DRAINAGE DESIGN MANUAL

VOLUME I

HYDROLOGY

FCD

Drainage Design Manual for Maricopa County, Arizona

Volume I

Hydrology

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Flood Control District
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FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

AGENDA FORM

Contract/Lease for ☐ NEW ☐ RENEWAL ☐ AMENDMENT ☐ CANCELLATION
(for existing, record Encumbrance No. below)

LOW ORG. NO. 6900 DEPARTMENT: Flood Control District CONTROL NUMBER: FCD-1241

ENCUMBRANCE NO. ______ AGENCY: Public Works CONTROL NUMBER: PW-1241

1. BRIEF DESCRIPTION OF PROPOSAL AND REQUESTED BOARD ACTION: It is requested that the Board of Directors approve a resolution adopting volume one of a two-volume drainage design manual. Entitled the Hydrologic Design Manual for Maricopa County, volume one provides technical procedures for estimating stormwater runoff to assist engineers in the design of storm drainage facilities. Volume two of the drainage design manual will provide "hydraulic" design guidelines as opposed to "hydrologic" procedures and will be presented for the Board's consideration at a future date. Development of the manuals was among the objectives of a multi-jurisdictional task force formed by the District in 1985 to establish a common basis for drainage management within Maricopa County. By formally adopting volume one, the Board will establish the hydrologic design procedures described in the manual for use by District staff, by jurisdictions cost-sharing with the District in flood control projects, by contractors performing work for the District and, beginning January 1, 1992, by all parties submitting drainage reports and studies to the District for review and approval. The Flood Control Advisory Board recommended adoption of this resolution at its January 23, 1991 meeting.

2. COMPLIANCE WITH MARICOPA COUNTY PROCUREMENT CODE N/A (article) N/A (paragraph) [signature] (Procurement Officer)

SOLE SOURCE JUSTIFICATION ______

3. CONTINUED FROM MEETING OF ______

DISCUSSED IN MEETING OF ______

4. ☐ **THIS DEPARTMENT WILL CAUSE PUBLICATION**
☐ **CLERK OF THE BOARD TO CAUSE PUBLICATION**

5. MOTION: It is moved that the Flood Control District of Maricopa County Board of Directors adopt Resolution FCD 91-03, the Hydrologic Design Manual for Maricopa County, thereby requiring its use by jurisdictions cost-sharing with the District in flood control projects, by contractors working for the District, and beginning January 1, 1992, by all parties submitting drainage reports and studies to the District for review and approval.

6. FINANCIAL: ☐ Expenditure ☐ Revenue ☐ Budgeted ☐ Contingency ☐ Budget Amendment ☐ Transfer ☐ Grant or other
Adopt Resolution

$ 0	N/A	[signature]	4-2-91
Total	Fund	Financial Officer	Date

7. PERSONNEL: ______ Personnel Director ______ Date

8. FLOOD CONTROL DISTRICT: [signature] Action Recommended by 3-26-91 Date

9. MATERIALS MANAGEMENT:
A. ______ Materials Management Director ______ Date
B. ______ W/MBE Representative ______ Date

10. LEGAL: Approved as to form and within the powers and authority granted under the laws of the State of Arizona to the Flood Control District of Maricopa County Board of Directors.
[signature] General Counsel 3-27-91 Date

11. OTHER: ______ Signature ______ Date

12. APPROVED FOR AGENDA: [signature] Approving Official 3-28-91 Date

13. OTHER: ______ Signature ______ Date

15. RECOMMENDATION OF COUNTY MANAGER:
☒ Approve ☐ Disapprove
Comments:
[signature: Roy R. Pederson] County Manager ______ Date

14. BOARD OF DIRECTORS: Action taken:
☒ Approved ☐ Amended ☐ Disapproved ☐ Deleted
Continued to: ______ (Date and type of meeting)
[signature] Clerk of the Board APR 15 1991 Date

6910-001 R5-90

Executive Summary

The objective of the *Drainage Design Manual for Maricopa County, Volume I, Hydrology*, (hereinafter referred to as the *Hydrology Manual*) is to provide technical procedures for the estimation of flood discharges for the purpose of designing stormwater drainage facilities in Maricopa County. Two methodologies are defined for the development of design discharges; the Rational Method, and rainfall-runoff modeling using a design storm. For small, urban watersheds, less than 160 acres and fairly uniform land-use, the Rational Method is acceptable. Use of this method will only produce peak discharges and runoff volumes and this method should not be used if a complete runoff hydrograph is needed, such as for routing through detention facilities. For larger, more complex watersheds or drainage networks, a rainfall-runoff model should be developed. The *Hydrology Manual* provides guidance in the development of such a model and the estimation of the necessary input parameters to the model. Although not necessarily required, the use of the U.S. Army Corps of Engineers' HEC-1 Flood Hydrology Program facilitates the use of the procedures that are contained in the *Hydrology Manual. (The Hydrology Manual* was written to supplement the *HEC-1 User's Manual.*)

The *Hydrology Manual* can be used to develop design discharge magnitudes for storms of frequencies up to and including the 100-year event. The design storm is of 6-hour duration and that storm is to be used for the design of all stormwater drainage facilities except detention and retention basins. According to the *Uniform Drainage Policies and Standards for Maricopa County, Arizona* (February 25, 1987), all development shall make provisions to retain the peak flow and volume of runoff from rainfall events up to and including the 100-year, 2-hour duration storm falling within the boundaries of the proposed development. Accordingly, the criteria to be applied to the 2-hour storm is also provided in the *Hydrology Manual.*

The rainfall-runoff modeling procedure that is contained in the manual is physically based, that is, the procedures are based—to the extent practical—on the physical processes that occur during the generation of storm runoff from rainfall. While the basic procedure is physically based, this does not assure that the rigorous application of the procedures will, in fact, reproduce the actual rainfall-runoff phenomenon of any storm that has occurred or may occur in the future. However, the procedure, when applied with good hydrologic judgement, should yield consistent results for design purposes.

Throughout the development of the *Hydrology Manual* three benchmarks were continually applied in judging the applicability of individual procedures and the overall methodologies; accuracy, practicality, and reproducibility. *Accuracy* is a measure of how well the results of the procedure reproduce the physical process being simulated. Although accuracy is highly desired, it is theoretically impossible to achieve in an earth science such as hydrology, and in a practical sense, accuracy is not feasible to assess except for a few situations where adequate verification data are available. Relative accuracy was assessed throughout the development of the procedures in the manual through testing and verification against recorded data.

Practicality is a user's decision regarding the best and most appropriate level of technology to apply considering the information that is available, anticipated user, consequences of error, and desired or required output. Whereas both simpler procedures and more sophisticated procedures are available, the adopted methodologies provide a compromise between these two extremes, and the best practical level of technology is judged to be recommended in the manual considering the state of current hydrologic knowledge of arid and semi-arid lands.

Reproducibility is a characteristic that provides a reasonable assurance that consistent results will be achieved by all qualified users. Reproducibility is highly desirable for a design standard in order to eliminate—to the extent possible—unnecessary conflicts over the interpretation and application of the design method. Reproducibility is achieved through clear and concise manual procedures and user guidance. Every effort has been made toward this end.

A brief discussion of the contents of each chapter of the *Hydrology Manual* follows:

Chapter 1, *Introduction*: The introduction states the purpose, scope and limitations, and general use of the manual.

Chapter 2, *Rainfall*: The characteristics of severe storms in Maricopa County are documented as a setting for defining the design rainfall criteria. Procedures and information are provided for the determination of depth-duration-frequency statistics of storms in Maricopa County. These are derived from NOAA Atlas 2, Arizona, which is the most comprehensive and authoritative source of such information. The limitations and potential inaccuracy of the NOAA Atlas are recognized and until an equivalently accepted source of rainfall statistics is provided, this source must be used. Recent reanalysis of the short duration (less than 1-hour) rainfalls by the National Oceanographic and Atmospheric Administration have been used as a supplement to the NOAA Atlas.

The temporal distribution of rainfall for the majority of design conditions is a 6-hour local storm. The 6-hour storm distribution is based on an analysis by the U.S. Army Corps of Engineers, Los Angeles District, of the August 19, 1954 Queen Creek storm. The Corps' distribution has been modified somewhat to reflect the design rainfall criteria that is desired for use in Maricopa County, and this modification includes using the hypothetical distribution for drainage areas less than 0.5 square mile. The temporal distribution is a function of drainage area and this is to reflect the spatial variability of rainfall intensities that are known to exist with severe local storms in Maricopa County. A 2-hour distribution is provided for use in the design of detention/retention facilities. The reduction of rainfall depth with storm area for the 6-hour rainfall is accounted for by a depth-area reduction curve based on the 1954 Queen Creek storm. In some cases a general storm may be the accepted design rainfall. In Maricopa County, the general storm to be used is the SCS Type II pattern using NWS HYDRO-40 areal reductions of point rainfall.

Chapter 3, *Rational Method*: Use of the Rational Method is to be limited to areas of up to 160 areas, and is generally limited to urbanized conditions. The watershed should be of uniform land use for application of this method. Intensity-duration-frequency (I-D-F) statistics are to be obtained from the information contained in Chapter 2, and an I-D-F curve for general use is contained in the manual. An equation for the estimation of time of concentration is provided which is a partial function of rainfall intensity. Values of the runoff coefficient "C" to be applied to various land uses in Maricopa County are provided.

Chapter 4, *Rainfall Losses*: The preferred method for the estimation of rainfall losses is the Green and Ampt infiltration equation with an estimate of surface retention loss. This requires the classification of soil according to soil texture, which is available for most of Maricopa County. Adjustment of the loss rate is available as a function of vegetation cover. Other methods are available to estimate rainfall losses if adequate soils and/or vegetation data are not available.

Chapter 5, *Unit Hydrograph Procedures*: The use of unit hydrographs to route rainfall excess from the land's surface is recommended and the procedures recommended to do so are either the Clark unit hydrograph or the application of selected S-graphs. The Clark unit hydrograph is recommended for watersheds or subbasins less than five square miles in size with an upper limit of application of ten square miles. Procedures are provided for the estimation of the two numeric parameters: time of concentration and storage coefficient. Two default time-area relations are provided; one for urban watersheds and the other for natural watersheds. Four S-graphs have been selected for use in flood hydrology studies of major watercourses in Maricopa County. The Phoenix Mountain, Phoenix Valley, Desert/Rangeland, and the Agricultural S-graphs are described and guidelines are provided for their selection. A procedure is provided for the estimation of the S-graph parameter, lag.

Chapter 6, *Channel Routing*: General guidance is provided for the use of Kinematic Wave routing, Muskingum and Muskingum-Cunge routing, and Normal-Depth routing. Kinematic Wave routing can be applied to urbanized or artificial channels and closed conduits. Muskingum routing is to be used for large natural channels where parameter calibration data exists. Muskingum-Cunge or Normal-Depth routing may be used in all other cases.

Chapter 7, *Application*: General guidelines and some specific aids in the use of the manual are provided in this chapter.

Appendices: Loss rate tables for soils in Maricopa County, Textural Class Diagram, selected blank figures, worksheets, and other supporting information are provided in the appendices. Appendix H compares flood estimates obtained using the methods in this manual with estimates obtained by other methods that are, or have been, used in Maricopa County.

Examples: Detailed examples are provided that clearly illustrate the use of the procedures in practical applications.

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Drainage Design Manual for Maricopa County Volume I, Hydrology Revision I

Changes to the original *Hydrologic Design Manual for Maricopa County* dated September 1, 1990:

1. The title of the document has changed. The hydrology and hydraulics manuals are now the *Drainage Design Manual for Maricopa County, Volumes I and II,* respectively.

2. A copy of the Agenda Form, signed by the Board of Directors on April 15, 1991, is included. This form indicates formal adoption of the manual, requiring its use by jurisidictions that cost-share with the District in flood control projects, by contractors working for the District, and by all parties submitting drainage reports and studies to the District for review and approval.

3. Page numbering has changed to section numbering rather than consecutive (i.e., 1-1, 2-1, 3-1, etc.).

4. *Chapter 2*: The rainfall chapter has been substantially condensed. The computer program PREFRE has been added to ease development of rainfall statistics for sites outside the Phoenix metropolitan area. The PREFRE user's manual is included with the manual as Appendix J. An additional isopluvial map with 2-hour, 100-year depths has been added.

5. *Chapter 3*: New roughness factor descriptions were developed. "C" coefficients will now be adjusted to reflect storm frequency, and a new table is included. A computer program RATIONAL.EXE is included for development of discharges and volumes using the Rational Method.

6. *Chapter 4*: The methodology used to develop Green and Ampt loss parameters has been substantially modified and simplified. The section on the Initial plus Uniform Loss Rate Method has been reduced, and limitations for the use of that method are provided. An equation is provided for calculation of the XKSAT vegetation adjustment coefficient.

7. *Chapter 5*: New land classification descriptions are provided to facilitate selection of parameters in the K_b equation. An error was corrected in the Lag equation (the Corps of Engineers uses $C = 24\ K_n$ instead of $C = 20\ K_n$). The MCUHP1 and MCUHP2 computer programs were revised to reflect our change of address, some additional data inputs were added to facilitate review, and an error was corrected in the 2-hour storm distribution (the program was underestimating Tc because of an incorrect summation of the first three rainfall excess values).

8. *Chapter 6*: The routing chapter now includes guidance on using the Muskingum-Cunge routing option recently available in HEC-1. A sample problem is included in the Examples section.

9. Chapter 7, the Appendices, and the Examples have all been updated to incorporate the changes outlined above.

Drainage Design Manual for Maricopa County Volume I, Hydrology Revision II

In addition to the correction of a few typographical errors, changes of January 1, 1995 revision of the *Drainage Design Manual, Volume I, Hydrology* include the following:

1. *Chapter 2*: The SCS Type II rainfall distribution is recommended for use for the 24-hour general design storm. Areal reductions of point rainfall are to be made with Table 2.1a which is based on the NWS-HYDRO 40 data. Guidelines have also been added as to when to select the general storm for use in design hydrology in Maricopa County.

2. *Chapter 3*: The RATIONAL.EXE program has been updated to better match 10-year rainfall intensities for durations between 10 and 20 minutes as shown on the I-D-F curve, Figure 3.2. The revised program is supplied on the DDMS diskette available with this revision (see 6. below).

3. *Chapter 4*: A table has been added to help with the selection of IA, RTIMP, and percent vegetation cover for representative urban land use types in Maricopa County.

4. *Chapter 5*: Two new S-graphs have been added for use in Maricopa County. The newly added S-graphs are the Desert/Rangeland S-graph and the Agricultural S-graph. A table has also been added to facilitate the selection of S-graph type and Kn values for those S-graphs for estimation of basin lag time.

5. *Chapter 6*: The Normal-Depth routing method has been added to the Manual as an additional routing method for use in flood hydrology studies in Maricopa County.

6. *Appendix I*: A new computer program and user's guide have been added to this revision of the Manual. The new program brings together the PREFRE program, a modified version of the loss parameter spreadsheet functionality, and the MCUHP programs to speed up the creation of HEC-1 models using the methodologies recommended in the Manual. Additionally, two changes have been made to the MCUHP programs. First, the SCS Type II 24-hour design storm temporal distribution has been corrected and is now entered into the HEC-1 data file as a 15 minute distribution. Second, the two S-graphs added to Chapter 5 have been incorporated into the MCUHP2 program.

7. *Appendix K*: An appendix of Kn values for various real watersheds has been supplied for additional help in the selection of watershed Kn values. These data were taken from a report by George V. Sabol Consulting Engineers, Inc., performed for the District since the last Manual revision.

Acknowledgments

The information, procedures, and recommendations that are presented in this manual are mainly the result of previously published efforts of many diligent and talented engineers and scientists. The authors of this manual have made every effort to cite the original authors and researchers whose contributions to this manual, and to the science of hydrology, are gratefully appreciated.

The authors of this manual are indebted to the many individuals and organizations, including the staff at the Flood Control District, that have supported this effort through recommendations, technical guidance, encouragement, and review of draft sections of this manual. In particular, the following people have provided immeasurable assistance without which this manual could not have been completed in this form. Those individuals, in alphabetical order, are:

Arthur G. Cudworth, Jr., Former Head (retired), Flood Section, Surface Water Branch, U.S. Bureau of Reclamation, Denver, Colorado.

Leonard J. Lane, Ph.D., Arid Lands Watershed Management Research Unit, U.S. Department of Agriculture, Tucson, Arizona.

Robin McArthur (deceased), Hydrologist, Soil Conservation Service, U.S. Department of Agriculture, Phoenix, Arizona.

Harry Millsaps, Hydrologist, Soil Conservation Service, U.S. Department of Agriculture, Phoenix, Arizona.

Herbert B. Osborn, Ph.D., P.E., (retired) Arid Lands Watershed Management Research Unit, U.S. Department of Agriculture, Tucson, Arizona.

John T. Pedersen, P.E., Supervisor Hydraulic Engineer, U.S. Army Corps of Engineers, Los Angeles District.

Walter J. Rawls, Ph.D., Hydrologist, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland.

Kenneth G. Renard, Ph.D., P.E., Arid Lands Watershed Management Research Unit, U.S. Department of Agriculture, Tucson, Arizona.

Tim J. Ward, Ph.D., P.E., Professor of Civil, Agriculture, and Geologic Engineering, New Mexico State University, Las Cruces, New Mexico.

David Woolhiser, Ph.D., P.E., Arid Lands Watershed Management Research Unit, U.S. Department of Agriculture, Tucson, Arizona.

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1 Introduction

1.1 Purpose

In April 1985 a task force was formed by the Flood Control District of Maricopa County to establish a common basis for drainage management in all jurisdictions within Maricopa County. Among the goals of the task force were provisions for consistent analysis of drainage requirements, reducing costs and staff time when annexing County areas, and supplying equal and common protection from the hazards of stormwater drainage for all County residents. Additionally, developers would be benefitted by having only one set of drainage standards with which to comply when developing land within the incorporated or unincorporated areas of Maricopa County. The task force determined that these efforts would be achieved in three phases:

Phase 1 Research, evaluate, develop, and produce uniform criteria for drainage of new development which resulted in the *Uniform Drainage Policies and Standards for Maricopa County*.

Phase 2 Establish a *Drainage Design Manual* for use by all jurisdictional agencies within the County.

Phase 3 Prepare an in-depth evaluation of regional rainfall data and establish precipitation design rainfall guidelines and isohyetal maps for Maricopa County.

As a part of Phase 2, the *Drainage Design Manual for Maricopa County, Volume I, Hydrology*, will provide the necessary data for *Volume II, Hydraulics*.

1.2 Scope and Limitation

When using the procedures detailed in this manual, it is important to keep several things in mind. First, this is a *hydrologic design manual*. The methods, techniques and parameter values described herein are *not necessarily valid* for real-time prediction of flow values, nor for recreating historic events—although some of the methods are physically based and would be amenable for uses other than design hydrology.

Second, the lack of runoff data for urbanizing areas of the County, for the most part, precludes the use of flood frequency analysis for stormwater drainage design. For those watercourses with sufficient record, flood frequency analysis may be acceptable. Similarly, for those watercourses with established regulatory floodplains, the FEMA accepted flood frequency curves may be used for design purposes, unless they are demonstrably inappropriate. The purpose of this manual is to provide a means of assisting in the prediction of runoff which might result from a design storm of a given return interval.

Third, the design storm has no point of reference in terms of a singular historic event. Rather, it is intended to provide the best available information by utilizing historic data as well as other precipitation design concepts. The design storm provides not only the peak intensities which would be expected from a storm of a given duration and return interval, but also the volumes associated with it. The tables describing the temporal distribution of the design storm for use in a hydrologic model, i.e., HEC-1, are approximately equivalent to the graphs used to determine the rainfall intensity to be used in the Rational Method. The net effect is that regardless of the size of the area being investigated or the method of analysis, the same design storm is used as the driving input.

1.3 Using this Manual

The use of the methods presented in this manual, even the rigorous application thereof, in no way ensures that the predicted values are reasonable or correct. Hydrology is a discipline which, in some respects, is much like music—quality requires not only technical competence but also a *feel* for what is right. It often requires the exercise of *hydrologic judgement.* The Flood Control District of Maricopa County does not warrant or guarantee the reliability of the hydrologic methods, techniques, and/or parameter values set forth in this design manual. The user of the *Hydrologic Design Manual* has no right to rely or depend on the methodology, techniques, and/or parameter values described herein. The user of this manual is thus directed to validate the reasonableness of the predicted values by applying alternative methods, such as envelope curves, regression equations, or other checks which have been developed for this area. Failure to do so may result in erroneous values.

Section 7 of this manual is intended to provide some general suggestions for the user attempting to solve a particular problem. A number of examples were designed to aid the user with the development of input variables and parameter estimation.

It is not the intent nor purpose of this manual to inhibit sound innovative design or the use of new techniques. Therefore, where special conditions or needs exist, other methods and procedures may be used *with prior approval.*

It is anticipated that, over time, as more data becomes available and/or more appropriate techniques are developed, this manual will be revised. With the exception of minor editorial corrections, such revisions will probably take place every three to five years. If, in the intervening period, gross inadequacies/inaccuracies are found with any of these procedures, they should be brought to the attention of the Flood Control District of Maricopa County, or any other agency that might subscribe to these suggested procedures.

1.4 Application

The contents of this manual, with the exception of Chapter 3 (Rational Method), were prepared to supplement the HEC-1 User's Manual (U.S. Army Corps of Engineers, September, 1990). Although the use of the HEC-1 Flood Hydrology Program is not required in conjunction with the procedures in this manual, its use will greatly facilitiate the execution of the recommended procedures that are contained herein. To further enhance and simplify the use of the HEC-1 Program with the procedures in this manual, the Flood Control District has written two HEC-1 input loader programs, *MCUHP1* and *MCUHP2* (see Appendix I), that interactively convert screen-prompted keyboard input into a HEC-1 input file. MCUHP1 is written for use with the Clark Unit Hydrograph option and MCUHP2 is written for use with the S-graph option, and are provided with the *Hydrology Manual.*

2

Rainfall

2.1 General

Precipitation in Maricopa County is strongly influenced by variation in climate, changing from a warm and semi-arid desert environment at lower elevations to a seasonally cool and moderately humid mountain environment. Mean annual precipitation ranges from about 7 inches in the Phoenix vicinity to more than 25 inches in the mountain regions of northern Maricopa County. Precipitation is typically divided into two seasons of comparative rainfall depths: summer (June through October) and winter (December through March). Warm, moist tropical air can move into Arizona at anytime of the year, but most often does so in the summer months, resulting in severe storms and local flooding. Storms of large areal extent are usually associated with frontal or convergence storm activity that may result in long duration rainfall and flooding of major drainage watercourses. These types of storms and flooding usually occur in the winter, but occasionally occur in the summer.

