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HYDROLOGY MANUAL FOR ENGINEERING DESIGN AND FLOOD PLAIN MANAGEMENT WITHIN PIMA COUNTY, ARIZONA

SEPTEMBER, 1979

PIMA COUNTY
DEPARTMENT OF TRANSPORTATION AND FLOOD CONTROL DISTRICT
1313 SOUTH MISSION ROAD • TUCSON, ARIZONA 85713
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C. H. Huckelberry, R.L.S., P.E.
DIRECTOR

Dear User:

This Manual has been prepared for your use in the preparation of Hydrologic and Hydraulic Reports submitted to this Department for review and approval. As such, I am sure that it will be of benefit to you.

Although the use of this Manual will not be mandatory, I strongly recommend its use because I feel that it provides you with the best deterministic model that is presently available for the prediction of flood peaks from ungaged watersheds within Pima County, Arizona. Other prediction methods for estimating flood peaks will be accepted, but only provided that they meet with the prior approval of this Department.

Sincerely,

C. H. Huckelberry, R.L.S., P.E.
Director

CHH:mc

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DIRECTOR

MEMORANDUM

TO: All Holders of Hydrology Manual For Engineering Design and Flood Plain Management Within Pima County, Arizona

FROM: C.H. Huckelberry, R.L.S., P.E.
Director

DATE: September, 1979

RE: Hydrologic and Hydraulic Reports Submitted for Review and Approval to the Pima County Department of Transportation & Flood Control District

---

Each Hydrologic and Hydraulic Report submitted in conjunction with subdivision plats, development plans, and/or any other specific parcels of land which require drainage analysis, shall contain the following:

(1) A "Cover Sheet", which includes:

(a) Title of Report.
(b) Approximate location of project, including Section, Township & Range.
(c) Seal and Signature of a Registered Professional Civil Engineer.

(2) An "Introduction", which includes:

(a) Legal description of project, along with a Location Plan which shows the physical relationship of the project to nearby properties, as well as major streets and waterways within the immediate vicinity.
(b) A description of existing development within the watersheds affecting the project itself.
(c) A description of future development anticipated within the watersheds affecting the project, including the use(s) planned for the project.

(d) A recent aerial photo of the project area, at a scale no smaller than 1"=1,000'.

(e) Description of any physical features within the project, or contributing watersheds, which might be noteworthy from the standpoint of hydrologic and/or hydraulic considerations, such as ground cover, soil types, etc.

(f) A brief summary of any historical hydrologic and/or hydraulic information known to be available for the project. The source and date of information should be included.

(3) An "Objectives" section, which includes a brief description of the purpose of the report in relationship to development of the project.

(4) A "References" section, which contains all sources and dates of information used to compile the report.

(5) A "Procedure" section, which briefly describes the methodology and assumptions used in preparing the report.

(6) A "Computations" section, which includes:

(a) A watershed map, delineated on a 7.5 minute USGS quadrangle map or photocopy of same, which reflects the drainage areas and corresponding points of concentration affecting the project. A 15 minute USGS quadrangle map will be acceptable only for larger drainage areas, or when a 7.5 minute USGS quadrangle map is not available for the project area. Aerial photographs may only be employed as visual aids unless the drainage system and/or topographic relief is so ill-defined that use of USGS quadrangle maps alone is not possible. In such instances, elevations of the drainage divides, outlet points, points of significant slope breaks, as well as any other elevations which may be pertinent to hydrologic and hydraulic considerations, shall be included upon the aerial photographs utilized. <u>Watershed maps prepared on tracing paper are not acceptable</u>.

(b) All hydrologic data sheets prepared while determining the quantities of flow affecting the project, including design rainfall sheets. These sheets shall be identical in form to those provided in the Manual. A data sheet shall be required at each drainage concentration point where a significant watercourse enters and/or exits the project.

(c) All hydraulic data sheets prepared while determining the depth of flow, velocity of flow, and areal extent for each flood prone area contained within the project, clearly identified and labeled. Any sheets containing pertinent cross-sectional data, as well as all rating curves, shall be included. If computer analysis is employed, all input and output data shall be clearly labeled and included, along with cross-section sheets plotted to scale.

(d) All hydraulic sheets prepared in analyzing the influence upon the drainage within and/or adjacent to the project from existing and/or proposed structures such as levees, culverts, bridges, and roadways which act as weirs.

(7) A copy of a contour map or, if the project involves subdivision of land or commercial-industrial development, a copy of the tentative plat and/or development plan which includes:

(a) Delineation in a clear and precise manner of all flood prone areas subject to flows exceeding fifty (50) cubic feet per second (cfs.) during a 100-year flood event.

(b) Clear identification and labeling of each cross-section used in mapping the flood prone areas, so that easy cross-reference to associated hydrologic and hydraulic data sheets is possible.

(c) Labeling of all significant points of drainage concentration which enter and/or leave the project, accompanied by the quantities of flow and contributing drainage areas.

(d) Contours clearly plotted at intervals of two (2) feet, unless unusual topographic relief dictates otherwise.

(e) A scale no smaller than 1"=100', unless unusual physical features dictate otherwise.

(8) A "Results" section, which briefly discusses the findings of the report.

(9) A "Conclusion" and/or "Recommendations" section which describes in detail how the drainage affecting the project will be handled in a manner which will allow the development to occur as intended without conflicting with any State and/or County regulations or without adversly affecting adjacent properties and/or the project itself.

C.H. Huckelberry, R.L.S., P.E.
Director, Department of Transportation
and Flood Control District

CHH:cjq

HYDROLOGY MANUAL FOR ENGINEERING DESIGN AND FLOOD PLAIN MANAGEMENT WITHIN PIMA COUNTY, ARIZONA

FOR THE

PREDICTION OF PEAK DISCHARGES FROM SURFACE RUNOFF ON SMALL SEMIARID WATERSHEDS FOR 2-YEAR THROUGH 100-YEAR FLOOD RECURRENCE INTERVALS

Prepared By

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Tucson, Arizona
September, 1979

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PREFACE

The intent of this Manual is to provide a method for the prediction of peak discharges from surface runoff on small semi-arid watersheds that generates values which are consistent with observed flood peaks within Pima County, Arizona. No attempt will be made within the following pages to explain or examine the theory behind the method; but rather, the contents of this "Users Manual" are directed toward practical application with heavy emphasis on examples. An assumption has been made that the designer is familiar with the procedures presently in general use as aids to hydrologic analysis. For this reason, no discussion of the merits of these aids are contained herein. However, detailed hydrologic theory may be examined, if the user so desires, by study of the references listed at the end of this Manual.

The author wishes to gratefully acknowledge the continued cooperation and contributions provided during the preparation of this Manual by the Pima County Department of Transportation and Flood Control District, Tucson, Arizona; the United States Department of Agriculture Soil Conservation Service, Tucson and Phoenix, Arizona; the Southwest Rangeland Watershed Research Center, Western Region, Agricultural Research Service, United States Department of Agriculture, Tucson, Arizona; the United States Geological Survey, Tucson, Arizona; the United States Army Corps of Engineers, Los Angeles, California; the University of Arizona Water Resources Research Center, Tucson, Arizona; the Arizona Department of Transportation, Phoenix, Arizona; and the City of Tucson, Division of Engineering, Tucson, Arizona. In addition, the author is especially indebted to a large number of individuals whose names are too numerous to list; but without whose advice and criticisms, not to mention invaluable contributions, the completion of this Manual would not have been possible.

It is hoped that use of this Manual will minimize "hydrologic guesswork" and lead to the production of practically the same results when used by different individuals. This is of utmost necessity for areas, such as Pima County, Arizona, where lack of sufficient runoff-frequency data for small semiarid watersheds is available. However, whenever runoff data has been obtained, even in limited amounts, comparisons should be made with the results obtained via utilization of this Manual prior to the extrapolation of less frequent, more intense hydrologic events to other watersheds of similar hydrologic nature. Where inconsistencies or contradictions are apparent, the user is encouraged to contact the Pima County Department of Transportation and Flood Control District to dicuss and resolve same.

Finally, although its intended application is for engineering design and flood plain management with the boundaries of Pima County,

Arizona, the method may be applied to other semiarid southwest areas as well, provided adequate hydrologic data is available to determine the various factors.

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GENERAL OBJECTIVES

The need for accurately predicting peak rates of discharge which occur on the numerous small, ungaged semiarid watersheds within Pima County, Arizona; and, more importantly, the need for analysing the effects of urbanization upon hydraulic and hydrologic parameters which directly influence such peaks are the reasons for this Manual's composition. Because conditions are constantly changing during the transition from rural to urban land use, only empirical relationships between the parameters that affect runoff and peak rates of discharge have been developed at the present time. This Manual is the result of a considerable amount of research in developing these relationships in an attempt to provide a method for accurately predicting peak rates of discharge which may be expected to occur on both a frequent and infrequent basis. Nevertheless, procedures described within this Manual may be revised from time to time as more data becomes available. However, no revisions should be made by the user on existing relationships presently contained herein, as doing so could lead to serious errors in the estimation of peak rates of discharge from the watershed under investigation.

EFFECT OF URBANIZATION UPON HYDRAULIC AND HYDROLOGIC PARAMETERS

An urban or urbanizing watershed can be defined as an area in which all or part of the watershed will be covered by impervious structures, such as roads, sidewalks, parking lots and houses. Urban stream channels may also be supplemented by some form of artificial drainage system, such as paved gutters and storm sewers.

The effect of urbanization on the water regimen has long been recognized. Investigations to evaluate the factors involved have been going on for over 35 years. Ideally, hydrologic studies to determine volume and rates of runoff should be based on long-term stationary streamflow records for the area being investigated. Such records are seldom available for small drainage areas, and because of the time involved in converting a watershed from rural to urban conditions, available records normally are not adequate. It becomes necessary to estimate the magnitude and frequency of peak rates of runoff through modeling of measurable watershed characteristics. An understanding of these characteristics is required for judging how to alter parameters to reflect changing watershed conditions.

Urbanization of a watershed changes its response to precipitation. The most common effects are reduced infiltration and decreased travel time, which result in significantly higher peak rates of runoff. The volume of runoff is determined primarily by the amount of precipitation and by infiltration characteristics related to soil type, antecedent rainfall, type of vegetal cover, impervious surfaces and surface retention. Travel time is determined primarily by slope, flow length, depth of flow and roughness of flow surfaces. Peak rates of discharge are based on the relationship of the above parameters as well as the total drainage area of the watershed, the location of the development in relation to the total drainage area, and the effect of any flood control works or other man-made storage. Peak rates, especially within "thunderstorm prone" Pima County, Arizona, are also influenced by the distribution of rainfall within a given storm event.

RUNOFF VOLUME:

(a) Soil Group(s)

The increase in the volume of runoff due to urbanization depends more on the percentage of impervious area than on any of the other watershed constants. However, since urban areas are seldom completely covered by impervious structures, soil properties are an important factor in estimating the total volume of direct runoff. The infiltration and percolation rates of soils indicate their potential to absorb rainfall, and thereby reduce the amount of direct runoff. Soils having a high infiltration rate (sands or gravels) have a low runoff potential, and soils having a low infiltration rate (clays) have a high runoff potential. Urbanization on soils with a high

infiltration rate increases the volume of runoff and peak discharge more than urbanization on soils with a low infiltration rate. Additionally, investigations have shown that although runoff from small (less than annual) rainfall events comes primarily from the impervious areas,both the pervious and impervious areas contribute to runoff for the larger, less frequent events.

(b) Cover Type(s)

The type of cover and its hydrologic condition affects runoff volume through its influence on the infiltration rate of the soil. Fallow land yields more runoff than forested land for a given soil type. Covering areas with impervious material reduces surface storage and infiltration and increases the volume of runoff.

Some rainfall is retained on the surface and by vegetation before runoff begins. Interception is rainfall that is caught by foliage, twigs, branches, leaves, etc. This rainfall is lost to evaporation and, thus, never reaches the ground surface. Increasing the vegetal cover increases the amount of interception.

Surface depression storage begins when precipitation exceeds infiltration. Overland flow starts when the surface depressions are full. The water in depression storage is not available as direct runoff.

Initial abstraction is the sum of interception, depression storage and infiltration before runoff begins. It occurs on all types of cover, from pasture in good condition to concrete pavement. However, the amount of initial abstraction is less on concrete pavement than on pasture.

TIME OF CONCENTRATION:

Urbanization commonly increases the velocity at which water can flow from its point of impact on the watershed to the watershed outlet. The time of concentration is directly affected by the increased velocity. This parameter is widely used in determining peak rates of runoff.

Time of concentration is the time it takes for runoff to travel from the hydraulically most distant part of the watershed to the point of design. It is usually computed by determining the water travel time through the watershed, and is related to the physical properties of a watershed, such as area, length, surface roughness and slope. The extent of urbanization and stream modification affects the travel time of water through the watershed, which changes the time of concentration.

Two factors can contribute to a decrease in travel time. Urbanization generally decreases overland flow travel time by decreasing flow retardance and by reducing the interflow distance

because there are more points of interception by gutters and other conveyances. Channelization decreases travel time by increasing velocities in improved channels.

(a) Slope

Urbanization can change the effective slope of a watershed if flow paths are altered by channelization and by terracing areas for building lots, parking lots, roads and diversion ditches. The slopes of storm sewers, street gutters, roads, and overland flow areas as well as stream channels are significant in determining travel times through urban watersheds.

(b) Flow Length

Flow length may be reduced if natural meandering streams are changed to straight channels. It may be increased if overland flows are diverted through diversions, storm sewers or street gutters to larger collection systems.

(c) Surface Roughness

Flow velocity normally increases significantly when the flow path is changed from flow over rough surfaces of woodland, grassland, and natural channels to sheet flow over smooth surfaces of parking lots, diversions, storm sewers, gutters, lined channels, and paved streets.

GENERAL PROCEDURE

The method outlined within this Manual employs a concept in general use, namely that the peak discharge of a watershed occurs when the hydraulically most remote point of the watershed contributes at the outlet (i.e., the entire drainage area is contributing to the discharge). As a consequence of this fact, the most important factor needed for the determination of peak discharge is the often misused and misrepresented parameter "time of concentration", defined as the time required for water to travel from the hydraulically most remote point in the watershed to the outlet under investigation. A considerable amount of research has gone into the investigation of various formulas used to estimate the time of concentration for both gaged and ungaged watersheds. The equation which finally evolved for use within this Manual is semi-empirical in nature and is utilized because it has been determined that it reproduces with the most consistent accuracy measured peak discharges within Pima County, Arizona. The equation is:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{S_c^{.4}} q^{-.4}$$

where T_c is in hours, and:

n_b = A dimensionless constant which represents the visually estimated mean of the "n-factor", or roughness coefficient, of all principal watercourses within a watershed, hereafter to be referred to as the "basin factor".

L_c = The length of the longest watercourse within the watershed, in feet, measured from outlet to divide.

L_{ca} = The distance up the longest watercourse, in feet, from the outlet to a point opposite the center of the area of the watershed, or "length to center of gravity".

S_c = The mean slope, in feet/feet, of the longest watercourse within the watershed, as determined by the "incremental" or "uniform slope" method.

q = The runoff supply rate, in inches/hour.

50 = A conversion factor whose units are $ft^{.6}/in^{.4}\text{-}hr^{.6}$.

As can be seen from an inspection of this equation, the determination of T_c is an iterative process. Two (2) variables, T_c and q, are needed and neither are known at the beginning of the computation. Thus, as a first step, T_c is assumed, which is then used to compute q. The T_c associated with this computed q must be consistent with the assumed T_c. If the assumed T_c and that imposed by the computed

q do not compare favorably, a new T_c must be assumed, and the process repeated. Generally, three (3) interations are sufficient to get the assumed and computed T_c's to agree within ± .02 hours, or approximately one minute. When this condition is met, the watershed is assumed to be in "equilibrium". This should be the time at which the peak discharge occurs. (Note: It is usually best to convert T_c to minutes when its value will be less than one hour.)

The equation, therefore, differs from most formulas for time of concentration by the fact that recognition is given to the effect of rainfall depths (i.e., the hydraulic efficiency of the watershed is influenced by variable depths of flow), as well as the effect of hydraulic roughness upon travel time through a watershed.

The general procedure for the determination of peak discharge is a straightforward one once the time of concentration has been determined, and can be found by use of either of the following relationships:

i) $Q_p = 645.33qA$.

Where

645.33 = a conversion factor whose units are ft^3-hr/in-sec-sq. miles.

A = watershed area (square miles).

And

ii) $Q_p = 1.008qA$.

Where

1.008 = a conversion factor whose units are ft^3-hr/in-sec-acres.

A = watershed area (acres).

In both the aforementioned relationships, q represents the runoff supply rate as determined from the iterative solution of T_c. Also, as can be surmised from said relationships, the time of concentration (T_c) and time to peak (T_p) represent equivalent hydrologic parameters when used with the procedures described within this Manual. However, for the Manual's purposes, only the parameter time of concentration (T_c) shall be referred to in the future.

The following pages will provide both general guidelines and practical examples as to the application of this method over a wide range of hydrologic conditions which might be encountered within Pima County, Arizona. Although every attempt was made to analyze all conditions the designer might expect to encounter, there will no doubt be some that will arise which are not covered within these pages. In this event, the user is encouraged to contact the Pima County Department of Transportation and Flood Control District for discussion regarding the appropriate direction in which to proceed.

RECOMMENDED "PROCEDURAL APPROACH" FOR COMPUTING PEAK DISCHARGES

Step One (1):

From United States Geological Survey (U.S.G.S.) quad sheets and/or aerial photographs which cover the area containing the watershed under investigation, the contributing drainage area (A) should be determined, in acres or square miles.

Step Two (2):

From U.S.G.S. quad sheets and/or aerial photographs, the length of the longest watercourse (L_c) within the watershed under investigation should be determined from outlet to divide, in feet.

Step Three (3):

From U.S.G.S. quad sheets and/or aerial photographs, L_{ca} should be determined by visually estimating the center of the area (C_a) of the watershed under investigation, drawing a line perpendicular to L_c which passes through C_a, then measuring from this point to the outlet, in feet, a distance herein termed "the length to center of gravity".

Step Four (4):

From U.S.G.S. quad sheets and/or topographic maps, the streambed profile (change in length vs. change in elevation) for the longest watercourse within the watershed should be determined, and the mean slope (S_c) calculated as shown within the appendix section of this Manual (page 71).

Step Five (5):

From field investigation and/or aerial photographs and quad sheets, the watershed type should be determined. Consideration should be given to the maximum probable urbanization likely to occur within the watershed's boundaries when making such a determination.

Step Six (6):

From field investigation and/or aerial photographs, the basin factor (n_b) should be estimated from all principal watercourses within the watershed. Values to be used should correspond to those provided within the appendix section of this Manual (page 73).

Step Seven (7):

The 24-hour (P_{24}) and 6-hour (P_6) rainfall depths for the frequency storm under investigation should be determined from the National Weather Service (N.W.S.) charts provided within the appendix section of this Manual (pp. 76-93).

Step Eight (8):

The 1-hour (P_1), 2-hour (P_2) and 3-hour (P_3) rainfall depths for the frequency storm under investigation should be determined from the equations or charts provided within the appendix section of this Manual (pp.76-93).

Step Nine (9):

The appropriate soil group(s) within the area containing the watershed under investigation should be determined from the soils map provided within the appendix section of this Manual (page 97).

Step Ten (10):

The hydrologic soil-cover complex(es) and corresponding cover density (in percent) within the area under investigation should be determined via field investigation, examination of aerial photographs, or both.

Step Eleven (11):

From field investigation and/or aerial photographs, zoning maps and area plans, the degree of imperviousness (in percent) should be determined for maximum anticipated urbanization of the entire watershed under investigation. These values should generally correspond to those provided within the appendix section of this Manual (page 103).

Step Twelve (12):

A curve number (CN) should be determined for each type of hydrologic soil group within the watershed under investigation from the chart provided within the appendix section of this Manual (page 107).

Step Thirteen (13):

Using the curve numbers (CN's) determined from Step Twelve (12), for the natural (pervious) areas, an adjusted curve number (CN*) should be determined separately for each and a constant curve number of 99 chosen for all impervious areas. The adjusted curve numbers (CN*'s) should be determined by use of the chart and relationship provided within the appendix section of this Manual (page 108).

Step Fourteen (14):

Using the adjusted curve numbers (CN*'s) determined from Step Thirteen (13), and a constant curve number of 99 for all impervious areas, runoff to rainfall ratios (C's) for each area should be determined in accordance with the procedures described within the appendix section of this Manual (page 109).

Step Fifteen (15):

The runoff supply rate (q) should be determined by the method outlined within the appendix section of this Manual (page 109).

Step Sixteen (16):

Utilizing all of the appropriate values determined from Steps One (1) through Fifteen (15), the time of concentration (T_c) should be determined via use of the equation and iterative process outlined within the "General Procedure" section of this Manual. (Since the runoff supply rate (q) determined in Step Fifteen (15) is a function of the intensity (i), it is best to substitute i in place of q in the equation for the time of concentration (T_c) before beginning the iterative process so that the solution of the equation can be in terms of the known variable, intensity (i). The values for intensities may be determined from the charts and/or equations provided within the appendix section of this Manual) (page 113).

Step Seventeen (17):

Once the time of concentration (T_c) has been determined through the iterative process, the intensity (i) associated with said time should be substituted back into the relationship between itself and the runoff supply rate (q), thus establishing a numerical value for q.

Step Eighteen (18):

As the final step, the peak rate of discharge is determined from either of the following relationships:

i) $Q_p = 645.33qA$ (where A = square miles).

ii) $Q_p = 1.008qA$ (where A = acres).

(It should be noted at this point that if nonhomogeneity exists to any marked degree within the watershed, it becomes necessary to add an additional step in order to determine peak discharge. This additional step is described both within Example Five (5) and the appendix section of this Manual) (page 116).

GENERAL GUIDELINES

(a) For purposes of reports submitted to the Pima County Department of Transportation and Flood Control District, the 100-year frequency storm shall be of primary interest; the assumption being made that said storm generates the 100-year frequency flood.

(b) When times of concentration (T_c's) are in excess of three (3) hours or when rainfall depths are less than .88 inches, watersheds under investigation should be subdivided into smaller "subareas" and the peak discharges from same combined through flood routing techniques to produce the peak discharge from the entire watershed at the outlet in question.

(c) Hydrologic and hydraulic reports submitted to the Pima County Department of Transportation and Flood Control District should include hydrologic data sheets identical to those provided within the appendix section of this Manual, or be composed in a manner which incorporates all the components contained therein (see page 123).

(d) The determination of basin factors, intensities, degrees of imperviousness of a watershed, adjustments to curve numbers, hydrologic soil groups, vegetative cover and rainfall depths shall be in accordance with the values provided within the appendix section of this Manual, or supportive evidence in the form of documentation and/or photographs should be submitted to justify otherwise.

(e) When the area of a watershed under investigation exceeds ten (10) square miles, areal reduction of rainfall should be in accordance with depth-area curves developed by the National Weather Service for use in the determination of rainfall depth-frequency relationships. These are provided within the appendix section of this Manual(see page 91).

(f) When watersheds under investigation exhibit nonhomogeneity to any marked degree, division into "subareas" should be made and peak discharges for each subarea calculated separately. These subarea peaks should then be combined as outlined within the appendix section of this Manual(see page 116).

(g) A minimum time of concentration of five (5) minutes should be used where paths of flow are short and drainage areas small.

(h) In general, the maximum density for Desert Brush cover within Pima County, Arizona, should not exceed forty (40) percent.

(i) If the factor L_{ca} is difficult to measure reliably due to complicated drainage patterns or unusually shaped watersheds, the relationship $L_{ca} = 1/2\ L_c$ may be used in lieu thereof.

(j) When estimating a weighted basin factor ($\bar{n}_b$) for nonhomogeneous areas, weighting should be done by either (1): proportionalities of main channel lengths; or (2): contributing watershed areas, whichever applicable (see appendix - page 116).

(k) For purposes of hydraulic design, where structures are involved, the runoff supply rate (q) should not be less than ten percent (10%) of the rainfall intensity (i.e., $q \geq .10\ i$).

(l) When two (2) or more watercourses within a homogeneous watershed are of approximately equal length, times of concentration (T_c's) should be computed for each and the average value of said times used to determine the runoff supply rate (q) and corresponding peak discharge (Qp).

(m) When estimating L_{ca}, it is generally acceptable to do so by first locating the point along the longest watercourse (L_c) above and below which lie equal areas of the watershed, and then measuring from this point along said watercourse to the outlet under investigation, in feet.

(n) To calculate the mean slope (S_c), the number of incremental lengths utilized should be based upon the amount of change along the profile of the main channel length (L_c). New increments of length should be initiated whenever a significant change along said profile becomes apparent.

EXAMPLES

EXAMPLE ONE (1)

Determine the peak discharge (Qp) for a 100-year frequency flood within an ungaged, undeveloped watershed with well-defined channels and predominantly in the "foothills area", topographically.

The simplest case will be assumed - no urbanization of the watershed shall ever occur in the future. Then, following Steps One (1) through Eighteen (18) of the "Procedural Approach", yields:

1. Drainage Area = 1.80 square miles.
2. L_c = 20,000 feet.
3. L_{ca} = 11,000 feet.
4. Streambed Profile:

Incremental Change in Length (L_i)	Incremental Change in Height (H_i)
4,000 ft.	220 ft.
6,000 ft.	170 ft.
10,000 ft.	130 ft.

Then, by calculation:

$$I = \left[\frac{(4000)^3}{220}\right]^{\frac{1}{2}} + \left[\frac{(6000)^3}{170}\right]^{\frac{1}{2}} + \left[\frac{(10,000)^3}{130}\right]^{\frac{1}{2}} \text{ feet.}$$

$$I = 140,407.17 \text{ feet.}$$

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{20,000}{140,407.17}\right]^2 = .0203 \text{ ft./ft.}$$

5. Watershed Type = foothills.

6. Examination of aerial photographs and field investigation indicates that the principal watercourses show little or no evidence of braiding, contain some growth and/or stones, and have a good conveyance capacity. Therefore, in accordance with the values provided within the appendix section of this Manual, n_b = .035.

7. 24-hour, 100-year rainfall (P_{24}^{100}) = 4.62 inches.
   6-hour, 100-year rainfall (P_6^{100}) = 3.63 inches.
   (Since the watershed area is less than ten (10) square miles, areal reduction is not required).

8. 1-hour, 100-year rainfall (P_1^{100}) = 2.65 inches.
   2-hour, 100 year rainfall (P_2^{100}) = 2.98 inches.
   3-hour, 100-year rainfall (P_3^{100}) = 3.21 inches.
   (Again, areal reduction does not apply).

9. The hydrologic soil group is determined to be entirely of Group B.

10. Aerial photographs indicate a Desert Brush cover of approximately fifteen percent (15%).

11. No imperviousness exists within the watershed.

12. The curve number (CN) for the watershed is determined to be 83.

13. The <u>adjusted</u> curve number (CN*) is determined as follows:

$$CN^* = \frac{93\ (2.65-.88) + 66.00}{2.65} = 87.02\ .$$

14. Since there are no impervious areas within the watershed, no adjustment of the runoff to rainfall ratio (C) is necessary (since $C_I=0$, in this case). The "weighted" runoff ratio (C_W) is simply equal to the value determined by using the <u>adjusted</u> curve number (CN*) found in Step Thirteen (13).

Then

$$C_p = C_w = \frac{[2.65 - .2(1.49)]^2}{2.65[2.65+.8(1.49)]} = .543.$$

15. The runoff supply rate becomes:

$$q = C_w i = .543i \text{ inches/hour.}$$

[Note: For small drainage areas (less than one (1) square mile), accuracy to two (2) decimal places would be sufficient].

16. Using all of the appropriate values found in Steps One (1) through Fifteen (15), the time of concentration (T_C) is determined to be:

$$T_C = \frac{.035}{50} \frac{[(20,000)(11,000)]^{.3}}{(.0203)^{.4}} (.543i)^{-.4} \text{ hours.}$$

$$T_C = 1.35i^{-.4} \text{ hours.}$$

(Accuracy to two (2) decimal places is sufficient).

Now, we proceed to solve for T_C via the iterative process described within the "General Procedure" section of this Manual.

First, try

$$T_C = \text{one (1) hour.}$$

With

$$T_C = \text{one (1) hour, } i = 2.65 \text{ inches/hour.}$$

Then

$$T_C = 1.35(2.65)^{-.4} = .91 \text{ hours.}$$

Since the computed T_C is shorter than the assumed T_C, too long of a time was assumed. In addition, it is apparent that T_C will be less than one (1) hour; therefore, T_C should be converted to minutes.

Then

$$T_c = 81.0i^{-.4} \text{ minutes.}$$

(Accuracy to one (1) decimal place is sufficient).

Now, try

$$T_c = 45 \text{ minutes.}$$

For

$$T_c = 45 \text{ minutes, } i = FP_1 = (1.22)2.65 = 3.23 \text{ inches/hour.}$$

Then

$$T_c = 81.0(3.23)^{-.4} = 50.7 \text{ minutes.}$$

(The assumed T_c is too short).

Now, try

$$T_c = 53 \text{ minutes.}$$

For

$$T_c = 53 \text{ minutes, } i = FP_1 = (1.09)2.65 = 2.89 \text{ inches/hour.}$$

Then

$$T_c = 81.0(2.89)^{-.4} = 53 \text{ minutes.}$$

$$T_c = \underline{53 \text{ minutes.}}$$

17. Now, the runoff supply rate (q) is determined to be:

$$q = .543(2.89) = 1.57 \text{ inches/hour.}$$

(Since i = 2.89 inches/hour, at T_c = 53 minutes).

18. As the final step, the peak discharge for the 100-year frequency flood is determined to be:

$$Q_p^{100} = 645.33(1.57)(1.80) \text{ cfs.}$$

$$Q_p^{100} = \underline{\underline{1824 \text{ cfs.}}}$$

HYDROLOGIC DATA SHEET

Project Name and Location: Example One (1)

Drainage Concentration Point: —

Watershed Area (A): 1.80 acres/square miles.

Length of Watercourse (L_c): 20,000 ft. Length to Center of Gravity (L_{ca}): 11,000 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
4000	220
6000	170
10,000	130

Mean Slope (S_c): .0203 ft./ft. Watershed Type(s): Foothills ~~(future)~~

Basin Factor (n_b): .035 ~~(future)~~ Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.62 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.63 in. Areal Value: N/A in.

P_1 (1 hour): 2.65 in. Areal Value: N/A in.

P_2 (2 hour): 2.98 in. Areal Value: N/A in.

P_3 (3 hour): 3.21 in. Areal Value: Not Applicable in.

Soil Group(s): 100% B Cover Type(s): Desert Brush

Cover Density (pervious areas): 15% Impervious Cover: N/A ~~(future)~~

CN(s): 83 (pervious ~~& impervious~~ areas) CN*(s): 87.02
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .543 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .543 i in./hr. (function of i)

Time of Concentration (T_c): 1.35 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 53 hrs./mins.

Rainfall Intensity (i) at T_c: 2.89 in./hr.

Runoff Supply Rate (q) at T_c: 1.57 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 1824 cfs.

Note: For impervious areas, CN* = 99 (constant).

EXAMPLE TWO (2)

The identical watershed as described in Example One (1) will be used, but it is assumed that CR-1 (one residence per acre) development, evenly distributed throughout, will occur in the future. Determine the peak discharge for a 100-year frequency storm (Q_p^{100}).

Again, following Steps One (1) through Eighteen (18) of the "Procedural Approach", yields:

1. Drainage Area = 1.80 square miles.
2. L_c = 20,000 feet.
3. L_{ca} = 11,000 feet.
4. Mean channel slope (S_c) = .0203 ft./ft.
5. Watershed Type = suburban-foothills.
6. Basin Factor (n_b) = .032.
7. P_{24}^{100} = 4.62 inches, P_6^{100} = 3.63 inches.
8. P_1^{100} = 2.65 inches, P_2^{100} = 2.98 inches, P_3^{100} = 3.21 inches.

At this point, an examination of Steps One (1) through Eight (8) should be made. In Step Two (2), it is assumed that CR-1 development will not significantly alter the lengths of the paths of flow within the watershed. This is generally a valid assumption if drainage is to be carried in existing natural watercourses. However, if the paths of flow were to be over paved streets or within constructed channels, L_c would have to be modified accordingly, where applicable. In Step Five (5), it is assumed that slopes are unaltered as well. This is a safe assumption for most developments with only one residence per acre. In Step Six (6), it is assumed that the "basin roughness" or "resistance to flows" within the watershed is only modified slightly. Again, this is a safe assumption for most CR-1 type developments. However, where paths of flow are directed along paved streets (curbed) and/or contained within constructed channels, the basin factor (n_b) should be adjusted accordingly.

9. The hydrologic soil group is Group B.

10. The Desert Brush cover remains at fifteen percent (15%). It is not expected that urbanization will modify the existing natural vegetation or introduce grasses or landscaping to any significant degree.

11. The degree of imperviousness is estimated to be approximately twenty percent (20%).

12. The curve number (CN) for the watershed's pervious areas equals 83.

13. The adjusted curve number (CN*) for the natural (pervious) areas becomes:

CN* = 87.02 [as in Example One (1)].

The curve number (CN) and adjusted curve number (CN*) for the impervious areas of the watershed are both equal to 99. No adjustment is necessary since this value is assumed to be a constant.

14. The runoff to rainfall ratios (C_p and C_I) are determined to be:

$$C_p = \frac{[2.65 - .2(1.49)]^2}{2.65[2.65+.8(1.49)]} = .543 \text{ (pervious areas).}$$

$$C_I = \frac{[2.65 - .2(.101)]^2}{2.65[2.65+.8(.101)]} = .956 \text{ (impervious areas).}$$

15. The runoff supply rate (q) becomes:

$$q = C_w i = [.20(.956) + .80(.543)]i = .626i \text{ inches/hour.}$$

16. From the appropriate values obtained in Steps One (1) through Fifteen (15), the time of concentration (T_c) is determined to be:

$$T_c = \frac{.032}{50} \frac{[(20,000)(11,000)]^{.3}}{(.0203)^{.4}} (.626i)^{-.4} \text{ hours.}$$

$$T_c = 70.1\ i^{-.4} \text{ minutes.}$$

Here, it is assumed that T_c will be less than one (1) hour as a consequence of results obtained in Example One (1).

Now, we proceed with the iterative solution of T_c:

First, try

$$T_c = 45 \text{ minutes.}$$

With

$$T_c = 45 \text{ minutes, } i = FP_1 = (1.22)2.65 = 3.23 \text{ inches/hour.}$$

Then

$$T_c = 70.1(3.23)^{-.4} = 43.9 \text{ minutes.}$$

(The assumed T_c is too long).

Now, try

$$T_c = 43 \text{ minutes.}$$

With

$$T_c = 43 \text{ minutes, } i = FP_1 = (1.25)2.65 = 3.31 \text{ inches/hour.}$$

Then

$$T_c = 70.1(3.31)^{-.4} = 43.4 \text{ minutes.}$$

This is accuracy to within ± one (1) minute (± .02 hours). Therefore, assume

$$T_c = \underline{43 \text{ minutes.}}$$

17. Now, the runoff supply rate (q) is determined to be:

$$q = .626(3.31) = 2.07 \text{ inches/hour.}$$

(Since i = 3.31 inches/hour, at T_c = 43 minutes).

18. As the final step, the peak discharge for the 100-year frequency storm is computed:

$$Q_p^{100} = 645.33(2.07)(1.80) \text{ cfs.}$$

$$Q_p^{100} = \underline{\underline{2404 \text{ cfs.}}}$$

As can be seen in this Example, the net effect of CR-1 development upon the peak discharge of the watershed under investigation is to increase same from 1824 cfs. to 2404 cfs., an increase of 580 cfs., or approximately 31.8%.

HYDROLOGIC DATA SHEET

roject Name and Location: Example Two (2)

Drainage Concentration Point: ——

atershed Area (A): 1.80 acres/square miles.

Length of Watercourse (L_c): 20,000 ft. Length to Center of Gravity (L_{ca}): 11,000 ft.

ncremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
4000	220
6000	170
10,000	130

lean Slope (S_c): .0203 ft./ft. Watershed Type(s): Suburban - Foothills (future)

Basin Factor (n_b): .032 (future) Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.62 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.63 in. Areal Value: N/A in.

P_1 (1 hour): 2.65 in. Areal Value: N/A in.

P_2 (2 hour): 2.98 in. Areal Value: N/A in.

P_3 (3 hour): 3.21 in. Areal Value: Not Applicable in.

Soil Group(s): 100% B Cover Type(s): Desert Brush + Impervious

Cover Density (pervious areas): 15% Impervious Cover: 20% (future)

CN(s): 83 & 99 (pervious & impervious areas) CN*(s): 87.02 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .543 (pervious areas) .956 (impervious areas)

Rumoff Supply Rate (q): .626 i in./hr. (function of i)

Time of Concentration (T_c): 70.1 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 43 hrs. mins.

Rainfall Intensity (i) at T_c: 3.31 in./hr.

Runoff Supply Rate (q) at T_c: 2.07 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 2404 cfs.

Note: For impervious areas, CN* = 99 (constant).

EXAMPLE THREE (3)

This Example will be for a watershed predominantly in a "valley area", topographically. The watershed is to be developed into a CR-3 [three (3) residences per acre] urbanized area, evenly distributed throughout. Determine the peak discharge for the 100-year frequency storm (Q_p^{100}).

