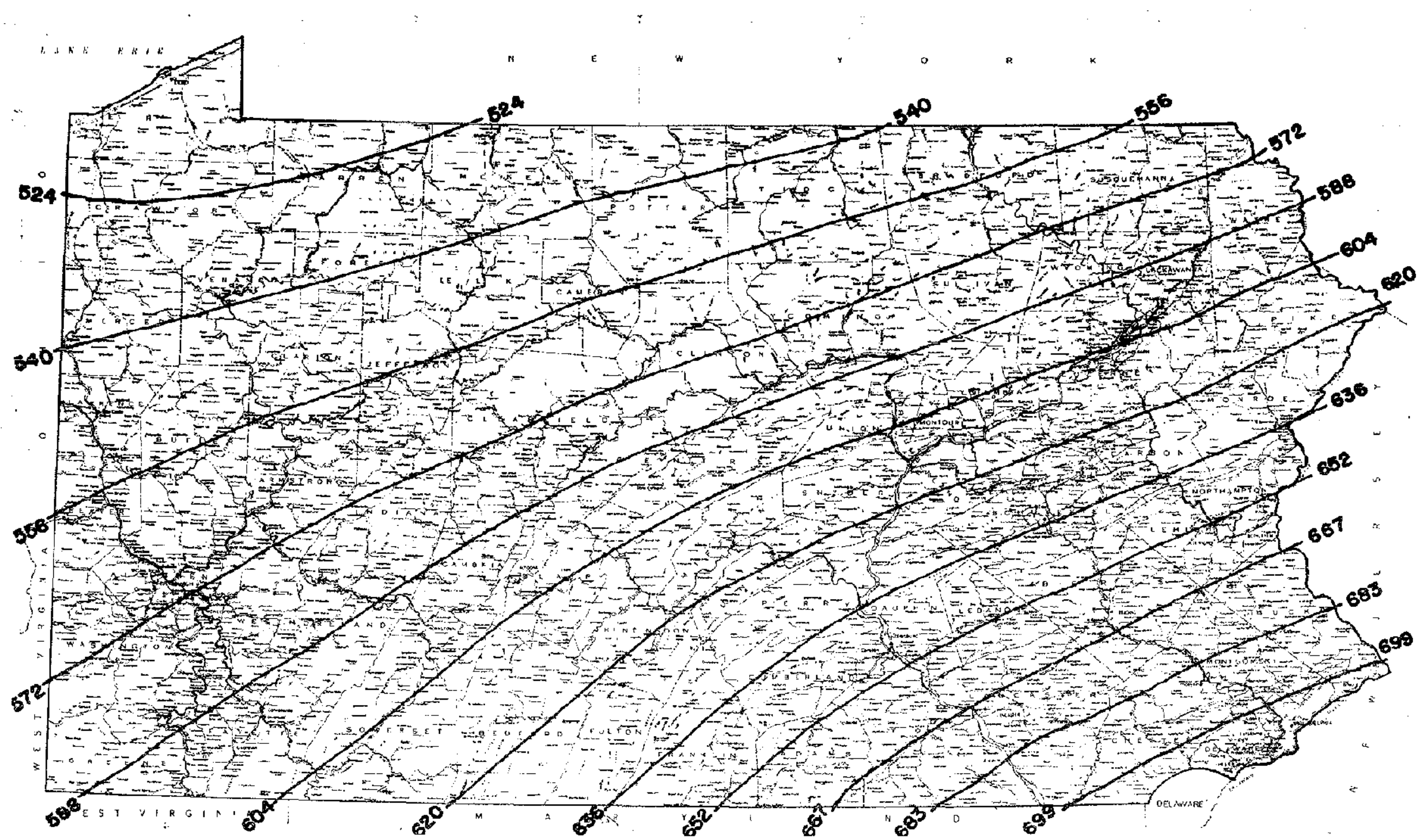
Appendix E-39. Isohyetal map of 10-year, 10-minute rainfall intensity for Ohio.



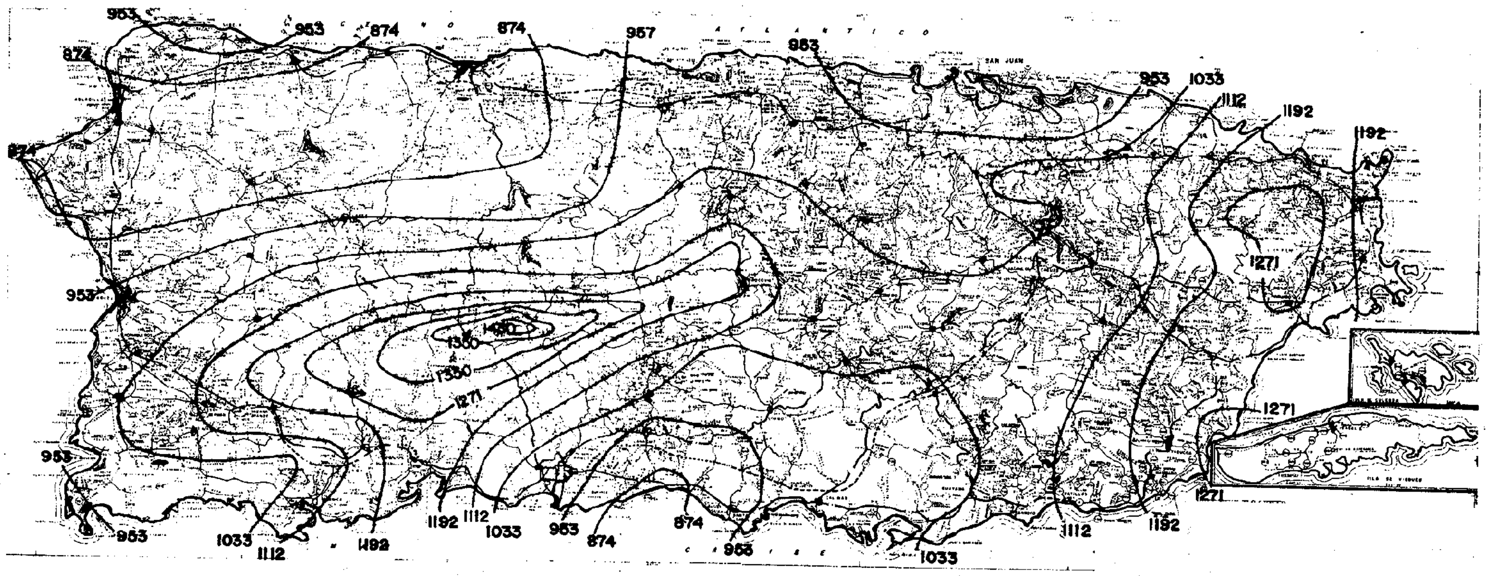
Appendix E-40. Isohyetal map of 10-year, 10-minute rainfall intensity for Oaklahoma.



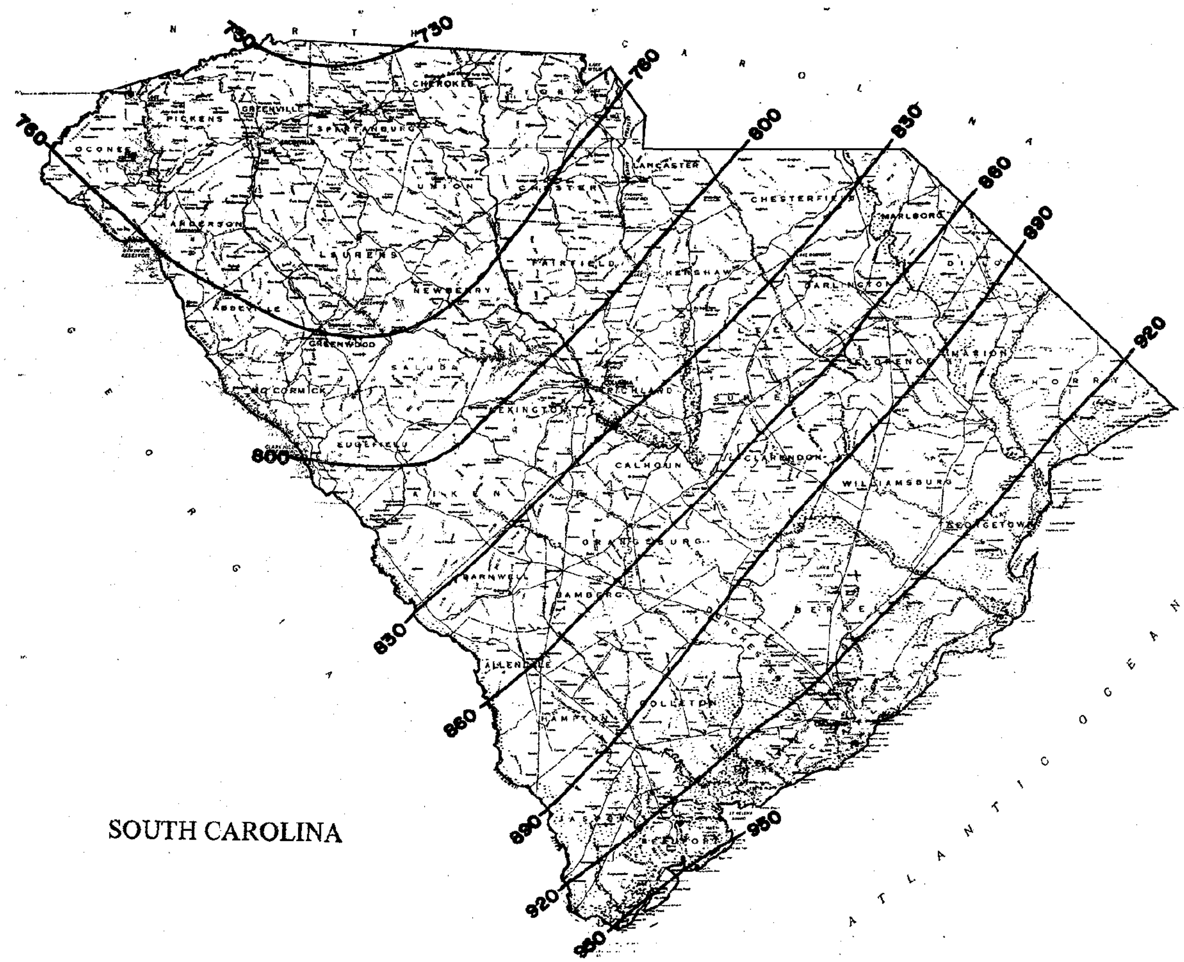
Appendix E-41. Isohyetal map of 10-year, 10-minute rainfall intensity for Oregon.



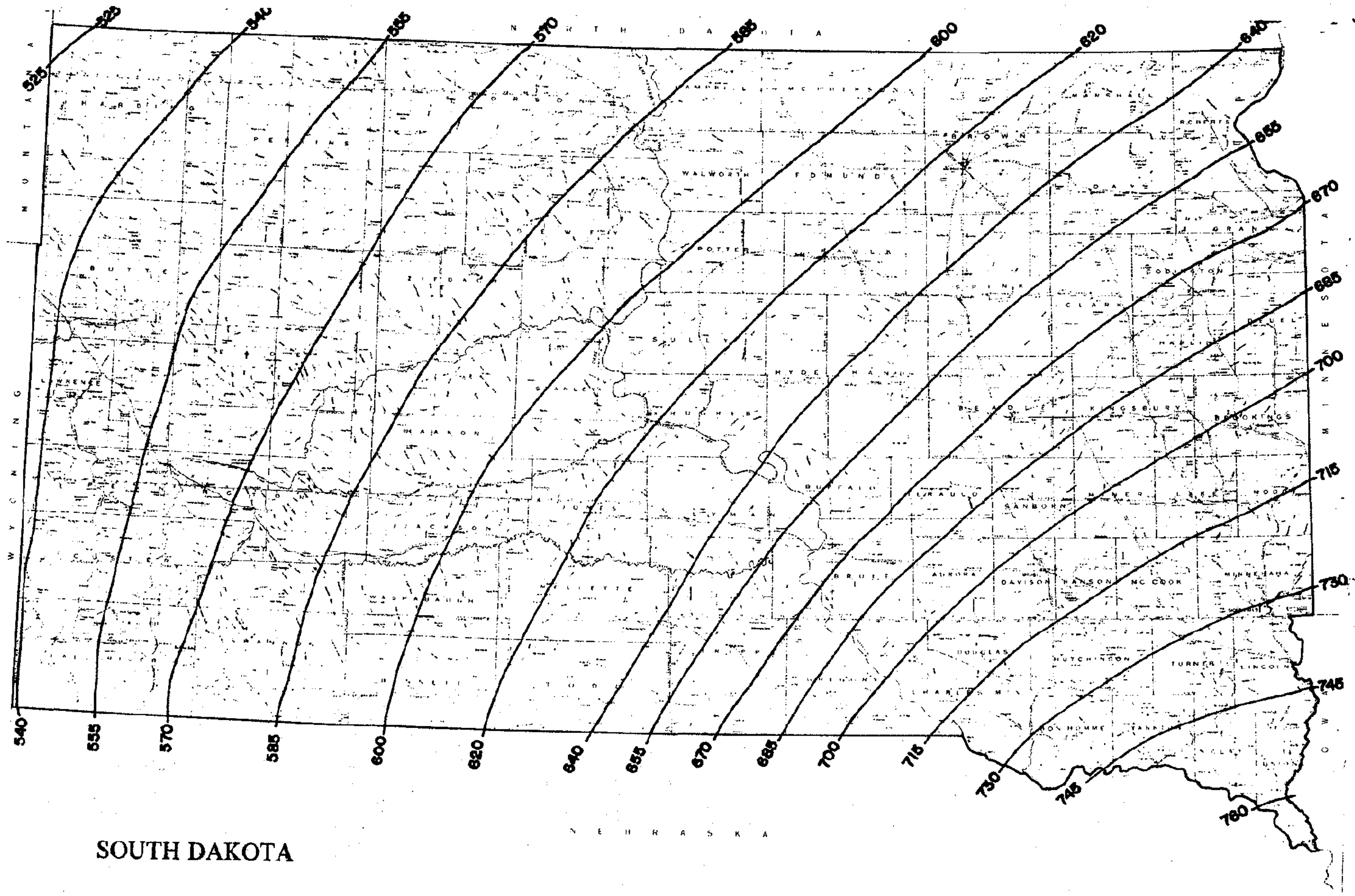
Appendix E-42. Isohyetal map of 10-year, 10-minute rainfall intensity for Pennsylvania.



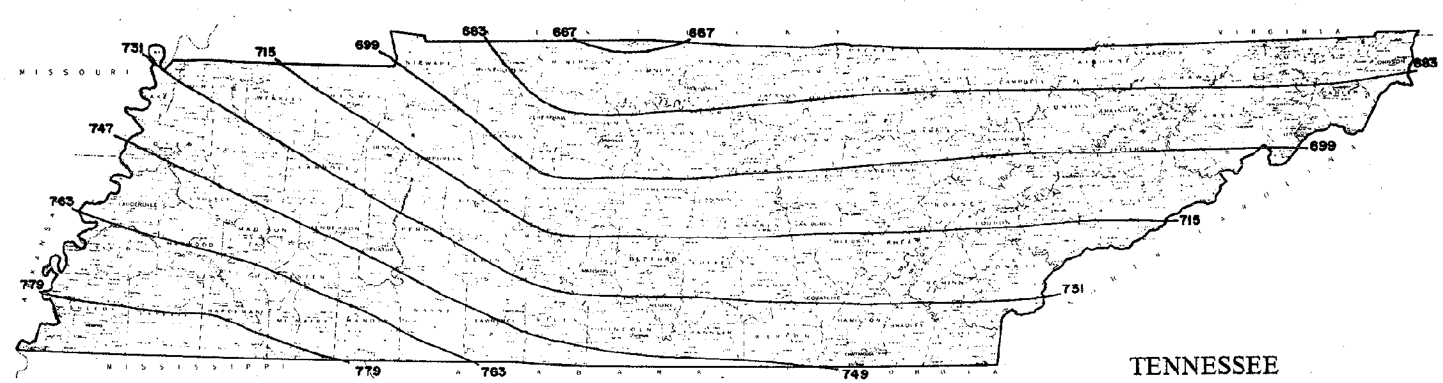
Appendix E -43. Isohyetal map of 10-year, 10-minute rainfall intensity for Puerto Rico.



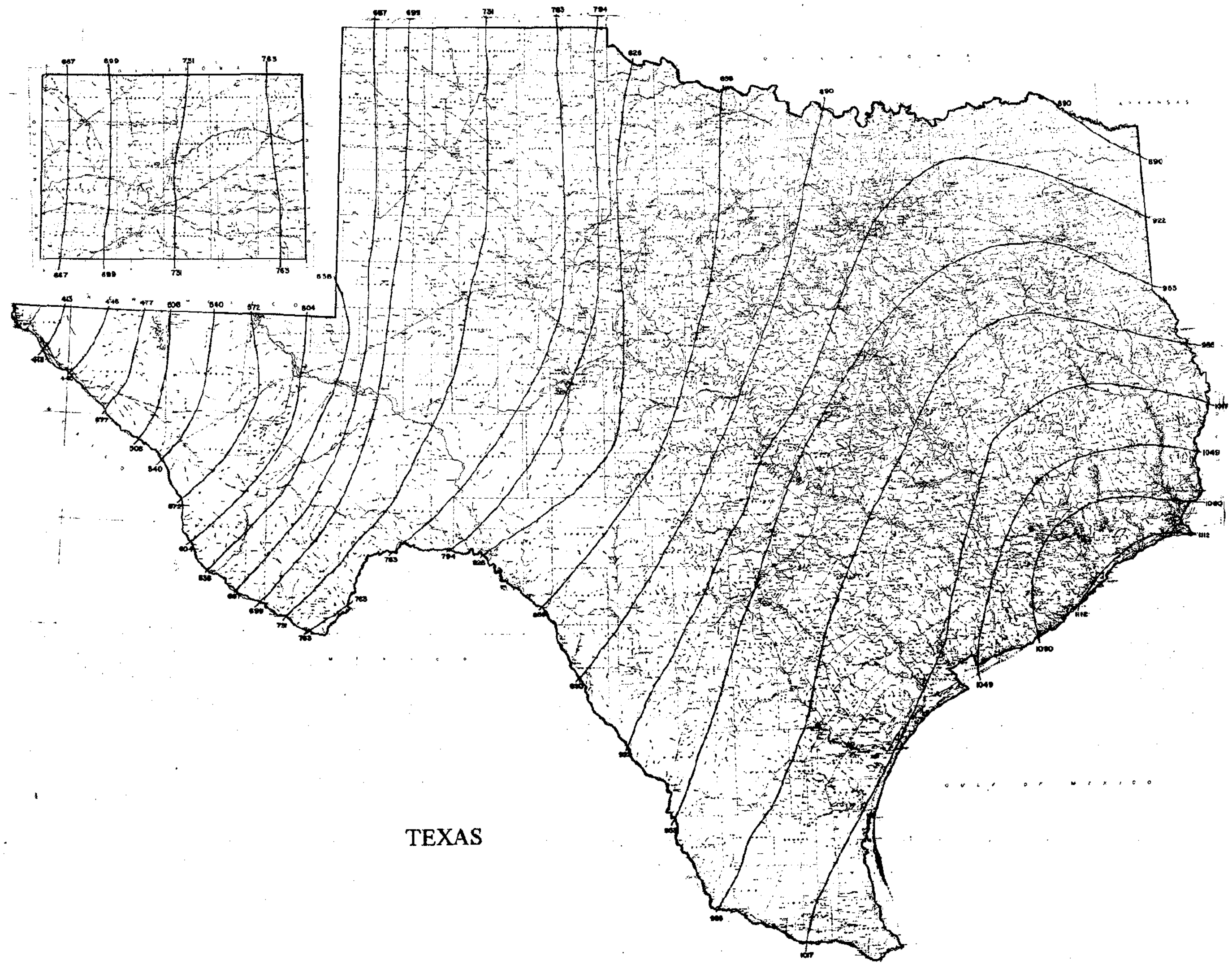
Appendix E-45. Isohyetal map of 10-year, 10-minute rainfall intensity for South Carolina.



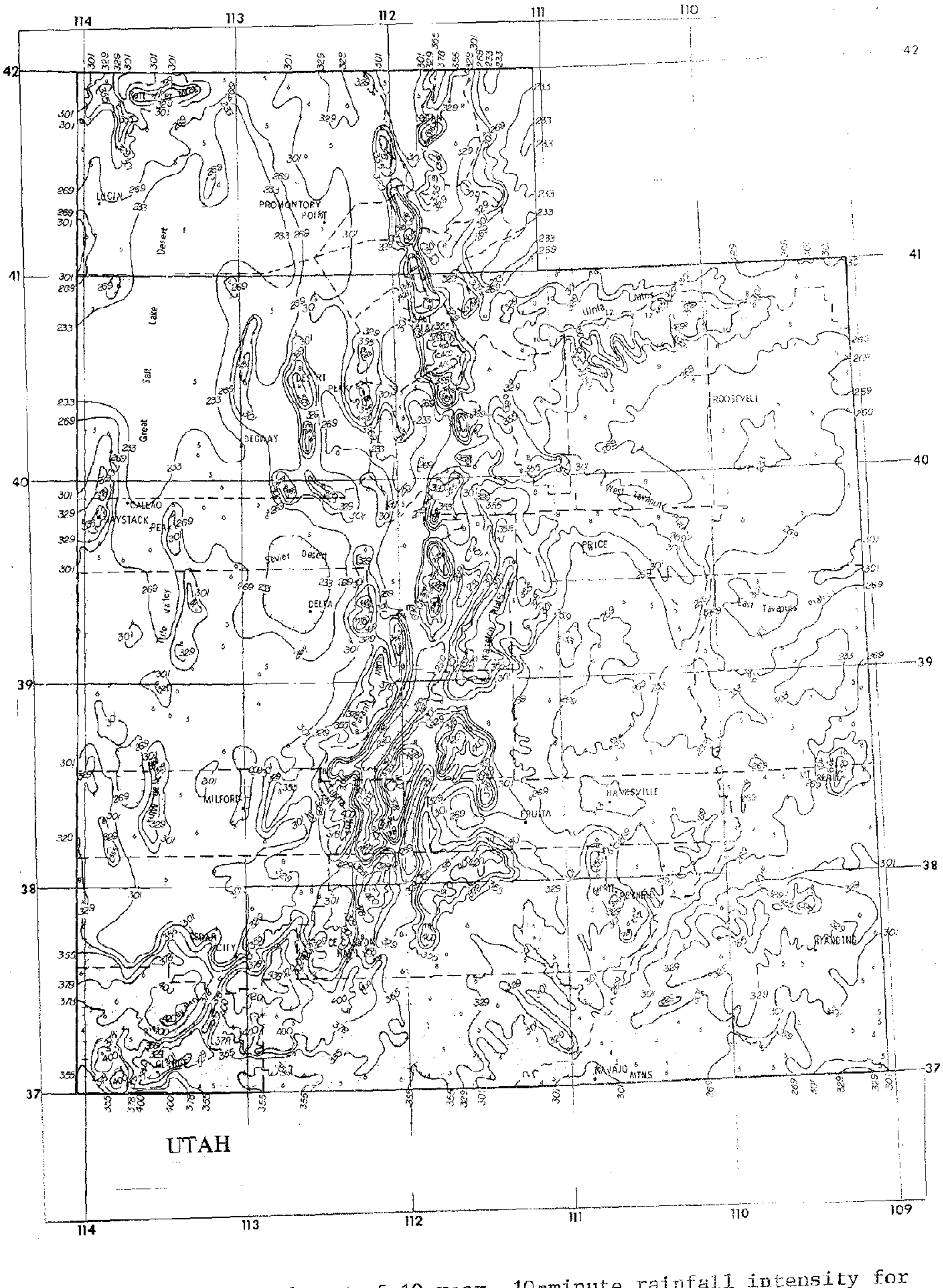
Appendix E-46. Isohyetal map of 10-year, 10-minute rainfall intensity for South Dakota.



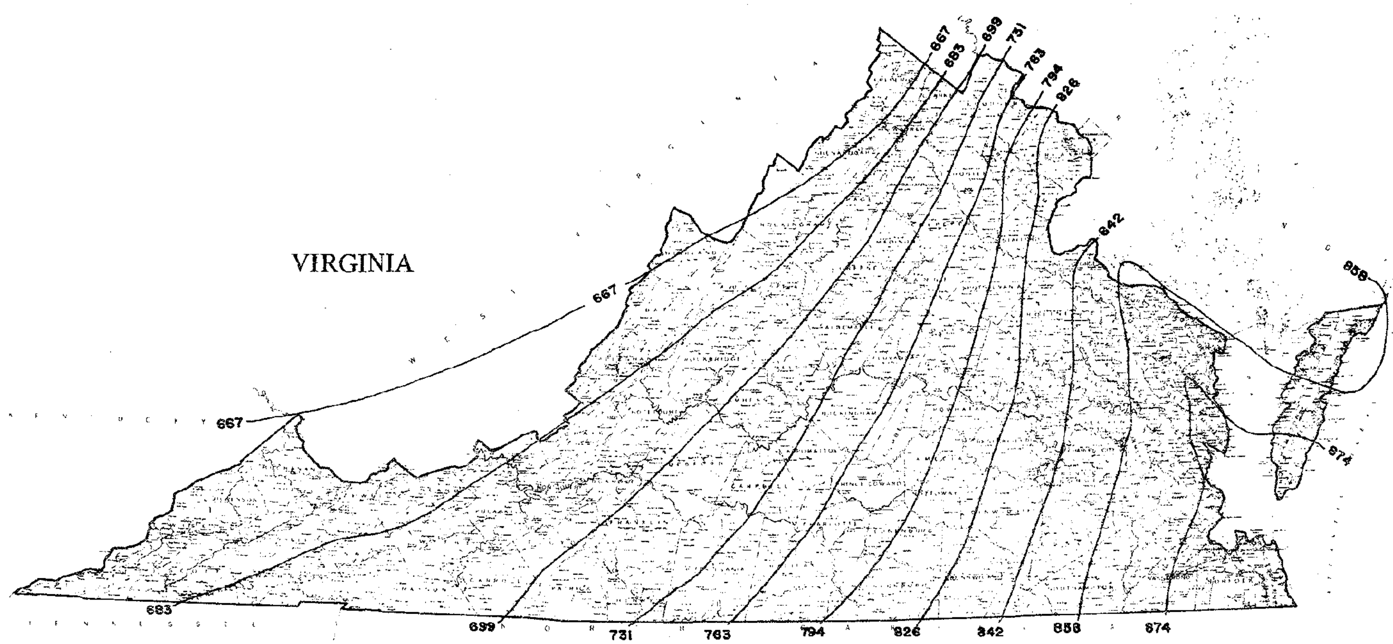
Appendix E-47. Isohyetal map of 10-year, 10-minute rainfall intensity for Tennessee.



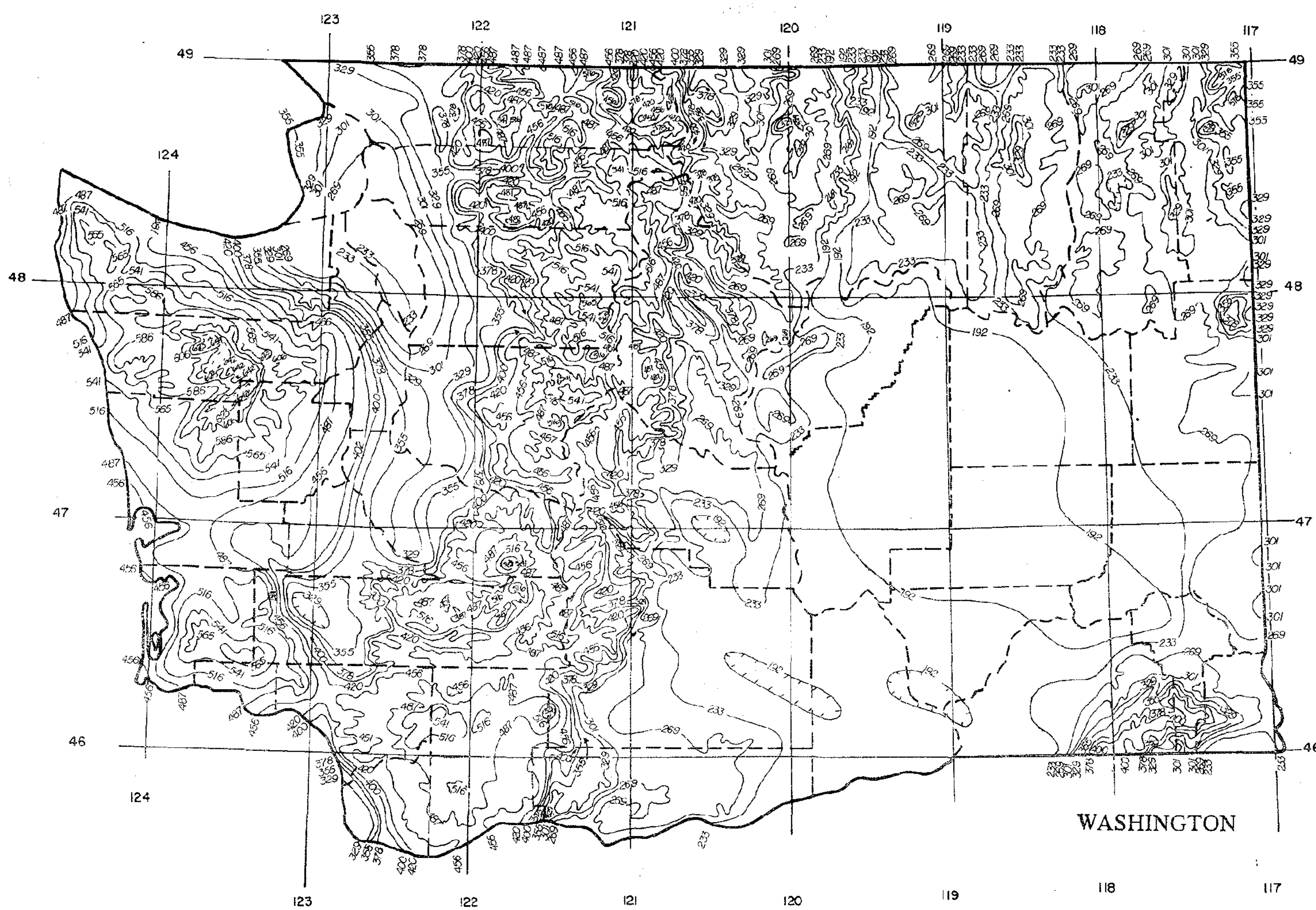
Appendix E-48. Isohyetal map of 10-year, 10-minute rainfall intensity for Texas.



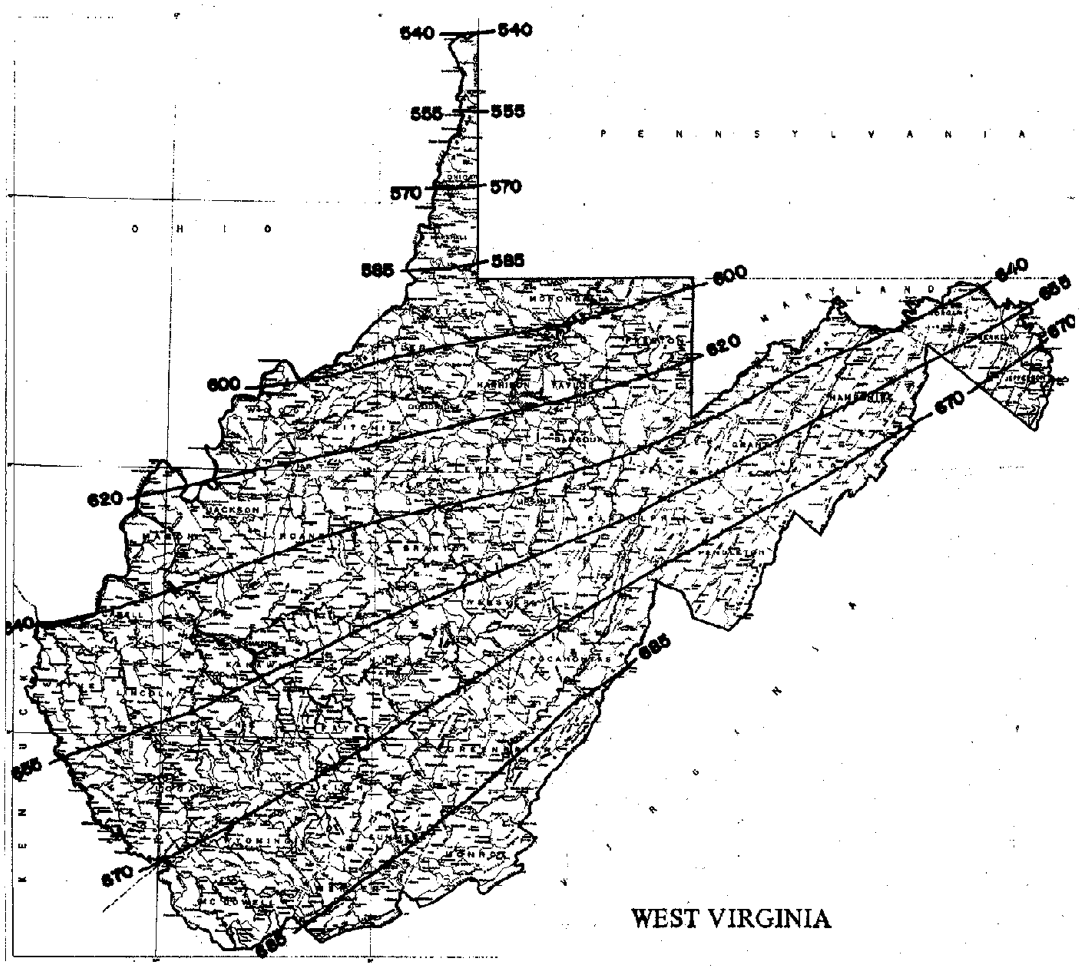
Appendix E-49. Isohyetal map of 10-year, 10-minute rainfall intensity for Utah.



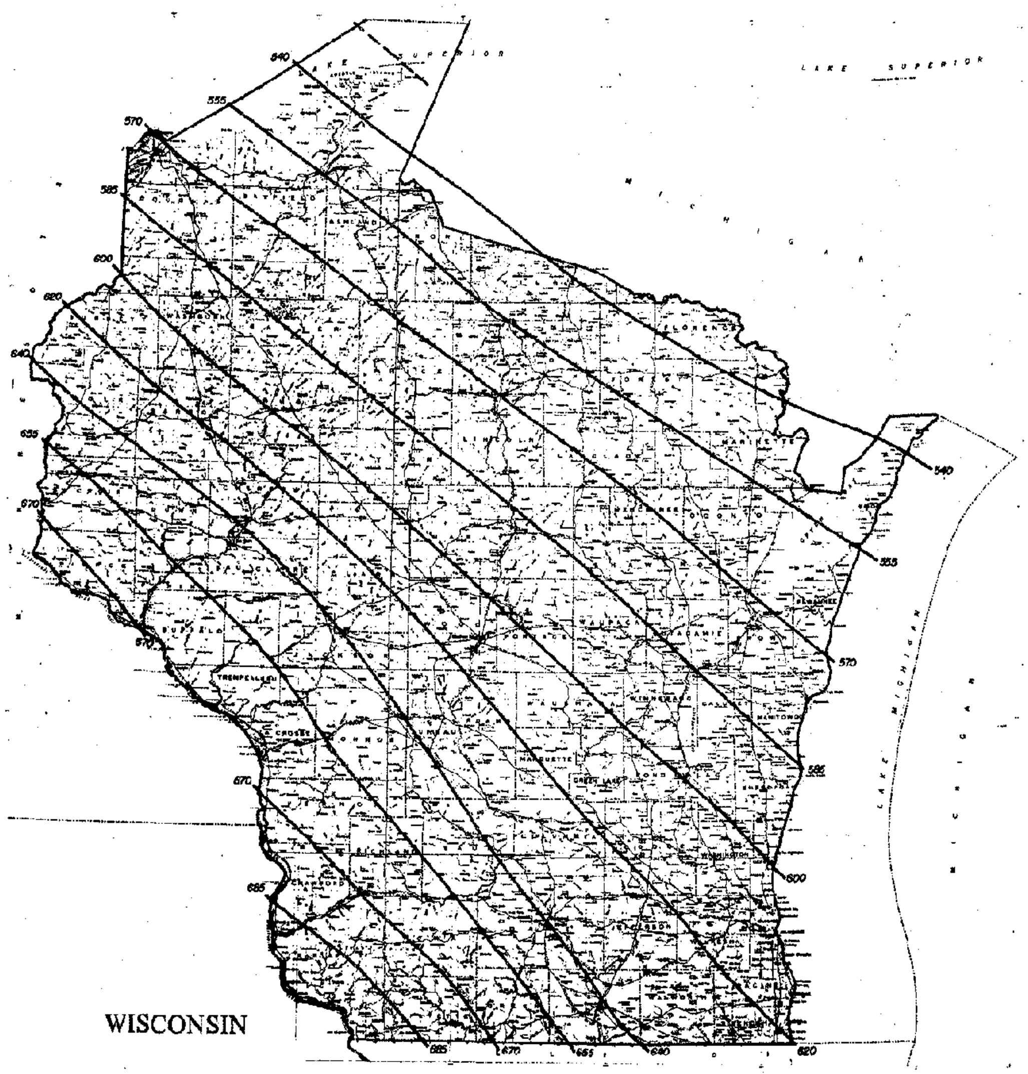
Appendix E-51. Isohyetal map of 10-year, 10-minute rainfall intensity for Virginia.



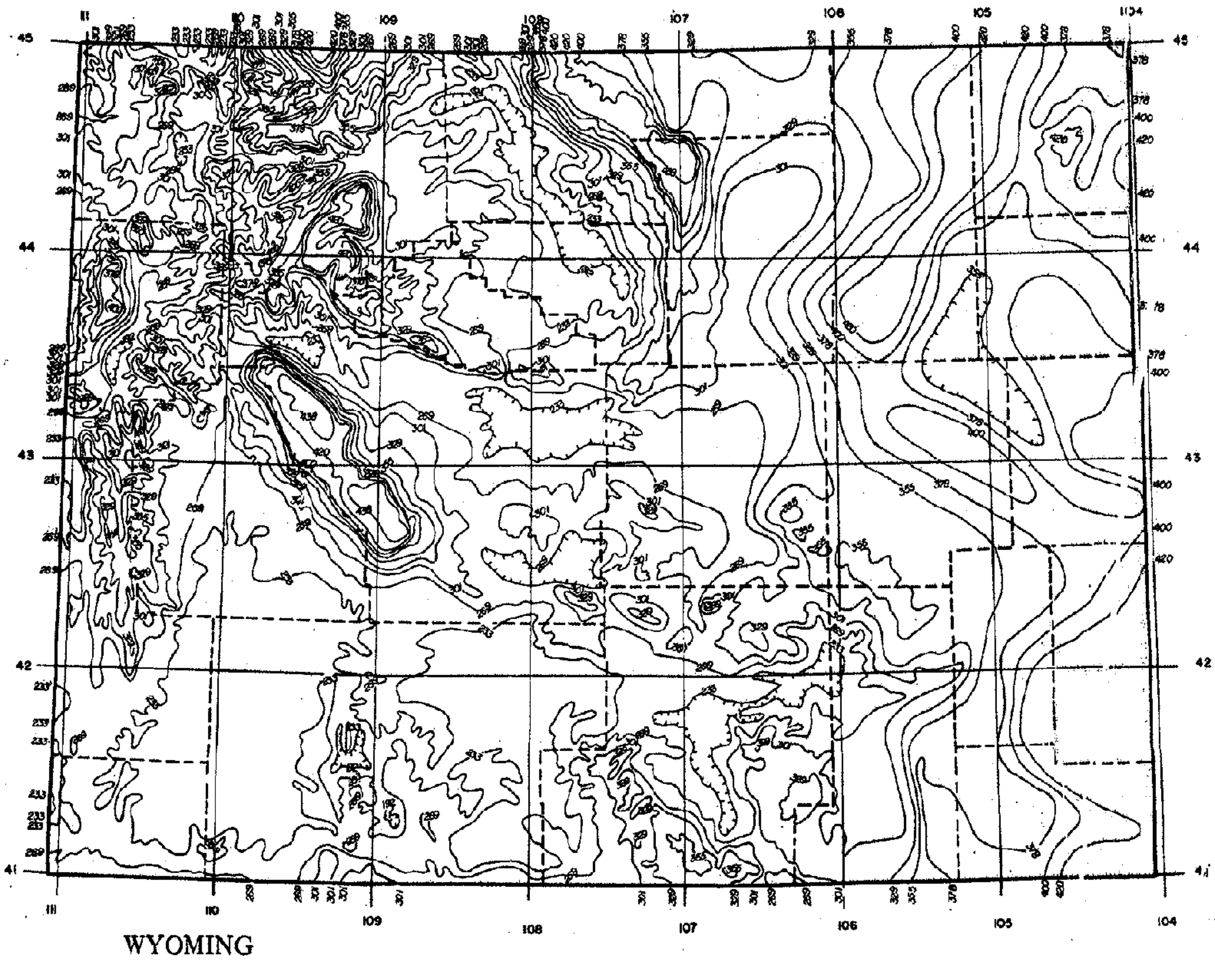
Appendix E-53. Isohyetal map of 10-year, 10-minute rainfall intensity for Washington.



Appendix E-54. Isohyetal map of 10-year, 10-minute rainfall intensity for West Virginia.



Appendix E-55. Isohyetal map of 10-year, 10-minute rainfall intensity for Wisconsin.



Appendix E-56. Isohyetal map of 10-year, 10-minute rainfall intensity for Wyoming.

APPENDIX F

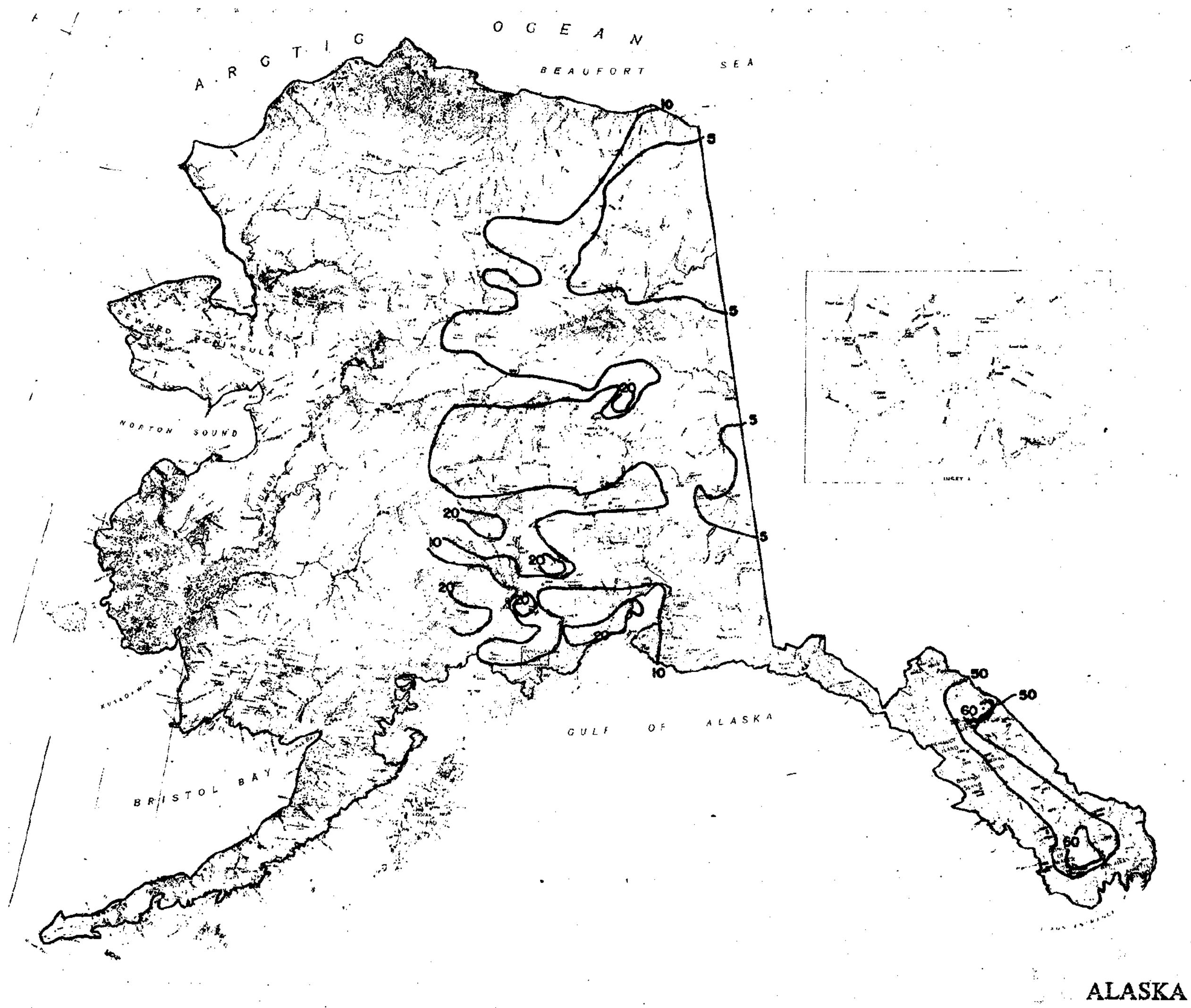
10-Year Snow Water Equivalent of the Western United States and Alaska.

Appendix F contains the 10-year April 1 snow water equivalent maps of each of the Western United States including Alaska. The maps were compiled using all of the snow course data for each state and determining the 10-year snow water equivalent for each station. These values were entered on the proper map and the isotopal lines constructed.

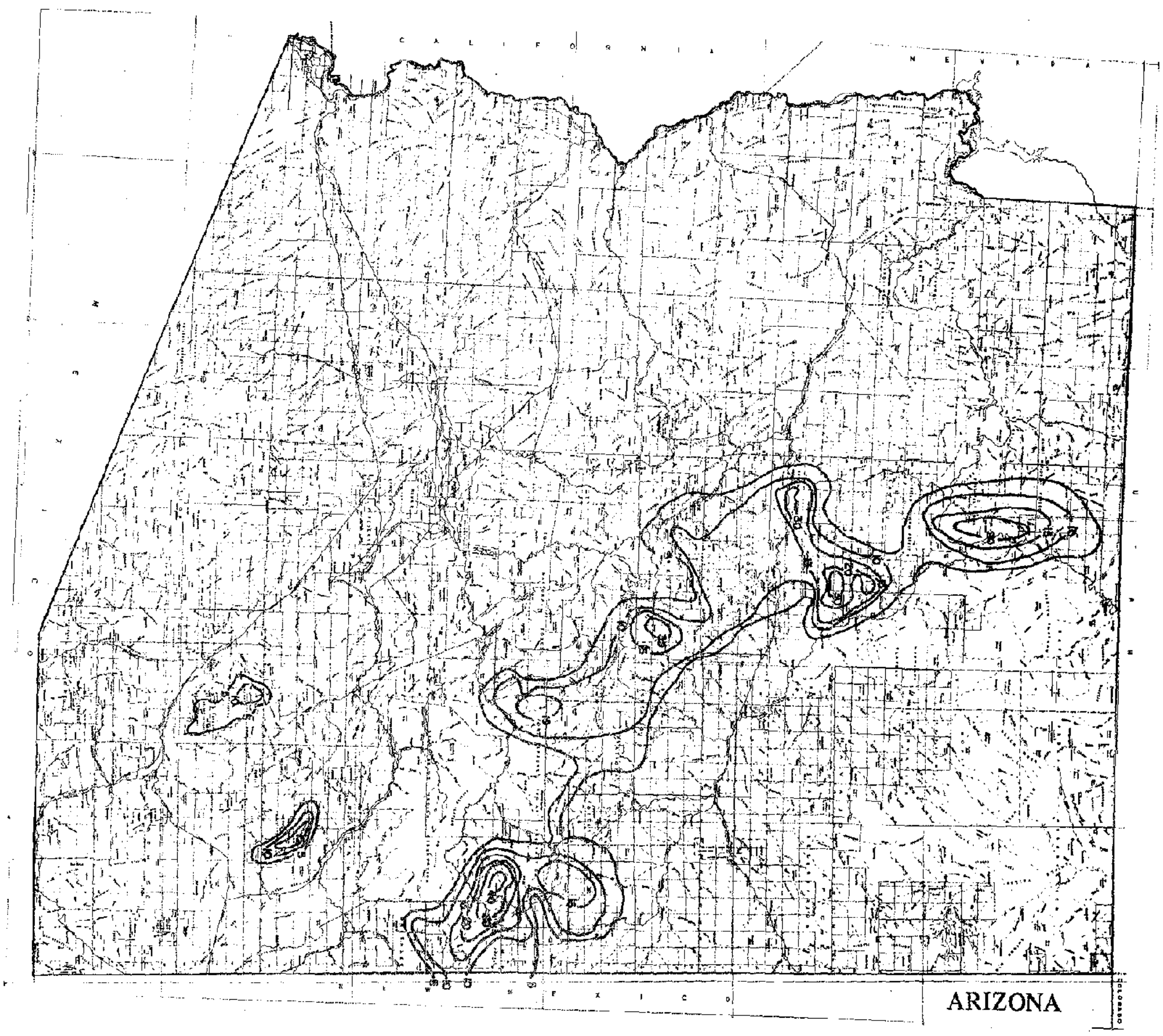
The states are arranged in alphabetical order.