2.1.1 Storm and Flood Occurrence in Maricopa County

Storms in Maricopa County are often classified as general winter, general summer, and local storms. General storms are usually frontal or convergence type that cover large areas and have traditionally contributed to flooding of the major drainage watercourses in the County. Local storms are usually associated with convective activity and hence normally occur in the summer, although local storm cells (typically of lesser intensity than without frontal activity) can be imbedded in larger, general storm systems.

General winter storms usually move in from the north Pacific Ocean, and produce light to moderate precipitation over relatively large areas. These storms occur between late October and May, producing the heaviest precipitation from December to early March. Such storms could last over several days with slight breaks between individual storms. Because of orographic effects, the mountain areas generally receive more precipitation than the lower desert areas. These storms are characterized by low intensity, long duration, and large areal extent, but on occasion, with an additional surge of moisture from the southwest, can contribute to substantial runoff volumes and peak discharge on major river systems.

General summer storms are often associated with tropical storms. The Pacific Ocean north of the equator and south of Mexico is a breeding ground for such storms. On the average, about two dozen tropical storms and hurricanes are generated in this area from June through early October. Most move in a northwesterly direction. The remnants of these storms can be caught up in the large scale circulation around a low pressure center in southern California and therefore can bring a persistent flow of moist tropical air into Arizona. The storm pattern consists of a band of locally heavy rain cells within a larger area of light to moderate rainfall. Whereas general winter storms can cover much of the state, general summer storms are more localized along a southeast to northwest band of rainfall. They are similar to winter storms in that higher elevations receive greater rainfall because of orographic influences. The period of late September through October may have storm patterns which are similar to both general summer and winter events.

Local storms consist of scattered heavy downpours of rain over areas of up to about 500 square miles for a time period of up to 6 hours. Within the storm area, exceptionally heavy rains usually cover up to 20 square miles and often last for less than 60 minutes. They are typically associated with lightning and thunder, and are referred to as thunderstorms or cloudbursts. While they can occur any time during the year, they are more frequent during summer months (July to September) when tropical moisture pushes into the area from the southeast or southwest. These storms turn into longer duration events in late summer and may be associated with general summer storms (see above). Local storms generally produce record peaks for small watersheds. They can result in flash floods, and, sometimes, loss of life and property damage.

2.1.2 Design Rainfall Criteria for Maricopa County

The critical flood-producing storm for most watersheds in Maricopa County is the local storm. The limit of such storms is generally less than 500 square miles with durations less than 6 hours. Local storms are characterized by central storm cells (possibly as large as 100 square miles) that produce very high intensity rainfalls for relatively short durations. The rainfall intensities diminish as the distance from the storm cell increases. Therefore, for the majority of watersheds and drainage areas in Maricopa County, the local storm will produce both the largest flood peak discharge and the greatest runoff volume. Based on a review of meteorologic studies for Arizona (U.S. Army Corps of Engineers, 1974 and 1982a) and a consideration of severe storms for Maricopa County, it was determined that the 6-hour local storm should be used as the design storm criteria for watersheds in Maricopa County with drainage areas of 100 square miles and less.

Record floods for large drainage areas, such as for the Salt River near Phoenix, were produced by large-scale general storms of multiple day duration and relatively low rainfall intensities. Therefore, based on that observation, for drainage areas larger than 500 square miles it was determined that the general storm should be used as the design storm criteria. Because of the infrequent need for design criteria for such large areas as well as other considerations, design rainfall criteria are not defined in this manual. General storm criteria are to be defined for such large, regional flood studies on a case-by-case basis so that the most appropriate meteorologic and hydrologic factors (possibly also including snowmelt for stream baseflow and watershed antecedent moisture conditions) can be properly considered in the flood analysis.

For drainage areas between the critical flood-producing upper limit for local storms (100 square miles), and the lower limit for general storms (20 square miles), it can not be determined whether a local storm or a general storm will produce the greatest flood peak discharges or the maximum flood volumes. For such drainage areas, generally between 20 and 100 square miles, it is necessary to consider both general storms and local storms. This may require that site-specific general storm criteria be developed for the watershed and that various local storms with critical storm centering assumptions be developed using the criteria in this manual. Both of these storm types would be modeled and executed in the watershed model to estimate flood discharges and runoff volumes. It is possible, in certain situations, that the local storm could result in the largest peak discharge and the general storm could result in the largest runoff volume.

The *Uniform Drainage Policies and Standards for Maricopa County, Arizona,* February 1987, stipulates that the 100-year, 2-hour rainfall be used for the design of retention/detention facilities. As such, criteria are provided in this manual to define the 100-year, 2-hour rainfall for use in Maricopa County.

The design rainfall criteria to be used in Maricopa County are summarized in Table 2.1. The specific procedures that are needed to define the design rainfall for the 100-year, 2-hour storm and the 6-hour local storm are provided in the following sections:

Table 2.1
Design Rainfall Criteria for Maricopa County

Purpose	Criteria
On-Site Retention/Detention Facilities	100-year, 2-hour rainfall as defined in this manual.
All Other Purposes:	
Drainage area: 0 to 20 square miles	6-hour local storm as defined in this manual.
Drainage area: 20 to 100 square miles	Either a critically centered 6-hour local storm as defined in this manual, or a 24-hour general storm using the SCS Type II distribution.
Drainage area: 100 to 500 square miles	24-hour general storm using the SCS Type II distribution.

2.2 Rainfall Depth

The most commonly used descriptor of rainfall is the rainfall depth; however, for modeling purposes, two other types of rainfall descriptors must be defined. First, the rainfall duration and frequency of occurrence of rainfall depth for that duration must be assigned. Second, since the rainfall depth is a descriptor of the rainfall occurrence at a point in space, both the spatial and the temporal distribution of the rainfall depth must be defined. In this section, the rainfall depth-duration-frequency statistics for use in Maricopa County are described. Subsequent sections describe the spatial and temporal distributions that are to be applied for the 6-hour local storm, and the temporal distribution for the 100-year, 2-hour storm.

2.2.1 Data Analyses

The most comprehensive and available source of rainfall data analysis for Maricopa County is the NOAA *Precipitation-Frequency Atlas of the Western United States,* (Miller and others, 1973). Until a more up-to-date data base and data analysis becomes available, the NOAA Atlas is to be used for all drainage design purposes in Maricopa County. The only deviation from the NOAA Atlas procedures that are currently recommended is the use of the short-duration (less than 1-hour) rainfall ratios that were published by Arkell and Richards (1986).

2.2.2 Depth-Duration-Frequency Statistics

The depth-duration-frequency (D-D-F) statistics in the NOAA Atlas are shown as a series of isopluvial maps of Arizona for specified durations and return periods (frequencies). Selected isopluvial maps for Maricopa County have been reproduced from the NOAA Atlas and these are contained in the Manual (Figures 2.1 through 2.13). It is possible that flood studies of certain large watersheds may require reference to the NOAA Atlas directly to determine the rainfall depths for the portion of the watershed that exists outside the boundaries of Maricopa County.

Table 2.1a
Depth-Area Reduction Factors for 24-Hour Duration Rainfall

Area Square Miles	Ratio to Point Rainfall
0	1
10	0.94
20	0.91
30	0.90
40	0.88
50	0.87
60	0.86
70	0.856
80	0.855
90	0.846
100	0.842
110	0.838
120	0.834
130	0.833
140	0.829
150	0.825
200	0.817
300	0.80
400	0.79
500	0.78

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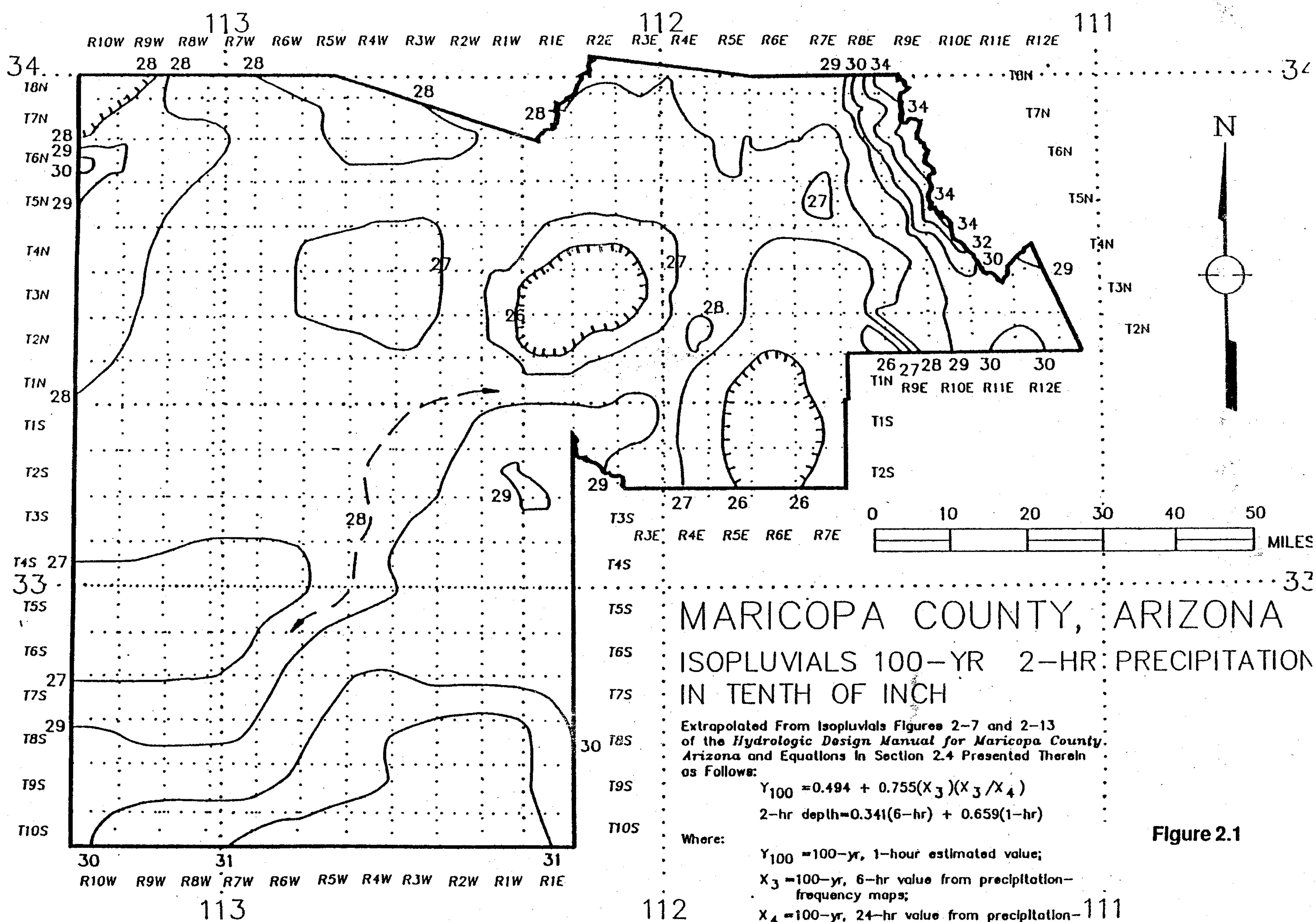


MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 100-YR 2-HR PRECIPITATION IN TENTH OF INCH

Extrapolated From Isopluvials Figures 2-7 and 2-13 of the *Hydrologic Design Manual for Maricopa County, Arizona* and Equations in Section 2.4 Presented Therein as Follows:

$$Y_{100} = 0.494 + 0.755(X_3)(X_3/X_4)$$

$$\text{2-hr depth} = 0.341(\text{6-hr}) + 0.659(\text{1-hr})$$

Where:

Y_{100} = 100-yr, 1-hour estimated value;

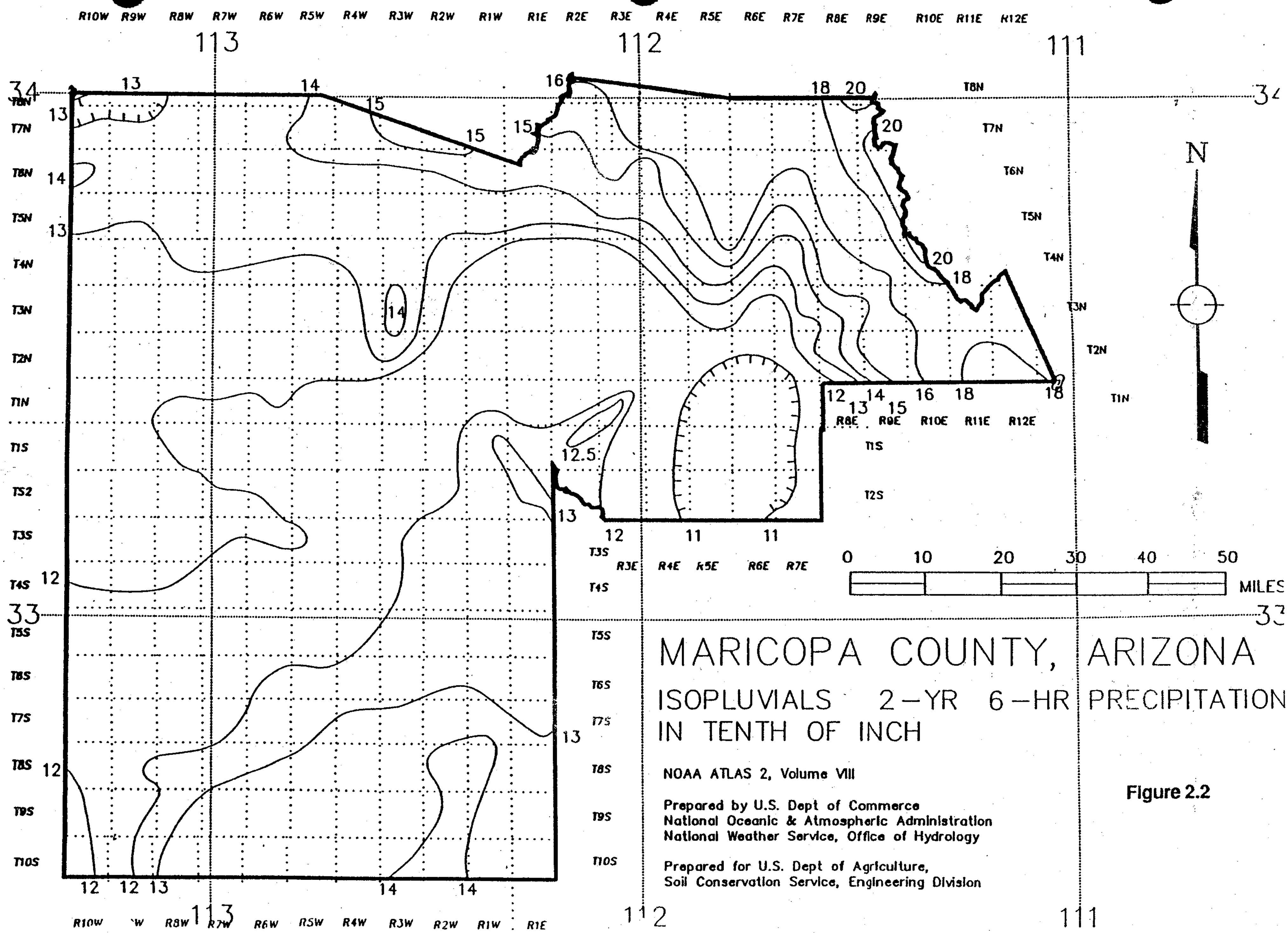
X_3 = 100-yr, 6-hr value from precipitation-frequency maps;

X_4 = 100-yr, 24-hr value from precipitation-frequency maps;

6-hr = Isopluvial values from figure 2.7;

1-hr = Y_{100} value as computed above.

Figure 2.1



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 2-YR 6-HR PRECIPITATION IN TENTH OF INCH

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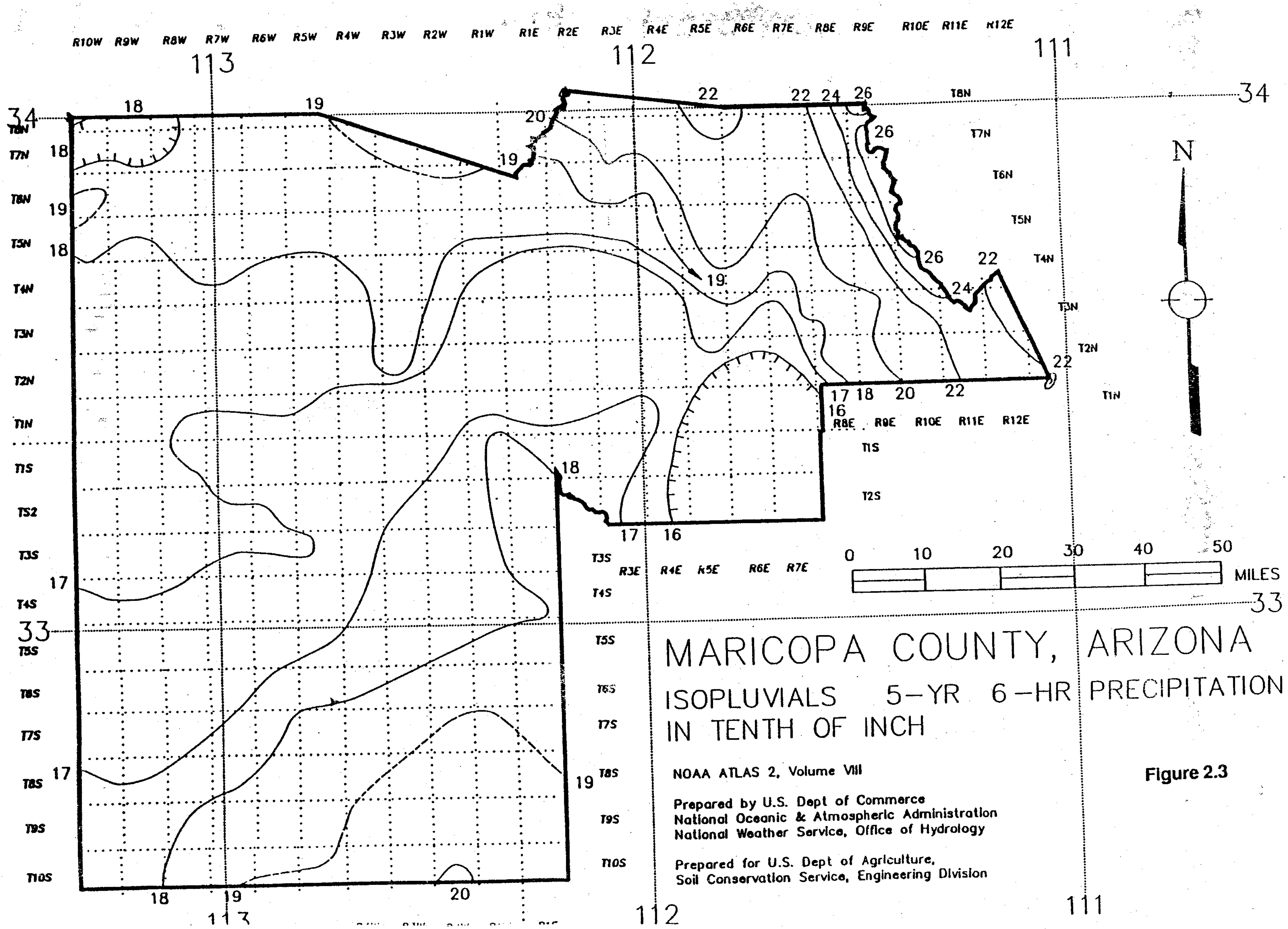
Figure 2.2



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 5–YR 6–HR PRECIPITATION IN TENTH OF INCH

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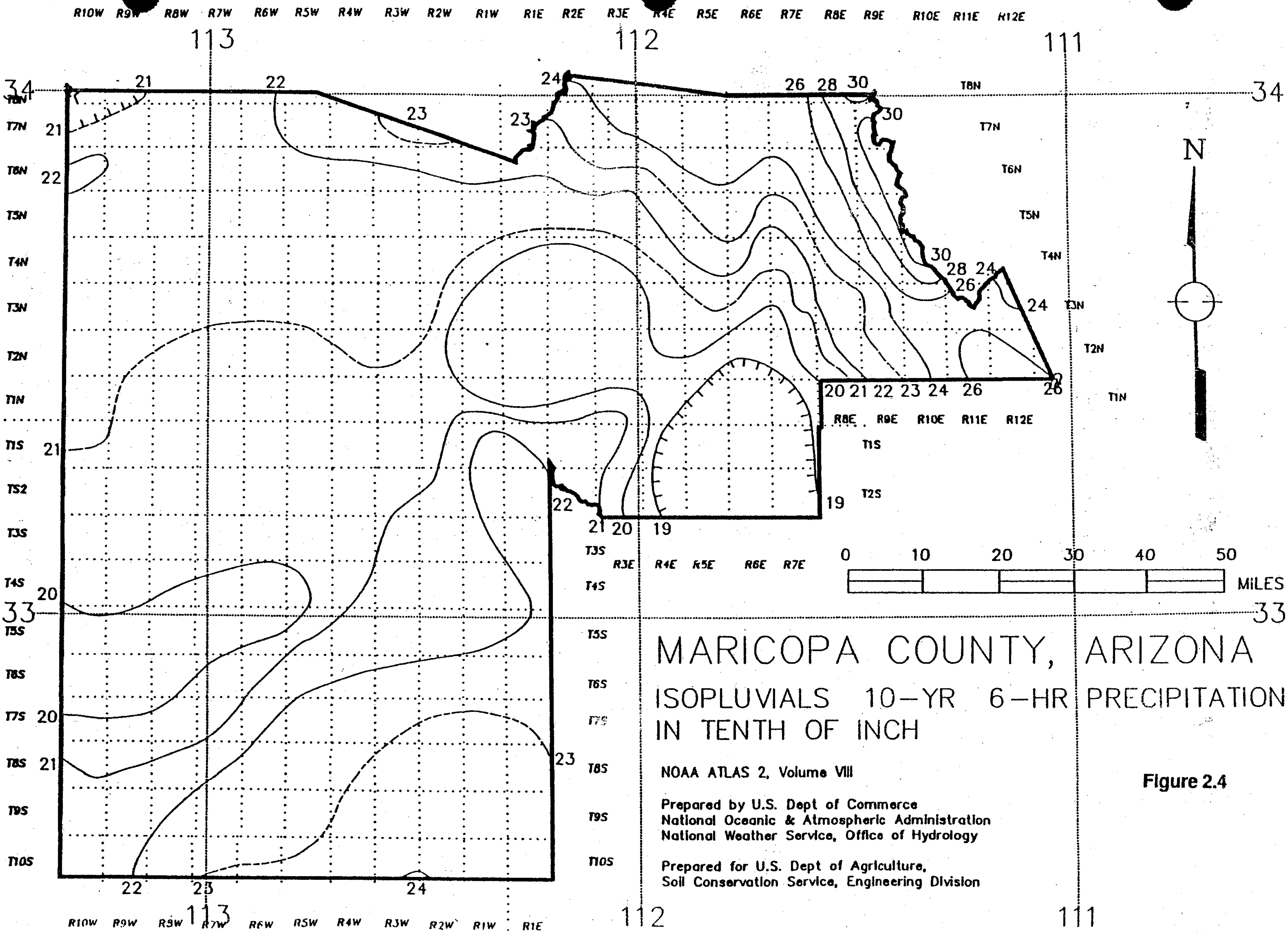
Figure 2.3