Proceeding as in the previous examples yields:

1. Drainage area = 460 acres.
2. L_c = 10,000 feet.
3. L_{ca} = 6,000 feet.
4. Streambed Profile:

Incremental Change in Length (L_i)	Incremental Change in Height (H_i)
3,500 ft.	80 ft.
6,500 ft.	49 ft.

Then, by calculation:

$$I = \left[\frac{(3500)^3}{80}\right]^{\frac{1}{2}} + \left[\frac{(6500)^3}{49}\right]^{\frac{1}{2}} = 98{,}014.15 \text{ feet.}$$

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{10{,}000}{98{,}014.15}\right]^2 = .0104 \text{ ft./ft.}$$

Before proceeding to Step Six (6), it is necessary to analyze the assumptions made in Steps One (1) through Five (5). Regardless of the use to which the watershed will be put, the area will remain a constant. However, it is quite probable that with high density development, such as CR-3, both the lengths and slopes of paths of flow may be altered considerably. Since in the present example, there is no plat available to determine paths of flow, it is assumed that the longest path determinable would not be greater than the length of the longest watercourse (L_c) to the divide. It is also assumed that the majority of drainage will be carried in curbed streets or constructed earthen channels, and that these streets and channels will be constructed to match existing grades. Therefore, the mean slope (S_c) will also remain the same as under natural conditions. However, it cannot be over-emphasized that when a plat is available (which should normally be the case), final paths of flow and mean slopes of same should be based upon its design.

5. Watershed Type = moderately urbanized.

6. Since the majority of the drainage will be within curbed streets or constructed earthen channels, most paths of flow will be over hydraulically efficient surfaces. Therefore, in accordance with the values recommended within the appendix section of this Manual, n_b = .022.

7. 24-hour, 100 year rainfall (P_{24}^{100}) = 4.07 inches.
6-hour, 100-year rainfall (P_6^{100}) = 3.28 inches.

(Areal reduction is not required).

8. 1-hour, 100-year rainfall (P_1^{100}) = 2.49 inches.
2-hour, 100-year rainfall (P_2^{100}) = 2.76 inches.
3-hour, 100-year rainfall (P_3^{100}) = 2.94 inches.

(Areal reduction is not required).

9. The hydrologic soil groups are found to consist of 80% Group B and 20% Group D.

10. Desert Brush cover is approximately thirty percent (30%); however, it is assumed that the pervious areas of the development will be grassed or landscaped with other than native vegetation (i.e., Urban Lawns). The amount of cover shall be estimated to be "poor" upon completion of said development.

11. The degree of imperviousness will be thirty-five percent (35%) upon completion of the development.

12. A curve number (CN) of 83 is chosen for the Type B soils, and a curve number (CN) of 91 for the Type D soils.

13. The adjusted curve numbers (CN*s) are determined to be:

$$CN^* = \frac{93.00(2.49-.88) + 66.00}{2.49} = 86.64 \text{ (Group B).}$$

$$CN^* = \frac{97.00(2.49-.88) + 75.24}{2.49} = 92.94 \text{ (Group D).}$$

The adjusted curve number (CN*) for the impervious areas is equal to 99.

14. The runoff to rainfall ratios become:

$$C_P^B = \frac{[2.49-.2(1.54)]^2}{2.49[2.49+.8(1.54)]} = .51 \text{ (Group B - pervious areas).}$$

$$C_P^D = \frac{[2.49-.2(.760)]^2}{2.49[2.49+.8(.760)]} = .71 \text{ (Group D - pervious areas).}$$

$$C_I = \frac{[2.49-.2(.101)]^2}{2.49[2.49+.8(.101)]} = .95 \text{ (Impervious areas).}$$

15. The runoff supply rate (q) is calculated as follows:

$$q = C_w i = [.65(.80)(.51) + .65(.20)(.71) + .35(.95)]i \text{ in./hr.}$$

Then

$q = .69i$ inches/hour. (Accuracy to two (2) decimal places is sufficient for drainage areas less than one (1) square mile).

16. Using the appropriate values found in Steps One (1) through Fifteen (15), the time of concentration (T_c) is determined to be:

$$T_c = \frac{.022}{50} \left[\frac{(10,000)(6,000)}{(.0104)^{.4}}\right]^{.3} (.69i)^{-.4} \text{ hours.}$$

$$T_c = 41.0i^{-.4} \text{ minutes.}$$

(T_c is converted to minutes since the coefficient in front of $i^{-.4}$ is less than 1.00).

Proceeding with the iterative solution of T_c:

First, try

$$T_c = 30 \text{ minutes.}$$

With

$$T_c = 30 \text{ minutes, } i = FP_1 = (1.58)2.49 = 3.93 \text{ inches/hour.}$$

Then

$$T_c = 41.0(3.93)^{-.4} = 23.7 \text{ minutes.}$$

(The assumed T_c is too long).

Now, try

$$T_c = 22 \text{ minutes.}$$

With

$$T_c = 22 \text{ minutes, } i = FP_1 \ (1.89)2.49 = 4.71 \text{ inches/hour.}$$

Then

$$T_c = 41.0(4.71)^{-.4} = 22.1 \text{ minutes.}$$

This is accuracy to within one (1) minute ($\pm$ .02 hours).

Therefore, assume

$$T_c = \underline{22 \text{ minutes.}}$$

17. Now, the runoff supply rate (q) becomes:

$$q = .69(4.71) = 3.25 \text{ inches/hour.}$$

(Since $i = 4.71$ inches/hour , at $T_c = 22$ minutes).

18. As the final step, the peak discharge for the 100-year frequency flood is calculated to be:

$$Q_p^{100} = 1.008(3.25)(460) \text{ cfs.}$$

$$Q_p^{100} = \underline{\underline{1507 \text{ cfs}}}.$$

In this example, it was assumed that very few yards would be grassed or landscaped upon completion of development. In light of current steps to encourage water conservation within Pima County, Arizona, this assumption would seem valid for future developments of the nature described herein. Therefore, in anticipation of this probability, the designer may wish to merely assume that native vegetation shall remain basically predominant, and proceed accordingly.

HYDROLOGIC DATA SHEET

:oject Name and Location: Example Three (3)

Drainage Concentration Point: ———

ıtershed Area (A): 460 (acres) square miles.

Length of Watercourse (L_c): 10,000 ft. Length to Center of Gravity (L_{ca}): 6000 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3500	80
6500	49

ean Slope (S_c): .0104 ft./ft. Watershed Type(s): Moderately Urbanized (future)

Basin Factor (n_b): .022 (future) Flood Frequency: 100 yrs.

24 (24 hour): 4.07 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.28 in. Areal Value: N/A in.

P_1 (1 hour): 2.49 in. Areal Value: N/A in.

2 (2 hour): 2.76 in. Areal Value: N/A in.

P_3 (3 hour): 2.94 in. Areal Value: Not Applicable in.

oil Group(s): 80% B & 20% D Cover Type(s): Urban Lawns + Impervious

Cover Density (pervious areas): "Poor" Impervious Cover: 35% (future)

CN(s): 83 & 91 & 99 (pervious & impervious areas) CN*(s): 86.64 & 92.94 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .51 & .71 (pervious areas) .95 (impervious areas)

Runoff Supply Rate (q): .69 i in./hr. (function of i)

Time of Concentration (T_c): 41.0 $i^{-.4}$ hrs. (mins.) (function of i)

Iterative Solution of T_c: 22 hrs. (mins.)

Rainfall Intensity (i) at T_c: 4.71 in./hr.

Runoff Supply Rate (q) at T_c: 3.25 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 1507 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

EXAMPLE FOUR (4)

An individual owns a ten (10) acre parcel at the corner of a busy intersection. He desires to develop this acreage as a shopping center to serve the local residents. There is a natural drainage pattern which crosses the property from a generally northeasterly to southwesterly direction. No off-site drainage affects the property. Determine the peak discharge for the 100-year frequency flood (Q_p^{100}).

Following the "Procedural Approach", as in previous examples, yields:

1. Drainage Area = 10 acres.
2. L_c = 900 feet.
3. L_{ca} = 450 feet.
4. The mean slope (S_c) of the area is determined to be .0130 ft./ft. from a grading plan of the proposed shopping center. The area will be graded to drain to the same outlet point as under natural conditions.

5. Watershed Type = commercial.

6. Since paths of flow will be entirely over paved surfaces, an n_b = .018 is chosen in accordance with the values recommended within the appendix section of this Manual.

7. 24-hour, 100-year rainfall (P_{24}^{100}) = 4.78 inches.
   6-hour, 100-year rainfall (P_6^{100}) = 3.85 inches.

   (Areal reduction is not required).

8. 1-hour, 100-year rainfall (P_1^{100}) = 2.84 inches.
   2-hour, 100-year rainfall (P_2^{100}) = 3.18 inches.
   3-hour, 100-year rainfall (P_3^{100}) = 3.41 inches.

   (Areal reduction is not required).

9. The soils map indicates that the area is entirely contained within hydrologic Group B.

10. In this example, natural soil cover-complexes will be removed and replaced with impervious surfaces.

11. The degree of imperviousness will be 100%.

12. A curve number (CN) for the pervious areas is not applicable.

13. An adjusted curve number (CN*) for the pervious areas is not applicable. An adjusted curve number (CN*) of 99 is used for the impervious areas.

14. The runoff to rainfall ratios are:

$C_p = 0$ (pervious areas).

$C_I = .96$ (impervious areas).

15. The runoff supply rate (q) is calculated to be:

$$q = [1.00(.96) + 0.00]i = .96i \text{ inches/hour.}$$

16. Using the appropriate values found in Steps One (1) through Fifteen (15), the time of concentration (T_c) is determined to be:

$$T_c = \frac{.018}{50} \frac{[(900)(450)]^{.3}}{(.0130)^{.4}} (.96i)^{-.4} \text{ hours.}$$

$$T_c = 6.0i^{-.4} \text{ minutes.}$$

Proceeding with the iterative solution of T_c:

Try $T_c = 5$ minutes.

For $T_c = 5$ minutes, $i = FP_1 = 3.48(2.84) = 9.88$ inches/hour.

Then $T_c = 6.0(9.88)^{-.4} = 2.4$ minutes.

Now, since the assumed T_c was too long, but the value computed was less than the recommended minimum for T_c (5 minutes), it is unnecessary to proceed further.

Therefore, assume

T_c = <u>5 minutes</u>.

17. Now, the runoff supply rate (q) is determined to be:

$$q = .96(9.88) = 9.48 \text{ inches/hour.}$$

(Since i = 9.88 inches/hour, at T_c = 5 minutes).

18. As the final step, the peak discharge for the 100-year frequency storm is computed:

$$Q_p^{100} = 1.008(9.48)(10) \text{ cfs.}$$

Q_p^{100} = <u>95.6 cfs</u>.

HYDROLOGIC DATA SHEET

Project Name and Location: Example Four (4)

Drainage Concentration Point: ——

Watershed Area (A): 10 acres/square miles.

Length of Watercourse (L_c): 900 ft. Length to Center of Gravity (L_{ca}): 450 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
900	12

Mean Slope (S_c): .0130 ft./ft. Watershed Type(s): Commercial (future)

Basin Factor (n_b): .018 (future) Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.78 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.85 in. Areal Value: N/A in.

P_1 (1 hour): 2.84 in. Areal Value: N/A in.

P_2 (2 hour): 3.18 in. Areal Value: N/A in.

P_3 (3 hour): 3.41 in. Areal Value: Not Applicable in.

Soil Group(s): 100% B Cover Type(s): Impervious Surfaces

Cover Density (pervious areas): 0% Impervious Cover: 100% (future)

CN(s): 99 (~~pervious &~~ impervious areas) CN*(s): 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): Not Applicable (pervious areas) .96 (impervious areas)

Runoff Supply Rate (q): .96 i in./hr. (function of i)

Time of Concentration (T_c): 6.0 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 5 hrs./mins. (minimum)

Rainfall Intensity (i) at T_c: 9.88 in./hr.

Runoff Supply Rate (q) at T_c: 9.48 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 95.6 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

EXAMPLE FIVE (5)

This example will illustrate how to compute peak discharge when the watershed under investigation is nonhomogeneous (i.e., runoff parameters are not evenly distributed throughout).

A developer plans on constructing a large industrial complex within the immediate future. The complex will cover 500 acres at the downstream end of a 2,000 acre watershed which lies within a "valley area", topographically. The upper 1,500 acres of the watershed are government-owned and will not be developed in the future. In addition, the developer intends to construct a channel (unlined) across his acreage to confine the flooding to within said channel's banks.

Determine the peak discharge for the 100-year frequency flood (Q_p^{100}).

Proceeding as in previous examples yields:

1. Drainage Area(s) = 1,500 acres (A); 500 acres (B).
2. L_c = 20,000 feet (A); 10,000 feet (B)
   L_c = 30,000 feet (total).
3. L_{ca} = 9,500 feet (A); 5,000 feet (B).
   L_{ca} = 14,000 feet (total).
4. The mean slope for both reaches (A&B) is determined to be .0079 ft./ft.

5. Watershed Type(s) = valley (A), moderate industrial (B).

6. Due to the poor channel characteristics (i.e., braiding, very little definition) of the undeveloped portion of the watershed (area A), an n_b = .040 is chosen as representative of this area. Since the developed portion of the watershed (area B) will have a constructed channel traversing its entire length, with most tributary channels over paved surfaces, an n_b = .020 is chosen as representative of this area.

7. 24-hour, 100-year rainfall (P_{24}^{100}) = 4.57 inches.
   6-hour, 100-year rainfall (P_6^{100}) = 3.58 inches.

   (Areal reduction is not required).

8. 1-hour, 100-year rainfall (P_1^{100}) = 2.61 inches.
   2-hour, 100-year rainfall (P_2^{100}) = 2.94 inches.
   3-hour, 100-year rainfall (P_3^{100}) = 3.16 inches.

   (Areal reduction is not required).

9. The soils map indicates that the entire 2,000 acre watershed is contained within Hydrologic Group B.

10. The soil cover-complex consists entirely of Desert Brush Cover is approximately thirty percent (30%).

11. The degree of imperviousness of the undeveloped portion (area A) will remain zero percent (0%). The degree of imperviousness of the developed portion of the watershed (area B) upon completion of the project will be seventy-five percent (75%).

12. A curve number (CN) of 82 is chosen for all pervious areas.

13. The adjusted curve number (CN*) becomes:

$$CN^* = \frac{92.5(2.61-.88) + 65.12}{2.61} .$$

$$CN^* = 86.26 \text{ (pervious areas)} .$$

An adjusted curve number (CN*) of 99 is used for the impervious areas.

14. The runoff to rainfall ratios are:

$$C_P = \frac{[2.61-.2(1.59)]^2}{2.61[2.61+.8(1.59)]} = .518 \text{ (areas A\&B - pervious areas)}.$$

$$C_I = \frac{[2.61-.2(.101)]^2}{2.61[2.61+.8(.101)]} = .955 \text{ (area B - impervious areas)}.$$

15. Runoff supply rates (q's) become:

$$q_A = .518 \text{ inches/hour (area A)}.$$

$$q_B = .75(.955)i + .25(.518)i = .846 \text{ inches/hour (area B)}.$$

16. Using the appropriate values found in Steps One (1) through Fifteen (15), the times of concentration (T_c's) for areas A and B must be determined:

(a) $$T_c = \frac{.040}{50} \frac{[(20,000)(9500)]^{.3}}{(.0079)^{.4}} (.518i)^{-.4} \text{ hours}.$$

$$T_c = 2.20i^{-.4} \text{ hours (area A)}.$$

(b) $$T_c = \frac{.020}{50} \frac{[(10,000)(5000)]^{.3}}{(.0079)^{.4}} (.846i)^{-.4} \text{ hours}.$$

$$T_c = 36.3i^{-.4} \text{ minutes (area B)}.$$

Solving the two (2) equations by the iterative process yields:

$$T_c = 1.83 \text{ hours (area A)}.$$

$$T_c = 18 \text{ minutes (area B)}.$$

17. Now, the runoff supply rates (q's) are determined to be:

q_A = .518 (1.58)= .818 inches/hour (area A).

(Since i = 1.58 inches/hour, at T_c = 1.83 hours).

q_B = .846(5.48) = 4.64 inches/hour (area B).

(Since i = 5.48 inches/hour, at T_c = 18 minutes).

18. The peak discharges for the 100-year frequency flood become:

Q_p^{100} = 1.008(.818)(1500) = <u>1237</u> cfs. (area A).

Q_p^{100} = 1.008(4.64)(500) = <u>2339</u> cfs. (area B).

19. It now becomes necessary to add an additional step which involves summing the peak discharges from areas A and B, thus obtaining the peak discharge from the entire watershed (2000 acres). The summation of the peaks is not a simple additive relationship. Generally, flood routing techniques involving the lagging of subarea flood hydrographs and development of a composite flood hydrograph are necessary to compute the peak discharge from the total watershed. However, in this example, the simplified method outlined within the appendix section of this manual will be employed (Page 116).

The first step involves computing the "weighted basin factor"($\bar{n}_b$). Since only one watercourse is involved in this instance, weighting is done by channel length proportionalities.

Therefore,

$$\bar{n}_b = \frac{20,000}{30,000}(.040) + \frac{10,000}{30,000}(.020) = .033.$$

Next, the weighted runoff to rainfall ratio (C_w) is determined as follows:

$$C_w = .75(.518) + .25\,[.75(.955) + .25(.518)] = .600.$$

Then, using L_c and L_{ca} for the <u>entire basin</u>, the time of concentration (T_c) is calculated:

$$T_c = \frac{.033}{50}\,\frac{[(30,000)(14,000)]}{(.0079)^{.4}}\,(.600i)^{-.4} \text{ hours.}$$

$$T_c = 2.17i^{-.4} \text{ hours.}$$

The iterative solution to the above yields:

T_c = <u>1.80 hours.</u>

The weighted runoff supply rate (q) then becomes equal to the following:

$$q = C_w i = .600(1.60) = .960 \text{ inches/hour.}$$

(Since i = 1.60 in./hr., at T_c = 1.80 hours).

The peak rate of discharge from the <u>entire basin</u> determined by weighting basin parameters becomes:

$$Q_p^{100} = 1.008(.960)(2000) = \underline{\underline{1935 \text{ cfs}}}.$$

A comparison of results indicates that the peak discharge from subarea B alone produces the maximum peak during a 100-year frequency flood (2339 cfs.), and this value should be used for design purposes.

The approach of computing the peak rate of discharge by weighting the basin parameters resulted in an underestimation of the maximum peak discharge by 404 cfs., meaning that the maximum peak would actually be 20.9% higher than the value computed in this manner. However, this is due in part to the large differences in hydraulic efficiencies between subareas, as well as the large differences in basin lengths. The designer should find that, in most instances similar to this example, the maximum peak will occur when the entire basin is contributing at the outlet in question.

(It should be noted that the peak rate of discharge for subarea A need not have been computed in order to determine the maximum peak, but was done so in this example for purposes of clarity. Normally, the designer will compute the peak contributing from the nearest subarea, or subareas, and compare same with the peak from the entire watershed. The largest value is then used for design purposes).

HYDROLOGIC DATA SHEET

Project Name and Location: Example Five (5) - Sheet 1 of 4

Drainage Concentration Point: Area A Outlet (Inlet to Area B)

Watershed Area (A): 1500 (acres)/square miles.

Length of Watercourse (L_c): 20,000 ft. Length to Center of Gravity (L_{ca}): 9500 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
20,000	158

Mean Slope (S_c): .0079 ft./ft. Watershed Type(s): Valley (future)

Basin Factor (n_b): .040 (future) Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.57 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.58 in. Areal Value: N/A in.

P_1 (1 hour): 2.61 in. Areal Value: N/A in.

P_2 (2 hour): 2.94 in. Areal Value: N/A in.

P_3 (3 hour): 3.16 in. Areal Value: Not Applicable in.

Soil Group(s): 100% B Cover Type(s): Desert Brush

Cover Density (pervious areas): 30% Impervious Cover: N/A (future)

CN(s): 82 (curve number) (pervious ~~& impervious~~ areas) CN*(s): 86.26 (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .518 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .518 i in./hr. (function of i)

Time of Concentration (T_c): 2.20 $i^{-.4}$ (hrs.)/mins. (function of i)

Iterative Solution of T_c: 1.83 (hrs.)/mins.

Rainfall Intensity (i) at T_c: 1.58 in./hr.

Runoff Supply Rate (q) at T_c: .818 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 1237 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET

Project Name and Location: Example Five (5) - Sheet 2 of 4

Drainage Concentration Point: Area B outlet (Not including Area A)

Watershed Area (A): 500 (acres)/square miles.

Length of Watercourse (L_c): 10,000 ft. Length to Center of Gravity (L_{ca}): 5000 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
10,000	79

Mean Slope (S_c): .0079 ft./ft. Watershed Type(s): Moderate Industrial (future)

Basin Factor (n_b): .020 (future) Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.57 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.58 in. Areal Value: N/A in.

P_1 (1 hour): 2.61 in. Areal Value: N/A in.

P_2 (2 hour): 2.94 in. Areal Value: N/A in.

P_3 (3 hour): 3.16 in. Areal Value: Not Applicable in.

Soil Group(s): 100% B Cover Type(s): Desert Brush + Impervious

Cover Density (pervious areas): 30% Impervious Cover: 75% (future)

CN(s): 82 & 99 (pervious & impervious areas) CN*(s): 86.26 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .518 (pervious areas) .955 (impervious areas)

Runoff Supply Rate (q): .846 i in./hr. (function of i)

Time of Concentration (T_c): 36.3 $i^{-.4}$ hrs. (mins.) (function of i)

Iterative Solution of T_c: 18 hrs. (mins.)

Rainfall Intensity (i) at T_c: 5.48 in./hr.

Runoff Supply Rate (q) at T_c: 4.64 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 2339 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

Example Five (5) Sheet 3 of 4

HYDROLOGIC DATA SHEET

* For Determination of "Weighted" Parameters

Watershed Subarea: 1500 (acres)/square miles Watershed Type: Valley

Length of Watercourse (L_c): 20,000 ft. Length to Center of Gravity (L_{ca}): 9500 ft.

Incremental Change in Length (L_i) - ft.		Incremental Change in Height (H_i) - ft.
20,000	(Area A)	158

Soil Group(s): 100% B Cover Type(s): Desert Brush

Cover Density (pervious areas): 30% Impervious Cover: 0% (future)

CN(s): 82 (curve number) CN*(s): 86.26 (adjusted curve number)

Basin Factor (n_b): .040 Runoff to Rainfall Ratio (C): .518

Watershed Subarea: 500 (acres)/square miles Watershed Type: Moderate Industrial

Length of Watercourse (L_c): 10,000 ft. Length to Center of Gravity (L_{ca}): 5000 ft.

Incremental Change in Length (L_i) - ft.		Incremental Change in Height (H_i) - ft.
10,000	(Area B)	79

Soil Group(s): 100% B Cover Type(s): Desert Brush + Impervious

Cover Density (pervious areas): 30% Impervious Cover: 75% (future)

CN(s): 82 & 99 (curve number) CN*(s): 86.26 & 99 (adjusted curve number)

Basin Factor (n_b): .020 Runoff to Rainfall Ratio (C): .518 & .955

~~Watershed Subarea: _____ acres/square miles Watershed Type: _____~~

~~Length of Watercourse (L_c): _____ ft. Length to Center of Gravity (L_{ca}): _____ ft~~

~~Incremental Change in Length (L_i) - ft. Incremental Change in Height (H_i) - ft~~

~~Soil Group(s): _____ Cover Type(s): _____~~

~~Cover Density (pervious areas): _____ Impervious Cover: _____ (future)~~

~~CN(s): _____ (curve number) CN*(s): _____ (adjusted curve number)~~

~~Basin Factor (n_b): _____ Runoff to Rainfall Ratio (C): _____~~

* Weighted Basin Factor ($\bar{n}_b$): .033 (future) Weighted Runoff to Rainfall Ratio (C_w): .600

HYDROLOGIC DATA SHEET

Project Name and Location: Example Five (5) – Sheet 4 of 4

Drainage Concentration Point: Area B outlet (including Area A)

Watershed Area (A): 2000 (acres)/square miles.

Length of Watercourse (L_c): 30,000 ft. Length to Center of Gravity (L_{ca}): 14,000 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
20,000	158
10,000	79

Mean Slope (S_c): .0079 ft./ft. Watershed Type(s): Valley & Moderate Indus. (future)

Weighted Basin Factor ($\bar{n}_b$): .033 (future) (see sheet 3 of 4) Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.57 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.58 in. Areal Value: N/A in.

P_1 (1 hour): 2.61 in. Areal Value: N/A in.

P_2 (2 hour): 2.94 in. Areal Value: N/A in.

P_3 (3 hour): 3.16 in. Areal Value: Not Applicable in.

Soil Group(s): 100% B Cover Type(s): Desert Brush

Cover Density (pervious areas): 30% Impervious Cover: 18.8% (future)

CN(s): 82 & 99 (pervious & impervious areas) CN*(s): 86.26 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .518 (pervious areas) .955 (impervious areas)

Runoff Supply Rate (q): .600 i in./hr. (function of i) (See sheet 3 of 4)

Time of Concentration (T_c): 2.17 $i^{-.4}$ (hrs.)/mins. (function of i)

Iterative Solution of T_c: 1.80 (hrs.)/mins.

Rainfall Intensity (i) at T_c: 1.60 in./hr.

Runoff Supply Rate (q) at T_c: .960 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 1935 cfs.

645.33qA (square miles): _____ cfs.

Maximum Peak comes from area B, alone.

Note: For impervious areas, CN* = 99 (constant).

EXAMPLE SIX (6)

Determine the 2, 5, 10, 25, 50 and 100-year frequency peak discharges (present) for the Big (Enchanted Hills) Wash located at Mission Road, 0.6 miles north of State Highway 86, in Tucson.

Proceeding in the same manner as in Examples one (1) through Five (5) yields:

1. Drainage Area = 2.75 square miles.
2. L_c = 28,000 feet.
3. L_{ca} = 17,200 feet.
4. Streambed Profile:

Incremental Change in Length (L_i)	Incremental Change in Height (H_i)
3,500 ft.	100 ft.
9,500 ft.	200 ft.
6,750 ft.	100 ft.
8,250 ft.	80 ft.

Then, by calculation:

$$I = \left[\frac{(3500)^3}{100}\right]^{\frac{1}{2}} + \left[\frac{(9500)^3}{200}\right]^{\frac{1}{2}} + \left[\frac{(6750)^3}{100}\right]^{\frac{1}{2}} + \left[\frac{(8250)^3}{80}\right]^{\frac{1}{2}} \text{ feet.}$$

$$I = 225{,}416.57 \text{ feet.}$$

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{28{,}000}{225{,}416.57}\right]^2 = .01543 \text{ ft./ft.}$$

5. Watershed Type = foothills.

6. From field investigation and a review of aerial photos, an n_b of .032 is chosen as a representative basin factor for the watershed. This is due to the large conveyance capacities of the principal watercourses (i.e., no overbanking is likely to occur), as well as the absence of vegetation within said watercourses - which consist mainly of sandy bottoms with almost vertical side slopes, containing relatively few, if any, small boulders and/or stones.

7. P_{24}^{100} = 4.89 inches. P_6^{100} = 4.00 inches.

P_{24}^{50} = 4.34 inches. P_6^{50} = 3.53 inches.

P_{24}^{25} = 3.79 inches. P_6^{25} = 3.08 inches.

P_{24}^{10} = 3.19 inches. P_6^{10} = 2.58 inches.

P_{24}^{5} = 2.71 inches. P_{6}^{5} = 2.20 inches.

P_{24}^{2} = 2.00 inches. P_{6}^{2} = 1.60 inches.

(Areal reduction is not required).

8. P_1^{100} = 2.96 inches. P_2^{100} = 3.31 inches. P_3^{100} = 3.55 inches.

P_1^{50} = 2.61 inches. P_2^{50} = 2.92 inches. P_3^{50} = 3.13 inches.

P_1^{25} = 2.29 inches. P_2^{25} = 2.56 inches. P_3^{25} = 2.74 inches.

P_1^{10} = 1.91 inches. P_2^{10} = 2.14 inches. P_3^{10} = 2.29 inches.

P_1^{5} = 1.63 inches. P_2^{5} = 1.82 inches. P_3^{5} = 1.95 inches.

P_1^{2} = 1.19 inches. P_2^{2} = 1.33 inches. P_3^{2} = 1.42 inches.

(Areal reduction is not required).

9. The soil group is determined to be entirely within Hydrologic Group D, as determined from the soils map on Page 99 of this Manual.

10. Aerial photos indicate a Desert Brush cover of approximately twenty percent (20%).

11. The degree of imperviousness of the watershed can be considered as negligible.

12. The base curve number (CN) for the entire watershed is determined to be 91, since impervious areas are considered to be negligible.

13. The adjusted curve numbers (CN*'s) become:

CN^*_{100} = 93.58. CN^*_{10} = 91.70.

CN^*_{50} = 93.12. CN^*_{5} = 90.79.

CN^*_{25} = 92.58. CN^*_{2} = 88.50.

14. The runoff to rainfall ratios are determined to be:

$$C_p^{100} = \frac{[2.96 - .2(.686)]^2}{2.96[2.96 + .8(.686)]} = .767.$$

$$C_p^{50} = \frac{[2.61 - .2(.739)]^2}{2.61[2.61 + .8(.739)]} = .726.$$

$$C_p^{25} = \frac{[2.29 - .2(.801)]^2}{2.29[2.29+.8(.801)]} = .676.$$

$$C_p^{10} = \frac{[1.91 - .2(.905)]^2}{1.91[1.91+.8(.905)]} = .594.$$

$$C_p^{5} = \frac{[1.63 - .2(1.01)]^2}{1.63[1.63+.8(1.01)]} = .512.$$

$$C_p^{2} = \frac{[1.19 - .2(1.30)]^2}{1.19\ [1.19+.8(1.30)]} = .326.$$

15. The runoff supply rates (q's)become (in inches/hour):

$q_{100} = .767i.$ $q_{25} = .676i.$ $q_5 = .512i.$

$q_{50} = .726i.$ $q_{10} = .594i.$ $q_2 = .326i.$

16. The times of concentration (T_c's) must now be determined for each frequency storm utilizing the values obtained from Steps One (1) through Fifteen (15):

$$T_c^{100} = \frac{.032}{50} \frac{[(28{,}000)\ (17{,}200)]^{.3}}{(.01543)^{.4}} (.767i)^{-.4} \text{ hours.}$$

$$T_c^{100} = 1.37(.767i)^{-.4} = 1.52\ i^{-.4} \text{ hours.}$$

Note that the value 1.37 is a physical constant characteristic of the subject watershed. This same value will be used in all calculations of T_c which are to follow; the only variable being the runoff supply rate (q).

Continuing yields:

$$T_c^{50} = 1.37\ (.726i)^{-.4} = 1.56i^{-.4} \text{ hours.}$$

$$T_c^{25} = 1.37\ (.676i)^{-.4} = 1.60i^{-.4} \text{ hours.}$$

$$T_c^{10} = 1.37\ (.594i)^{-.4} = 1.69i^{-.4} \text{ hours.}$$

$$T_c^{5} = 1.37\ (.512i)^{-.4} = 1.79i^{-.4} \text{ hours.}$$

$$T_c^{2} = 1.37\ (.326i)^{-.4} = 2.15i^{-.4} \text{ hours.}$$

Solving each of these relationships via the iterative process described within the text (and shown within the previous examples of this Manual) results in the following:

T_c^{100} = <u>59 minutes.</u>

T_c^{50} = 1.10 hours.

T_c^{25} = 1.24 hours.

T_c^{10} = 1.50 hours.

T_c^{5} = 1.79 hours.

T_c^{2} = 2.85 hours.

17. The runoff supply rates (q's) for the various frequencies become:

q_{100} = .767 (2.99) = 2.29 inches/hour.

[Since i = 2.99 in./hr., at T_c = 59 minutes].

q_{50} = .726 (2.40) = 1.74 inches/hour.

[Since i = 2.40 in./hr., at T_c = 1.10 hours].

q_{25} = .676 (1.90) = 1.28 inches/hour.

[Since i = 1.90 in./hr., at T_c = 1.24 hours].

q_{10} = .594 (1.35) = .802 inches/hour.

[Since i = 1.35 in./hr., at T_c = 1.50 hours].

q_5 = .512 (.994) = .509 inches/hour.

[Since i =.994 in./hr., at T_c = 1.79 hours].

q_2 = .326 (.494) = .161 inches/hour.

[Since i = .494 in./hr., at T_c = 2.85 hours].

18. Finally, we must compute the peak discharges for the various frequencies:

Q_p^{100} = 645.33 (2.29)(2.75) = 4064 cfs.

Q_p^{50} = 645.33 (1.74)(2.75) = 3088 cfs.

Q_p^{25} = 645.33 (1.28)(2.75 = 2272 cfs.

$$Q_p^{10} = 645.33\ (.802)(2.75) = \underline{1423\ \text{cfs.}}$$

$$Q_p^{5} = 645.33\ (.509)(2.75) = \underline{903\ \text{cfs.}}$$

$$Q_p^{2} = 645.33\ (.161)(2.75) = \underline{286\ \text{cfs.}}$$

As a final tabulation:

Frequency (years)	Discharge (cfs.)
2	286
5	903
10	1423
25	2272
50	3088
100	4064

As a comparison to measured stream-gauge records compiled by the U.S.G.S. from water year 1965 to water year 1975, we have:

Water Year	Discharge (cfs.)
1965	1000
1966	240
1967	50
1968	65
1969	0
1970	1070
1971	3000
1972	285
1973	300
1974	0
1975	0

A Log Pearson - Type III frequency analysis of this data versus the results obtained via utilization of this Manual yields:

Frequency	Discharge (freq. analysis)	Discharge (computed)
2-year	231 cfs.	286 cfs.
5-year	927 cfs.	903 cfs.
10-year	1762 cfs.	1423 cfs.
25-year	3223 cfs.	2272 cfs.
50-year	4759 cfs.	3088 cfs.
100-year	6821 cfs.	4064 cfs.

As can be seen, comparison is good for the 2-year through 10-year frequencies. It is understandable that a divergence might occur for less frequent storms since only eleven (11) years of record were analyzed for this particular watershed (a frequency analysis based upon only 11 years of record is likely to generate questionable values for the 25, 50 and 100-year frequency storms, especially in light of the large event which occurred in 1971).