NOTE:

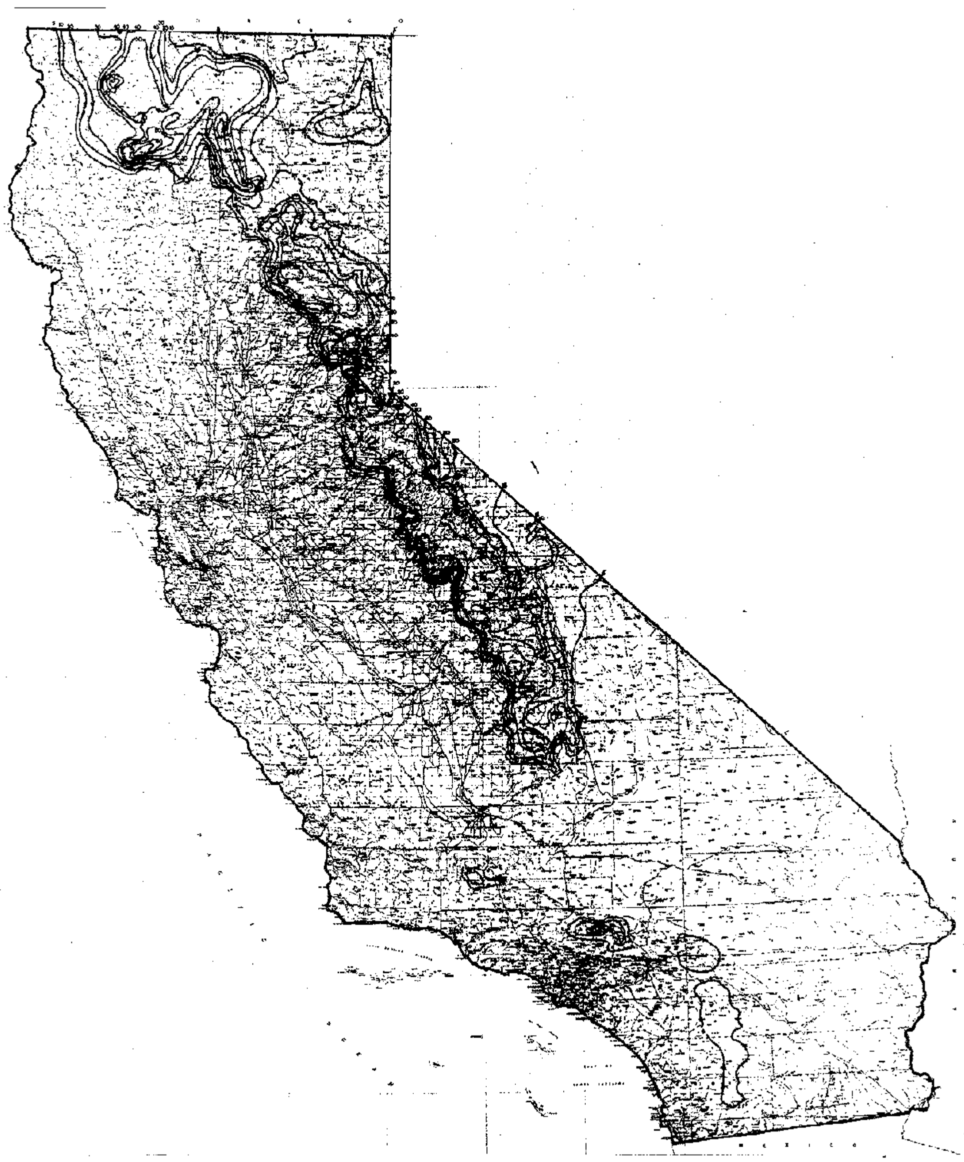
Scales of maps are different because some maps were not available in a proper scale or it would be impractical to show for example Texas in the same scale as Rhode Island.



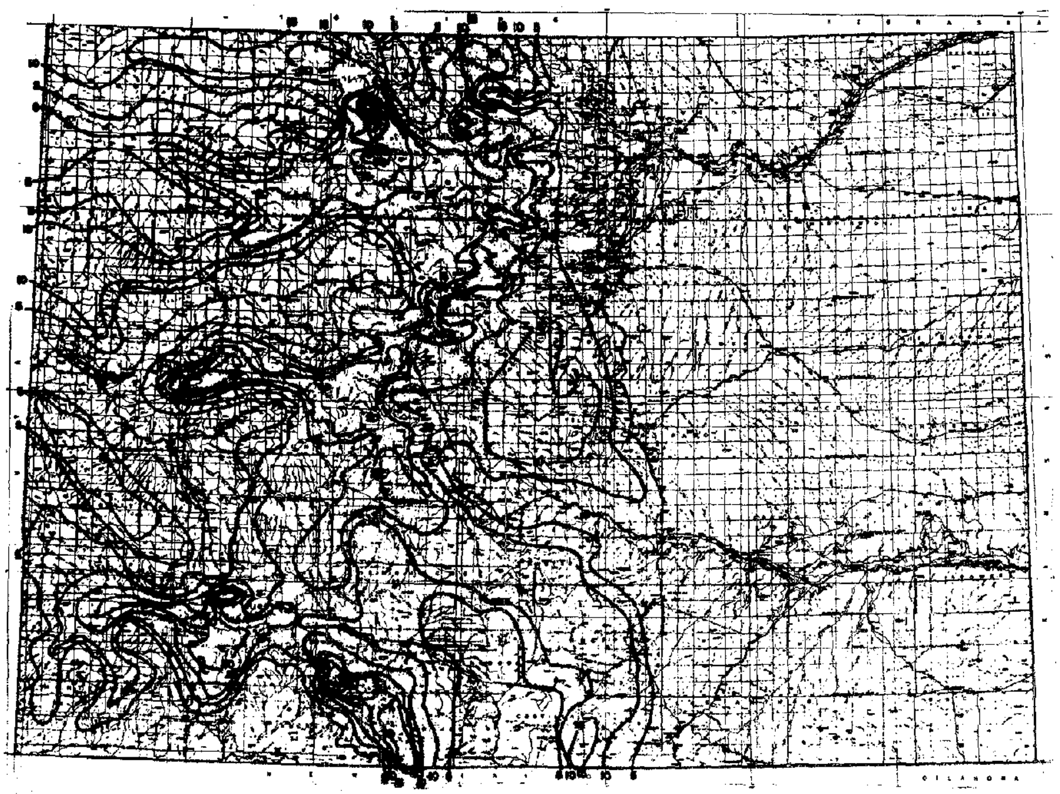
Appendix F-02. Isopotal map of 10-year, 1 April snow water equivalent for Alaska.



Appendix F-04. Isopotal map of 10-year, 1 April snow water equivalent for Arizona.

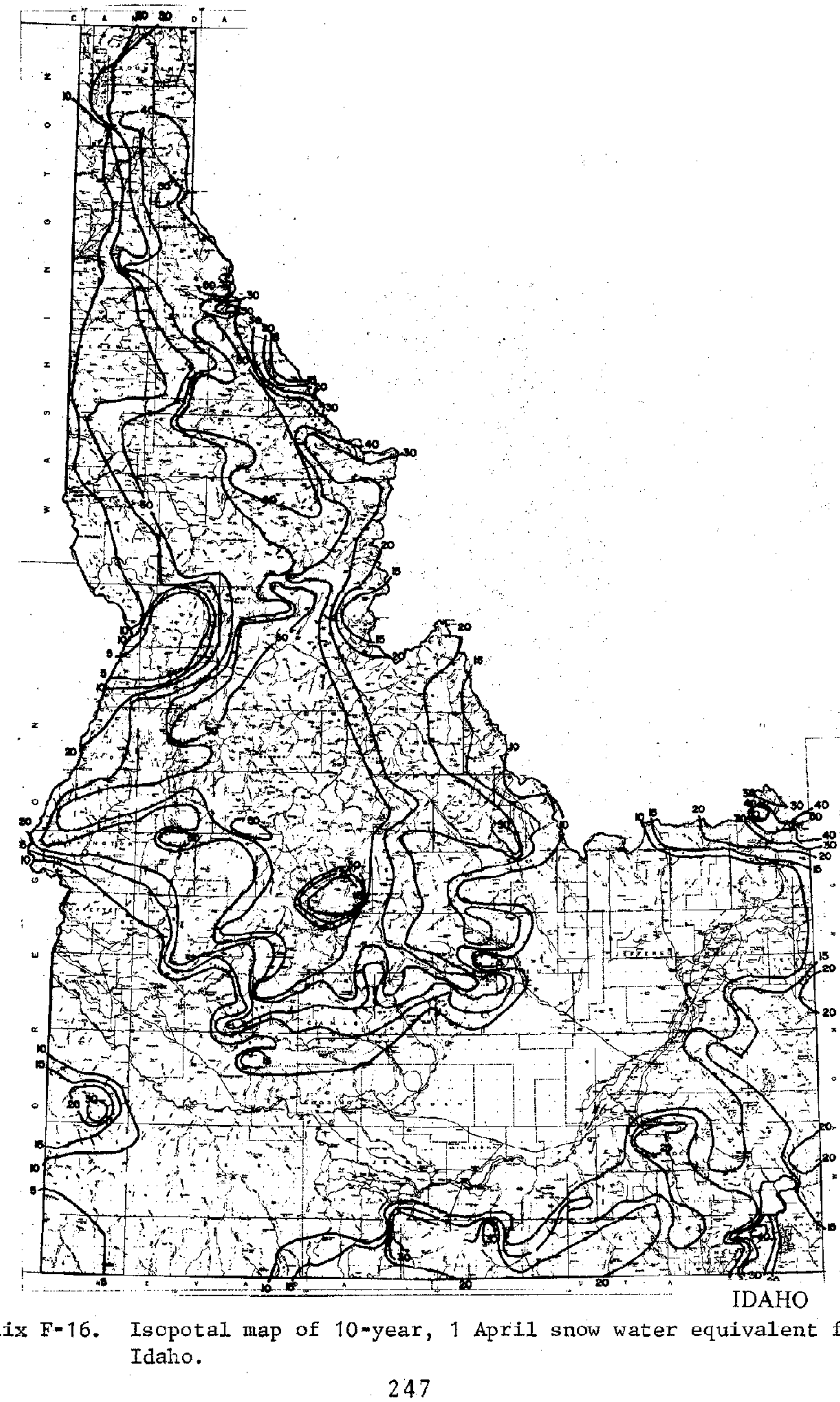


Appendix F-06. Isopotal map of 10-year, 1 April snow water equivalent for California.

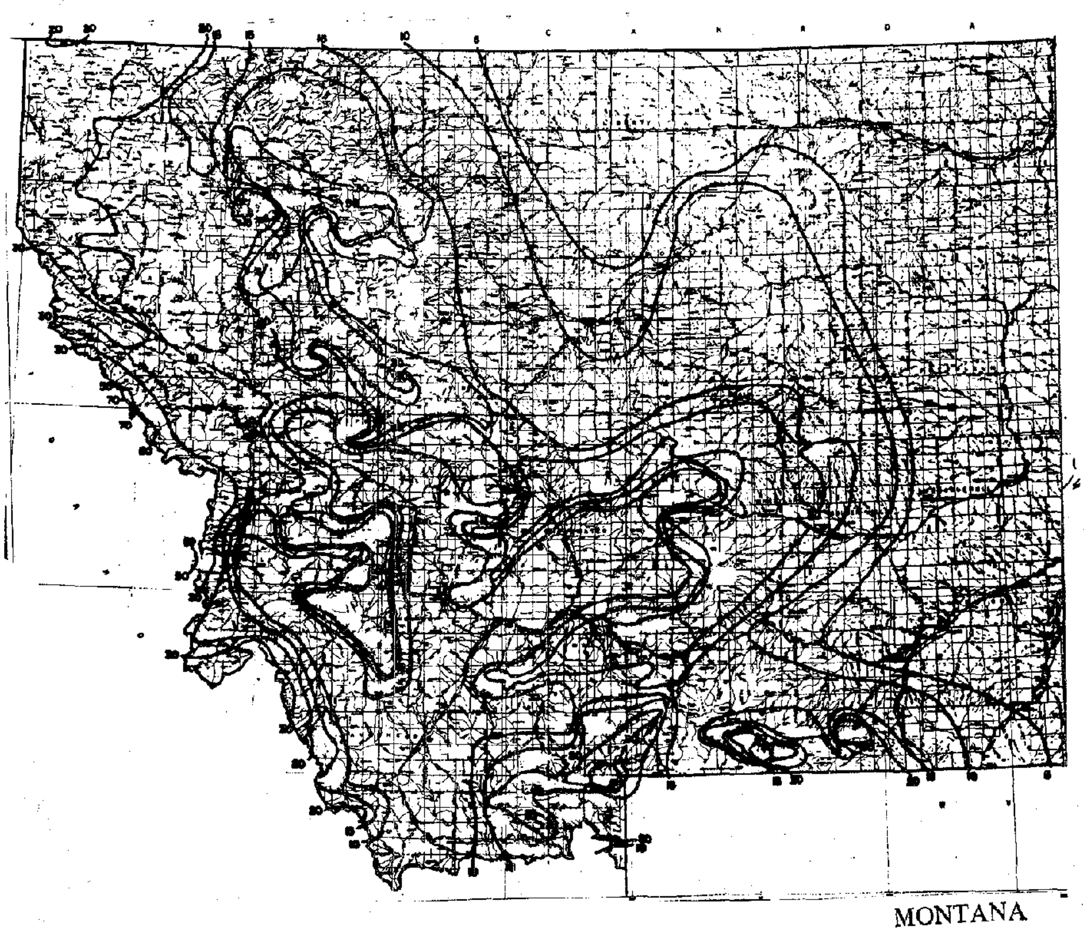


COLORADO

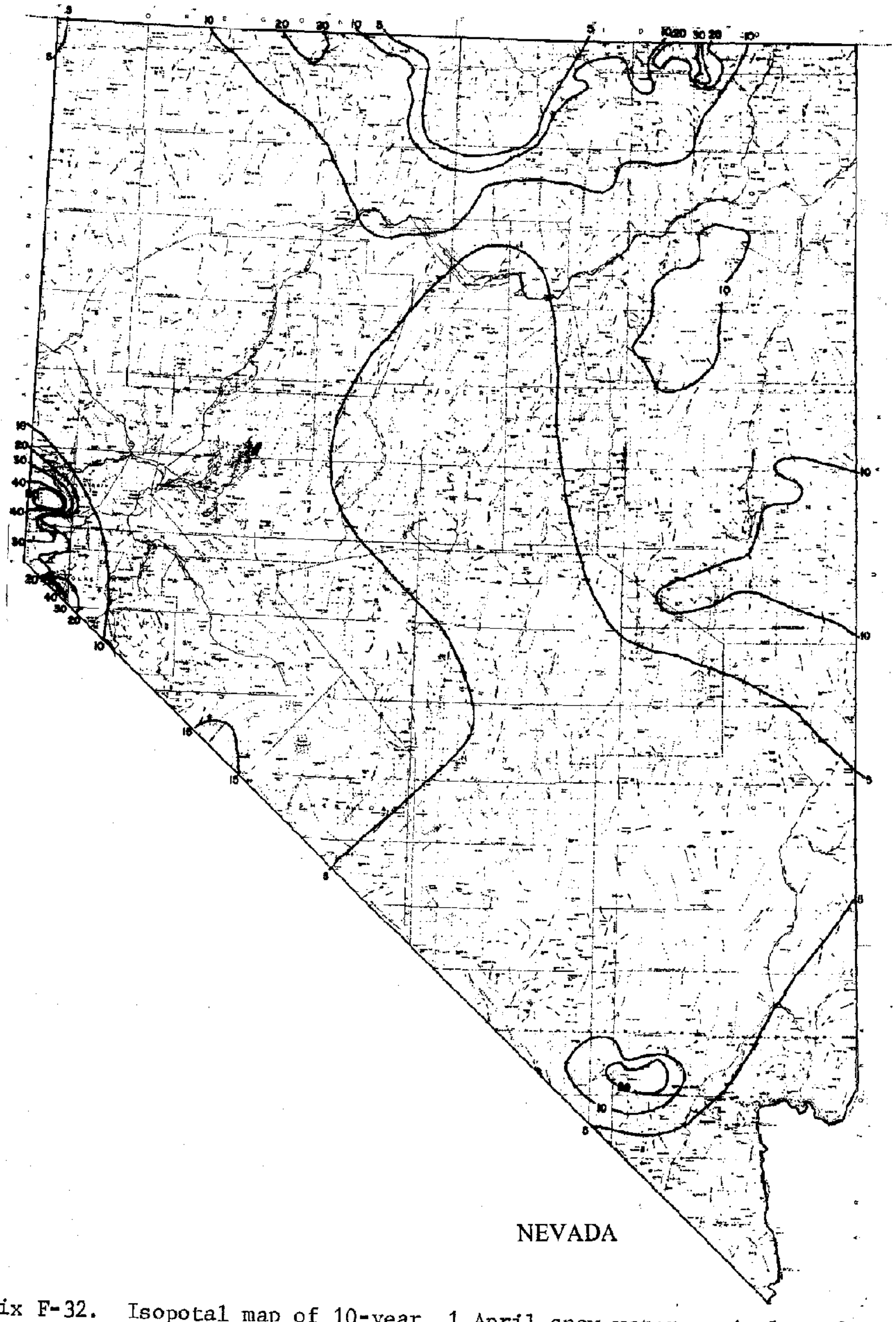
Appendix F-08. Isopotal map of 10-year, 1 April snow water equivalent for Colorado.



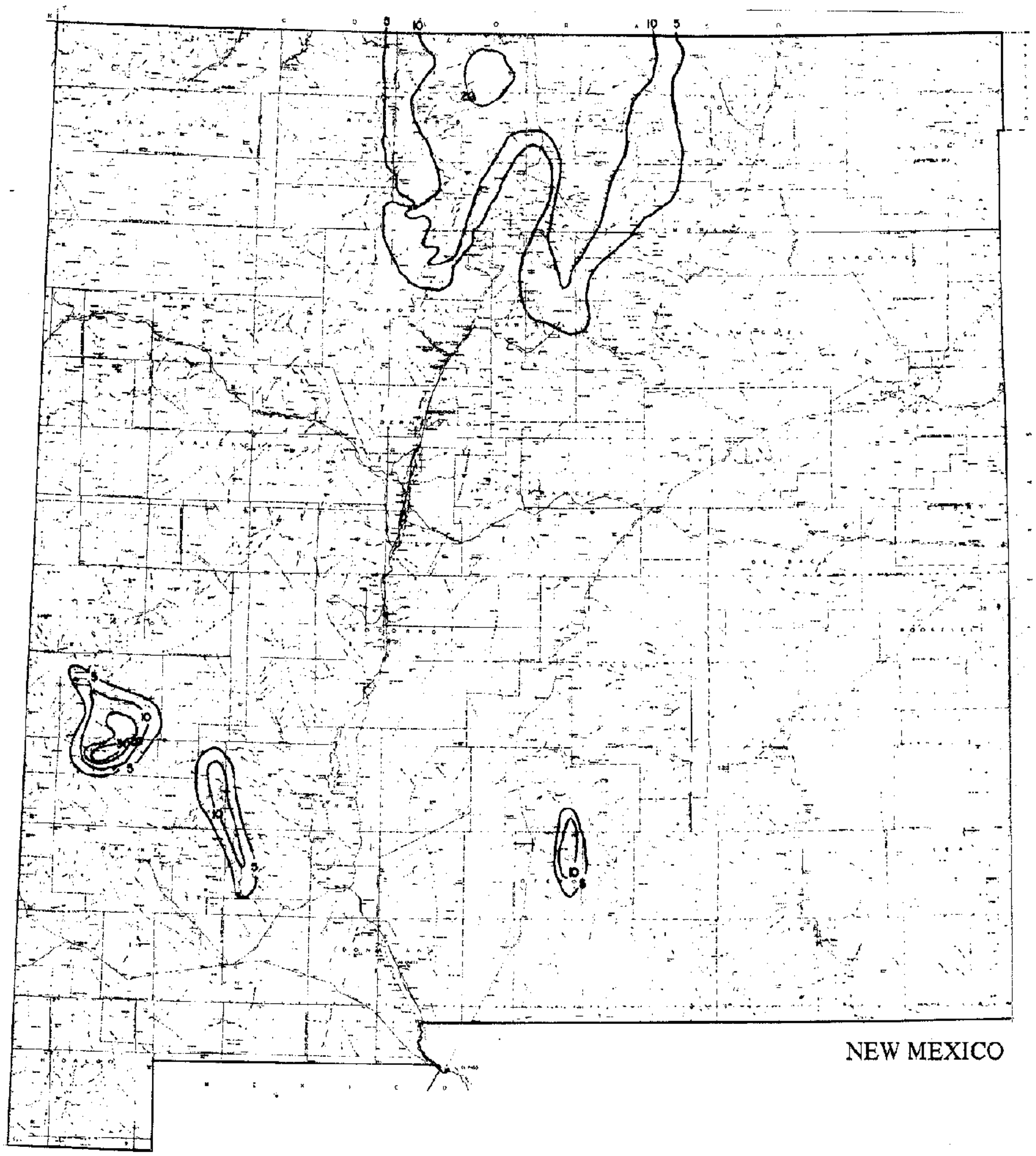
Appendix F-16. Iscpotal map of 10-year, 1 April snow water equivalent for Idaho.



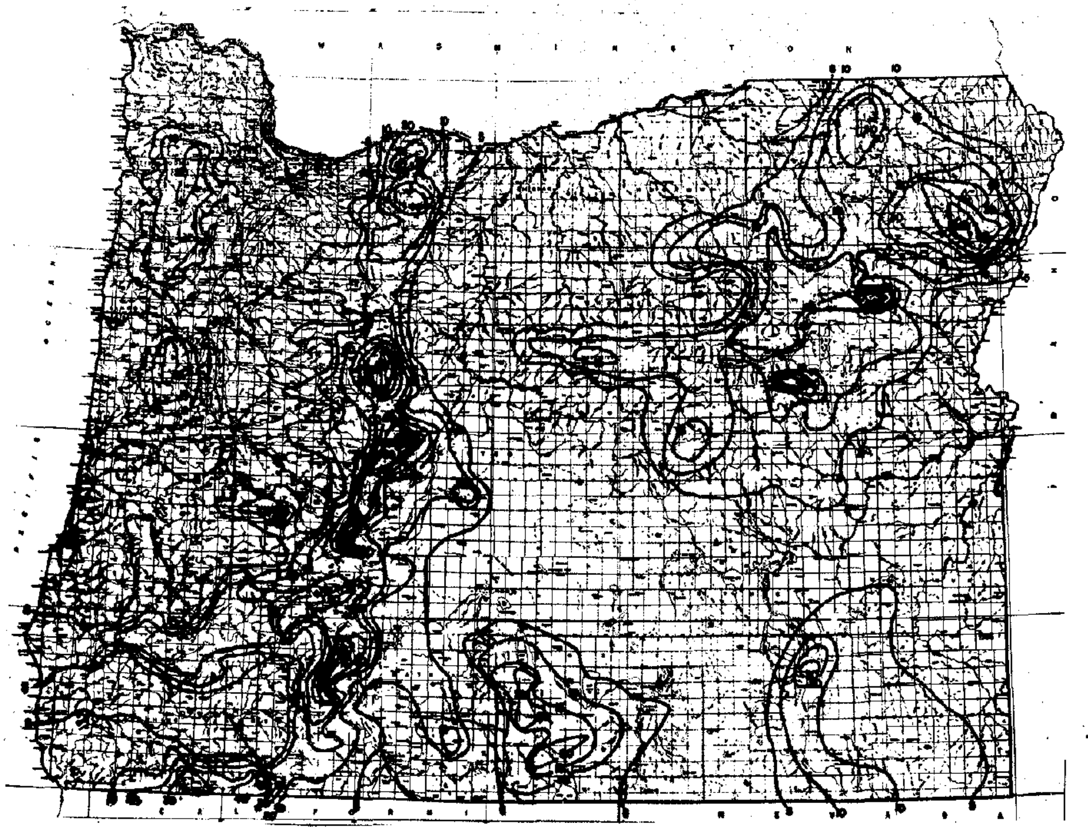
Appendix F-30. Isopotal map of 10-year, 1 April snow water equivalent for Montana.



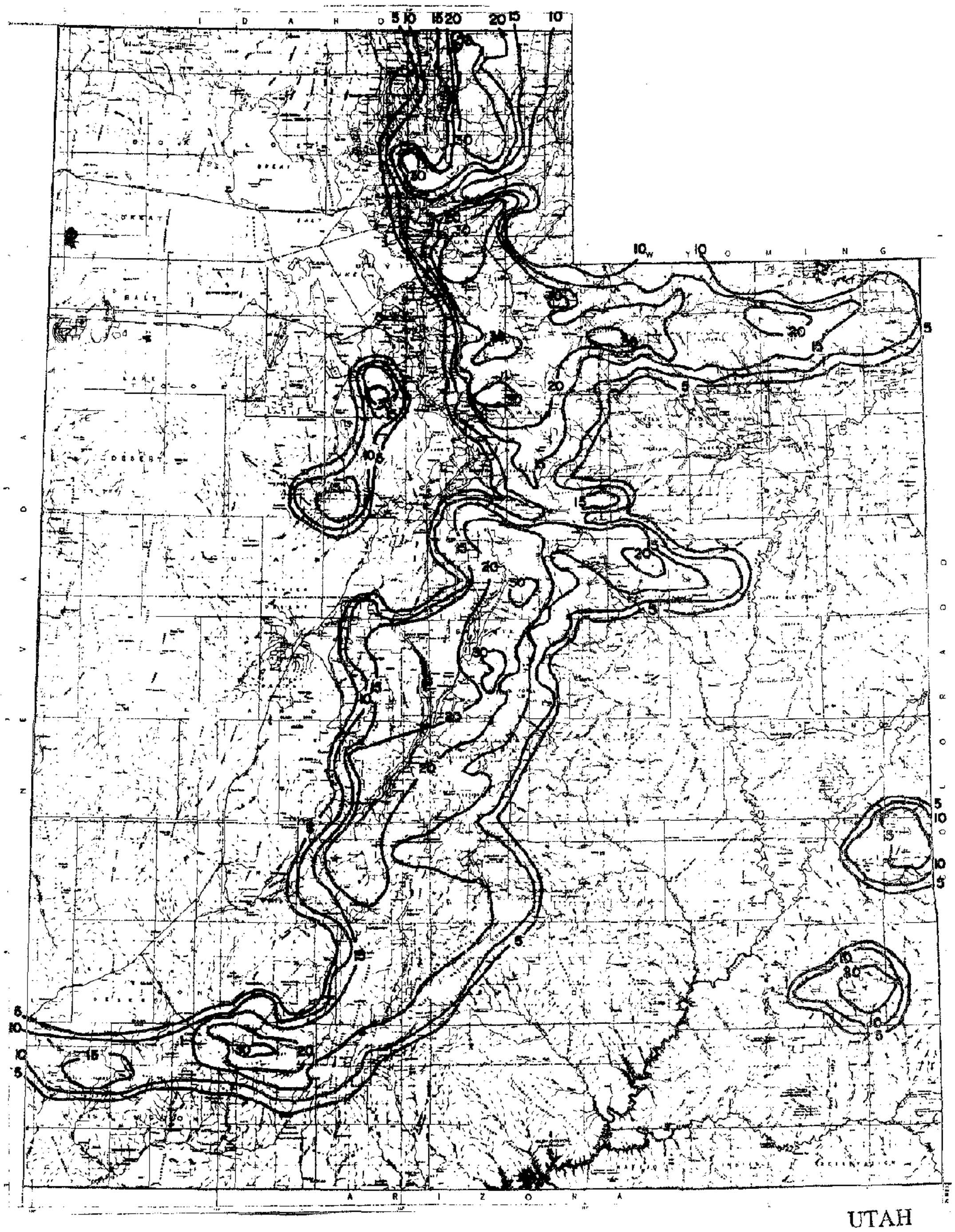
Appendix F-32. Isopotal map of 10-year, 1 April snow water equivalent for Nevada.



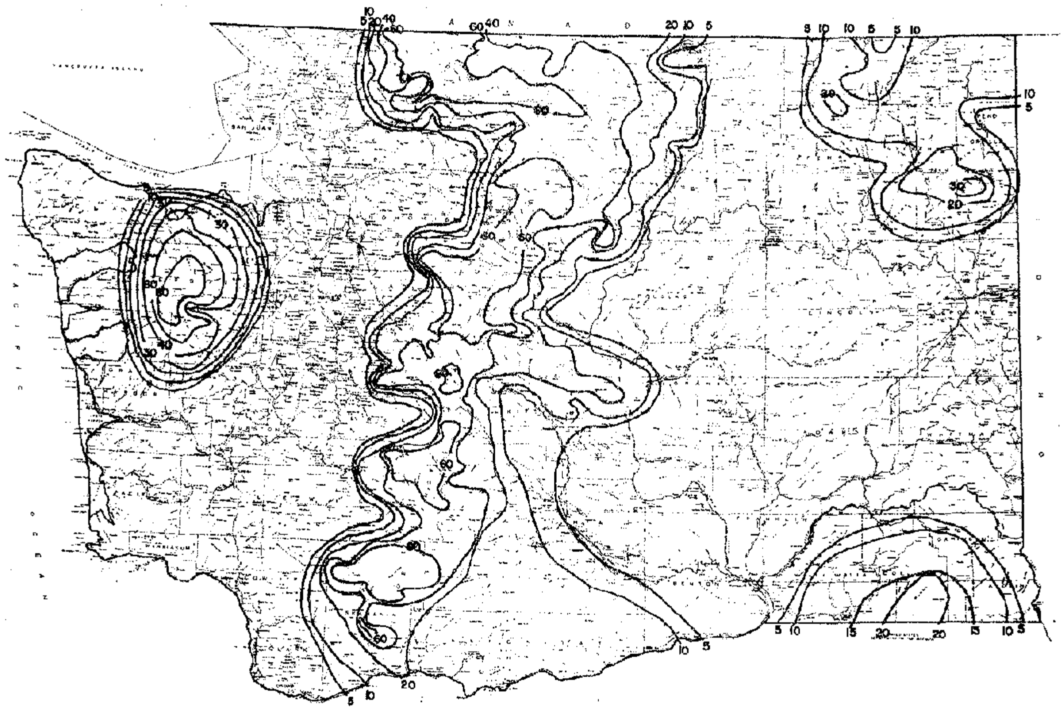
Appendix F-35. Isopotal map of 10-year, 1 April snow water equivalent for New Mexico.



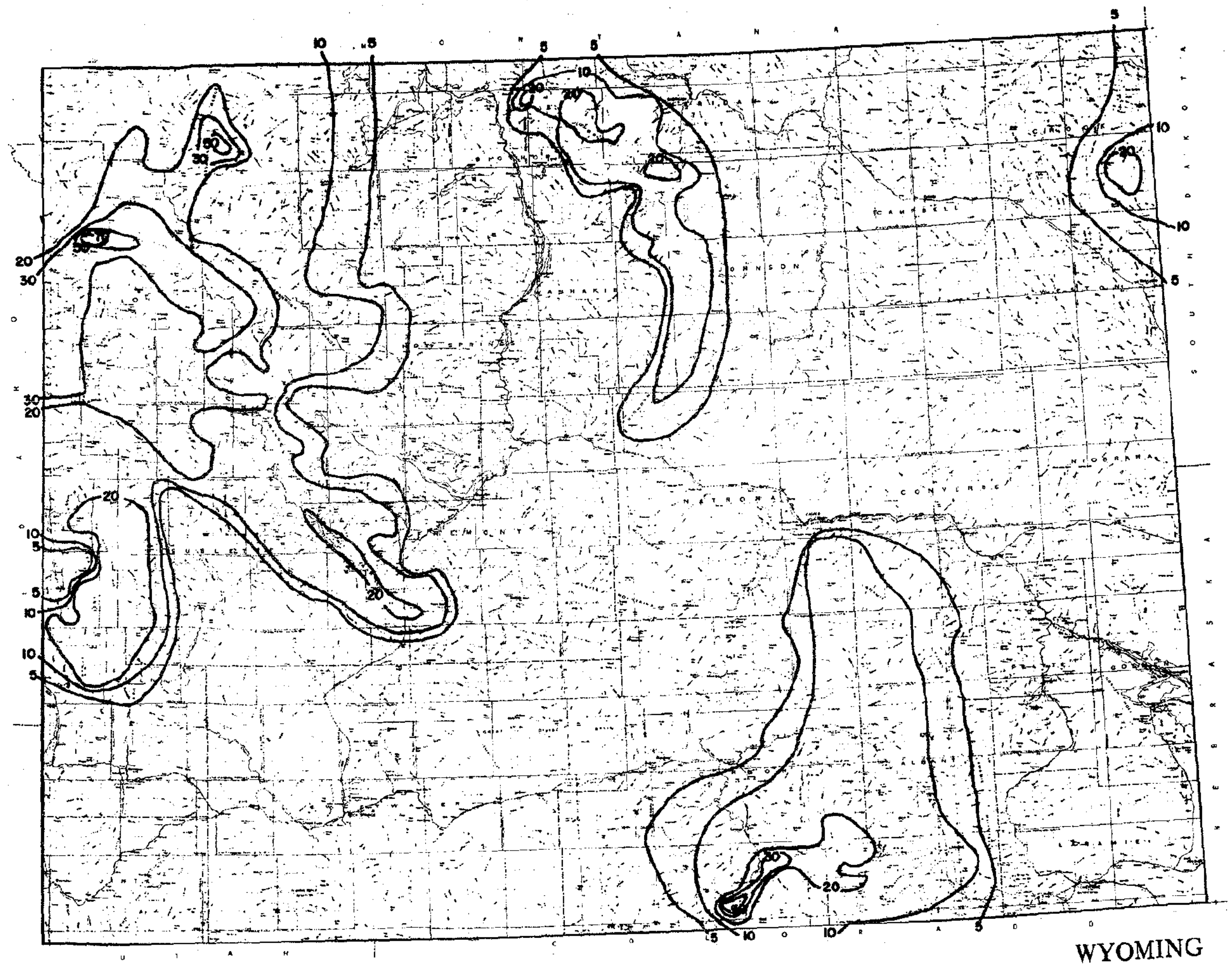
Appendix F-41. Isopotal map of 10-year, 1 April snow water equivalent for Oregon.



Appendix F-49. Isopotal map of 10-year, 1 April snow water equivalent for Utah.



Appendix F-53. Isopotal map of 10-year, 1 April snow water equivalent for Washington.



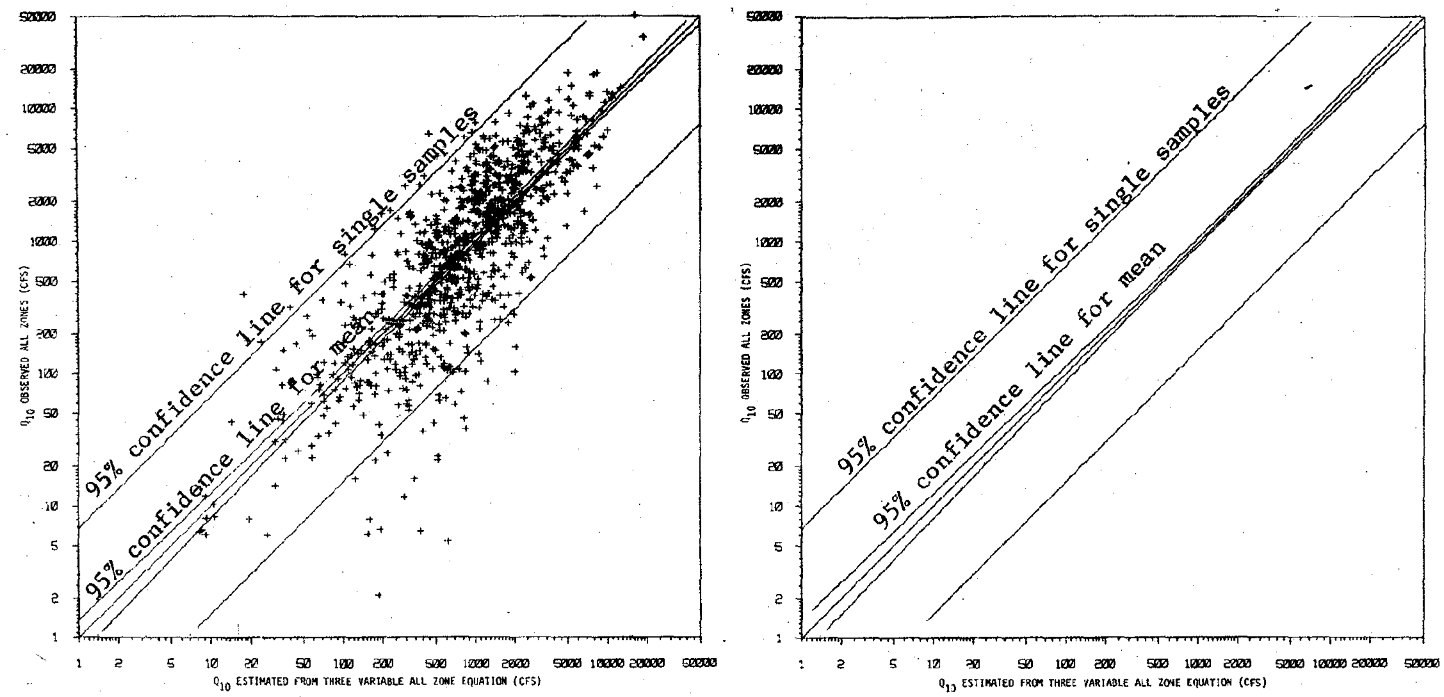
Appendix F-56. Isopotal map of 10-year, 1 April snow water equivalent for Wyoming.

APPENDIX G

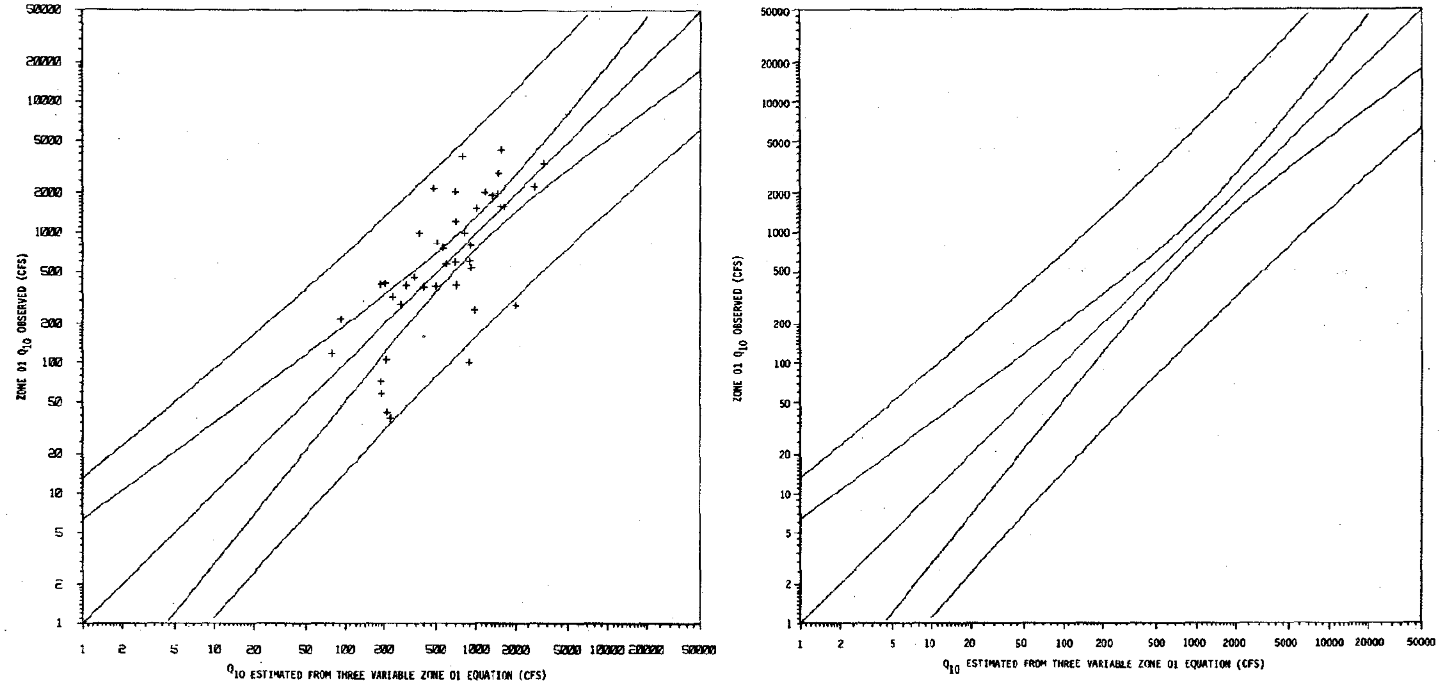
Scatter Diagrams for the Relationship Between the Measured and Estimated 10-Year Peak Flows with the 95 Percent Confidence Intervals for the Mean and Point Estimates for all of the United States (Lumped) and for Each of the 24 Hydrophysiographical Zones.

Appendix G contains scatter diagrams for the relationship between the measured and estimated 10-year peak flows with the 95 percent confidence intervals for the mean and single samples for the complete United States and Puerto Rico and for each of the 24 hydrophysiographic zones delineated in the present study using 3-parameter lumped and zones equations. The first or left-hand graph shows the point scatter, and the right-hand graph shows the regression line and the two sets of 95 percent confidence interval lines. Appendix G-00 is labeled to show the pattern for Figures throughout this Appendix.

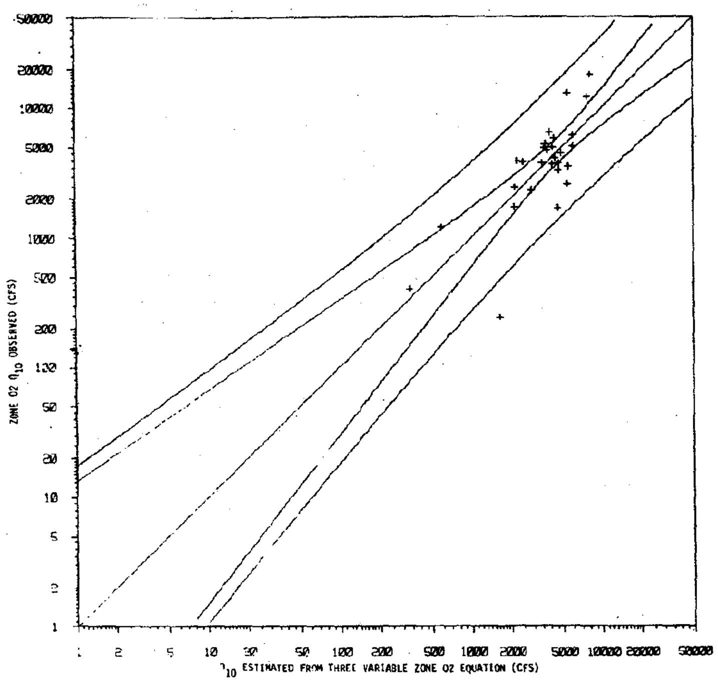
The figures are arranged with the all zone equation called zero and each of the general equations with their respective zone numbers on them.

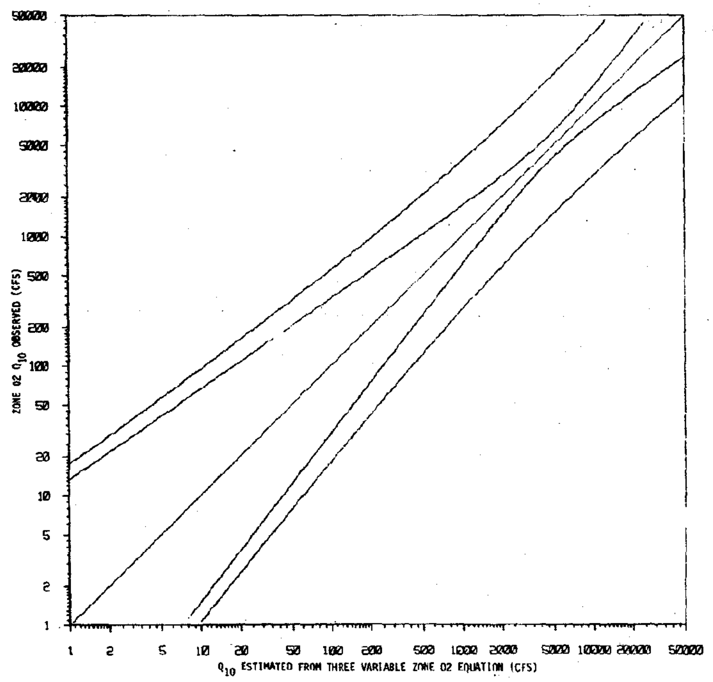


Appendix G-00. 95% mean and point estimate confidence intervals for three variable all zone equation.