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 10-YR 6-HR PRECIPITATION IN TENTH OF INCH

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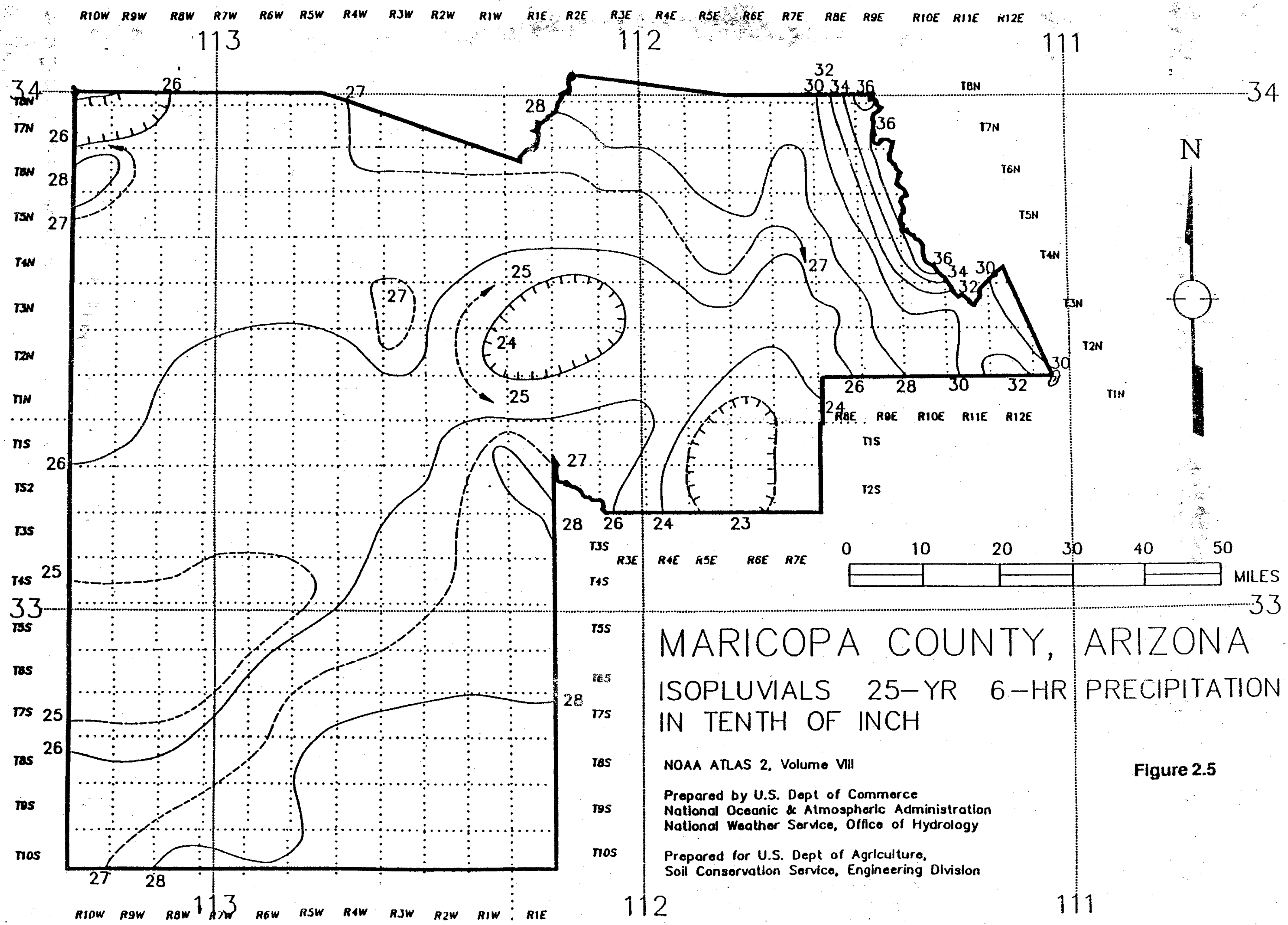
Figure 2.4



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 25–YR 6–HR PRECIPITATION IN TENTH OF INCH

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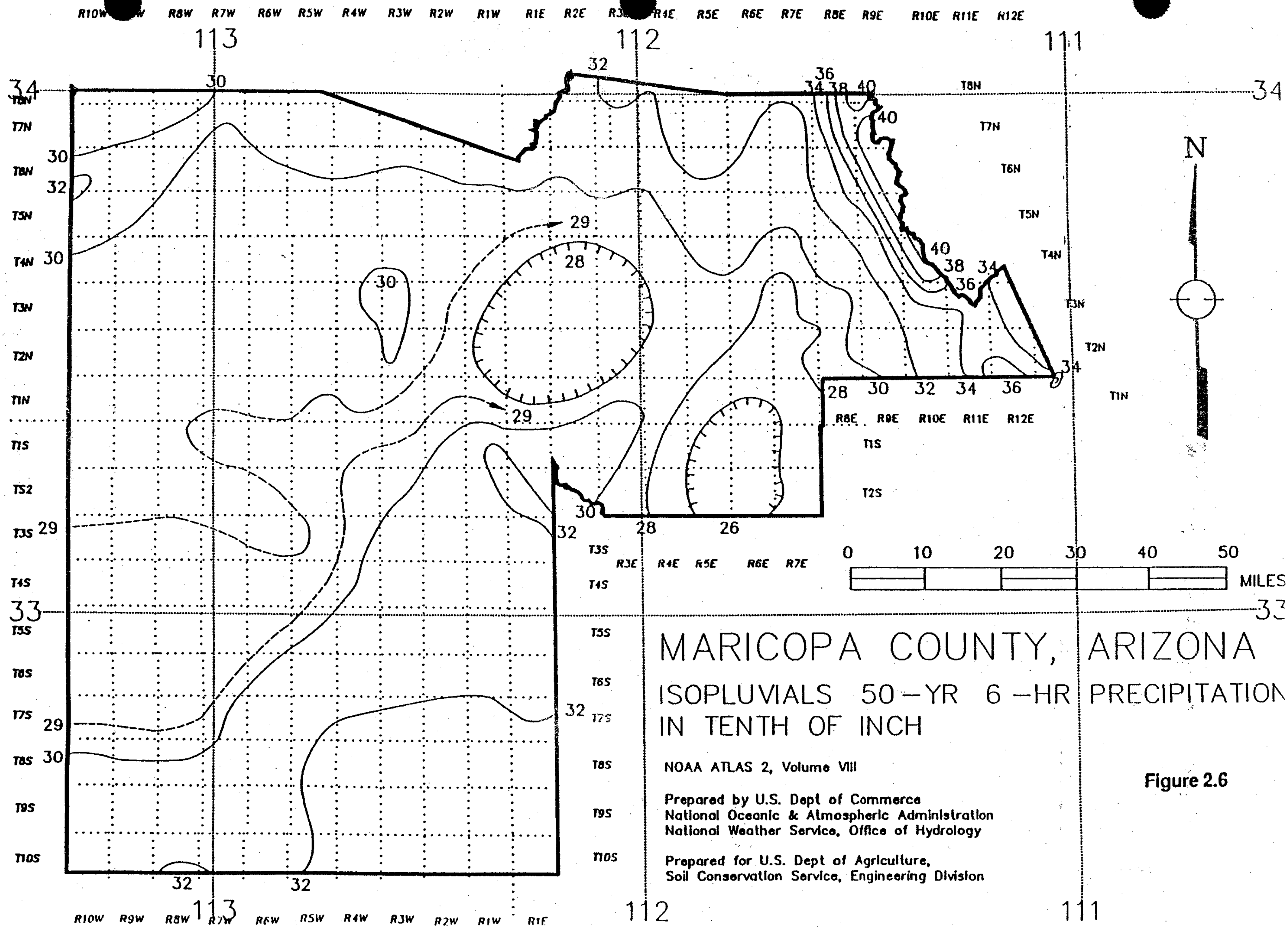
Figure 2.5



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 50–YR 6–HR PRECIPITATION IN TENTH OF INCH

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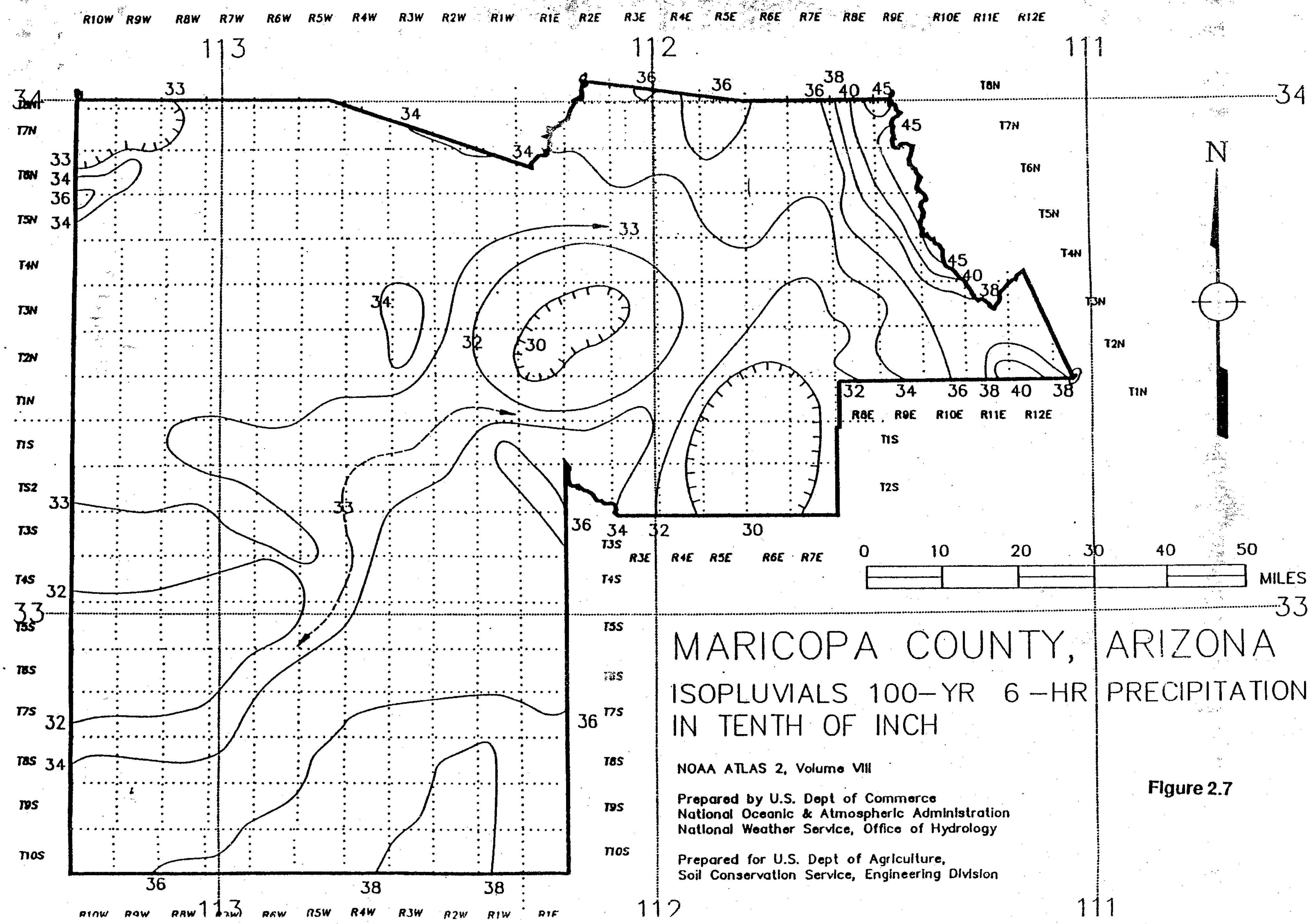
Figure 2.6



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 100–YR 6–HR PRECIPITATION IN TENTH OF INCH

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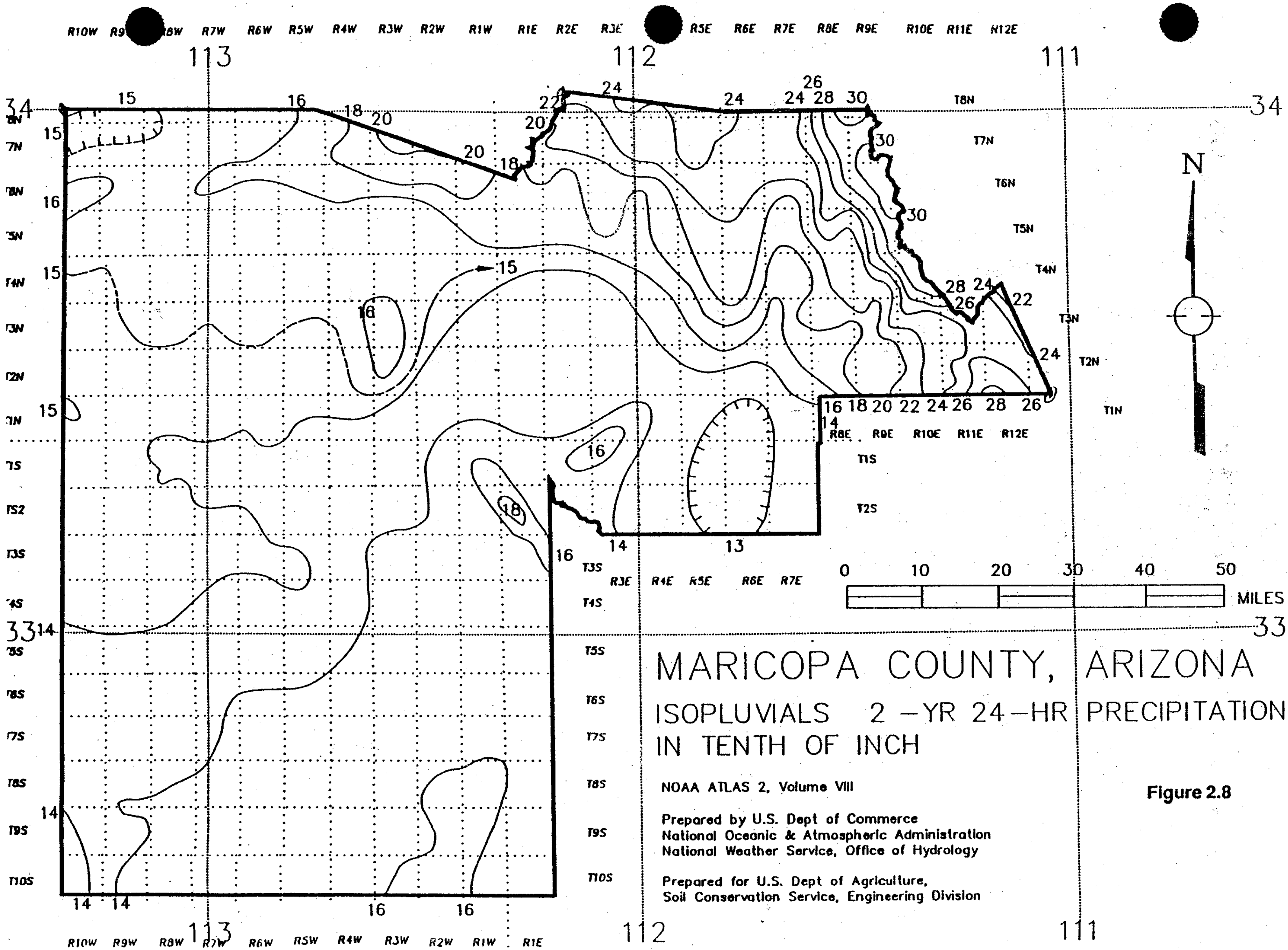
Figure 2.7



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 2 –YR 24–HR PRECIPITATION IN TENTH OF INCH

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Figure 2.8

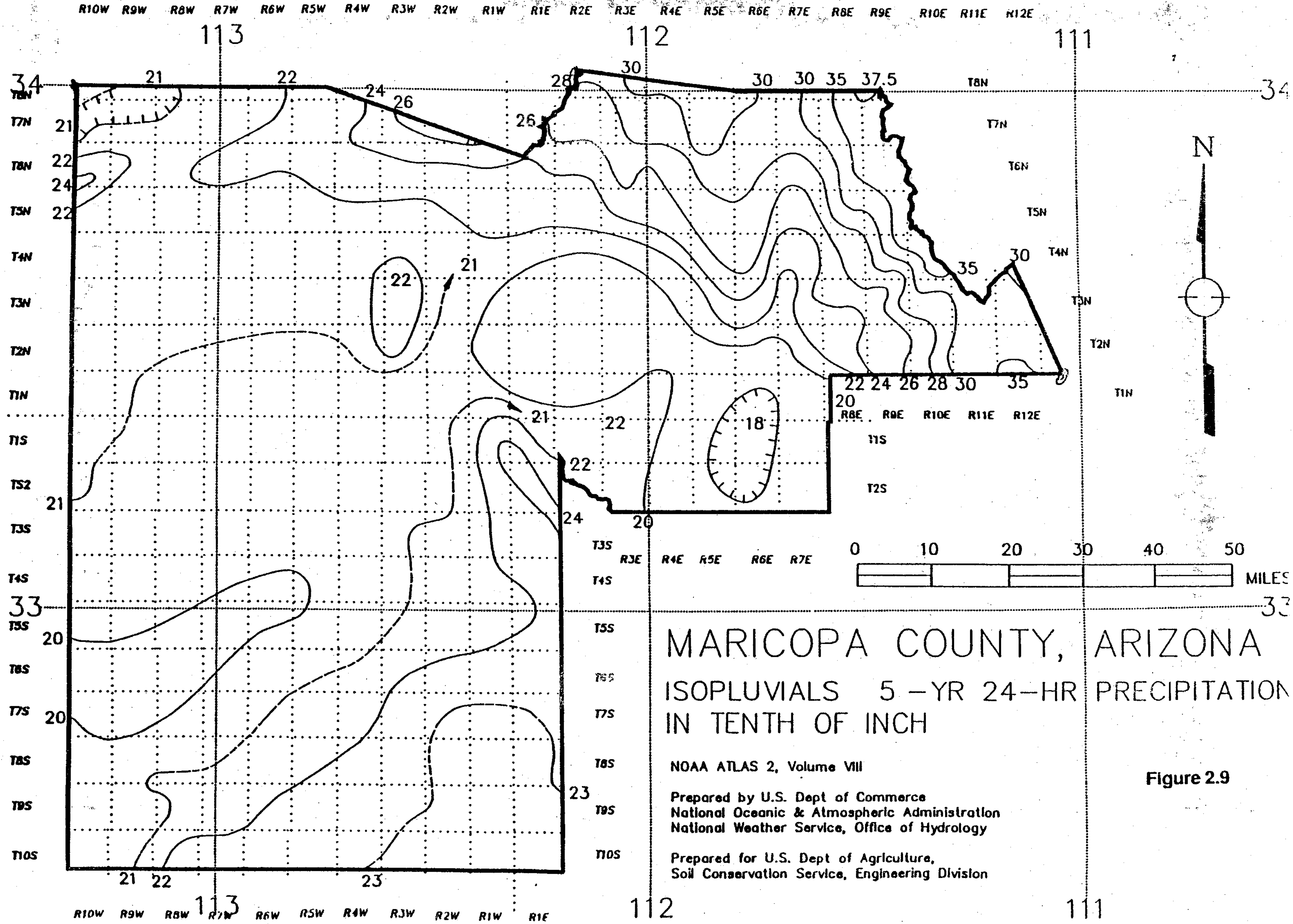
MARICOPA COUNTY, ARIZONA
ISOPLUVIALS 5-YR 24-HR PRECIPITATION
IN TENTH OF INCH
NOAA ATLAS 2, Volume VIII
Prepared by U.S. Dept of Commerce
National Oceanic & Atmospheric Administration
National Weather Service, Office of Hydrology
Prepared for U.S. Dept of Agriculture,
Soil Conservation Service, Engineering Division
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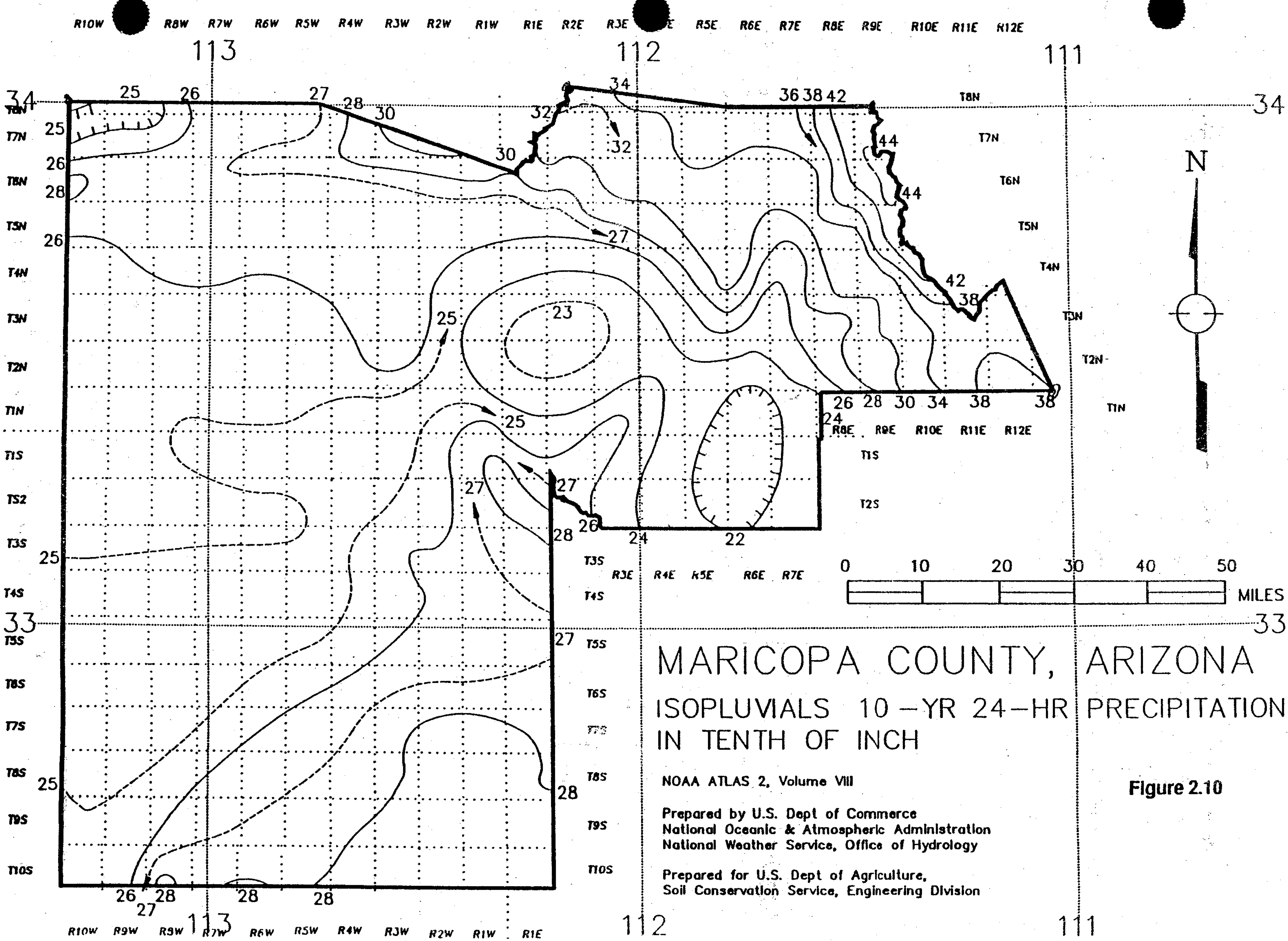
Figure 2.9