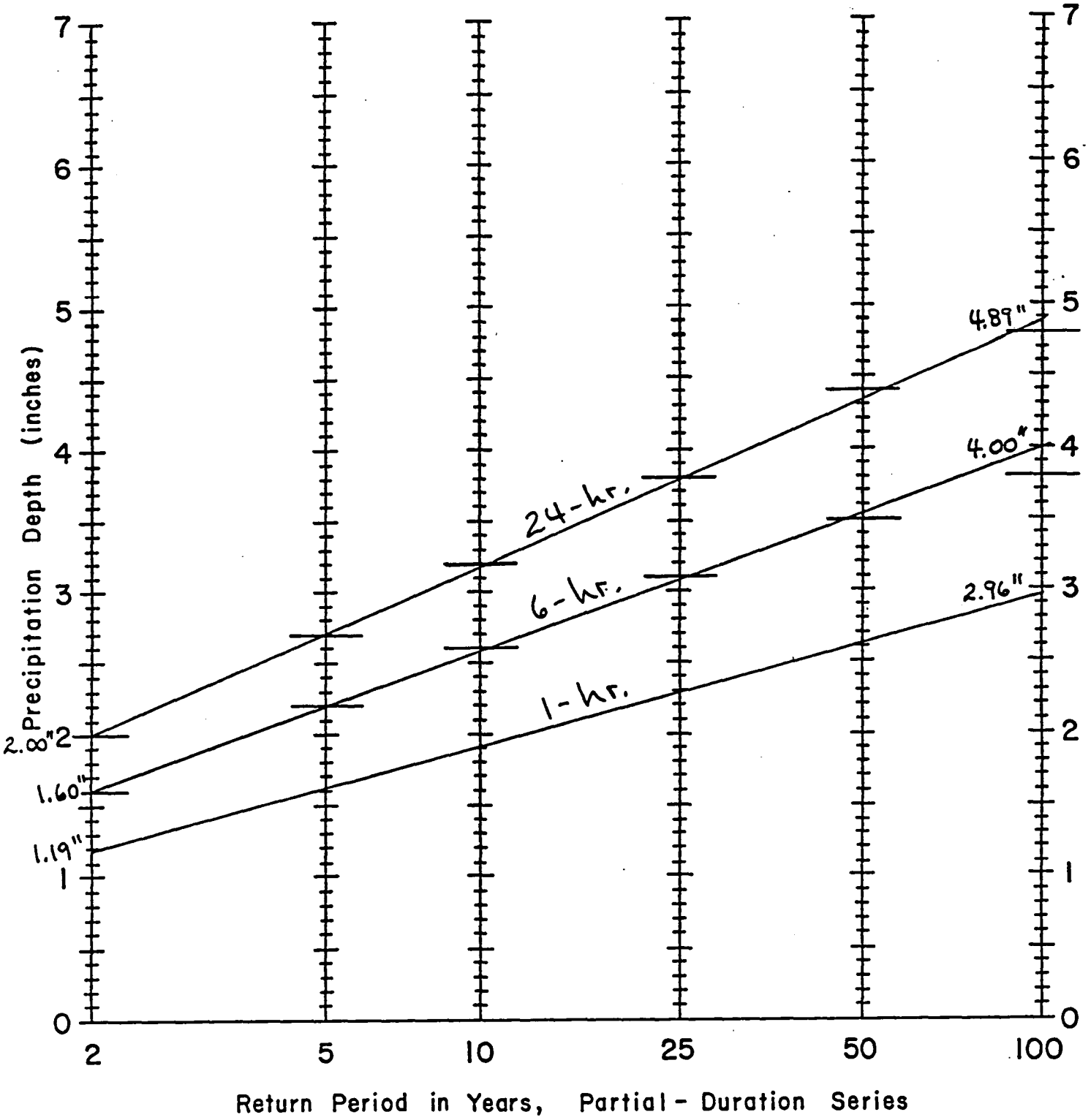
Example Six (6)

Return Period (Years)	Precipitation Values (inches)			
	6 Hour Duration		24 Hour Duration	
	Map Value	Corrected Value	Map Value	Corrected Value
2	1.60	1.60	2.00	2.00
5	2.20	2.20	2.70	2.71
10	2.60	2.58	3.20	3.19
25	3.10	3.08	3.80	3.79
50	3.50	3.53	4.40	4.34
100	3.80	4.00	4.80	4.89

Big (Enchanted Hills) Wash

Latitude 32°11'15" Longitude 111°2'30"

Example Six (6) Sheet 2 of 9

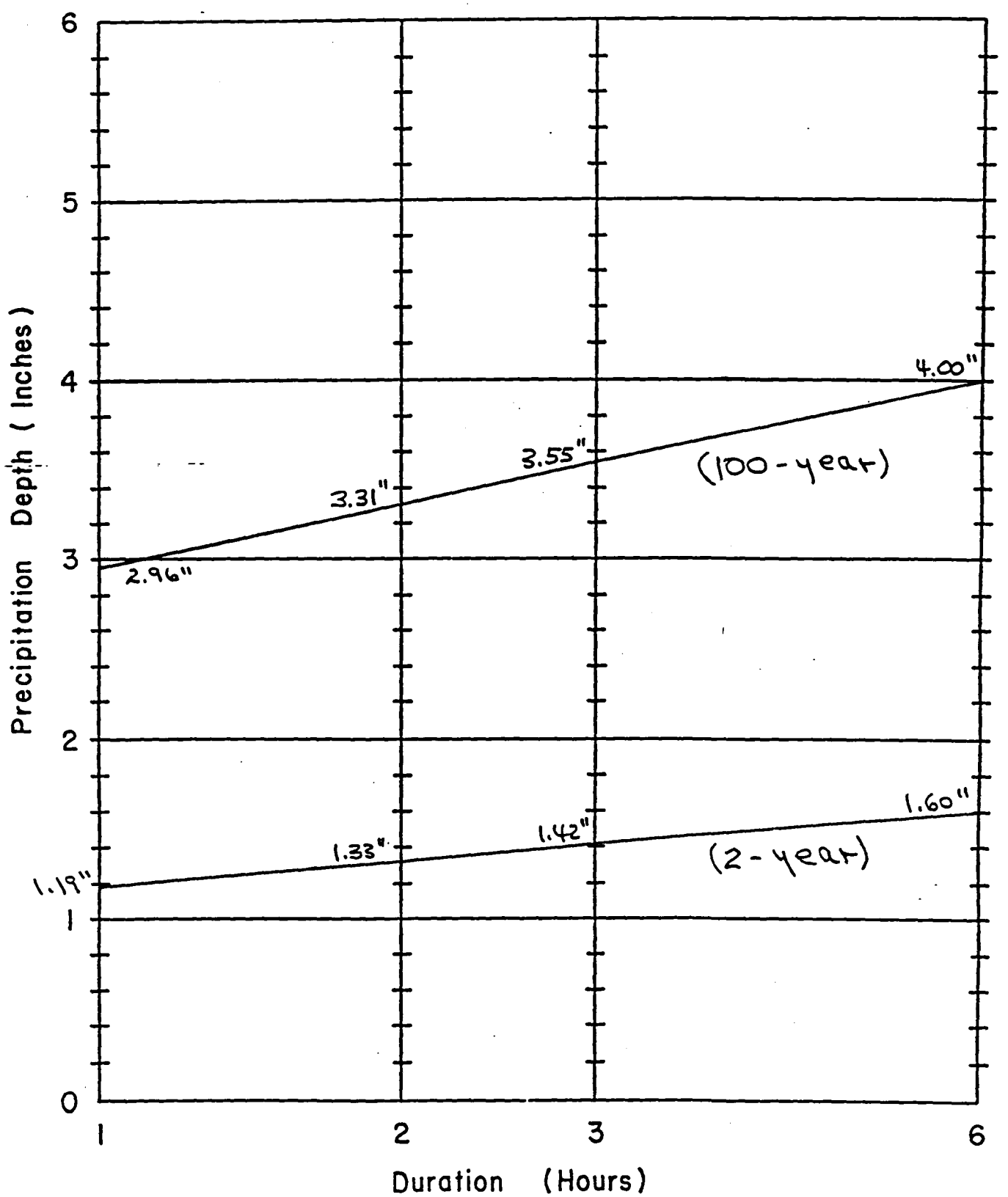


Big (Enchanted Hills) Wash

Precipitation Depth Versus Return Period For Partial - Duration Series

Example Six (6)

Precipitation Depth - Duration Diagram (1 - 6 Hours)



Big (Enchanted Hills) Wash

HYDROLOGIC DATA SHEET

Project Name and Location: Example Six (6) - Big (Enchanted Hills) Wash

Drainage Concentration Point: At Mission Road, Tucson

Watershed Area (A): 2.75 acres/(square miles.)

Length of Watercourse (L_c): 28,000 ft. Length to Center of Gravity (L_{ca}): 17,200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3500	100
9500	200
6750	100
8250	80

Mean Slope (S_c): .01543 ft./ft. Watershed Type(s): Foothills ~~(future)~~

Basin Factor (n_b): .032 ~~(future)~~ Flood Frequency: 2 yrs.

P_{24} (24 hour): 2.00 in. Areal Value: Not Applicable in.

P_6 (6 hour): 1.60 in. Areal Value: N/A in.

P_1 (1 hour): 1.19 in. Areal Value: N/A in.

P_2 (2 hour): 1.33 in. Areal Value: N/A in.

P_3 (3 hour): 1.42 in. Areal Value: Not Applicable in.

Soil Group(s): 100% D Cover Type(s): Desert Brush

Cover Density (pervious areas): 20% Impervious Cover: N/A ~~(future)~~

CN(s): 91 (pervious ~~& impervious~~ areas) CN*(s): 88.50
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .326 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .326 i in./hr. (function of i)

Time of Concentration (T_c): 2.15 $i^{-.4}$ (hrs)/mins. (function of i)

Iterative Solution of T_c: 2.85 (hrs)/mins.

Rainfall Intensity (i) at T_c: .494 in./hr.

Runoff Supply Rate (q) at T_c: .161 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 286 cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET

Project Name and Location: Example Six (6) – Big (Enchanted Hills) Wash

Drainage Concentration Point: At Mission Road, Tucson

Watershed Area (A): 2.75 acres/(square miles)

Length of Watercourse (L_c): 28,000 ft. Length to Center of Gravity (L_{ca}): 17,200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3500	100
9500	200
6750	100
8250	80

Mean Slope (S_c): .01543 ft./ft. Watershed Type(s): Foothills ~~(future)~~

Basin Factor (n_b): .032 ~~(future)~~ Flood Frequency: 5 yrs.

P_{24} (24 hour): 2.71 in. Areal Value: Not Applicable in.

P_6 (6 hour): 2.20 in. Areal Value: N/A in.

P_1 (1 hour): 1.63 in. Areal Value: N/A in.

P_2 (2 hour): 1.82 in. Areal Value: N/A in.

P_3 (3 hour): 1.95 in. Areal Value: Not Applicable in.

Soil Group(s): 100% D Cover Type(s): Desert Brush

Cover Density (pervious areas): 20% Impervious Cover: N/A ~~(future)~~

CN(s): 91 (pervious ~~& impervious~~ areas) CN*(s): 90.79
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .512 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .512 i in./hr. (function of i)

Time of Concentration (T_c): 1.79 $i^{-.4}$ (hrs)/mins. (function of i)

Iterative Solution of T_c: 1.79 (hrs)/mins.

Rainfall Intensity (i) at T_c: .994 in./hr.

Runoff Supply Rate (q) at T_c: .509 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 903 cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET Sheet 6 of 9

Project Name and Location: Example Six (6) - Big (Enchanted Hills) Wash

Drainage Concentration Point: At Mission Road, Tucson

Watershed Area (A): 2.75 acres/square miles.

Length of Watercourse (L_c): 28,000 ft. Length to Center of Gravity (L_{ca}): 17,200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3500	100
9500	200
6750	100
8250	80

Mean Slope (S_c): .01543 ft./ft. Watershed Type(s): Foothills ~~(future)~~

Basin Factor (n_b): .032 ~~(future)~~ Flood Frequency: 10 yrs.

P_{24} (24 hour): 3.19 in. Areal Value: Not Applicable in.

P_6 (6 hour): 2.58 in. Areal Value: N/A in.

P_1 (1 hour): 1.91 in. Areal Value: N/A in.

P_2 (2 hour): 2.14 in. Areal Value: N/A in.

P_3 (3 hour): 2.29 in. Areal Value: Not Applicable in.

Soil Group(s): 100% D Cover Type(s): Desert Brush

Cover Density (pervious areas): 20% Impervious Cover: N/A ~~(future)~~

CN(s): 91 (curve number) (pervious ~~& impervious~~ areas) CN*(s): 91.70 (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .594 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .594 i in./hr. (function of i)

Time of Concentration (T_c): 1.69 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 1.50 hrs./mins.

Rainfall Intensity (i) at T_c: 1.35 in./hr.

Runoff Supply Rate (q) at T_c: .802 in./hr.

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 1423 cfs.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET

roject Name and Location: Example Six (6) - Big (Enchanted Hills) Wash

Drainage Concentration Point: At Mission Road, Tucson

'atershed Area (A): 2.75 acres/(square miles.)

'.ength of Watercourse (L_c): 28,000 ft. Length to Center of Gravity (L_{ca}): 17,200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3500	100
9500	200
6750	100
8250	80

Mean Slope (S_c): .01543 ft./ft. Watershed Type(s): Foothills ~~(future)~~

Basin Factor (n_b): .032 ~~(future)~~ Flood Frequency: 25 yrs.

P_{24} (24 hour): 3.79 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.08 in. Areal Value: N/A in.

P_1 (1 hour): 2.29 in. Areal Value: N/A in.

P_2 (2 hour): 2.56 in. Areal Value: N/A in.

P_3 (3 hour): 2.74 in. Areal Value: Not Applicable in.

Soil Group(s): 100% D Cover Type(s): Desert Brush

Cover Density (pervious areas): 20% Impervious Cover: N/A ~~(future)~~

CN(s): 91 (pervious ~~& impervious~~ areas) CN*(s): 92.58
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .676 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .676 i in./hr. (function of i)

Time of Concentration (T_c): 1.60 $i^{-.4}$ (hrs.)/mins. (function of i)

Iterative Solution of T_c: 1.24 (hrs.)/mins.

Rainfall Intensity (i) at T_c: 1.90 in./hr.

Runoff Supply Rate (q) at T_c: 1.28 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 2272 cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET

Project Name and Location: Example Six (6) - Big (Enchanted Hills) Wash

Drainage Concentration Point: At Mission Road, Tucson

Watershed Area (A): 2.75 acres/square miles.

Length of Watercourse (L_c): 28,000 ft. Length to Center of Gravity (L_{ca}): 17,200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3500	100
9500	200
6750	100
8250	80

Mean Slope (S_c): .01543 ft./ft. Watershed Type(s): Foothills ~~(future)~~

Basin Factor (n_b): .032 ~~(future)~~ Flood Frequency: 50 yrs.

P_{24} (24 hour): 4.34 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.53 in. Areal Value: N/A in.

P_1 (1 hour): 2.61 in. Areal Value: N/A in.

P_2 (2 hour): 2.92 in. Areal Value: N/A in.

P_3 (3 hour): 3.13 in. Areal Value: Not Applicable in.

Soil Group(s): 100% D Cover Type(s): Desert Brush

Cover Density (pervious areas): 20% Impervious Cover: N/A ~~(future)~~

CN(s): 91 (pervious ~~& impervious~~ areas) CN*(s): 93.12
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .726 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .726 i in./hr. (function of i)

Time of Concentration (T_c): 1.56 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 1.10 hrs./mins.

Rainfall Intensity (i) at T_c: 2.40 in./hr.

Runoff Supply Rate (q) at T_c: 1.74 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 3088 cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET Sheet 9 of 9

Project Name and Location: Example Six (6) - Big (Enchanted Hills) Wash

Drainage Concentration Point: At Mission Road, Tucson

Watershed Area (A): 2.75 acres/square miles.

Length of Watercourse (L_c): 28,000 ft. Length to Center of Gravity (L_{ca}): 17,200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
3500	100
9500	200
6750	100
8250	80

Mean Slope (S_c): .01543 ft./ft. Watershed Type(s): Foothills ~~(future)~~

Basin Factor (n_b): .032 ~~(future)~~ Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.89 in. Areal Value: Not Applicable in.

P_6 (6 hour): 4.00 in. Areal Value: N/A in.

P_1 (1 hour): 2.96 in. Areal Value: N/A in.

P_2 (2 hour): 3.31 in. Areal Value: N/A in.

P_3 (3 hour): 3.55 in. Areal Value: Not Applicable in.

Soil Group(s): 100 % D Cover Type(s): Desert Brush

Cover Density (pervious areas): 20% Impervious Cover: N/A ~~(future)~~

CN(s): 91 (pervious ~~& impervious~~ areas) CN*(s): 93.58
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .767 (pervious areas) N/A (impervious areas)

Runoff Supply Rate (q): .767 i in./hr. (function of i)

Time of Concentration (T_c): 1.52 $i^{-.6}$ hrs./mins. (function of i)

Iterative Solution of T_c: 59 hrs./mins.

Rainfall Intensity (i) at T_c: 2.99 in./hr.

Runoff Supply Rate (q) at T_c: 2.29 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 4064 cfs.

Note: For impervious areas, CN* = 99 (constant).

EXAMPLE SEVEN (7)

Determine the 2, 5, 10, 25, 50 and 100 year frequency peak discharges (present) for the High School Wash Experimental Watershed located at North Cherry Avenue, approximately .25 miles north of Broadway Boulevard, in Tucson.

Proceeding in the same manner as in Examples One (1) through Six (6) yields:

1. Drainage Area = 0.90 square miles.
2. L_c = 8100 feet.
3. L_{ca} = 4200 feet.
4. Streambed Profile:

Incremental Change in Length (L_i)	Incremental Change in Height (H_i)
1500 ft.	20 ft.
2400 ft.	30 ft.
2200 ft.	20 ft.
2000 ft.	10 ft.

Then, by calculation:

$$I = \left[\frac{(1500)^3}{20}\right]^{\frac{1}{2}} + \left[\frac{(2400)^3}{30}\right]^{\frac{1}{2}} + \left[\frac{(2200)^3}{20}\right]^{\frac{1}{2}} + \left[\frac{(2000)^3}{10}\right]^{\frac{1}{2}} \text{ feet.}$$

$$I = 85{,}814.70 \text{ feet.}$$

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{8100}{85{,}814.70}\right]^2 = .0089 \text{ ft./ft.}$$

5. Watershed Type = moderately urbanized.

6. Since the watershed is moderately urbanized, and most paths of flow are over paved, curbed streets, a basin factor (n_b) = .022 is chosen as representative for the watershed.

7. P_{24}^{100} = 4.45 inches. P_6^{100} = 3.42 inches.
   P_{24}^{50} = 3.94 inches. P_6^{50} = 3.09 inches.
   P_{24}^{25} = 3.42 inches. P_6^{25} = 2.71 inches
   P_{24}^{10} = 2.88 inches. P_6^{10} = 2.32 inches.
   P_{24}^{5} = 2.42 inches. P_6^{5} = 2.02 inches.
   P_{24}^{2} = 1.75 inches. P_6^{2} = 1.55 inches.

   (Areal reduction is not required).

8. P_1^{100} = 2.48 inches. P_2^{100} = 2.80 inches. P_3^{100} = 3.01 inches.

P_1^{50} = 2.24 inches. P_2^{50} = 2.53 inches. P_3^{50} = 2.72 inches.

P_1^{25} = 2.01 inches. P_2^{25} = 2.25 inches. P_3^{25} = 2.41 inches.

P_1^{10} = 1.77 inches. P_2^{10} = 1.96 inches. P_3^{10} = 2.08 inches.

P_1^{5} = 1.58 inches. P_2^{5} = 1.73 inches. P_3^{5} = 1.83 inches.

P_1^{2} = 1.28 inches. P_2^{2} = 1.37 inches. P_3^{2} = 1.43 inches.

(Areal reduction is not required).

9. From an examination of the soils map provided within the appendix Section of this Manual (Page 99) it is determined that the watershed lies within an area which contains 80% Hydrologic Group B soils, and 20% Hydrologic Group D soils.

10. The type of cover within the watershed is considered to be Urban Lawns of "average" cover density.

11. The degree of imperviousness within the watershed is calculated to be 28.8%.

12. The curve numbers (CN's) for the watershed are determined to be:

CN_p^B = 79 (B Soils - pervious areas).

CN_p^D = 90 (D Soils - pervious areas).

CN_I = 99 (impervious areas).

13. The adjusted curve numbers (CN*'s) become:

CN_{100}^* = 83.73 (B soils); 92.06 (D soils).

CN_{50}^* = 82.95 (B soils); 91.59 (D soils).

CN_{25}^* = 82.02 (B soils); 91.03 (D soils).

CN_{10}^* = 80.81 (B soils); 90.29 (D soils).

CN_5^* = 79.58 (B soils); 89.54 (D soils).

CN_2^* = 76.91 (B soils); 87.91 (D soils).

[CN* = 99 (constant) for impervious areas for all return intervals].

14. The runoff to rainfall ratios (C'S) are determined as follows:

$$C_P^{100} = \frac{[2.48 - .2(1.94)]^2}{2.48[2.48+.8(1.94)]} = .44 \text{ (B soils - pervious areas).}$$

$$C_P^{100} = \frac{[2.48 - .2(.862)]^2}{2.48[2.48+.8(.862)]} = .68 \text{ (D Soils - pervious areas).}$$

$$C_I^{100} = \frac{[2.48 - .2\ (.101)]^2}{2.48[2.48+.8(.101)]} = .95 \text{ (impervious areas).}$$

Continuing in the same manner for the 50-year through 2-year return intervals yields:

C_P^{50} = .38 (B soils - pervious areas).

C_P^{50} = .63 (D soils - pervious areas).

C_I^{50} = .95 (impervious areas).

C_P^{25} = .33 (B soils - pervious areas).

C_P^{25} = .58 (D soils - pervious areas).

C_I^{25} = .94 (impervious areas).

C_P^{10} = .26 (B soils - pervious areas).

C_P^{10} = .52 (D soils - pervious areas).

C_I^{10} = .93 (impervious areas).

C_P^{5} = .20 (B soils - pervious areas).

C_P^{5} = .46 (D soils - pervious areas).

C_I^{5} = .93 (impervious areas).

C_P^{2} = .10 (B soils - pervious areas).

C_P^{2} = .33 (D soils - pervious areas).

C_I^{2} = .91 (impervious areas).

15. The runoff supply rates (q's) are determined by weighting the runoff to rainfall ratios (C's) in proportion to their areal extents:

$$q_{100} = .712\ [.80(.44) + .20(.68)]i + .288(.95)i \text{ inches/hour.}$$

$$q_{100} = .62i \text{ inches/hour.}$$

Proceeding in the same manner for the 50-year through 2-year return intervals yields (in inches/hour):

$q_{50} = .58i.$ $\quad q_{10} = .49i.$ $\quad q_2 = .37i.$

$q_{25} = .54i.$ $\quad q_5 = .45i.$

16. The times of concentration (T_c's) must now be determined for each frequency storm utilizing the values obtained from Steps One (1) through Fifteen (15):

$$T_c^{100} = \frac{.022}{50} \frac{[(8100)(4200)]^{.3}}{(.0089)^{.4}} (.62i)^{-.4} \text{ hours.}$$

$$T_c^{100} = .53(.62i)^{-.4} \text{ hours; or,}$$

$$T_c^{100} = 31.7(.62i)^{-.4} \text{ minutes.}$$

Then

$$T_c^{100} = 38.4i^{-.4} \text{ minutes.}$$

Note that the value 31.7 (for Tc in minutes) is a physical constant characteristic of the subject watershed. This same value will be used in all calculations of T_c which are to follow; the only variable being the runoff supply rate (q).

Continuing in the same manner yields:

$$T_c^{50} = 39.4i^{-.4} \text{ minutes.}$$

$$T_c^{25} = 40.6i^{-.4} \text{ minutes.}$$

$$T_c^{10} = 42.2i^{-.4} \text{ minutes.}$$

$$T_c^{5} = 43.6i^{-.4} \text{ minutes.}$$

$$T_c^{2} = 47.2i^{-.4} \text{ minutes.}$$

Solving each of these relationships via the iterative process described within the text (and shown within the previous examples of this Manual) results in the following:

T_c^{100} = <u>20 minutes</u>.

T_c^{50} = <u>22 minutes</u>.

T_c^{25} = <u>24 minutes</u>.

T_c^{10} = <u>27 minutes</u>.

T_c^{5} = <u>30 minutes</u>.

T_c^{2} = <u>38 minutes</u>.

17. The runoff supply rates (q's) for the various frequencies become:

q_{100} = .62(4.94) = 3.06 inches/hour.
[since i = 4.94 in./hr., at T_c = 20 minutes].

q_{50} = .58(4.23)= 2.45 inches/hour.
[since i = 4.23 in./hr., at T_c = 22 minutes].

q_{25} = .54(3.62) = 1.95 inches/hour.
[since i = 3.62 in./hr., at T_c = 24 minutes].

q_{10} = .49(2.97) = 1.46 inches/hour.
[since i = 2.97 in./hr., at T_c = 27 minutes].

q_5 = .45(2.50) = 1.13 inches/hour.
[since i = 2.50 in./hr., at T_c = 30 minutes].

q_2 = .37(1.80)= .64 inches/hour.
[since i = 1.74 in./hr., at T_c = 38 minutes].

18. Finally, we must compute the peak discharges for the various frequencies:

Q_p^{100} = 645.33(3.06)(0.90) = 1777 cfs.
Q_p^{50} = 645.33(2.45)(0.90) = 1423 cfs.
Q_p^{25} = 645.33(1.95)(0.90) = 1133 cfs.
Q_p^{10} = 645.33(1.46)(0.90) = 848 cfs.
Q_p^{5} = 645.33(1.13)(0.90) = 656 cfs.
Q_p^{2} = 645.33(.67)(0.90) = 372 cfs.

As a final tabulation:

Frequency (years)	Discharge (cfs)
2	372
5	656
10	848
25	1133
50	1423
100	1777

As a comparison to measured stream-gauge records compiled by the Water Resources Research Center, University of Arizona, from water year 1968 to water year 1975, we have:

Water Year	Discharge (cfs)
1968	195
1969	126
1970	204
1971	800
1972	664
1973	409
1974	341
1975	486

A Log Pearson - Type III frequency analysis of this data versus the results obtained via utilization of this Manual yields:

Frequency	Discharge (freq. analysis)	Discharge (computed)
2-year	381	372
5-year	628	656
10-year	836	848
25-year	1058	1133
50-year	1308	1423
100-year	1522	1777

Although only eight (8) years of records were used for the frequency analysis, it can be seen that the agreement between the two methods is very good for all return intervals.

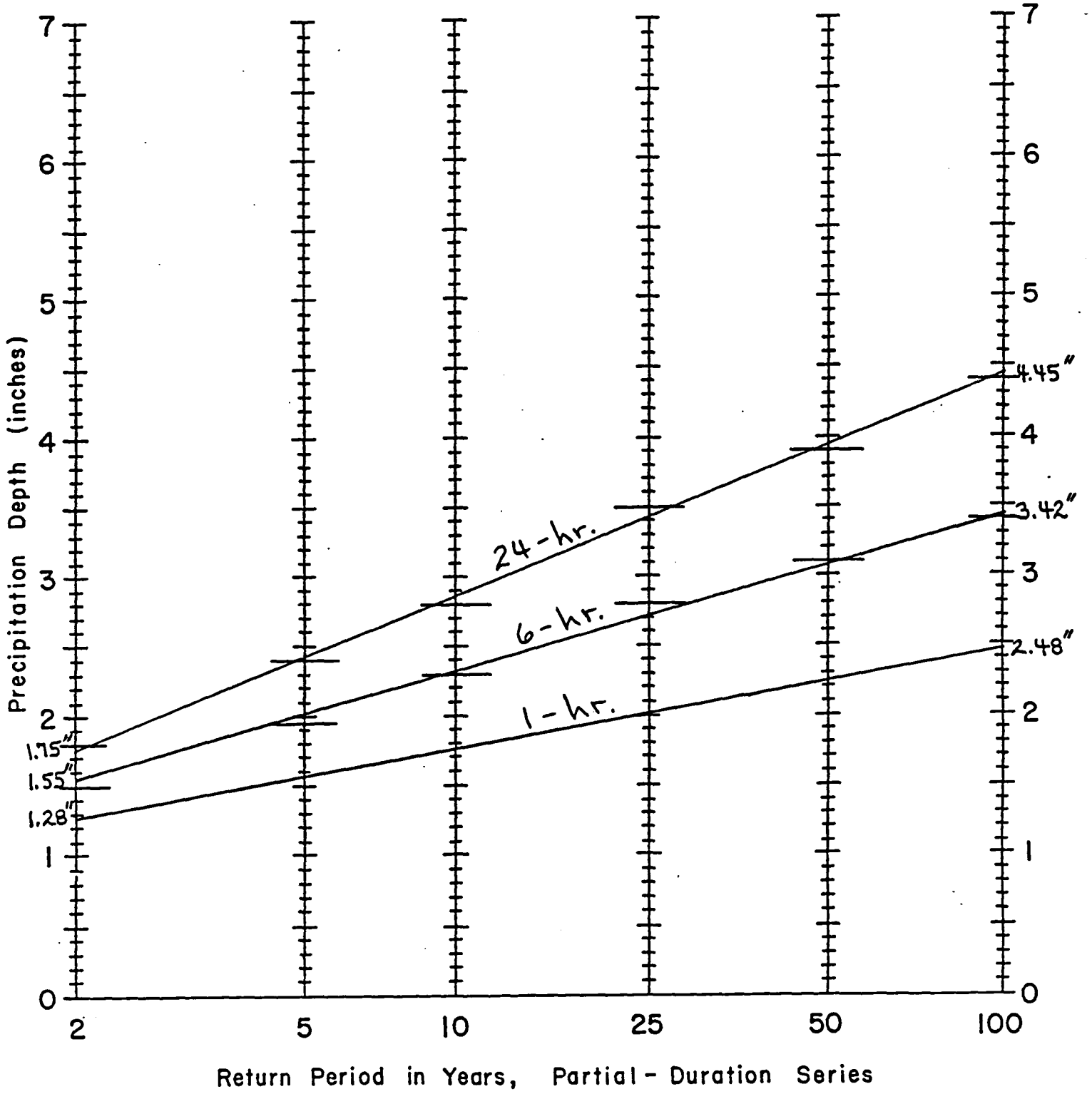
Example Seven (7)

Return Period (Years)	Precipitation Values (inches)			
	6 Hour Duration		24 Hour Duration	
	Map Value	Corrected Value	Map Value	Corrected Value
2	1.50	1.55	1.80	1.75
5	1.95	2.02	2.40	2.42
10	2.30	2.32	2.80	2.88
25	2.80	2.71	3.50	3.42
50	3.10	3.09	3.90	3.94
100	3.40	3.42	4.40	4.45

High School Wash

Latitude 32° 13' 30" Longitude 110° 56' 45"

Example Seven (7) Sheet 2 of 9

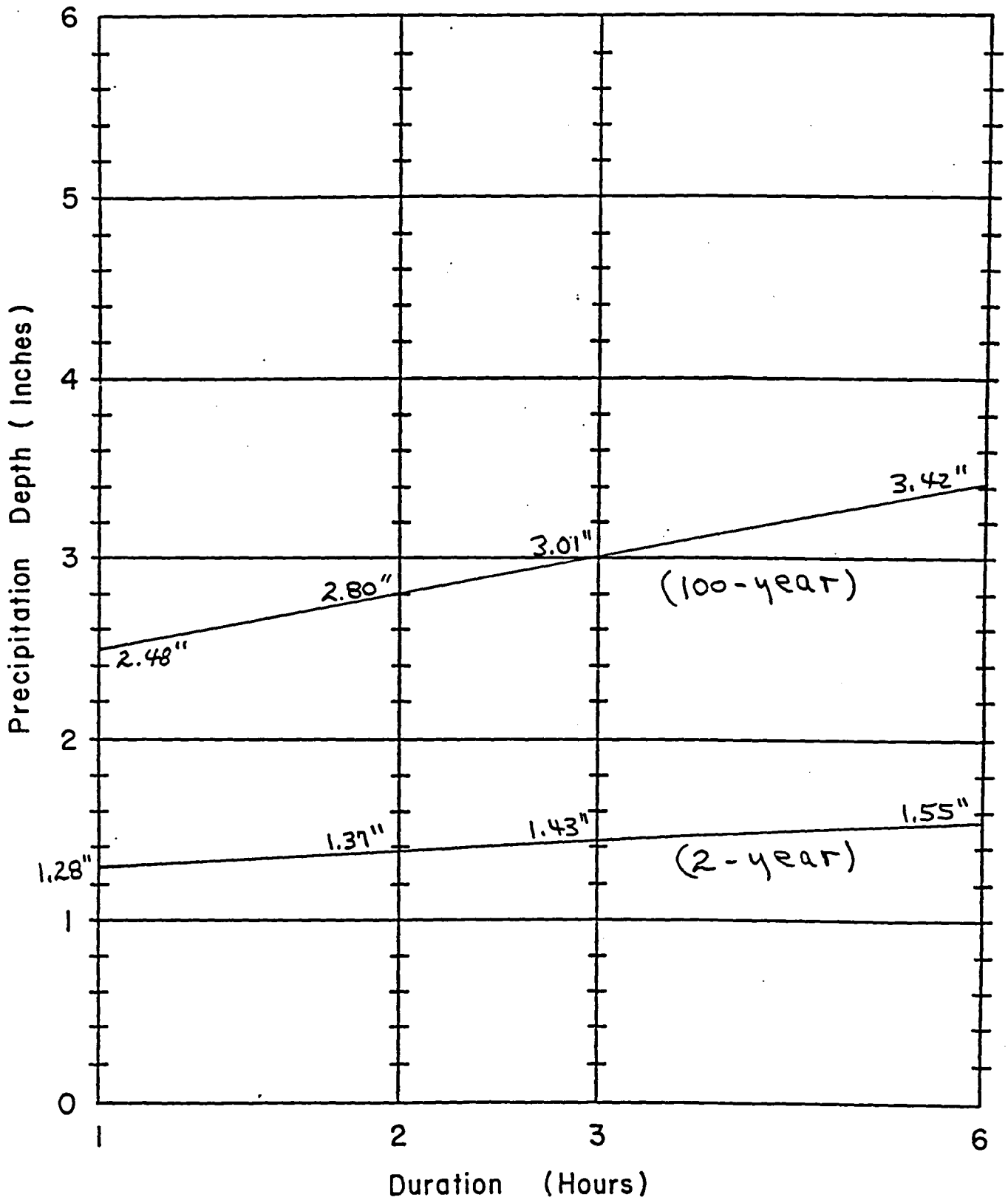


High School Wash

Precipitation Depth Versus Return Period For Partial-Duration Series

Example Seven (7)

Precipitation Depth - Duration Diagram (1 - 6 Hours)



High School Wash

HYDROLOGIC DATA SHEET

Project Name and Location: Example Seven (7) - High School Wash

Drainage Concentration Point: At N. Cherry Ave., Tucson

Watershed Area (A): .90 acres/square miles.

Length of Watercourse (L_c): 8100 ft. Length to Center of Gravity (L_{ca}): 4200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
1500	20
2400	30
2200	20
2000	10

Mean Slope (S_c): .0089 ft./ft. Watershed Type(s): Moderately Urbanized ~~(future)~~

Basin Factor (n_b): .022 ~~(future)~~ Flood Frequency: 2 yrs.

P_{24} (24 hour): 1.75 in. Areal Value: Not Applicable in.

P_6 (6 hour): 1.55 in. Areal Value: N/A in.

P_1 (1 hour): 1.28 in. Areal Value: N/A in.

P_2 (2 hour): 1.37 in. Areal Value: N/A in.

P_3 (3 hour): 1.43 in. Areal Value: Not Applicable in.

Soil Group(s): 80% B & 20% D Cover Type(s): Urban Lawns + Impervious

Cover Density (pervious areas): "Average" Impervious Cover: 28.8% ~~(future)~~

CN(s): 79 & 90 & 99 (pervious & impervious areas) CN*(s): 76.91 & 87.91 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .10 & .33 (pervious areas) .91 (impervious areas)

Runoff Supply Rate (q): .37 i in./hr. (function of i)

Time of Concentration (T_c): 47.2 $i^{-.4}$ hrs./mins (function of i)

Iterative Solution of T_c: 38 hrs./mins

Rainfall Intensity (i) at T_c: 1.74 in./hr.

Runoff Supply Rate (q) at T_c: .64 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 372 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET

Project Name and Location: Example Seven (7) - High School Wash

Drainage Concentration Point: At N. Cherry Ave., Tucson

Watershed Area (A): .90 acres/square miles.

Length of Watercourse (L_c): 8100 ft. Length to Center of Gravity (L_{ca}): 4200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
1500	20
2400	30
2200	20
2000	10

Mean Slope (S_c): .0089 ft./ft. Watershed Type(s): Moderately Urbanized ~~(future)~~

Basin Factor (n_b): .022 ~~(future)~~ Flood Frequency: 5 yrs.

P_{24} (24 hour): 2.42 in. Areal Value: Not Applicable in.

P_6 (6 hour): 2.02 in. Areal Value: N/A in.

P_1 (1 hour): 1.58 in. Areal Value: N/A in.

P_2 (2 hour): 1.73 in. Areal Value: N/A in.

P_3 (3 hour): 1.83 in. Areal Value: Not Applicable in.

Soil Group(s): 80% B, 20% D Cover Type(s): Urban Lawns + Impervious

Cover Density (pervious areas): "Average" Impervious Cover: 28.8% ~~(future)~~

CN(s): 79 & 90 & 99 (pervious & impervious areas) CN*(s): 79.58 & 89.54 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .20 & .46 (pervious areas) .93 (impervious areas)

Runoff Supply Rate (q): .45 i in./hr. (function of i)

Time of Concentration (T_c): 43.6 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 30 hrs./mins.

Rainfall Intensity (i) at T_c: 2.50 in./hr.

Runoff Supply Rate (q) at T_c: 1.13 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 656 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET Sheet 6 of 9

Project Name and Location: Example Seven (7) - High School Wash

Drainage Concentration Point: At N. Cherry Ave., Tucson

Watershed Area (A): .90 acres/(square miles)

Length of Watercourse (L_c): 8100 ft. Length to Center of Gravity (L_{ca}): 4200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
1500	20
2400	30
2200	20
2000	10

Mean Slope (S_c): .0089 ft./ft. Watershed Type(s): Moderately Urbanized ~~(future)~~

Basin Factor (n_b): .022 ~~(future)~~ Flood Frequency: 10 yrs.

P_{24} (24 hour): 2.88 in. Areal Value: Not Applicable in.

P_6 (6 hour): 2.32 in. Areal Value: N/A in.

P_1 (1 hour): 1.77 in. Areal Value: N/A in.

P_2 (2 hour): 1.96 in. Areal Value: N/A in.

P_3 (3 hour): 2.08 in. Areal Value: Not Applicable in.

Soil Group(s): 80% B, 20% D Cover Type(s): Urban Lawns + Impervious

Cover Density (pervious areas): "Average" Impervious Cover: 28.8% (future)

CN(s): 79 & 90 & 99 (pervious & impervious areas) CN*(s): 80.81 & 90.29 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .26 & .52 (pervious areas) .93 (impervious areas)

Runoff Supply Rate (q): .49 i in./hr. (function of i)

Time of Concentration (T_c): 42.2 $i^{-.4}$ hrs./(mins.) (function of i)

Iterative Solution of T_c: 27 hrs./(mins.)

Rainfall Intensity (i) at T_c: 2.97 in./hr.

Runoff Supply Rate (q) at T_c: 1.46 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 848 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET

roject Name and Location: Example Seven (7) - High School Wash

Drainage Concentration Point: At N. Cherry Ave., Tucson

atershed Area (A): .90 acres/square miles.

Length of Watercourse (L_c): 8100 ft. Length to Center of Gravity (L_{ca}): 4200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
1500	20
2400	30
2200	20
2000	10

lean Slope (S_c): .0089 ft./ft. Watershed Type(s): Moderately Urbanized ~~(future)~~

Basin Factor (n_b): .022 ~~(future)~~ Flood Frequency: 25 yrs.