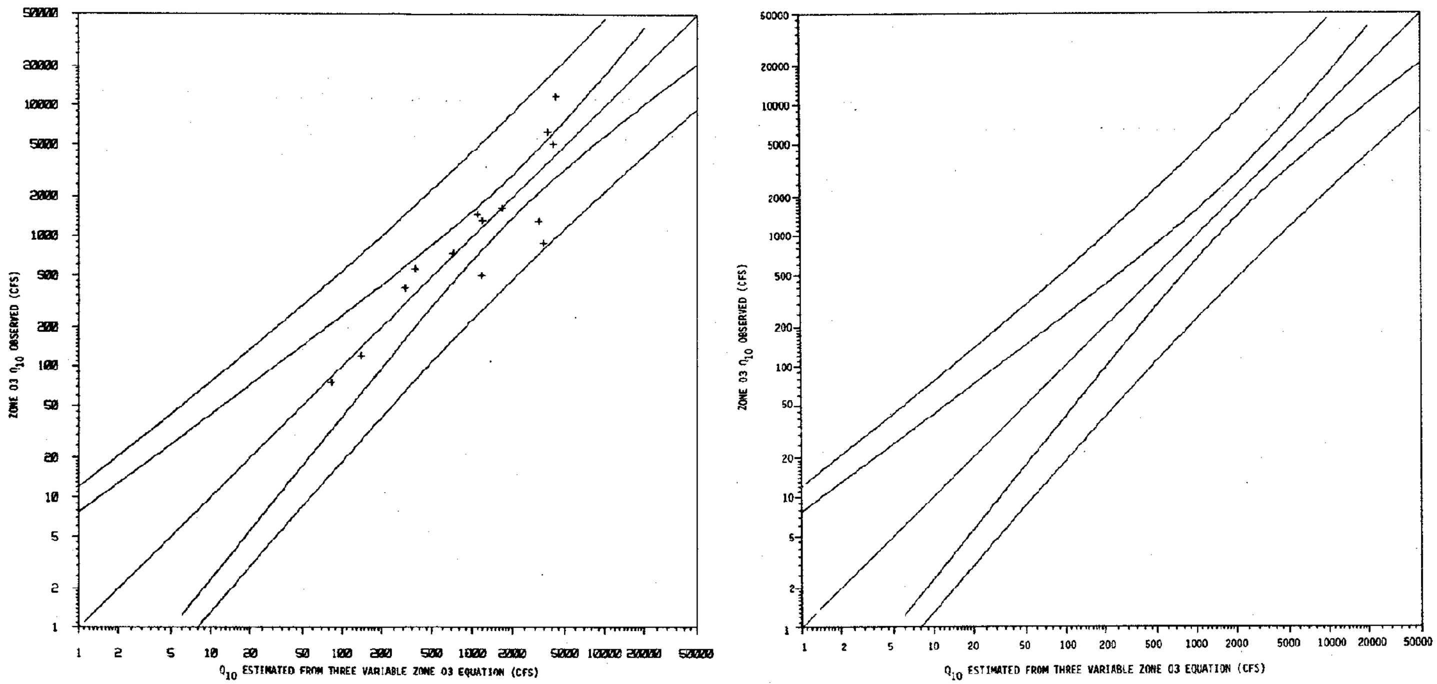


Appendix G-01. 95% mean and point estimate confidence intervals for three variable Zone 01 equation.

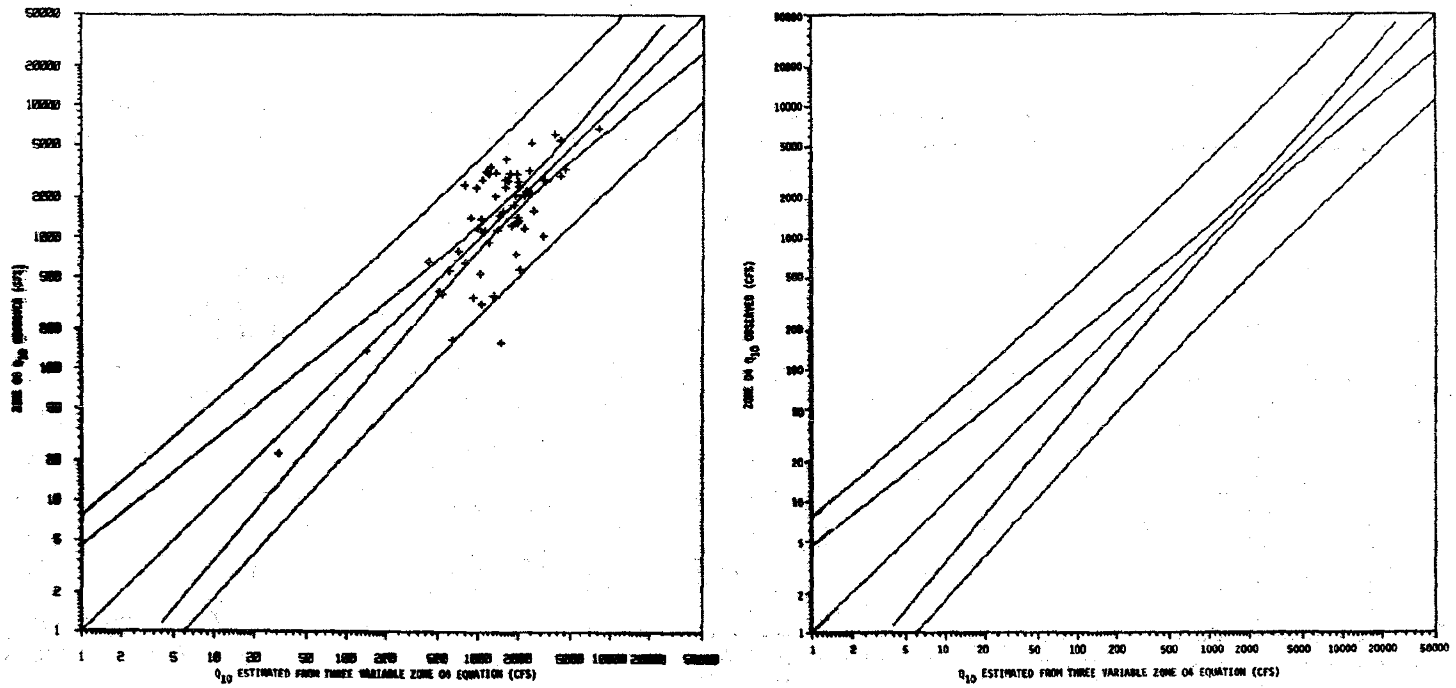




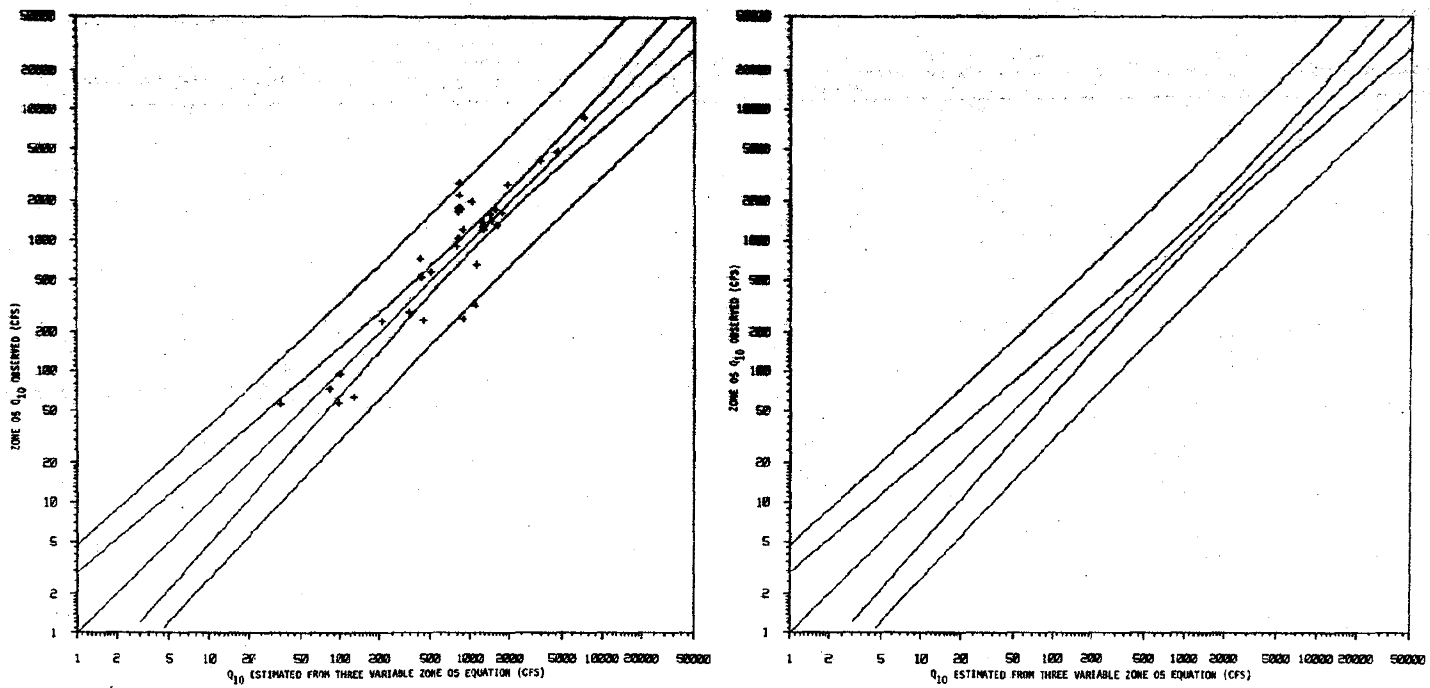
Appendix G-02. 95% mean and point estimate confidence intervals for three variable Zone 02 equation.



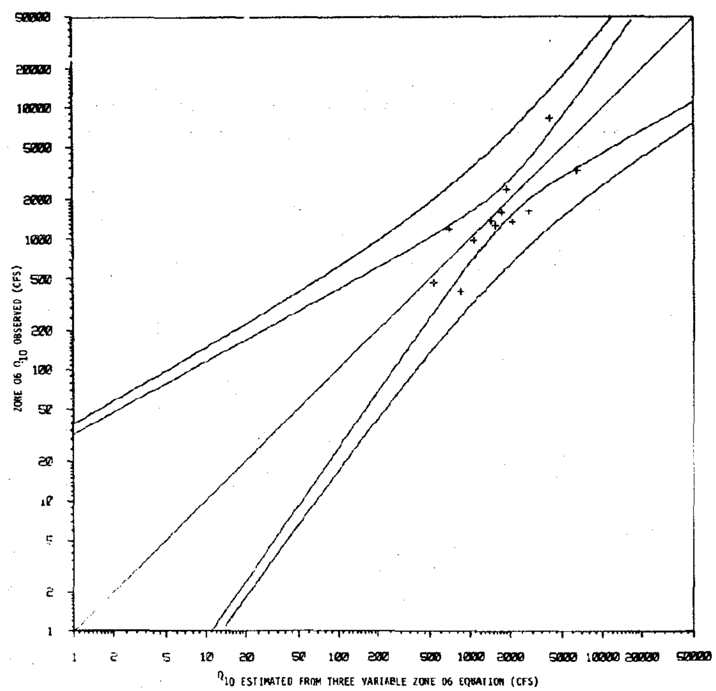
Appendix G-03. 95% mean and point estimate confidence intervals for three variable Zone 03 equation.

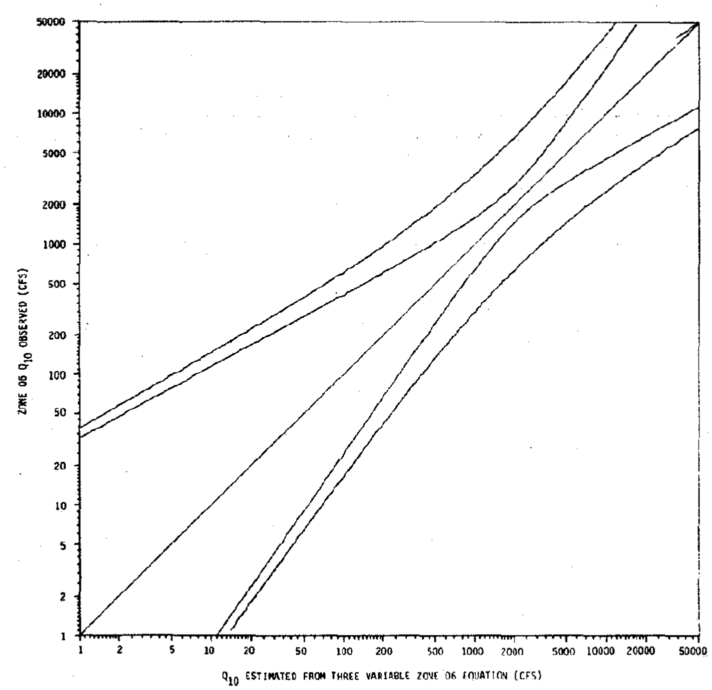


Appendix G-04. 95% mean and point estimate confidence intervals for three variable Zone 04 equation.

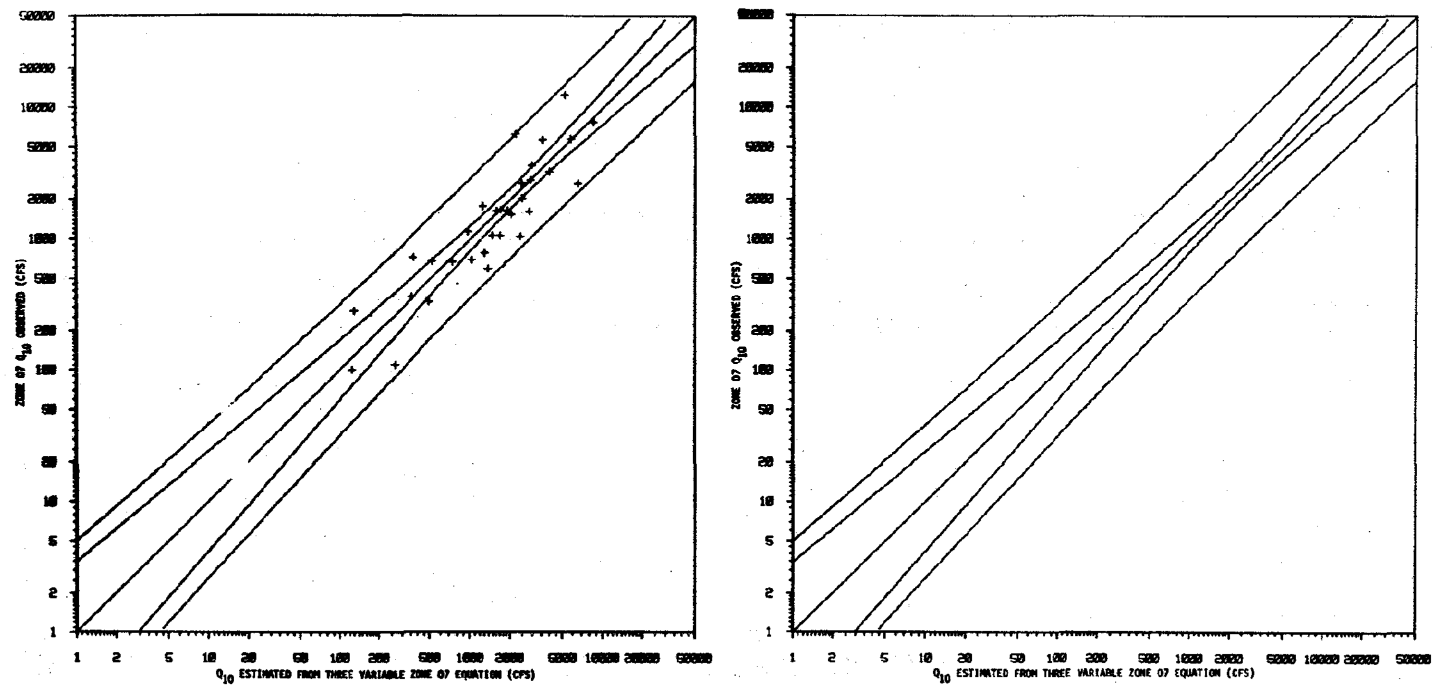


Appendix G-05. 95% mean and point estimate confidence intervals for three variable Zone 05 equation.

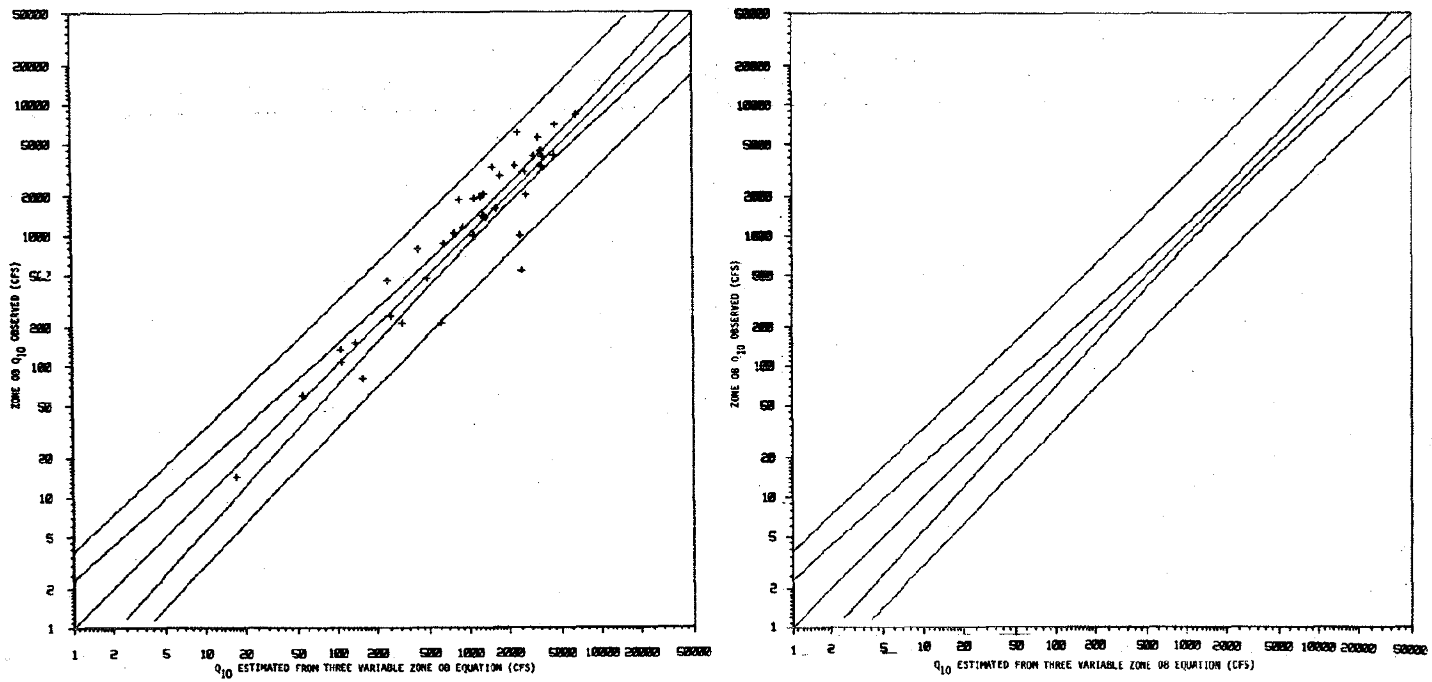




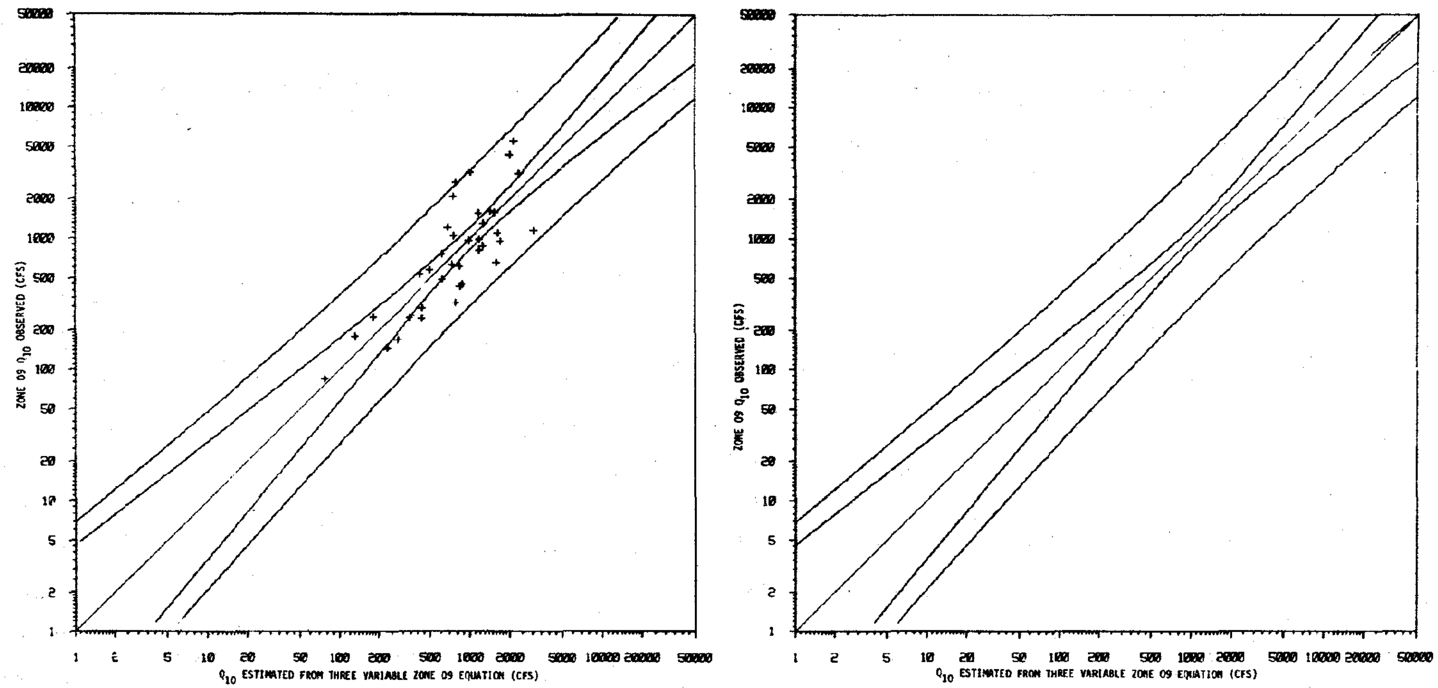
Appendix G-06. 95% mean and point estimate confidence intervals for three variable Zone 06 equation.



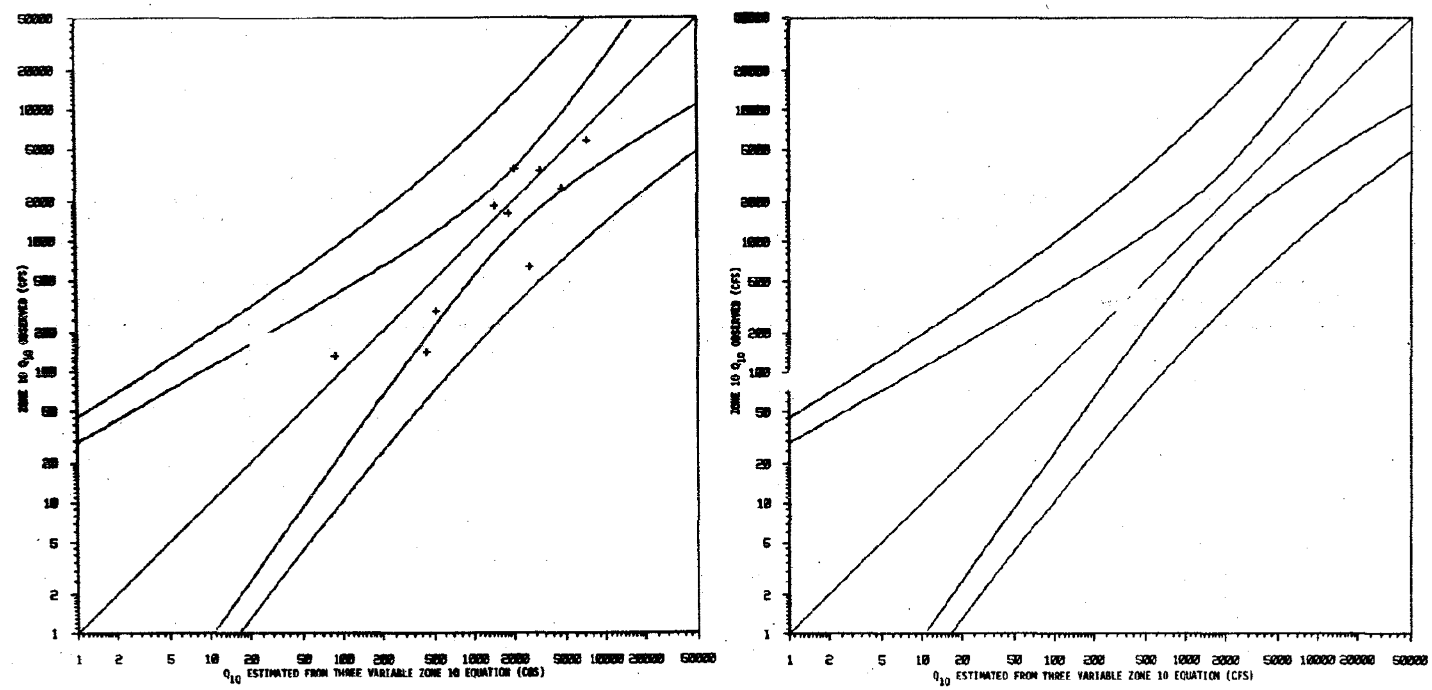
Appendix G-07. 95% mean and point estimate confidence intervals for three variable Zone 07 equation.



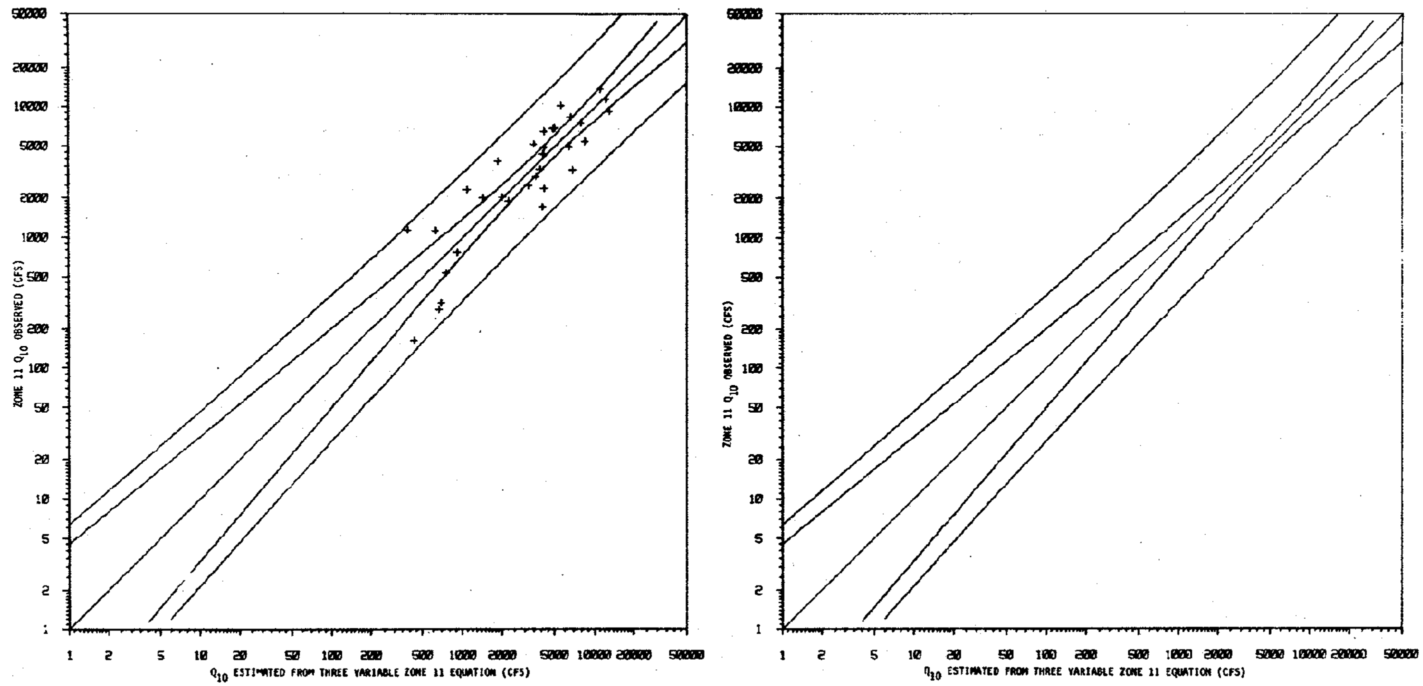
Appendix G-08. 95% mean and point estimate confidence intervals for three variable Zone 08 equation.



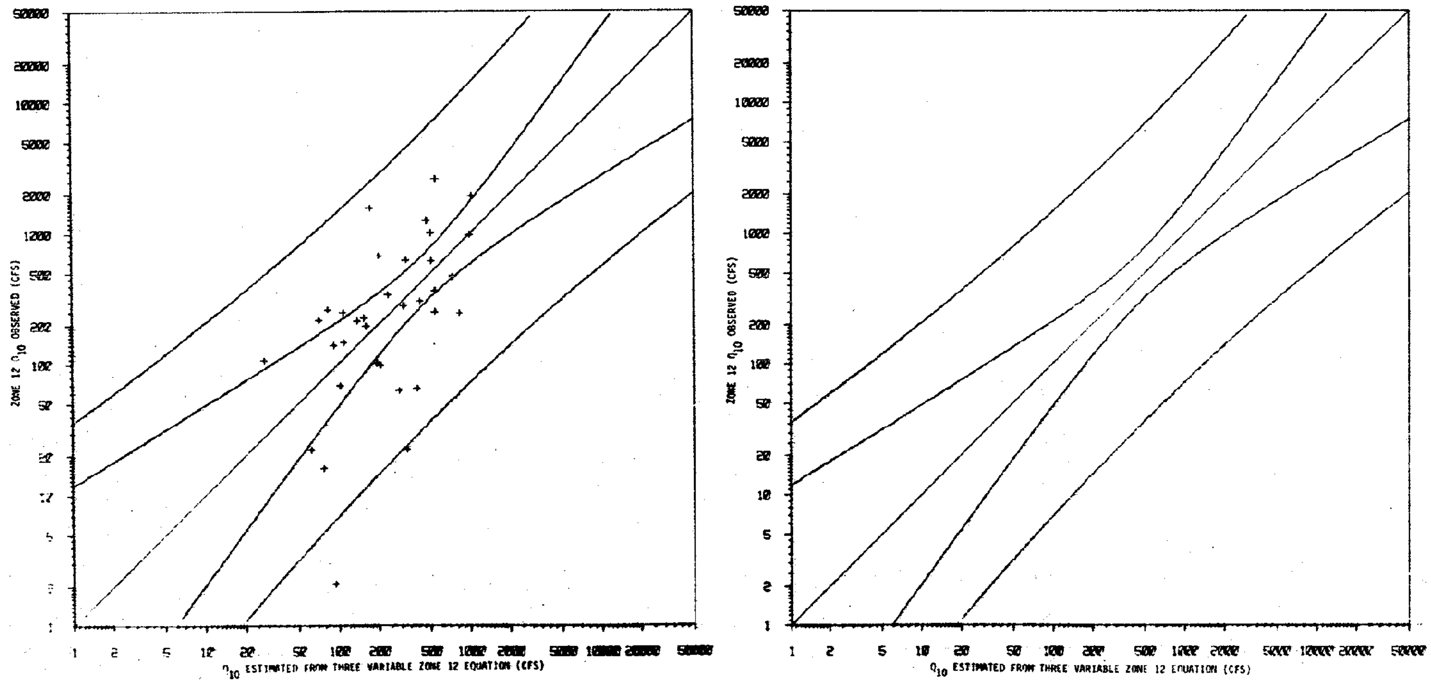
Appendix G-09. 95% mean and point estimate confidence intervals for three variable Zone 09 equation.



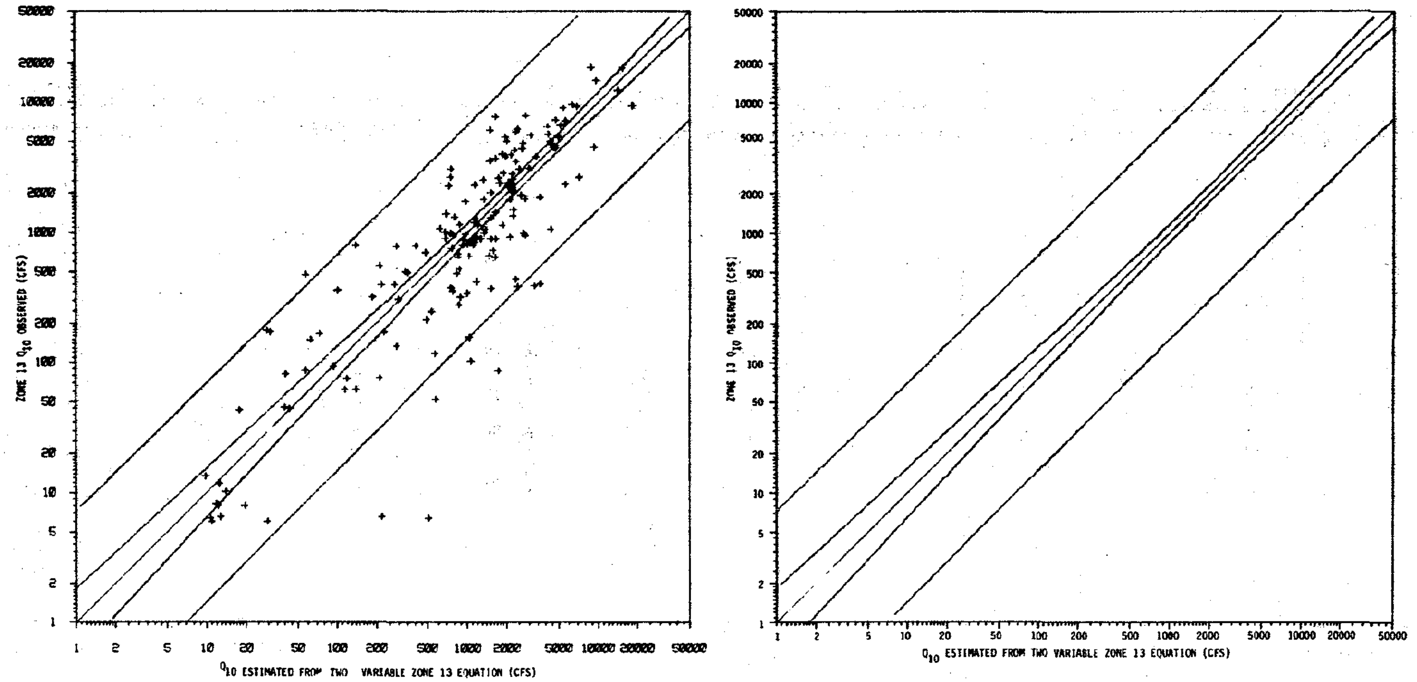
Appendix G-10. 95% mean and point estimate confidence intervals for three variable Zone 10 equation.



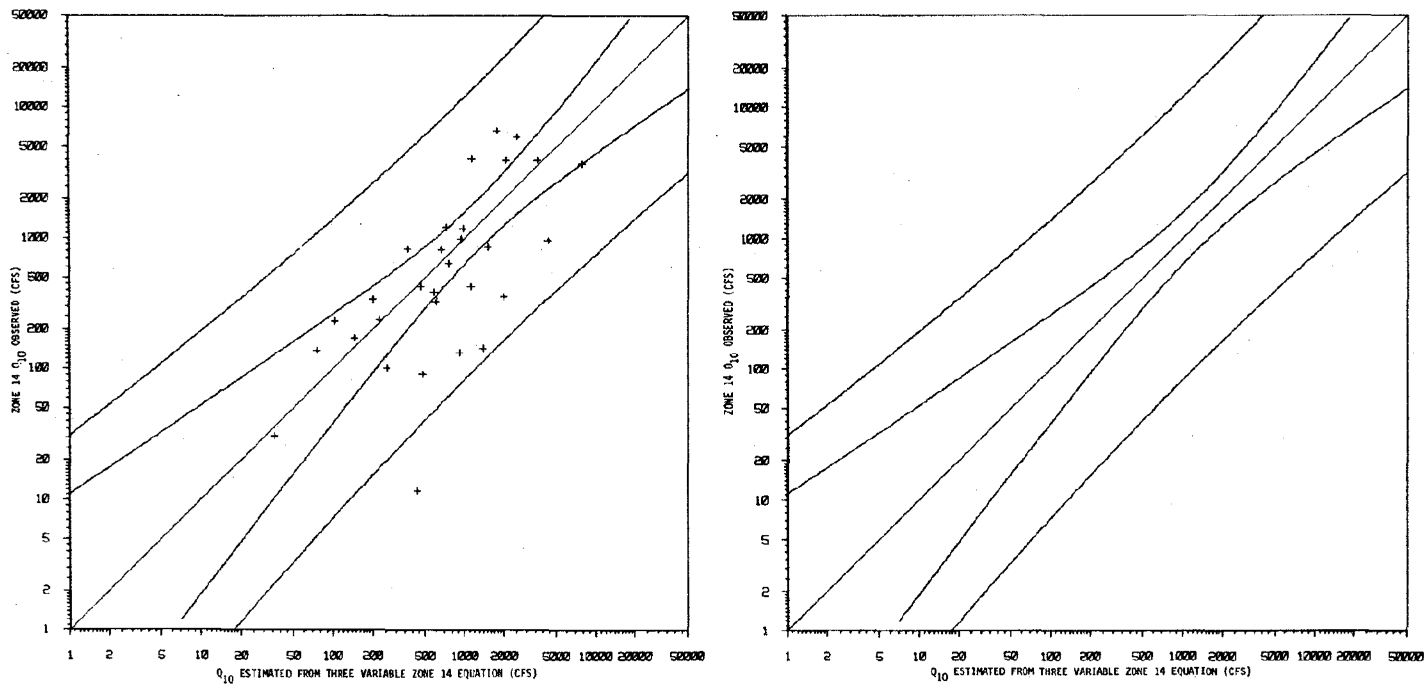
Appendix G-11. 95% mean and point estimate confidence intervals for three variable Zone 11 equation.



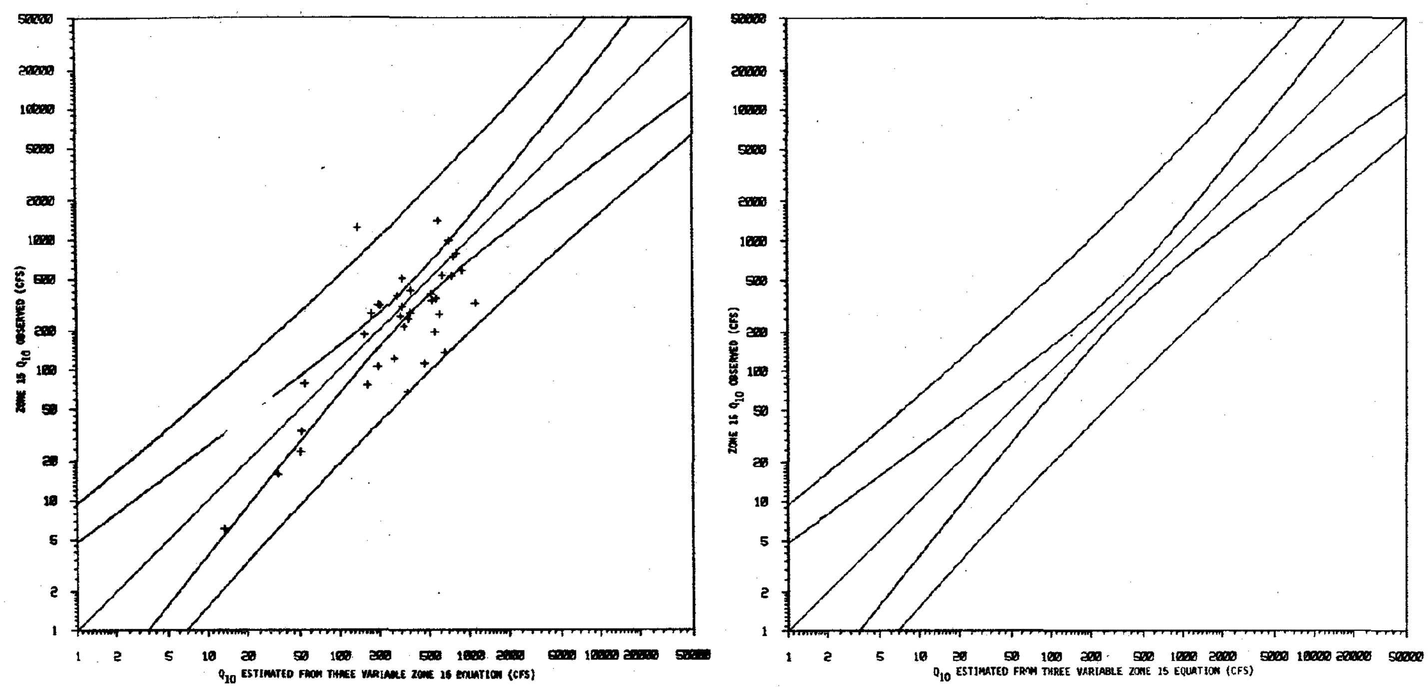
Appendix G-12. 95% mean and point estimate confidence intervals for three variable Zone 12 equation.



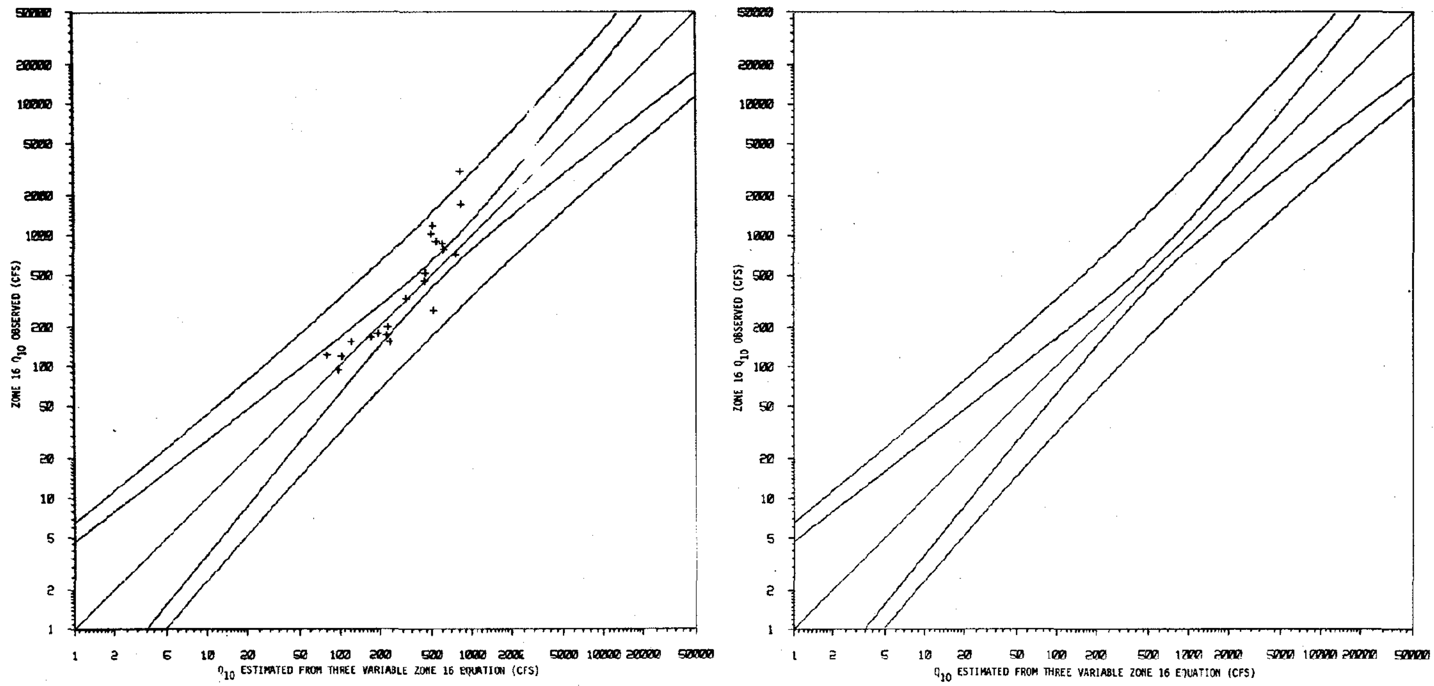
Appendix G-13. 95% mean and point estimate confidence intervals for three variable Zone 13 equation.



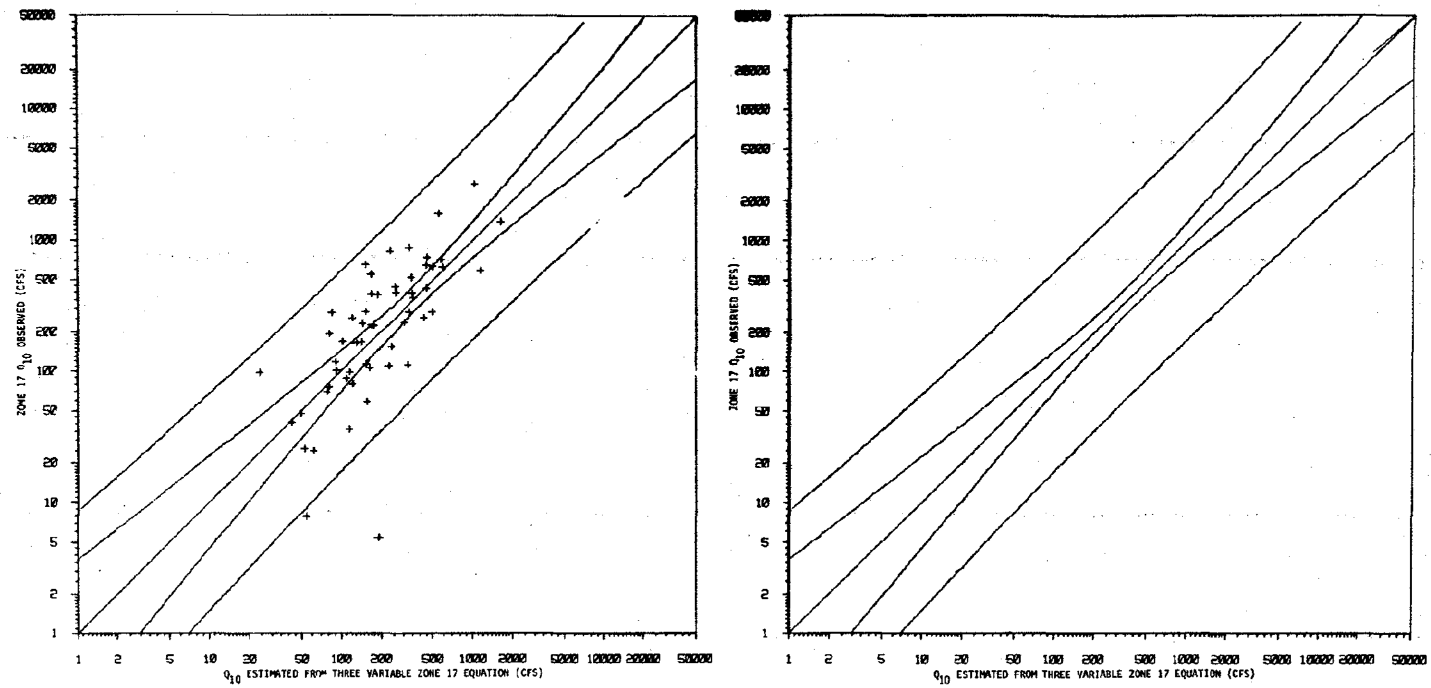
Appendix G-14. 95% mean and point estimate confidence intervals for three variable Zone 14 equation.