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 10-YR 24-HR PRECIPITATION IN TENTH OF INCH

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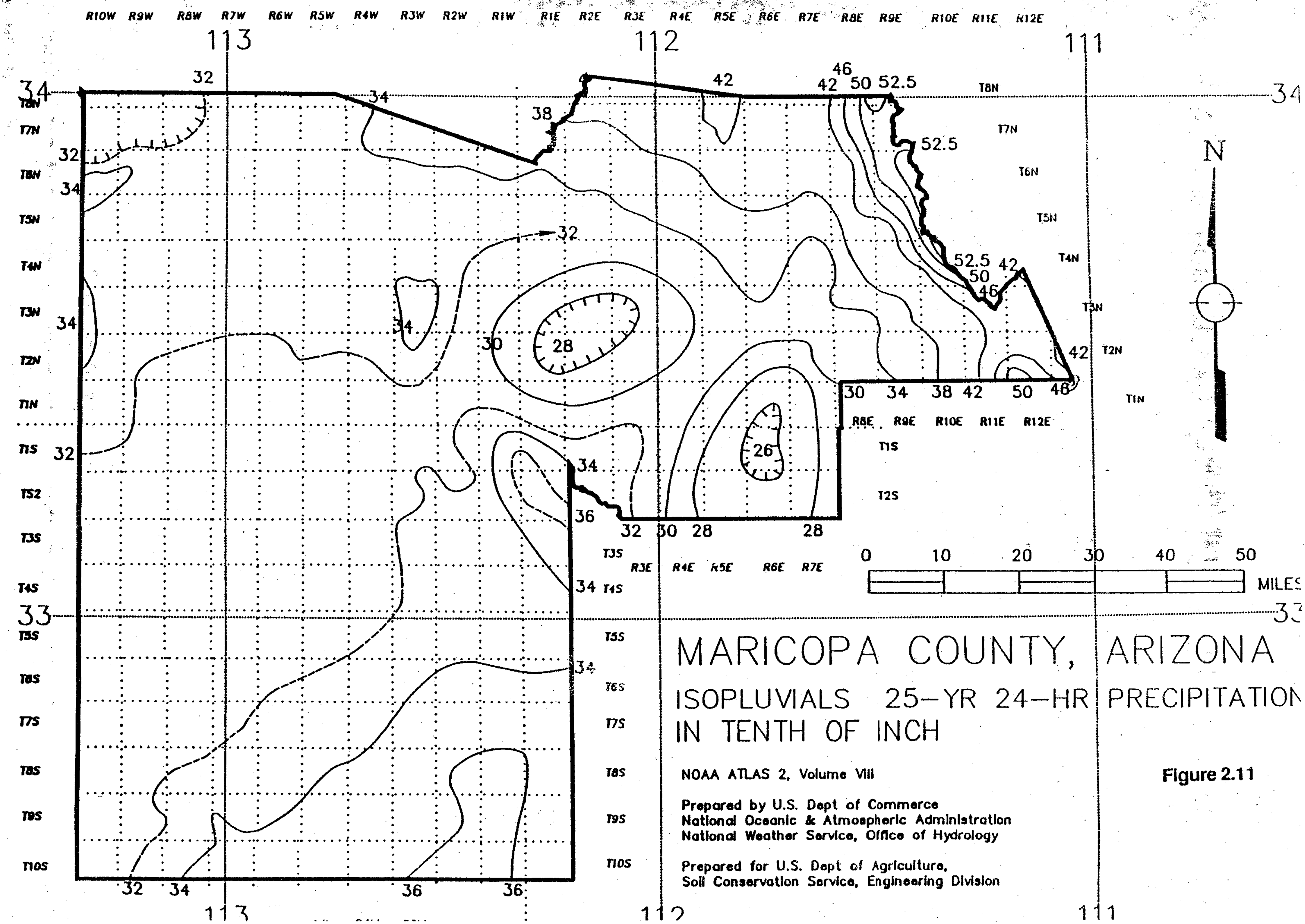
Figure 2.10



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 25-YR 24-HR PRECIPITATION IN TENTH OF INCH

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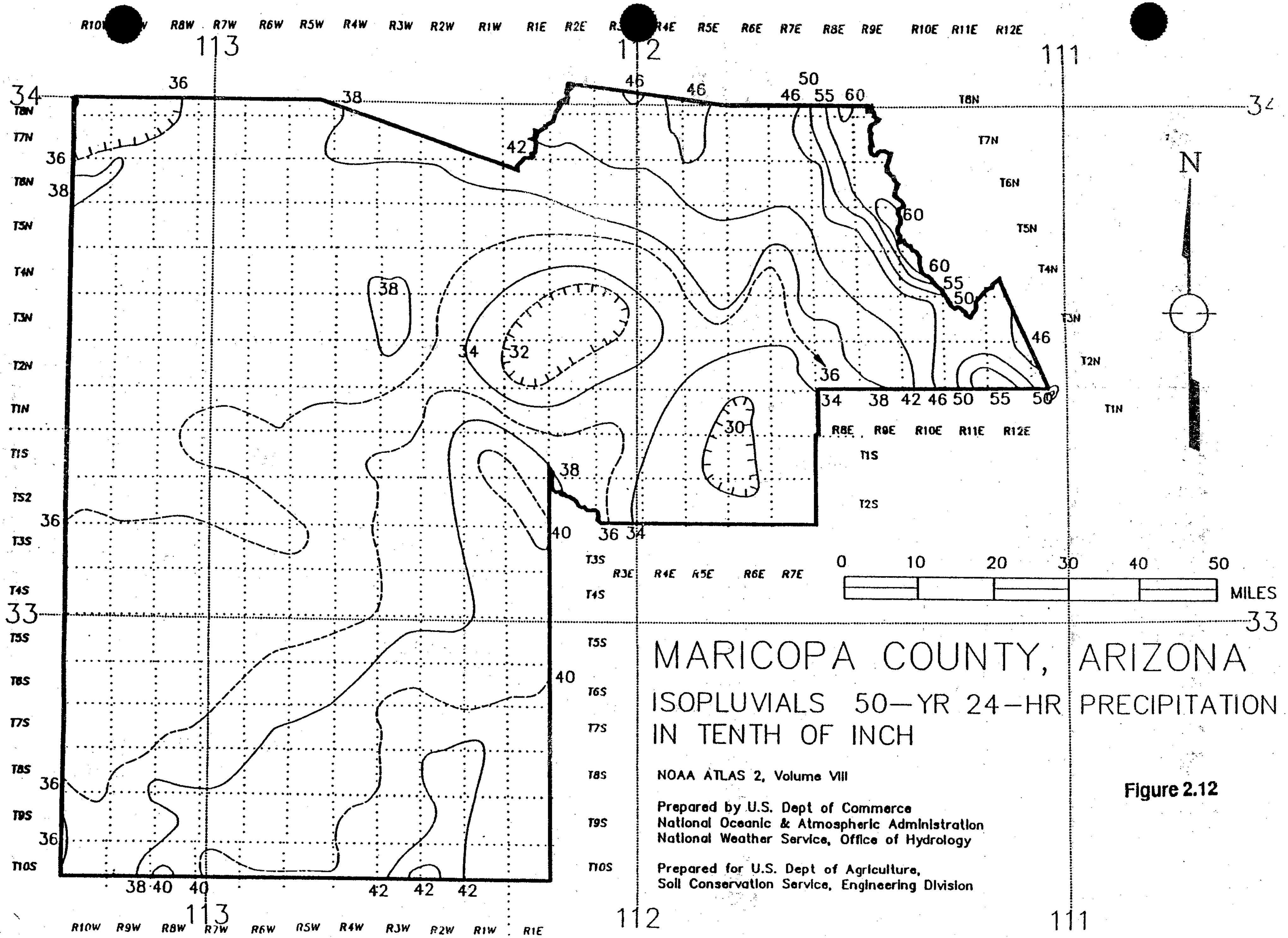
Figure 2.11



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 50—YR 24—HR PRECIPITATION IN TENTH OF INCH

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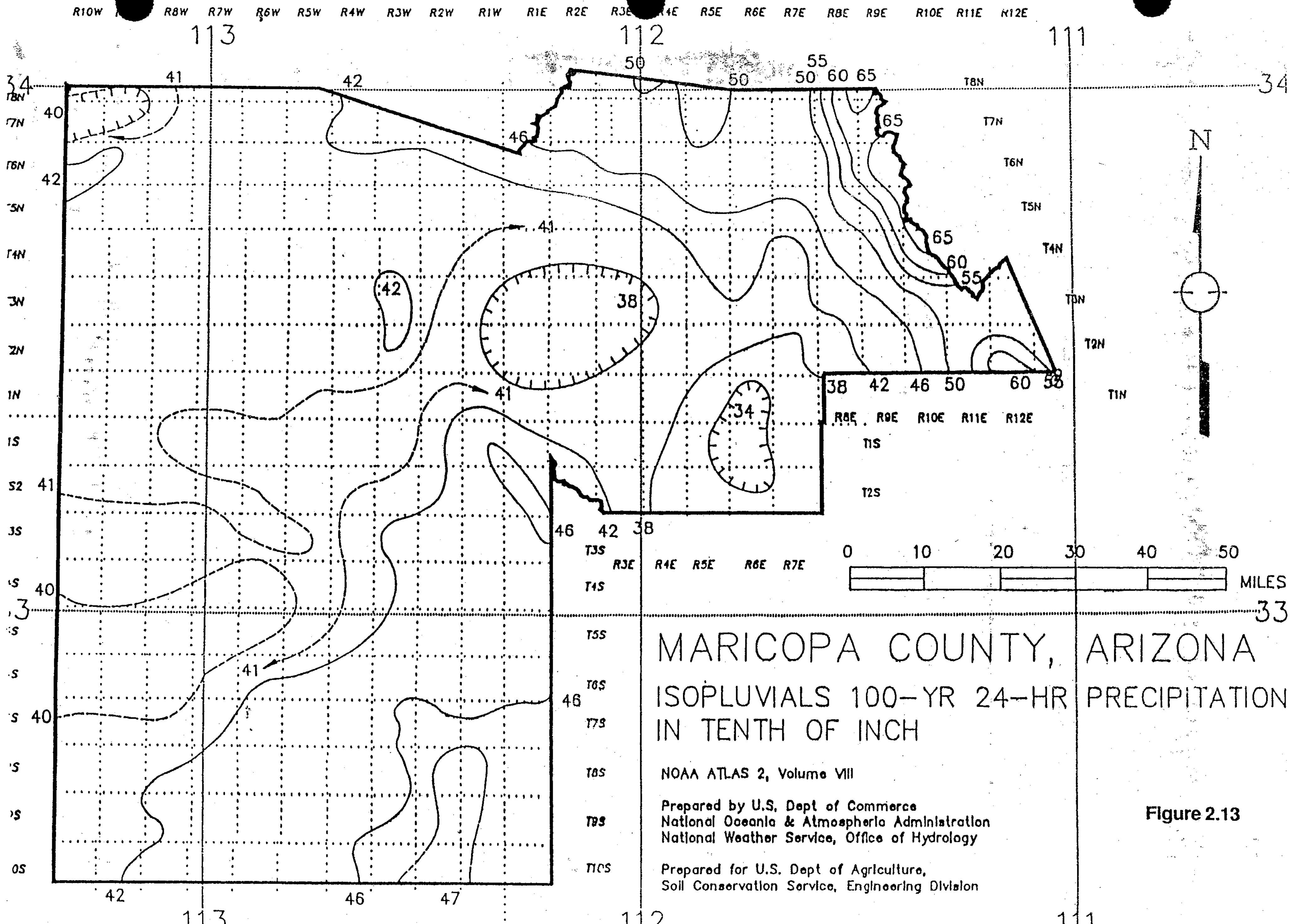
Figure 2.12



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 100-YR 24-HR PRECIPITATION IN TENTH OF INCH

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Figure 2.13

2.2.3 Rainfall Statistics for Special Purposes

There may arise situations for special purposes where it is necessary to define rainfall D-D-F statistics other than those provided in Figures 2.1 through 2.13. In those situations, the isopluvial maps and procedures that are contained in the NOAA Atlas along with the short-duration rainfall ratios from Arkell and Richards (1986) should be used. As an aid in the analyses and development of D-D-F statistics, a program (PREFRE) written by the Office of Hydrology, National Oceanic and Atmospheric Administration, and as modified and documented by the U.S. Bureau of Reclamation (1988), is provided. Use of the PREFRE program to calculate D-D-F statistics for special purposes is encouraged to minimize analysis errors and to increase the reproducibility of the rainfall depths that may be calculated by different users and reviewers. The diskette included in this manual contains the PREFRE program as well as the MCUHP1 and MCUHP2 programs. The PREFRE users' manual is contained in Appendix J. Appendix F contains a graph form for plotting rainfall depth-frequency values.

Users of this manual who may also be interested in defining general storm criteria for large watersheds, should note that it may be necessary to consider storms of durations longer than 24 hours. Provision of the 24-hour rainfall statistics does not preclude the use of a longer duration rainfall if deemed appropriate for a particular watershed or study. The 24-hour isopluvial maps are provided in this manual for the user's convenience because this is the rainfall depth often specified for general storms. If rainfall depths are needed for a duration longer than 24 hours, plot the rainfall depth versus rainfall duration for 1-hour to 24-hour (for a given rainfall frequency) on log-log paper and fit a straight line to the data points. Extend the straight line to the desired duration(s) and read the corresponding rainfall depth(s).

2.3 Depth-Area Relation

The rainfall depths from the isopluvial maps in Figures 2.1 through 2.13 are point rainfalls for specified frequencies and durations. This is the depth of rainfall that is expected to occur at a point or points in a watershed for the specified frequency and duration. However, this depth is not the areally-averaged rainfall over the basin that would occur during a storm. A reduction factor is used to convert the point rainfall to an equivalent uniform depth of rainfall over the entire watershed. As the watershed area increases, the reduction factor decreases, reflecting the greater nonhomogeneity of rainfall for storms of larger areas.

Regional research by the Agricultural Research Service, U.S. Department of Agriculture, for the Walnut Gulch Experimental Watershed near Tombstone, Arizona, indicates that local storms are characterized by relatively small areas of high intensity rainfall resulting in depth-area reduction curves that decrease rapidly with increasing area. The U.S. Army Corps of Engineers studied historic storms in Arizona and published the results of those studies (U.S. Army Corps of Engineers, 1974). The depth-area reduction curve that is to be used in Maricopa County is the curve that was developed by the U.S. Army Corps of Engineers for the 19 August 1954 Queen Creek Storm. That curve is shown in Figure 2.14 and in Table 2.2.

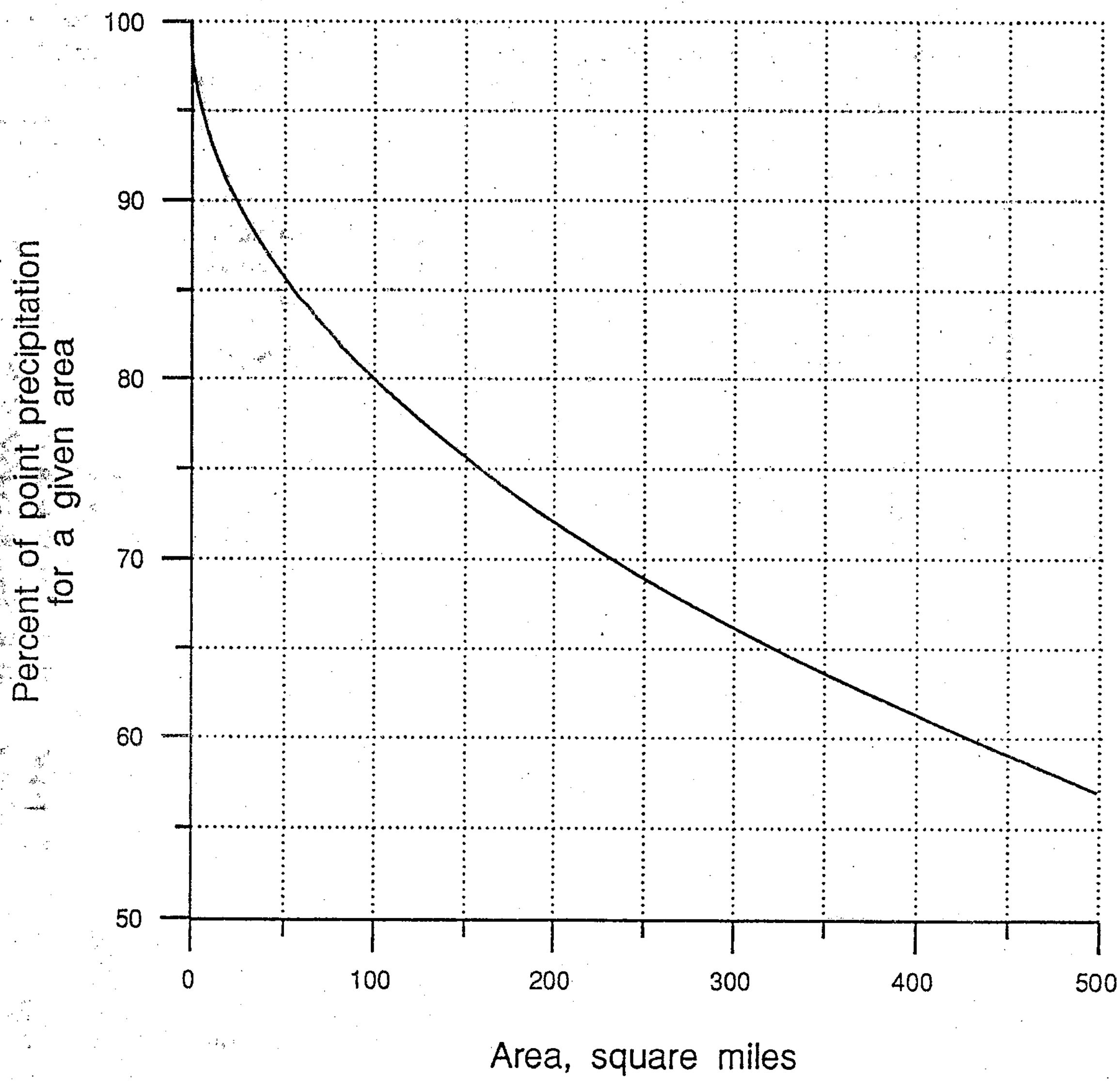


Figure 2.14
Depth-Area Curve for Maricopa County 6-hour Storm

Table 2.2
Depth-Area Reduction Factors
for 6-Hour Duration Rainfall

Area, Square Miles	Ratio to Point of Rainfall
0	1.0
1	0.987
5	0.96
10	0.94
20	0.91
30	0.89
40	0.87
50	0.86
100	0.80
200	0.72
300	0.66
400	0.61
500	0.57

Use the depth-area reduction values from Figure 2.14 or Table 2.2 to correct the 6-hour point rainfall depth from the isopluvial maps (Figures 2.2 through 2.7) for all flood studies in which the 6-hour local storm is the design rainfall criteria (see Table 2.1).

If the flood study is for the design of a retention/detention facility for a small drainage area and the design rainfall criteria is the 100-year, 2-hour storm, then the point rainfall depths from Figure 2.1 are not to be reduced for area. This is because local retention/detention basins will be provided only for very small drainage areas and the point rainfall from Figure 2.1 is representative of the equivalent uniform depth of rainfall over the entire contributing area.