P_{24} (24 hour): 3.42 in. Areal Value: Not Applicable in.

P_6 (6 hour): 2.71 in. Areal Value: N/A in.

P_1 (1 hour): 2.01 in. Areal Value: N/A in.

P_2 (2 hour): 2.25 in. Areal Value: N/A in.

P_3 (3 hour): 2.41 in. Areal Value: Not Applicable in.

Soil Group(s): 80% B, 20% D Cover Type(s): Urban Lawns + Impervious

Cover Density (pervious areas): "Average" Impervious Cover: 28.8% ~~(future)~~

CN(s): 79 & 90 & 99 (pervious & impervious areas) CN*(s): 82.02 & 91.03 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s), (C): .33 & .58 (pervious areas) .94 (impervious areas)

Runoff Supply Rate (q): .54 i in./hr. (function of i)

Time of Concentration (T_c): 40.6 $i^{-.4}$ hrs. mins. (function of i)

Iterative Solution of T_c: 24 hrs. mins.

Rainfall Intensity (i) at T_c: 3.62 in./hr.

Runoff Supply Rate (q) at T_c: 1.95 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 1133 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET Sheet 8 of 9

roject Name and Location: Example Seven (7) - High School Wash

Drainage Concentration Point: At N. Cherry Ave., Tucson

atershed Area (A): .90 acres/square miles.

Length of Watercourse (L_c): 8100 ft. Length to Center of Gravity (L_{ca}): 4200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
1500	20
2400	30
2200	20
2000	10

Mean Slope (S_c): .0089 ft./ft. Watershed Type(s): Moderately Urbanized ~~(future)~~

Basin Factor (n_b): .022 ~~(future)~~ Flood Frequency: 50 yrs.

P_{24} (24 hour): 3.94 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.09 in. Areal Value: N/A in.

P_1 (1 hour): 2.24 in. Areal Value: N/A in.

P_2 (2 hour): 2.53 in. Areal Value: N/A in.

P_3 (3 hour): 2.72 in. Areal Value: Not Applicable in.

Soil Group(s): 80% B, 20% D Cover Type(s): Urban Lawns + Impervious

Cover Density (pervious areas): "Average" Impervious Cover: 28.8% ~~(future)~~

CN(s): 79 & 90 & 99 (pervious & impervious areas) CN*(s): 82.95 & 91.59 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .38 & .63 (pervious areas) .95 (impervious areas)

Runoff Supply Rate (q): .58 i in./hr. (function of i)

Time of Concentration (T_c): 39.4 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 22 hrs./mins.

Rainfall Intensity (i) at T_c: 4.23 in./hr.

Runoff Supply Rate (q) at T_c: 2.45 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 1423 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

HYDROLOGIC DATA SHEET

Project Name and Location: Example Seven (7) - High School Wash

Drainage Concentration Point: At N. Cherry Ave., Tucson

Watershed Area (A): .90 acres/square miles.

Length of Watercourse (L_c): 8100 ft. Length to Center of Gravity (L_{ca}): 4200 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
1500	20
2400	30
2200	20
2000	10

Mean Slope (S_c): .0089 ft./ft. Watershed Type(s): Moderately Urbanized ~~(future)~~

Basin Factor (n_b): .022 ~~(future)~~ Flood Frequency: 100 yrs.

P_{24} (24 hour): 4.45 in. Areal Value: Not Applicable in.

P_6 (6 hour): 3.42 in. Areal Value: N/A in.

P_1 (1 hour): 2.48 in. Areal Value: N/A in.

P_2 (2 hour): 2.80 in. Areal Value: N/A in.

P_3 (3 hour): 3.01 in. Areal Value: Not Applicable in.

Soil Group(s): 80% B, 20% D Cover Type(s): Urban Lawns + Impervious

Cover Density (pervious areas): "Average" Impervious Cover: 28.8% ~~(future)~~

CN(s): 79 & 90 & 99 (pervious & impervious areas) CN*(s): 83.73 & 92.06 & 99
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): .44 & .68 (pervious areas) .95 (impervious areas)

Runoff Supply Rate (q): .62 i in./hr. (function of i)

Time of Concentration (T_c): 38.4 $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: 20 hrs./mins.

Rainfall Intensity (i) at T_c: 4.94 in./hr.

Runoff Supply Rate (q) at T_c: 3.06 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): 1777 cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, CN* = 99 (constant).

EXAMPLE EIGHT (8)

Determine the peak discharge (Q_p) for a 100-year frequency flood on the Agua Caliente Wash at a point just below its confluence with the Molino Canyon Wash, near Tucson, Arizona.

Proceeding as in the previous examples yields:

1. Drainage area = 24.7 square miles.
   (Agua Caliente = 17.7 sq. miles; Molino = 7.0 sq.miles.)
2. L_c = 53,300 feet (longest watercourse).
3. L_{ca} = 29,300 feet.
4. Streambed Profile:

Incremental Change in Length (L_i)	Incremental Change in Height (H_i)
6600 ft.	1600 ft.
27,700 ft.	620 ft.
19,000 ft.	1060 ft.

Then, by calculation:

$$I = \left[\frac{(6600)^3}{1600}\right]^{\frac{1}{2}} + \left[\frac{(27,700)^3}{620}\right]^{\frac{1}{2}} + \left[\frac{(19,000)^3}{1060}\right]^{\frac{1}{2}} = 278,995.70 \text{ feet.}$$

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{53,300}{278,995.70}\right]^2 = .0365 \text{ ft./ft.}$$

5. Watershed Type = mountain.

6. From field investigation and aerial photographs, two (2) distinct basin factors are evident within the watershed. Molina Canyon Wash is assigned an n_b of .050, while Agua Caliente Wash is assigned an n_b of .045, since less ruggedness exists within this subwatershed. Now, since the confluence of two watercourses with different basin factors is the case in this instance, the "weighted basin factor " ($\bar{n}_b$) is determined via areal proportionalities.

Therefore,

$$\bar{n}_b = \left[\frac{7.0}{24.7}\right](.050) + \left[\frac{17.7}{24.7}\right](.045) = .0464.$$

7. 24-hour, 100-year rainfall (P_{24}^{100}) = 4.48 inches.

   6-hour, 100-year rainfall (P_6^{100}) = 3.55 inches.

These values are determined by weighting all the point values (isohyets) which are within the watershed boundaries.

Now, since the drainage area under investigation is greater than ten (10) square miles, areal reduction is required. Using the depth-area curves provided in the appendix section of this Manual yields:

P_{24}^{100} = 4.34 inches.

P_6^{100} = 3.39 inches.

8. 1-hour, 100-year rainfall (P_1^{100}) = 2.62 inches
2-hour, 100-year rainfall (P_2^{100}) = 2.94 inches
3-hour, 100-year rainfall (P_3^{100}) = 3.15 inches.

Areal reduction is also required for these values.

Therefore:

P_1^{100} = 2.30 inches.

P_2^{100} = 2.66 inches.

P_3^{100} = 2.96 inches.

9. Investigation of the soils map indicates the following breakdown of hydrologic soil groups within the subject watershed:

Group C = 14%.
Group D = 86%.

10. A vegetative cover of thirty percent (30%), with 30% in Desert Brush areas and the remaining 70% (above 4,000 feet in elevation) containing Mountain Brush, Herbaceous, etc., is chosen as representative of the area.

11. The degree of imperviousness of the watershed is zero (0) percent.

12. The curve numbers (CN's) are determined to be:

CN = 85 for Group C.
CN = 90 for Group D.

13. The adjusted curve numbers (CN*'s) become:

$$CN^* = \frac{94(2.30-.88) + 68.20}{2.30} = 87.69 \text{ (Group C)}.$$

$$CN^* = \frac{96.5(2.30-.88) + 73.92}{2.30} = 91.72 \text{ (Group D)}.$$

(Note that the value for P_1^{100} determined from the depth-area curves (i.e., by areal reduction) was used in the equations for CN*).

14. The runoff to rainfall ratios become:

C_p^c = .518 (Group C-pervious areas).

$C_p^d = .646$ (Group D - pervious areas).

15. The runoff supply rate (q) is determined to be:

$$q = [.14(.518) + .86(.646)]i = .628i \text{ inches/hour.}$$

Again, as in the case of determining CN*, the value of P_1^{100} used in the relationship for q is the value determined from the depth-area curves (i.e., by areal reduction).

(In this example, accuracy for q is carried to three (3) decimal places due to the large drainage area involved).

16. Now, utilizing the values obtained from Steps One (1) through Fifteen (15), the time of concentration (T_c) is determined to be:

$$T_c = \frac{.0464}{50} \frac{[(53,300)\ (29,300)]^{.3}}{(.0365)^{.4}} (.628i)^{-.4} \text{ hours.}$$

$$T_c = 2.41\ i^{-.4} \text{ hours.}$$

Proceeding with the iterative solution of T_c, first try

$$T_c = 2 \text{ hours.}$$

With

$$T_c = 2 \text{ hours, } i = 1.33 \text{ inches/hour.}$$

Then $T_c = 2.41\ (1.33)^{-.4} = 2.15$ hours. (Assumed T_c is too short).

Try $T_c = 2.22$ hours.

With $T_c = 2.22$ hours, i= 1.23 inches/hour.

Then $T_c = 2.41\ (1.23)^{-.4} = 2.22$ hours.

Therefore,

$$\underline{T_c = 2.22 \text{ hours.}}$$

17. The runoff supply rate becomes:

$$q = .628\ (1.23) = .772 \text{ inches/hour.}$$

(Since i = 1.23 in./hr., at T_c = 2.22 hours).

18. The peak discharge for the 100-year frequency storm is determined to be:

$$Q_p^{100} = 645.33(.772)\ (24.7) = \underline{\underline{12,305\ cfs}}.$$

(A comparison of the 100-year peak discharge obtained by the U. S. Army Corps of Engineers for this watershed shows the Corps' value as being 12,000 cfs.; a difference of only 2.5%).

Example Eight (8)

HYDROLOGIC DATA SHEET

* For Determination of "Weighted" Parameters

ershed Subarea: 17.7 acres (square miles) Watershed Type: Mountain

ngth of Watercourse (L_c): 53,300 ft. Length to Center of Gravity (L_{ca}): 29,300 ft.

Incremental Change in Length (L_i) - ft.		Incremental Change in Height (H_i) - ft.
6600	(Longest	1600
27,700	Watercourse)	620
19,000		1060

oil Group(s): 14% C, 86% D Cover Type(s): Desert & Mountain Brush + Herbaceous

ver Density (pervious areas): 30% Impervious Cover: N/A (future)

N(s): 85 & 90 (curve number) CN*(s): 87.69 & 91.72 (adjusted curve number)

sin Factor (n_b): .045 Runoff to Rainfall Ratio (C): .628

tershed Subarea: 7.0 acres/square miles Watershed Type: Mountain

Length of Watercourse (L_c): N/A ft. Length to Center of Gravity (L_{ca}): N/A ft.

Incremental Change in Length (L_i) - ft.		Incremental Change in Height (H_i) - ft.
	Not Required -	
N/A	(Use Longest	N/A
	Watercourse).	

oil Group(s): 14% C, 86% D Cover Type(s): Desert & Mountain Brush + Herbaceous

ver Density (pervious areas): 30% Impervious Cover: N/A (future)

N(s): 85 & 90 (curve number) CN*(s): 87.69 & 91.72 (adjusted curve number)

asin Factor (n_b): .050 Runoff to Rainfall Ratio (C): .628

ershed Subarea: _____ acres/square miles Watershed Type: _____

Length of Watercourse (L_c): _____ ft. Length to Center of Gravity (L_{ca}): _____ ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Height (H_i) - ft.

oil Group(s): _____ Cover Type(s): _____

Cover Density (pervious areas): _____ Impervious Cover: _____ (future)

N(s): _____ (curve number) CN*(s): _____ (adjusted curve number)

Basin Factor (n_b): _____ Runoff to Rainfall Ratio (C): _____

Weighted Basin Factor ($\bar{n}_b$): .0464 (future) Weighted Runoff to Rainfall Ratio (C_w): .628

HYDROLOGIC DATA SHEET Sheet 2 of 2

oject Name and Location: Example Eight (8) - Agua Caliente & Molino Washes

rainage Concentration Point: Just Above Confluence

tershed Area (A): 24.7 acres/(square miles.)

ength of Watercourse (L_c): 53,300 ft. Length to Center of Gravity (L_{ca}): 29,300 ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
6600	1600
27,700	620
19,000	1060

an Slope (S_c): .0365 ft./ft. Watershed Type(s): Mountain (future)

sin Factor (n_b): .0464 (future) (See Sheet 1 of 2) Flood Frequency: 100 yrs.

P_{24} (24 hour):	4.48 in.	Areal Value:	4.32 in.
(6 hour):	3.55 in.	Areal Value:	3.39 in.
P_1 (1 hour):	2.62 in.	Areal Value:	2.30 in.
(2 hour):	2.94 in.	Areal Value:	2.66 in.
P_3 (3 hour):	3.15 in.	Areal Value:	2.96 in.

oil Group(s): 14% C & 86% D Cover Type(s): Desert & Mt. Brush + Herbaceous

over Density (pervious areas): 30% Impervious Cover: N/A (future)

CN(s): 85 & 90 (pervious ~~& impervious~~ areas) CN*(s): 87.69 & 91.72
(curve number) (adjusted curve number)

unoff to Rainfall Ratio(s),(C): .518 & .646 (pervious areas) N/A (impervious areas)

unoff Supply Rate (q): .628 i in./hr. (function of i)

Time of Concentration (T_c): 2.41 $i^{-.4}$ hrs./mins. (function of i)

terative Solution of T_c: 2.22 hrs./mins.

Rainfall Intensity (i) at T_c: 1.23 in./hr.

unoff Supply Rate (q) at T_c: .772 in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

eak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): 12,305 cfs.

Note: For impervious areas, CN* = 99 (constant).

APPENDIX

DETERMINATION OF MEAN SLOPE (S_c)

To determine the mean slope (S_c) of the longest watercourse within a watershed, the following equation should be used:

$$S_c = \left[\frac{L_c}{I}\right]^2 \quad \text{(ft./ft.)}.$$

Where

L_c = the length of the longest watercourse within the watershed, in feet.

$$I = \left[\frac{L_1{}^3}{H_1}\right]^{\frac{1}{2}} + \left[\frac{L_2{}^3}{H_2}\right]^{\frac{1}{2}} + \left[\frac{L_3{}^3}{H_3}\right]^{\frac{1}{2}} + \ldots\text{(feet)}.$$

And

L_1, L_2, L_3, etc. = incremental changes in length (L_i) along longest watercourse, in feet.

H_1, H_2, H_3, etc. = incremental changes in height (H_i) along longest watercourse, in feet.

This equation is defined as a hypothetical uniform slope for the longest watercourse within a watershed which would give the same travel time through the watershed as reach by reach calculation. (An assumption is made in the derivation of the equation that the roughness coefficient and hydraulic radius of the watercourse are the same for all reaches of the watershed; that is, the watershed is homogeneous).

EXAMPLE:

The longest watercourse within a watershed has a length of 15,000 feet, and the following profile:

Incremental Change in Length (L_i)	Incremental Change in Height (H_i)
3,000 feet	300 feet
8,000 feet	200 feet
4,000 feet	40 feet

Determine the mean slope (S_c).

First, "I" is computed:

$$I = \left[\frac{(3000)^3}{300}\right]^{\frac{1}{2}} + \left[\frac{(8000)^3}{200}\right]^{\frac{1}{2}} + \left[\frac{(4000)^3}{40}\right]^{\frac{1}{2}} \text{ feet}.$$

$$I = 100{,}083 \text{ feet}.$$

Then

$$S_c = \left[\frac{15,000}{100,083}\right]^2 = \underline{\underline{.0225 \text{ ft./ft.}}}$$

Note that if the slope for the watershed had been calculated in the conventional manner, dividing the total length by the total change in height, a value of .036 ft./ft. would have resulted, leading to a shorter time of concentration and consequently higher peak rate of discharge than might actually occur.

The number of "slope breaks", or incremental segments of channel length, to be utilized in calculating the mean slope (S_c) depends to a great extent upon the profile along the main channel length (L_c). However, the maximum number of segments generally need not exceed four (4) unless the watershed under investigation is unusually complex and contains numerous topographic variations. Typically, new incremental segments should be initiated whenever a significant change in the slope of the main channel length profile becomes apparent. This can usually best be estimated with the use of U.S.G.S. quad sheets and/or topographic maps.

GUIDE FOR ESTIMATING THE BASIN FACTOR (n_b)

The basin factor (n_b) represents the visually estimated mean of the n-factor (Manning's) or roughness coefficient of all principal watercourses within a watershed. When estimating the basin factor (n_b) of a watershed, a field observation of several representative channel locations should be made to provide a basis from which to make an accurate determination. In addition, the designer should remember to take into account the maximum land development expected to occur within the watershed in the foreseeable future since urban land use will greatly affect the type of runoff surfaces present within the watershed. This will generally reduce (in some cases, significantly) the value of its basin factor (n_b).

The basin factors (n_b's) presented in the following outline are to serve as a general guide; and, as such, cover a wide range of values. However, as a general rule, the values indicated as being "normal" for the type of area under investigation are to be utilized. Adjustments to these "normal" values should be made on the basis of the influence of any surface characteristics which might affect the time of concentration (T_c) of the watershed, provided that supportive photographic evidence accompanies the use of such adjustments.

A. Undeveloped Areas

Watershed Type	Mean Slope (S_c)	n_b (Min.)	n_b (Norm.)	n_b (Max.)
I. Mountain	Generally greater than .04 ft./ft.	.040	.050	.060

Typically, the drainage area is quite rugged, with sharp edges and narrow, steep canyons through which watercourses meander around sharp bends, over large boulders, and considerable debris obstruction. The ground cover, excluding small areas of rock outcrops, includes many trees and considerable underbrush. No drainage improvements exist in the area.

Watershed Type	Mean Slope (S_c)	n_b (Min.)	n_b (Norm.)	n_b (Max.)
II. Foothills	Generally from .01 to .04 ft./ft.	.030	.035	.040

Typically, the drainage area is generally rolling, with rounded ridges and moderate side slopes. Watercourses meander in fairly straight unimproved channels with some boulders and lodged debris. Ground cover includes scattered brush and grasses. No drainage improvements exist in the area.

Watershed Type	Mean Slope (S_c)	n_b(Min.)	n_b(Norm.)	n_b(Max.)
III. Valley	Generally less than .01 ft./ft.	.027	.030 - .040	.050

Typically, the drainage area has compartively uniform, gentle slopes and surface characteristics such that, in many cases, well-defined channelization does not occur. Ground cover consists of growths of grass and small shrubs, cacti, or similar vegetation. No drainage improvements exist in the area.

B. Developed Areas

Watershed Type	Density	n_b(Min.)	n_b(Norm.)	n_b(Max.)
IV. Suburban-Foothills	Less than 1 house per acre	.029	.034	.038
Suburban-Valley	Less than 1 house per acre	.027	.029 - .038	.047
Suburban-Foothills	1 to 2 houses/acre	.028	.032	.036
Suburban-Valley	1 to 2 houses/acre	.026	.028 - .036	.045

Typically, the drainage area has fairly uniform, gentle slopes with some watercourses either improved or along paved streets.

Watershed Type	Density	n_b(Min.)	n_b(Norm.)	n_b(Max.)
V. Light to Moderate Urbanization (Includes light industrial)	3 to 5 houses per acre (detached)	.020	.022	.025

Typically, the drainage area has fairly uniform, gentle slopes with most watercourses either improved or along paved streets.

Watershed Type	Density	n_b(Min.)	n_b(Norm.)	n_b(Max.)
VIa. Highly Urbanized	Multiple Dwellings Moderate Industrial and Light Commercial	.018	.020	.022

Typically, the drainage area is similar to a lightly to moderately urbanized basin, except that appreciable areas are developed to the extent that a large percentage of the watershed is impervious and essentially all watercourses are either improved or along paved streets and/or surfaces.

Watershed Type	Density	n_b(Min.)	n_b(Norm.)	n_b(Max.)
VIb Highly Urbanized	Heavy Commercial and Industrial	.015	.018	.020

Typically, the drainage area has fairly uniform, gentle slopes with essentially all watercourses either improved or along paved streets and/or surfaces. Areas are normally developed to the extent that only a minor percentage of the watershed remains pervious (less than 15%).

Watershed Type	n_b (Paved Surfaces)	n_b (Paved & Natural Surfaces)	n_b (Natural Surfaces)
*VII. Shallow Sheet Flow Area (not including flood plain/overbank flow along a watercourse or parallel channel and/or braided flow)	.040	.05 (moderate urban) .055 (light urban) .060 (suburban)	.06 (smooth) .07 (normal) .08 (rough)

Typically, the drainage area has extremely uniform, flat slopes and surface characteristics such that channelization does not occur and depths of flow do not exceed 0.50 feet. Along natural surfaces, ground cover usually consists of cultivated crops or substantial growths of grass and fairly dense small shrubs, cacti or similar vegetation. Generally, no drainage improvements exist in the area. (Normally, shallow sheet flow occurs within minor watersheds, over relatively short distances).

NOTES:

(1) The basin factors (n_b's) provided within the preceding outline assume that, where applicable, watersheds will be fully developed (i.e., maximum urbanization allowed under the applicable zoning ordinance will occur). However, if existing conditions indicate otherwise, basin factors (n_b's) should be adjusted accordingly.

(2) For watersheds containing combinations of suburban/urban development distributed approximately uniformly within their boundaries a basin factor (n_b) somewhere between the recommended "normal" values for each separate type of developed area should be chosen. For example, if 50 percent of a valley watershed contains, on the average, one house/acre and the remaining 50 percent contains three houses/acre, the recommended basin factor would be:

$$n_b = .50(.036) + .50(.022) = \underline{\underline{.029}}.$$

*(3) Prior to classifying a watershed as a "Shallow Sheet Flow Area", the designer should contact the Pima County Department of Transportation and Flood Control District for concurrence in the use of said classification.

RAINFALL

Rainfall depths for storm durations of one hour through twenty-four hours for the selected design frequency should be obtained by the following procedure:

Step One (1):

From the precipitation maps on pages 79 through 90, by means of latitude and longitude, determine the precipitation values for the 6 and 24 hour duration storms for return periods of 2, 5, 10, 25, 50 and 100 years. Tabulate these values in the column headed "Map Values" within the following Table:

Return Period (Years)	Precipitation Values (inches)			
	6 Hour Duration		24 Hour Duration	
	MAP VALUE	CORRECTED VALUE	MAP VALUE	CORRECTED VALUE
2				
5				
10				
25				
50				
100				

NOTE: There is a possibility of making an error while reading the maps because, (1) a site is not easy to locate precisely on a series of 12 maps, (2) there may be some slight registration differences in printing, and (3) precise interpolation between isolines is difficult. In order to minimize any errors in reading the maps, these values should be plotted on the diagram "Precipitation Depth versus Return Period" contained within this section (Page 92).

Step Two (2):

Plot these values on the diagram "Precipitation Depth versus Return Period" on Page 92.

Step Three (3):

Draw a line of best fit through the 6 hour precipitation values and another line through the 24 hour precipitation values.

Step Four (4):

Tabulate the values represented by the lines of best fit, obtained in Step 3, in the column entitled "Corrected Value" found in the Table on Page 76.

NOTE: The 1 hour precipitation value is needed to determine the 2 and 3 hour values as well as the 5, 10, 15 and 30 minute values.

Step Five (5):

Using the 6 and 24 hour values for the 2 year and 100 year return periods from the Table on Page 76, (corrected values), solve the following equations to determine the 1 hour values:

$$Y_2 = -0.011 + 0.942\ (X_1^2/X_2).$$

$$Y_{100} = 0.494 + 0.755\ (X_3^2/X_4).$$

Where

Y_2 = 2 year 1 hour value.

Y_{100} = 100 year 1 hour value.

X_1 = 2 year 6 hour value from Table on Page 76.

X_2 = 2 year 24 hour value from Table on Page 76.

X_3 = 100 year 6 hour value from Table on Page 76.

X_4 = 100 year 24 hour value from Table on Page 76.

Step Six (6):

To determine 1 hour precipitation values for the other return periods, first plot the 2 year 1 hour value and the 100 year 1 hour value on the diagram on Page 92. Connect the two points by a straight line. The values on this line will give the 1 hour precipitation values for the various return periods.

Step Seven (7):

To determine the 2 and 3 hour precipitation values, use the following formulae with data for the appropriate return period as determined in Step Five (5), and the Table on Page 76 (corrected values):

2 hour = 0.341 (6 hour) + 0.659 (1 hour).
3 hour = 0.569 (6 hour) + 0.431 (1 hour).

An alternate method in lieu of the above equations is to use the figure on Page 93.

Step Eight (8):

The 12 hour precipitation value for any return period is determined by the following equation:

$$P_{12}\text{ hr.} = P_{24}\text{ hr.} - .51\ (P_{24}\text{ hr.} - P_{6}\text{ hr.}).$$

Step Nine (9):

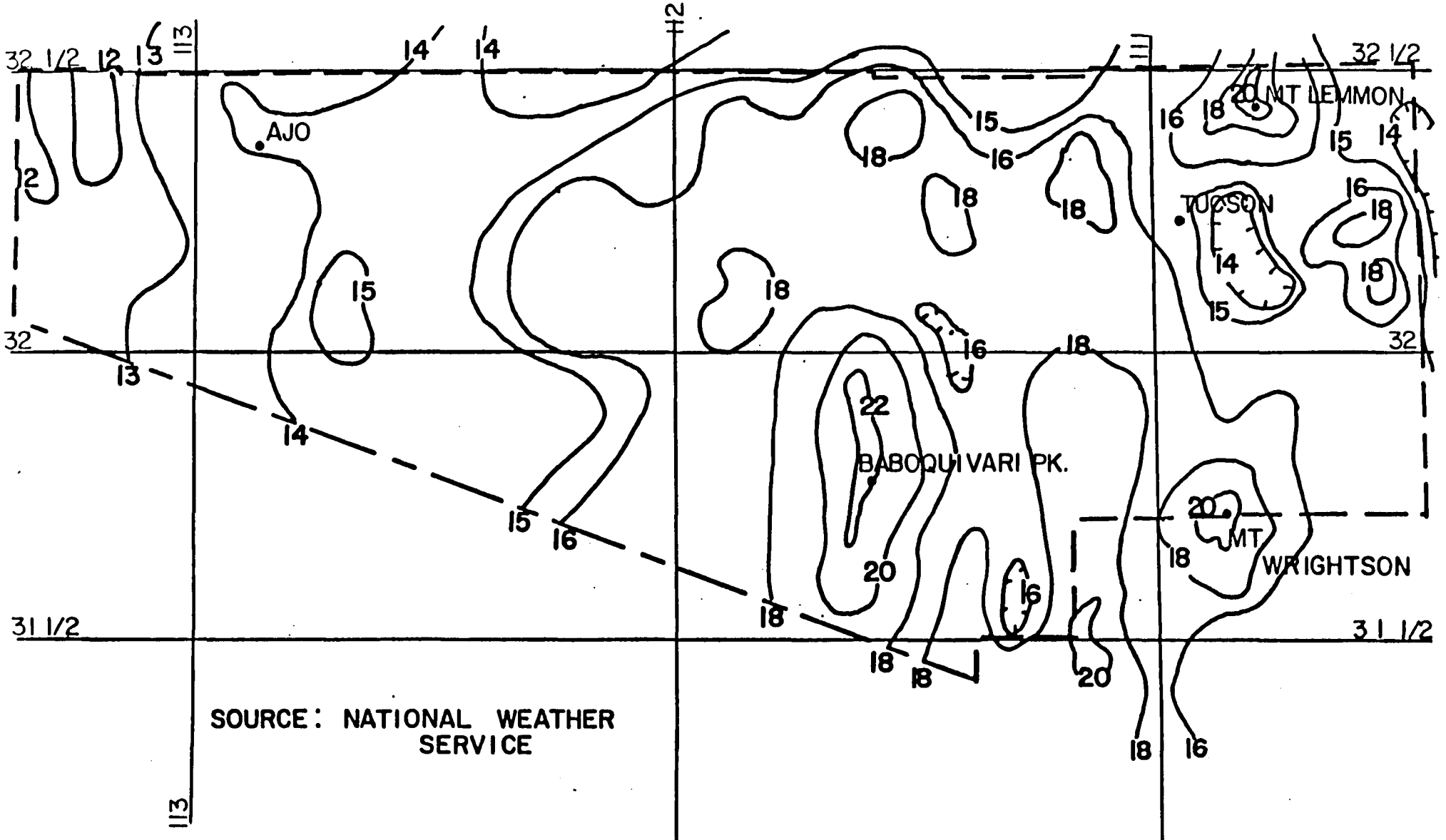
To determine precipitation values for durations less than 1 hour for any return period, the following relationships apply:

Duration (Minutes)	5	10	15	30
Ratio to one hour	.29	.45	.57	.79

Step Ten (10):

To determine the areal reduction of point precipitation values obtained via the aforementioned procedure (Steps 1 through 9), obtain the adjusted rainfall depth(s) from the figure on Page 91 by applying the percent of point rainfall corresponding to the drainage area to the depth of the design storm.

NOTE: The method of computing runoff described within this Manual is based upon the assumption that the average depth of rainfall is distributed uniformly over the entire drainage area. Since the Precipitation Maps included in the appendix reflect only point precipitation values, a reduction from point values to average areal values is required. This reduction is necessary because the rainfall depth from a storm centered over a large area is not constant over the total area, i.e., the maximum rainfall depth occurs at the center of the storm with the depth decreasing towards the edges. The curves within the figure on Page 91 indicate that for areas larger than 10 square miles the point precipitation values obtained from the Precipitation Maps on Pages 79 through 90 will be reduced according to the size of the drainage area and the storm duration.

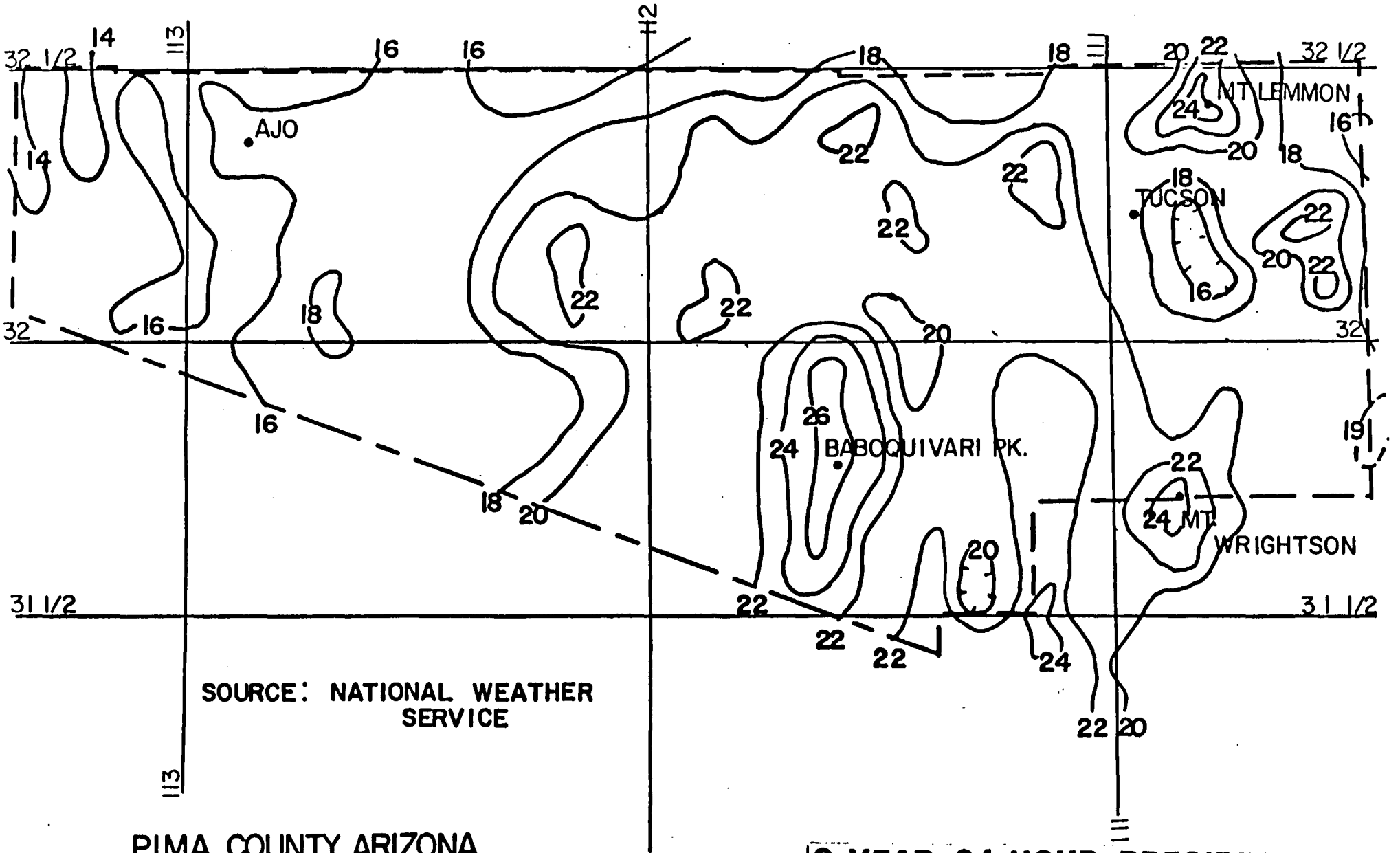


PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

2-YEAR 6-HOUR PRECIPITATION

—10— ISOPLUVIALS OF 2-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH



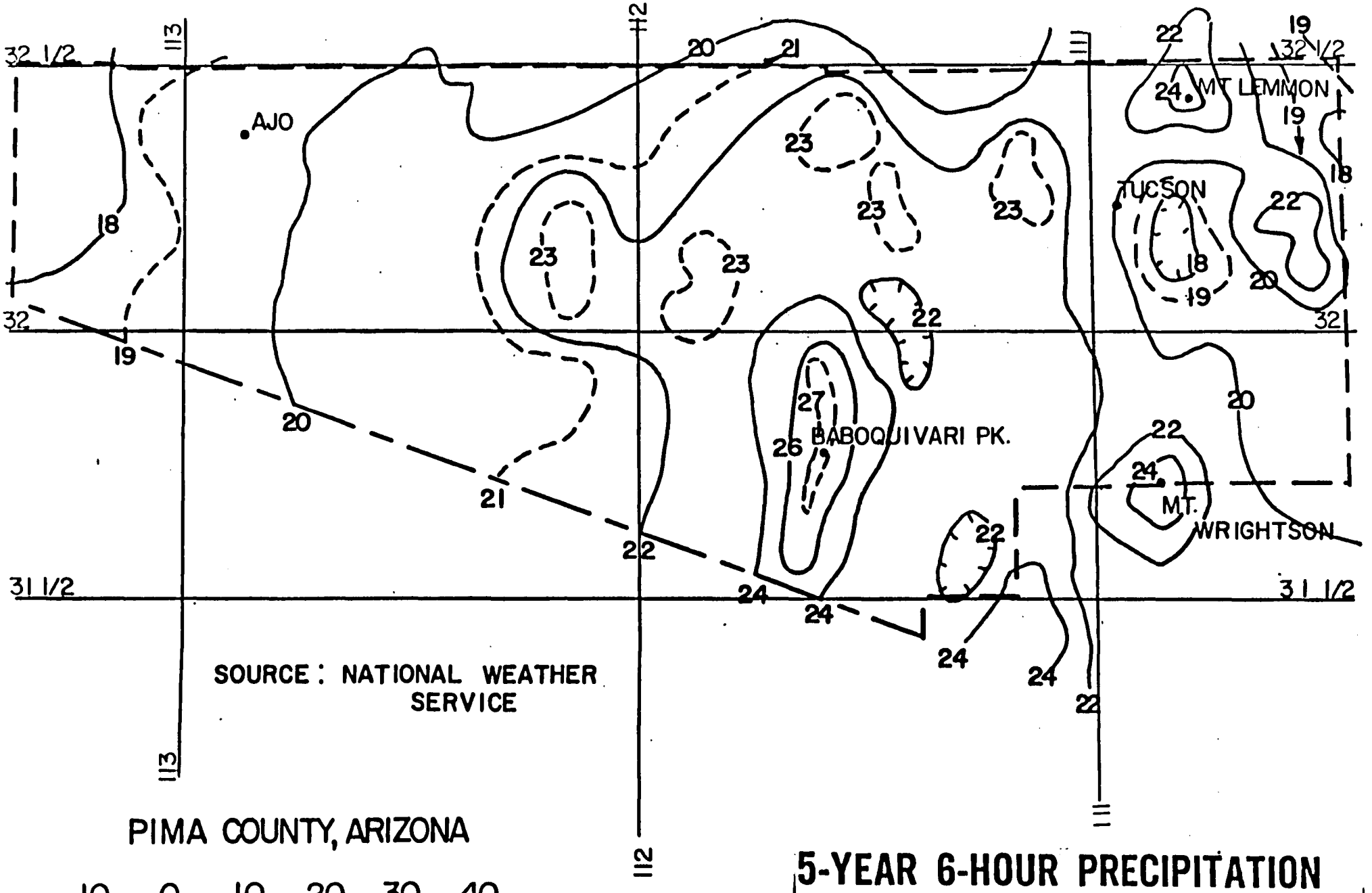
PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