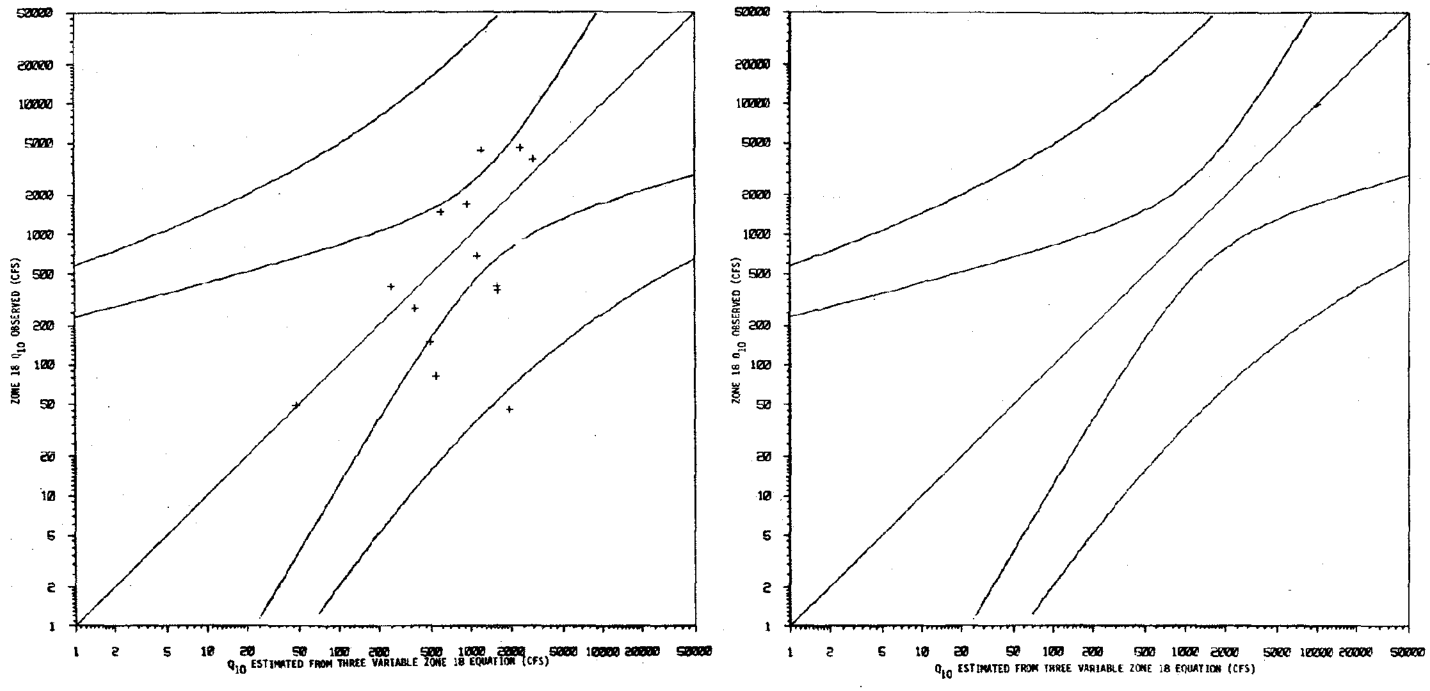
Appendix G-15. 95% mean and point estimate confidence intervals for three variable Zone 15 equation.



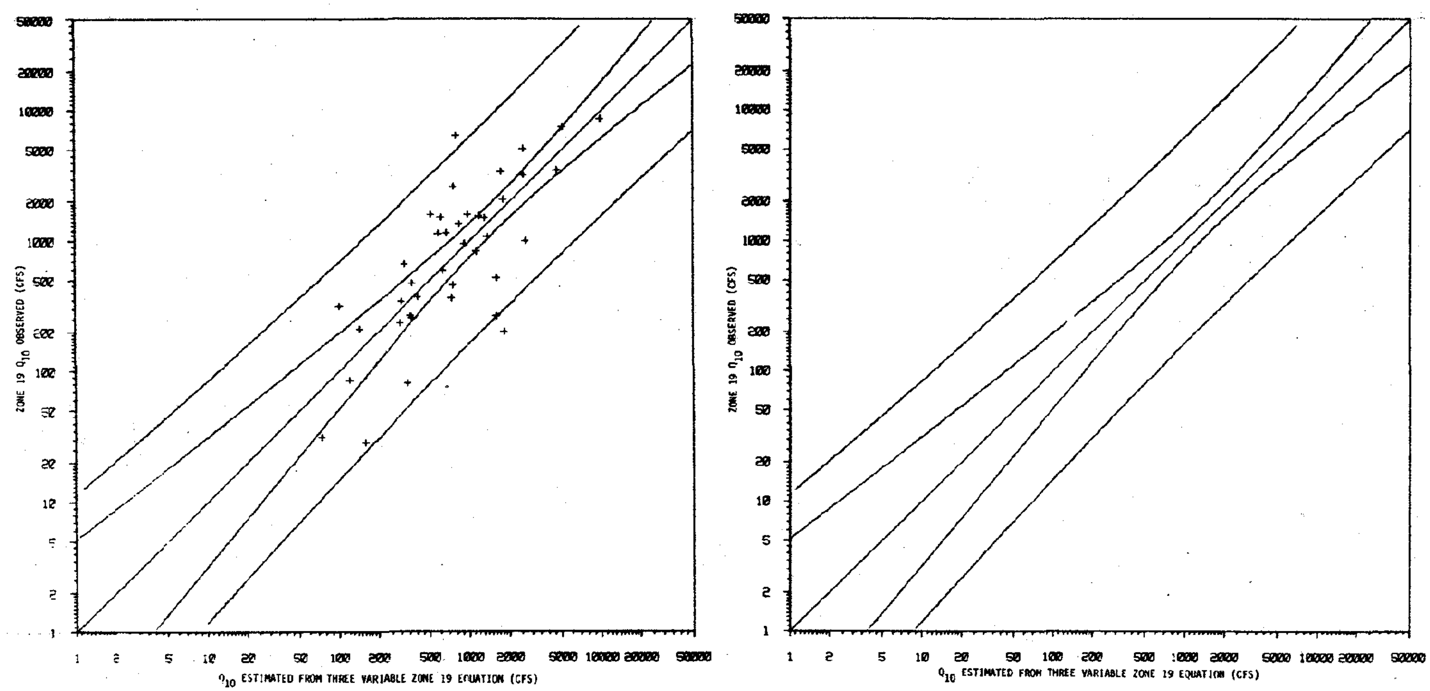
Appendix G-16. 95% mean and point estimate confidence intervals for three variable Zone 16 equation.



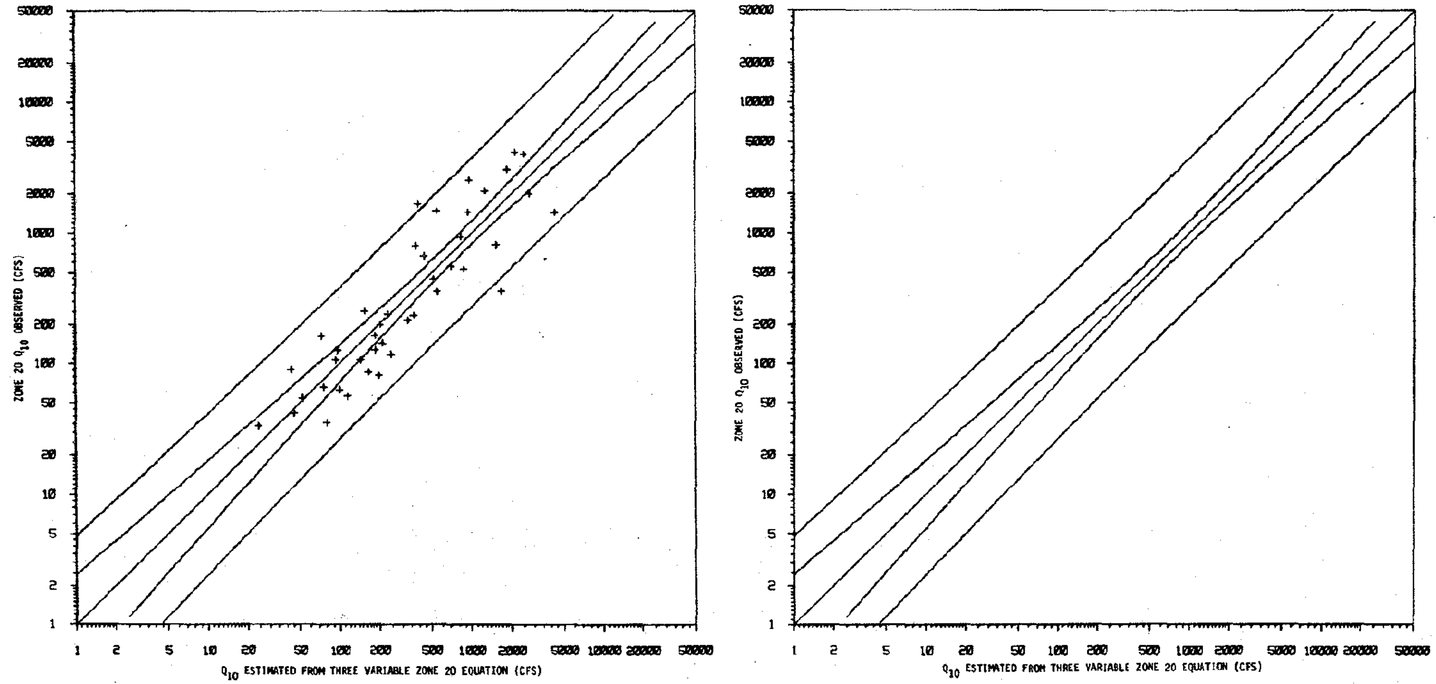
Appendix G-17. 95% mean and point estimate confidence intervals for three variable Zone 17 equation.



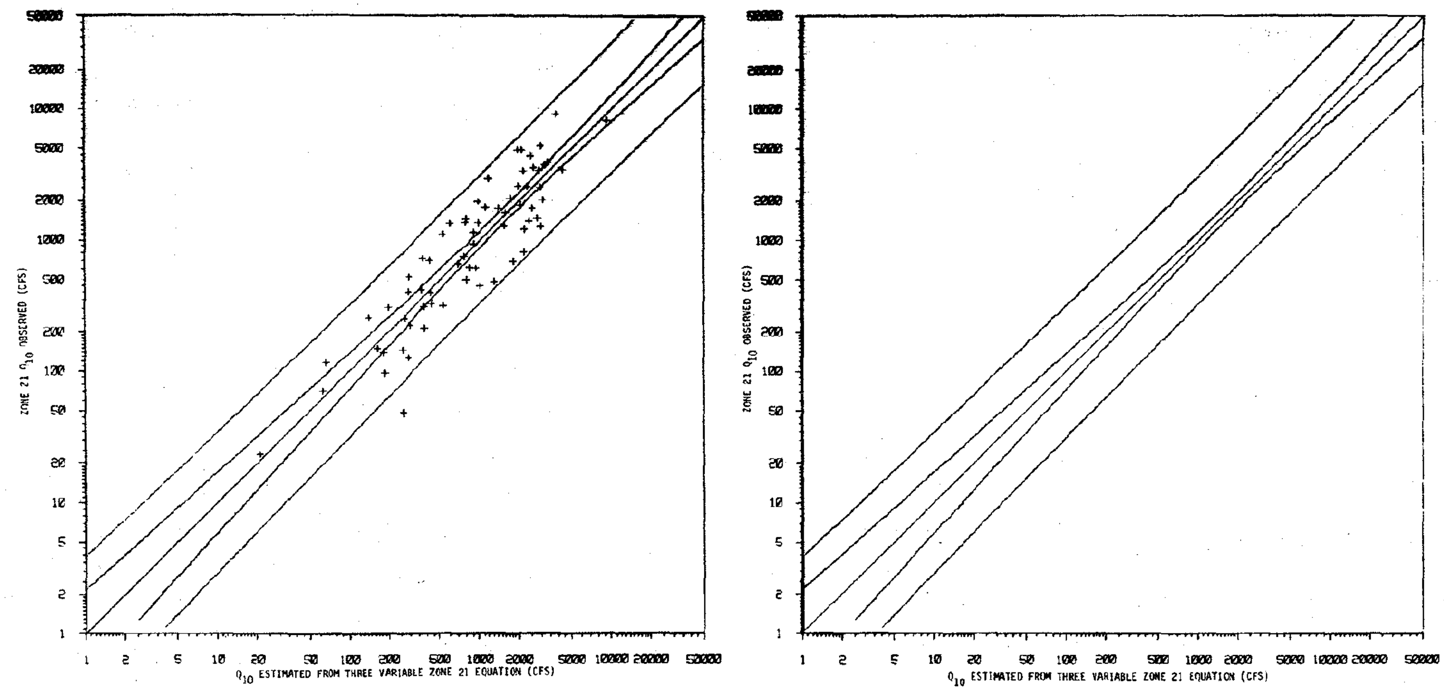
Appendix G-18. 95% mean and point estimate confidence intervals for three variable Zone 18 equation.



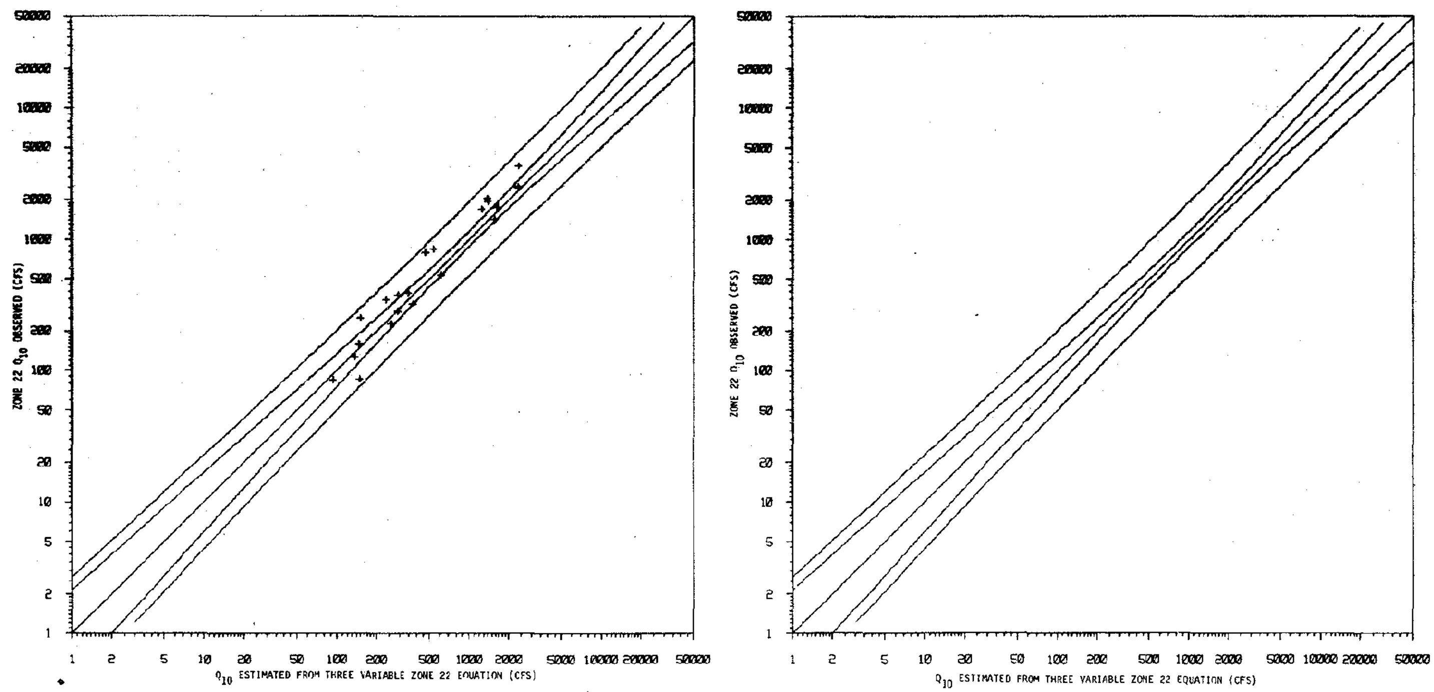
Appendix G-19. 95% mean and point estimate confidence intervals for three variable Zone 19 equation.



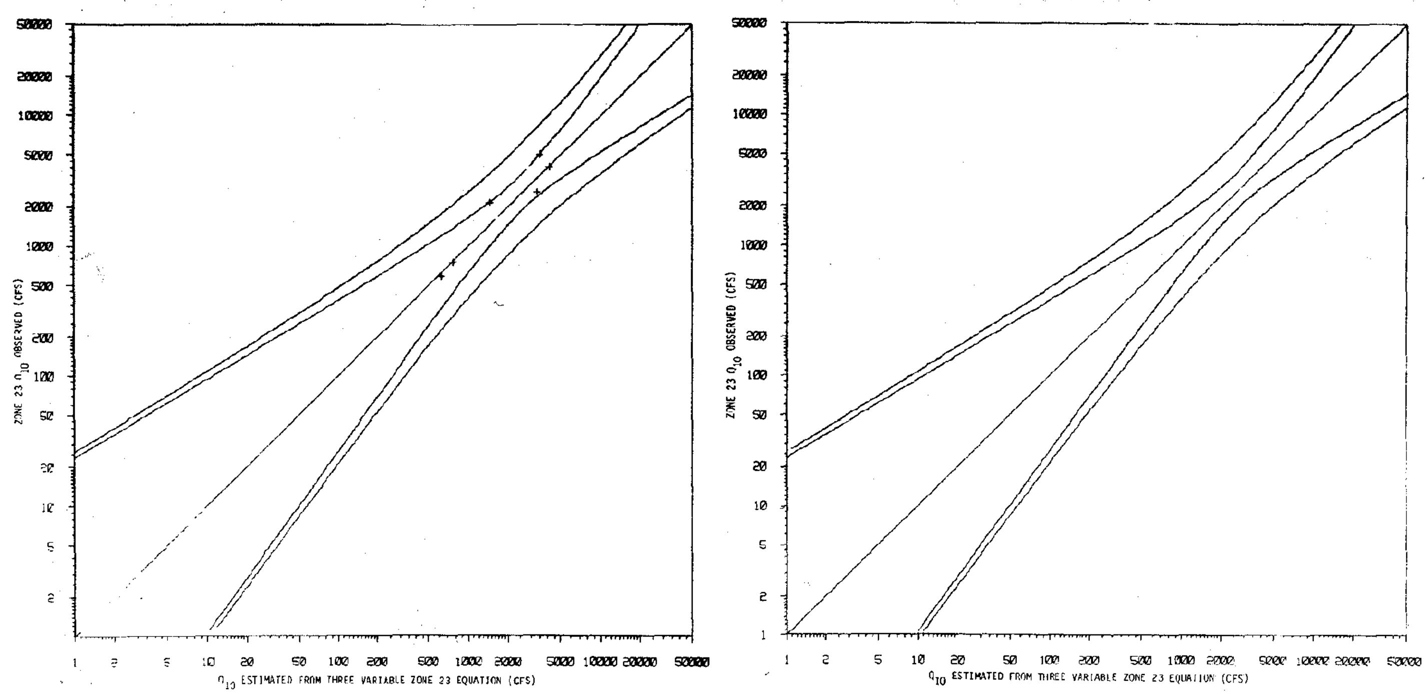
Appendix G-20. 95% mean and point estimate confidence intervals for three variable Zone 20 equation.



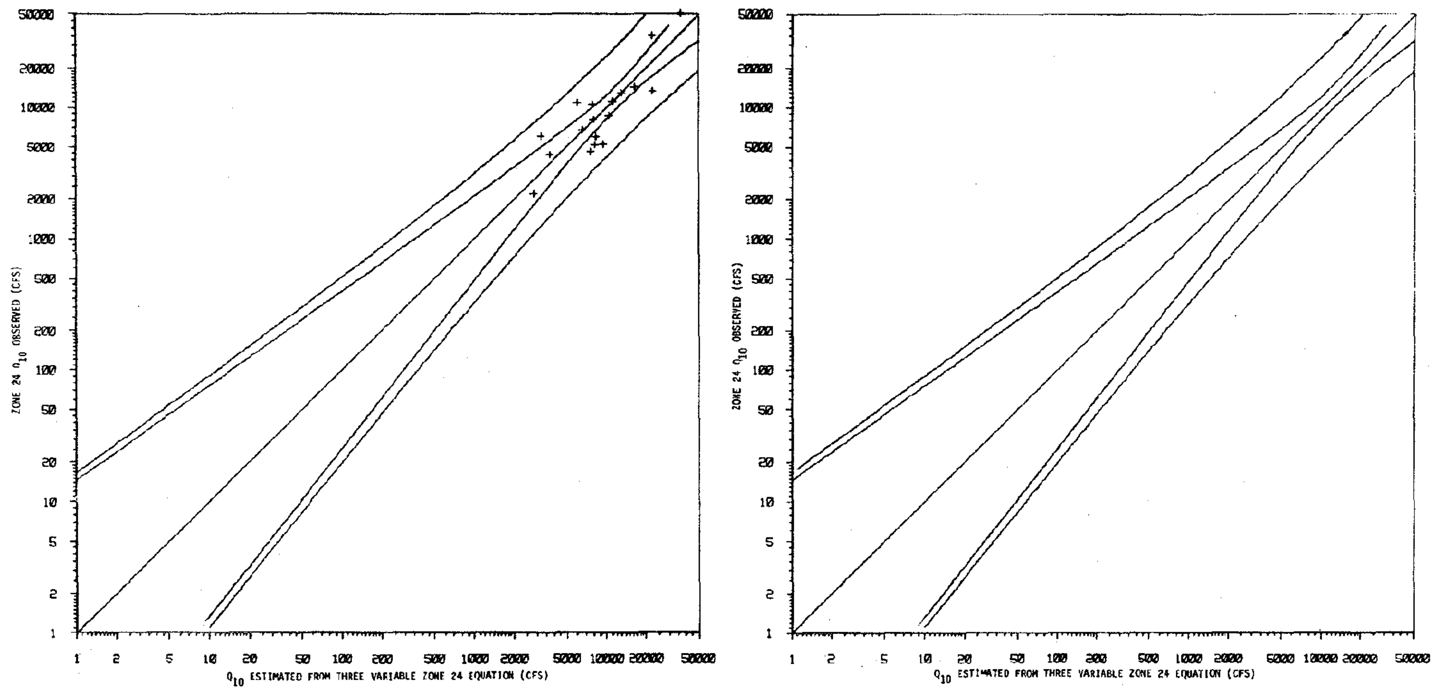
Appendix G-21. 95% mean and point estimate confidence intervals for three variable Zone 21 equation.



Appendix G-22. 95% mean and point estimate confidence intervals for three variable Zone 22 equation.



Appendix G-23. 95% mean and point estimate confidence intervals for three variable Zone 23 equation.



Appendix G-24. 95% mean and point estimate confidence intervals for three variable Zone 24 equation.

APPENDIX H

Equations, Nomographs, and Correction Curves for Each of the 24 Hydrophysiographic Zones of the United States and Puerto Rico

Appendix H contains nomographs for the all zone equation derived from lumping all of the data together.

The three sets of equations derived for the same areas are included as tables H-1, H-2, and H-3 for the 3-Parameter, 5-Parameter, and 7-Parameter Equations respectively. In addition, a set of correction curves, K, for each of the zones using the 3-Parameter all zone equation is given along with a tabulation of the correction equations themselves.

Use of Nomograph:

Enter the nomograph with values of A and R and draw a line. Mark the point of intersection on the turning axis and enter the chart again with value of ΔH. Connect ΔH with the marked point on turning axis. The $\hat{q}_{10}$ is at the intersection of q_{10} scale.

Table H-1. The 3-Parameter regression equations for each of the 24 hydrophysiographic zones with their standard errors of estimate.

Zone	Correction Equation	(1) PS_{EE} %	(2) PS_e %	(3) n	(4) r
All Zone	$\hat{q}_{10} = 1.28015\ A^{0.56172}\ R^{0.94356}\ DH^{0.16887}$	119	13	898	0.854
1	$\hat{q}_{10} = 0.02137\ A^{0.43975}\ R^{1.16383}\ DH^{0.78453}$	84	13	42	0.774
2	$\hat{q}_{10} = 11.8893\ A^{0.57269}\ R^{0.44271}\ DH^{0.29510}$	60	7	28	0.798
3	$\hat{q}_{10} = 10410.4\ A^{0.54499}\ R^{-0.69141}\ DH^{0.32389}$	108	9	14	0.925
4	$\hat{q}_{10} = 76.7226\ A^{0.64795}\ R^{0.24744}\ DH^{0.03546}$	56	9	62	0.795
5	$\hat{q}_{10} = 1.14069\ A^{0.81060}\ R^{0.81127}\ DH^{0.16225}$	44	8	35	0.927
6	$\hat{q}_{10} = 10^{5.03658}\ A^{0.22735}\ R^{-2.07865}\ DH^{0.71475}$	88	7	12	0.840
7	$\hat{q}_{10} = 141.135\ A^{0.88572}\ R^{-0.13043}\ DH^{0.13981}$	76	7	33	0.918
8	$\hat{q}_{10} = 95.0775\ A^{0.58571}\ R^{0.07355}\ DH^{0.18493}$	51	7	39	0.952
9	$\hat{q}_{10} = 0.50051\ A^{0.69229}\ R^{0.74166}\ DH^{0.39729}$	85	8	37	0.850
10	$\hat{q}_{10} = 0.000613\ A^{1.30615}\ R^{3.28114}\ DH^{-0.54172}$	67	12	10	0.882
11	$\hat{q}_{10} = 1111.47\ A^{0.67899}\ R^{-0.76204}\ DH^{0.58914}$	43	7	32	0.902
12	$\hat{q}_{10} = 0.01961\ A^{0.47391}\ R^{1.68758}\ DH^{0.30700}$	115	21	34	0.672
13	$\hat{q}_{10} = 6.18115\ A^{0.56694}\ R^{0.87434}\ DH^{0.01023}$	83	12	166	0.897
	or $\hat{q}_{10} = 6.6082\ A^{0.67054}\ R^{0.87120}$				
14	$\hat{q}_{10} = 0.00353\ A^{0.42562}\ R^{1.64552}\ DH^{0.82680}$	132	17	30	0.762
15	$\hat{q}_{10} = 412.131\ A^{1.00832}\ R^{-0.43497}\ DH^{-0.18943}$	91	14	37	0.795
16	$\hat{q}_{10} = 5.99340\ A^{0.69400}\ R^{0.81381}\ DH^{-0.02694}$	95	8	21	0.897
17	$\hat{q}_{10} = 41.2165\ A^{0.95643}\ R^{0.90116}\ DH^{-0.49291}$	89	15	56	0.784
18	$\hat{q}_{10} = 5399.80\ A^{0.61776}\ R^{-0.20988}\ DH^{-0.28469}$	107	23	14	0.643
19	$\hat{q}_{10} = 0.67503\ A^{0.44020}\ R^{1.26786}\ DH^{0.24140}$	83	13	40	0.833
20	$\hat{q}_{10} = 0.88267\ A^{0.94684}\ R^{1.01373}\ DH^{0.06857}$	103	10	42	0.926
21	$\hat{q}_{10} = 8.80096\ A^{0.90473}\ R^{0.44704}\ DH^{0.15937}$	67	8	68	0.924
22	$\hat{q}_{10} = 0.76272\ A^{0.69452}\ R^{0.85611}\ DH^{0.23777}$	36	5	22	0.974
23	$\hat{q}_{10} = 9687.77\ A^{0.99975}\ R^{0.16025}\ DH^{-0.58516}$	35	5	6	0.961
24	$\hat{q}_{10} = 12.8566\ A^{0.86854}\ R^{1.17343}\ DH^{-0.37794}$	56	5	18	0.882

Notes explaining the column headings:

(1) PS_{EE} is the standard error of estimate expressed as a percent of the zone $\overline{q}_{10}$. It is calculated by the equation:

$$PS_{EE} = \frac{100}{\overline{q}_{10}} \sqrt{\frac{\Sigma (q_{10} - \hat{q}_{10(K)})^2}{n-2}}$$

(2) PS_e is the standard error of the $\log_{10}$ linear equation expressed as a percent of $\log_{10}\overline{q}_{10}$. It is calculated by the equation:

$$PS_e = \frac{100}{\log_{10}\overline{q}_{10}} \sqrt{\frac{\Sigma(\log_{10} q_{10} - \log_{10} \hat{q}_{10(K)})^2}{n-2}}$$

(3) n is the number of watersheds used in deriving the equation.

(4) r is the simple correlation coefficient between q_{10} and $\hat{q}_{10}$. It is calculated by the equation:

$$r = \frac{\Sigma(x - \overline{x})(y - \overline{y})}{\sqrt{\Sigma (x - \overline{x})^2 (y - \overline{y})^2}}$$

where x and y are any two independent and dependent variables respectively.

Table H-2. The 5-Parameter regression equations for each of the 24 hydrophysiographic zones with their standard errors of estimate.

Zone	Correction Equation	(1) PS_{EE} %	(2) PS_e %	(3) n	(4) r
All Zone	$\hat{q}_{10} = 1.5102\ A^{0.4707}\ R^{0.8386}\ DH^{0.1718}\ L^{0.1764}\ P_{60}^{0.3476}$	116	13	898	0.856
1	$\hat{q}_{10} = 0.31006\ A^{-0.1672}\ R^{0.1278}\ DH^{0.6261}\ L^{1.1489}\ P_{60}^{3.3884}$	76	11	42	0.844
2	$\hat{q}_{10} = 22.5512\ A^{0.8067}\ R^{0.5364}\ DH^{0.2743}\ L^{-0.4967}\ P_{60}^{-0.7727}$	59	7	28	0.818
3	$\hat{q}_{10} = 13954\ A^{0.9374}\ R^{-0.5560}\ DH^{0.5672}\ L^{-0.7957}\ P_{60}^{-1.6664}$	110	10	14	0.930
4	$\hat{q}_{10} = 43.1724\ A^{0.6940}\ R^{0.1581}\ DH^{0.0566}\ L^{-0.1062}\ P_{60}^{1.1102}$	54	9	62	0.809
5	$\hat{q}_{10} = 1.6364\ A^{1.0387}\ R^{0.6437}\ DH^{0.1830}\ L^{-0.4034}\ P_{60}^{0.2926}$	51	8	35	0.931
6	$\hat{q}_{10} = 10^{-6.2116}\ A^{1.0853}\ R^{5.0977}\ DH^{0.7256}\ L^{-1.2867}\ P_{60}^{-12.5327}$	32	4	12	0.970
7	$\hat{q}_{10} = 324.432\ A^{0.9306}\ R^{-0.3690}\ DH^{0.1133}\ L^{-0.0603}\ P_{60}^{0.7463}$	76	7	33	0.919
8	$\hat{q}_{10} = 53.0874\ A^{0.2186}\ R^{0.1945}\ DH^{0.1319}\ L^{0.6958}\ P_{60}^{0.2223}$	47	6	39	0.964
9	$\hat{q}_{10} = 7.7165\ A^{0.5814}\ R^{0.0547}\ DH^{0.3865}\ L^{0.0990}\ P_{60}^{0.8217}$	87	8	37	0.865
10	$\hat{q}_{10} = 35.8044\ A^{1.6863}\ R^{0.4101}\ DH^{-0.6609}\ L^{-0.6123}\ P_{60}^{5.4323}$	68	13	10	0.905
11	$\hat{q}_{10} = 5518.33\ A^{0.8658}\ R^{-1.4337}\ DH^{0.7315}\ L^{-0.6144}\ P_{60}^{2.3248}$	42	6	32	0.921
12	$\hat{q}_{10} = 0.00404\ A^{-0.1357}\ R^{2.0116}\ DH^{0.2913}\ L^{1.0946}\ P_{60}^{-0.3881}$	115	20	34	0.749
13	$\hat{q}_{10} = 19.0892\ A^{0.7919}\ R^{0.5162}\ DH^{0.0065}\ L^{-0.2461}\ P_{60}^{0.9819}$	82	12	166	0.899
14	$\hat{q}_{10} = 10^{-3.0471}\ A^{0.9278}\ R^{1.9168}\ DH^{1.0534}\ L^{-1.1568}\ P_{60}^{-0.2637}$	134	17	30	0.789
15	$\hat{q}_{10} = 227.5250\ A^{1.0024}\ R^{-0.2697}\ DH^{-0.1705}\ L^{-0.0099}\ P_{60}^{-0.4591}$	91	14	37	0.800
16	$\hat{q}_{10} = 53.9760\ A^{0.2406}\ R^{0.7042}\ DH^{-0.3647}\ L^{0.9690}\ P_{60}^{1.4407}$	73	7	21	0.940
17	$\hat{q}_{10} = 18.0037\ A^{0.8562}\ R^{1.1895}\ DH^{-0.5077}\ L^{0.1432}\ P_{60}^{-1.9185}$	71	14	56	0.809
18	$\hat{q}_{10} = 713.6839\ A^{0.4249}\ R^{0.7032}\ DH^{-0.4949}\ L^{0.6922}\ P_{60}^{-2.8743}$	88	24	14	0.708
19	$\hat{q}_{10} = 0.7227\ A^{0.4635}\ R^{1.2180}\ DH^{0.2569}\ L^{-0.0658}\ P_{60}^{0.2060}$	82	13	40	0.833
20	$\hat{q}_{10} = 1.9367\ A^{0.9351}\ R^{0.8322}\ DH^{0.0042}\ L^{0.00042}\ P_{60}^{1.1826}$	104	9	42	0.936
21	$\hat{q}_{10} = 15.8713\ A^{0.7602}\ R^{0.3027}\ DH^{0.0516}\ L^{0.3632}\ P_{60}^{0.6480}$	68	7	68	0.931
22	$\hat{q}_{10} = 2.3789\ A^{0.5215}\ R^{0.7463}\ DH^{0.0614}\ L^{0.4754}\ P_{60}^{0.4184}$	34	4	22	0.979
23	Insufficient observations for deriving a 5-parameter equation	–	–	6	–
24	$\hat{q}_{10} = 1.4209\ A^{0.6925}\ R^{2.0837}\ DH^{-0.6376}\ L^{0.5060}\ P_{60}^{-1.7726}$	42	4	18	0.917

Notes explaining the column headings:

(1) PS_{EE} is the standard error of estimate expressed as a percent of the zone $\overline{q}_{10}$. It is calculated by the equation:

$$PS_{EE} = \frac{100}{\overline{q}_{10}} \sqrt{\frac{\Sigma (q_{10} - \hat{q}_{10(K)})^2}{n-2}}$$

(2) PS_e is the standard error of the $\log_{10}$ linear equation expressed as a percent of $\log_{10} \overline{q}_{10}$. It is calculated by the equation:

$$PS_e = \frac{100}{\log_{10} \overline{q}_{10}} \sqrt{\frac{\Sigma (\log_{10} q_{10} - \log_{10} \hat{q}_{10(K)})^2}{n-2}}$$

(3) n is the number of watersheds used in deriving the equation.

(4) r is the simple correlation coefficient between q_{10} and $\hat{q}_{10}$. It is calculated by the equation:

$$r = \frac{\Sigma (x - \overline{x})(y - \overline{y})}{\sqrt{\Sigma (x - \overline{x})^2 (y - \overline{y})^2}}$$

where x and y are any two independent and dependent variables respectively.

Table H-3. The 7-Parameter regression equations for each of the 24 hydrophysiographic zones with their standard errors of estimate.

Zone	Correction Equation	(1) PS_{EE} %	(2) PS_e %	(3) n	(4) r
All Zone	$\hat{q}_{10} = 1.8816\ A^{0.3977}\ R^{0.8323}\ DH^{0.1461} L^{-0.0236}\ LL^{0.2613} P_{10}^{-0.1891}\ P_{60}^{0.4666}$	116	12	898	0.860
1	$\hat{q}_{10} = 10^{-9.9593} A^{-0.2759}\ R^{0.7417}\ DH^{0.5174} L^{0.2372}\ LL^{0.7087} P_{10}^{17.7125}\ P_{60}^{-16.1845}$	67	11	42	0.876
2	$\hat{q}_{10} = 10^{-7.1187} A^{0.8277}\ R^{0.3514}\ DH^{0.2154} L^{-0.9658}\ LL^{0.3287} P_{10}^{17.2401}\ P_{60}^{-17.2234}$	59	7	28	0.831
3	$\hat{q}_{10} = 10^{-16.2047} A^{0.9416}\ R^{0.1385}\ DH^{0.3787} L^{-0.5201}\ LL^{-0.1639} P_{10}^{34.1291}\ P_{60}^{-31.9517}$	97	11	14	0.934
4	$\hat{q}_{10} = 21.8893\ A^{0.6964}\ R^{0.1096}\ DH^{0.0598} L^{-0.1066}\ LL^{-0.0016} P_{10}^{0.5004}\ P_{60}^{1.0049}$	53	9	62	0.809
5	$\hat{q}_{10} = 2.9109\ A^{1.0119}\ R^{-0.3553}\ DH^{0.2164} L^{-0.1787}\ LL^{-0.1948} P_{10}^{2.5203}\ P_{60}^{-0.0776}$	45	8	35	0.942
6	$\hat{q}_{10} = 10^{-5.1795} A^{1.1351}\ R^{5.4283}\ DH^{0.7420} L^{-1.3539}\ LL^{-0.0742} P_{10}^{-2.6780}\ P_{60}^{-10.9168}$	33	5	12	0.971
7	$\hat{q}_{10} = 10^{6.6029}\ A^{0.7048}\ R^{-0.2011}\ DH^{0.1907} L^{-0.0621}\ LL^{0.1642}\ P_{10}^{-9.2707}\ P_{60}^{10.1924}$	79	7	33	0.929
8	$\hat{q}_{10} = 24.1002\ A^{0.0918}\ R^{-0.2570}\ DH^{0.0988} L^{0.5322}\ LL^{0.3114}\ P_{10}^{1.5265}\ P_{60}^{0.3177}$	44	6	39	0.968
9	$\hat{q}_{10} = 50.8080\ A^{0.3799}\ R^{-0.1432}\ DH^{0.3401} L^{0.0917}\ LL^{0.2879}\ P_{10}^{-0.9655}\ P_{60}^{1.8748}$	83	8	37	0.879
10	$\hat{q}_{10} = 10^{-5.0890} A^{0.9409}\ R^{4.1273}\ DH^{1.0784} L^{-0.4183}\ LL^{0.8884}\ P_{10}^{0.7275}\ P_{60}^{4.2278}$	47	17	10	0.914
11	$\hat{q}_{10} = 5.97844\ A^{0.8616}\ R^{-1.3797}\ DH^{0.6271} L^{-0.7835}\ LL^{0.1630}\ P_{10}^{5.9753}\ P_{60}^{-3.6368}$	39	6	32	0.923
12	$\hat{q}_{10} = 807.3722\ A^{0.5358}\ R^{1.3781}\ DH^{0.3457} L^{0.7867}\ LL^{0.9198}\ P_{10}^{-6.7780}\ P_{60}^{9.3897}$	89	19	34	0.793
13	$\hat{q}_{10} = 6.4357\ A^{0.7761}\ R^{0.4431}\ DH^{0.0095} L^{-0.4107}\ LL^{0.1424}\ P_{10}^{1.1422}\ P_{60}^{-0.1526}$	85	12	166	0.901
14	$\hat{q}_{10} = 10^{-6.3139} A^{1.1471}\ R^{2.3576}\ DH^{1.2258} L^{-0.9411}\ LL^{-0.5105} P_{10}^{4.8292}\ P_{60}^{-5.6504}$	133	18	30	0.796
15	$\hat{q}_{10} = 55.3750\ A^{0.8433}\ R^{-0.2586}\ DH^{-0.1705} L^{-0.1117}\ LL^{0.2228} P_{10}^{1.1934}\ P_{60}^{-1.6825}$	97	14	37	0.808
16	$\hat{q}_{10} = 57.4029\ A^{0.3052}\ R^{0.7823}\ DH^{-0.3973} L^{1.0963}\ LL^{-0.1118} P_{10}^{0.0259}\ P_{60}^{1.4146}$	72	7	21	0.941
17	$\hat{q}_{10} = 157.4954\ A^{0.5615}\ R^{1.2801}\ DH^{-0.6249} L^{-0.0429}\ LL^{0.4032}\ P_{10}^{-1.5484}\ P_{60}^{-0.5034}$	76	14	56	0.825
18	$\hat{q}_{10} = 10^{16.0040} A^{-0.1026}\ R^{1.0758}\ DH^{0.3202} L^{1.3339}\ LL^{-0.0842} P_{10}^{-35.7861}\ P_{60}^{16.6781}$	117	20	14	0.857
19	$\hat{q}_{10} = 48.8575\ A^{0.4962}\ R^{1.2266}\ DH^{0.2391} L^{0.0945}\ LL^{-0.0867} P_{10}^{-3.7389}\ P_{60}^{3.2559}$	82	13	40	0.838
20	$\hat{q}_{10} = 7.8890\ A^{0.8790}\ R^{0.8465}\ DH^{-0.0200} L^{-0.1091}\ LL^{0.1515}\ P_{10}^{-1.1600}\ P_{60}^{1.9546}$	106	10	42	0.937
21	$\hat{q}_{10} = 26.7400\ A^{0.7867}\ R^{0.3960}\ DH^{0.0539} L^{0.3939}\ LL^{-0.0486} P_{10}^{-0.4260}\ P_{60}^{0.9483}$	69	8	68	0.931
22	$\hat{q}_{10} = 0.00184\ A^{0.1791}\ R^{0.7746}\ DH^{0.0885} L^{0.4975}\ LL^{0.2660}\ P_{10}^{6.0977}\ P_{60}^{-4.2623}$	30	4	22	0.986
23	Insufficient observations for deriving a 7-parameter equation	-	-	6	-
24	$\hat{q}_{10} = 101.2426\ A^{0.6478}\ R^{1.7080}\ DH^{-0.7366} L^{0.5271}\ LL^{0.1474}\ P_{10}^{-1.6416}\ P_{60}^{0.0956}$	34	4	18	0.924

Notes explaining the column headings:

(1) PS_{EE} is the standard error of estimate expressed as a percent of the zone $\overline{q}_{10}$. It is calculated by the equation:

$$PS_{EE} = \frac{100}{\overline{q}_{10}} \sqrt{\frac{\Sigma\,(q_{10} - \hat{q}_{10(K)})^2}{n-2}}$$

(2) PS_e is the standard error of the $\log_{10}$ linear equation expressed as a percent of $\log_{10} \overline{q}_{10}$. It is calculated by the equation:

$$PS_e = \frac{100}{\log_{10} \overline{q}_{10}} \sqrt{\frac{\Sigma(\log_{10} q_{10} - \log_{10} \hat{q}_{10(K)})^2}{n-2}}$$

(3) n is the number of watersheds used in deriving the equation.

(4) r is the simple correlation coefficient between q_{10} and $\hat{q}_{10}$. It is calculated by the equation:

$$r = \frac{\Sigma(x - \overline{x})(y - \overline{y})}{\sqrt{\Sigma(x - \overline{x})^2\,(y - \overline{y})^2}}$$

where x and y are any two independent and dependent variables respectively.

Table H-4. Correction equations for the 3-Parameter all zone equation for each of the 24 hydrophysiographic zones of the United States and Puerto Rico.

Zone	Correction Equation	(1) $\bar{q}_{10}$ cfs	(2) PS_{EE} %	(3) PS_e %	(4) n	(5) r
01	$\hat{q}_{10(K)} = 0.16166\ \hat{q}_{10(3AZ)}^{1.21261}$	1058	92	16	42	0.595
02	$\hat{q}_{10(K)} = 2.10583\ \hat{q}_{10(3AZ)}^{0.89446}$	4747	67	8	28	0.754
03	$\hat{q}_{10(K)} = 3.01000\ \hat{q}_{10(3AZ)}^{0.86834}$	2295	105	9	14	0.912
04	$\hat{q}_{10(K)} = 0.94719\ \hat{q}_{10(3AZ)}^{0.99893}$	1979	60	9	62	0.770
05	$\hat{q}_{10(K)} = 0.02681\ \hat{q}_{10(3AZ)}^{1.40804}$	1472	75	8	35	0.912
06	$\hat{q}_{10(K)} = 1.16675\ \hat{q}_{10(3AZ)}^{0.92518}$	2014	92	10	12	0.622
07	$\hat{q}_{10(K)} = 0.10677\ \hat{q}_{10(3AZ)}^{1.38890}$	2306	88	7	33	0.893
08	$\hat{q}_{10(K)} = 0.74039\ \hat{q}_{10(3AZ)}^{1.06262}$	2079	62	7	39	0.944
09	$\hat{q}_{10(K)} = 0.17280\ \hat{q}_{10(3AZ)}^{1.26937}$	1170	88	9	37	0.800
10	$\hat{q}_{10(K)} = 0.01207\ \hat{q}_{10(3AZ)}^{1.59770}$	1986	83	14	10	0.745
11	$\hat{q}_{10(K)} = 0.24744\ \hat{q}_{10(3AZ)}^{1.25355}$	4320	61	9	32	0.764
12	$\hat{q}_{10(K)} = 0.64332\ \hat{q}_{10(3AZ)}^{1.05533}$	461	107	23	34	0.587
13	$\hat{q}_{10(K)} = 0.98668\ \hat{q}_{10(3AZ)}^{1.10579}$	2260	91	13	166	0.887
14	$\hat{q}_{10(K)} = 0.34563\ \hat{q}_{10(3AZ)}^{1.25915}$	1304	121	18	30	0.704
15	$\hat{q}_{10(K)} = 0.98994\ \hat{q}_{10(3AZ)}^{0.94859}$	356	101	21	37	0.375
16	$\hat{q}_{10(K)} = 0.60069\ \hat{q}_{10(3AZ)}^{1.13470}$	624	73	8	21	0.893
17	$\hat{q}_{10(K)} = 0.57246\ \hat{q}_{10(3AZ)}^{1.04500}$	368	98	18	56	0.622
18	$\hat{q}_{10(K)} = 23.5251\ \hat{q}_{10(3AZ)}^{0.64862}$	1311	124	23	14	0.520
19	$\hat{q}_{10(K)} = 2.44605\ \hat{q}_{10(3AZ)}^{1.02879}$	1586	84	13	40	0.807
20	$\hat{q}_{10(K)} = 0.17546\ \hat{q}_{10(3AZ)}^{1.31670}$	759	131	12	42	0.883
21	$\hat{q}_{10(K)} = 0.16894\ \hat{q}_{10(3AZ)}^{1.32661}$	1625	138	11	68	0.836
22	$\hat{q}_{10(K)} = 0.15938\ \hat{q}_{10(3AZ)}^{1.30941}$	1013	38	5	22	0.966
23	$\hat{q}_{10(K)} = 0.30461\ \hat{q}_{10(3AZ)}^{1.190085}$	2519	40	6	6	0.886
24	$\hat{q}_{10(K)} = 0.87269\ \hat{q}_{10(3AZ)}^{1.06360}$	12277	72	6	18	0.772

Notes explaining the column headings:

(1) $\bar{q}_{10}$ is the mean ten year peak flow calculated from the observed ten year peak flows for each zone.