If a general storm is the accepted design rainfall criteria (as opposed to the 6-hour local storm as defined in this manual), then the appropriate depth-area reduction curve will need to be defined to correspond with the rainfall duration and the temporal distribution of the general storm. Usually the general storm for use in Maricopa County is the SCS Type II 24-hour design rainfall. Areal reductions for point rainfall for this 24-hour storm should be performed using Table 2.1a. The data for Table 2.1a have been taken from Figure 15 of the NWS HYDRO-40 (Zehr and Myers, 1984). For other general storms, the depth-area reduction and temporal distribution will need to be performed on a case-by-case basis depending on the purpose of the study, location of the watershed, and other meteorological and hydrological factors.

2.3.1 Procedure for Depth-Area Adjustment

The following procedure is to be used with the 6-hour local storm rainfall depths (Figures 2.2 through 2.7):

1. Determine the size of the drainage area.

2. Calculate the point rainfall depth, or the areally-averaged point rainfall depth, from Figures 2.2 through 2.7 depending on the desired rainfall frequency.

3. Use either Figure 2.14 or Table 2.2 to determine the depth-area reduction factor.

4. Multiply the point rainfall depth by the appropriate depth-area reduction factor. This is the equivalent uniform depth of rainfall that is to be applied to the entire watershed.

2.4 Design Storm Distributions

According to Table 2.1, three types of design storm distributions are to be used in Maricopa County. This Manual contains information for two of those design storm distributions; the 2-hour storm for the design of retention/detention basins, and the 6-hour local storm. Information for the SCS Type II 24-hour storm has been encoded in the MCUHP programs. Otherwise data regarding the SCS 24-hour storm is generally available elsewhere. Distributions for other general storms for larger watersheds will need to be developed on a case-by-case basis based on appropriate meteorologic and hydrologic factors.

2.4.1 2-hour Storm Distribution

The 2-hour storm distribution is to be used for the design of retention/detention basins (see Table 2.1). The 2-hour distribution shown in Figure 2.15 and Table 2.3 is a dimensionless form of the 2-hour hypothetical distribution for the Phoenix Sky Harbor Airport location. This distribution can be applied throughout Maricopa County for the design of retention/detention facilities.

Table 2.3
2-Hour Storm Distribution for Retention Design

Time (minutes)	% Rainfall Depth	Time (minutes)	% Rainfall Depth
0	0.0		
5	1.1	65	60.1
10	1.8	70	74.3
15	2.3	75	86.3
20	2.8	80	90.1
25	3.2	85	93.0
30	4.6	90	95.4
35	7.1	95	96.2
40	10.0	100	97.0
45	13.7	105	97.7
50	17.6	110	98.2
55	23.2	115	99.2
60	32.7	120	100.0

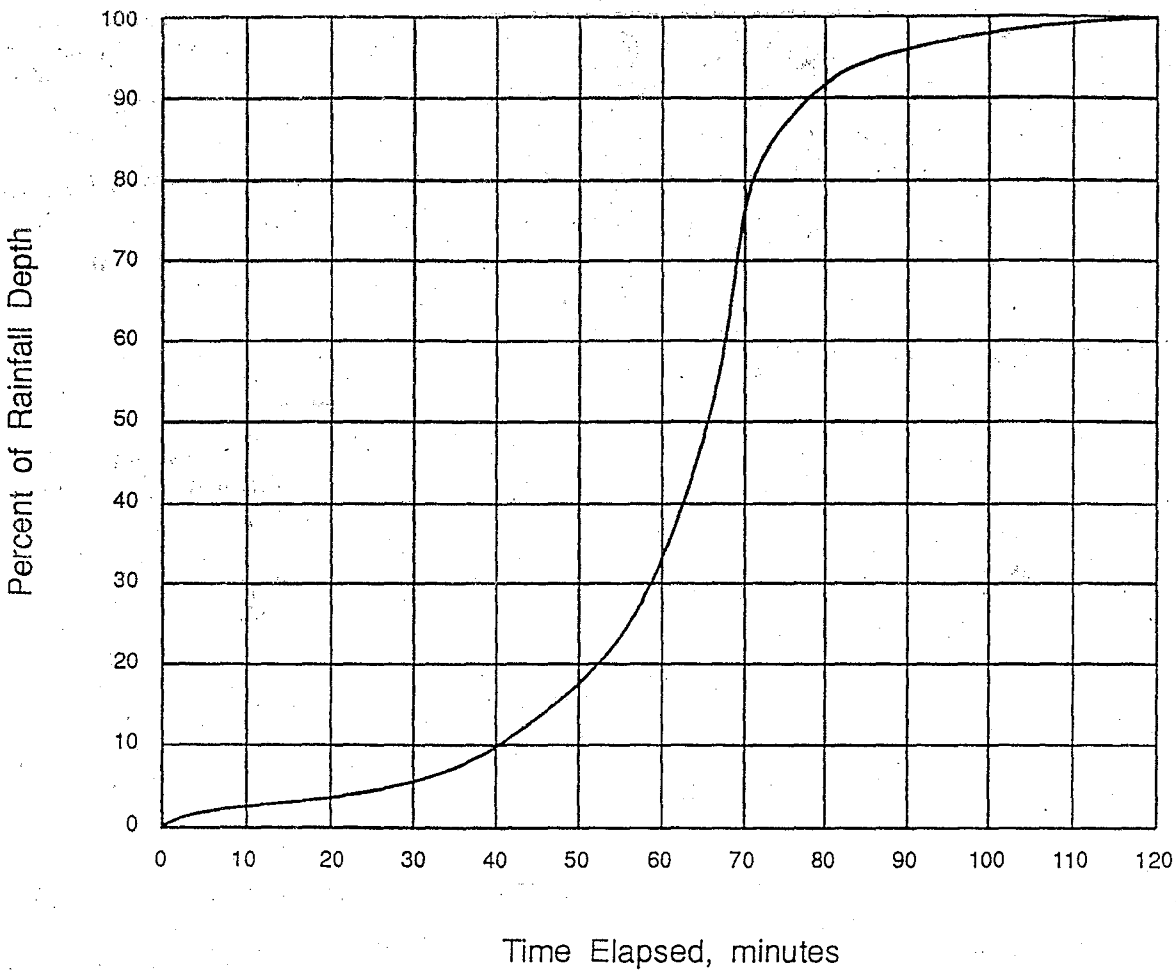


Figure 2.15
2-Hour Mass Curve for Retention Design

2.4.2 6-hour Storm Distribution

The 6-hour storm distributions are used for flood studies in Maricopa County of drainage areas less than 20 square miles, except for on-site retention/detention facilities (see Table 2.1). These distributions would also be used for drainage areas larger than 20 square miles and smaller than 100 square miles by critically centering the storm over all or portions of the drainage area to estimate the peak flood discharges that could be realized on such watersheds due to the occurrence of a local storm over the watershed.

The Maricopa County 6-hour local storm distributions consist of five dimensionless storm patterns. Pattern No. 1 represents the rainfall intensities that can be expected in the "eye" of a local storm. These high, short-duration rainfall intensities would only occur over a relatively small area near the center of the storm cell. Pattern No. 1 is an offset, dimensionless form of the hypothetical distribution derived from rainfall statistics found in *NOAA Atlas for the Western United States, Arizona* (Miller and others, 1973) and Arkell and Richards (1986) for the Phoenix Sky Harbor Airport location. Pattern Numbers 2 through 5 are modifications of the U.S. Army Corps of Engineers (1974) analysis of the Queen Creek storm of 19 August 1954. The dimensionless form of these 6-hour storm distributions are shown in Figure 2.16 and Table 2.4.

Inspection of the storm patterns in Figure 2.16 indicates that the peak rainfall intensities are much greater for Pattern No. 1 than for the other pattern numbers, and that peak rainfall intensity decreases as the pattern number increases. The selection of the pattern number is based on the size of the drainage area under consideration, as shown in Figure 2.17. As illustrated by Figures 2.16 and 2.17, the maximum rainfall intensities, averaged over the entire drainage area, decrease as the size of the drainage area increases. This is to account for the spatial variability of local storm rainfall wherein the maximum rainfall intensities occur at the relatively small eye of the storm but that the *average* rainfall intensities over the storm area decrease as the storm area increases.

Procedure for using the 6-hour Storm Patterns

The following procedure is to be used for 6-hour Local Storm criteria:

1. Determine the size of the drainage area.

2. The equivalent uniform depth of rainfall for the drainage area would be calculated as described in Section 2.3.1.

3. Figure 2.17 is used to select the appropriate pattern number (round to the nearest 0.1 of the pattern number).

4. Use the dimensionless 6-hour distributions of Figure 2.16 or Table 2.4 to calculate the dimensionless distribution by linear interpolation between the two bounding pattern numbers.

5. Multiply the dimensionless values of the calculated storm pattern (in decimal) by the equivalent uniform depth of rainfall from step 2. The resultant distribution is the design rainfall mass diagram for the equivalent uniform depth of rainfall and rainfall intensities averaged over the *entire* drainage area.

As an alternative to the above procedure, the MCUHP1 and the MCUHP2 programs will convert the point rainfall depth into the appropriate storm pattern based on a given drainage area.

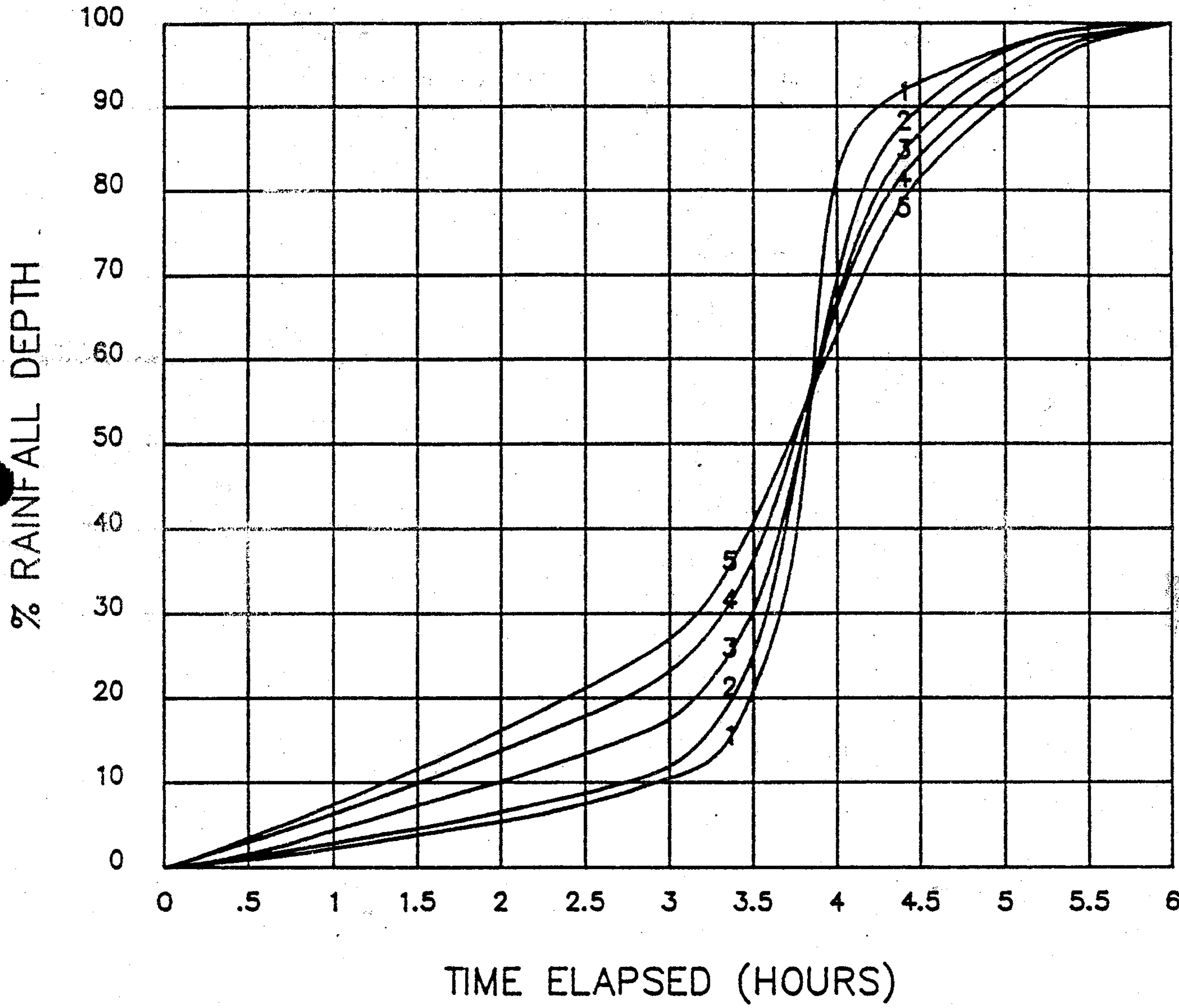


Figure 2.16
6-Hour Mass Curves for Maricopa County

Table 2.4
6-Hour Distributions*

Time (hrs)	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5
0:00	0.0	0.0	0.0	0.0	0.0
0:15	0.8	0.9	1.5	2.1	2.4
0:30	1.6	1.6	2.0	3.5	4.3
0:45	2.5	2.5	3.0	5.1	5.9
1:00	3.3	3.4	4.8	7.1	7.8
1:15	4.1	4.2	6.3	8.7	9.8
1:30	5.0	5.1	7.6	10.5	11.9
1:45	5.8	5.9	9.0	12.5	14.1
2:00	6.6	6.7	10.5	14.3	16.2
2:15	7.4	7.6	11.9	16.0	18.6
2:30	8.7	8.7	13.5	17.9	21.2
2:45	9.9	10.0	15.2	20.1	23.9
3:00	11.8	12.0	17.5	23.2	27.1
3:15	13.8	16.3	22.2	28.1	32.1
3:30	21.6	25.2	30.4	36.4	40.8
3:45	37.7	45.1	47.2	50.0	51.5
4:00	83.4	69.4	67.0	65.8	62.7
4:15	91.1	83.7	79.6	77.3	73.5
4:30	93.1	90.0	86.8	84.1	81.4
4:45	95.0	93.8	91.2	88.8	86.4
5:00	96.2	95.0	94.6	92.7	90.7
5:15	97.2	96.3	96.0	94.5	93.0
5:30	98.3	97.5	97.3	96.4	95.4
5:45	99.1	98.8	98.7	98.2	97.7
6:00	100.0	100.0	100.0	100.0	100.0

*Pattern represents percent Rainfall Depth.

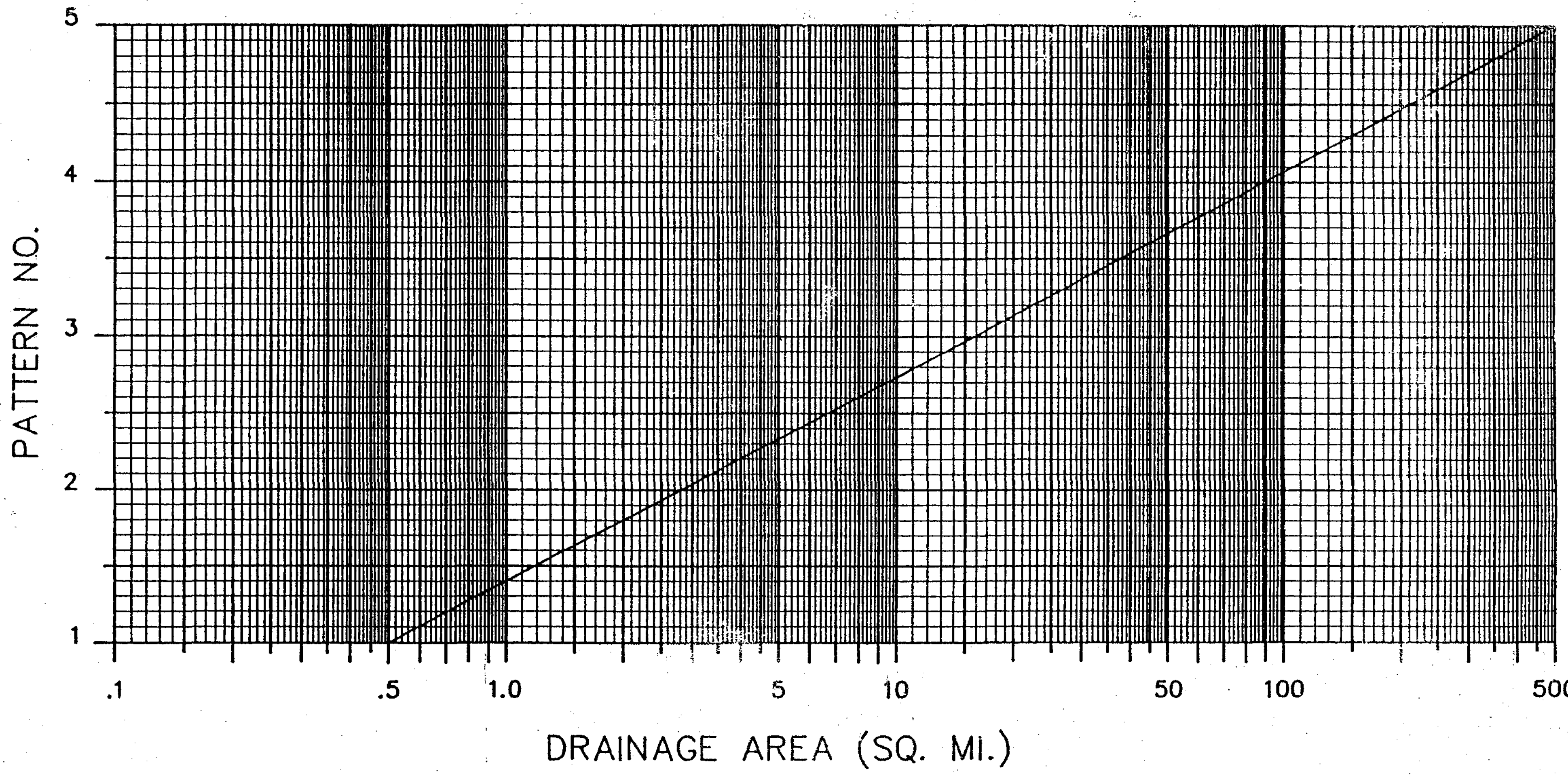


Figure 2.17
Area Versus Pattern Number for Maricopa County

3 Rational Method

3.1 General

The Rational Method was originally developed to estimate runoff from small areas and its use should be generally limited to those conditions. For the purposes of this manual, its use should be limited to areas of up to 160 acres. In such cases, the peak discharge and the volume of runoff from rainfall events up to and including the 100-year, 2-hour duration storm falling within the boundaries of the proposed development are to be retained. If the development involves channel routing, the procedures given in Chapters 4 through 6 should be used, since the peak generated by the Rational Method cannot be directly routed.

3.2 Rational Equation

The Rational Equation relates rainfall intensity, a runoff coefficient and the watershed size to the generated peak discharge. The following shows this relationship:

$$Q = CiA \tag{3.1}$$

where

Q	=	the peak discharge (cfs) from a given area.
C	=	a coefficient relating the runoff to rainfall.
i	=	average rainfall intensity (inches/hour), lasting for a Tc.
Tc	=	the time of concentration (hours).
A	=	drainage area (acres).

The Rational Equation is based on the concept that the application of a steady, uniform rainfall intensity will produce a peak discharge at such a time when all points of the watershed are contributing to the outflow at the point of design. Such a condition is met when the elapsed time is equal to the time of concentration, Tc, which is defined to be the floodwave travel time from the most remote part of the watershed to the point of design. The time of concentration should be computed by applying the following equation developed by Papadakis and Kazan (1987):

$$Tc = 11.4\, L^{0.5} K_b^{0.52} S^{-0.31} i^{-0.38} \tag{3.2}$$

where

Tc	=	time of concentration in hours
L	=	length of the longest flow path in miles
K_b	=	watershed resistance coefficient (see Figure 3.1, or Table 3.1)
S	=	watercourse slope in feet/mile
i	=	rainfall intensity in inches/hour*

*It should be noted that i is the "rainfall excess intensity" as originally developed. However, when used in the Rational Equation, rainfall intensity and rainfall excess intensity provide similar values because of the hydrologic characteristics of small, urban watersheds which result in minimal rainfall loss. This is because of the extent of imperviousness associated with urban watersheds and the fact that the time of concentration is usually very short.