2-YEAR 24-HOUR PRECIPITATION

—30— ISOPLUVIALS OF 2-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH

(80)



SOURCE: NATIONAL WEATHER SERVICE

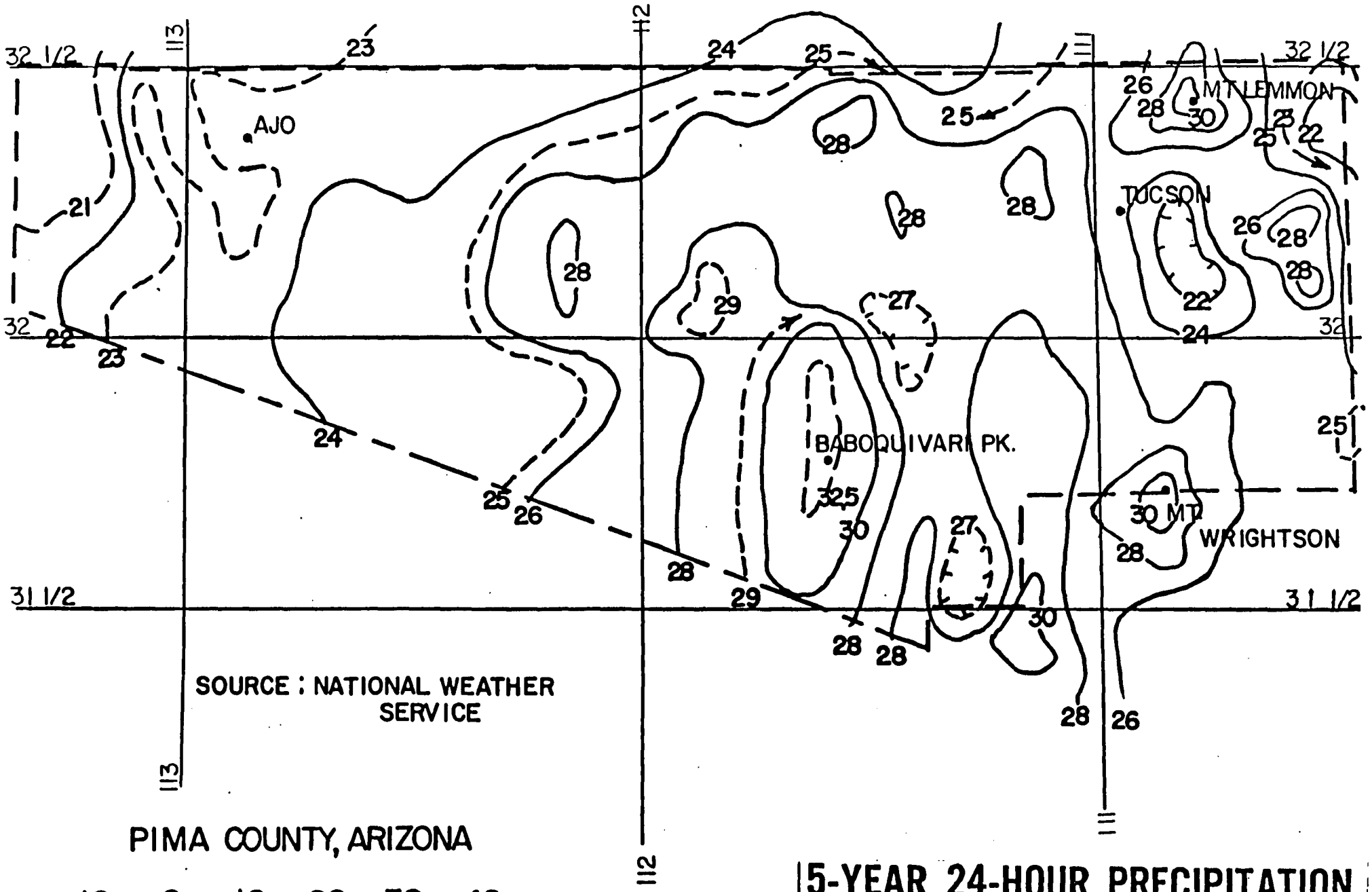
PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

5-YEAR 6-HOUR PRECIPITATION

—30— ISOPLUVIALS OF 5-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH

(81)

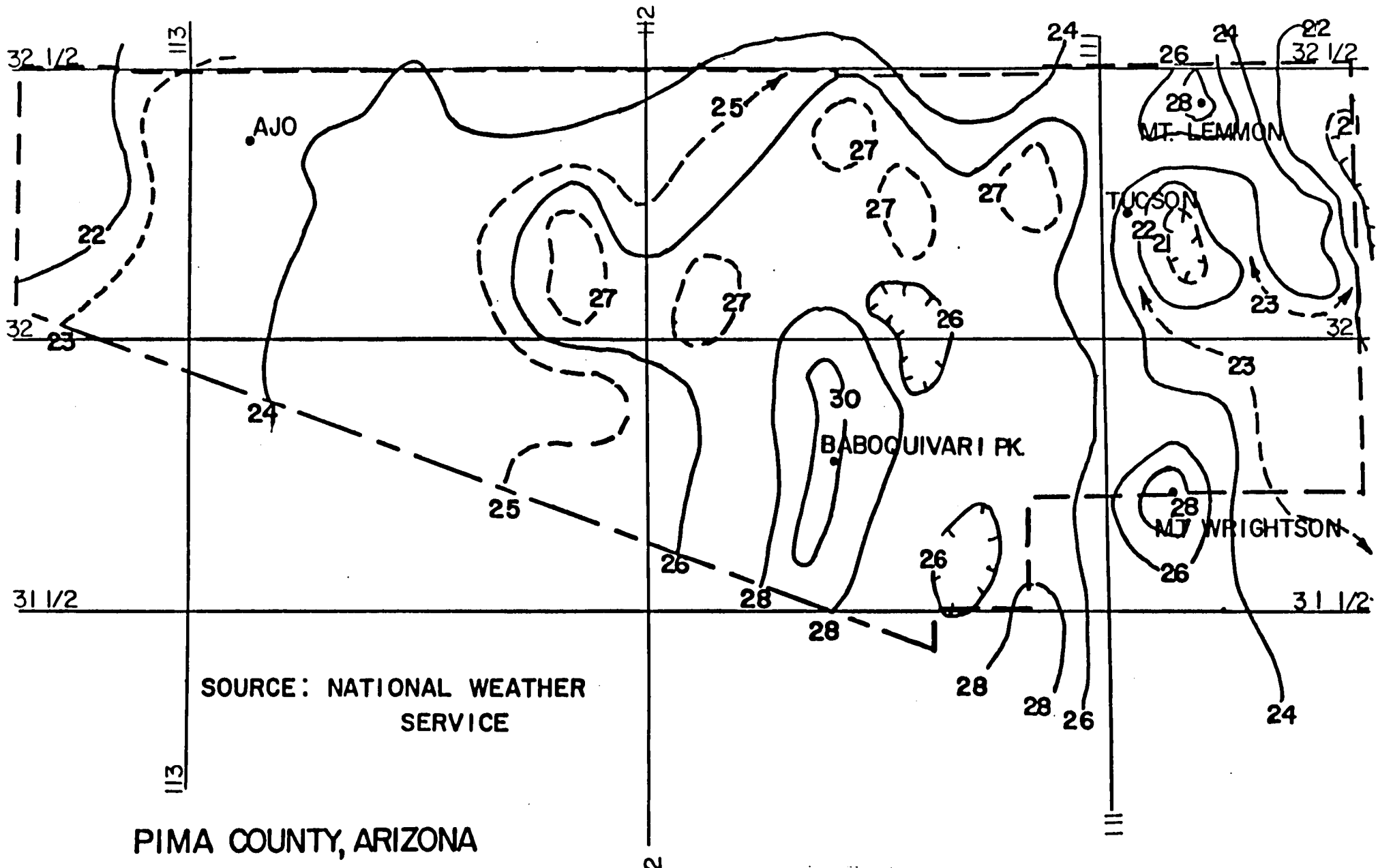


PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

5-YEAR 24-HOUR PRECIPITATION

—20— ISOPLUVIALS OF 5-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH

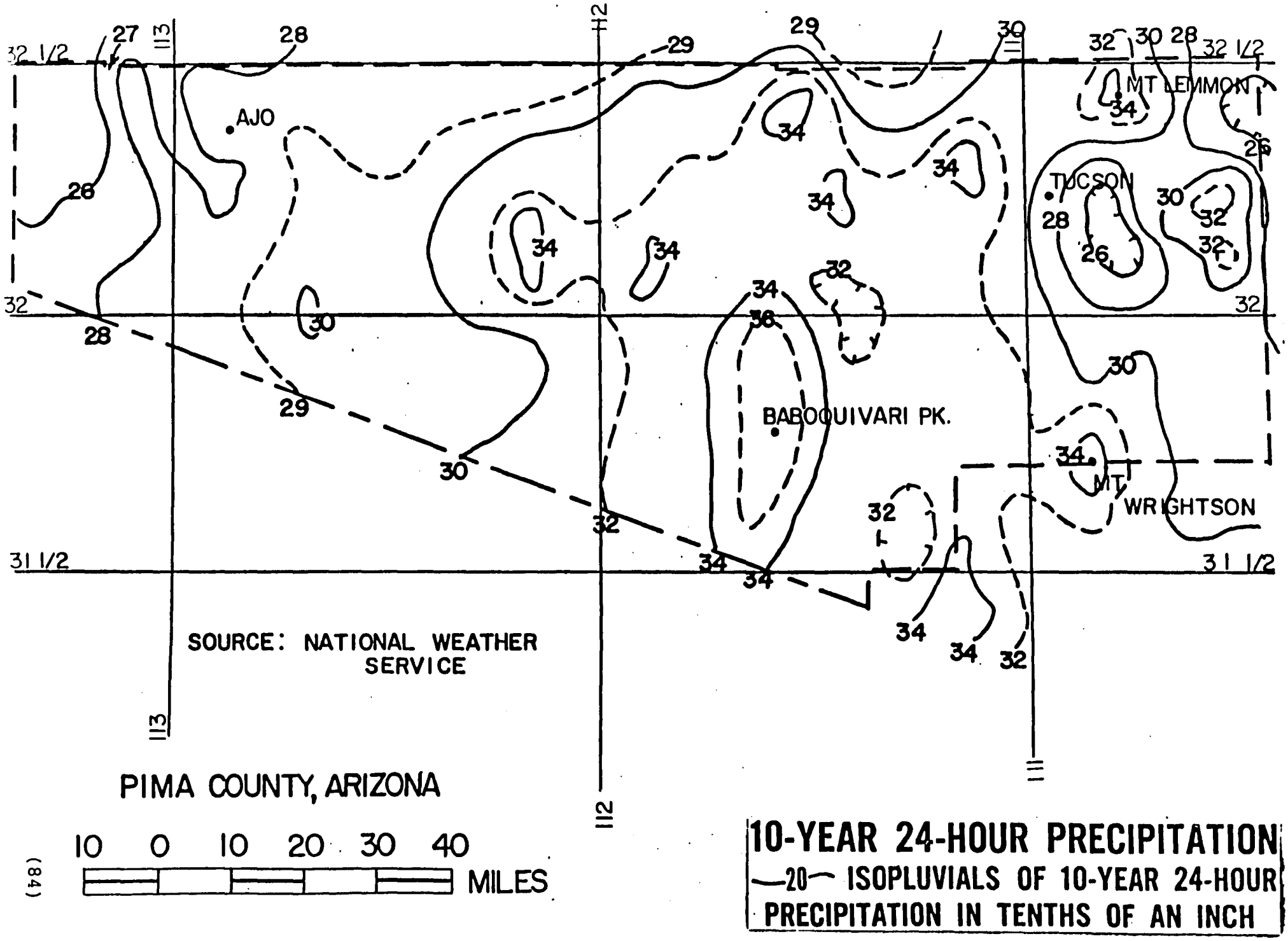


PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

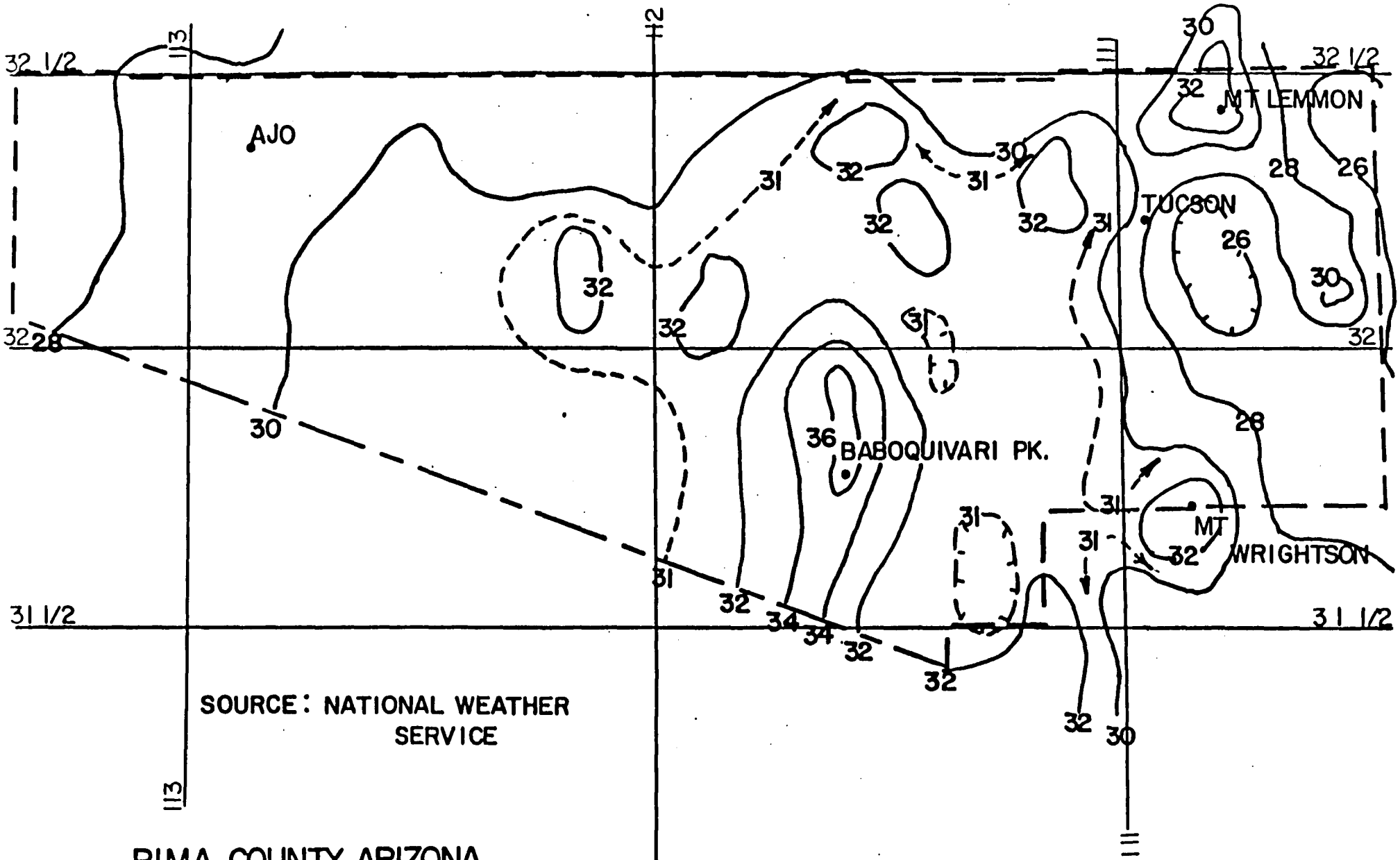
10-YEAR 6-HOUR PRECIPITATION

—20— ISOPLUVIALS OF 10-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH



10-YEAR 24-HOUR PRECIPITATION

—20— ISOPLUVIALS OF 10-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH

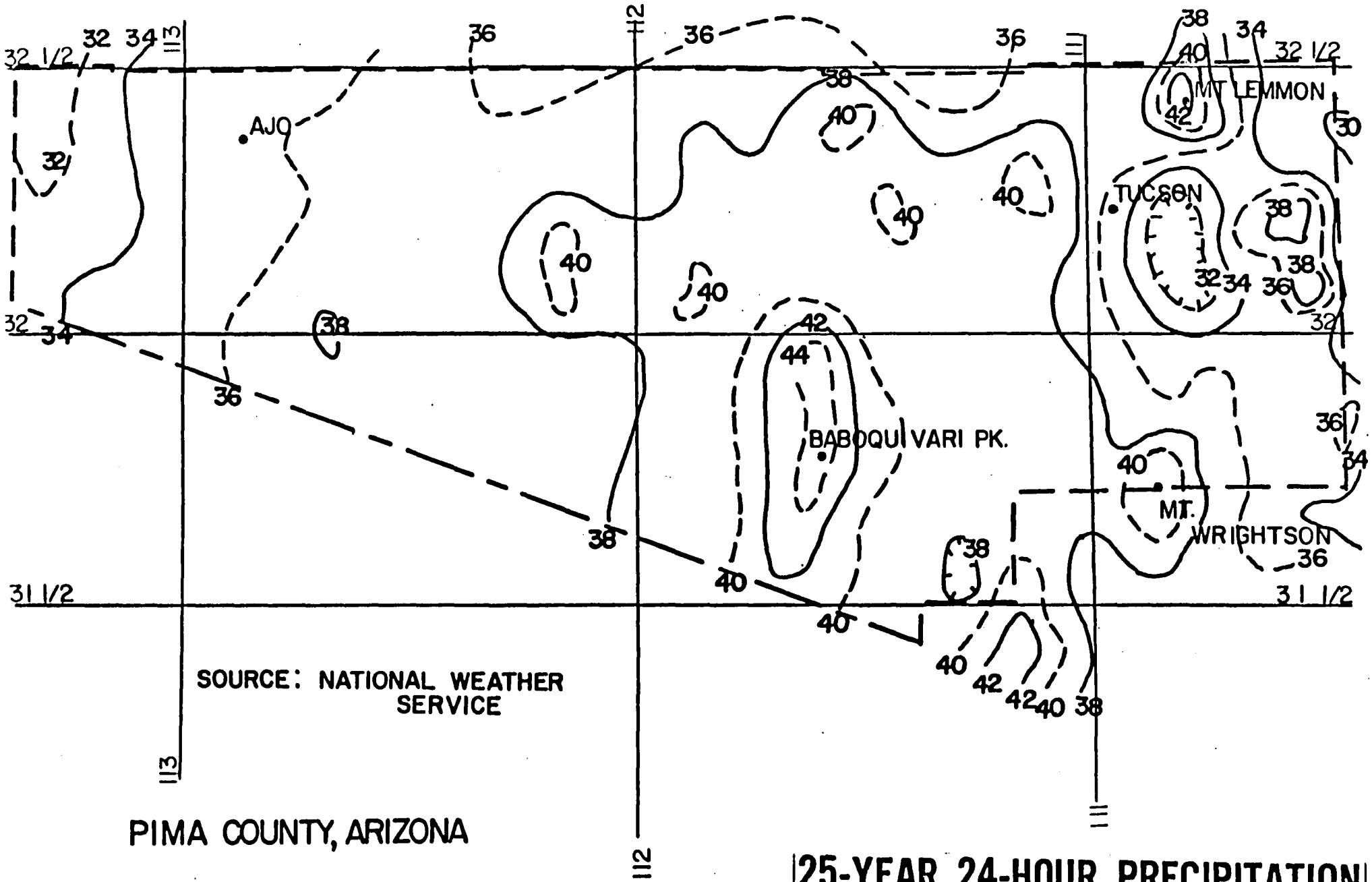


PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

25-YEAR 6-HOUR PRECIPITATION

—20— ISOPLUVIALS OF 25-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH



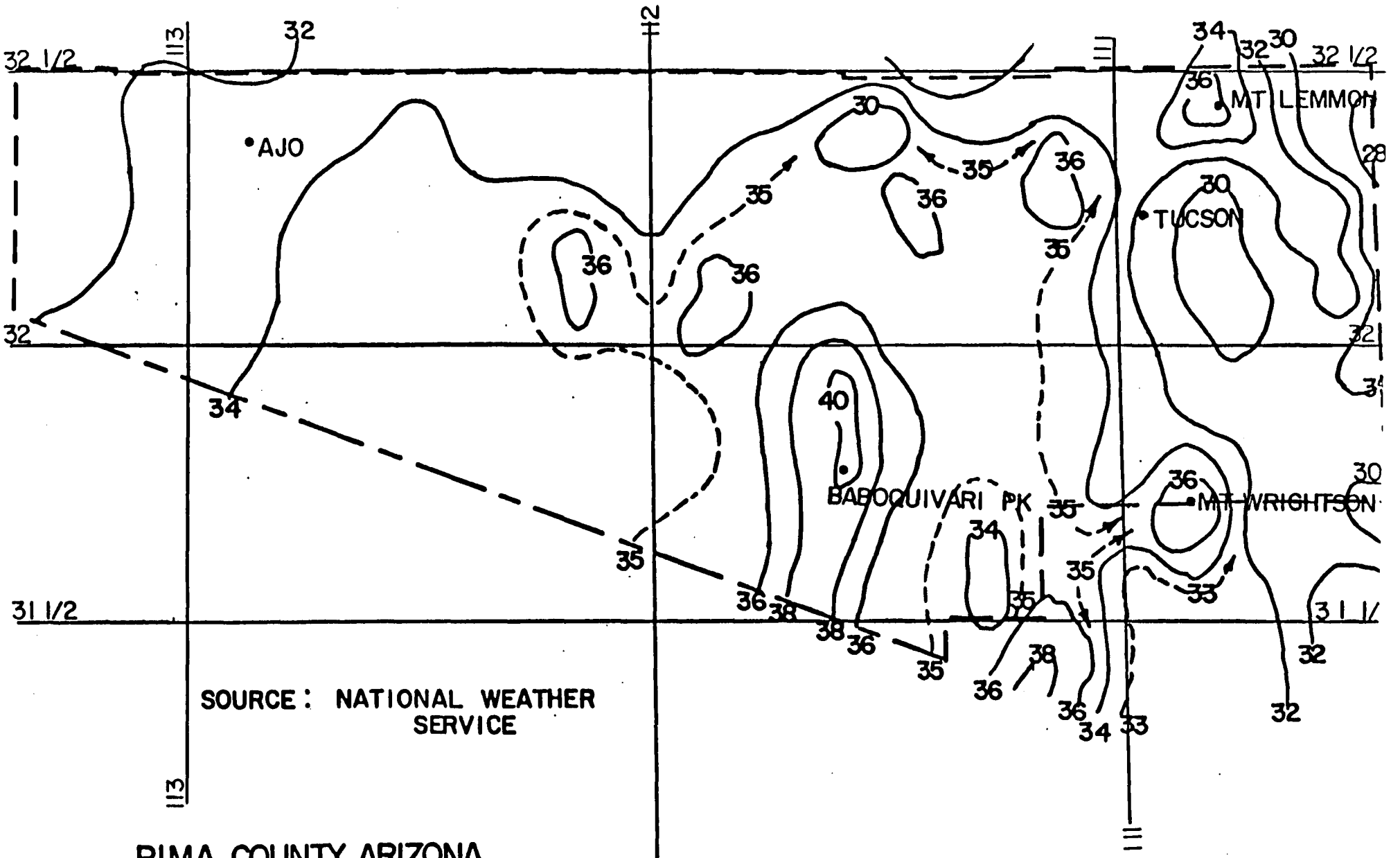
PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

(98)

25-YEAR 24-HOUR PRECIPITATION

—30— ISOPLUVIALS OF 25-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH



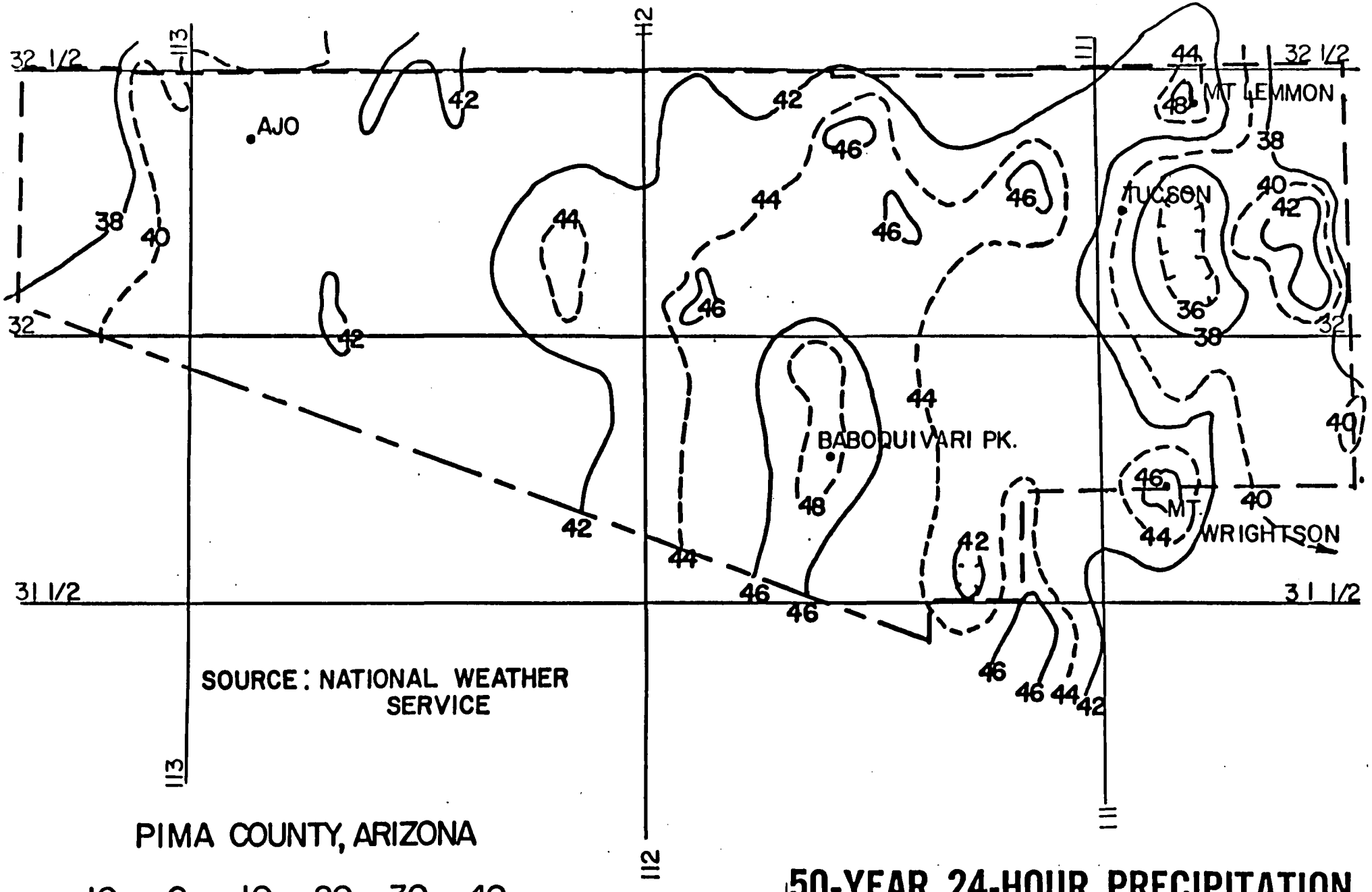
PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

(87)

50-YEAR 6-HOUR PRECIPITATION

—30— ISOPLUVIALS OF 50-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH



SOURCE: NATIONAL WEATHER SERVICE

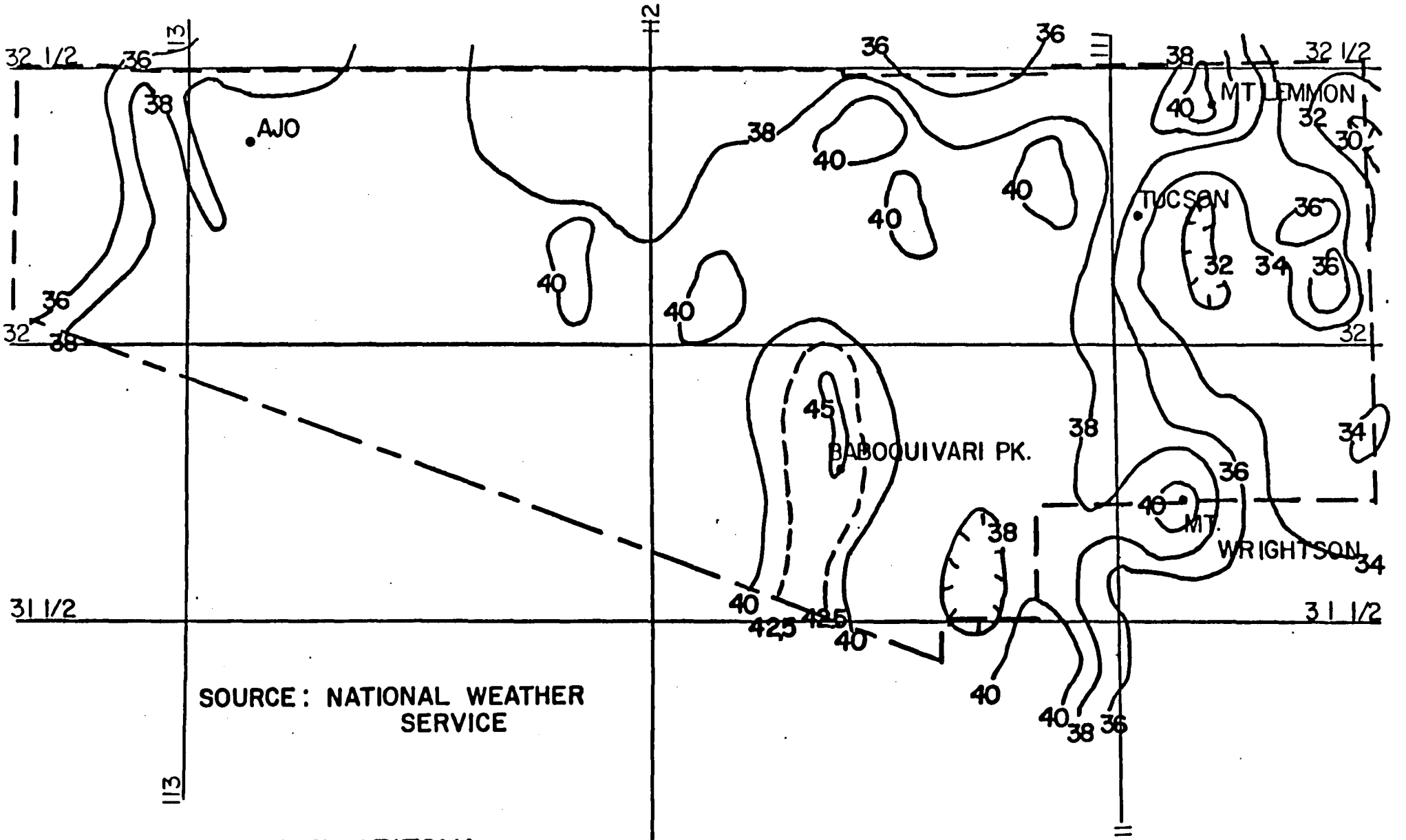
PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

50-YEAR 24-HOUR PRECIPITATION

—30— ISOPLUVIALS OF 50-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH

(88)



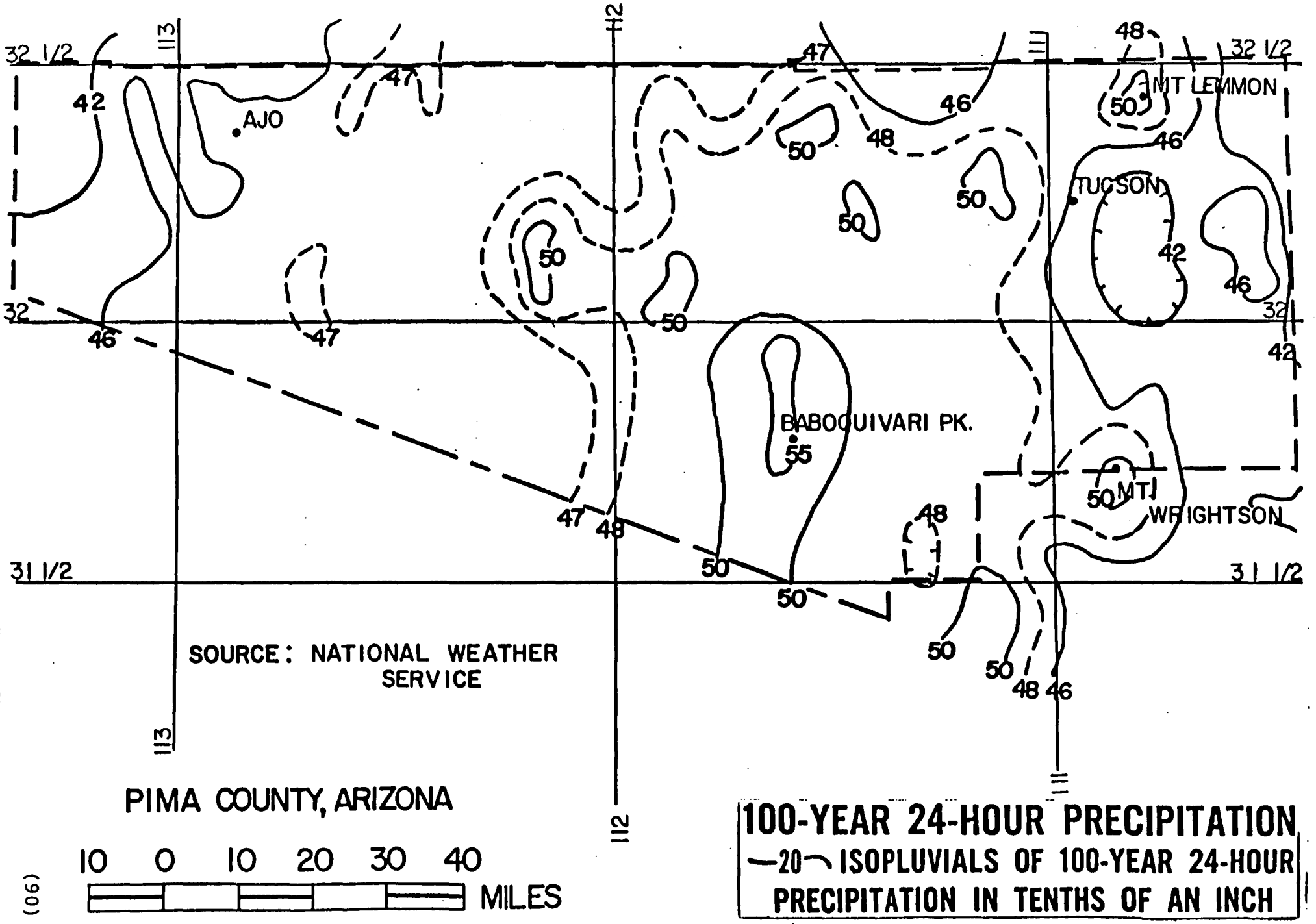
PIMA COUNTY, ARIZONA

10 0 10 20 30 40 MILES

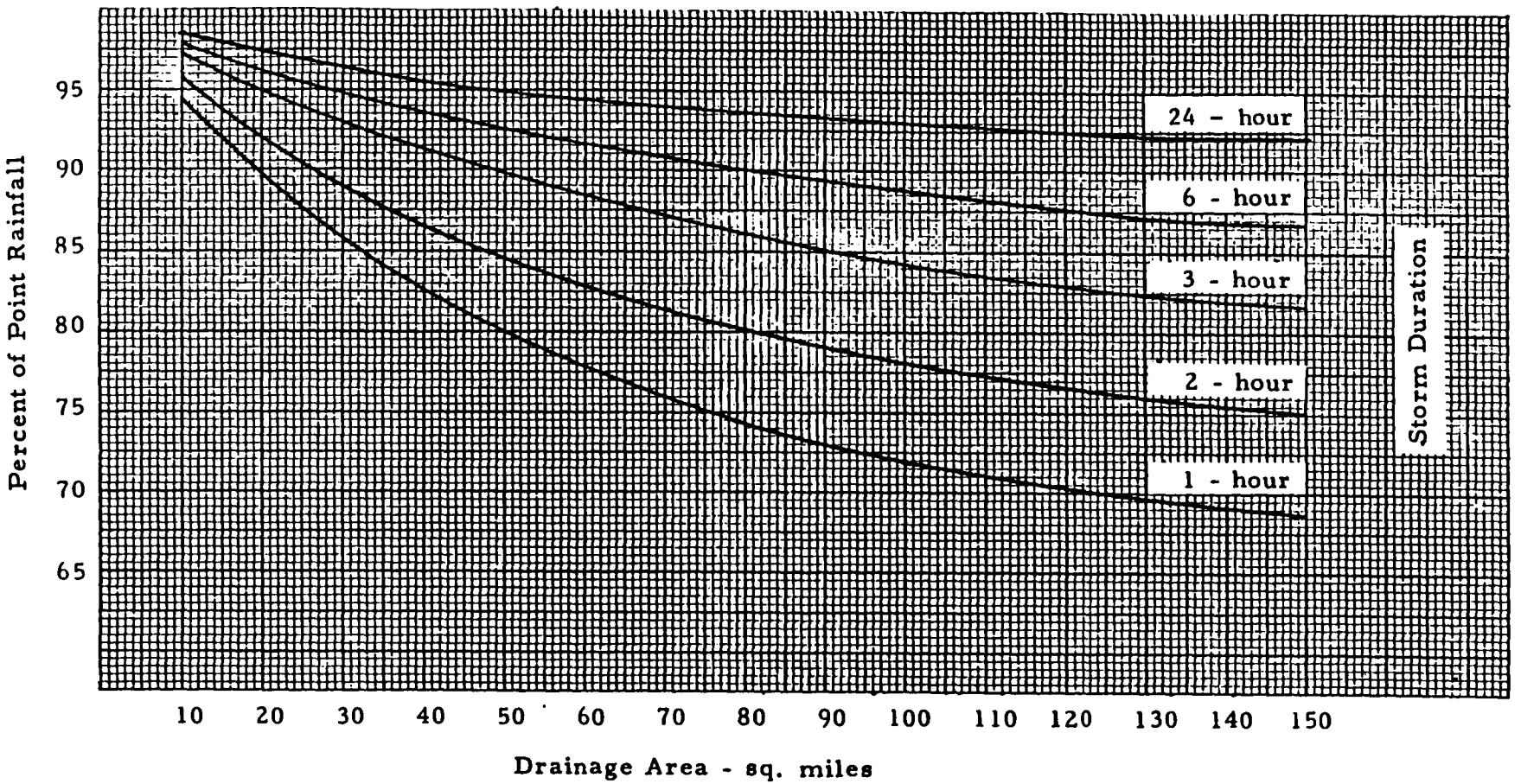
(89)