(2) PS_{EE} is the standard error of estimate expressed as a percent of the zone $\bar{q}_{10}$. It is calculated by the equation:

$$PS_{EE} = \frac{100}{\bar{q}_{10}} \sqrt{\frac{\Sigma (q_{10} - \hat{q}_{10(K)})^2}{n-2}}$$

(3) PS_e is the standard error of the $\log_{10}$ linear equation expressed as a percent of $\log_{10} \bar{q}_{10}$. It is calculated by the equation:

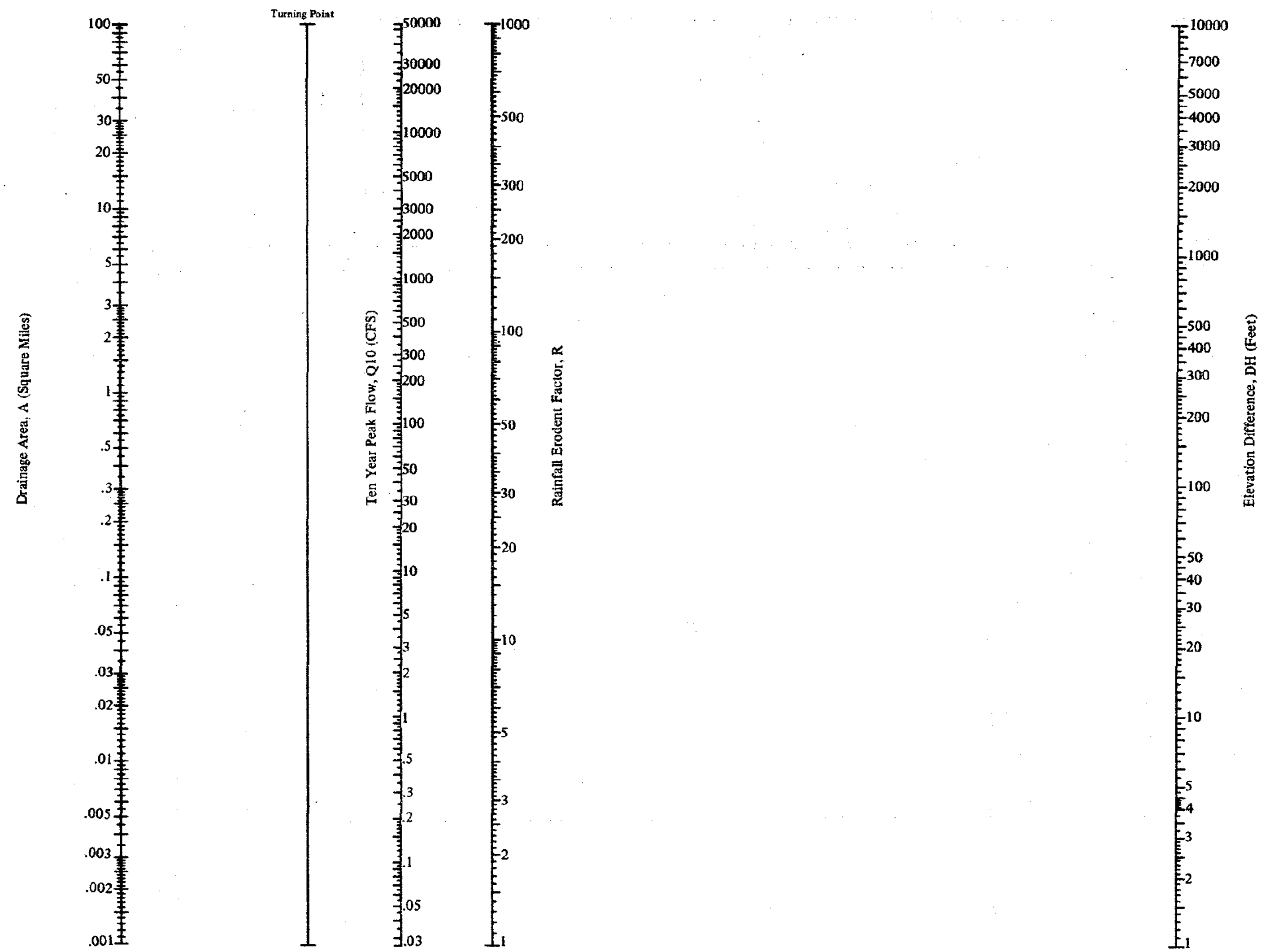
$$PS_e = \frac{100}{\log_{10} \bar{q}_{10}} \sqrt{\frac{\Sigma (\log_{10} q_{10} - \log_{10} \hat{q}_{10(K)})^2}{n-2}}$$

(4) n is the number of watersheds used in deriving the equation.

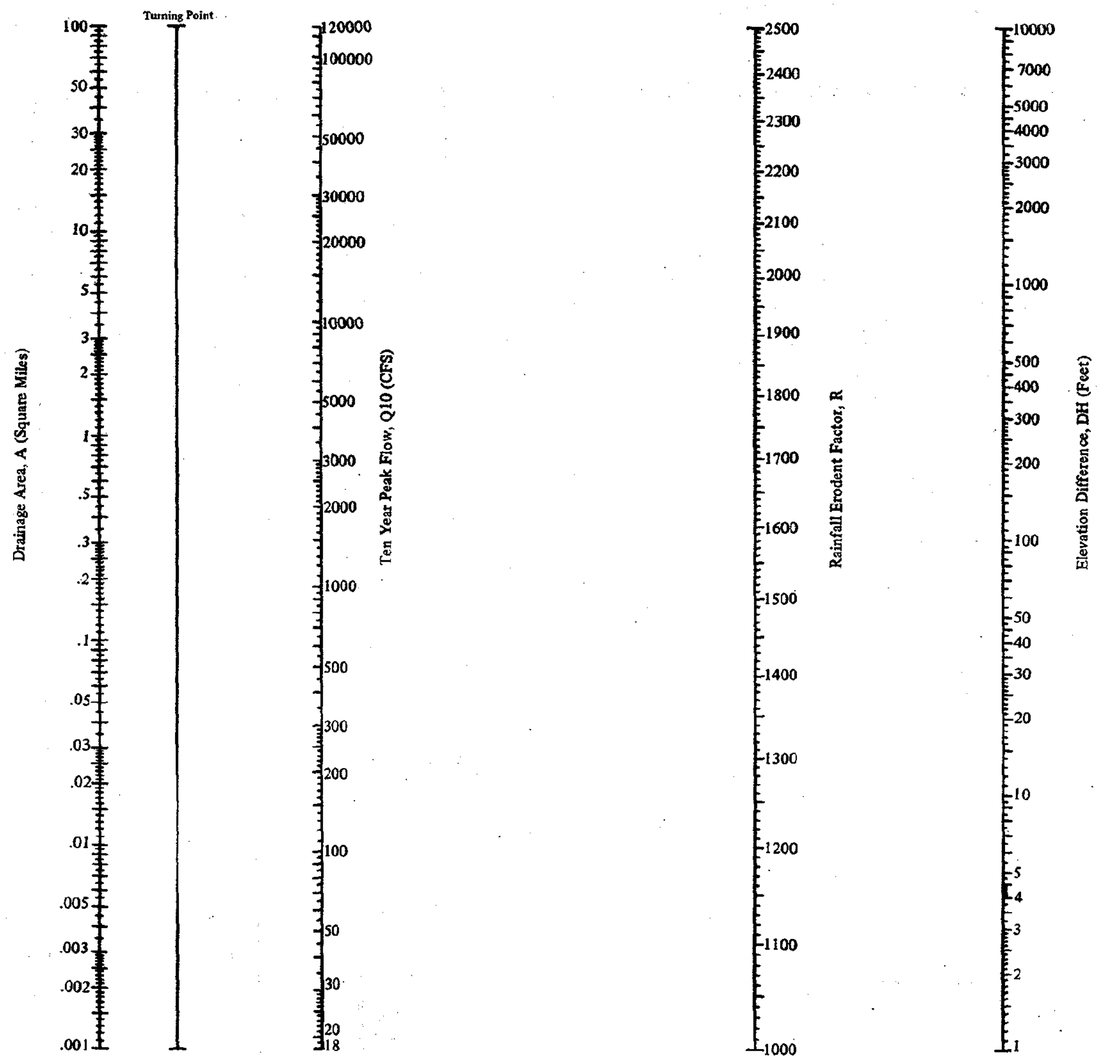
(5) r is the simple correlation coefficient between q_{10} and $\hat{q}_{10}$. It is calculated by the equation:

$$r = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\sqrt{\Sigma(x-\bar{x})^2 (y-\bar{y})^2}}$$

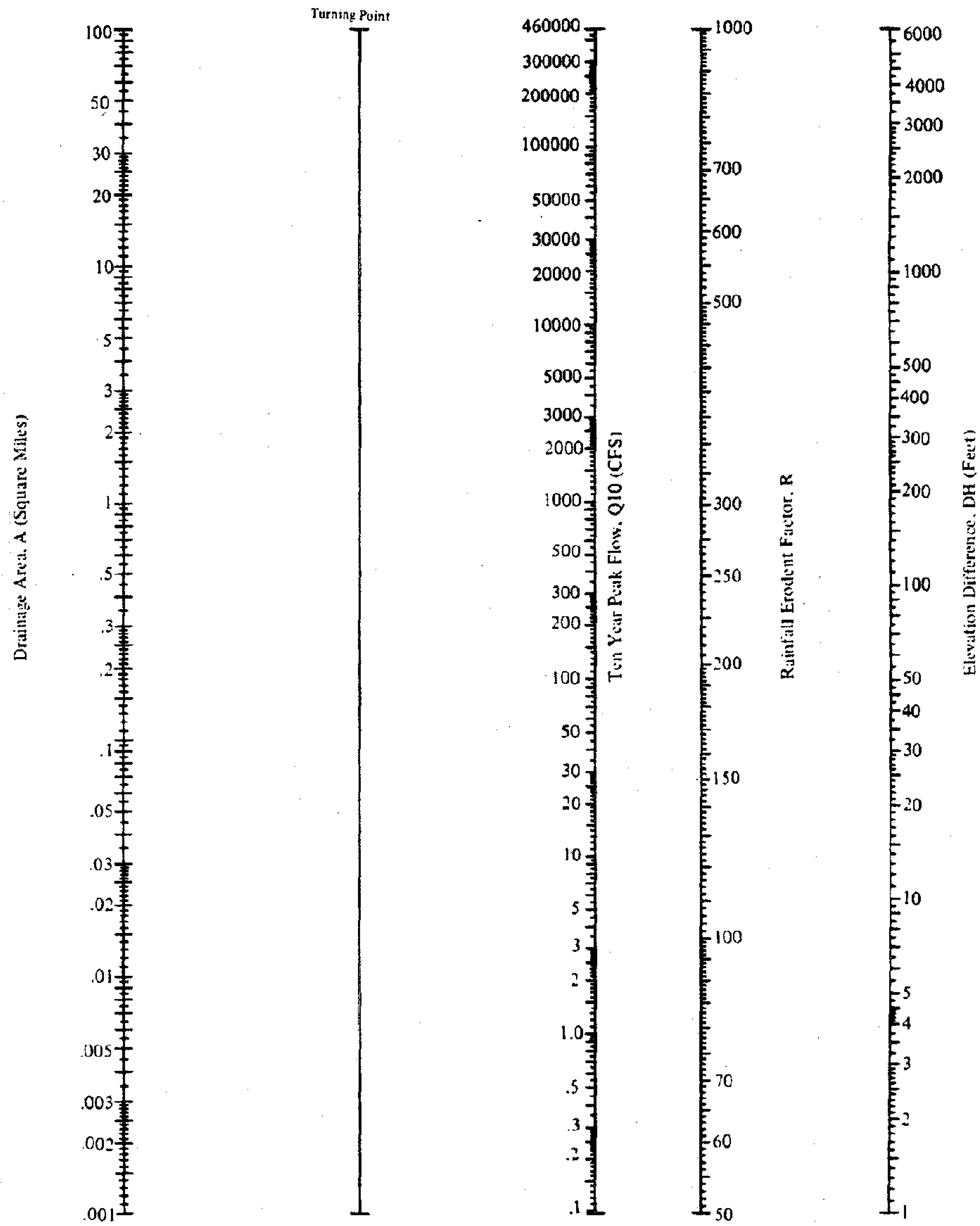
where x and y are any two independent and dependent variables respectively.



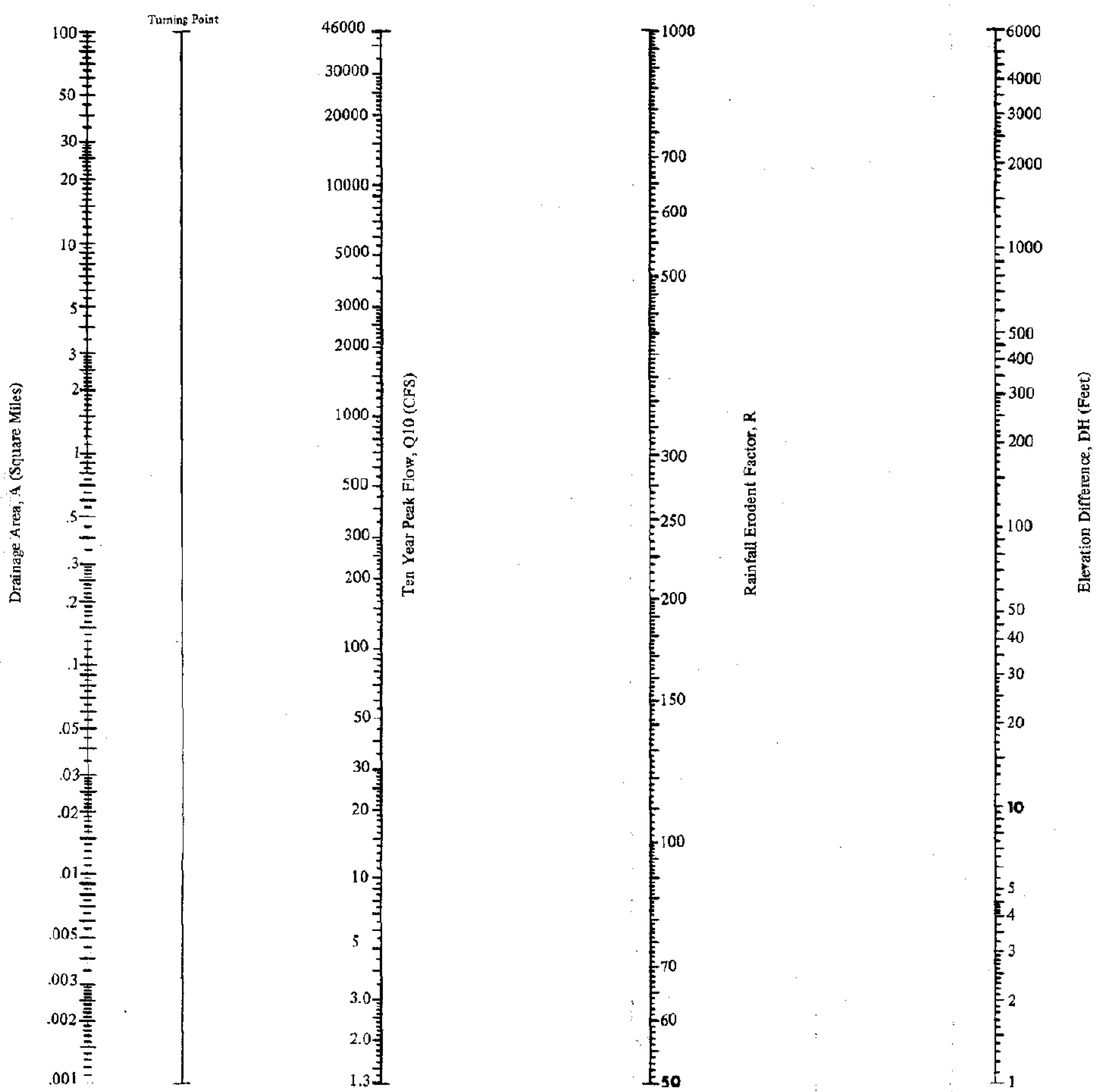
Appendix H-00. Three parameter all zone nomograph R=1-1000. $\hat{q}_{10} = 1.28015\, A^{0.56172}\, R^{0.94356}\, DH^{0.16887}$



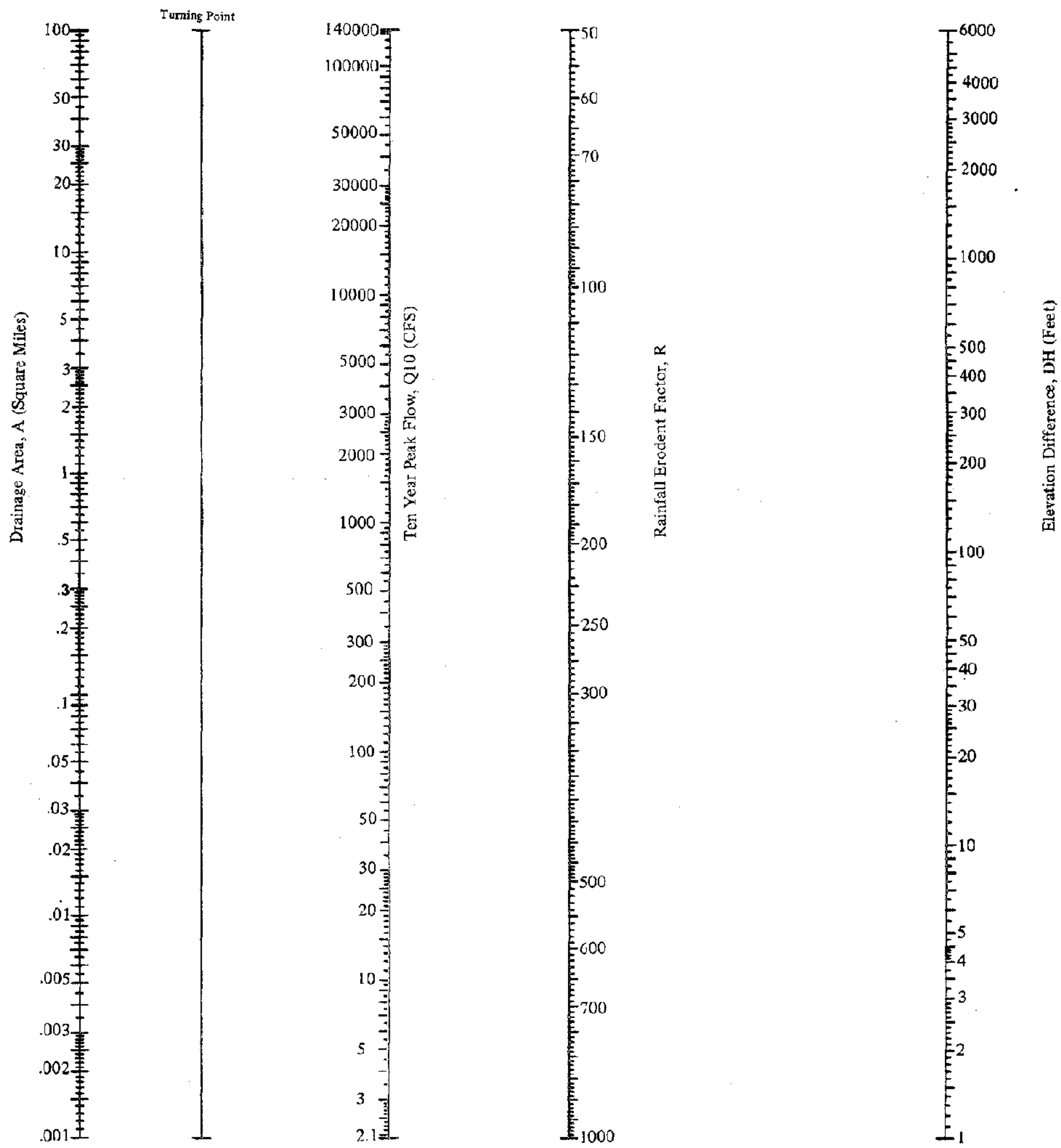
Appendix H-00. Three parameter all zone nomograph R=1000-2500.



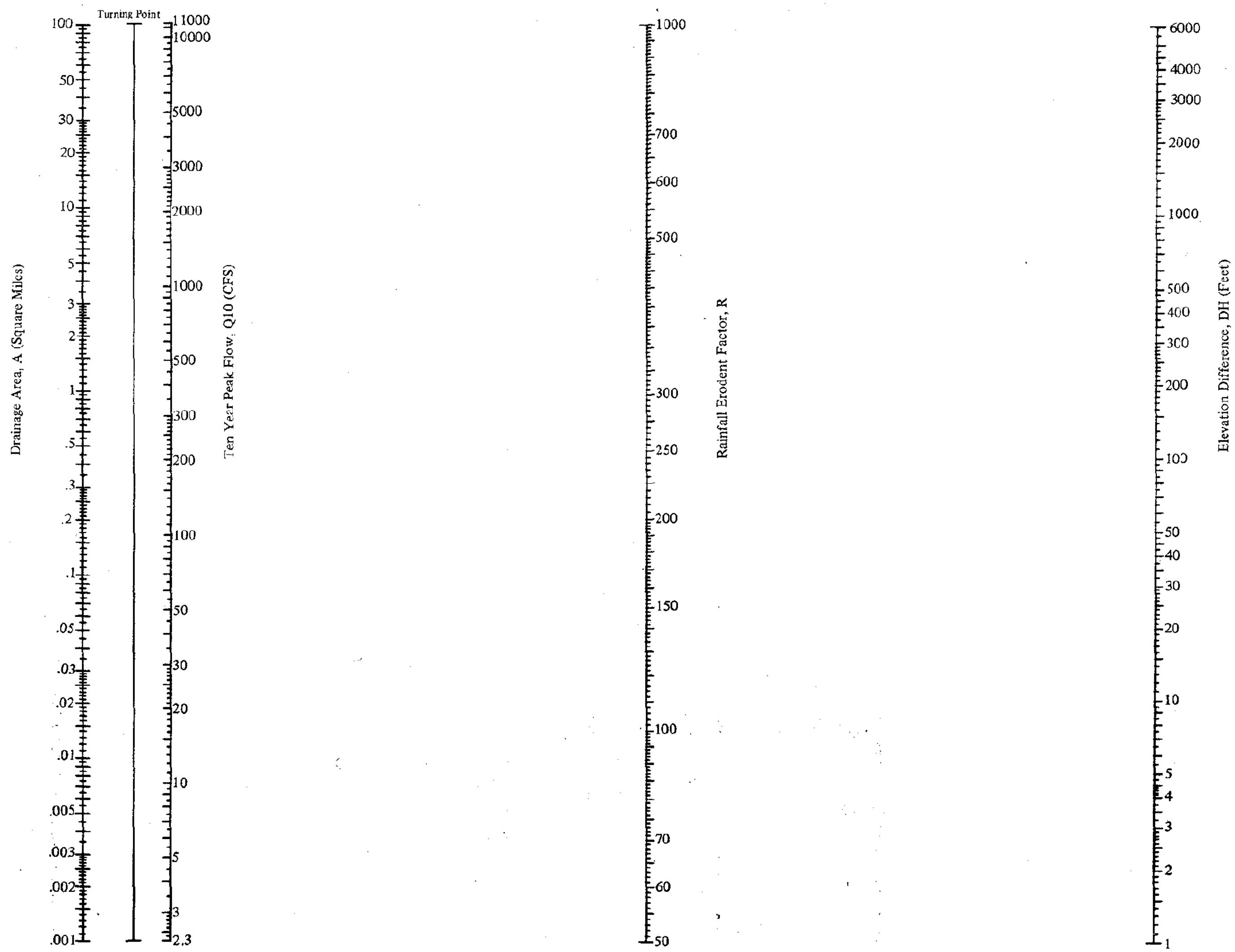
Appendix H-01. Three parameter zone 1 nomograph. $\hat{q}_{10} = 0.02137 A^{0.43975} R^{1.16383} DH^{0.78453}$



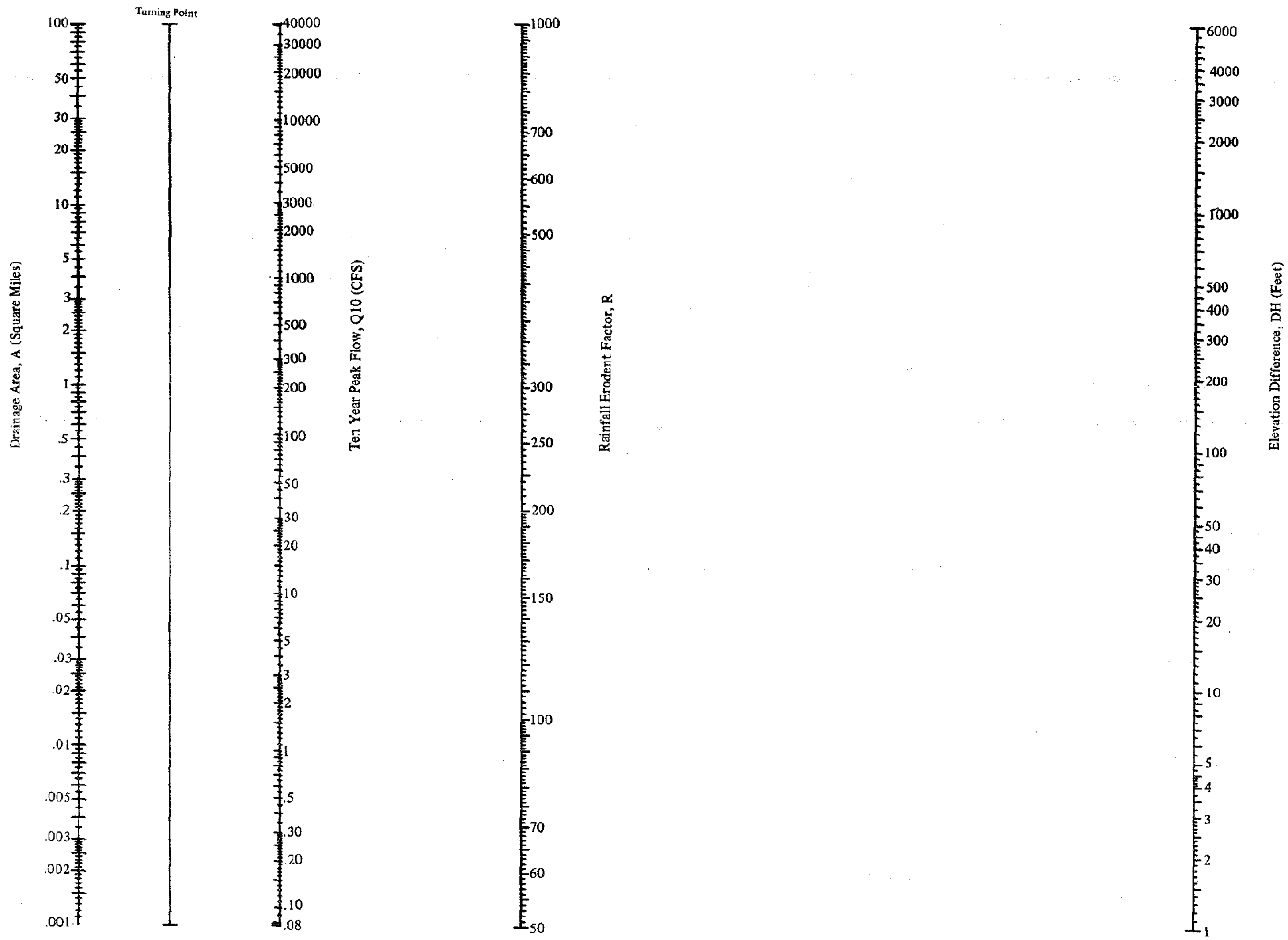
Appendix H-02. Three parameter zone 2 nomograph. $\hat{q}_{10} = 11.8893\, A^{0.57269}\, R^{0.44271}\, DH^{0.29510}$



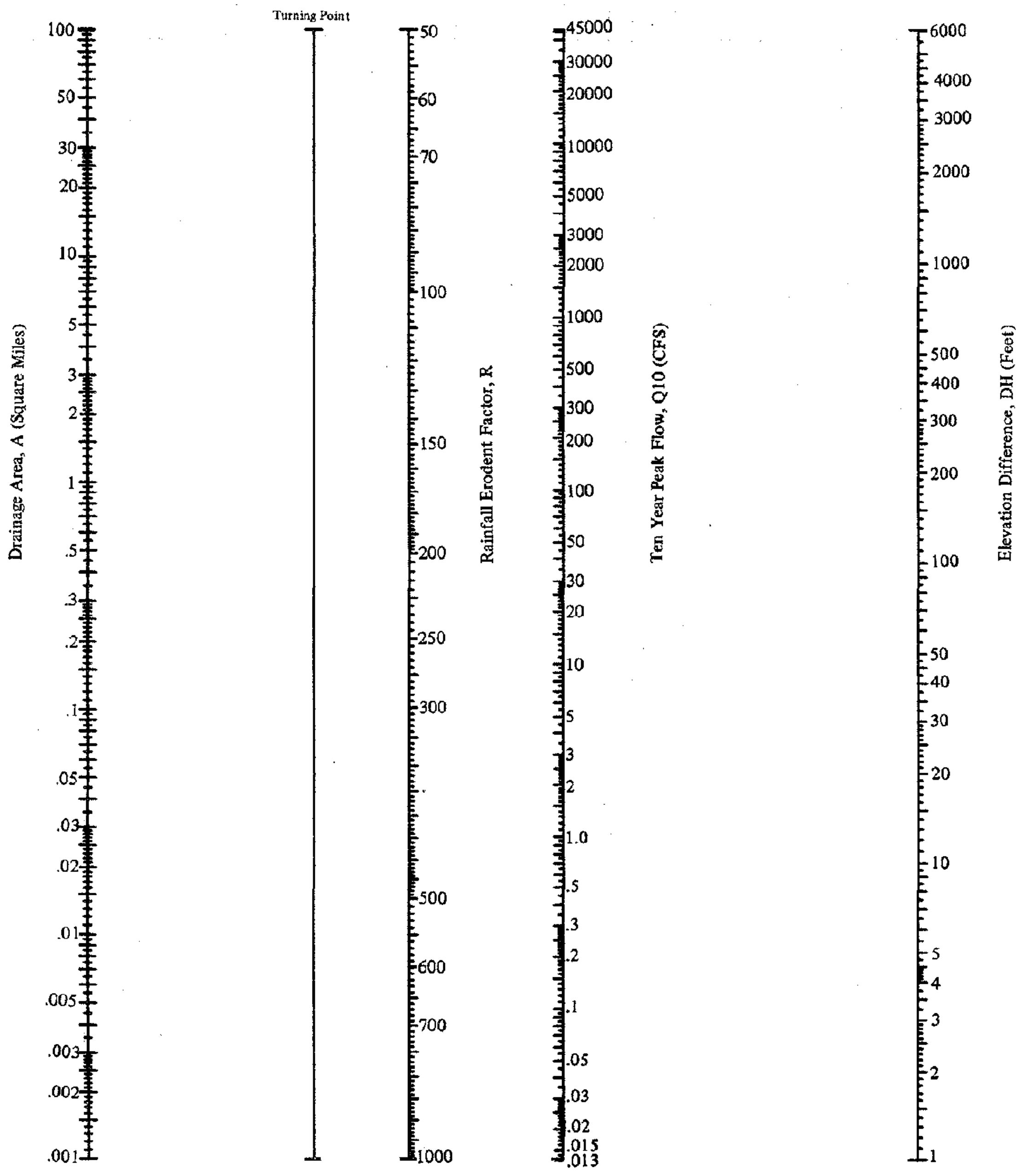
Appendix H-03. Three parameter zone 3 nomograph. $\hat{q}_{10} = 10410.4\, A^{0.54499}\, R^{-0.69141}\, DH^{0.32389}$



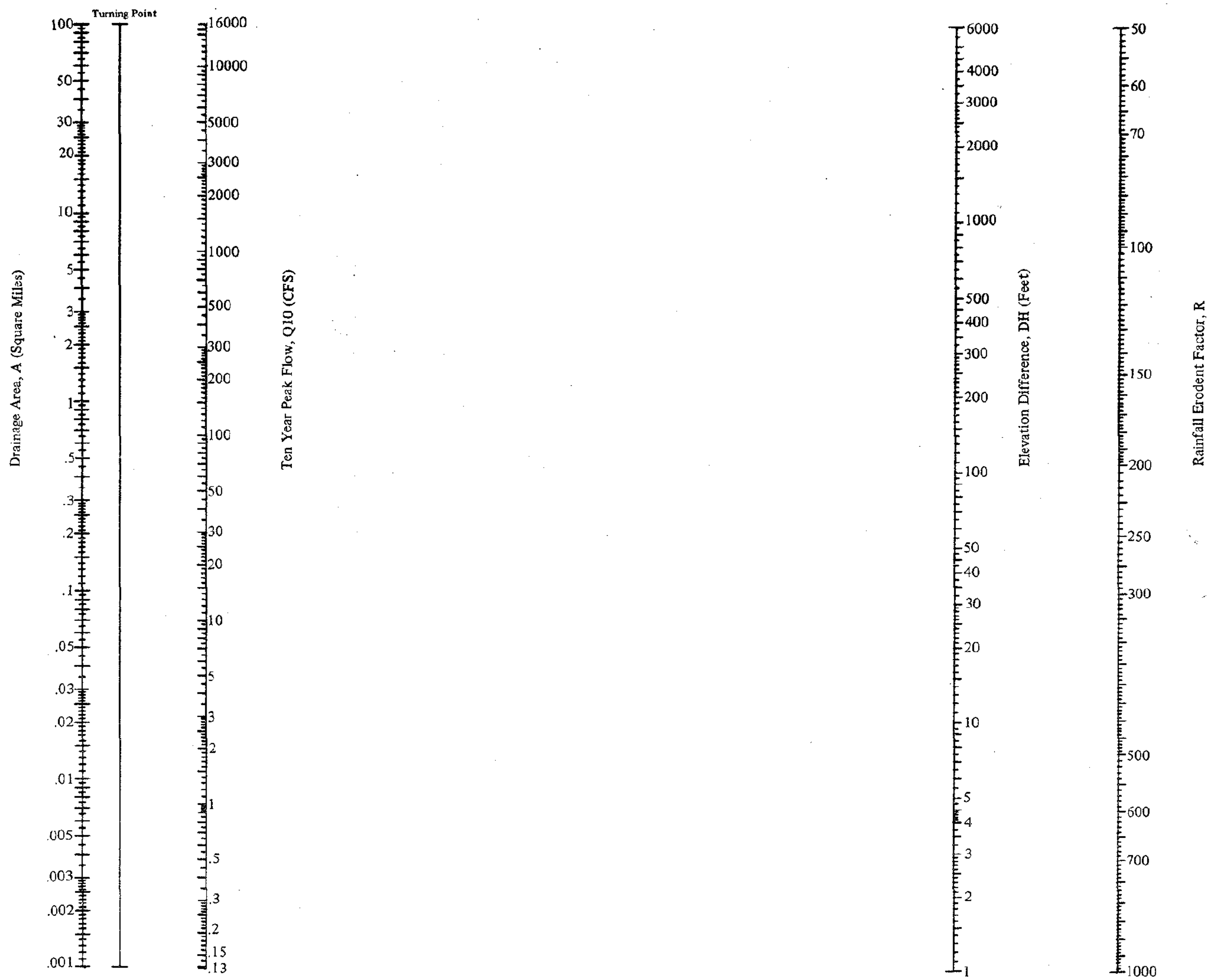
Appendix H-04. Three parameter zone 4 nomograph. $\hat{q}_{10} = 76.7226\, A^{0.64795}\, R^{0.24744}\, DH^{0.03546}$



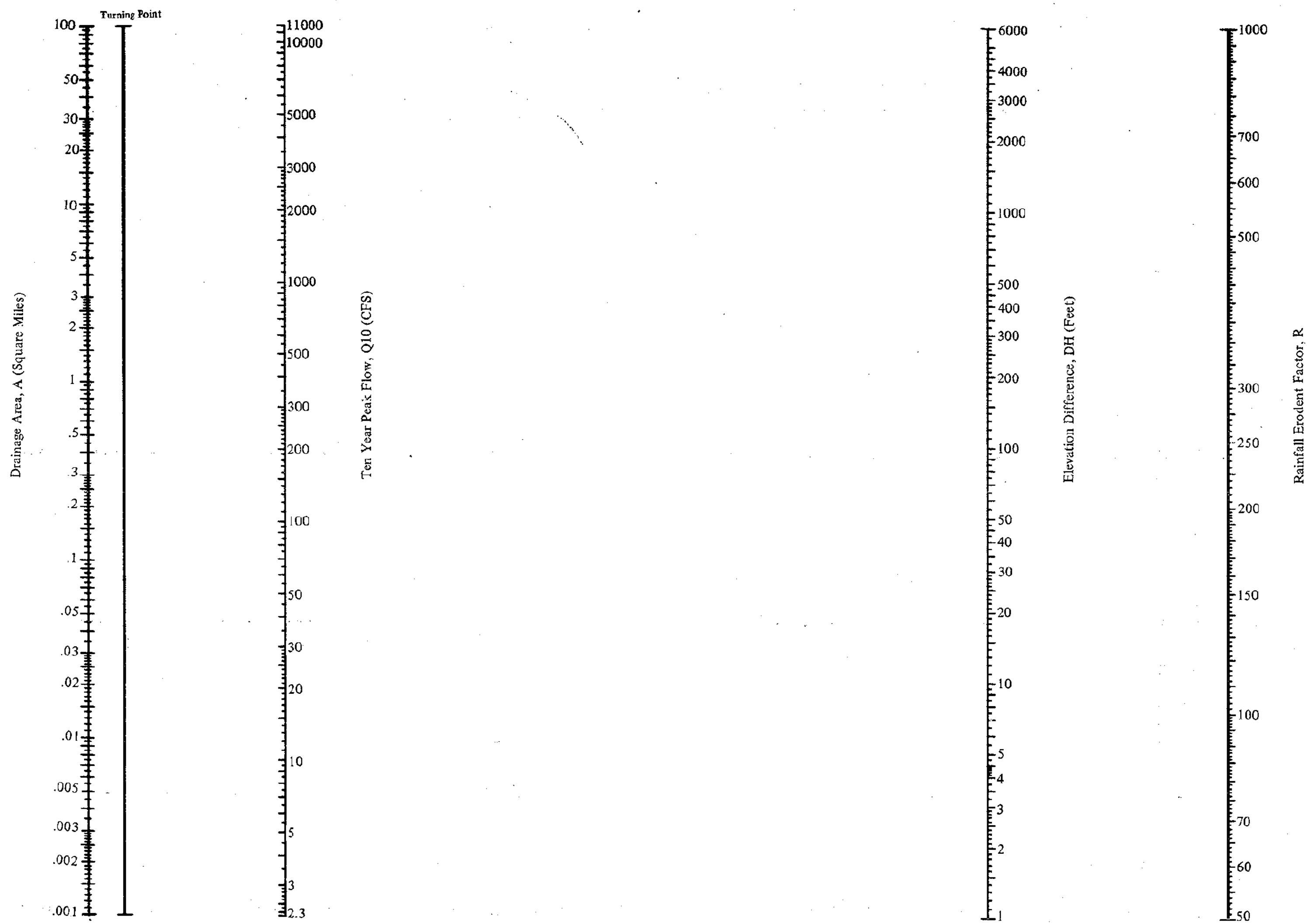
Appendix H-05. Three variable zone 5 nomograph. $\hat{q}_{10} = 1.14069\, A^{0.81060}\, R^{0.81127}\, DH^{0.16225}$



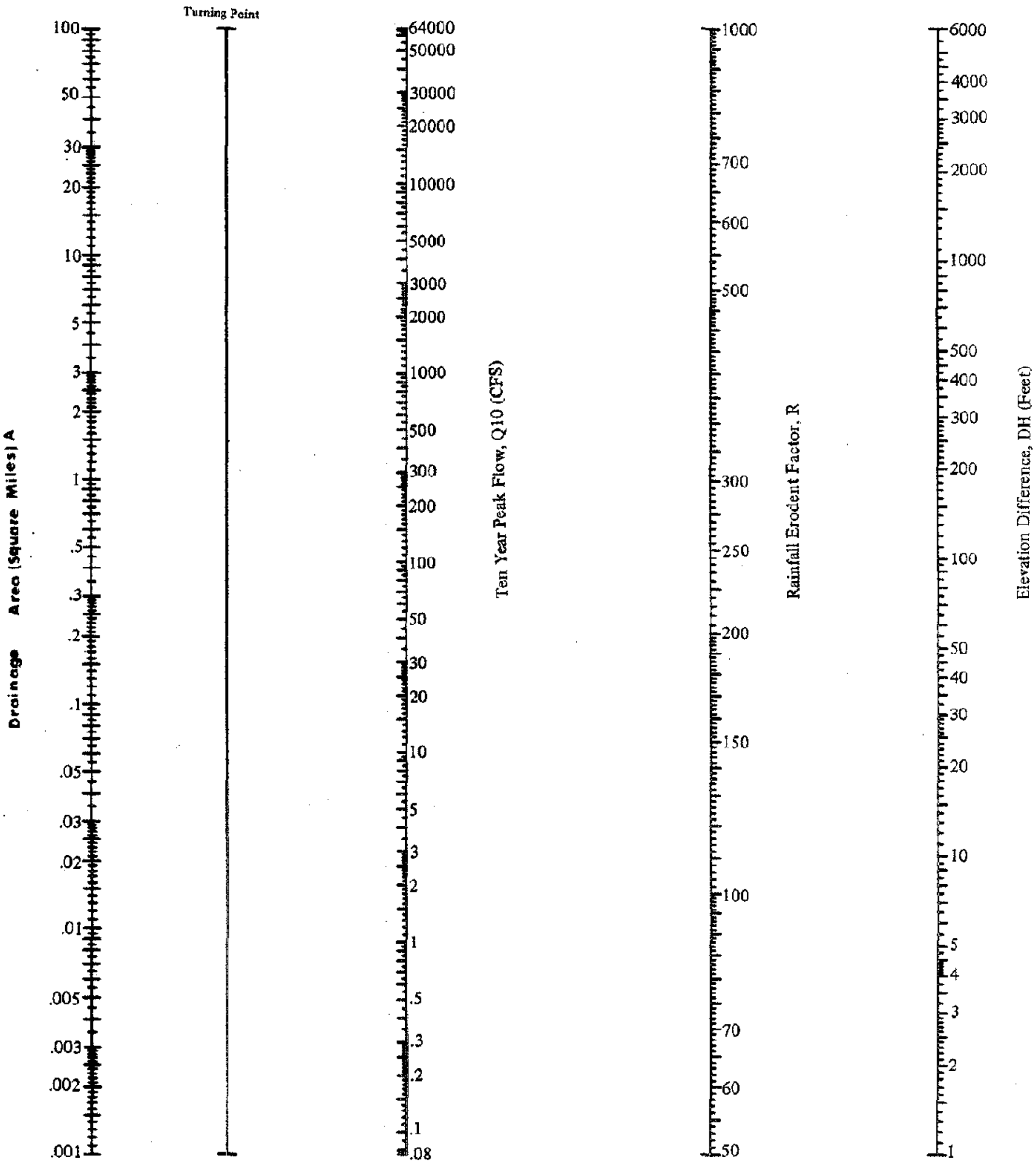
Appendix H-06. Three parameter zone 6 nomograph. $\hat{q}_{10} = 10^{5.03658} A^{0.22735} R^{-2.07865} DH^{0.71475}$



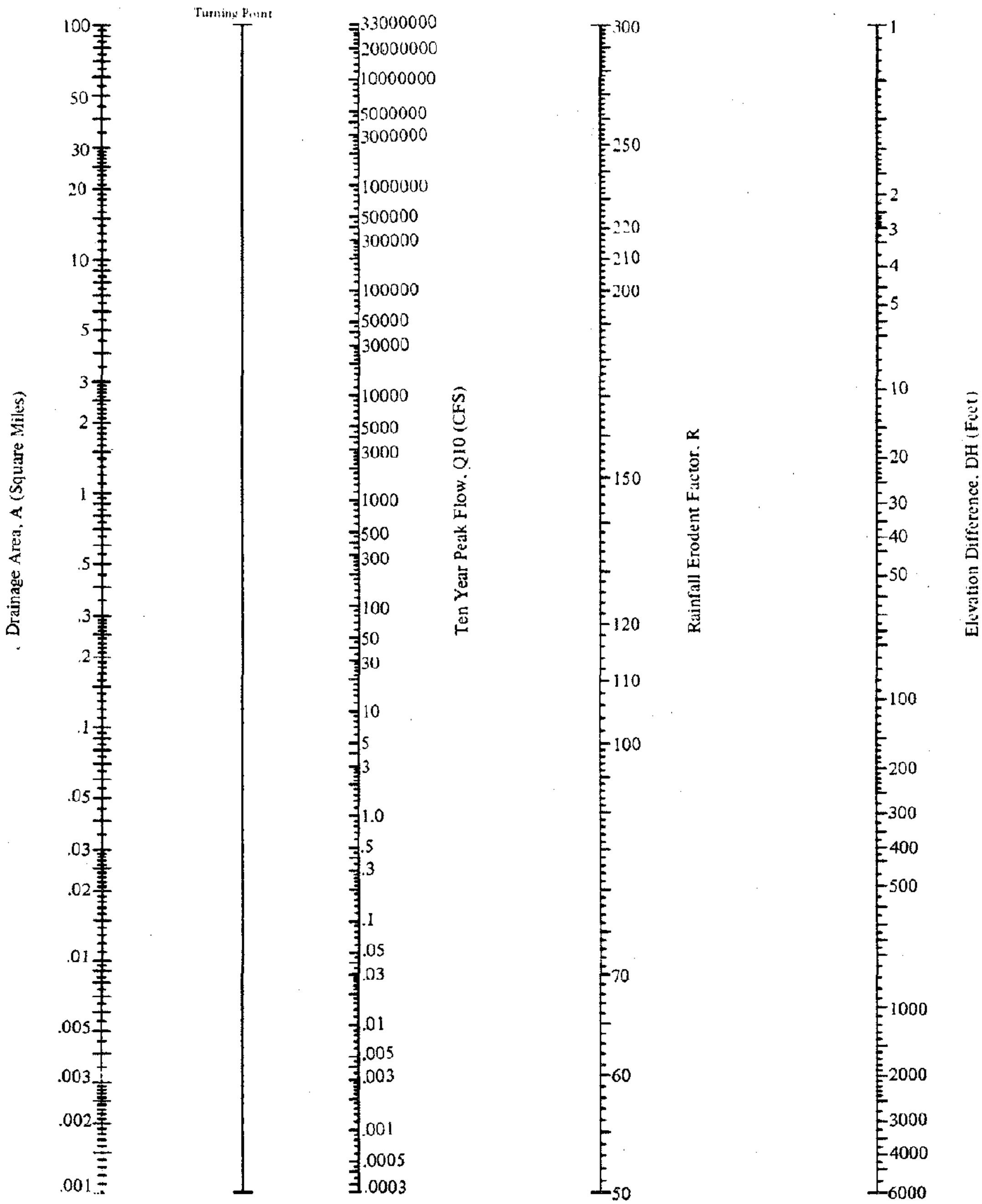
Appendix H-07. Three parameter zone 7 nomograph. $\hat{Q}_{10} = 141.135\, A^{0.88572}\, R^{-0.13043}\, DH^{0.13981}$