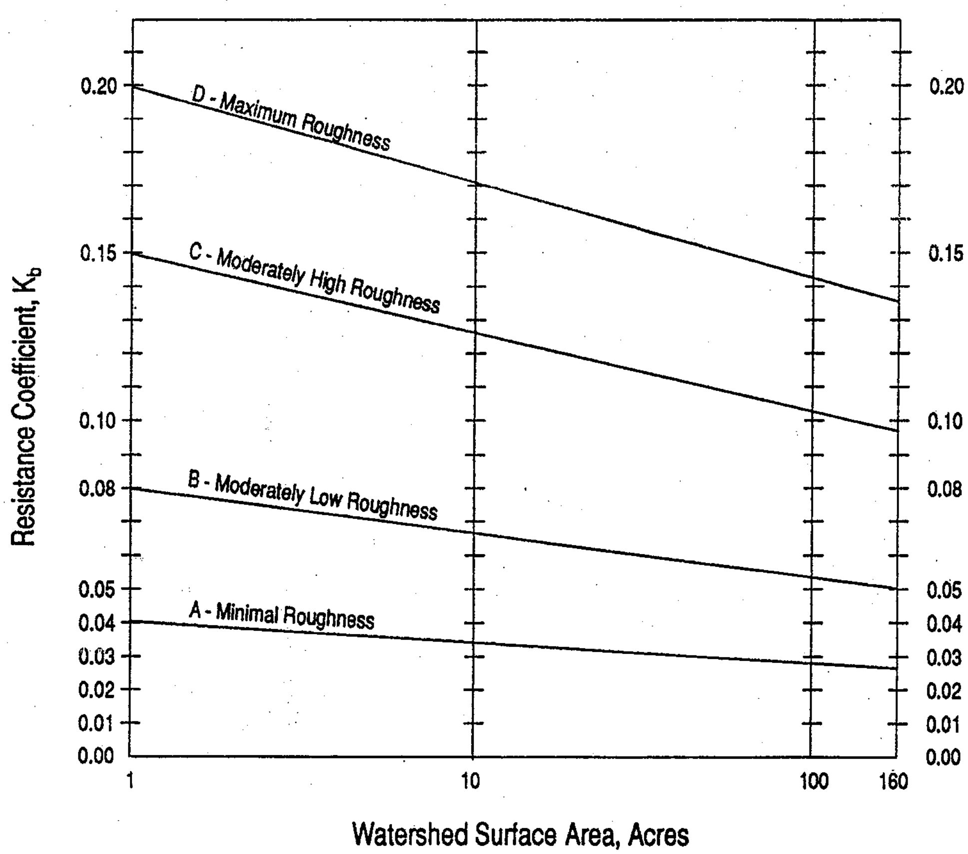


Figure 3.1
Resistance Coefficient K_b as a Function of Watershed Size

Table 3.1
Equation for Estimating K_b in the Tc Equation

$$K_b = m \log A + b$$

Where A is drainage area, in acres

Type	Description	Typical Applications	Equation Parameters m	b
A	Minimal roughness: Relatively smooth and/or well graded and uniform land surfaces. Surface runoff is sheet flow.	Commercial/ industrial areas Residential area Parks and golf courses	–0.00625	0.04
B	Moderately low roughness: Land surfaces have irregularly spaced roughness elements that protrude from the surface but the overall character of the surface is relatively uniform. Surface runoff is predominately sheet flow around the roughness elements.	Agricultural fields Pastures Desert rangelands Undeveloped urban lands	–0.01375	0.08
C	Moderately high roughness: Land surfaces that have significant large- to medium-sized roughness elements and/or poorly graded land surfaces that cause the flow to be diverted around the roughness elements. Surface runoff is sheet flow for short distances draining into meandering drainage paths.	Hillslopes Brushy alluvial fans Hilly rangeland Disturbed land, mining, etc. Forests with underbrush	–0.025	0.15
D	Maximum roughness: Rough land surfaces with torturous flow paths. Surface runoff is concentrated in numerous short flow paths that are often oblique to the main flow direction.	Mountains Some wetlands	–0.030	0.20

3.3 Assumptions

Application of the Rational Equation requires consideration of the following:

1. The peak discharge rate corresponding to a given intensity would occur only if the rainfall duration is at least equal to the time of concentration.

2. The calculated runoff is directly proportional to the rainfall intensity.

3. The frequency of occurrence for the peak discharge is the same as the frequency for the rainfall producing that event.

4. The runoff coefficient increases as storm frequency decreases.

3.4 Limitations

Application of the Rational Method is appropriate for watersheds less than 160 acres in size. This is based on the assumption that the rainfall intensity is to be uniformly distributed over the drainage area at a uniform rate lasting for the duration of the storm. The Maricopa County Unit Hydrograph Procedure described in Chapter 5 may also be used for areas less than 160 acres where hydrograph routing is desired, or, in cases where the Rational Method assumptions do not apply.

3.5 Application

The Rational Method can be used to calculate the generated peak discharge and runoff volume from drainage areas less than 160 acres.

3.5.1 Peak Discharge Calculation

1. Determine the area within the development boundaries.

2. Select the runoff coefficient, C from Table 3.2

3. Calculate time of concentration (see Example 4). This is to be done by an iterative process. Select a duration from the I-D-F curves, Figure 3.2. This value should not be longer than two hours and normally it will be less than an hour. Determine the maximum rainfall intensity indicated on the I-D-F curve for a frequency that includes the 100-year. The intensity value of the corresponding Tc in the above is for the Phoenix Metro area. Use i_p in the following equation for estimating i for other areas:

$$i = i_p \frac{(P^6 10)}{2.07} \tag{3.3}$$

where

i	=	the desired intensity for a given duration and frequency.
ip	=	the intensity for the Phoenix Metro area.
$P^6 10$	=	the 10-year, 6-hour precipitation depth at the point of interest. (Can be read from Figure 2.4.)

4. Use the adjusted intensity in Equation 3.2 to calculate time of concentration. Repeat this process until the selected and computed Tc values are reasonably close. For more details see Example 1.

5. Determine peak discharge (Q) by using the above value of i in Equation 3.1.

6. As an alternative to the above procedure, the computer program RATIONAL.EXE may be used to calculate peak discharges.

Table 3.2
C Coefficients for Use with the Rational Method

Land Use	Return Period			
	2-10 Year	25 Year	50 Year	100 Year
Streets and Roads				
Paved Roads	0.75 – 0.85	0.83 – 0.94	0.90 – 0.95	0.94 – 0.95
Gravel Roadways & Shoulders	0.60 – 0.70	0.66 – 0.77	0.72 – 0.84	0.75 – 0.88
Industrial Areas				
Heavy	0.70 – 0.80	0.77 – 0.88	0.84 – 0.95	0.88 – 0.95
Light	0.60 – 0.70	0.66 – 0.77	0.72 – 0.84	0.75 – 0.88
Business Areas				
Downtown	0.75 – 0.85	0.83 – 0.94	0.90 – 0.95	0.94 – 0.95
Neighborhood	0.55 – 0.65	0.61 – 0.72	0.66 – 0.78	0.69 – 0.81
Residential Areas				
Lawns – Flat	0.10 – 0.25	0.11 – 0.28	0.12 – 0.30	0.13 – 0.31
– Steep	0.25 – 0.40	0.28 – 0.44	0.30 – 0.48	0.31 – 0.50
Suburban	0.30 – 0.40	0.33 – 0.44	0.36 – 0.48	0.38 – 0.50
Single Family	0.45 – 0.55	0.50 – 0.61	0.54 – 0.66	0.56 – 0.69
Multi-Unit	0.50 – 0.60	0.55 – 0.66	0.60 – 0.72	0.63 – 0.75
Apartments	0.60 – 0.70	0.66 – 0.77	0.72 – 0.84	0.75 – 0.88
Parks/Cemetaries	0.10 – 0.25	0.11 – 0.28	0.12 – 0.30	0.13 – 0.31
Playgrounds	0.40 – 0.50	0.44 – 0.55	0.48 – 0.60	0.50 – 0.63
Agricultural Areas	0.10 – 0.20	0.11 – 0.22	0.12 – 0.24	0.13 – 0.25
Bare Ground	0.20 – 0.30	0.22 – 0.33	0.24 – 0.36	0.25 – 0.38
Undeveloped Desert	0.30 – 0.40	0.33 – 0.44	0.36 – 0.48	0.38 – 0.50
Mountain Terrain (Slopes > 10%)	0.60 – 0.80	0.66 – 0.88	0.72 – 0.95	0.75 – 0.95

Note: Values of C for 25, 50 and 100 Year were derived using frequency adjustment factors of 1.10, 1.20, and 1.25, respectively, with an upper limit of 0.95 for C for the 2-10 Year values.

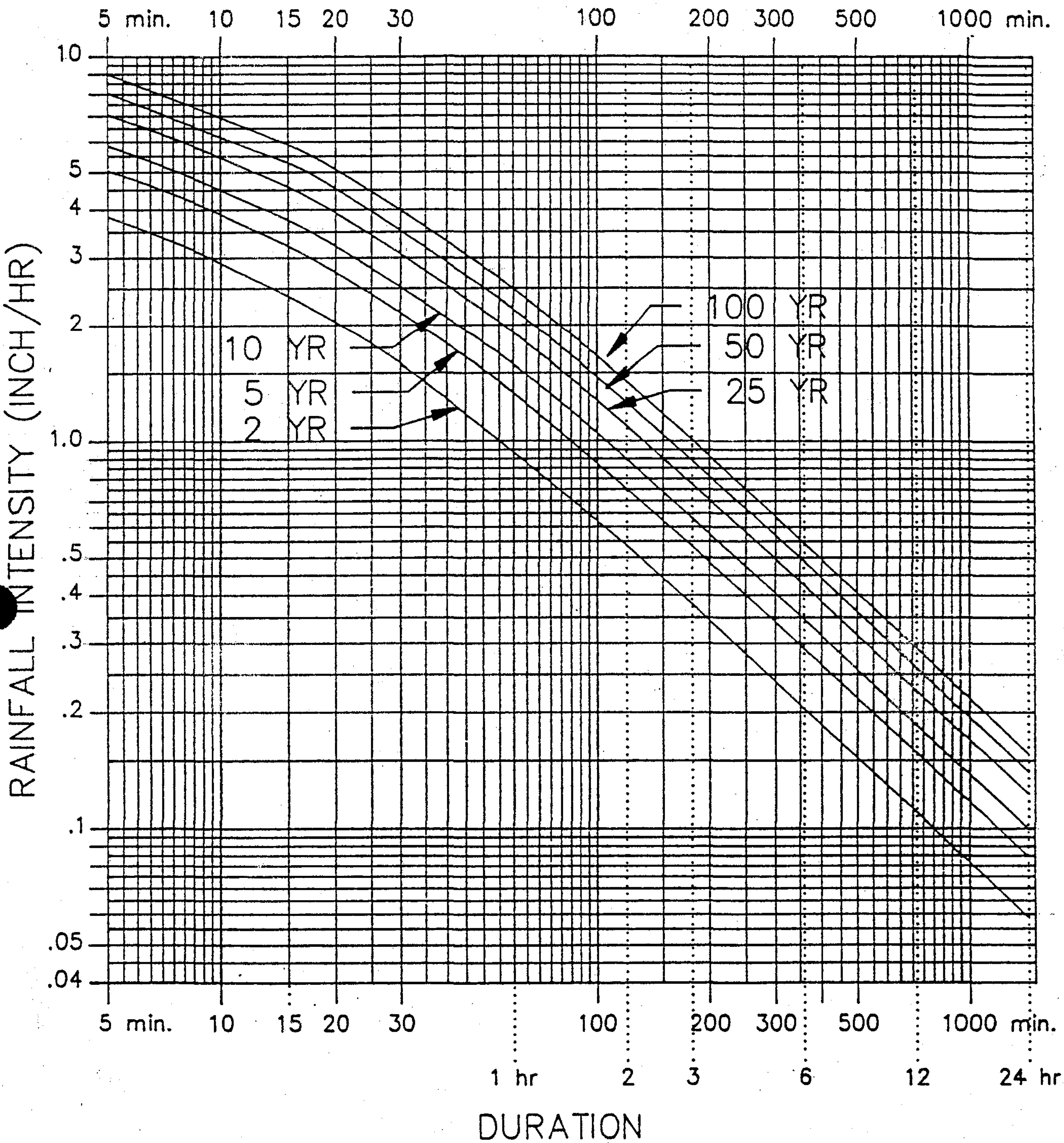
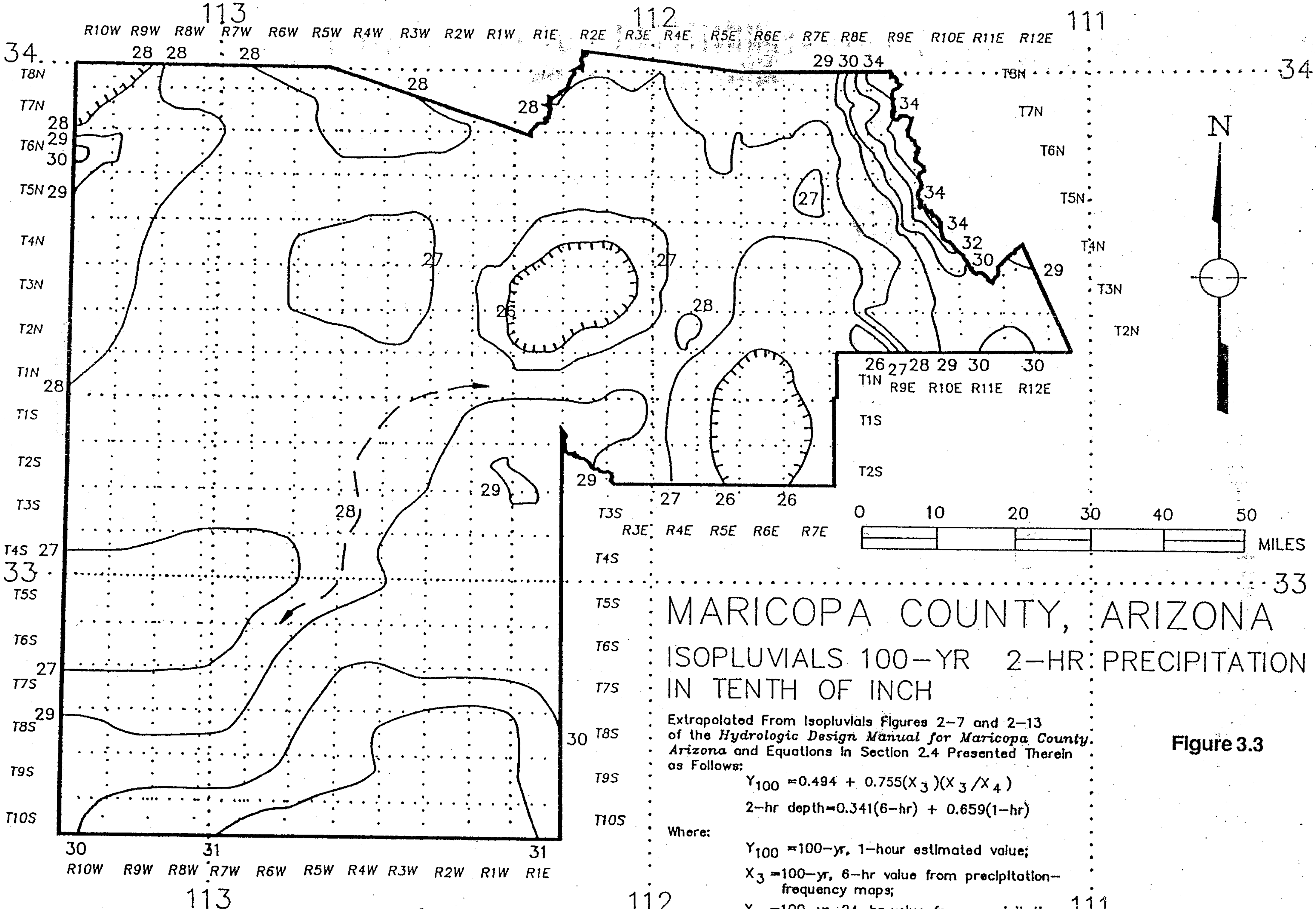


Figure 3.2
Rainfall Intensity-Duration-Frequency Relation
(Phoenix Metro Area)



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 100-YR 2-HR PRECIPITATION IN TENTH OF INCH

Extrapolated From Isopluvials Figures 2-7 and 2-13 of the *Hydrologic Design Manual for Maricopa County, Arizona* and Equations in Section 2.4 Presented Therein as Follows:

$$Y_{100} = 0.494 + 0.755(X_3)(X_3/X_4)$$

$$\text{2-hr depth} = 0.341(\text{6-hr}) + 0.659(\text{1-hr})$$

Where:

Y_{100} = 100-yr, 1-hour estimated value;

X_3 = 100-yr, 6-hr value from precipitation-frequency maps;

X_4 = 100-yr, 24-hr value from precipitation-frequency maps;

6-hr = isopluvial values from figure 2.7;

1-hr = Y_{100} value as computed above.

Figure 3.3

3.5.2 Volume Calculations

Volume calculation should be done by applying the following equation:

$$V = C\left(\frac{P}{12}\right)A \qquad (3.4)$$

where

V	=	Calculated volume in acre-feet
C	=	Runoff coefficient from Table 3.2
P	=	Rainfall depth in inches
A	=	Drainage area in acres

In the case of volume calculations for retention/detention design, P equals the 100-year, 2-hour depth, in inches, from Section 2.2 or Figure 3.3.

4

Rainfall Losses

4.1 General

Rainfall excess is that portion of the total rainfall depth that drains directly from the land surface by overland flow. By a mass balance, rainfall excess plus rainfall loss equals precipitation. When performing a flood analysis using a rainfall-runoff model, the determination of rainfall excess is of utmost importance. Rainfall excess integrated over the entire watershed results in runoff volume, and the temporal distribution of the rainfall excess will, along with the hydraulics of runoff, determine the peak discharge. Therefore, the estimation of the magnitude and time distribution of rainfall losses should be performed with the best practical technology, considering the objective of the analysis, economics of the project, and consequences of inaccurate estimates.

Rainfall losses are generally considered to be the result of evaporation of water from the land surface, interception of rainfall by vegetal cover, depression storage on the land surface (paved or unpaved), and infiltration of water into the soil matrix. A schematic representation of rainfall losses for a uniform intensity rainfall is shown in Figure 4.1. As shown in the figure, evaporation can start at an initially high rate depending on the land surface temperature, but the rate decreases very rapidly and would eventually reach a low, steady-state rate. From a practical standpoint, the magnitude of rainfall loss that can be realized from evaporation during a storm of sufficient magnitude to cause flood runoff is negligible.

Interception, also illustrated in Figure 4.1, varies depending upon the type of vegetation, maturity, and extent of canopy cover. Experimental data on interception have been collected by numerous investigators (Linsley and others, 1982), but little is known of the interception values for most hydrologic problems. Estimates of interception for various vegetation types (Linsley and others, 1982) are:

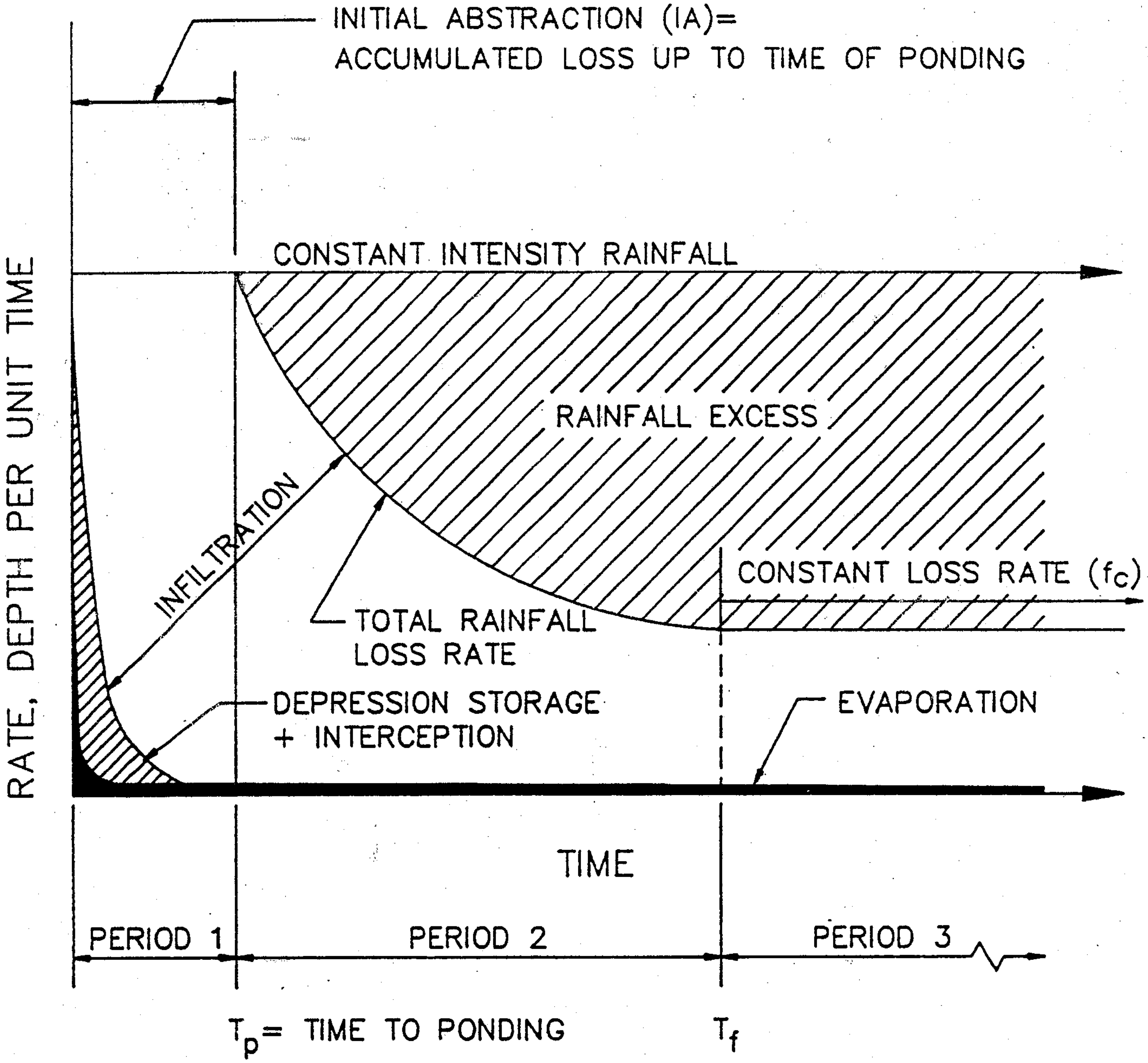


Figure 4.1
Schematic Representation of Rainfall Losses for a Uniform Intensity Rainfall

Vegetation Type	Interception, Inches
hardwood tree	0.09
cotton	0.33
alfalfa	0.11
meadow grass	0.08

No interception estimates are known for natural vegetation that occurs in Maricopa County. For most applications in Maricopa County the magnitude of interception losses is essentially 0.0, and for practical purposes interception is not considered for flood hydrology in Maricopa County.

Depression storage and infiltration losses comprise the majority of the rainfall loss as illustrated in Figure 4.1. The estimates of these two losses will be discussed in more detail in later sections of this manual.

Three periods of rainfall losses are illustrated in Figure 4.1, and these must be understood and their implications appreciated before applying the procedures in this manual. First, there is a period of initial loss when no rainfall excess (runoff) is produced. During this initial period, the losses are a function of the depression storage, interception, and evaporation rates plus the initially high infiltration capacity of the soil. The accumulated rainfall loss during this period with no runoff is called the *initial abstraction.* The end of this initial period is noted by the onset of ponded water on the surface, and the time from start of rainfall to this time is the *time of ponding* (Tp). It is important to note that losses during this first period are a summation of losses due to all mechanisms including infiltration.

The second period is marked by a declining infiltration rate and generally very little losses due to other factors.