100-YEAR 6-HOUR PRECIPITATION

—30— ISOPLUVIALS OF 100-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH

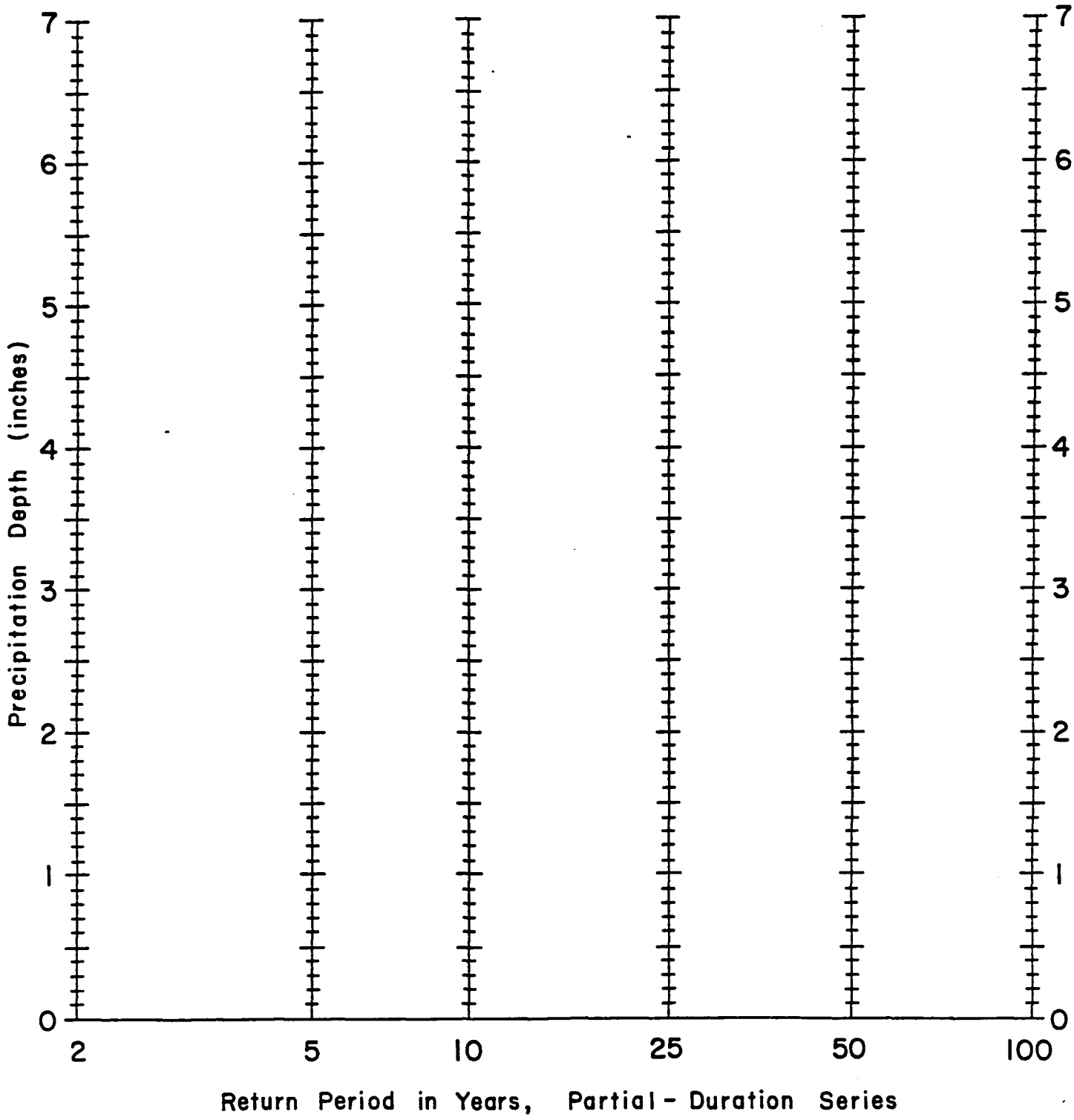

32 1/2
32
31 1/2
113
112
111
AJO
MT LEMMON
TUCSON
BABOQUIVARI PK.
MT. WRIGHTSON
42
46
47
48
50
55
SOURCE: NATIONAL WEATHER SERVICE
PIMA COUNTY, ARIZONA
10 0 10 20 30 40
MILES
100-YEAR 24-HOUR PRECIPITATION
—20— ISOPLUVIALS OF 100-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH

(90)



AREA - DEPTH CURVES

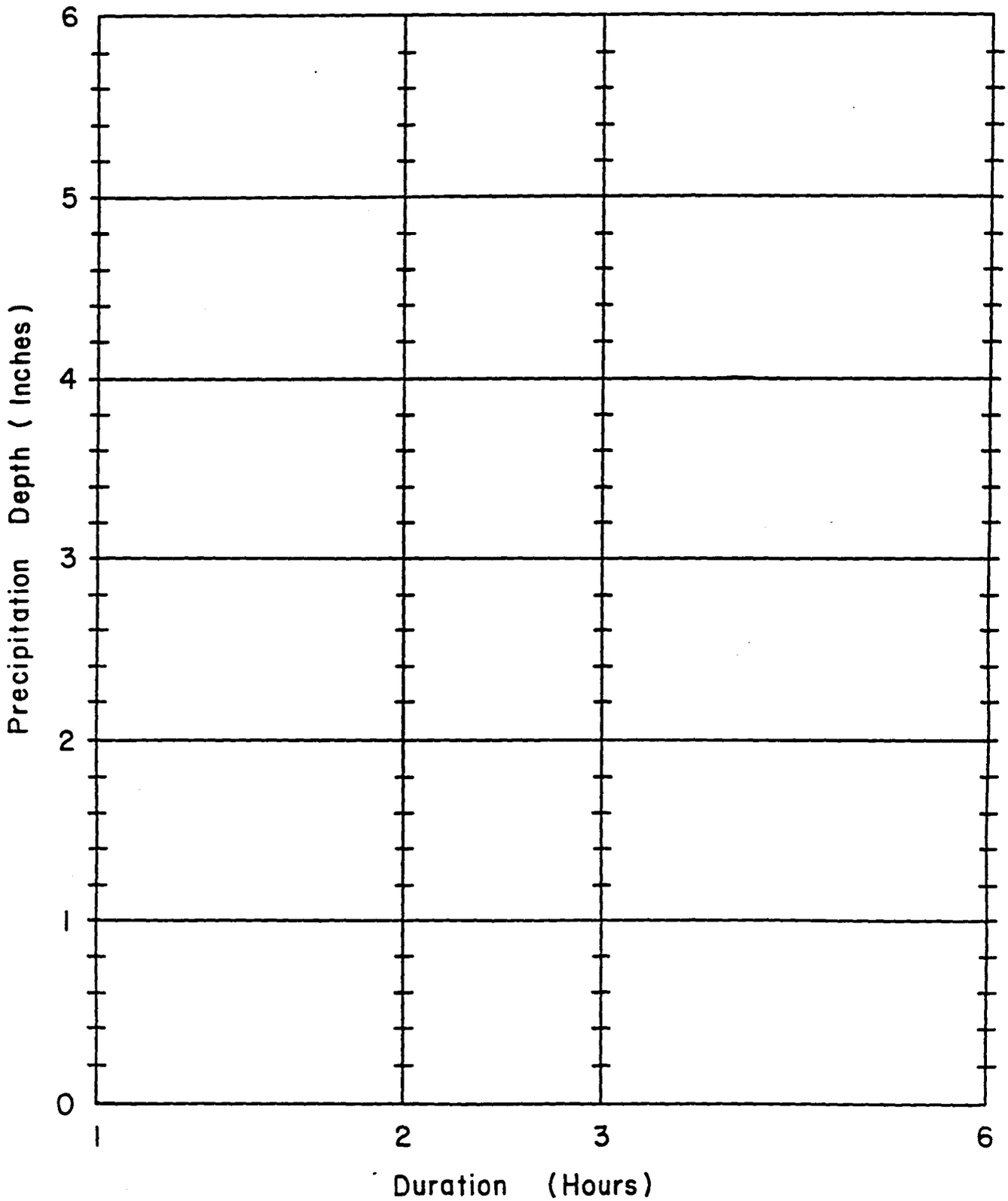
Latitude _____ Longitude _____



Precipitation Depth Versus Return Period For Partial - Duration Series

Precipitation Depth - Duration

Diagram (1 - 6 Hours)



HYDROLOGIC SOIL GROUPS

An hydrologic soil group represents a group of soils having the same runoff potential under similar storm and cover conditions. Surface soils which materially affect the rate of runoff have been classified into four major groups according to the infiltration rate of each soil. The distribution of these soils in Pima County, Arizona may be determined from the legend and figures shown on Pages 95 through 99. These soils are defined as follows:

GROUP A: (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively well drainage sands or gravels. These soils have a high rate of water transmission. Group A soils are generally not found within Pima County, Arizona.

GROUP B: Soils having moderate infiltration rates when thoroughly wetted, consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

GROUP C: Soils having slow infiltration rates when thoroughly wetted, consisting chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine to fine texture and a slow infiltration rate. These soils have a slow rate of water transmission.

GROUP D: (High runoff potential). Soils having a very slow infiltration rate when thoroughly wetted, consisting chiefly of clay soils with a high swelling potential; soils with claypan or clay layer at or near the surface; and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission.

LEGEND

HYPERTHERMIC (VERY HOT) ARID SOILS:

1. Gilman-Antho-Valencia association: Deep soils on floodplains and alluvial fans. Hydrologic soil group(s) = 100% B.

2. Mohall-Laveen-Coolidge association: Deep soils on the valley plains and old terraces. Hydrologic soil group(s) = 100% B.

3. Gunsight-Rillito-Harqua association: Deep, gravelly, calcareous soils on the upper slopes. Hydrologic soil group(s) = 88% B and 12% C.

4. Rock Outcrop-Lomitas, Cherioni association: Rock outcrop and very shallow and shallow soils on low hills and mountains. Hydrologic soil group(s) = 100% D.

THERMIC (HOT) ARID AND SEMI-ARID SOILS:

5. Grabe-Gila-Pima association: Deep soils of the floodplains. Hydrologic soil group(s) = 100% B.

6. Anthony - Sonoita association: Deep, arid soils on the alluvial fans and valley slopes. Hydrologic soil group(s) = 100% B.

7. Continental-Sonoita-Tubac association: Deep, arid soils on uplands. Hydrologic soil group(s) = 36% B and 64% C.

8. Mohave-Tres Hermanos-Anway association: Deep, arid soils on the valley plans. Hydrologic soil group(s) = 100% B.

9. Pinaleno-Nickel-Palos Verdes association: Deep, arid, gravelly soils on deeply dissected uplands. Hydrologic soil group(s) = 100% B.

10. Rillino-Latene-Cave association: Deep to very shallow, arid calcareous soils on uplands. Hydrologic soil group(s) = 80% B and 20% D.

11. White House-Bernadino-Caralampi association: Deep, semiarid soils on uplands. Hydrologic soil group(s) = 27% B and 73% C.

12. Caralampi-Hathaway association: Deep, semiarid gravelly soils on deeply dissected uplands. Hydrologic soil group(s) = 100% B.

13. Rock Outcrop-Lampshire-Cellar association: Rock outcrop and very shallow and shallow semiarid soils of the mountains and foothills. Hydrologic soil group(s) = 100% D.

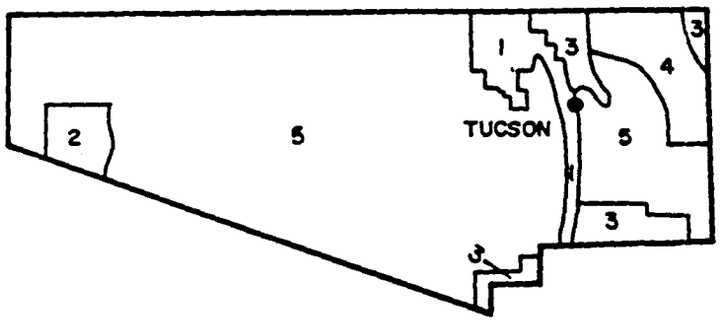
14. Rock Outcrop-Barkerville-Faraway association: Rock outcrop and very shallow and shallow subhumid soils of the mountains. Hydrologic soil group(s) = 40% C and 60% D.

LEGEND (Continued)

FRIGID (COLD) SUBHUMID SOILS:

15. Mirabal-Rock Outcrop association: very shallow to moderately deep soils and rock outcrop of the higher mountains. Hydrologic soil group(s) = 71% C and 29% D.

✓✓ Isolated areas of Rock Outcrop and shallow soils.



BASIS OF SOIL DATA

1. Generalized from Tuscon-Avra Valley Detailed Survey - published 1972

2. Generalized from Organ Pipe Cactus National Monument Detailed Survey - 1972

3. Generalized from unpublished Recon. and Low Intensity Surveys

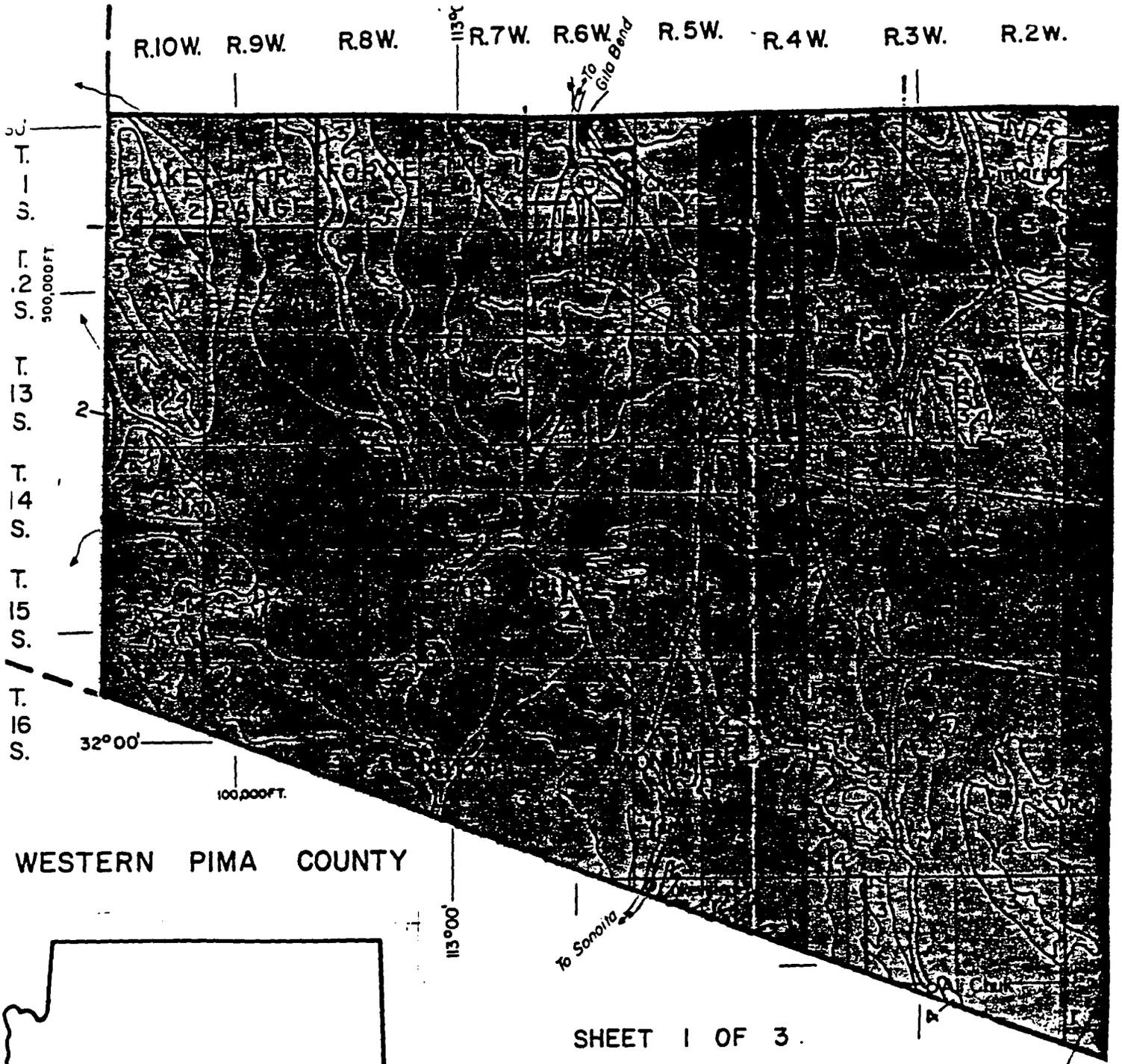
4. Generalized from uncorrelated Forest Service Soil Surveys

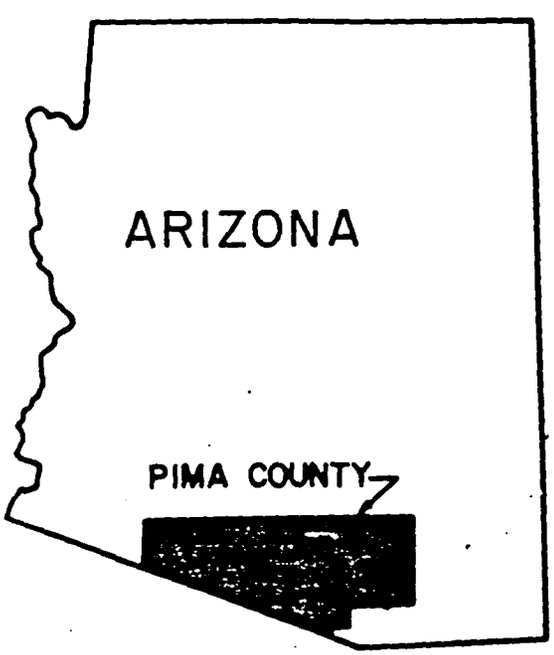
5. Limited Field and Air Inspection and general Geologic and Topographic information

Note: Interpretations for areas 4 and 5 have a lower reliability level than areas 1, 2, and 3. These interpretations would be used as a general guide and on site investigation is needed.

Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.

Source: U. S. Department of Agriculture Soil Conservation Service.





LOCATION MAP

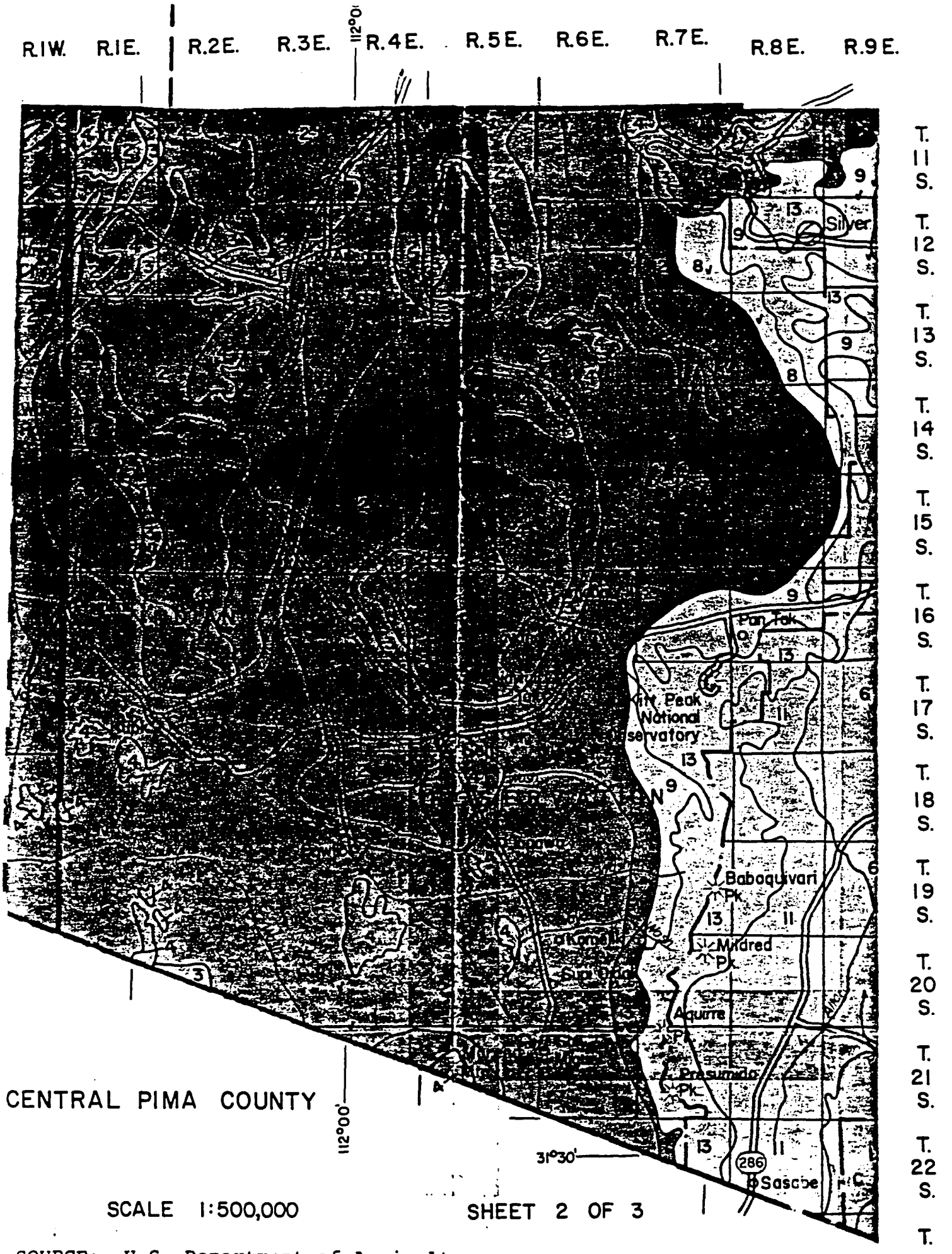
GENERAL SOIL MAP
PIMA COUNTY
ARIZONA

SOURCE: U.S. Department of Agriculture Soil Conservation Service

FEBRUARY 1974

10 0 10 20 MILES

SCALE 1:500,000

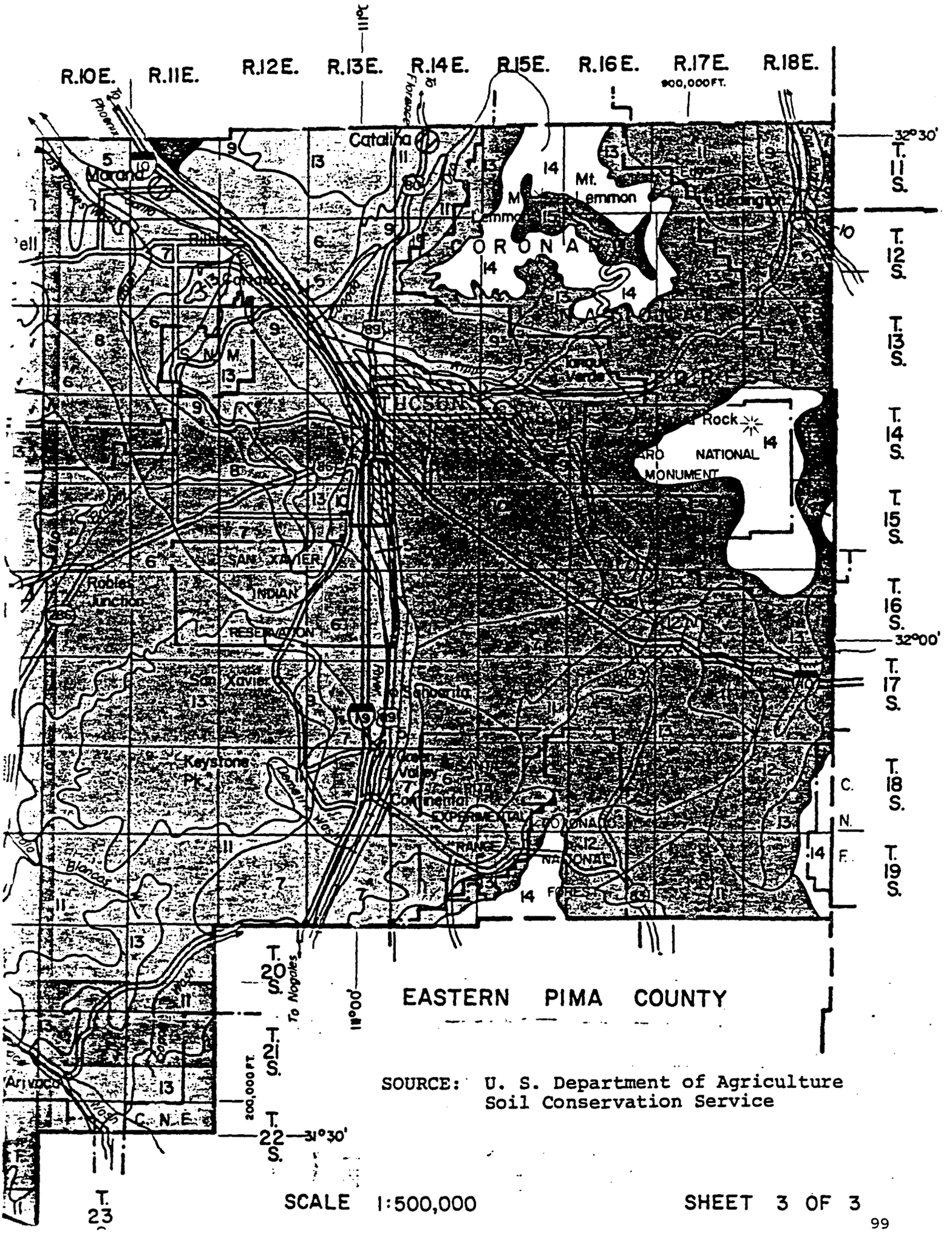


CENTRAL PIMA COUNTY

SCALE 1:500,000

SHEET 2 OF 3

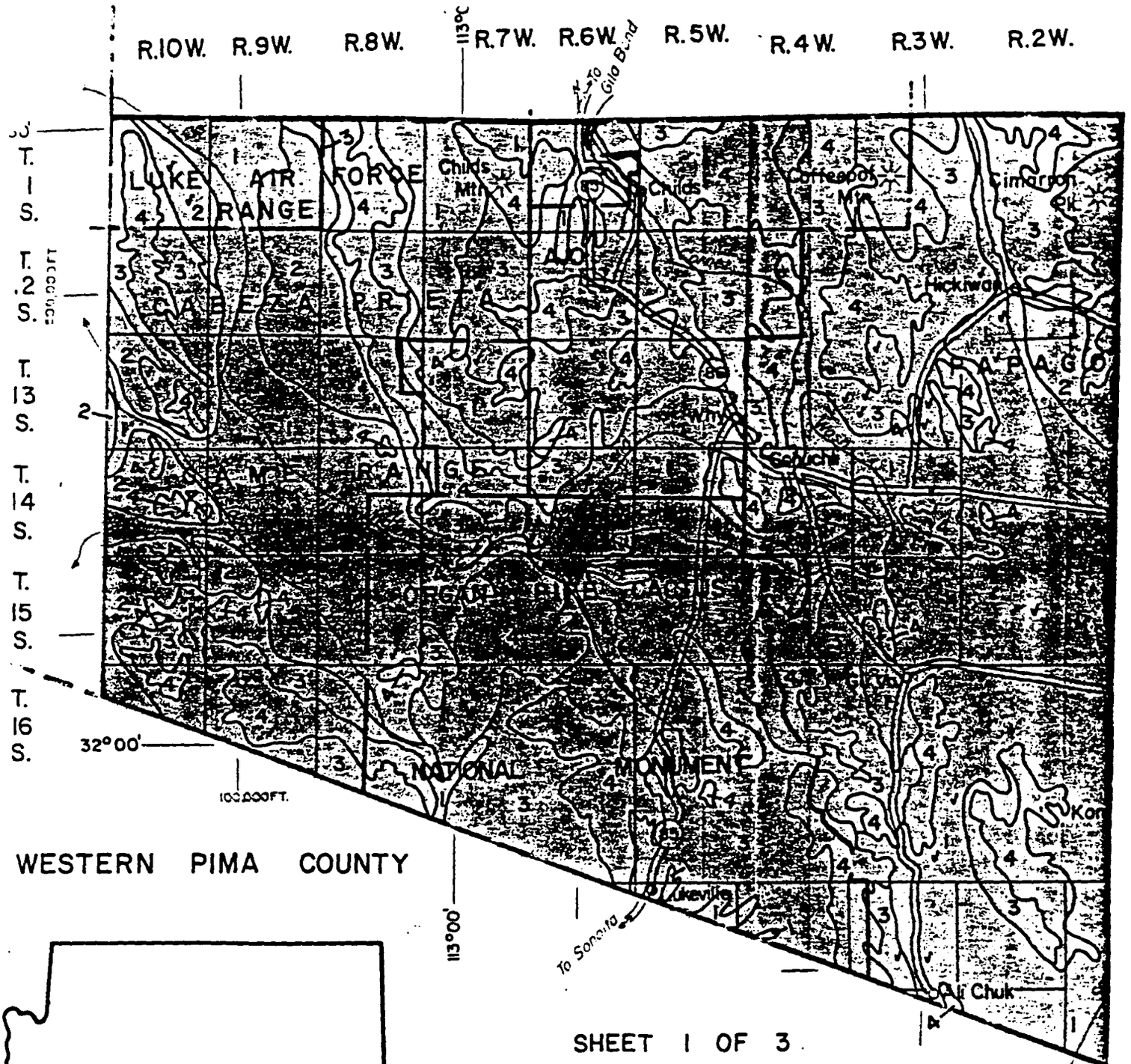
SOURCE: U.S. Department of Agriculture
Soil Conservation Service



SOURCE: U. S. Department of Agriculture
Soil Conservation Service

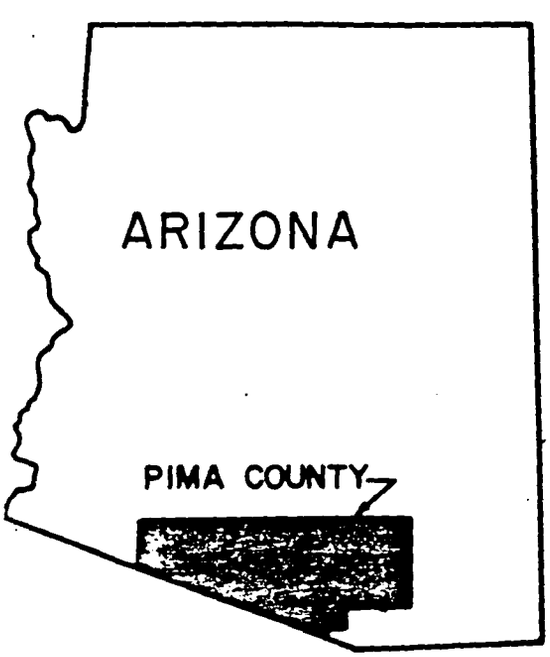
SCALE 1:500,000

SHEET 3 OF 3



WESTERN PIMA COUNTY

SHEET 1 OF 3



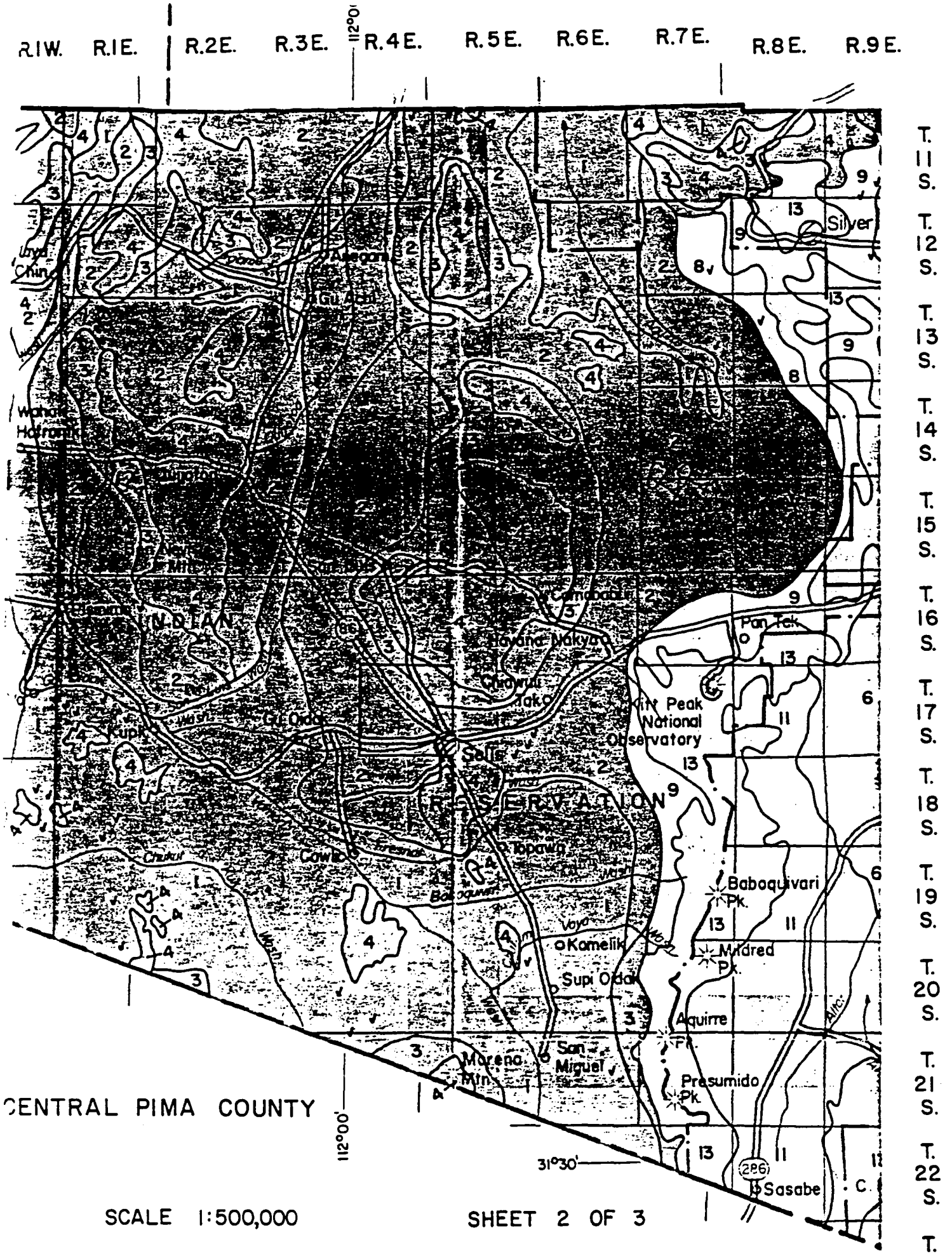
LOCATION MAP

GENERAL SOIL MAP
PIMA COUNTY
ARIZONA

SOURCE: U.S. Department of Agriculture Soil Conservation Service
FEBRUARY 1974

10 0 10 20 MILES

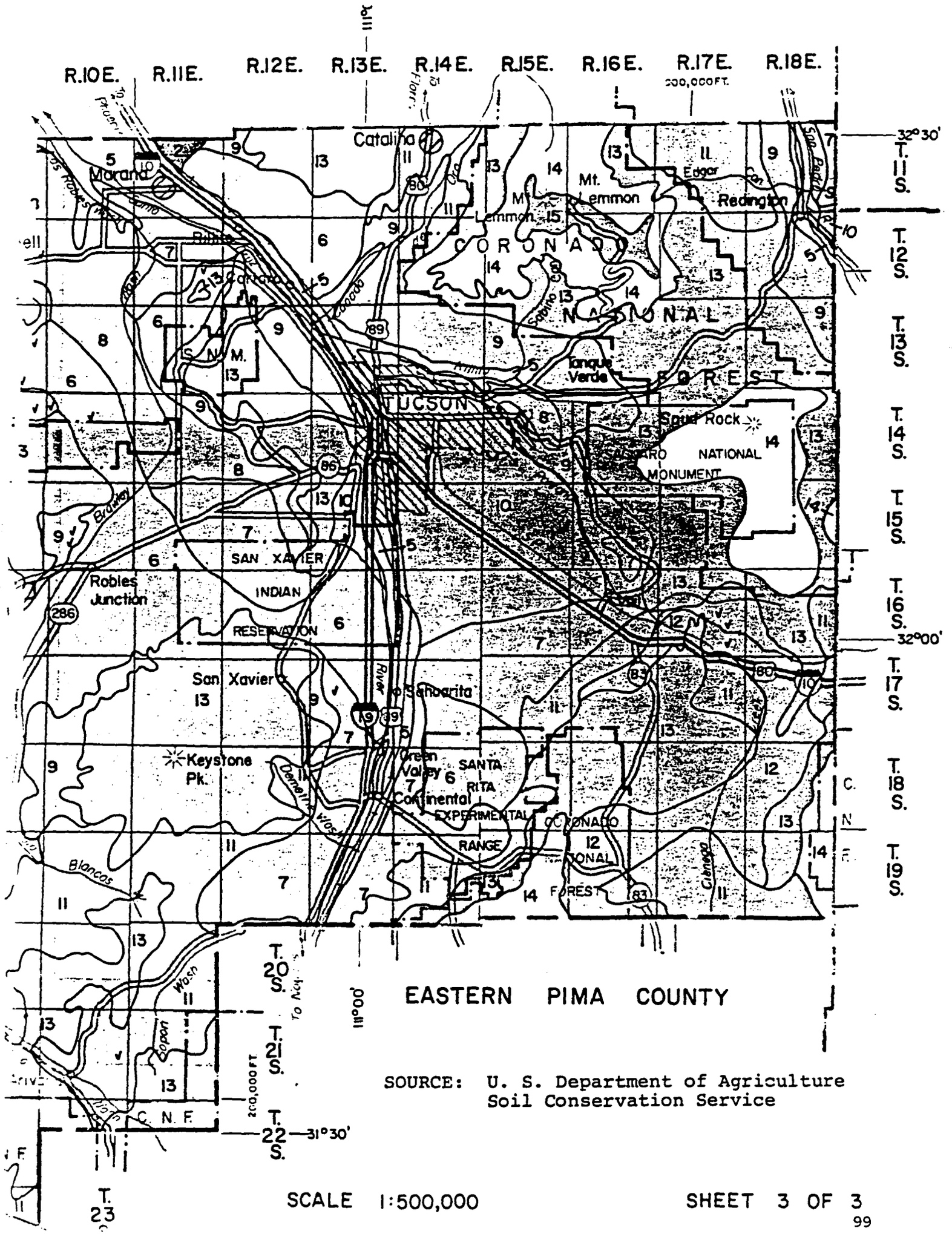
SCALE 1:500,000



SCALE 1:500,000

SHEET 2 OF 3

SOURCE: U.S. Department of Agriculture
Soil Conservation Service



SOURCE: U. S. Department of Agriculture
Soil Conservation Service

SCALE 1:500,000

SHEET 3 OF 3

HYDROLOGIC COVER TYPES

Vegetative types that basically affect the runoff process are divided into the following groups:

DESERT BRUSH:

Desert Brush includes such plants as mesquite, creosote bush, catclaw, cactus, etc., - desert brush is typical of lower elevations and low annual rainfall. Maximum elevations generally do not exceed 4000 feet above mean sea level.