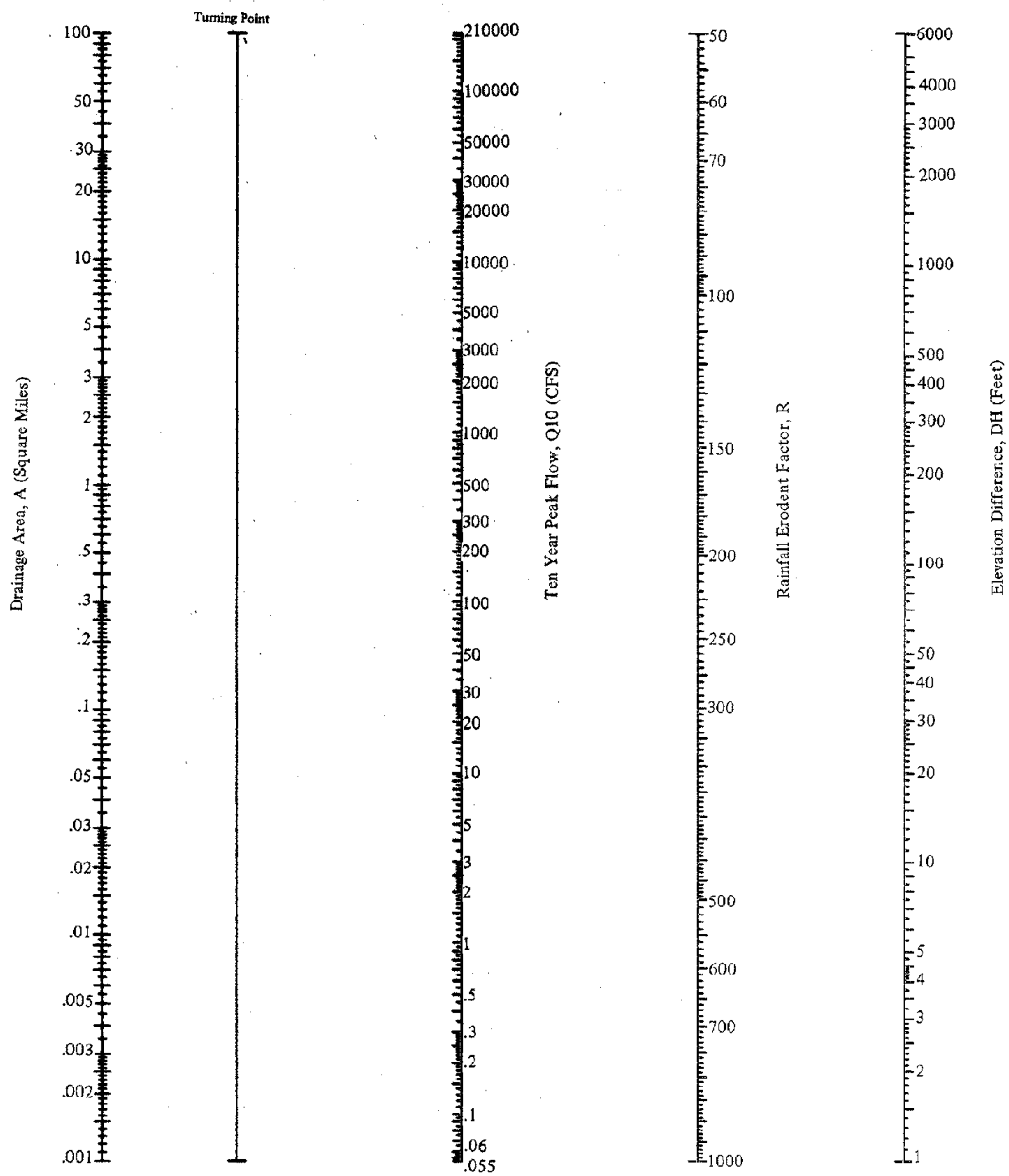
Appendix H-08. Three parameter zone 8 nomograph. $\hat{q}_{10} = 95.0775\, A^{0.58571}\, R^{0.07355}\, DH^{0.18493}$



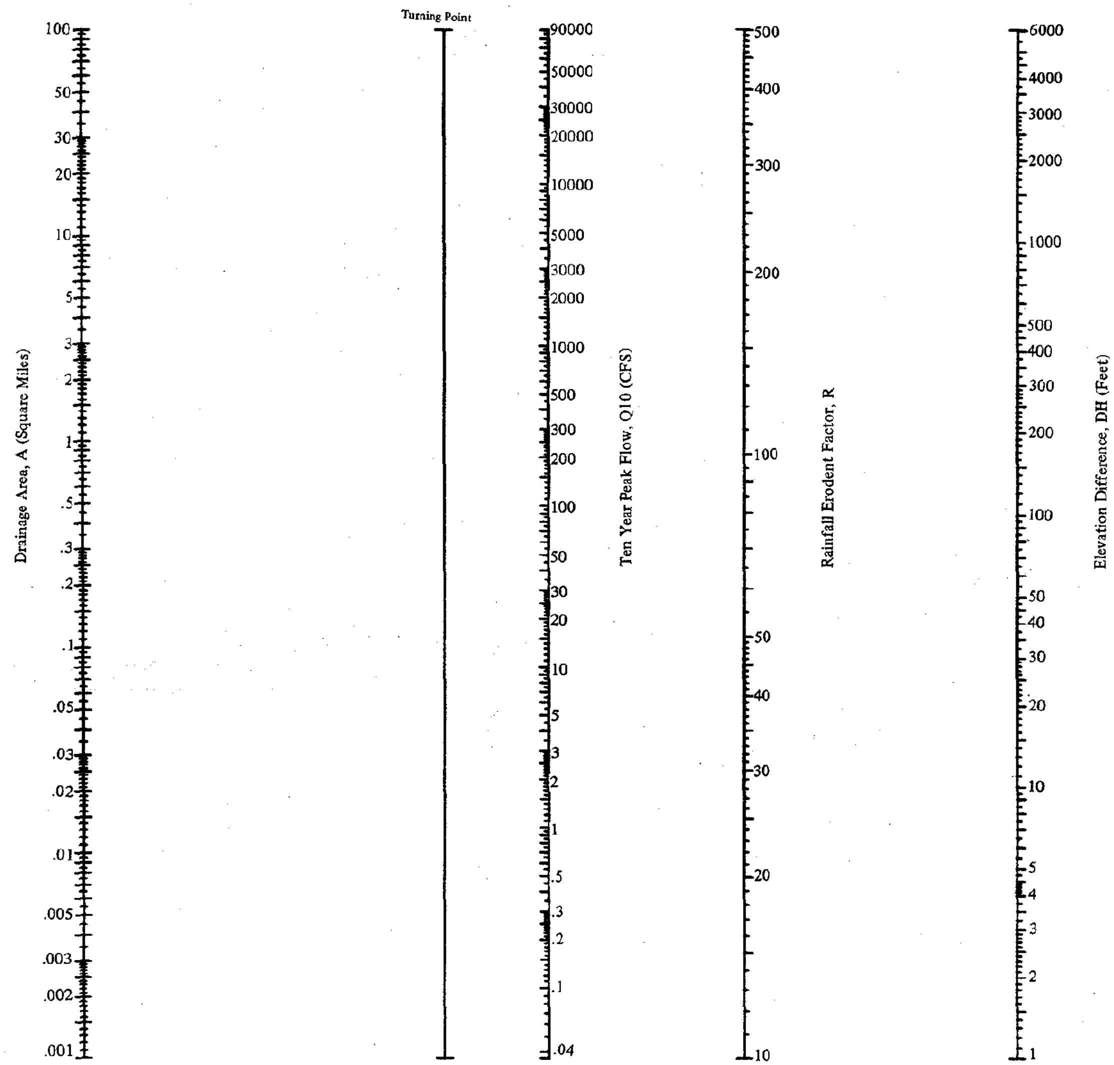
Appendix H-09. Three parameter zone 9 nomograph. $\hat{q}_{10} = 0.50051\, A^{0.69229}\, R^{0.74156}\, DH^{0.39729}$



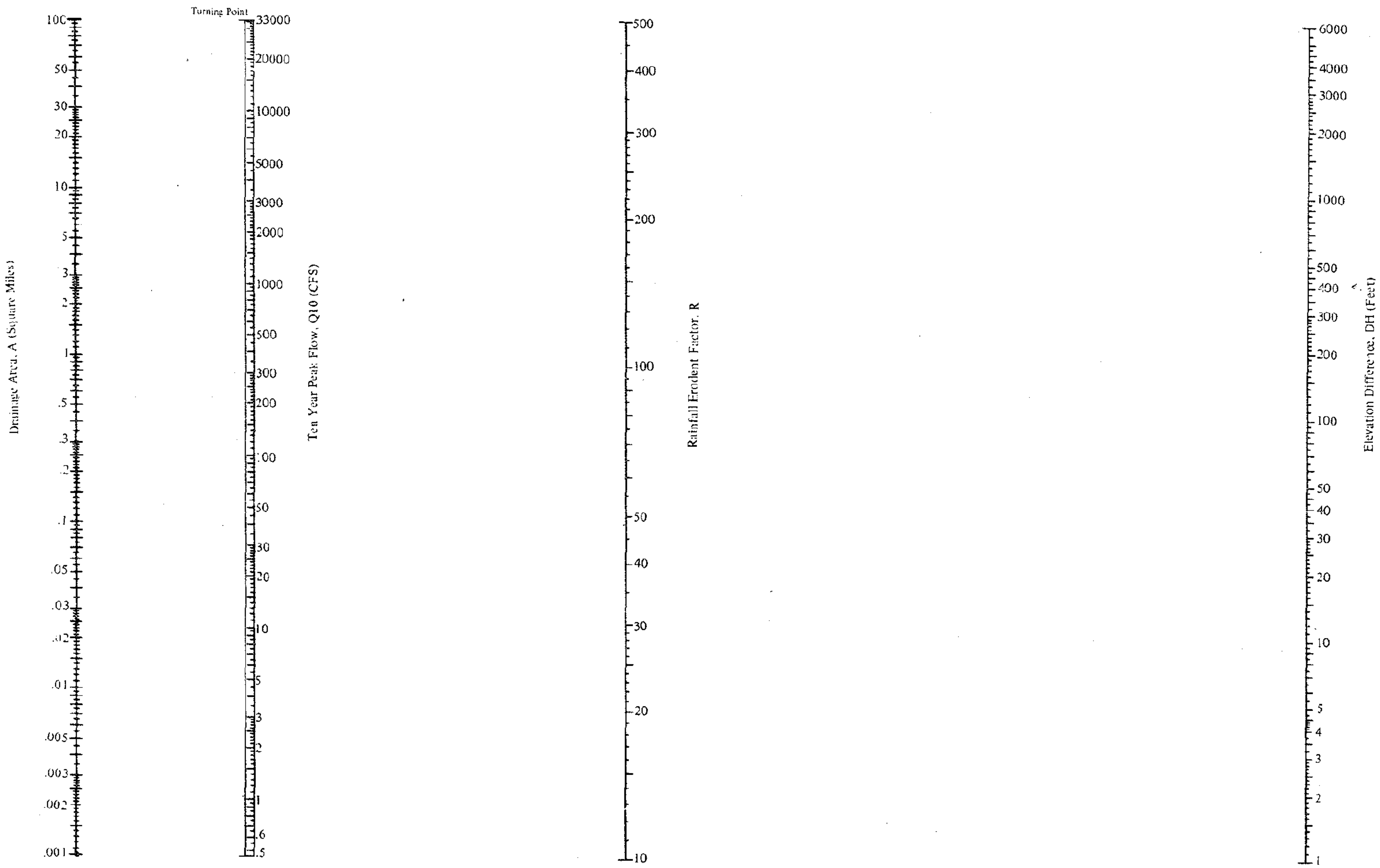
Appendix H-10. Three parameter zone 10 nomograph. $\hat{q}_{10} = 0.000613\, A^{1.30515}\, R^{3.28114}\, DH^{-0.54172}$



Appendix H-11. Three parameter zone 11 nomograph. $\hat{q}_{10} = 1111.47\, A^{0.67899}\, R^{-0.76204}\, DH^{0.58914}$



Appendix H-12. Three parameter zone 12 nomograph. $\hat{q}_{10} = 0.01961\, A^{0.47391}\, R^{1.68758}\, DH^{0.30700}$

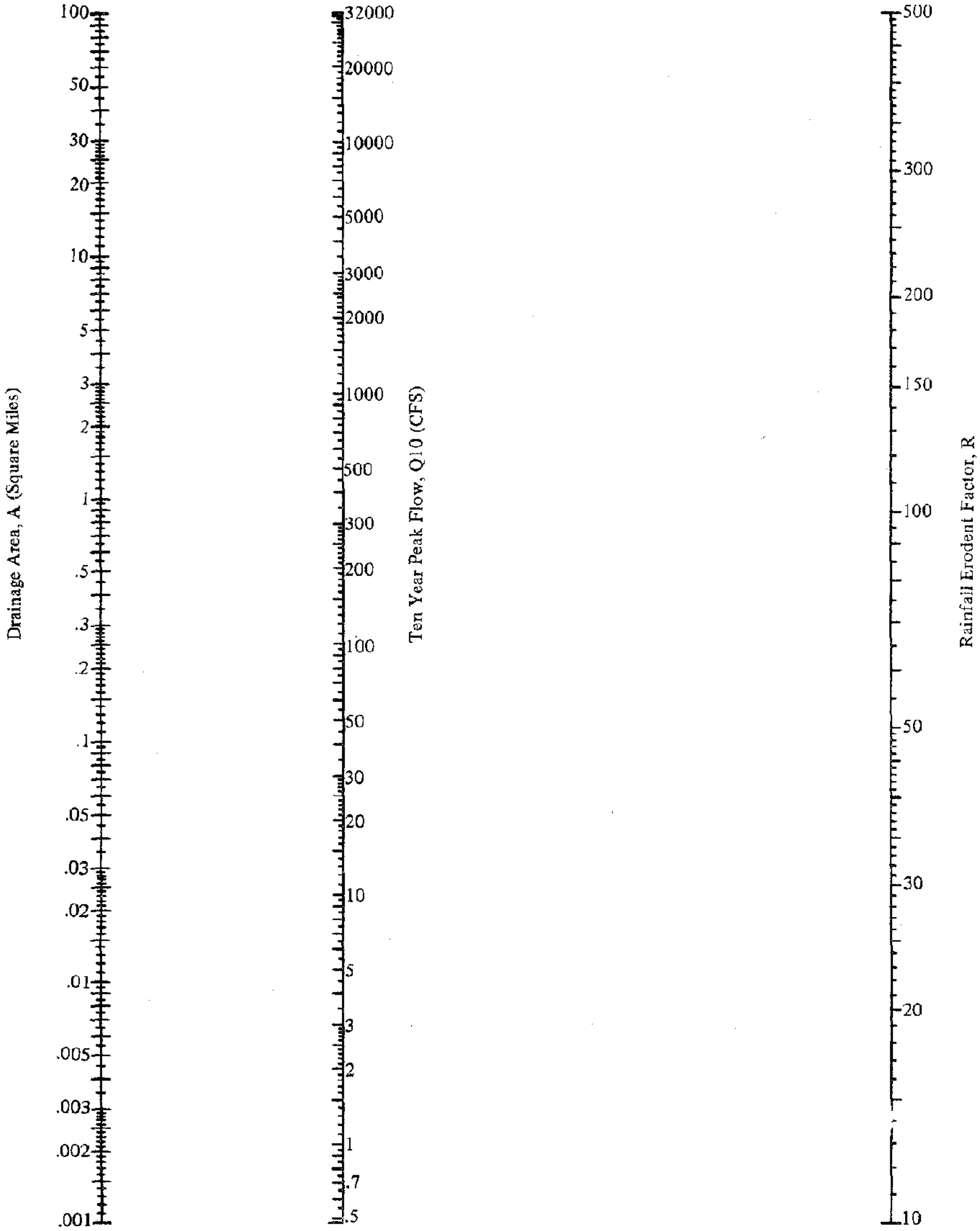


Appendix H-13. Three parameter zone 13 nomograph.

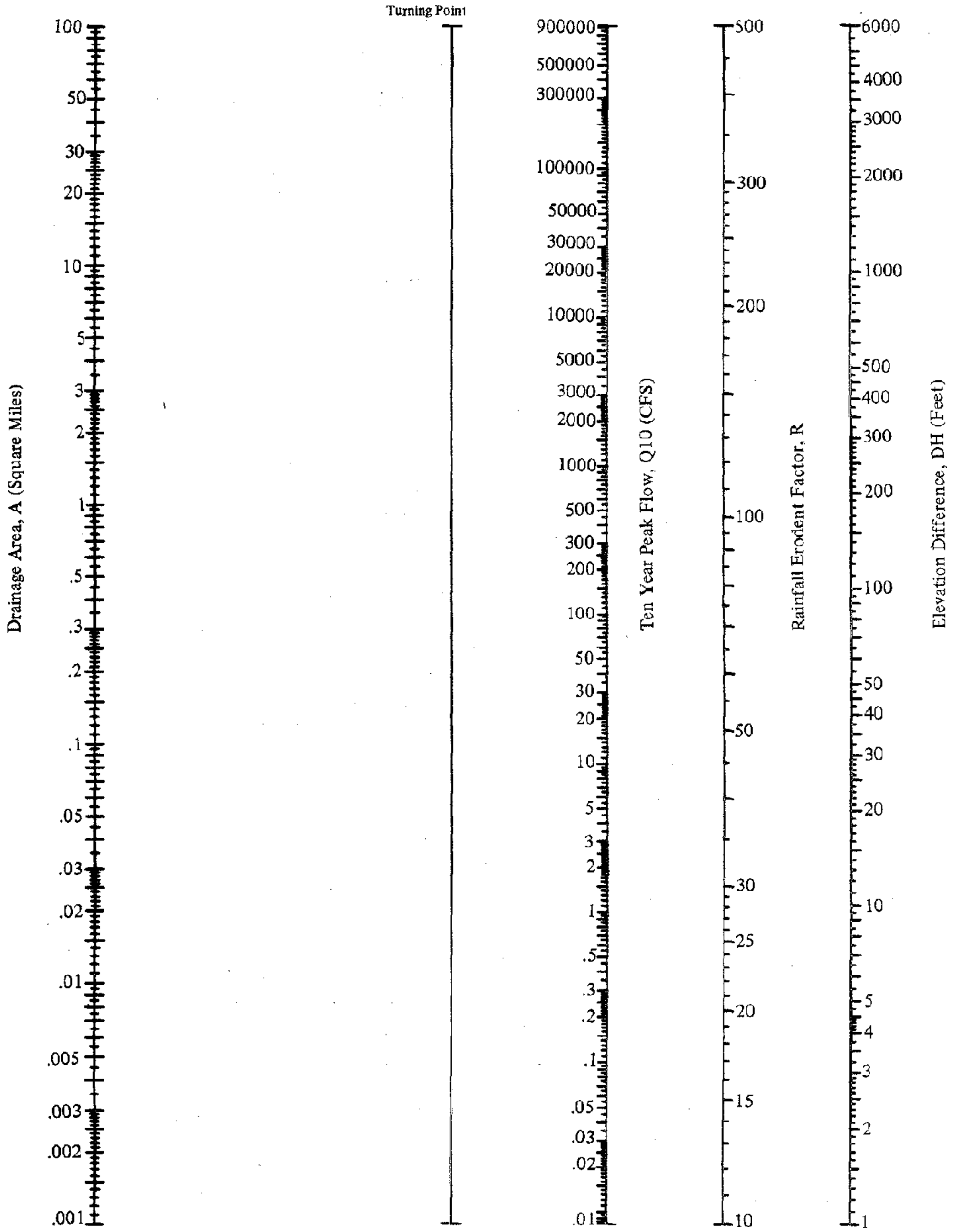
$$\hat{q}_{10} = 6.18115\, A^{0.66694}\, R^{0.87434}\, DH^{0.01023}$$

or

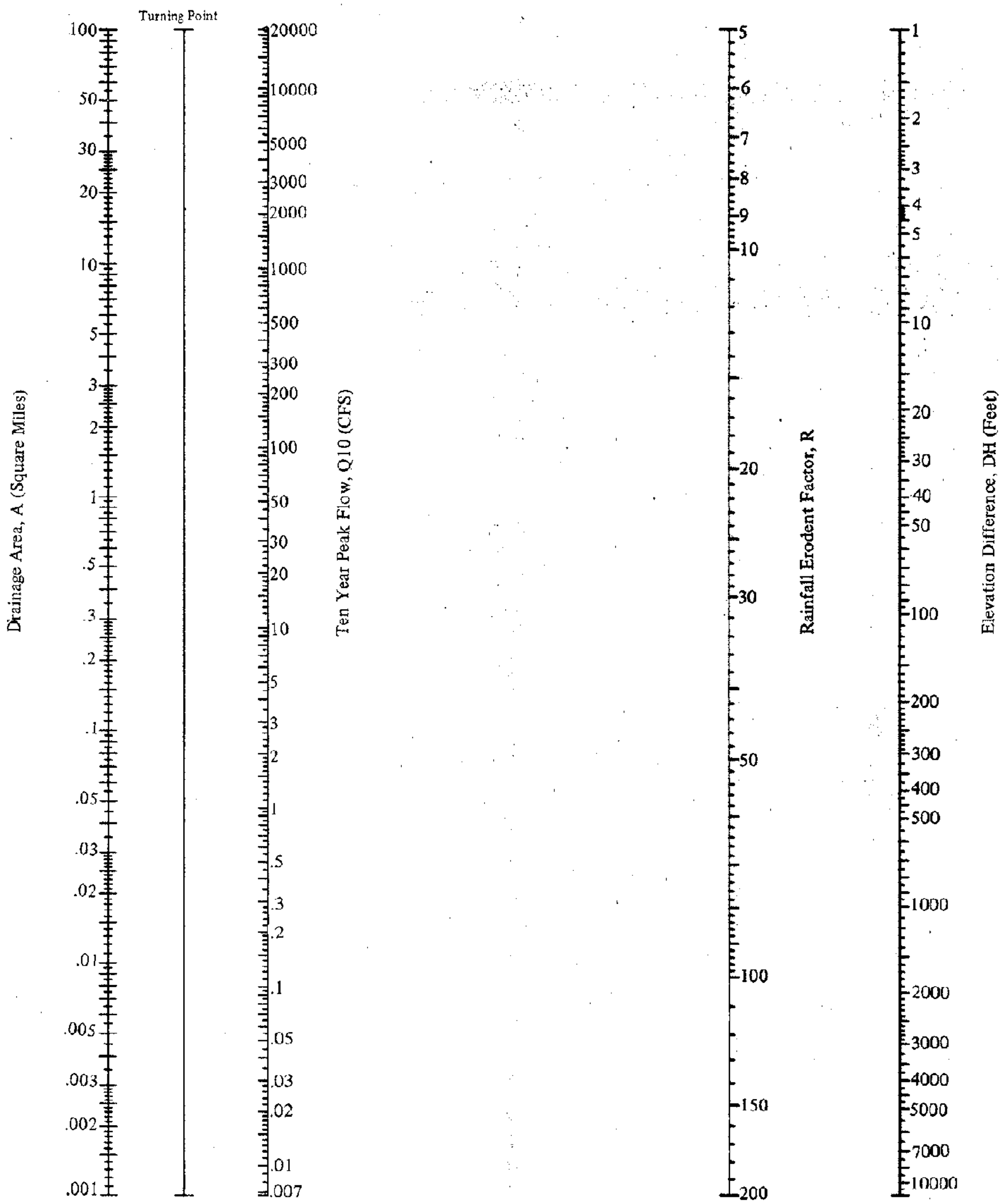
$$\hat{q}_{10} = 6.6082\, A^{0.67054}\, R^{0.87120}$$



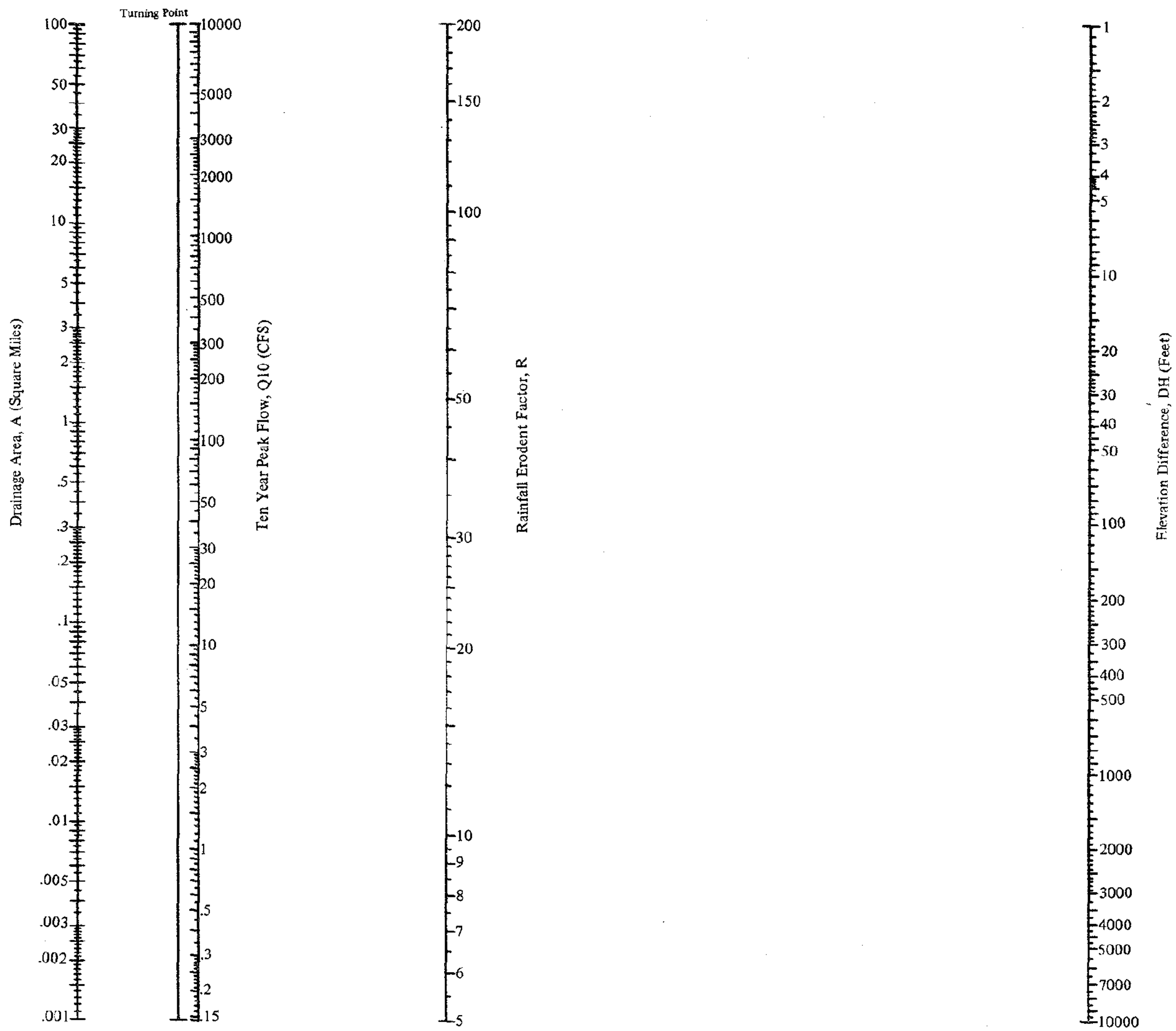
Appendix H-13. Two parameter zone 13 nomograph.



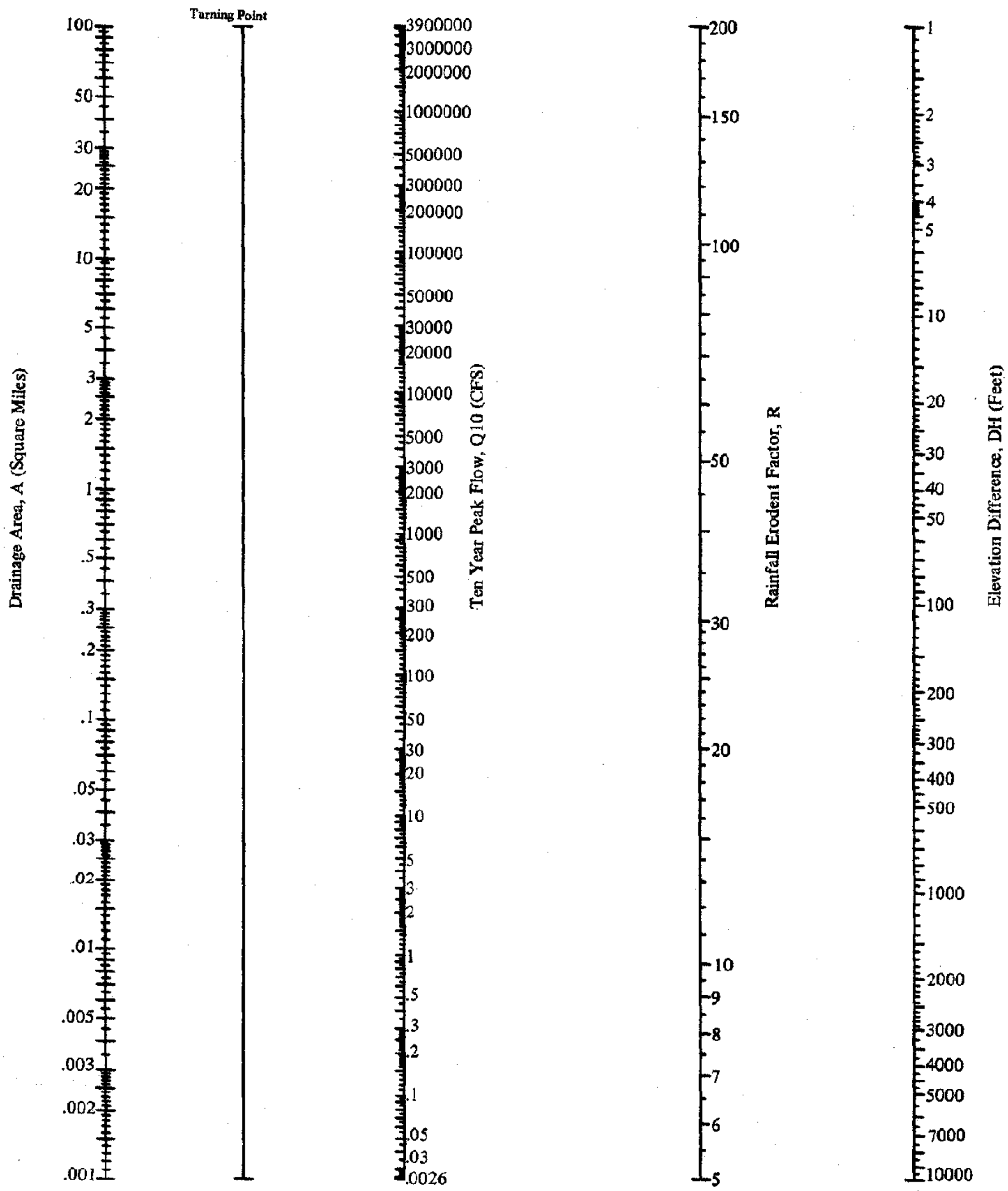
Appendix H-14. Three parameter zone 14 nomograph. $\hat{q}_{10} = 0.00353\ A^{0.42562}\ R^{1.64552}\ DH^{0.82680}$



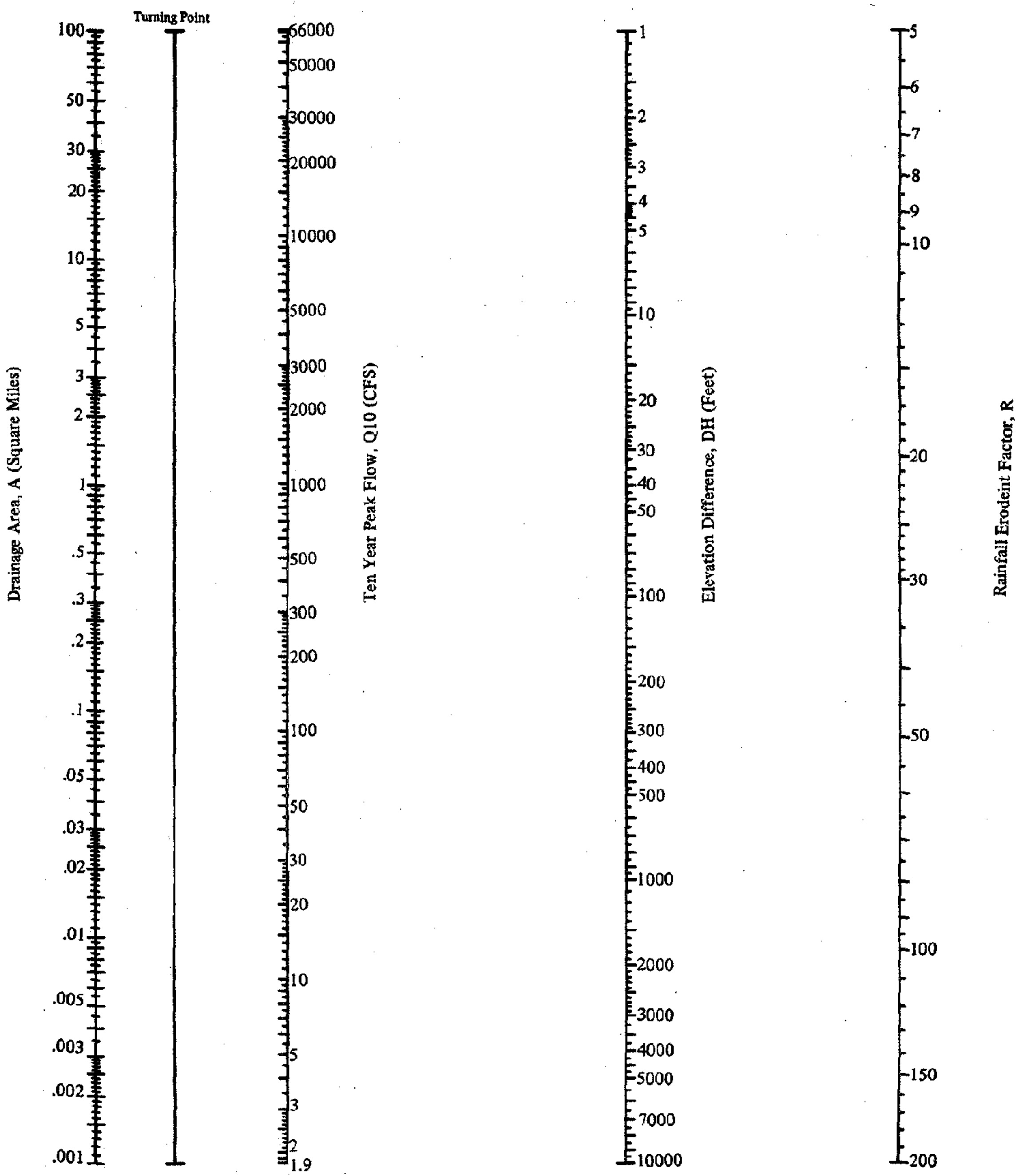
Appendix H-15. Three parameter zone 15 **nomograph.** $\hat{q}_{10} = 412.131\ A^{1.00832}\ R^{-0.43497}\ DH^{-0.18943}$



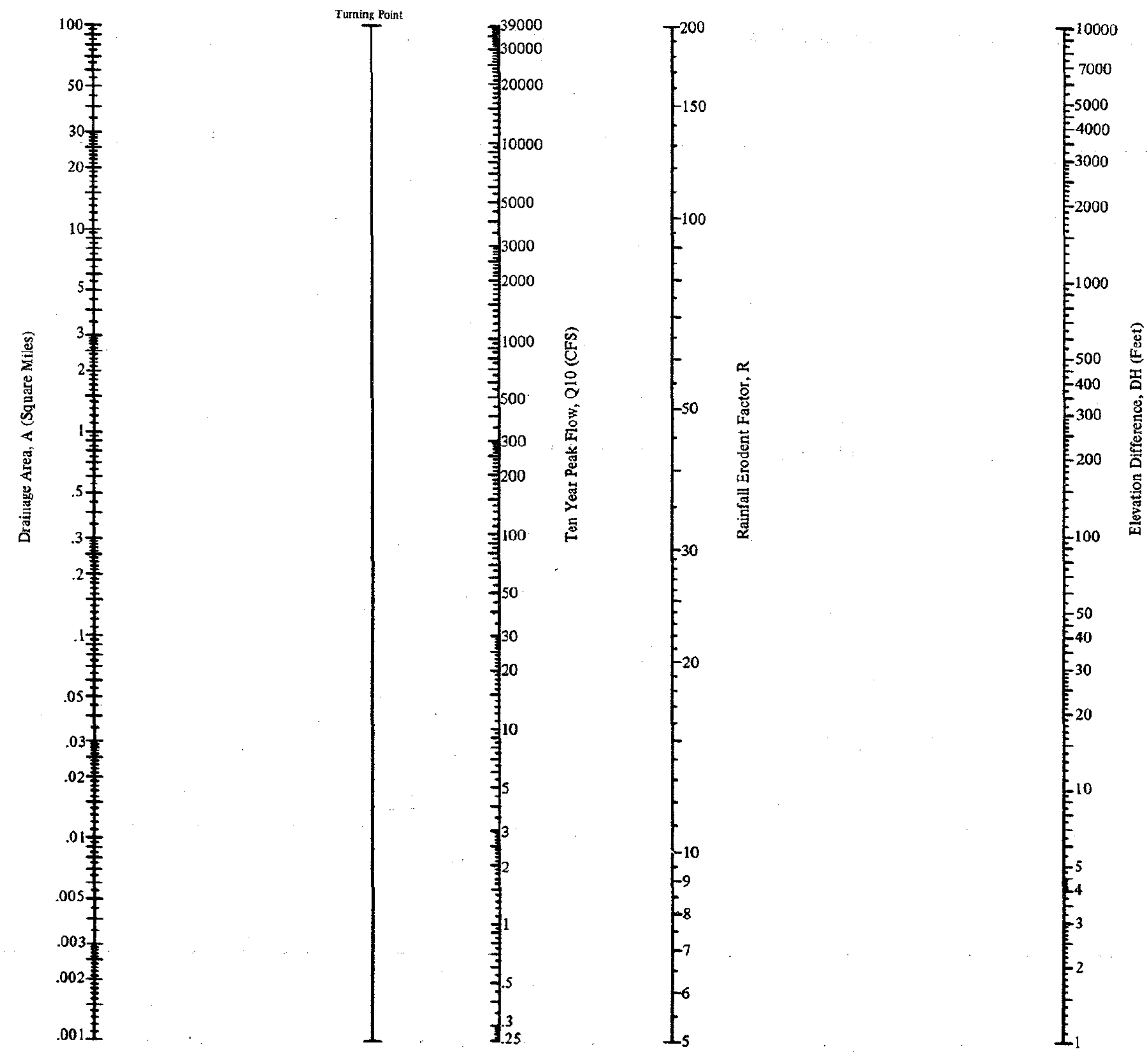
Appendix H-16. Three parameter zone 16 nomograph. $\hat{q}_{10} = 5.99340\ A^{0.69400}\ R^{0.81381}\ DH^{-0.02694}$



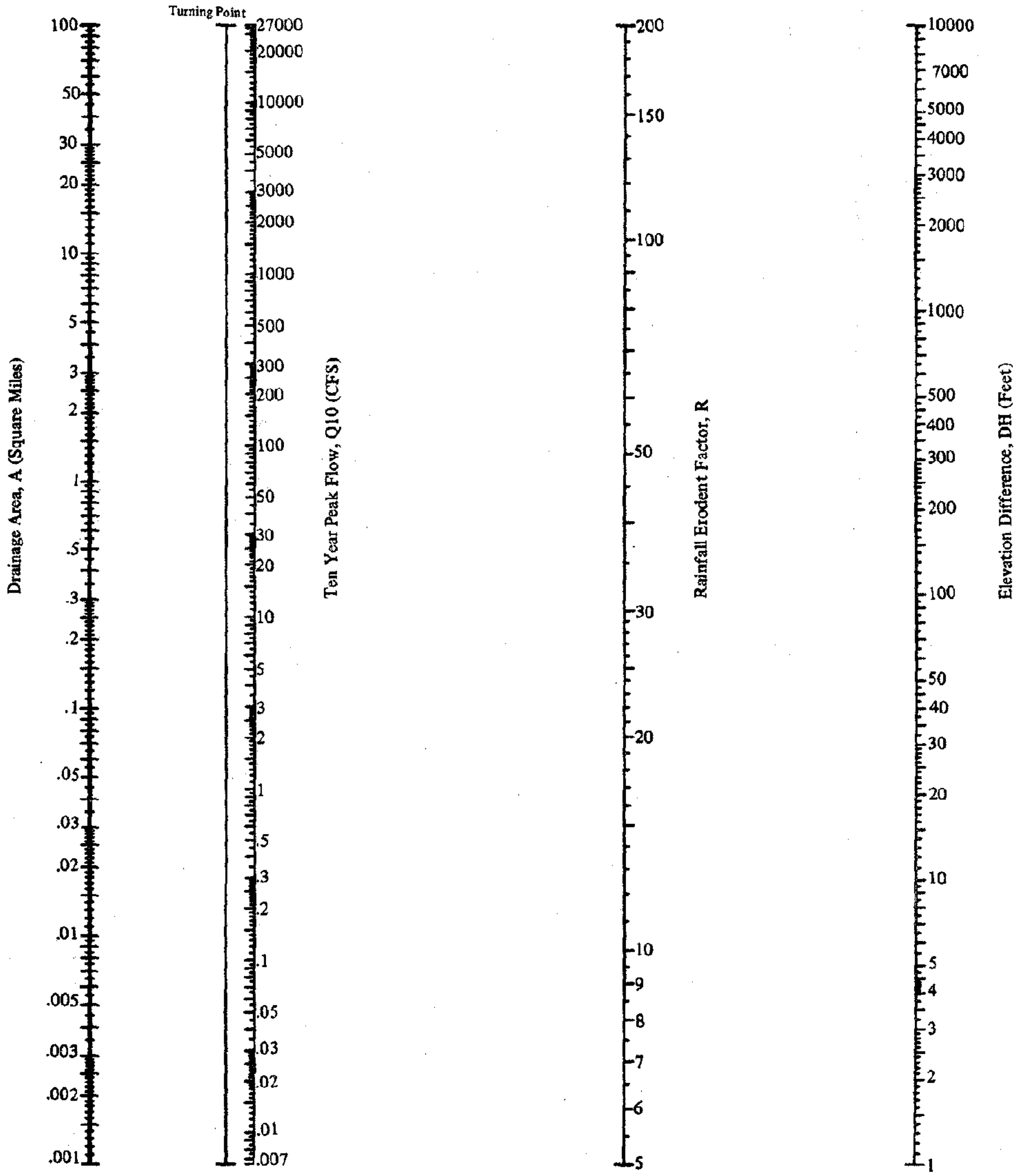
Appendix H-17. Three parameter zone 17 nomograph. $\hat{q}_{10} = 41.2165\, A^{0.95643}\, R^{0.90116}\, DH^{-0.49291}$



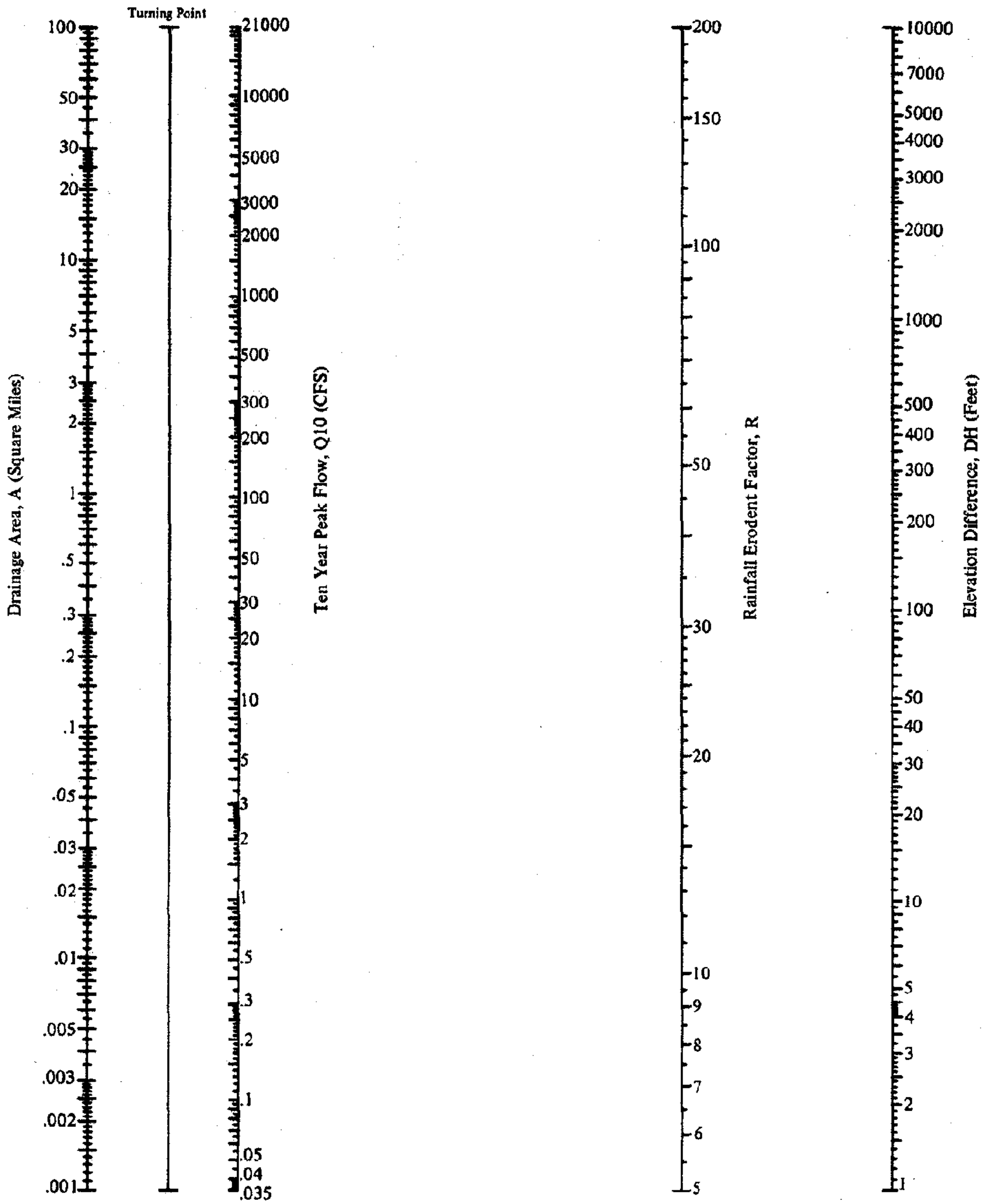
Appendix H-18. Three parameter zone 18 nomograph. $\hat{q}_{10} = 5399.80\, A^{0.61776}\, R^{-0.20988}\, DH^{-0.28469}$



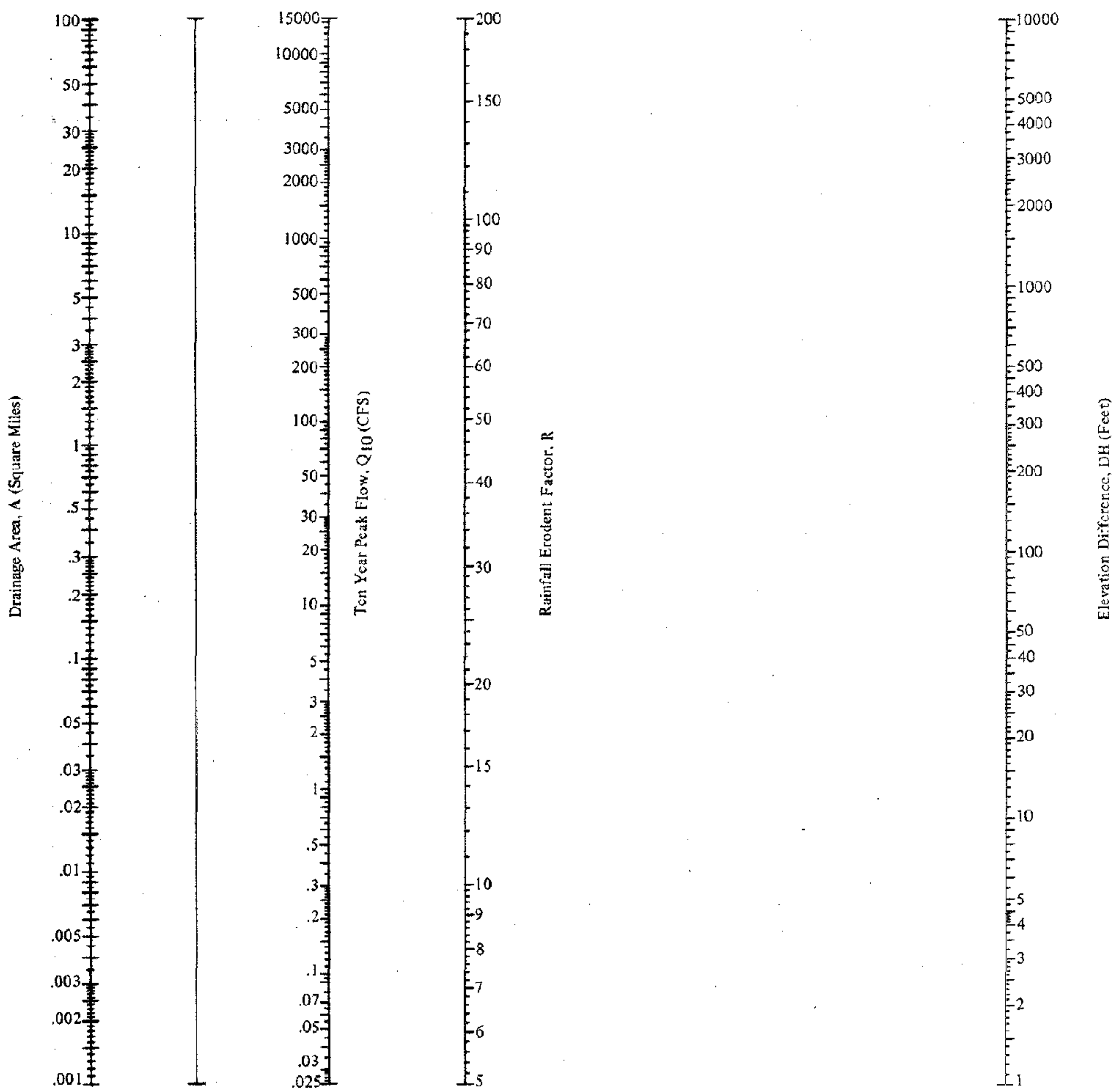
Appendix H-19. Three parameter zone 19 nomograph. $\hat{q}_{10} = 0.67503\, A^{0.44020}\, R^{1.26786}\, DH^{0.24140}$