The third, and final, period occurs for rainfalls of sufficient duration for the infiltration rate to reach the *steady-state, equilibrium rate of the soil* (fc). The only appreciable loss during the final period is due to infiltration.

The actual loss process is quite complex and there is a good deal of interdependence of the loss mechanisms on each other and on the rainfall itself. Therefore, simplifying assumptions are usually made in the modeling of rainfall losses. Figure 4.2 represents a simplified set of assumptions that can be made. In Figure 4.2, it is assumed that surface retention loss is the summation of all losses other than those due to infiltration, and that this loss occurs from the start of rainfall and ends when the accumulated rainfall equals the magnitude of the capacity of the surface retention loss. It is assumed that infiltration does not occur during this time. After the surface retention is satisfied, infiltration begins. If the infiltration capacity exceeds the rainfall intensity, then no rainfall excess is produced. As the infiltration capacity decreases, it may eventually equal the rainfall intensity. This would occur at the time of ponding (Tp) which signals the beginning of surface runoff. As illustrated in both Figures 4.1 and 4.2, after the time of ponding the infiltration rate decreases exponentially and may reach a steady-state, equilibrium rate (fc). It is these simplified assumptions and processes, as illustrated in Figure 4.2, that are to be modeled by the procedures in this manual.

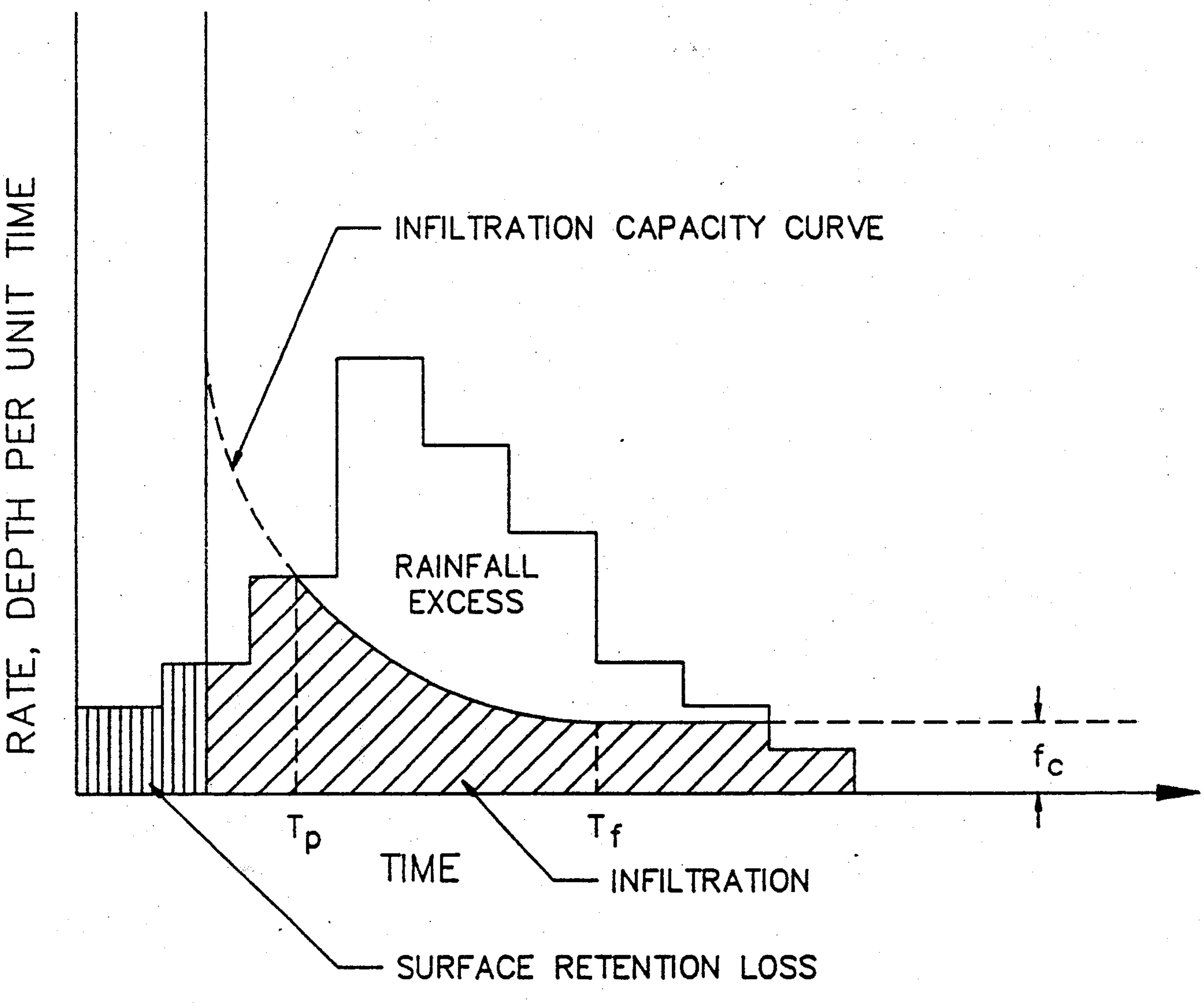


Figure 4.2
Simplified Representation of Rainfall Losses
A Function of Surface Retention Losses Plus Infiltration

4.2 Surface Retention Loss

Surface retention loss, as used herein, is the summation of all rainfall losses other than infiltration. The major component of surface retention loss is depression storage; relatively minor components of surface retention loss are due to interception and evaporation, as previously discussed. Depression storage is considered to occur in two forms. First, in-place depression storage occurs at, and in the near vicinity of, the raindrop impact. The mechanism for this depression storage is the microrelief of the soil and soil cover. The second form of depression storage is the retention of surface runoff that occurs away from the point of raindrop impact in surface depressions such as puddles, roadway gutters and swales, roofs, irrigation bordered fields and lawns, and so forth.

A relatively minor contribution by interception is also considered as a part of the total surface retention loss. Estimates of surface retention loss are difficult to obtain and are a function of the physiography and land-use of the area.

The surface retention loss on impervious surfaces has been estimated to be in the range 0.0625 inch to 0.125 inch by Tholin and Keefer (1960), 0.11 inch for 1 percent slope to 0.06 inch for 2.5 percent slopes by Viessman (1967), and 0.04 inch based on rainfall-runoff data for an urban watershed in Albuquerque by Sabol (1983). Hicks (1944) provides estimates of surface retention losses during intense storms as 0.20 inch for sand, 0.15 inch for loam, and 0.10 inch for clay. Tholin and Keefer (1960) estimated the surface retention loss for turf to be between 0.25 to 0.50 inch. Based on rainfall simulator studies on undeveloped alluvial plains in the Albuquerque area, the surface retention loss was estimated as 0.1 to 0.2 inch (Sabol and others, 1982a). Rainfall simulator studies in New Mexico result in estimates of 0.39 inch for eastern plains rangelands and 0.09 inch for pinon-juniper hillslopes (Sabol and others, 1982b). Surface retention losses for various land-uses and surface cover conditions in Maricopa County have been extrapolated from these reported estimates and these are shown in Table 4.1.

Table 4.1
Surface Retention Loss for Various Land Surfaces in Maricopa County

Land-use and/or Surface Cover (1)	Surface Retention Loss IA, Inches (2)
Natural	
Desert and rangeland, flat slope	0.35
Hillslopes, Sonoran Desert	0.15
Mountain, with vegetated surface	0.25
Developed (Residential and Commercial)	
Lawn and turf	0.20
Desert landscape	0.10
Pavement	0.05
Agricultural	
Tilled fields and irrigated pasture	0.50

4.3 Infiltration

Infiltration is the movement of water from the land surface into the soil. Gravity and capillary forces drawing water into and through the pore spaces of the soil matrix are the two forces that drive infiltration. Infiltration is controlled by soil properties, by vegetation influences on the soil structure, by surface cover of rock and vegetation, and by tillage practices. The distinction between infiltration and percolation is that percolation is the movement of water through the soil *subsequent to* infiltration.

Infiltration can be controlled by percolation if the soil does not have a sustained drainage capacity to provide access for more infiltrated water. However, before percolation can be assumed to restrict infiltration for the design rainfalls being considered in Maricopa County, the extent by which percolation can restrict infiltration of rainfall should be carefully evaluated. SCS soil scientists have defined hydrologic soil group D as:

> "Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material."

This definition indicates that hydrologic soil groups A, B, or C could be classified as D if a near impervious strata of clay, caliche, or rock is beneath them. When these soils are considered in regard to long-duration rainfalls (the design events for many parts of the United States) this definition may be valid. However, when considered for short-duration and relatively small design rainfall depths in Maricopa County, this definition could result in underestimation of the rainfall losses. This is because even a relatively shallow horizon of soil overlaying an impervious layer still has the ability to store a significant amount of infiltrated rainfall.

For example, consider the situation where only 4 inches of soil covers an impervious layer. If the effective porosity is 0.30, then 1.2 inches (4 inches x 0.30) of water can be infiltrated and stored in the shallow soil horizon. For design rainfalls in Maricopa County, this represents a significant storage volume for infiltrated rainfall and so when developing loss rate parameters for areas of Maricopa County that contain significant areas classified as hydrologic soil group D, the reason for that classification should be determined.

Hydrologic soil group D should be retained only for:

- » clay soils,
- » soils with a permanent high water table, and
- » rock outcrop.

Hydrologic soil group D should probably *not* be retained in all situations where the classification is based on shallow soils over nearly impervious layers; site specific studies and sensitivity analyses should be performed to estimate the loss rates to be used for such soils.

4.4 Recommended Methods for Estimating Rainfall Losses

Many methods have been developed for estimating rainfall losses; five are listed as options in the HEC-1 Flood Hydrology Package. They are:

1. Holtan Infiltration Equation
2. Exponential Loss Rate
3. SCS Curve Numbers (CN) Loss Rate
4. Green and Ampt Infiltration Equation
5. Initial Loss Plus Uniform Loss Rate (IL+ULR)

Of these five, however, only two—Green and Ampt and IL+ULR—are recommended for estimating rainfall losses in Maricopa County for the reasons discussed below.

The **Holtan Infiltration Equation** is an exponential decay type of equation for which the rainfall loss rate asymptotically diminishes to the minimum infiltration rate (fc). The Holtan equation is not extensively used and there is no known application of this method in Arizona. Data and procedures to estimate the parameters for use in Maricopa County are not available. Therefore, the Holtan equation is not recommended for general use in Maricopa County.

The **Exponential Loss Rate Method** is a four parameter method that is not extensively used, but it is a method preferred by of the U.S. Army Corps of Engineers. Data and procedures are not available to estimate the parameters for this method for all physiographic regions in Maricopa County, but Exponential loss rate parameters have been developed from the reconstitution of flood events for a flood hydrology study in a portion of Maricopa County (U.S. Army Corps of Engineers, 1982a). However, adequate data are not available to estimate the necessary parameters for all soil types and land uses in Maricopa County, and this method is not recommended for general use in Maricopa County.

The **SCS CN** method is the most extensively used rainfall loss rate method in Maricopa County and Arizona and it has wide acceptance among many agencies, consulting engineering firms, and individuals throughout the community. However, because of both theoretical concerns and practical limitations, the SCS CN method is not recommended for general use in Maricopa County.

As mentioned previously, the two recommended methods for estimating rainfall losses in Maricopa County are the Green and Ampt infiltration equation and the initial loss and uniform loss rate (IL+ULR) method. Both methods, as programmed into HEC-1, can be used to simulate the rainfall loss model as depicted in Figure 4.2. (For a full discussion of these methods, see Sections 4.4.1 and 4.4.2.) The IL+ULR is a simplified model that has been used extensively for flood hydrology and data often are available to estimate the two parameters for this method. The Green and Ampt infiltration equation is a physically based model that has been in existence since 1911, and has recently been incorporated as an option in HEC-1.

The preferred method, and the most theoretically accurate, is the Green and Ampt infiltration equation. This method should be used for most studies in Maricopa County where the land surface is soil, the infiltration of water is controlled by soil texture (see Appendix D), and the bulk density of the soil is affected by vegetation. Procedures were developed, and are presented, to estimate the three parameters of the Green and Ampt infiltration equation. The alternative method of IL+ULR can be used in situations where the Green and Ampt infiltration method is recommended, but its use in those situations is not encouraged, and, in general, should be avoided. Rather, the IL+ULR method should be used in situations where the Green and Ampt infiltration equation with parameters based on soil texture is not appropriate. Examples of situations where the IL+ULR method *is* recommended are: large areas of rock outcrop, talus slopes, forests underlain with a thick mantle of duff, land surfaces of volcanic cinder, and surfaces that are predominantly sand and gravel. Because of the diversity of conditions that could exist for which the IL+ULR method is to be used, it is not possible to provide extensive guidance for the selection of the two parameters of the IL+ULR method.

Other methods should be used only if there is technical justification for a variance from these recommendations and if adequate information is available to estimate the necessary parameters. Use of rainfall loss methods other than those recommended should not be undertaken unless previously approved by the Flood Control District and the local regulatory agency.

4.4.1 Green and Ampt Infiltration Equation

This model, first developed in 1911 by W.H. Green and G.A. Ampt, has since the early 1970s, received increased interest for estimating rainfall infiltration losses. The model has the form:

$$f = K_S\left(1 + \frac{\psi\theta}{F}\right) \quad \text{for } f < i \qquad (4.1)$$

$$f = i \quad \text{for } f \geq i$$

where

f	=	infiltration rate (L/T),
i	=	rainfall intensity (L/T),
K_S	=	hydraulic conductivity, wetted zone, steady-state rate (L/T)
Ψ	=	average capillary suction in the wetted zone (L),

θ	=	soil moisture deficit (dimensionless), equal to effective soil porosity times the difference in final and initial volumetric soil saturations, and
F	=	depth of rainfall that has infiltrated into the soil since the beginning of rainfall (L).

A sound and concise explanation of the Green and Ampt equation is provided by Bedient and Huber (1988).

It is important to note that as rain continues, F increases and f approaches K_S, and therefore, f is inversely related to time. Equation 4.1 is implicit with respect to f which causes computational difficulties. Eggert (1976) simplified Equation 4.1 by expanding the equation in a power series and truncating all but the first two terms of the expansion. The simplified solution (Li and others, 1976) is:

$$F = -0.5\,(2F - K_S\,\Delta t) + 0.5\,[(2F - K_S\,\Delta t)^2 + 8K_S\Delta t\,(\theta\psi + F)]^{1/2} \tag{4.2}$$

where

Δt	=	the computation interval
F	=	accumulated depth of infiltration at the start of Δt.

The average infiltration rate is:

$$f = \frac{\Delta F}{\Delta t} \tag{4.3}$$

Use of the Green and Ampt equation as coded in HEC-1 involves the simulation of rainfall loss as a two phase process, as illustrated in Figure 4.2. The first phase is the simulation of the surface retention loss as previously described; this loss is called the initial loss (IA) in HEC-1. During this first phase, all rainfall is lost (zero rainfall excess generated) during the period from the start of rainfall up to the time that the accumulated rainfall equals the value of IA. It is assumed, for modeling purposes, that no infiltration of rainfall occurs during this first phase. Initial loss (IA) is primarily a function of land-use and surface cover, and recommended values of IA for use with the Green and Ampt equation are presented in Table 4.1. For example, about 0.35 inches of rainfall will be lost to runoff due to surface retention for desert and rangelands on relatively flat slopes in Maricopa County.

The second phase of the rainfall loss process is the infiltration of rainfall into the soil matrix. For modeling purposes, the infiltration begins immediately after the surface retention loss (IA) is completely satisfied, as illustrated in Figure 4.2. The three Green and Ampt equation infiltration parameters as coded in HEC-1 are:

» hydraulic conductivity at natural saturation (XKSAT) equal to K_S in Equation 4.1;

» wetting front capillary suction (PSIF) equal to Ψ in Equation 4.1; and

» volumetric soil moisture deficit at the start of rainfall (DTHETA) equal to θ in Equation 4.1.

The three infiltration parameters are functions of soil characteristics, ground surface characteristics, and land management practices. The soil characteristics of interest are particle size distribution (soil texture), organic matter, and bulk density. The primary soil surface characteristics are vegetation canopy cover, ground cover, and soil crusting. The land management practices are identified as various tillages as they result in changes to soil porosity.

Values of Green and Ampt equation parameters as a function of soil characteristics alone (bare ground condition) have been obtained from published reports (Rawls and others, 1983; Rawls and Brakensiek, 1983), and average values of XKSAT and PSIF for each of the soil texture classes are shown in Columns (2) and (3) of Table 4.2. The values of XKSAT and PSIF from Table 4.2 or Figure 4.3 should be used if general soil texture classification of the drainage area is available. References used to create Table 4.2 can be found in the Documentation Manual.

In Table 4.2, loamy sand and sand are combined. The parameter values that are shown in the table are for loamy sand. The hydraulic conductivity (XKSAT) for sand is often used as 4.6 inches/hour, and the capillary suction (PSIF) is often used as 1.9 inches. Using those parameter values for drainage areas can result in the generation of no rainfall excess—which may or may not be correct. Incorrect results could cause serious consequences for flood control planning and design. Therefore, it is recommended that—for watersheds consisting of relatively small subareas of sand—the Green and Ampt parameter values for loamy sand be used for the sand portion of the watershed. If the area contains a large portion of sand, then either the Green and

Table 4.2
Green and Ampt Loss Rate Parameter Values for Bare Ground

Soil Texture Classification (1)	XKSAT Inches/hour (2)	PSIF Inches (3)	DTHETA[1]		
			Dry (4)	Normal (5)	Saturated (6)
loamy sand & sand	1.2	2.4	0.35	0.30	0
sandy loam	0.40	4.3	0.35	0.25	0
loam	0.25	3.5	0.35	0.25	0
silty loam	0.15	6.6	0.40	0.25	0
silt	0.10	7.5	0.35	0.15	0
sandy clay loam	0.06	8.6	0.25	0.15	0
clay loam	0.04	8.2	0.25	0.15	0
silty clay loam	0.04	10.8	0.30	0.15	0
sandy clay	0.02	9.4	0.20	0.10	0
silty clay	0.02	11.5	0.20	0.10	0
clay	0.01	12.4	0.15	0.05	0

[1] Selection of DTHETA:
Dry = Nonirrigated lands, such as desert and rangeland;
Normal = Irrigated lawn, turf, and permanent pasture;
Saturated = Irrigated agricultural land.

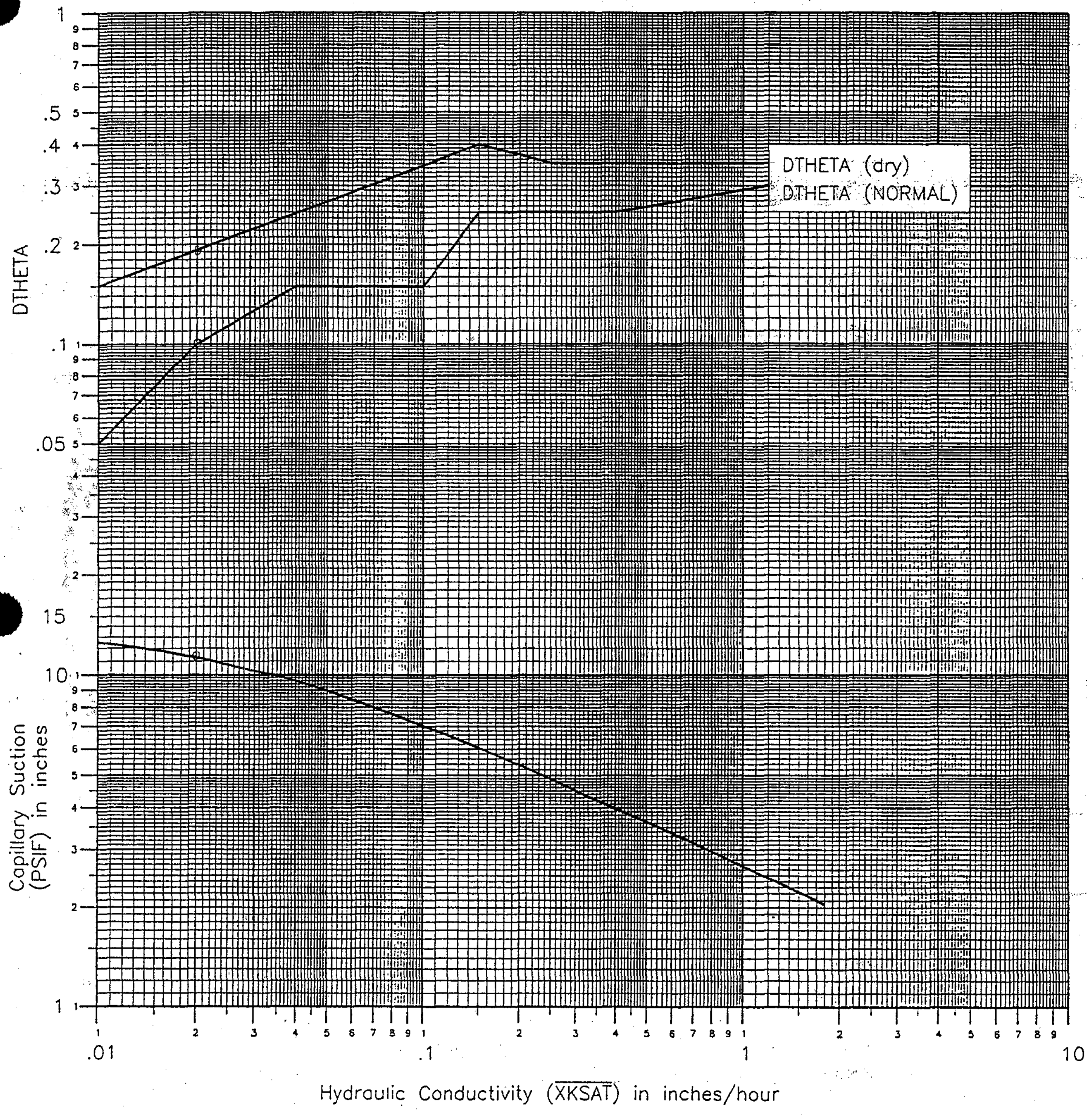


Figure 4.3
Composite Values of PSIF and DTHETA as a function of XKSAT
(To be used for area-weighted averaging of Green and Ampt parameters.)