HERBACEOUS:

Herbaceous includes short desert grasses with some brush, herbaceous is typical of intermediate elevations and higher annual rainfall than desert areas. Elevations generally range from a minimum of 1500 feet to a maximum of 5000 feet above mean sea level.

MOUNTAIN BRUSH:

Mountain brush includes mixtures of oak, aspen, mountain mahogany, manzanita, bitter brush, maple, etc., - mountain brush is typical of intermediate elevations and generally higher annual rainfall than herbaceous areas. Elevations generally range from a minimum of 4000 feet to a maximum of 7000 feet above mean sea level.

JUNIPER-GRASS:

Juniper areas are mixed with varying grass cover that is generally heavier than desert grasses due to higher annual precipitation - typical of higher elevations. Elevations generally range from a minimum of 6500 feet to the tops of the highest peaks, which are about 9500 feet above mean sea level.

PONDEROSA PINE:

Ponderosa Pine forests are typical of high elevations and high annual precipitation. These forests are usually only found within the vicinity of the tops of the highest mountain peaks.

URBAN LAWNS:

Urban Lawns include grasses, shrubs and trees, plus any other types of vegetation not normally indigenous to the Southwest, which are used by man for landscape purposes within urban areas. Generally found at elevations below 4,000 feet above mean sea level.

HYDROLOGIC COVER DENSITY

Hydrologic cover density is defined as the percent of the ground surface covered by the crown canopy of live plants and litter.

The Soil Conservation Service determines vegetation cover density by field surveys of carefully selected locations within the drainage area. However, where runoff from numerous small drainage areas is to be determined, an approximation of the vegetative cover based on visual observation will be adequate.

Three broad ranges of vegetative cover density have been established:

Poor	0 - 20% Vegetative cover
Fair	20% - 40% Vegetative cover
Good	40% + Vegetative cover

When possible, vegetative cover densities should be determined by field investigation conducted in the following manner:

1. An area representing the typical vegetative cover density for the drainage area is selected.

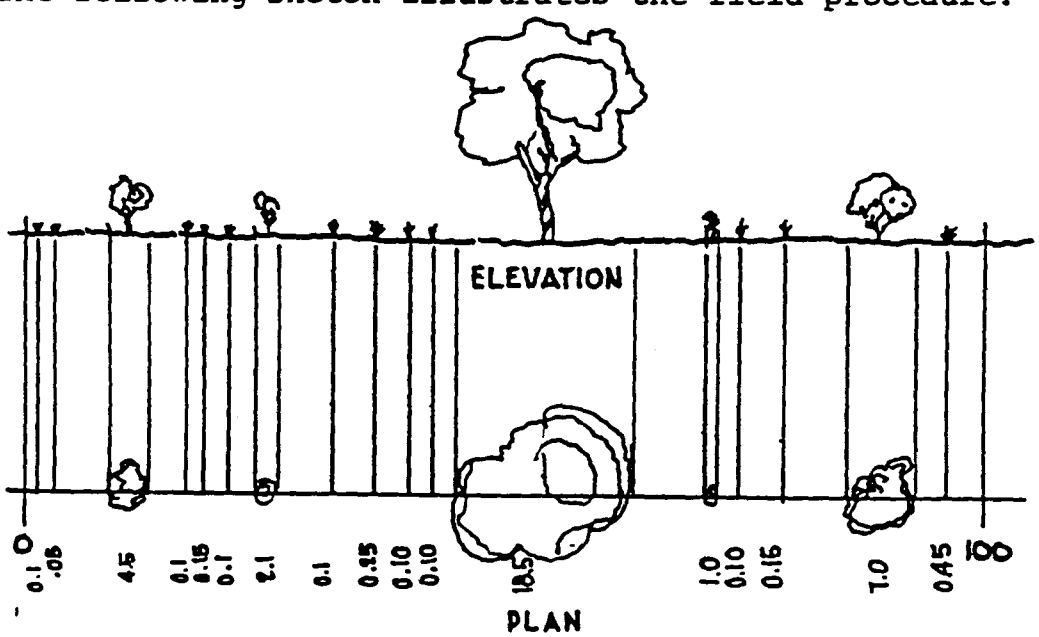
2. A 100 foot chain is stretched out between two posts, approximately 3 feet above ground level.

3. The intercepts of the vegetative cover along the 100 foot length are noted.

4. The total distance covered by vegetation and litter along the 100 foot length are summed up and represent the percent of vegetative cover for the selected area.

5. Several determinations may have to be made to compute the average percent of cover for the drainage area.

The following sketch illustrates the field procedure:



VEGETATIVE COVER = .1 + .05 + 4.5 + .1 + .15 + .1 + 2.1 +
.1 + .25 + .1 + .1 +18.5 + 1.0 +.1 +15 +
7.0 + .45.

DENSITY = 34.85%.

While the aforementioned field procedure is not required for drainage studies, an understanding of the method used in determining the vegetative cover density by field survey methods will aid in the visual determinations.

When large scale aerial photographs are available, they may be used in a similar manner to determine the vegetative cover density.

ESTIMATION OF IMPERVIOUS COVER

The values presented in the following table are intended to serve as a general guide; and, as such, cover a wide range of values. However, as a general rule, the values indicated as being "average" for the type of development anticipated should be utilized. Adjustments to these "average" values should be made on the basis of proposed subdivision plats and/or area plans, neighborhood plans, and existing development, etc., which would affect the degree of imperviousness of the watershed(s) under investigation.

* Type of Development Anticipated in Watershed	Percent of Impervious Cover Minimum	Average	Maximum
Suburban:			
(a) Less than 1 house/acre	5%	10%	20%
(b) 1 house/acre	15%	20%	25%
(c) 2 houses/acre	25%	30%	35%
Light to Moderate Urbanization:			
(a) 3 houses/acre	30%	35%	40%
(b) 4 houses/acre (detached)	35%	40%	45%
(c) 5 houses/acre (detached)	45%	50%	55%
Highly Urbanized:			
(a) Multiplied Dwellings (4 units/acre, or more)	50%	65%	90%
(b) Light Industrial & Commercial	50%	65%-75%	80%
(c) Heavy Industrial & Commercial	80%	85%-95%	100%

*It is assumed, in all cases, that paved streets are adjacent to at least one side of a developed lot.

CURVE NUMBERS (CN's) AND ADJUSTED CURVE NUMBERS (CN*'s)

The runoff to rainfall ratios that need to be determined for use with the method described within this Manual are dependent directly upon the U. S. Department of Agriculture Soil Conservation Service Curve Number Method of estimating direct runoff from rainfall. The curve numbers indicated upon the figure on Page 107 are the standard curve numbers (CN's) used to determine the volume of direct runoff from the design rainfall. These standard curve numbers (CN's), except those listed under the classification "Urban Lawns", were developed by the Soil Conservation Service specifically for the State of Arizona, and represent values that might normally be expected to be encountered within the State in conjunction with the types of hydrologic soil groups, vegetative growth and vegetative cover densities present statewide (curve numbers (CN's) for "Urban Lawns" were developed from local urban runoff data). These values generally reflect short duration (one hour, or less) storms occurring at times when average antecedent moisture conditions prevail (i.e., .5 to 1.1 inches of rain having fallen, dormant season; or, 1.4 to 2.1 inches having fallen, growing season, during the five (5) days previous to the storm event).

As indicated within the figure on Page 107, these curve numbers (CN's), and consequently direct runoff, vary with vegetation type, vegetative cover density and hydrologic soil groups. In addition, however, recent hydrologic investigations conducted upon semiarid range and forest areas by both the U.S. Soil Conservation Service and the U.S. Agricultural Research Service, Southwest Watershed, Research Center (offices in Tucson, Arizona), have revealed that curve numbers are dependent upon the amount of rainfall that falls during a specified storm duration (i.e., they are function of rainfall intensity). The locales where these investigations were conducted, near the towns of Safford and Tombstone, Arizona, are hydrologically and hydraulically similar in nature to the area covered by this Manual. Therefore, the assumption has been made that the information obtained from said investigations is equally valid for all areas within Pima County, Arizona.

The occurrence of the aforementioned phenomenon, according to experts in the fields of hydrology and meteorology, is due to the impact of raindrops on the nearly bare soil of the semiarid regions of the Southwest. This impact causes the "pores" of the soil, so to speak, to "seal up" and greatly reduce the infiltration rate that would normally be expected to occur in the affected soil. The investigations have shown that the higher the rainfall intensity, the lower the infiltration rate; therefore, the higher the curve number of the particular soil. An often used expression for this phenomenon is "the Caliche Effect", since it appears that the soil actually becomes impervious in nature, like caliche, during short periods of intense rainfall. To account for runoff variations due

to this so called "Caliche Effect", the computational procedure for estimation of peak discharge must incorporate the paramenter adjusted curve number (CN*).

The determination of the adjusted curve numbers (CN*'s), found on Page 108, is based upon several assumptions. First, it is assumed that the watershed is in the dry condition prior to the rainfall event of interest. Statistics show that this is the predominant condition within semiarid southwestern regions similar in nature to Pima County, Arizona. Second, since the standard curve numbers (CN's) provided within this Manual are based upon short duration storms of one (1) hour or less; logically, rainfall intensities normally used in the determination of adjusted curve numbers (CN*'s) would be for storms of one (1) hour duration. However, since the intensity of a storm of one (1) hour duration is equivalent, numerically, to the amount of rainfall that falls during this time period, one (1) hour rainfall depths are employed as a convenience in lieu of intensities when determining CN*.

The procedure for determining adjusted curve numbers (CN*'s) is as follows:

From the Figure on Page 107,

(1) Determine the standard curve number (CN) for the type of soil, vegetative cover and cover density encountered within the watershed under investigation.

(2) Determine the appropriate one (1) hour rainfall depth (P_1) for the frequency storm under investigation.

(3) Using the standard curve number (CN) obtained in Step One (1), determine the values of R_1 and R_2 from the figure on Page 108.

(4) Substitute the values obtained from Steps Two (2) and Three (3) into the following equation for the adjusted curve number (CN*):

$$CN^* = \frac{R_1 \ (P_1 - .88) + R_2}{P_1}.$$

(The areal value of P_1 should be used, when applicable).

The above equation was developed, in part, from information contained within the hydrologic investigations conducted by the agencies cited earlier, and in part, from comparisons between observed and predicted flood peaks upon gaged watersheds when utilizing similar equations.

NOTE: In order to determine CN*, P_1 must be greater than .88 inches.

EXAMPLE:

A watershed under investigation is found to contain soils lying entirely within Hydrologic Soil Group B. The vegetative cover consists entirely of desert brush, and cover density is approximately 10%. Determine the adjusted curve number (CN*) when the one (1) hour rainfall depth (P_1) equals 2.60 inches.

SOLUTION:

(1) From the figure on Page 107, the standard curve number (CN) is determined to be 83.

(2) Then, the adjusted curve number (CN*) is calculated as follows:

(a) From the figure on Page 108 (using CN=83) we find that R_1 = 93.00 and R_2 = 66.00.

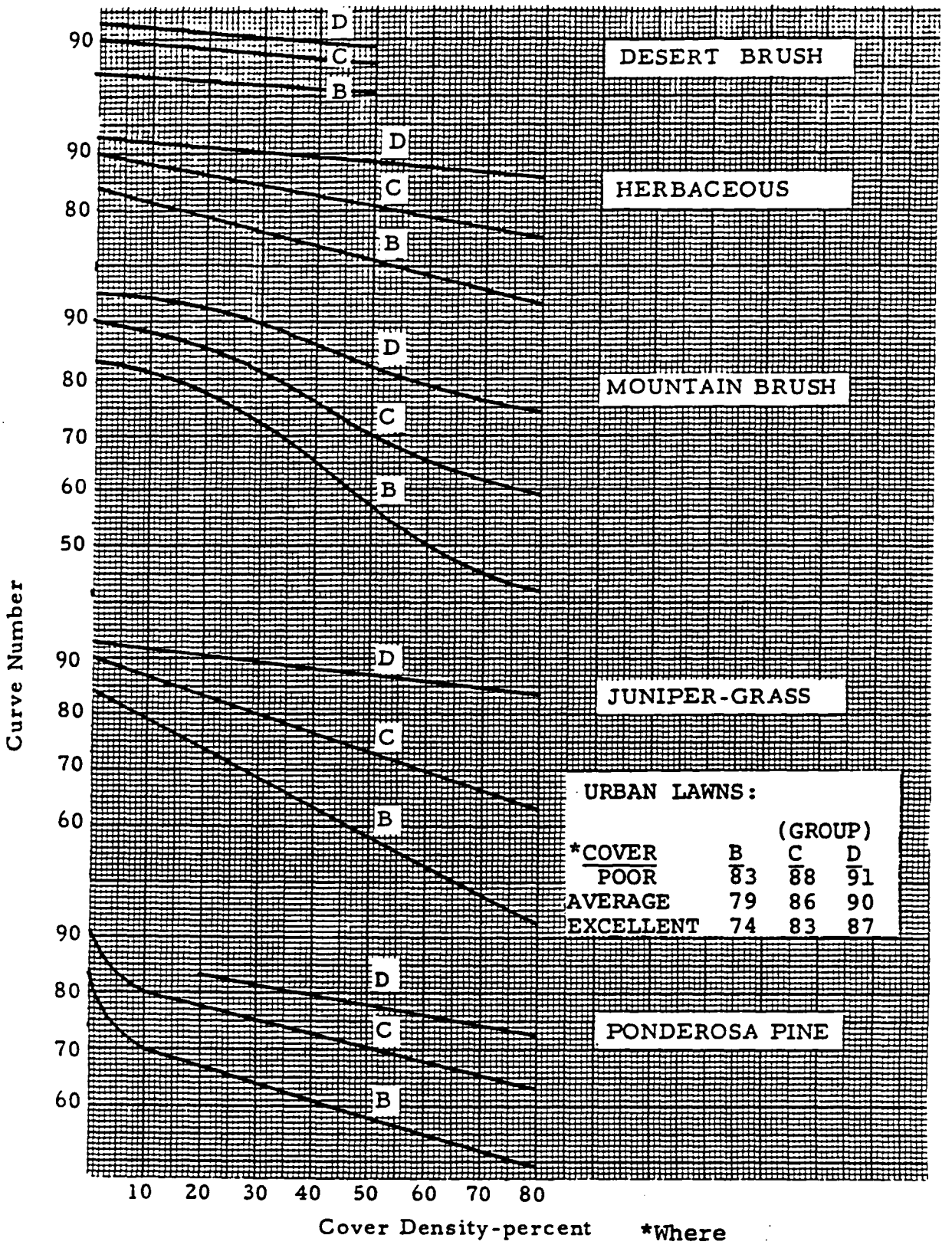
(b) Therefore,

$$CN^* = \frac{93.00(2.60 - .88) + 66.00}{2.60} = \underline{\underline{86.91}}.$$

(The adjusted curve number (CN*) is usually determined to two (2) significant digits.)

NOTE:

If the standard curve number (CN), determined in Step One (1), is not a whole number, an interpolation may be made between the values for R_1 and R_2 when determining the adjusted curve number (CN*).



URBAN LAWNS:

*COVER	(GROUP) B	C	D
POOR	83	88	91
AVERAGE	79	86	90
EXCELLENT	74	83	87

*Where
Poor = Less than 1/3.
Average = 1/3 to 2/3.
Excellent = more than 2/3.

HYDROLOGIC SOIL - COVER COMPLEXES
AND ASSOCIATED CURVE NUMBERS

Source : Soil Conservation Service
(Except Urban Lawns)

CHART FOR ADJUSTED CURVE NUMBERS (CN*'s)

CN	R_1	R_2
95	98.67	80.08
94	98.33	78.76
93	98.00	77.44
92	97.50	76.12
91	97.00	75.24
90	96.50	73.92
89	96.00	72.60
88	95.50	71.72
87	95.00	70.40
86	94.50	69.52
85	94.00	68.20
84	93.50	66.88
83	93.00	66.00
82	92.50	65.12
81	92.00	63.80
80	91.50	62.92
79	91.00	62.04
78	90.00	60.72
77	89.50	59.84
76	89.00	58.96
75	88.50	58.08
74	88.00	56.76
73	87.00	55.88
72	86.50	55.00
71	86.00	54.12
70	85.00	53.24
69	84.50	52.36
68	84.00	51.04
67	83.00	50.16
66	82.50	49.28
65	82.00	48.40
64	81.00	47.52
63	80.00	46.64
62	79.00	45.76
61	78.50	44.88
60	78.00	44.00

$$CN^* = \frac{R_1(P_1 - .88) + R_2}{P_1}$$

Where

P_1 = 1 hour rainfall depth.

(Use areal depth, if applicable).

Notes: (1) P_1 must always be greater than .88 inches.

(2) For impervious areas, CN* = 99 (constant).

RUNOFF TO RAINFALL RATIO(S) - (C), AND RUNOFF SUPPLY RATE (q)

The equation used within this Manual for the determination of runoff to rainfall ratios (C's) is a modification of the U.S. Department of Agriculture Soil Conservation Service's "Rainfall-Runoff Relation". For a detailed derivation of this relationship, the designer should refer to the following source:

> The Soil Conservation Service National Engineering Handbook, Section 4 - Hydrology, Chapter 10: Estimation of Direct Runoff From Storm Rainfall.

The equation is:

$$C = \frac{(P_1 - .2S)^2}{P_1(P_1 + .8S)} \quad \text{(dimensionless).}$$

Where

P_1 = one (1) hour rainfall depth.

$S = \frac{1000}{CN^*} - 10$ = potential abstraction.

(CN* - adjusted curve number)

Several important facts must be kept in mind when using this equation:

(1) The adjusted curve number (CN*) is equal to a constant (never varies) for impervious areas. This constant is equal to 99.

(2) Separate runoff to rainfall ratios (C's) must be determined for each type of hydrologic group (pervious and/or impervious) within a particular watershed under investigation. That is, a weighted runoff to rainfall ratio (C) cannot be determined by first weighting the adjusted curve numbers (CN*'s) before solving the aforementioned equation (such an approach would lead to a gross underestimation of peak rates of discharge from more frequent events such as the two (2) year storm).

Once the runoff to rainfall ratio or ratios (C's) have been determined, the runoff supply rate (q) becomes:

$$q = C_w i \quad \text{(inches/hour).}$$

Where

C_w = weighted runoff to rainfall ratios (C's).

i = intensity of rainfall at the time of concentration (T_c), in inches/hour.

The determination of C_w is a simple one. After all runoff to rainfall ratios (C's) have been determined for each distinct hydrologic group within the watershed under investigation, the weighted runoff to rainfall ratio (C_w) is merely calculated according to the areal proportionalities of these groups, i.e.:

$$C_w = \frac{C_A A_A + C_B A_B + C_C A_C + C_D A_D + C_I A_I}{A_T}.$$

Where

C_A, C_B, C_C, C_D, C_I = runoff to rainfall ratios for Hydrologic Groups A, B, C, D, and impervious areas, respectively.

A_A, A_B, A_C, A_D, A_I = area of subarea within the watershed under investigation consisting entirely of Hydrologic Groups A, B, C, D, and impervious areas, respectively.

A_T = the total area of the watershed under investigation.

EXAMPLE:

A watershed under investigation consists hydrologically, of 80% Soil Group B and 20% Soil Group D. The vegetative cover type is 100% Desert Brush and cover density is approximately 10%. Impervious surfaces cover 15% of the watershed. The one (1) hour rainfall depth is equal to 2.60 inches. Determine (a) the runoff to rainfall ratios (C's), and (b) the runoff supply rate (q).

SOLUTION:

(1) First, we must determine the adjusted curve numbers (CN*'s) for each hydrologic group:

CN = 83 (Soil Group B). CN = 92 (Soil Group D).

[From the figure on Page 107].

Then

$$CN^* = \frac{93.00(2.60 - .88) + 66.00}{2.60} = \underline{86.91} \text{ (Group B).}$$

$$CN^* = \frac{97.50(2.60 - .88) + 76.12}{2.60} = \underline{93.78} \text{ (Group D).}$$

$$CN^* = \underline{99} \quad \text{(impervious surfaces).}$$

[from the figure on Page 108,and recalling that $CN^* = \underline{99}$ is a constant for impervious areas].

(2) Next, we must determine the runoff to rainfall ratio (C) for each distinct hydrologic group:

$$C_B = \frac{[2.60 - .2(1.51)]^2}{2.60[2.60 + .8\ (1.51)]} = \underline{\underline{.53}} \text{ (Group B).}$$

(to two (2) significant digits)

Where

$$S = \frac{1000}{86.91} - 10 = 1.51 \text{ (potential abstraction).}$$

And

$$C_D = \frac{[2.60 - .2(.663)]^2}{2.60[2.60 + .8\ (.663)]} = \underline{\underline{.75}} \text{ (Group D).}$$

(to two (2) significant digits)

Where

$$S = \frac{1000}{93.78} - 10 = .663 \text{ (potential abstraction).}$$

And

$$C_I = \frac{[2.60 - .2(.101)]^2}{2.60[2.60 + .8(.101)]} = \underline{\underline{.95}} \text{ (impervious areas).}$$

(to two (2) significant digits

Where

$$S = \frac{1000}{99} - 10 = .101 \text{ (potential abstraction).}$$

(3) Finally, we must determine the runoff supply rate (q) as follows:

(a) $C_W^P = .80\ (.53) + .20(.75) = \underline{.57}$ (pervious areas).

Where

C_W^P = <u>weighted</u> runoff to rainfall ratio, pervious areas only.

(b) $C_I = .95$ (impervious areas).

(c) $C_w = C_w^p(.85) + C_I(.15) = .57(.85) + .95(.15) = \underline{.63}$.

(d) Therefore,

$$q = C_w i = \underline{\underline{.63i}} \quad \text{(inches/hour)}.$$

Once the runoff supply rate (q) has been determined, its value may be substituted into the equation for the time of concentration (T_c). This enables the solution of the time of concentration to be obtained in terms of the known variable, intensity (i).

DETERMINATION OF INTENSITY

(A) To determine the intensity at any time of concentration (T_c) less than one hour for any frequency storm, the following procedure should be employed:

First, for the time of concentration (T_c) assumed to the nearest minute, read the corresponding multiplication factor (F) from the chart on Page 115.

Next, multiply this factor times the rainfall depth (P_1) for the one-hour storm under investigation.

EXAMPLE: Find the intensities for the 2-year and 100-year frequency storms when the assumed time of concentration (T_c) is equal to twenty (20)minutes, and P_1^2 (2-year) = 1.19 inches, P_1^{100} (100-year) = 2.84 inches.

SOLUTION: From the chart, at T_c equal to twenty (20) minutes, read F = 1.99.

Then,

i_2 = 1.99 (1.19) = 2.37 inches/hour (2-year).

i_{100} = 1.99 (2.84) = 5.65 inches/hour (100-year).

(B) To determine the intensity at any time of concentration (T_c) greater than one hour for any frequency storm, the following procedure should be employed:

First, for the time of concentration (T_c) assumed, make a linear interpolation between known rainfall depths at known times.

Next, divide this value by the assumed time of concentration (T_c).

EXAMPLE: Find the intensity for the 100-year frequency storm when the assumed time of concentration (T_c) is equal to 1.5 hours, 2.75 hours and 4.0 hours, and P_1 = 2.62 inches, P_2 = 2.95 inches, P_3 = 3.18 inches and P_6 = 3.60 inches.

SOLUTION: From the information given,

$$i_{1.5} = \frac{(P_2-P_1).5 + P_1}{1.5} = \frac{(2.95 - 2.62).5 + 2.62}{1.5} = 1.86 \text{ inches/hour.}$$

$$i_{2.75} = \frac{(P_3-P_2).75 + P_2}{2.75} = \frac{(3.18 - 2.95).75 + 2.95}{2.75} = 1.14 \text{ inches/hour.}$$

$$i_{4.0} = \frac{(P_6-P_3).33 + P_3}{4.0} = \frac{(3.60 - 3.18).33 + 3.18}{4.0} = .83 \text{ inches/hour.}$$

(Notice that interpolation is made between the known values which are the closest from either end of the scale to the desired value).

NOTE:

The figure on Page 93 may be used for determination of intensities for durations of up to six (6) hours, in lieu of the method described in Part (B) on Page 113, by merely dividing the rainfall depth obtained from the figure by the assumed time of concentration (T_c).

FACTORS (F's) FOR DETERMINING RAINFALL INTENSITIES(i's)
WHEN DURATIONS ARE LESS THAN ONE (1) HOUR

T (minutes)	F	T (minutes)	F
5	3.48	33	1.48
6	3.32	34	1.46
7	3.15	35	1.43
8	2.99	36	1.41
9	2.84	37	1.38
10	2.70	38	1.36
11	2.61	39	1.34
12	2.52	40	1.31
13	2.44	41	1.29
14	2.37	42	1.27
15	2.28	43	1.25
16	2.22	44	1.23
17	2.16	45	1.22
18	2.10	46	1.20
19	2.04	47	1.18
20	1.99	48	1.17
21	1.93	49	1.15
22	1.89	50	1.13
23	1.84	51	1.12
24	1.80	52	1.10
25	1.75	53	1.09
26	1.71	54	1.08
27	1.68	55	1.06
28	1.64	56	1.05
29	1.61	57	1.04
30	1.58	58	1.02
31	1.54	59	1.01
32	1.51	60	1.00

Where

$$i = FP_1.$$

i = rainfall intensity during time T.
F = multiplication factor.
P_1 = 1-hour rainfall depth.
(Use areal depth , if applicable).

SIMPLIFIED FLOOD ROUTING PROCEDURE FOR NONHOMOGENEOUS WATERSHEDS

The flood routing procedure described herein is only an approximation and, as such, should be used only in conjunction with this Manual and for the sole purpose of estimating peak discharges from nonhomogeneous watersheds. Admittedly, several assumptions are somewhat of an oversimplification, but when used within the context intended, reasonable results should be obtained. If not, a much more detailed and complete flood routing procedure should be employed.

Actually, the method employed is one of "weighting" basin parameters and combining same to produce a peak discharge from the entire drainage basin which will reflect the nonhomogeneity present within its boundaries. The procedure consists of two (2) steps. First, computing the peak discharges from individual subareas; and second, computing the peak discharge from the entire basin, using the "weighted" basin parameters. However, when the basin consists of more than two (2) subareas, it becomes necessary to also compute "weighted" basin parameters for combinations of subareas and determine their respective peaks in addition to determining the peak from the entire basin. The maximum peak produced by these various combinations should be the design value used for all hydraulic calculations, unless the peak discharge from the subarea nearest the outlet under investigation produces a larger value alone [See example five (5)].

Weighting of the basin parameters consists of calculating (1) a weighted basin factor ($\bar{n}_b$), (2) a weighted runoff to rainfall ratio (C_w), and (3) a weighted (mean)slope (S_c). The weighted runoff to rainfall ratio (C_w) is determined in a straightforward manner; by areal proportionalities. The weighted (mean)slope (S_c) is determined as outlined within the appendix section of this Manual. However, the weighted basin factor ($\bar{n}_b$) is determined by two (2) distinct methods, depending upon the characteristics of the watershed.

First, if the same watercourse drains all subareas of a watershed, the weighted basin factor ($\bar{n}_b$) should be determined by main channel length proportionalities, i.e.:

$$\bar{n}_b = \frac{n_{b1}L_1}{L_c} + \frac{n_{b2}L_2}{L_c} + \frac{n_{b3}L_3}{L_c} + \ldots .$$

Where

n_{b1}, n_{b2}, n_{b3}, etc. = basin factors for respective subareas 1,2,3, etc.

L_1, L_2, L_3, etc. = channel lengths for respective subareas 1, 2, 3, etc.

L_c = total length of channel.

Second, if separate watercourses drain individual subareas, the weighted basin factor ($\bar{n}_b$) above the confluence of said watercourses should be determined by areal proportionalities, i.e.:

$$\bar{n}_b = \frac{n_{b1}A_1}{A} + \frac{n_{b2}A_2}{A} + \frac{n_{b3}A_3}{A} + \ldots$$

Where

n_{b1}, n_{b2}, n_{b3}, etc. = basin factor for respective subareas 1, 2, 3, etc.

A_1, A_2, A_3, etc. = areas for respective subareas 1, 2, 3, etc.

A = total area of watershed above confluence of subareas.

Examples:

Area 1		Area 2		Area 3	
A =	200 ac.	A =	900 ac.	A =	500 ac.
L =	5,000 ft.	L =	15,000 ft.	L =	10,000 ft.
L_{ca} =	2,500 ft.	L_{ca} =	7,500 ft.	L_{ca} =	5,000 ft.
S_c =	.010 ft./ft.	S_c =	.020 ft./ft.	S_c =	.040 ft./ft.
n_b =	.025	n_b =	.035	n_b =	.050
P_1 =	2.60 in.	P_1 =	2.60 in.	P_1 =	2.60 in.
P_2 =	2.94 in.	P_2 =	2.94 in.	P_2 =	2.94 in.
C =	.75	C =	.60	C =	.70
T_c =	14 min.	T_c =	39 min.	T_c =	29 min.
Q_p =	930 cfs.	Q_p =	1,890 cfs.	Q_p =	1,480 cfs.

(1) First, it is assumed that the same watercourse drains all the subareas.

Then, the weighted runoff to rainfall ratio (C_w) is determined:

$$C_w = \left[\frac{200}{1600}\right](.75) + \left[\frac{900}{1600}\right](.60) + \left[\frac{500}{1600}\right](.70) = .65.$$

Next, the weighted (mean) slope (S_c) is determined as follows:

The changes in elevation (H) for subareas 1, 2 and 3, respectively, are:

H_1 = 50 feet. H_2 = 300 feet. H_3 = 400 feet.

Now, since the same watercourse drains all the subareas,

L_c = 30,000 feet (total length).

Then

$$I = \left[\frac{(5000)^3}{50}\right]^{\frac{1}{2}} + \left[\frac{(15,000)^3}{300}\right]^{\frac{1}{2}} + \left[\frac{(10,000)^3}{400}\right]^{\frac{1}{2}} \text{ feet.}$$

I = 206,066 feet.

And

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{30,000}{206,066}\right]^2 = .021 \text{ ft./ft.}$$

Finally, the weighted basin factor ($\bar{n}_b$) is determined by main channel length proportionalities (since the same watercourse drains all subareas), i.e.:

$$\bar{n}_b = \frac{5,000}{30,000}(.025) + \frac{15,000}{30,000}(.035) + \frac{10,000}{30,000}(.050).$$

$\bar{n}_b$ = .038 (to three (3) significant digits).

The time of concentration (T_c) for the <u>entire</u> basin (1600 acres) becomes:

$$T_c = \frac{.038}{50}\frac{[(30,000)\ (15,000)]^{.3}}{(.021)^{.4}}(.65i)^{-.4} \text{ hours.}$$

$T_c = 1.67i^{-.4}$ hours.

The iterative solution of this equation yields:

T_c = 1.22 hours.

Therefore,

q = .65(2.19) = 1.42 inches/hour.

(Since i = 2.19 in./hr., at T_c = 1.22 hours).

The peak discharge from the <u>entire</u> basin (1600 acres), using "weighted" basin parameters, becomes:

Q_p = 1.008 (1.42)(1600) = <u>2290 cfs</u>.

At this point, the problem is not complete as the resultant peak contributing from subareas 1 and 2 alone must be determined to see if same exceeds other calculated peaks. Proceeding as in the previous manner, we have:

$$C_w = \left[\frac{200}{1100}\right](.75) + \left[\frac{900}{1100}\right](.60) = .63.$$

(Note that only the combined areas of subareas 1 and 2 are used when calculating C_w, <u>not</u> the entire 1,600 acres).

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{20,000}{156,066}\right]^2 = .016 \text{ ft./ft.}$$

Where L_c = total length of watercourse through subareas 1 and 2 alone, and I equals value determined for the slope profile of subareas 1 and 2 alone.

$$\bar{n}_b = \frac{5,000}{20,000}(.025) + \frac{15,000}{20,000}(.035) = .033.$$

(Again, note that only the combined lengths of subareas 1 and 2 are utilized).

The time of concentration (T_c) for subareas 1 and 2 alone (1100 acres) becomes:

$$T_c = \frac{.033}{50}\left[\frac{(20,000)(10,000)}{(.016)^{.4}}\right]^3 (.63i)^{-.4} \text{ hours.}$$

$$T_c = 1.28i^{-.4} \text{ hours.}$$

The iterative solution of this equation yields:

$$T_c = 50 \text{ minutes.}$$

Therefore,

$$q = .63(2.94) = 1.85 \text{ inches/hour.}$$

(Since i = 2.94 in./hr., at T_c = 50 minutes).

The peak discharge from subareas 1 and 2 alone (1100 acres), using "weighted" basin parameters, becomes:

$$Q_p = 1,008\ (1.86)(1100) = \underline{\underline{2051 \text{ cfs}}}.$$

As can be seen, the maximum peak (2290 cfs.) occurs when the entire basin contributes at the outlet. However, the resultant peak contributing from subareas 1 and 2 alone is very near this maximum peak. This example demonstrates the need to calculate resultant subarea peaks when encountering <u>nonhomogeneous</u> watersheds to make sure that no combination of these peaks exceeds the peak from the <u>entire</u> watershed alone.

(2) In this example, it will be assumed that separate watercourses drain individual subareas, and that the outlet in question is immediately below the point where all three subarea watercourses meet.

The weighted runoff to rainfall ratio is determined in the same manner as in the preceding example. Then,

$$C_w = .65 .$$

The weighted (mean) slope is simply the slope of the longest subarea watercourse, i.e.:

$$S_c = .020 \text{ ft./ft. (subarea 2)}.$$

The weighted basin factor ($\bar{n}_b$) in this case is determined by areal proportionalities (since separate watercourses drain individual subareas):

$$\bar{n}_b = \left[\frac{200}{1600}\right](.025) + \left[\frac{900}{1600}\right](.035) + \left[\frac{500}{1600}\right](.050) = .038.$$

(In this instance, $\bar{n}_b$ is the same value, to three (3) significant digits, as determined using channel length proportionalities in Example One (1), but this is purely coincidental to the present example. In general, it would not be the case).