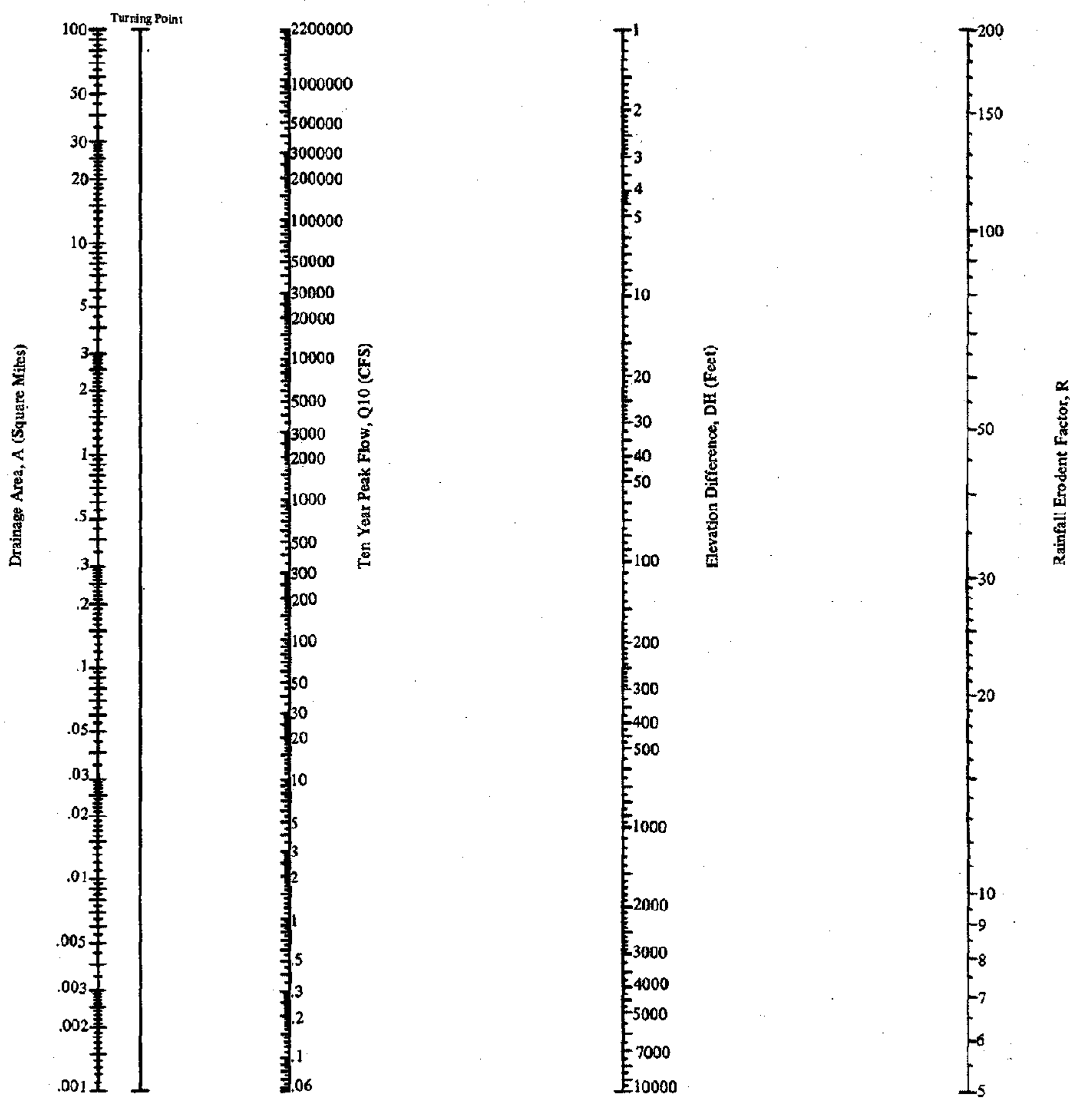
Appendix H-20. Three parameter zone 20 nomograph. $\hat{q}_{10} = 0.88267 A^{0.94684} R^{1.01373} DH^{0.06857}$



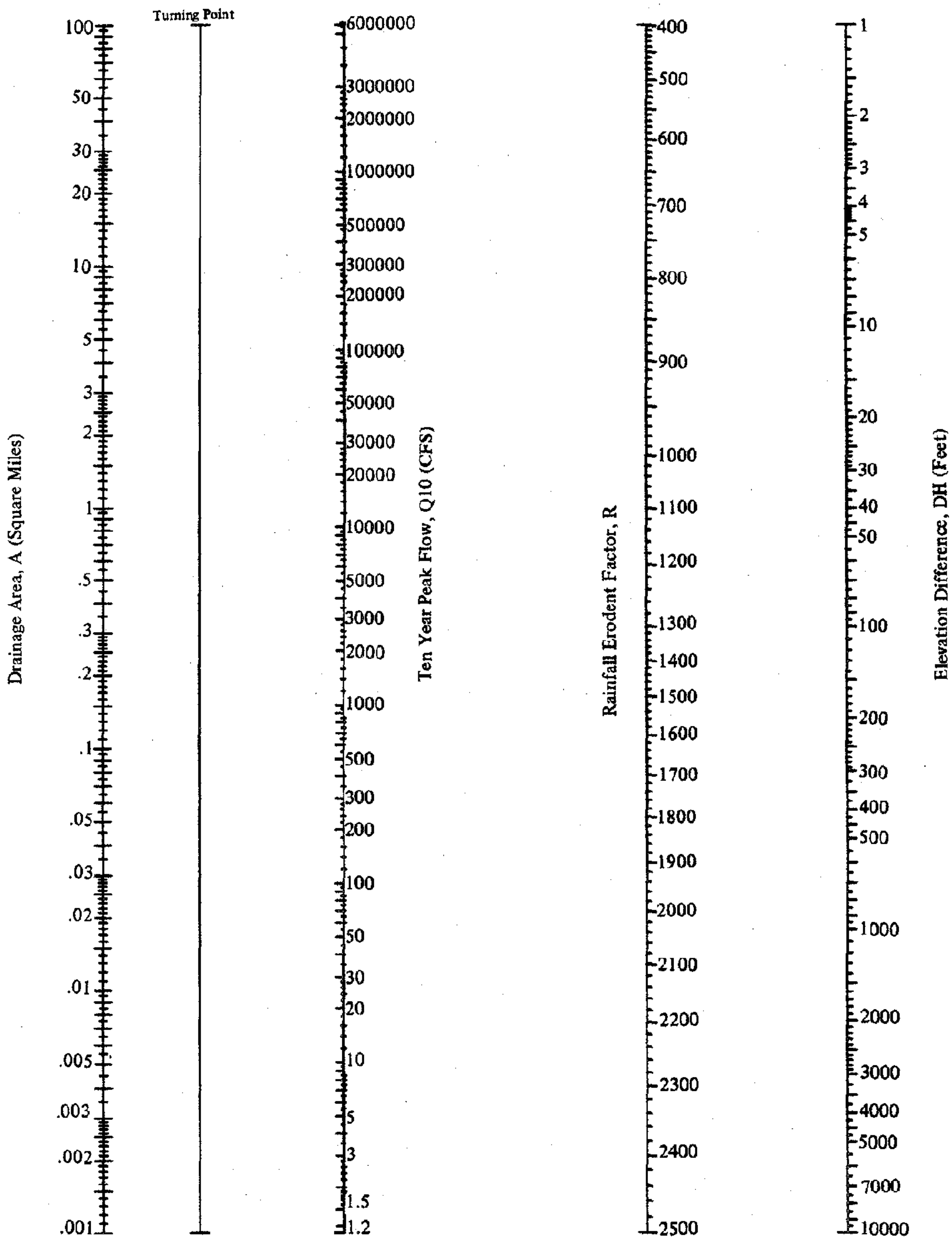
Appendix H-21. Three parameter zone 21 nomograph. $\hat{q}_{10} = 8.80096\, A^{0.90473}\, R^{0.44704}\, DH^{0.13937}$



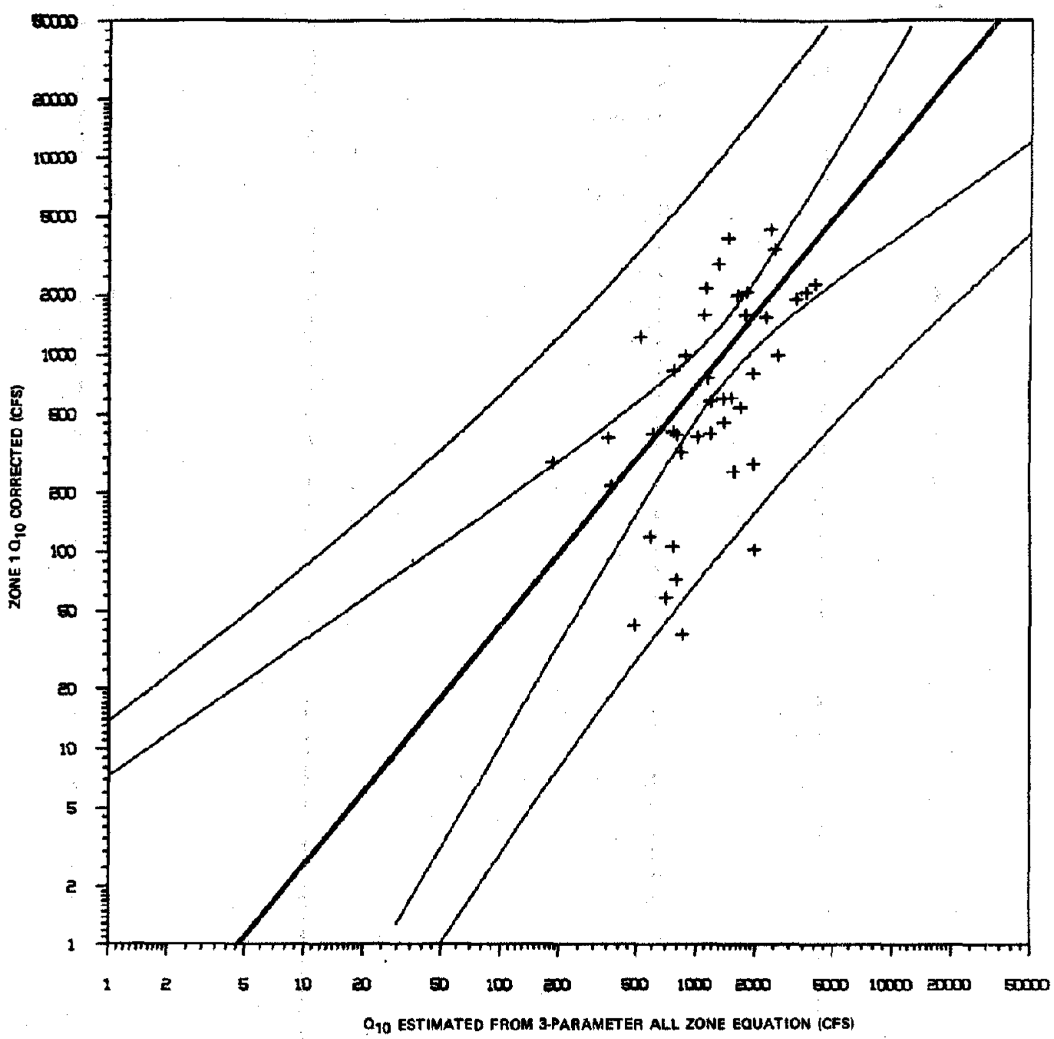
Appendix H-22. Three parameter zone 22 nomograph. $\hat{q}_{10} = 0.76272\, A^{0.69452}\, R^{0.85611}\, DH^{0.23777}$



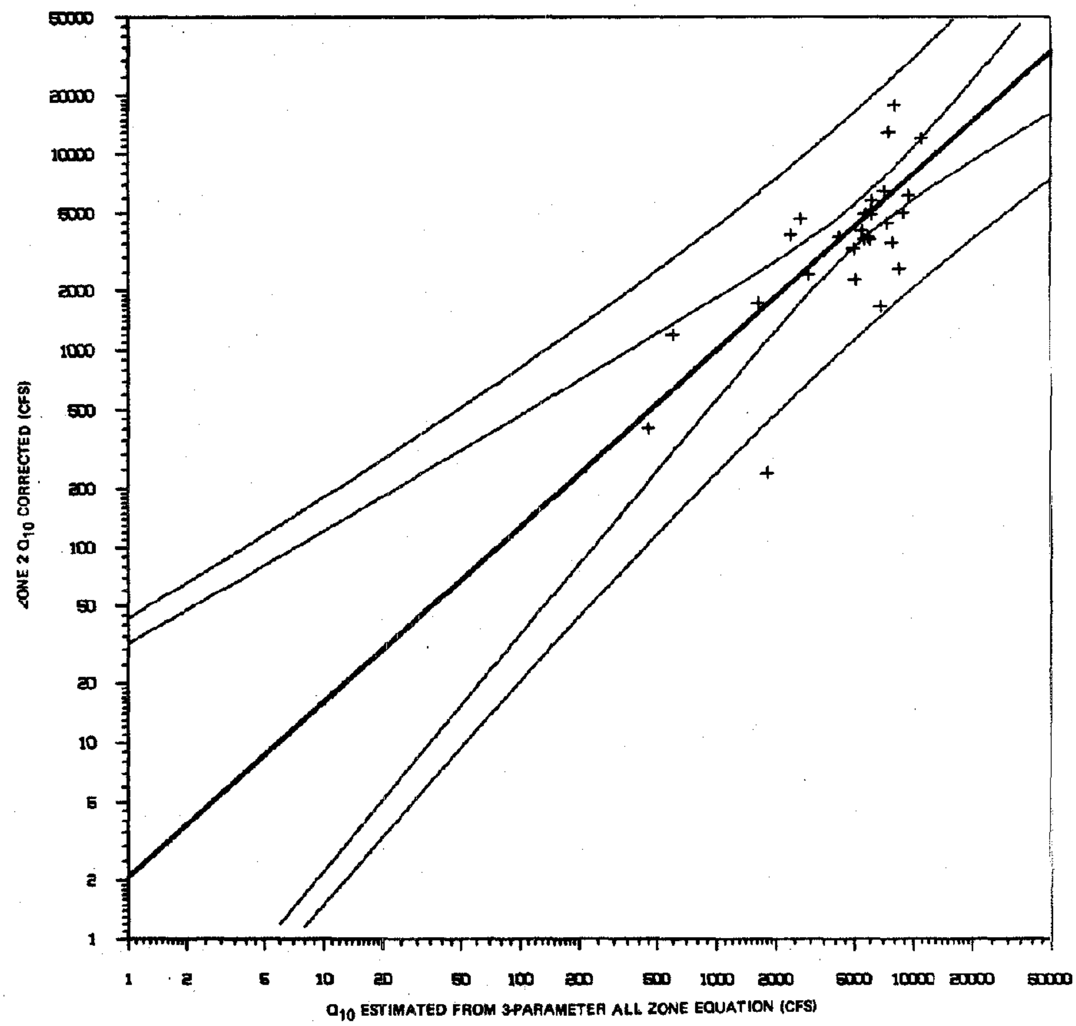
Appendix H-23. Three parameter zone 23 nomograph. $\hat{q}_{10} = 9687.77\, A^{0.99975}\, R^{0.16025}\, DH^{-0.58516}$



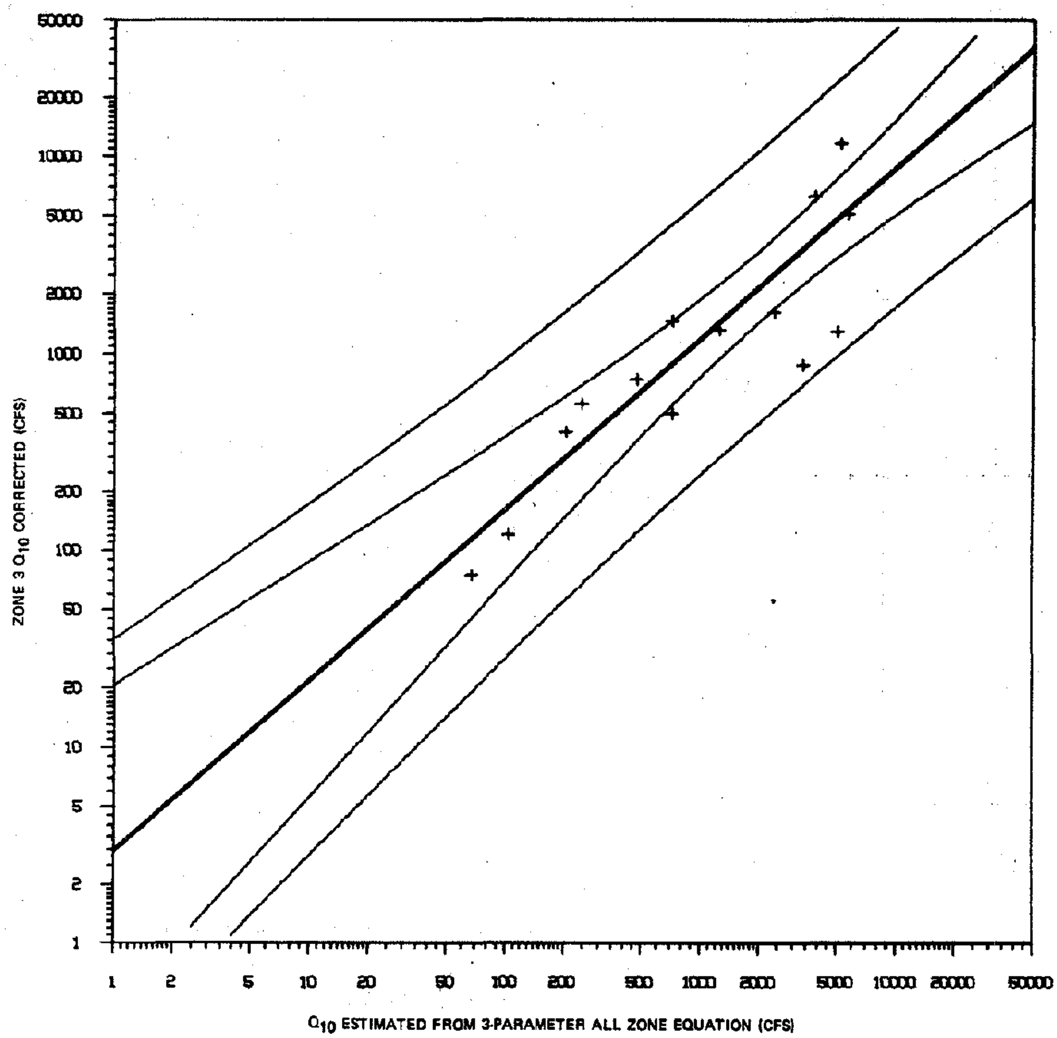
Appendix H-24. Three parameter zone 24 nomograph. $\hat{q}_{10} = 12.8566\, A^{0.86854}\, R^{1.17343}\, DH^{-0.37794}$



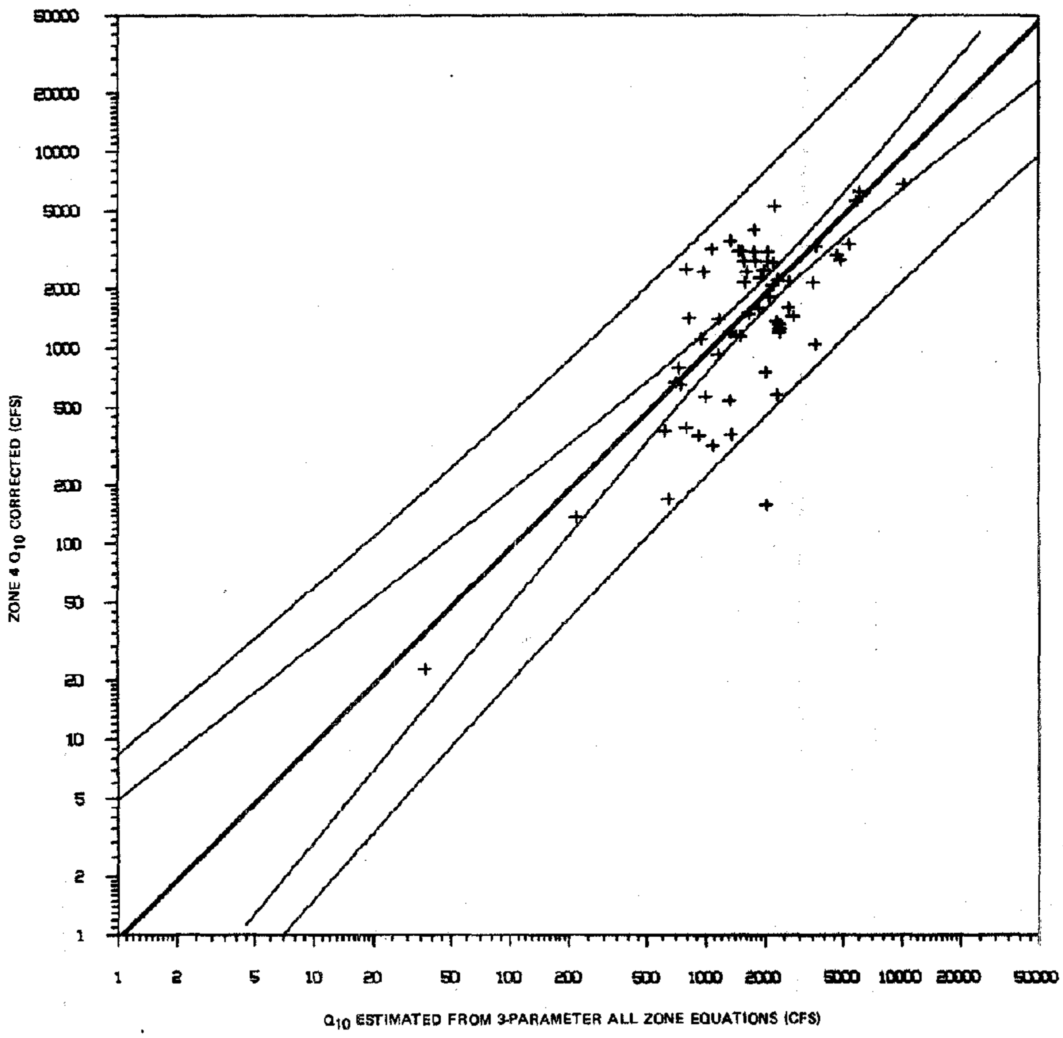
Appendix H-25. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 01 with the 95% confidence intervals for a mean and a point estimate shown.



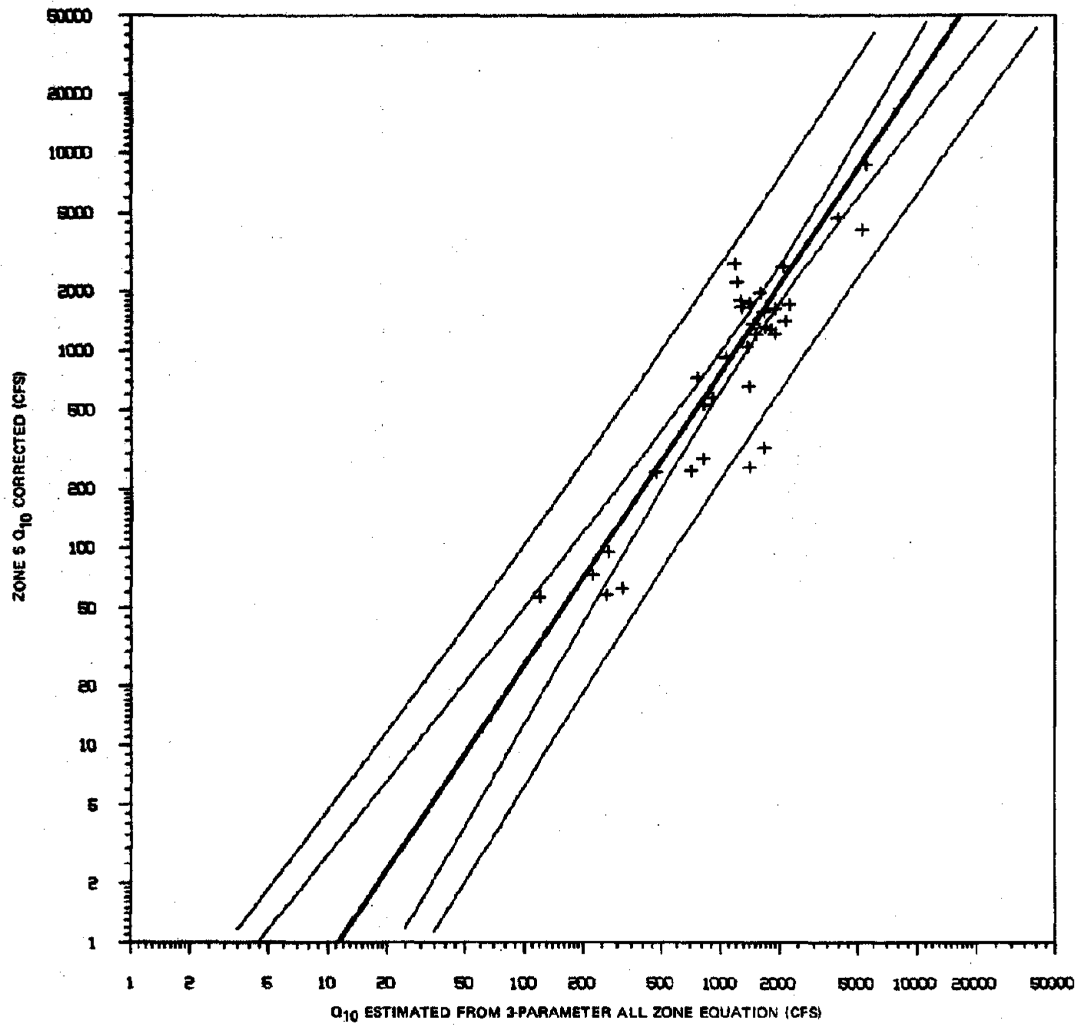
Appendix H-26. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 02 with the 95% confidence intervals for a mean and a point estimate shown.



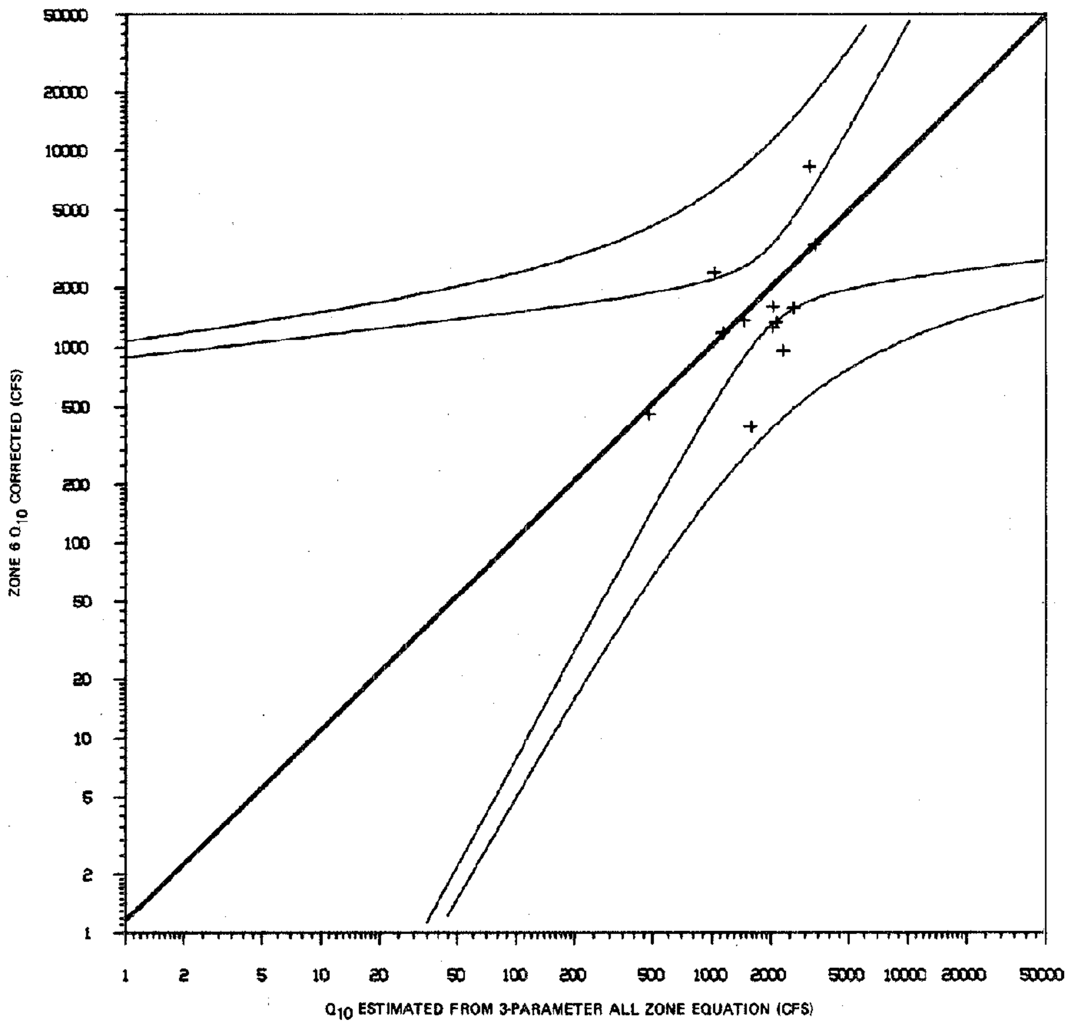
Appendix H-27. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 03 with the 95% confidence intervals for a mean and a point estimate shown.



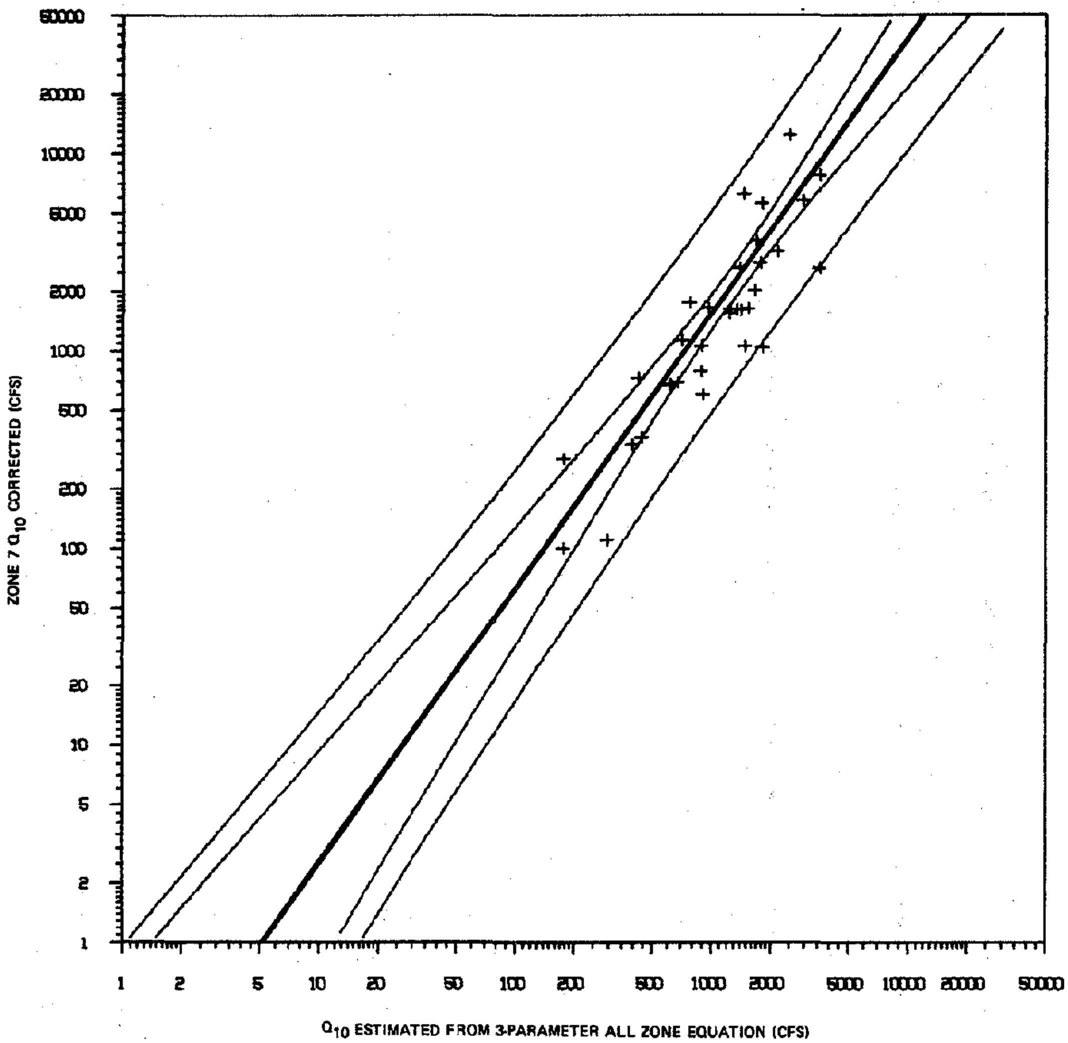
Appendix H-28. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 04 with the 95% confidence intervals for a mean and a point estimate shown.



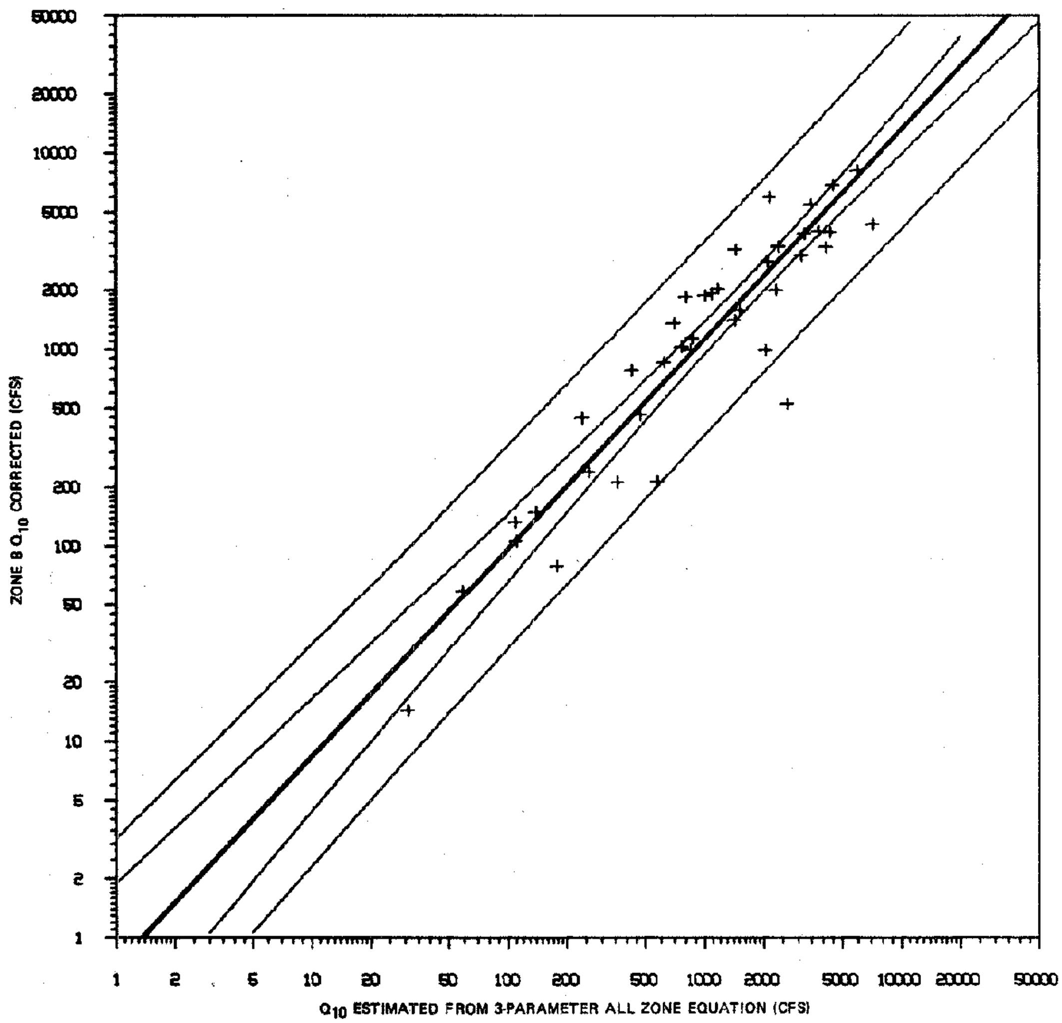
Appendix H-29. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 05 with the 95% confidence intervals for a mean and a point estimate shown.



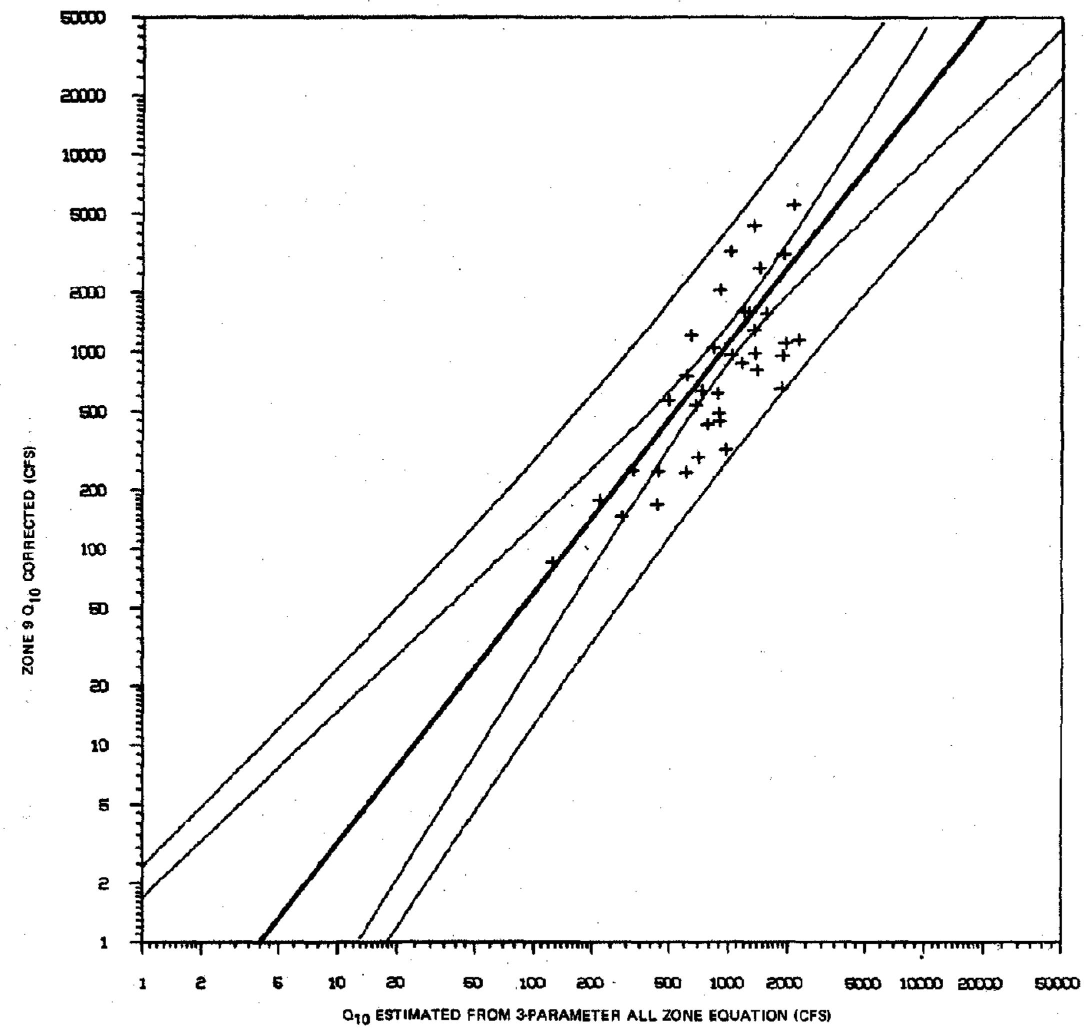
Appendix H-30. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 06 with the 95% confidence intervals for a mean and a point estimate shown.



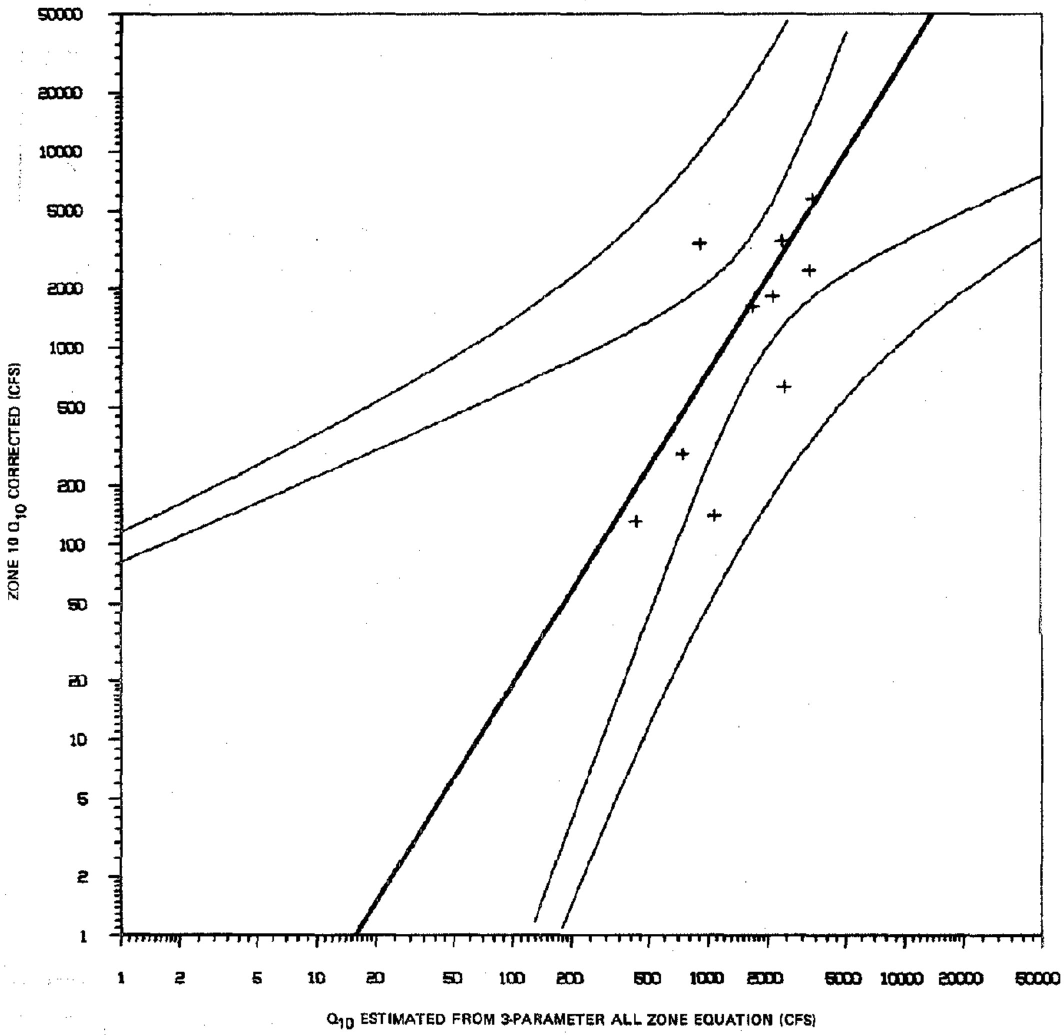
Appendix H-31. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 07 with the 95% confidence intervals for a mean and a point estimate shown.



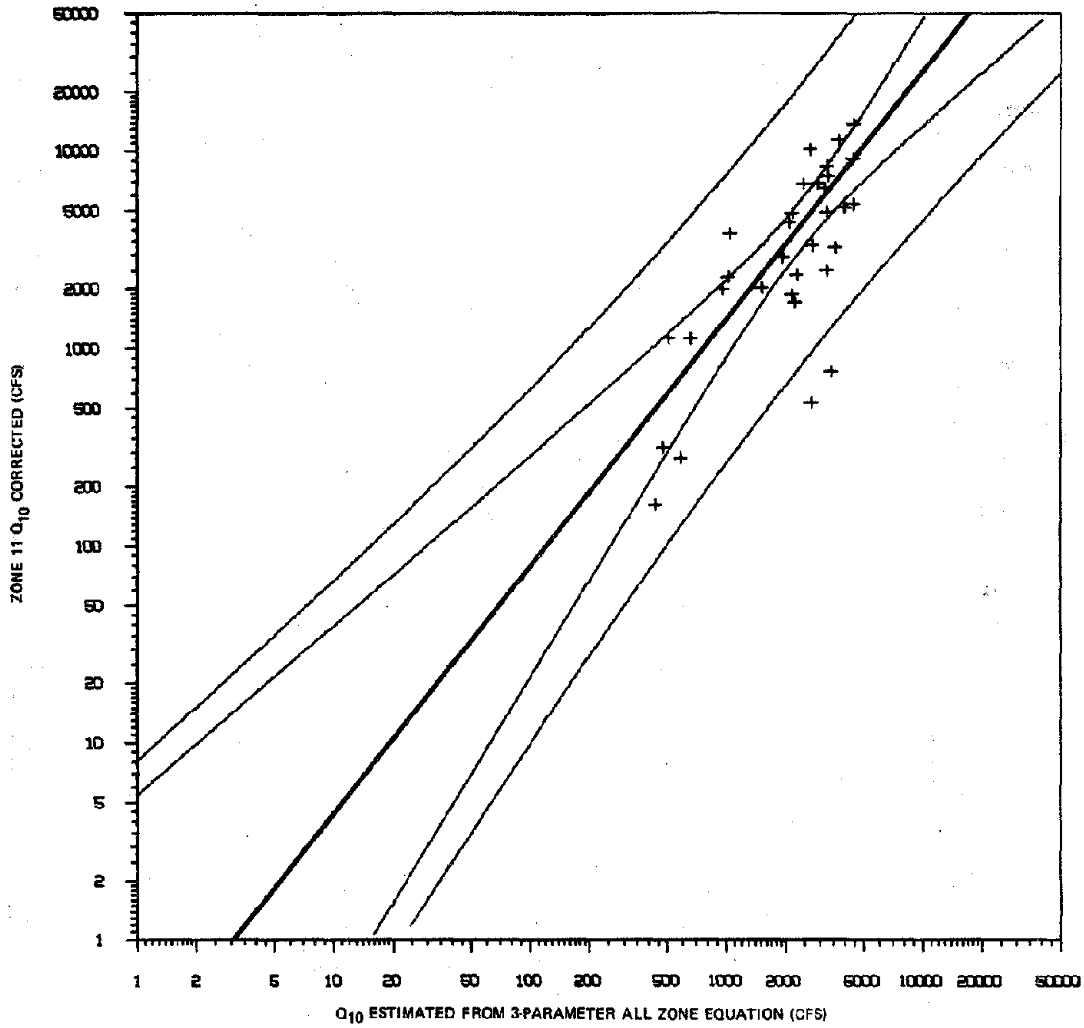
Appendix H-32. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 08 with the 95% confidence intervals for a mean and a point estimate shown.