The time of concentration (T_c) for the watershed becomes:

$$T_c = \frac{.038}{50}\left[\frac{(15{,}000)(7{,}500)}{(.020)^{.4}}\right](.65i)^{-.4} \text{ hours.}$$

$$T_c = 1.12i^{-.4} \text{ hours.}$$

(Note that in this example, the hydraulically most remote point within the watershed (subarea 2) is used in the computation of T_c. This is always the case when dealing with a <u>nonhomogeneous</u> watershed containing separate watercourses which drain individual subareas).

The iterative solution of the preceding equation yields:

$$T_c = 42 \text{ minutes.}$$

Therefore,

$$q = .65(3.30) = 2.15 \text{ inches/hour}.$$

(Since $i = 3.30$ in./hr., at $T_c = 42$ minutes).

The peak discharge from the <u>entire</u> basin (1600 acres), using "weighted" basin parameters, becomes:

$$Q_p = 1.008\ (2.15)(1600) = \underline{\underline{3468 \text{ cfs.}}}$$

(3) This example will employ a combination of the two (2) previous examples. That is, subareas 2 and 3 will meet at the upstream end of subarea 1 and drain through same to the outlet point at the end of the subareas.

In this case, the weighted (mean) slope (S_c) and weighted basin factor ($\bar{n}_b$) will differ from the previous examples. However, the weighted runoff to rainfall ratio (C_w) will still be computed in the same manner. This is true because C_w depends only upon areal proportionalities.

Therefore,

$$C_w = .65.$$

The weighted (mean) slope is computed as follows:

$$I = \left[\frac{(5,000)^3}{50}\right]^{\frac{1}{2}} + \left[\frac{(15,000)^3}{300}\right]^{\frac{1}{2}} = 156,066 \text{ feet.}$$

(The longest path of flow is utilized since this generally is the hydraulically most remote point within the watershed).

$$S_c = \left[\frac{L_c}{I}\right]^2 = \left[\frac{20,000}{156,066}\right]^2 = .016 \text{ ft./ft.}$$

The weighted basin factor ($\bar{n}_b$), in this case, must be determined in two (2) steps. First, $\bar{n}_b$ is determined for the combination of subareas 2 and 3 by weighting, as in Example Two (2), using areal proportionalities. Second, this value is then used in combining subareas 2 and 3 with subarea 1, as in Example One (1), using channel length proportionalities, i.e.;

$$\bar{n}_b = \frac{15,000}{20,000}\left(\left[\frac{900}{1400}\right](.035) + \left[\frac{500}{1400}\right](.050)\right) + \left[\frac{5,000}{20,000}\right](.025).$$

$$\bar{n}_b = .037 \text{ (to three (3) significant digits).}$$

(Note that only the combined areas of subareas 2 and 3 are used to first calculate the weighted basin factor ($\bar{n}_b$) for these areas prior to weighting with subarea 1, which determines $\bar{n}_b$ for the <u>entire</u> basin).

Now, the time of concentration (T_c) for the <u>entire</u> basin becomes:

$$T_c = \frac{.037}{50}\left[\frac{(20,000)(10,000)}{(.016)^{.4}}\right]^{.3}(.65i)^{-.4} \text{ hours.}$$

$$T_c = 1.42i^{-.4} \text{ hours.}$$

(Again, the hydraulically most remote point of the watershed is used in determining T_c).

The iterative solution of the preceding equation yields:

T_c = 57 minutes.

Therefore,

$q = .65\ (2.70) = 1.76$ inches/hour.

(Since $i = 2.70$ in./hr., at T_c = 57 minutes).

The peak discharge from the entire basin (1600 ac.), using "weighted" basin parameters, becomes:

$q_p = 1.008\ (1.76)(1600) =$ 2839 cfs.

In this instance, the peak from the entire basin would obviously be the maximum, since the peak from subarea 1 alone is only 930 cfs.

The examples provided within this section are intended to cover the various types of problems that the designer might encounter when dealing with nonhomogeneous watersheds. If problems arise which do not seem to be covered by these examples, the Pima County Department of Transportation and Flood Control District should be consulted.

As a final note, it must be emphasized that the "simplified flood routing procedure" employed herein, utilizing the "weighting" of basin parameters, is intended only to reproduce with reasonable accuracy the peak discharge at the outlet of the nonhomogenous watershed. No attempt has been made to analyze flood hydrograph shapes or durations; nor, predict with accuracy the times to peak (T_p's) of same. This is due to the fact that times of concentration (T_c's) computed by "weighting' basin parameters are a result of the assumption that the entire watershed (or subareas) under investigation receives uniform areal coverage and intensity of rainfall, and is contributing at the outlet when the peak occurs. In reality, hydrograph shapes and times to peak (T_p's) may vary significantly due to variations in areal coverage and intensity of rainfall over the basin, making accurate predictions of these parameters nearly impossible for ungaged, nonhomogeneous watersheds.

SUPPLEMENTARY CALCULATION SHEETS

HYDROLOGIC DATA SHEET

roject Name and Location: _____

Drainage Concentration Point: _____

atershed Area (A): _____ acres/square miles.

Length of Watercourse (L_c): _____ ft. Length to Center of Gravity (L_{ca}): _____ ft.

ncremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
_____	_____
_____	_____
_____	_____
_____	_____

lean Slope (S_c): _____ ft./ft. Watershed Type(s): _____ (future)

Basin Factor (n_b): _____ (future) Flood Frequency: _____ yrs.

P_{24} (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): _____ in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

Soil Group(s): _____ Cover Type(s): _____

Cover Density (pervious areas): _____ Impervious Cover: _____ (future)

CN(s): _____ (pervious & impervious areas) CN^*(s): _____
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): _____ (pervious areas) _____ (impervious areas)

Runoff Supply Rate (q): _____ i in./hr. (function of i)

Time of Concentration (T_c): _____ $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: _____ hrs./mins.

Rainfall Intensity (i) at T_c: _____ in./hr.

Runoff Supply Rate (q) at T_c: _____ in./hr.

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): _____ cfs.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Note: For impervious areas, $CN^* = 99$ (constant).

HYDROLOGIC DATA SHEET

'roject Name and Location: _____

Drainage Concentration Point: _____

atershed Area (A): _____ acres/square miles.

Length of Watercourse (L_c): _____ ft. Length to Center of Gravity (L_{ca}): _____ ft.

ncremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
_____	_____
_____	_____
_____	_____
_____	_____

ean Slope (S_c): _____ ft./ft. Watershed Type(s): _____ (future)

Basin Factor (n_b): _____ (future) Flood Frequency: _____ yrs.

P_{24} (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): _____ in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

Soil Group(s): _____ Cover Type(s): _____

Cover Density (pervious areas): _____ Impervious Cover: _____ (future)

CN(s): _____ (pervious & impervious areas) CN^*(s): _____
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): _____ (pervious areas) _____ (impervious areas)

Runoff Supply Rate (q): _____ i in./hr. (function of i)

Time of Concentration (T_c): _____ $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: _____ hrs./mins.

Rainfall Intensity (i) at T_c: _____ in./hr.

Runoff Supply Rate (q) at T_c: _____ in./hr.

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): _____ cfs.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Note: For impervious areas, $CN^* = 99$ (constant).

HYDROLOGIC DATA SHEET

Project Name and Location: _____

Drainage Concentration Point: _____

Watershed Area (A): _____ acres/square miles.

Length of Watercourse (L_c): _____ ft. Length to Center of Gravity (L_{ca}): _____ ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
_____	_____
_____	_____
_____	_____
_____	_____

Mean Slope (S_c): _____ ft./ft. Watershed Type(s): _____ (future)

Basin Factor (n_b): _____ (future) Flood Frequency: _____ yrs.

P_{24} (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): _____ in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

Soil Group(s): _____ Cover Type(s): _____

Cover Density (pervious areas): _____ Impervious Cover: _____ (future)

CN(s): _____ (pervious & impervious areas) CN^*(s): _____
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): _____ (pervious areas) _____ (impervious areas)

Runoff Supply Rate (q): _____ i in./hr. (function of i)

Time of Concentration (T_c): _____ $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: _____ hrs./mins.

Rainfall Intensity (i) at T_c: _____ in./hr.

Runoff Supply Rate (q) at T_c: _____ in./hr.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): _____ cfs.

Note: For impervious areas, $CN^* = 99$ (constant).

HYDROLOGIC DATA SHEET

Project Name and Location: _____

Drainage Concentration Point: _____

Watershed Area (A): _____ acres/square miles.

Length of Watercourse (L_c): _____ ft. Length to Center of Gravity (L_{ca}): _____ ft.

Incremental Change in Length (L_i) - ft.	Incremental Change in Elevation (H_i) - ft.
_____	_____
_____	_____
_____	_____
_____	_____

Mean Slope (S_c): _____ ft./ft. Watershed Type(s): _____ (future)

Basin Factor (n_b): _____ (future) Flood Frequency: _____ yrs.

P_{24} (24 hour): _____ in. Areal Value: _____ in.

P_6 (6 hour): _____ in. Areal Value: _____ in.

P_1 (1 hour): _____ in. Areal Value: _____ in.

P_2 (2 hour): _____ in. Areal Value: _____ in.

P_3 (3 hour): _____ in. Areal Value: _____ in.

Soil Group(s): _____ Cover Type(s): _____

Cover Density (pervious areas): _____ Impervious Cover: _____ (future)

CN(s): _____ (pervious & impervious areas) CN^*(s): _____
(curve number) (adjusted curve number)

Runoff to Rainfall Ratio(s),(C): _____ (pervious areas) _____ (impervious areas)

Runoff Supply Rate (q): _____ i in./hr. (function of i)

Time of Concentration (T_c): _____ $i^{-.4}$ hrs./mins. (function of i)

Iterative Solution of T_c: _____ hrs./mins.

Rainfall Intensity (i) at T_c: _____ in./hr.

Runoff Supply Rate (q) at T_c: _____ in./hr.

Peak Discharge:

1.008 qA (acres): _____ cfs.

645.33qA (square miles): _____ cfs.

Equation for T_c:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{.3}}{(S_c)^{.4}} q^{-.4} \text{ hours.}$$

Note: For impervious areas, $CN^* = 99$ (constant).

HYDROLOGIC DATA SHEET

·tershed Subarea:_____acres/square miles Watershed Type:_____

. ıgth of Watercourse (L_c):_____ft. Length to Center of Gravity (L_{ca}):_____ft.

ıcremental Change in Length (L_i) - ft. Incremental Change in Height (H_i) - ft.

_____ _____

_____ _____

_____ _____

'oil Group(s):_____ Cover Type(s):_____

. ver Density (pervious areas):_____ Impervious Cover:_____(future)

CN(s):_____ CN*(s):_____
(curve number) (adjusted curve number)

E sin Factor (n_b):_____ Runoff to Rainfall Ratio (C):_____

. tershed Subarea:_____acres/square miles Watershed Type:_____

Length of Watercourse (L_c):_____ft. Length to Center of Gravity (L_{ca}):_____ft.

cremental Change in Length (L_i) - ft. Incremental Change in Height (H_i) - ft.

_____ _____

_____ _____

_____ _____

ioil Group(s):_____ Cover Type(s):_____

ver Density (pervious areas):_____ Impervious Cover:_____(future)

CN(s):_____ CN*(s):_____
(curve number) (adjusted curve number)

ıasin Factor (n_b):_____ Runoff to Rainfall Ratio (C):_____

ıtershed Subarea:_____acres/square miles Watershed Type:_____

Length of Watercourse (L_c):_____ft. Length to Center of Gravity (L_{ca}):_____ft.

ıcremental Change in Length (L_i) - ft. Incremental Change in Height (H_i) - ft.

_____ _____

_____ _____

_____ _____

oil Group(s):_____ Cover Type(s):_____

Cover Density (pervious areas):_____ Impervious Cover:_____(future)

CN(s):_____ CN*(s):_____
(curve number) (adjusted curve number)

Basin Factor (n_b):_____ Runoff to Rainfall Ratio (C):_____

Weighted Basin Factor ($\bar{n}_b$):_____(future) Weighted Runoff to Rainfall Ratio (C_w):_____

HYDROLOGIC DATA SHEET

tershed Subarea:_____acres/square miles Watershed Type:_____

Length of Watercourse (L_c):_____ft. Length to Center of Gravity (L_{ca}):_____ft.

Incremental Change in Length (L_i) - ft. Incremental Change in Height (H_i) - ft.

_____ _____

_____ _____

_____ _____

Soil Group(s):_____ Cover Type(s):_____

Cover Density (pervious areas):_____ Impervious Cover:_____(future)

CN(s):_____ CN*(s):_____

(curve number) (adjusted curve number)

Basin Factor (n_b):_____ Runoff to Rainfall Ratio (C):_____

Watershed Subarea:_____acres/square miles Watershed Type:_____

Length of Watercourse (L_c):_____ft. Length to Center of Gravity (L_{ca}):_____ft.

Incremental Change in Length (L_i) - ft. Incremental Change in Height (H_i) - ft.

_____ _____

_____ _____

_____ _____

Soil Group(s):_____ Cover Type(s):_____

Cover Density (pervious areas):_____ Impervious Cover:_____(future)

CN(s):_____ CN*(s):_____

(curve number) (adjusted curve number)

Basin Factor (n_b):_____ Runoff to Rainfall Ratio (C):_____

Watershed Subarea:_____acres/square miles Watershed Type:_____

Length of Watercourse (L_c):_____ft. Length to Center of Gravity (L_{ca}):_____ft.

Incremental Change in Length (L_i) - ft. Incremental Change in Height (H_i) - ft.

_____ _____

_____ _____

_____ _____

Soil Group(s):_____ Cover Type(s):_____

Cover Density (pervious areas):_____ Impervious Cover:_____(future)

CN(s):_____ CN*(s):_____

(curve number) (adjusted curve number)

Basin Factor (n_b):_____ Runoff to Rainfall Ratio (C):_____

Weighted Basin Factor ($\bar{n}_b$):_____(future) Weighted Runoff to Rainfall Ratio (C_w):_____

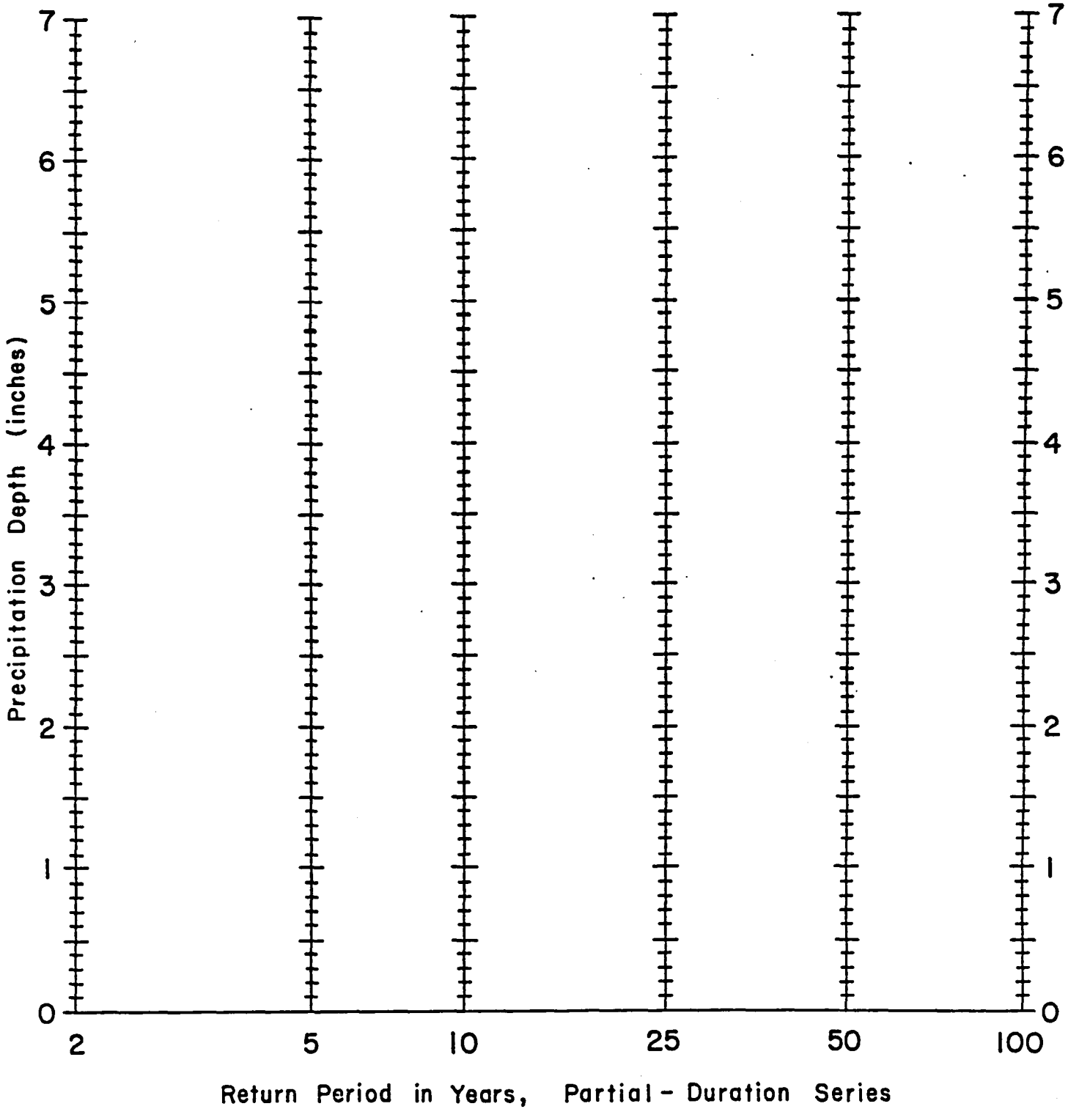
RAINFALL DATA SHEET

Return Period (Years)	Precipitation Values (inches)			
	6 Hour Duration		24 Hour Duration	
	Map Value	Corrected Value	Map Value	Corrected Value
2				
5				
10				
25				
50				
100				

RAINFALL DATA SHEET

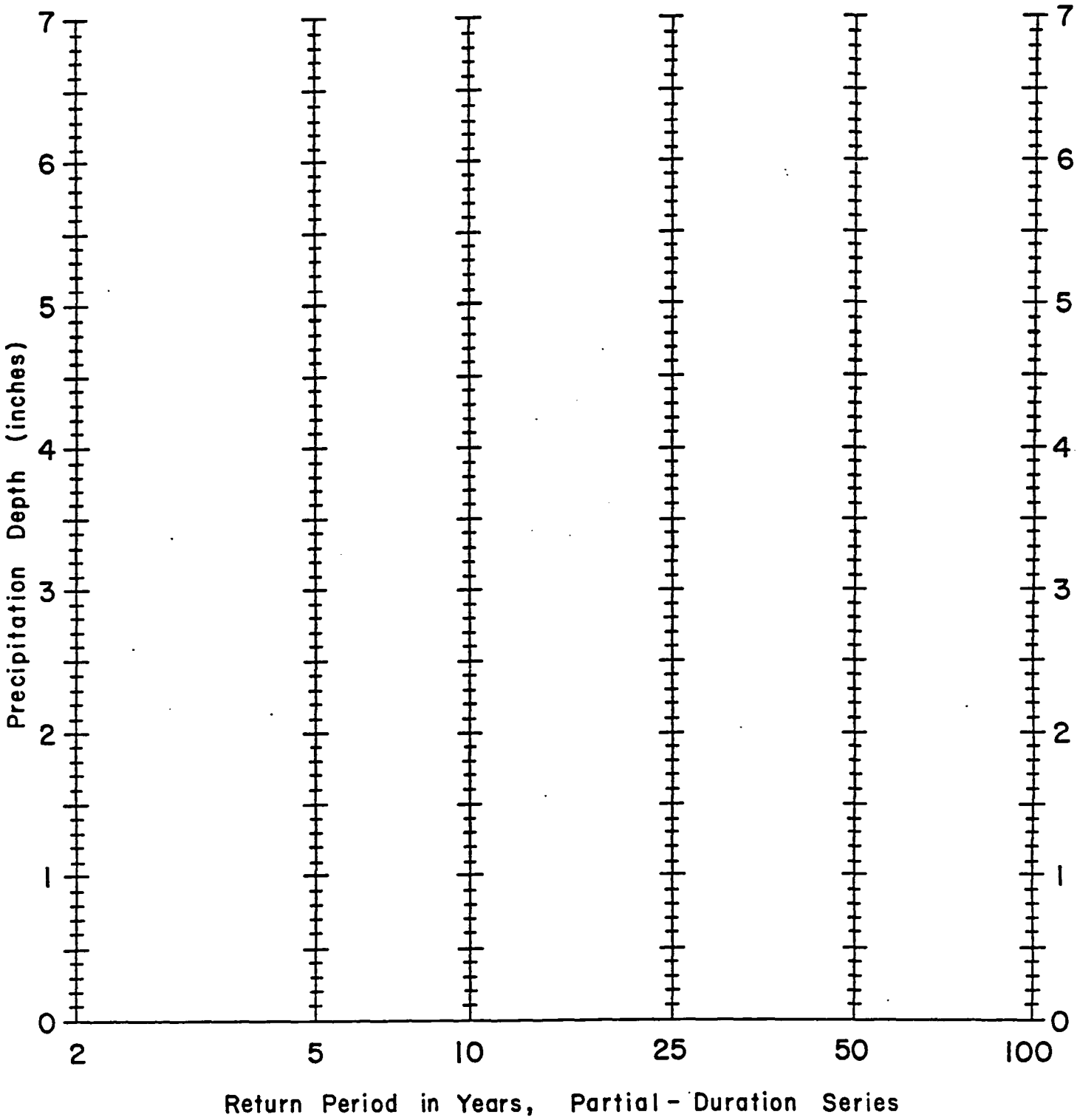
Return Period (Years)	Precipitation Values (inches)			
	6 Hour Duration		24 Hour Duration	
	Map Value	Corrected Value	Map Value	Corrected Value
2				
5				
10				
25				
50				
100				

Latitude _____ Longitude _____



Precipitation Depth Versus Return Period For
Partial - Duration Series

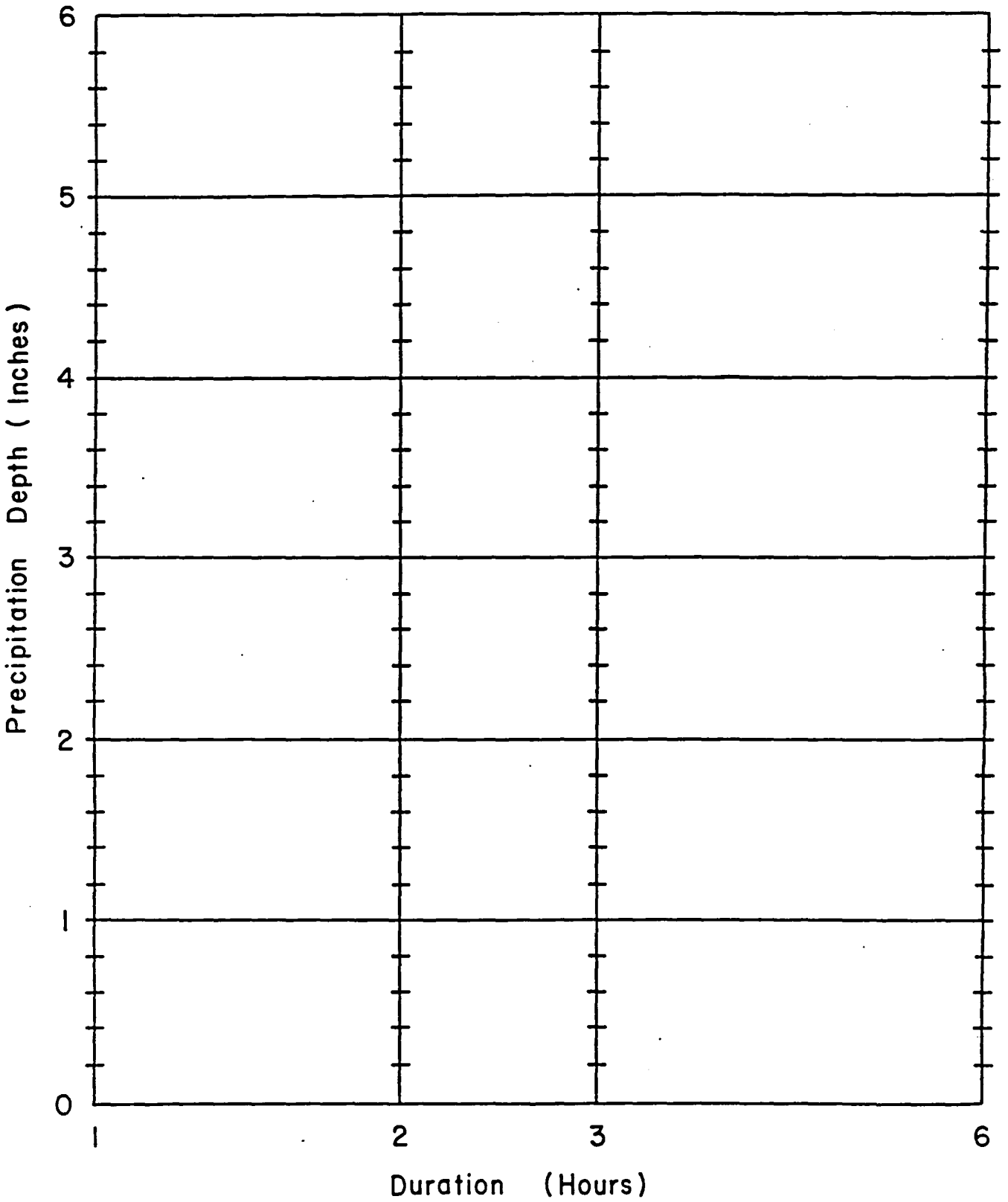
Latitude _____ Longitude _____



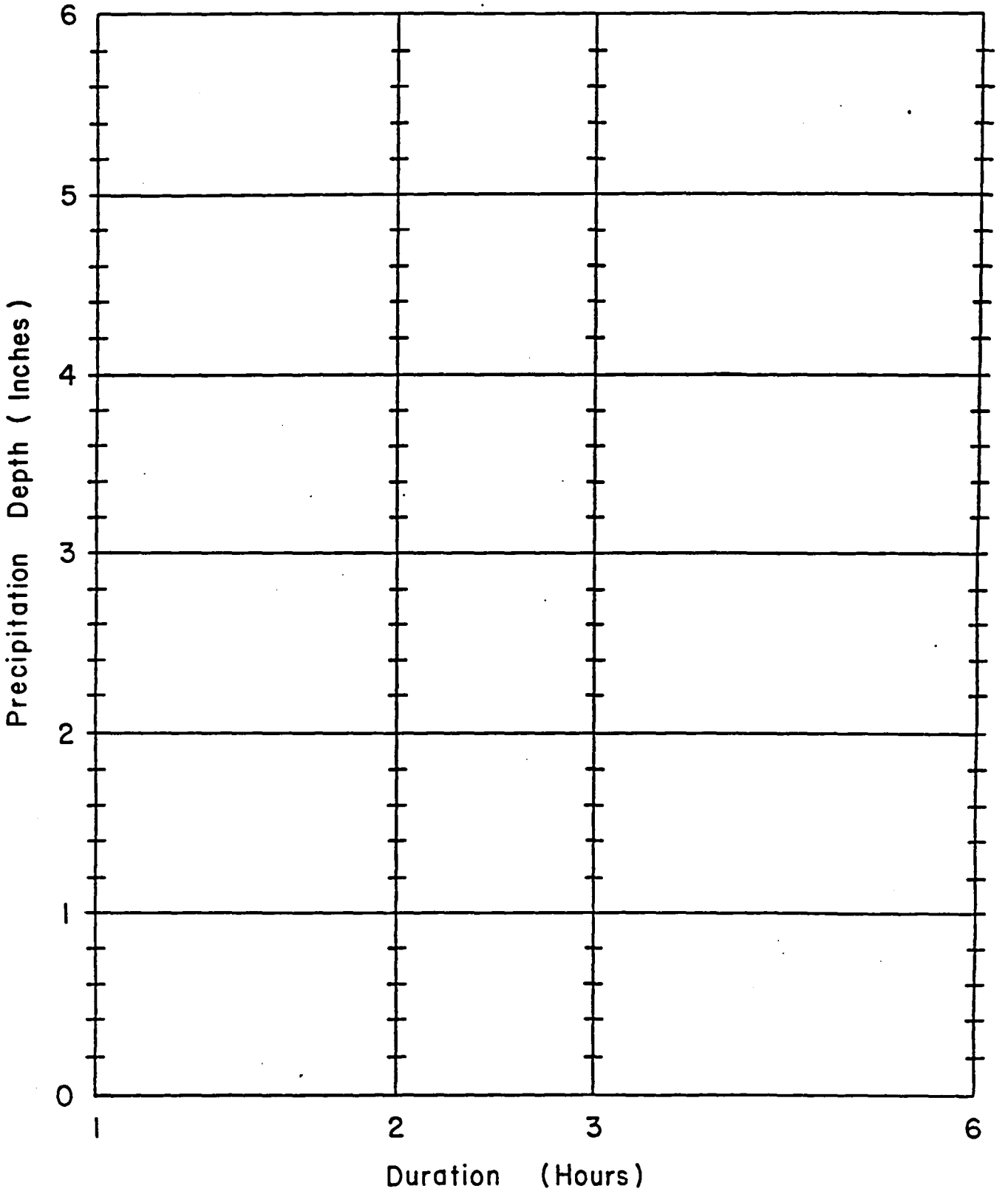
Precipitation Depth Versus Return Period For
Partial - Duration Series

Precipitation Depth - Duration

Diagram (1 - 6 Hours)



Precipitation Depth - Duration
Diagram (1 - 6 Hours)



"SHORT CUT" PROCEDURES

APPROXIMATE RATIOS OF LESSER MAGNITUDE FLOODS TO THE 100-YEAR FLOOD

In an attempt to both simplify and reduce the computational procedures and time involved in estimating peak discharge values for floods of lesser magnitude than the 100-year flood, the following procedure may be employed if the user so desires:

First, the predicted value for the peak discharge of the 100-year flood which would occur upon the watershed under investigation should be determined using the procedures as outlined within this Manual.

Next, peak discharge values for floods of lesser magnitude than the 100-year flood may be calculated approximately by multiplying the previously determined 100-year flood value for the watershed under investigation by the factors shown within the table below:

	RECURRENCE INTERVAL			
WATERSHED DEVELOPMENT	2-Yr.	10-Yr.	25-Yr.	50-Yr.
Rural	0.10	0.35	0.55	0.75
Suburban	0.15	0.40	0.60	0.80
Moderately Urban	0.20	0.45	0.65	0.85
Highly Urban	0.25	0.50	0.70	0.85

Where

Rural = Watersheds which will remain in a natural condition (undeveloped), or where the anticipated future development will be negligible.

Suburban = Watersheds which contain two (2) houses per acre, or less, with drainage improvements being relatively few or nonexistent.

Moderately Urban = Watersheds which contain from two (2) to five (5) houses per acre (detached), with moderate to extensive drainage improvements present.

Highly Urban = Watersheds which contain more than five (5) houses per acre (including multiple dwellings, commercial and industrial development), with extensive drainage improvements present.

It is to be noted that the above factors are only applicable under typically "average" watershed conditions upon generally homogeneous drainage basins. For atypical or nonhomogeneous watersheds, all flood peaks, whatever their recurrence intervals, should be determined in a complete and detailed manner as outlined within this Manual; otherwise, serious errors might easily arise as a consequence of choosing expediency over good engineering judgement.

GRAPHICAL SOLUTION FOR THE TIME OF CONCENTRATION (T_c)

The graph on the following page was developed as an aid in reducing the computational time involved with the iterative solution for the time of concentration (T_c), as described on pages five (5) and six (6) of this Manual.

The solution for T_c by use of the graph is a straightforward one. All steps of the "Procedural Approach", pages seven (7) through nine (9), remain identical except for Step Sixteen (16). At that point, the user need merely employ the graphical solution in the same manner as shown by the example below (See Example Three (3) within this Manual for comparison):

We have

$L = 10{,}000$ feet.
$L_{ca} = 6{,}000$ feet.
$S_c = .0104$ ft./ft.
$n_b = .022$.
$P_1 = 2.49$ inches.
$C_w = 0.69$.

Which yields

$$K = \frac{1.2\ n_b\ (LL_{ca})^{.3}}{(S_c P_1 C_w)^{.4}}\ .$$

$$K = \frac{1.2(.022)[(10{,}000)(6{,}000)]^{.3}}{[(.0104)(2.49)(0.69)]^{.4}}\ .$$

$$K = 28.5.$$

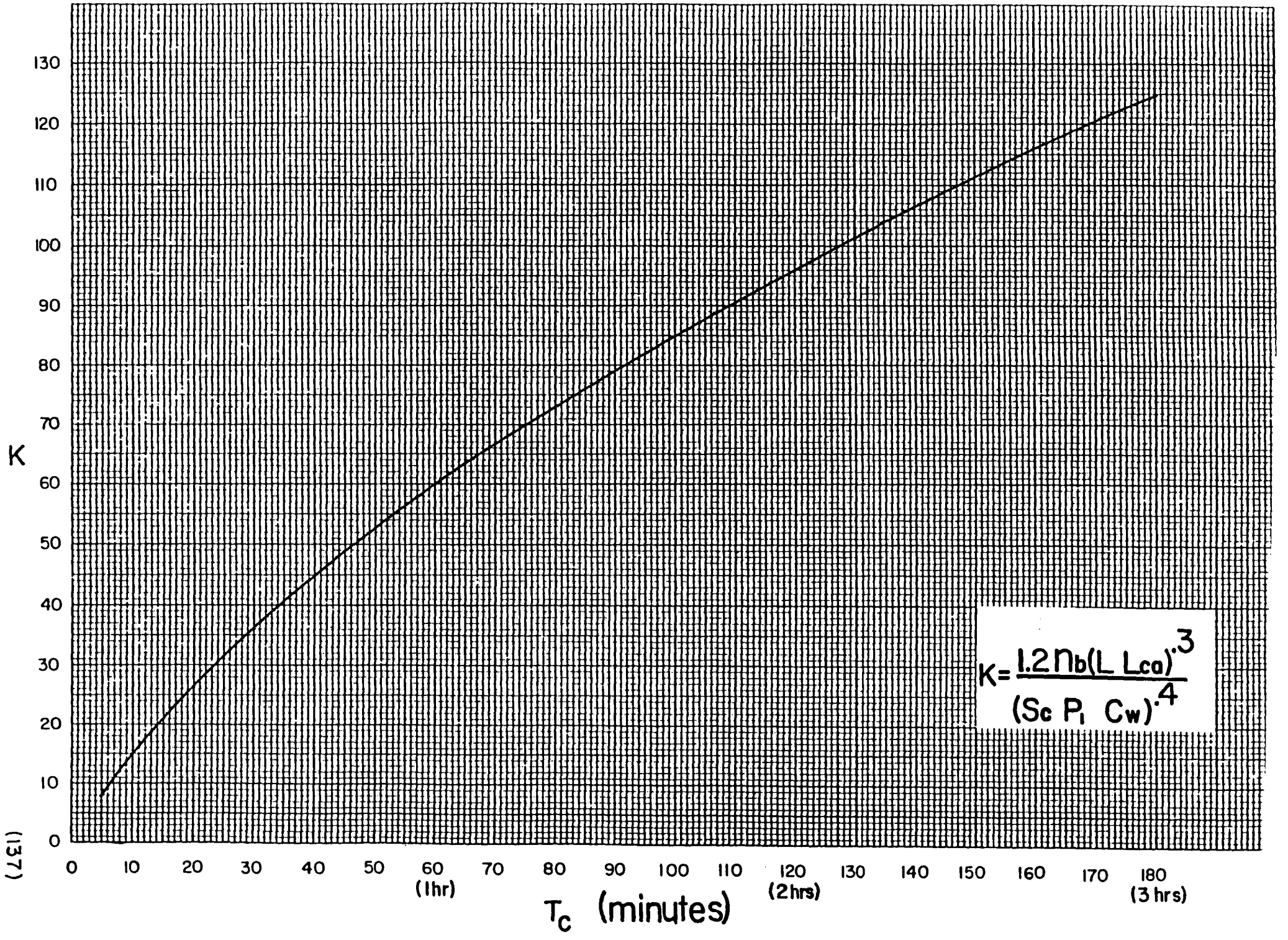
Now, proceeding vertically along the K axis to the value 28.5, then horizontally along the T_c axis to the point of intersection yields the solution for the time of concentration (T_c):

$$T_c = \underline{\underline{22 \text{ Minutes}}}\ .$$

As can be seen, the value obtained by graphical solution is identical to the value obtained via the iterative procedure used on Page twenty-two (22) of this Manual for solution of the same example.

The user is to be cautioned that application of the graph is limited to watersheds whose drainage areas do not exceed ten (10) square miles. Additionally, under no circumstances may the graph be extrapolated beyond three (3) hours (180 minutes).

Once T_c has been determined, the intensity (i) should be determined as outlined on Pages 113 through 115 of this Manual.


K
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
(1hr)
70
80
90
100
110
120
(2hrs)
130
140
150
160
170
180
(3 hrs)
T_c (minutes)
$K = \frac{1.2\, n_b (L\, L_{ca})^{.3}}{(S_c\, P_1\, C_w)^{.4}}$

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