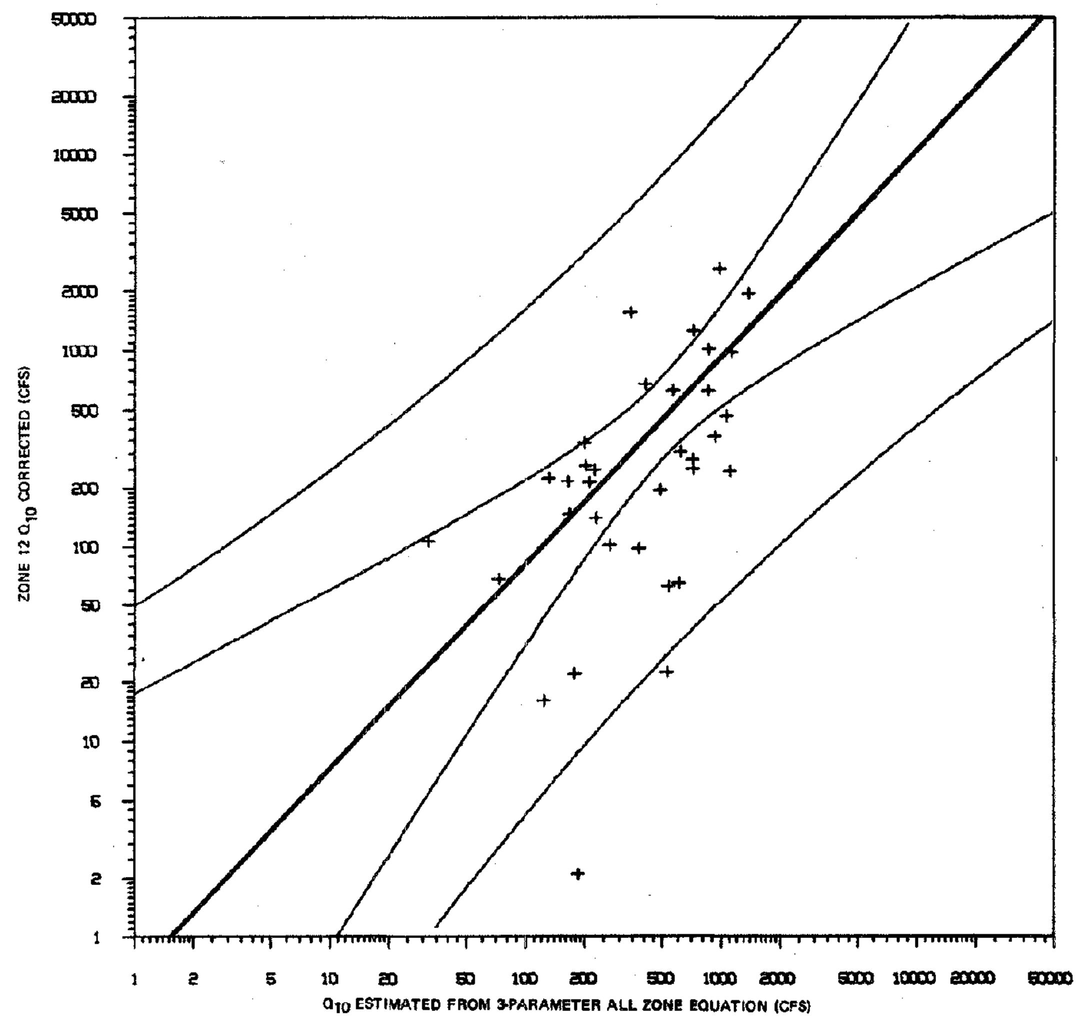
Appendix H-33. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 09 with the 95% confidence intervals for a mean and a point estimate shown.



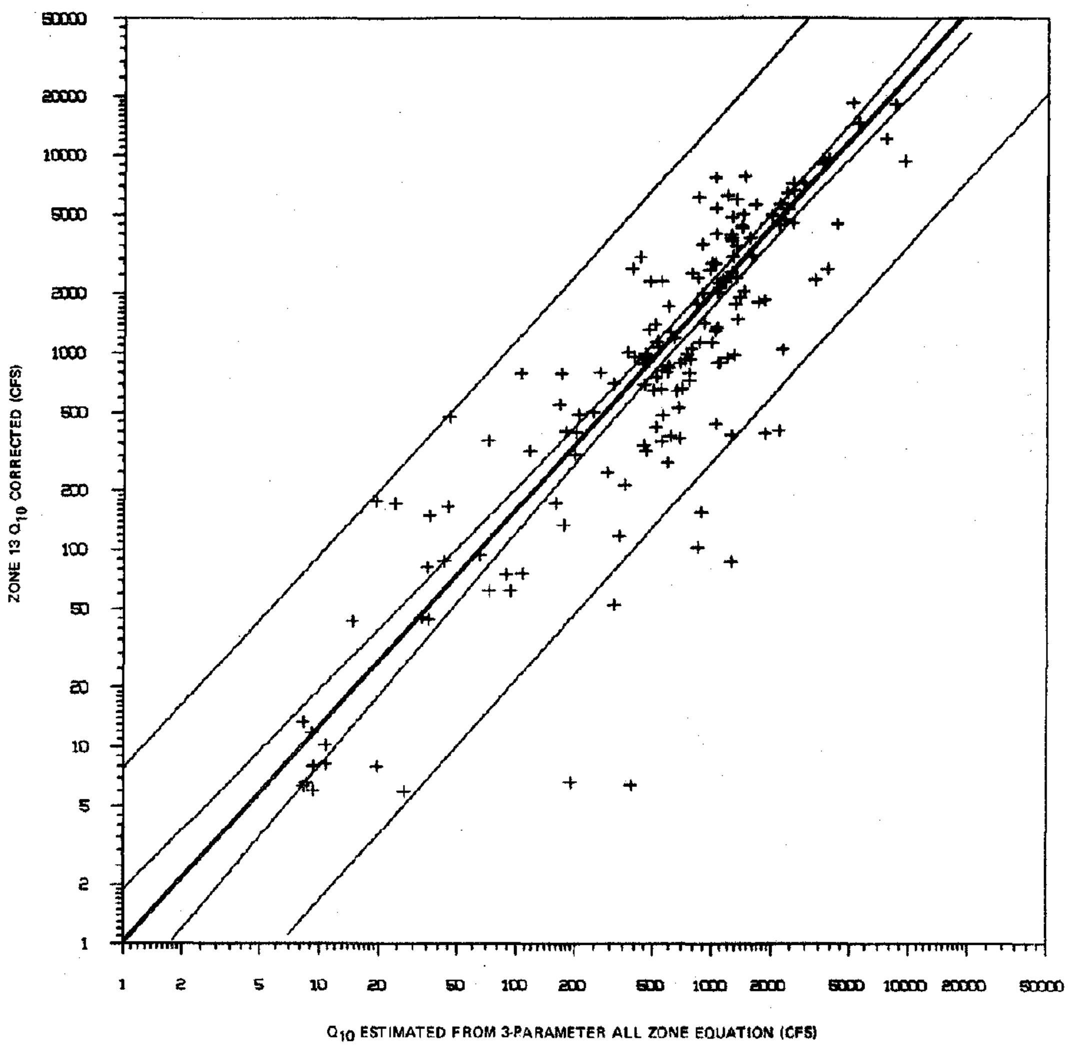
Appendix H-34. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 10 with the 95% confidence intervals for a mean and a point estimate shown.



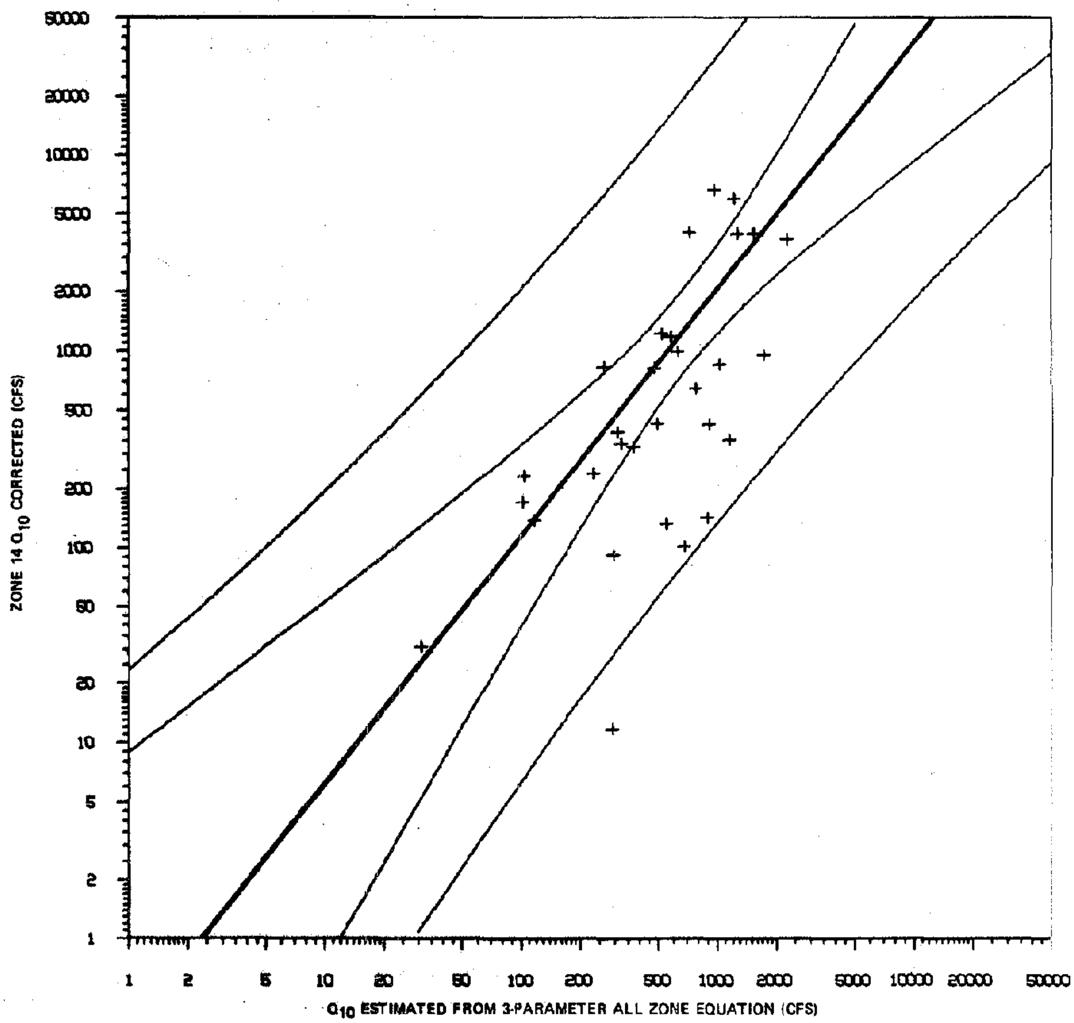
Appendix H-35. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 11 with the 95% confidence intervals for a mean and a point estimate shown.



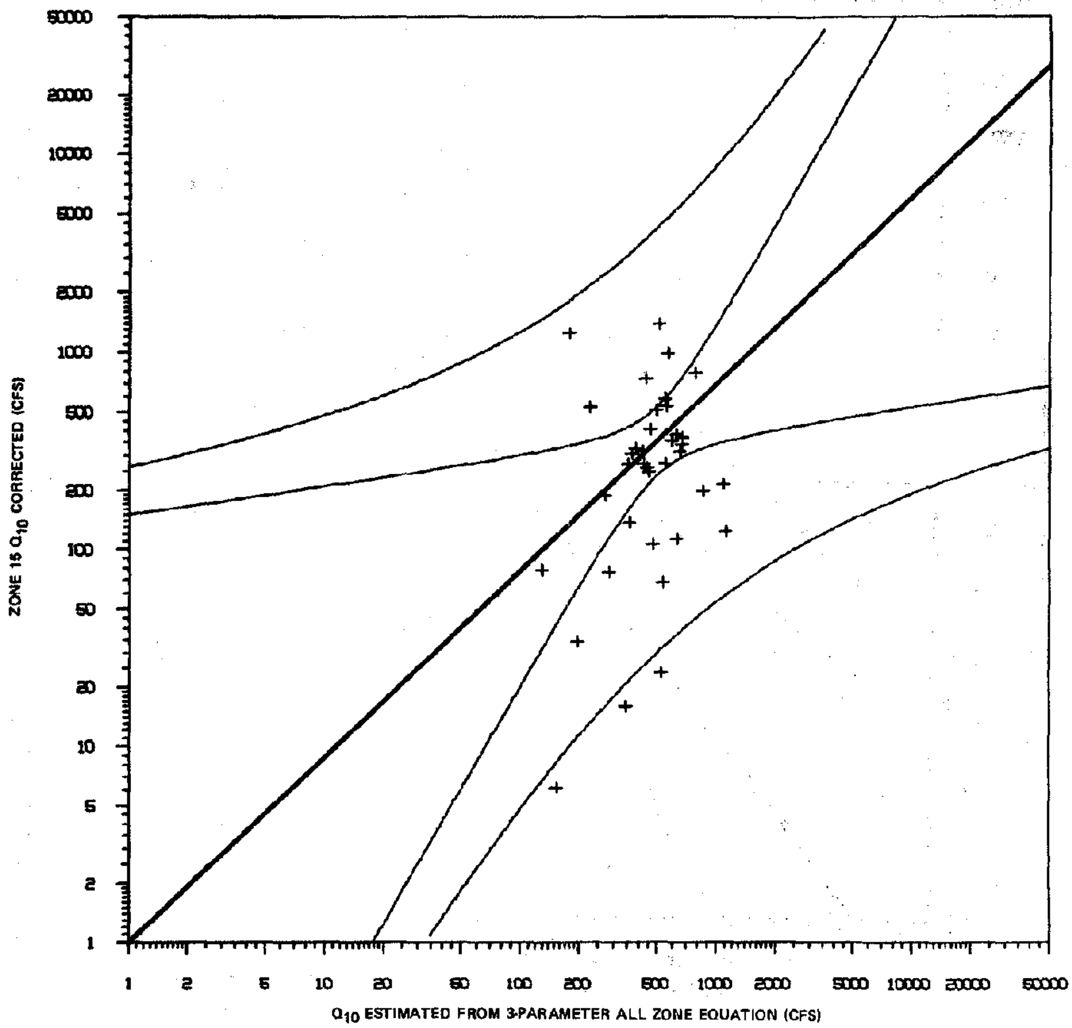
Appendix H-36. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 12 with the 95% confidence intervals for a mean and a point estimate shown.



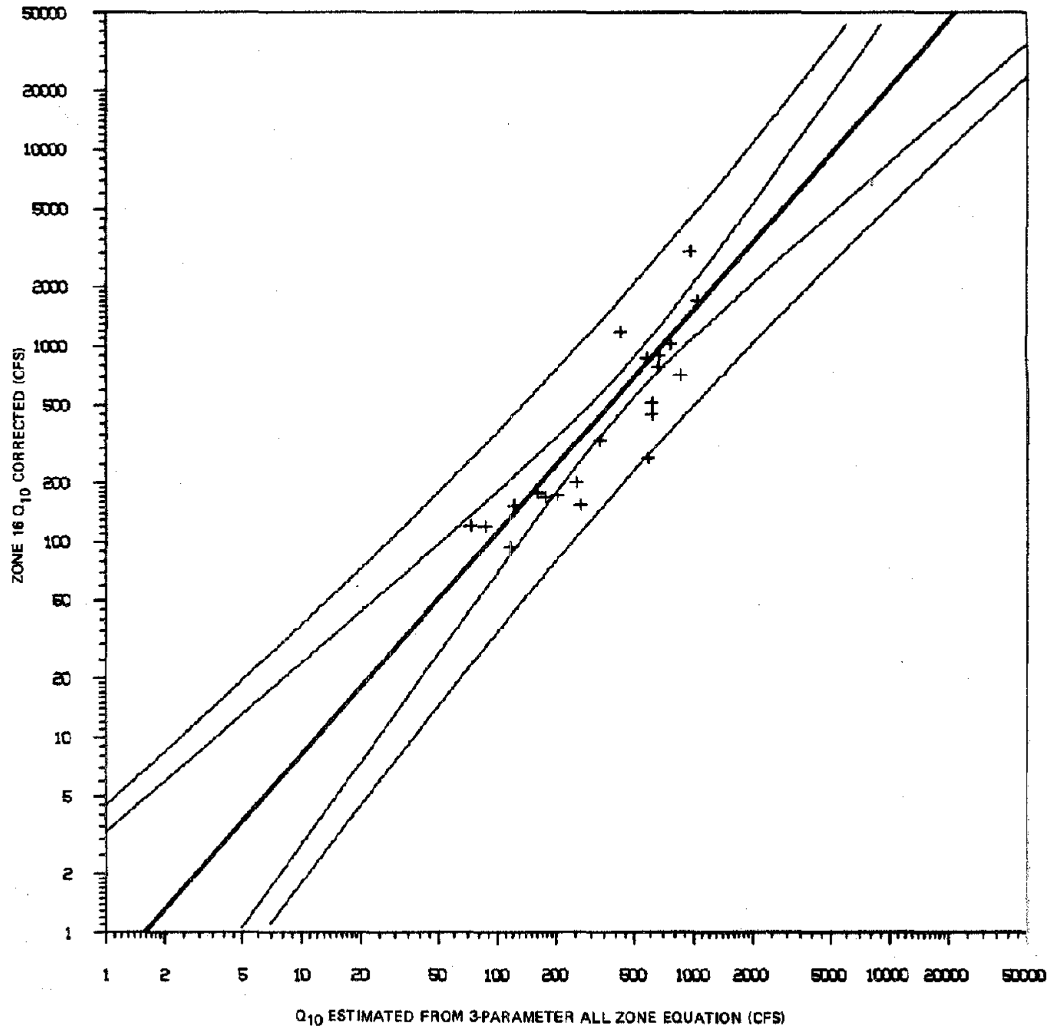
Appendix H-37. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 13 with the 95% confidence intervals for a mean and a point estimate shown.



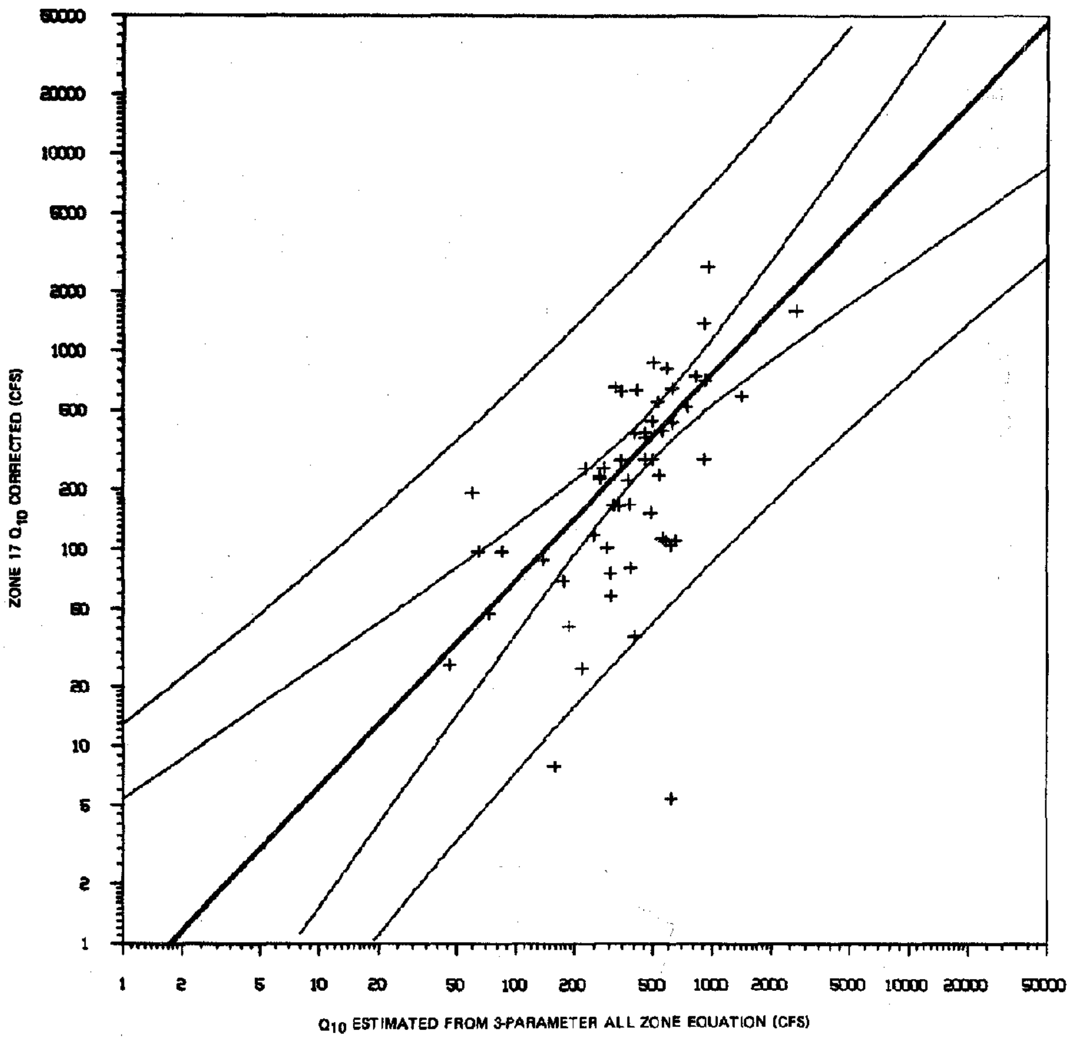
Appendix H-38. **Scatter diagram and** correction curve for the 3-parameter all **zone equation for** Zone 14 with the 95% confidence intervals for **a mean and a** point estimate shown.



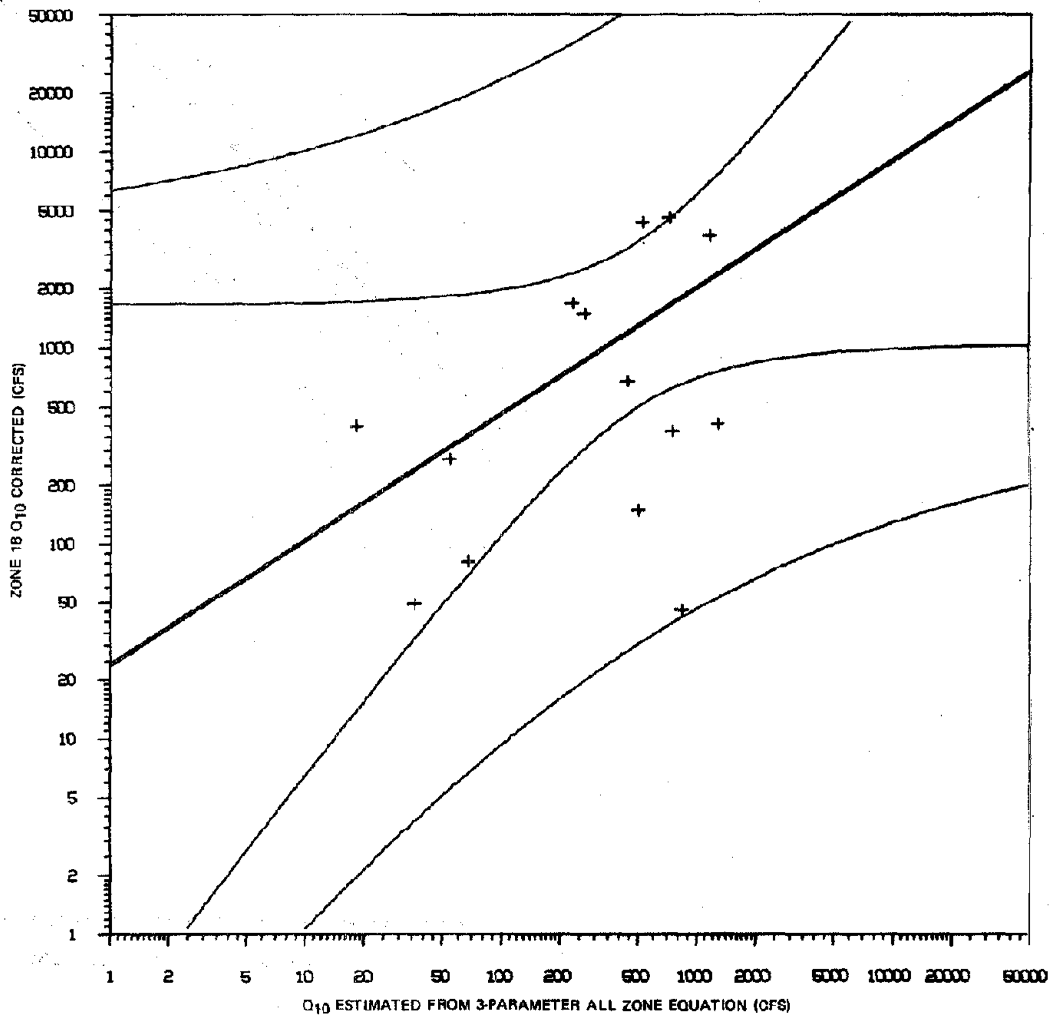
Appendix H-39. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 15 with the 95% confidence intervals for a mean and a point estimate shown.



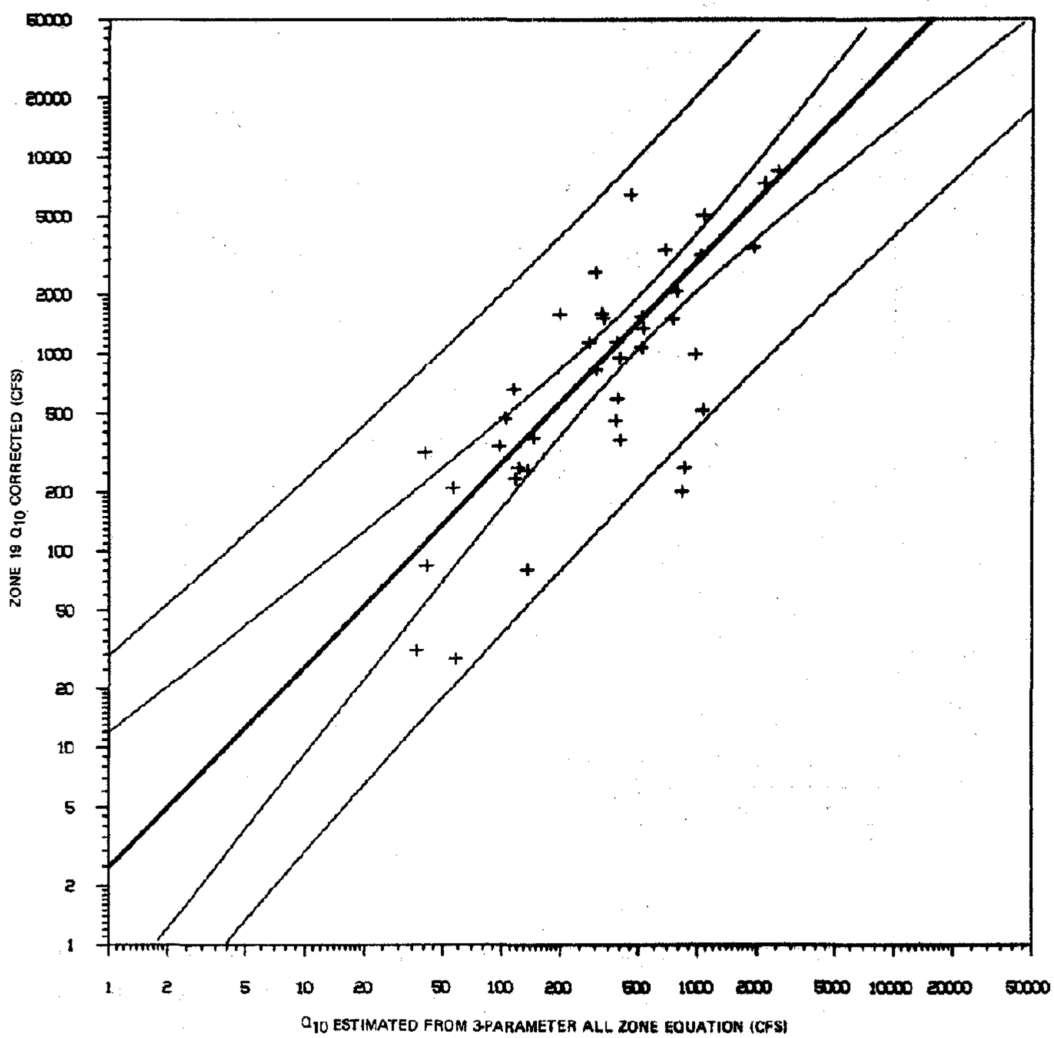
Appendix H-40. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 16 with the 95% confidence intervals for a mean and a point estimate shown.



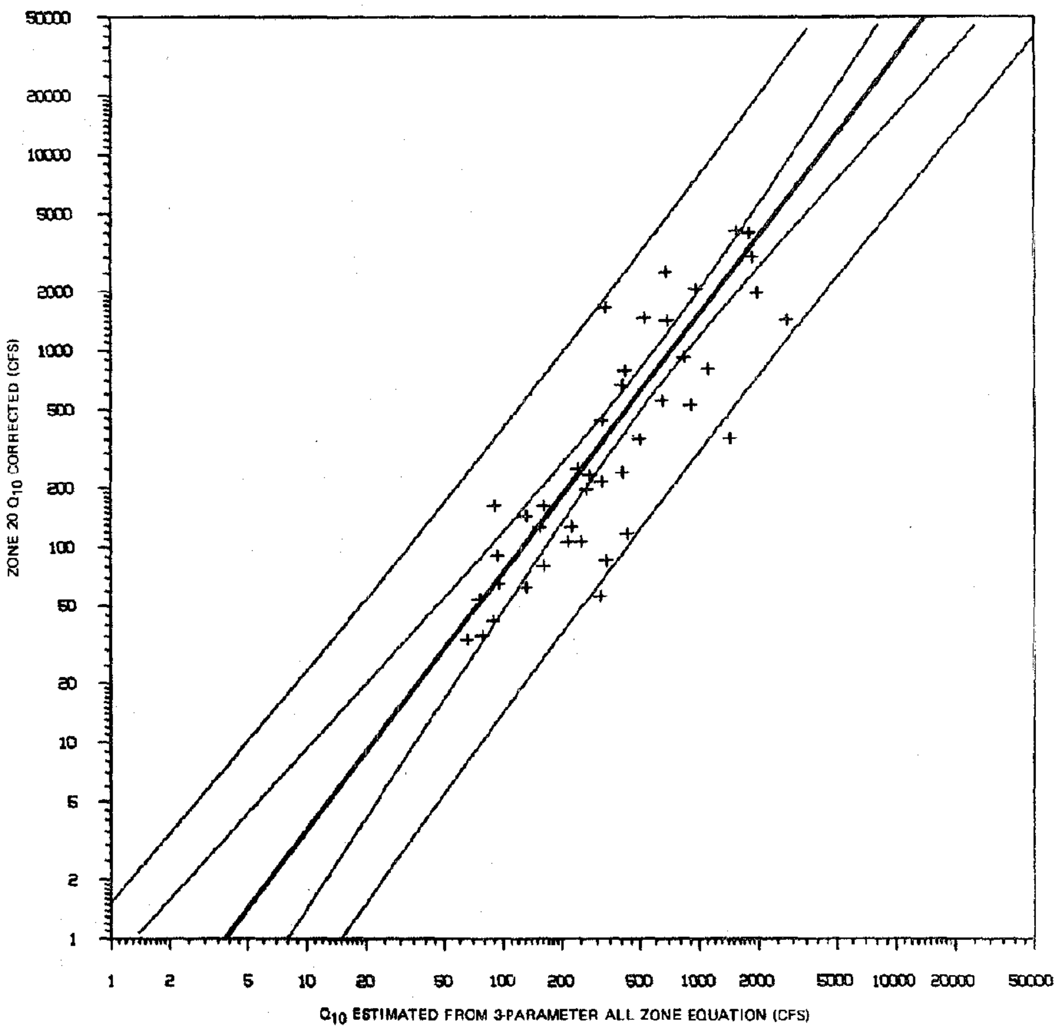
Appendix H-41. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 17 with the 95% confidence intervals for a mean and a point estimate shown.



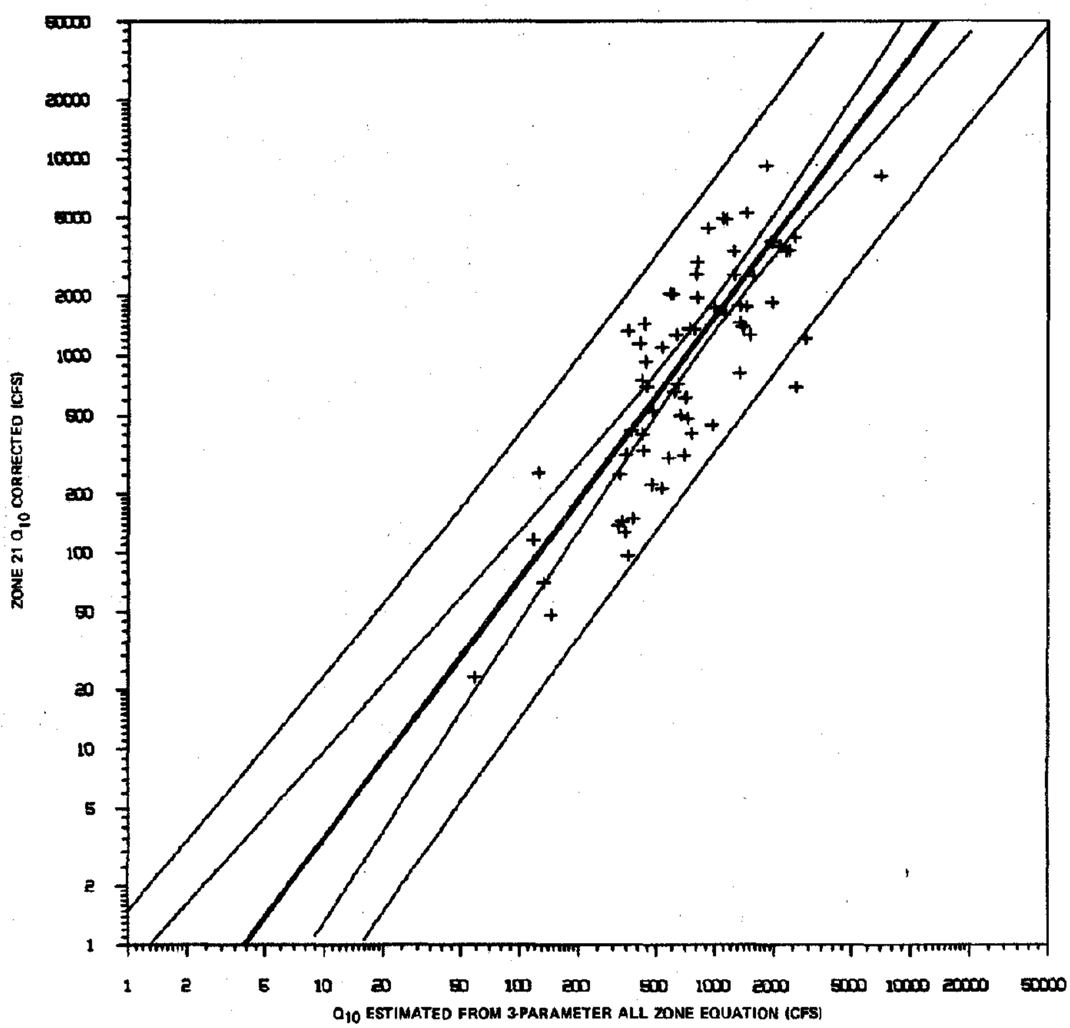
Appendix H-42. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 18 with the 95% confidence intervals for a mean and a point estimate shown.



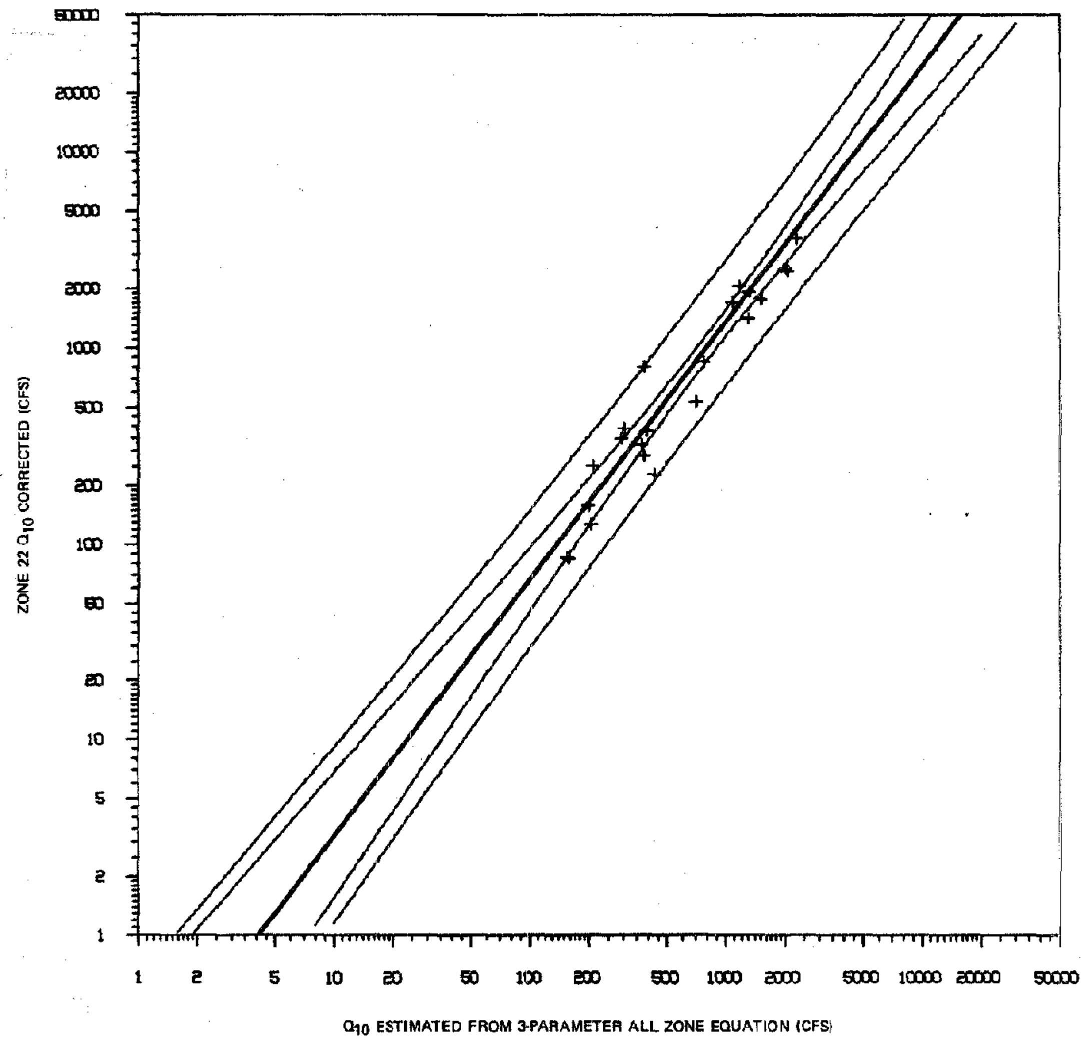
Appendix H-43. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 19 with the 95% confidence intervals for a mean and a point estimate shown.



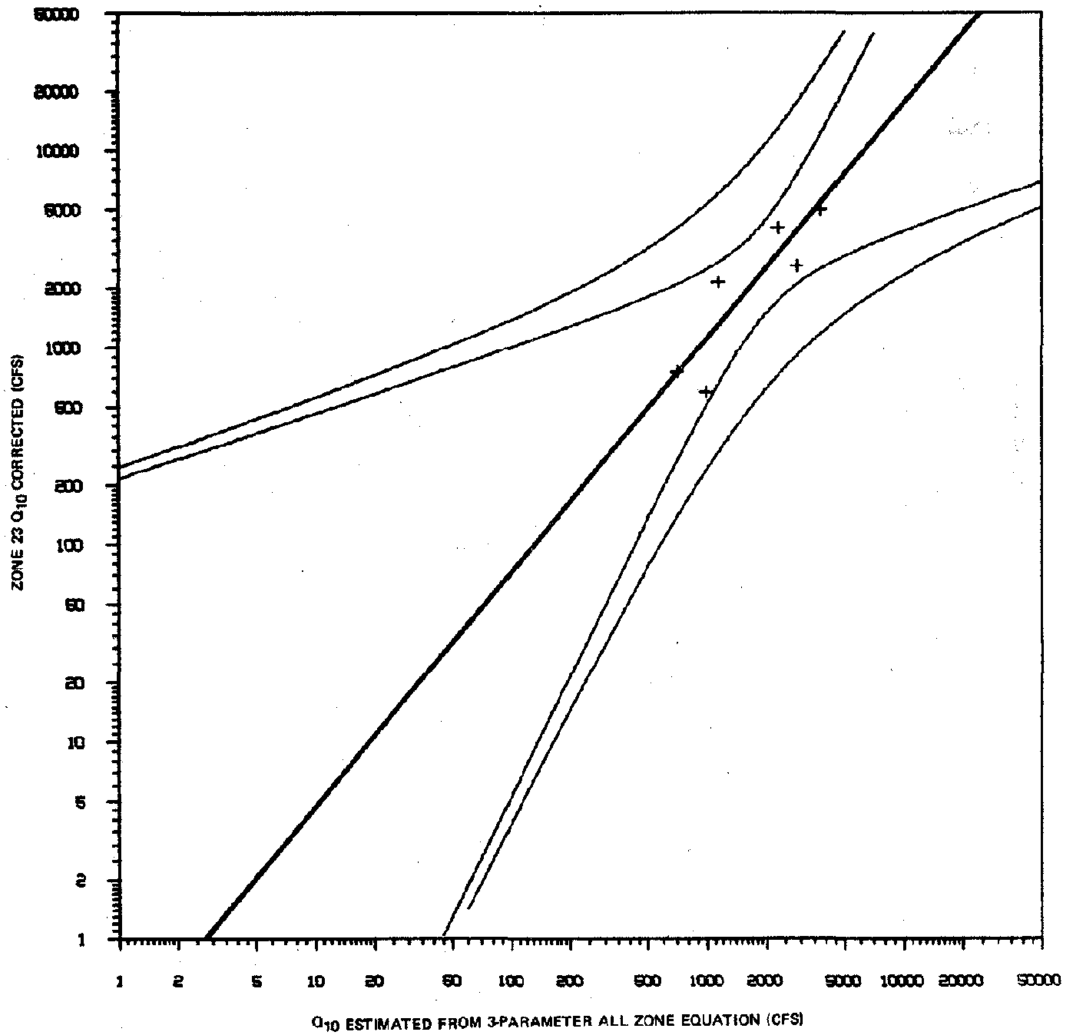
Appendix H-44. **Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 20 with the 95% confidence intervals for a mean and a point estimate shown.**



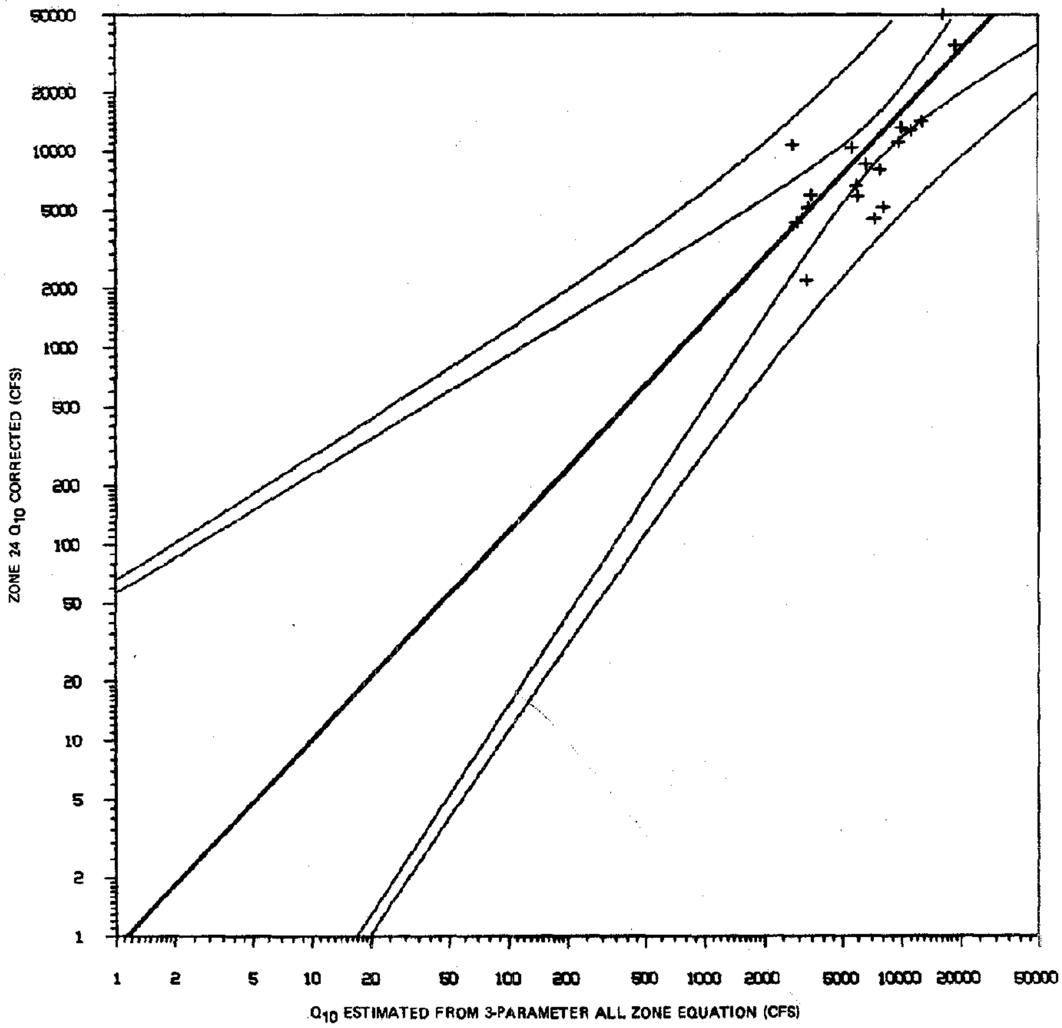
Appendix H-45. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 21 with the 95% confidence intervals for a mean and a point estimate shown.



Appendix H-46. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 22 with the 95% confidence intervals for a mean and a point estimate shown.



Appendix H-47. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 23 with the 95% confidence intervals for a mean and a point estimate shown.



Appendix H-48. Scatter diagram and correction curve for the 3-parameter all zone equation for Zone 24 with the 95% confidence intervals for a mean and a point estimate shown.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.