Ampt method should be used with parameter values for loamy sand or the IL+ULR method should be used with appropriately determined values for the parameters.

The soil moisture deficit (DTHETA) is a volumetric measure of the soil moisture storage capacity that is available at the start of the rainfall. DTHETA is a function of the effective porosity of the soil. The range of DTHETA is 0.0 to the effective porosity. If the soil is effectively saturated at the start of rainfall then DTHETA equals 0.0; if the soil is devoid of moisture at the start of rainfall then DTHETA equals the effective porosity of the soil.

Under natural conditions, soil seldom reaches a state of soil moisture less than the wilting point of vegetation. Due to the rapid drainage capacity of most soils in Maricopa County, at the start of a design storm the soil would not be expected to be in a state of soil moisture greater than the field capacity.

However, Maricopa County also has a large segment of its land area under irrigated agriculture, and it is reasonable to assume that the design frequency storm could occur during or shortly after certain lands have been irrigated. Therefore, it would be reasonable to assume that soil moisture for irrigated lands could be at or near effective saturation during the start of the design rainfall.

Three conditions for DTHETA have been defined for use in Maricopa County based on the antecedent soil moisture condition that could be expected to exist at the start of the design rainfall. These three conditions are:

» "Dry" for antecedent soil moisture near the vegetation wilting point;

» "Normal" for antecedent soil moisture condition near field capacity due to previous rainfall or irrigation applications on nonagricultural lands; and

» "Saturated" for antecedent soil moisture near effective saturation due to recent irrigation of agricultural lands.

Values of DTHETA have been estimated by subtracting the initial volumetric soil moisture for each of the three conditions from the soil porosity.

The value of DTHETA "Saturated" is always equal to 0.0 because for this condition there is no available pore space in the soil matrix at the start of rainfall. Values of DTHETA for the three antecedent soil moisture conditions are shown in Table 4.2. DTHETA "Dry" should be used for soil that is usually in a state of low soil moisture such as would occur in the desert and rangelands of Maricopa County. DTHETA "Normal" should be used for soil that is usually in a state of moderate soil moisture such as would occur in irrigated lawns, golf courses, parks, and irrigated pastures. DTHETA "Saturated" should be used for soil that can be expected to be in a state of high soil moisture such as irrigated agricultural land.

4.4.1.1 Procedure for Areally Averaging Green and Ampt Parameter Values: Most drainage areas or modeling subbasins will be composed of several subareas containing soils of different textures. Therefore, a composite value for the Green and Ampt parameters that are to be applied to the drainage areas or modeling subbasins needs to be determined. The procedure for determining the composite value is to average the area-weighted logarithms of the XKSAT values and to select the PSIF and DTHETA values from a graph.

The composite XKSAT is calculated by Equation 4.4:

$$\overline{XKSAT} = ALOG\left(\frac{\Sigma A_i \log XKSAT_i}{A_T}\right) \qquad (4.4)$$

where

$\overline{XKSAT}$ = composite subarea hydraulic conductivity, inches/hour

$XKSAT_i$ = hydraulic conductivity of a map unit, inches/hour (from Appendix A, B, or C)

A_i = size of subarea

A_T = size of the watershed or modeling subbasin

After $\overline{XKSAT}$ is calculated, the values of PSIF and DTHETA (normal or dry) are selected from Figure 4.3, at the corresponding value of $\overline{XKSAT}$.

4.4.1.2 Procedure for Adjusting XKSAT for Vegetation Cover: The hydraulic conductivity (XKSAT) can be affected by several factors besides soil texture. For example, hydraulic conductivity is reduced by soil crusting, increased by tillage, and increased by the influence of ground cover and canopy cover. The values of XKSAT that are presented for bare ground as a function of soil texture alone should be adjusted under certain soil cover conditions.

Ground cover, such as grass, litter, and gravel, will generally increase the infiltration rate over that of bare ground conditions. Similarly, canopy cover—such as from trees, brush, and tall grasses—can also increase the bare ground infiltration rate. The procedures and data that are presented are for estimating the Green and Ampt parameters based solely on soil texture and would be applicable for bare ground conditions. Past research has shown that the wetting front capillary suction parameter (PSIF) is relatively insensitive in comparison with the hydraulic conductivity parameter (XKSAT); therefore only the hydraulic conductivity parameter is adjusted for the influences of cover over bare ground.

Procedures have been developed (Rawls and others, 1989) for incorporating the effects of soil crusting, ground cover, and canopy cover into the estimation of hydraulic conductivity for the Green and Ampt equation; however, those procedures are not recommended for use in Maricopa County at this time. A simplified procedure to adjust the bare ground hydraulic conductivity for vegetation cover is shown in Figure 4.4. This figure is based on the documented increase in hydraulic conductivity due to various soil covers as reported by investigators using rainfall simulators on native western rangelands (Kincaid and others, 1964; Sabol and others, 1982a; Sabol and others, 1982b; Bach, 1984; Ward, 1986; Lane and others, 1987; Ward and Bolin, 1989). This correction factor can be used based on an estimate of vegetation cover as used by the Soil Conservation Service in soil surveys; that is, vegetation cover is evaluated on basal area for grasses and forbs, and is evaluated

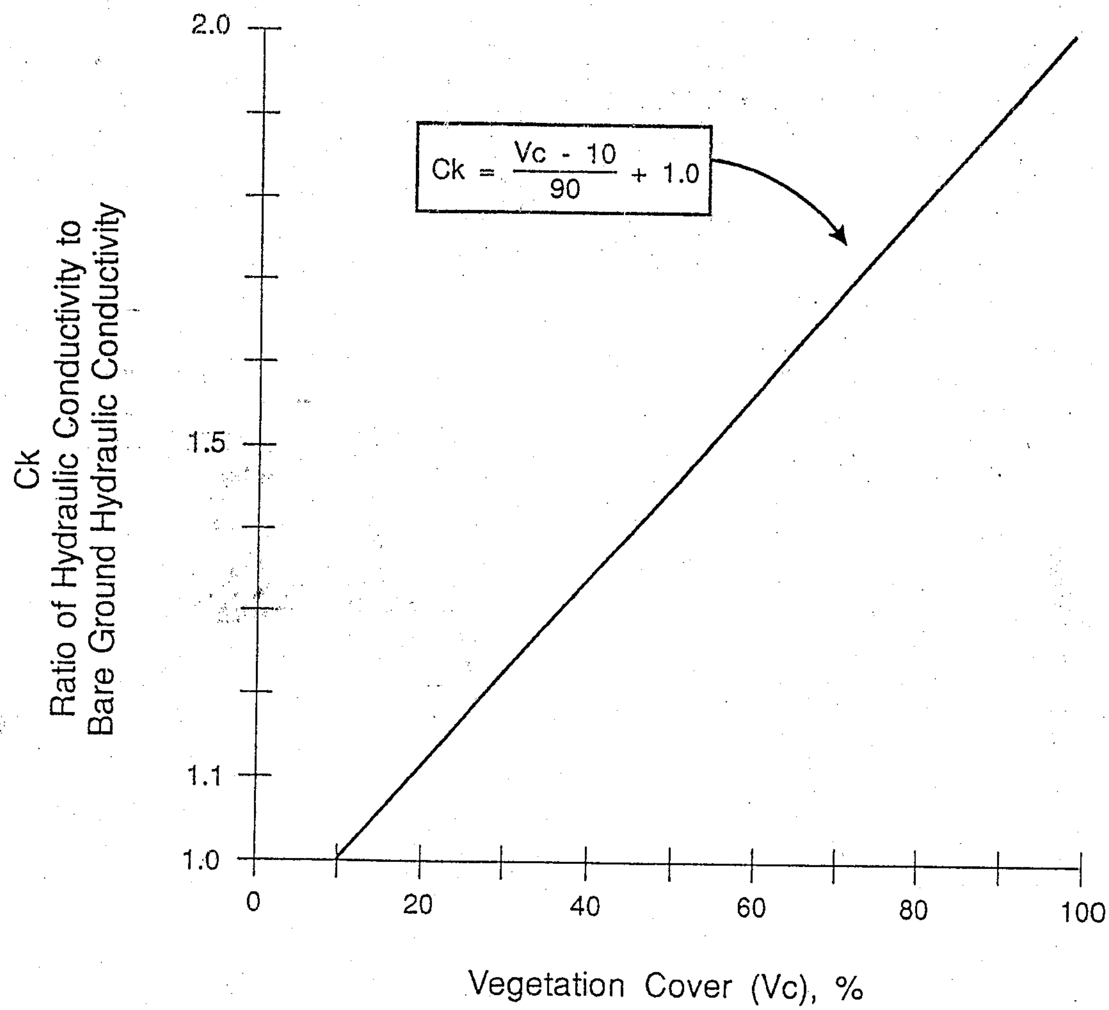


Figure 4.4
Effect of Vegetation Cover on Hydraulic Conductivity
For Hydraulic Soil Groups B, C, and D, and for all Soil Textures
***other than* Sand and Loamy Sand**

on canopy cover for trees and shrubs. Note that this correction can be applied only to soils other than sand and loamy sand.

The influence of tillage results in a change in total porosity and therefore a need to modify the three Green Ampt equation infiltration parameters. The effect of tillage systems on soil porosity and the corresponding changes to hydraulic conductivity, wetting front capillary suction, and water retention is available (Rawls and Brakensiek, 1983). Although this information is available, it is not presented in this manual, nor is it recommended that these adjustments be made to the infiltration parameters for design purpose use in Maricopa County, because for most flood estimation purposes it cannot be assumed that the soil will be in any particular state of tillage at the time of storm occurrence and therefore the base condition infiltration parameters, as presented, should be used for flood estimation purposes. However, appropriate adjustments to the infiltration parameters can be made, as necessary, for special flood studies such as reconstitution of storm events.

4.4.1.3 Selection of IA, RTIMP, and percent vegetation cover for urban areas: Table 4.2a contains suggested values for IA, RTIMP, and percent vegetation cover for six urban land use types. The values in Table 4.2a are meant as guidelines and are not to be taken as prescribed values for these parameters. Note that the values for RTIMP reflect effective impervious areas not total impervious areas. Also, one should note that the values for percent vegetation cover are for pervious areas only. These three parameter values are used in the calculation of average subbasin parameters for the Green and Ampt loss method as described above. Sound engineering judgement and experience should always be used when selecting rainfall loss parameters and assigning land use categories for any given watershed.

Table 4.2a also relates the six land use types to zoning units for several municipalities in Maricopa County. The assignment of zoning units for municipalities not listed in Table 4.2a could be made by comparison with those given in Table 4.2a. Likewise, the land use categories in Table 4.2a are not the only valid land use categories for use in Maricopa County.

4.4.2 Initial Loss Plus Uniform Loss Rate (IL+ULR)

This is a simplified rainfall loss method that is often used, and generally accepted, for flood hydrology. In using this simplified method it is assumed that the rainfall loss process can be simulated as a two-step procedure, as illustrated in Figure 4.5. First, all rainfall is lost to runoff until the accumulated rainfall is equal to the initial loss; and second, after the initial loss is satisfied, a portion of all future rainfall is lost at a uniform rate. All of the rainfall is lost if the rainfall intensity is less than the uniform loss rate.

According to HEC-1 nomenclature, two parameters are needed to use this method; the initial loss (STRTL) and the uniform loss rate (CNSTL).

Because this method is to be used for special cases where infiltration is not controlled by soil texture, or for drainage areas and subbasins that are predominantly sand, the estimation of the parameters will require model calibration, results of regional studies, or other valid techniques. It is not possible to provide complete guidance in the selection of these parameters; however, some general guidance is provided:

A. For the special cases of anticipated application, the uniform loss rate (CNSTL) will either be very low for nearly impervious surfaces, or possibly quite high for exceptionally fast-draining (highly pervious) land surfaces. For land surfaces with very low infiltration rates, the value of CNSTL will probably be 0.05 inches per hour or less. For sand, a CNSTL of 0.5 to 1.0 inch per hour or larger may be reasonable. Higher values of CNSTL for sand and other surfaces are possible, however, use of high values of CNSTL would require special studies to substantiate the use of such values.

B. Although the IL+ULR method is not recommended for watersheds where the soil textures can be defined and where the Green and Ampt method is encouraged, some general guidance in the selection of the uniform loss rate is shown in Tables 4.3 and 4.4. Table 4.4 was prepared based on the values in Table 4.3 and the hydraulic conductivities shown in Table 4.2. In Table 4.4, the initial infiltration (II) is an estimate of the infiltration loss that can be expected prior to the generation of surface runoff. The value of initial loss (STRTL) is the sum of initital infiltration (II) of Table 4.4 and surface retention loss (IA) of Table 4.1; STRTL = II + IA.

C. The estimation of initial loss (STRTL) can be made on the basis of calibration or special studies at the same time that CNSTL is estimated. Alternatively, since STRTL is equivalent to initial abstraction, STRTL can be estimated by use of the SCS CN equations for estimated initial abstraction, written as:

$$STRTL = \frac{200}{CN} - 2 \qquad (4.5)$$

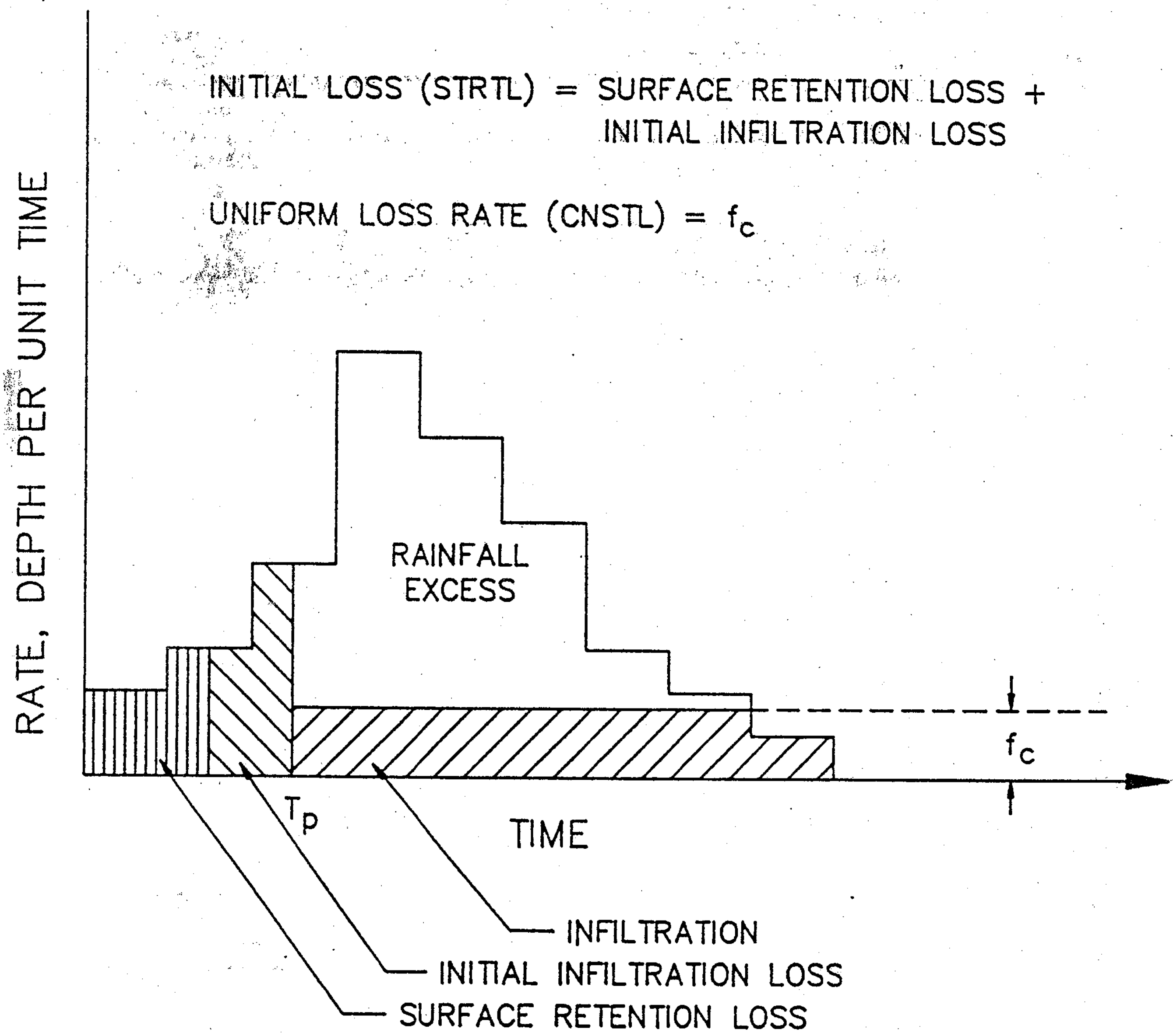


Figure 4.5
Representation of Rainfall Loss According to the Initial Loss Plus Uniform Loss Rate (IL+ULR)

Table 4.2a IA, RTIMP, and Percent Vegetation Cover for Representative Land Uses in Maricopa County

Land Use Category	IA (inches)	RTIMP ** (percent)	Percent ** Veg. Cover	Gilbert Zoning Unit	Gilbert Description	Chandler Zoning Unit	Chandler Description	Mesa Zoning Unit	Mesa Description	Tempe Zoning Unit	Tempe Description	County Zoning Unit	County Description	Phoenix Zoning Unit	Phoenix Description
Agriculture	0.5*	0*	85*	AG	Agriculture	AG-1	Agriculture	AG	Agriculture	AG	Agriculture				
Very Low Density Residential	0.3*	5*	30*					R1-90	Single Residence			RURAL-190	190,000 sq. ft./dwelling unit	S-1	Ranch or Farm Residential, > 1 acre
								SR	Suburban Ranch			RURAL-70	70,000 sq. ft./dwelling unit	S-2	Ranch or Farm Commercial
				R1-43	Rural							RURAL-43	one acre/dwelling unit	RE-43	Single Family, 1 acre minimum
Low Density Residential	0.3*	15*	50*	R1-35	Rural Residential	SF-33	Single Family	R1-35	Single Residence			R1-35	Single Family Residential,	RE-35	SF, 35,000 sq.ft min.
													35,000 sq. ft./dwelling unit	RE-24	SF, 24,000 sq.ft min.
				R1-20	SF, Residential	SF-18	Single Family					R1-18	SFR, 18,000 sq. ft./unit	R1-18	SF, 18,000 sq.ft min.
				R1-15	" "			R1-15	Single Residence	R1-15	One Family Residential			R1-14	SF, 14,000 sq.ft min.
Medium Density Residential	0.25*	30*	50*	R1-10	" "	SF-10	Single Family	R1-9	Single Residence	R1-10	One Family Residential	R1-10	SFR, 10,000 sq. ft./unit	R1-10	SF, 10,000 sq.ft min.
				R1-8	" "					R1-8	One Family Residential	R1-8	SFR, 8,000 sq. ft./unit	R1-8	SF, 8,000 sq.ft min.
				R1-7	" "	SF-7	Single Family	R1-7	Single Residence	R1-7	One Family Residential				
								R1-6	Single Residence	R1-6	One Family Residential	R1-6	SFR, 6,000 sq. ft./unit	R1-6	SF, 6,000 sq.ft min.
								TCR-1	Town Center, Single Family	RO	Residence/Office			R-O	Res. Office
Multiple Family Residential	0.25*	45*	50*	R-2	Duplex	MF-1	Medium Density	R-2	Restricted Multiple Resid.	R-2	Multi-Family Residential	R-2	2 Family Residence	R-2	MF, 4,000 sq.ft./unit
				R-3	Multi-Family, Apartments	MF-2	Multi-Family	R-3	Limited Multiple Resid.	R-3R	Multi-Family Restricted	R-3	Multiple Family, Residential	R-3	MF, 3,000 sq.ft./unit
				R-4	Multi-Family, General	MF-3	High Density	R-4	General Multiple Resid.	R-3	Multi-Family Limited	R-4	Multiple Family, Residential	R-4	MF, 1,500 sq.ft./unit
				R-5	Townhouse Residential					R-4	Multi-Family General	R-5	Multiple Family, Residential	R-4A	MF, 1,000 sq.ft./unit
										R-Th	Townhouse			R-5	MF, 1,000 sq.ft./unit
				MH	Mobile Home	MH-1	Mobile Homes	TCR-2	TC, Restricted Multi-Res.	RMH	Mobile Home Residence	MHR	Manufactured Housing, Resid.	CP/BP	Business Park
				CTP	Commercial Trailer Park			TCR-3	TC, General Res.	MHS	Manufactured Housing Subd.			R-H	Resort District
										TP	Trailer Park				
Industrial	0.15*	55*	60*	I-1	Garden Type Industrial			M-1	Limited Industrial	I-1	Light Industrial			IND PARK	Industrial Park
				I-2	Light Industrial	I-1	Light Industrial			I-2	General Industrial	I-2	Light Industrial	A-1	Light Industrial
				I-3	General Industrial	I-2	General Industrial	M-2	General Industrial	I-3	Heavy Industrial	I-3	Heavy Industrial	A-2	Heavy Industrial
Commercial	0.1*	80*	75*	C-1	Light Commercial	C-1	Neighborhood Commercial	C-1	Neighborhood Comm.	CCR	Convenience Commercial	C-1	Neighborhood Commercial	C-1	Neighborhood Commercial
				C-2	General Commercial	C-2	Community Commercial	C-2	Limited Comm.	C-1	Neighborhood Commercial	C-2	Intermediate Commercial	C-2	Intermediate Commercial
				C-3	Central Commercial	C-3	Regional Commercial	C-3	General Comm.	C-2	General Commercial	C-3	General Commercial	C-3	General Commercial
				RS	Residential Services			OS	Office-Sercives	CCD	Central Comm. District	C-O	Commercial Office	C-O	Commercial Office
				RCC	Residential Conveniences			TCC	TC,High Intensity Mixed Use					HR	High Rise District
								TCB-1	TC, Limited Comm./General Manufacturing						
								TCB-2	TC, General Comm./ Light Manufacturing						
MISCELLANEOUS CATEGORIES: These zoning units should be evaluated on a case by case basis.															
				PAD	Planned Area Development	PAD	Planned Area Development			S	Private School	PD	Planned Development Overlay	PAD	Planned Area Development
				PSC-1	Planned Neighborhood Shopping										
				PSC-2	Planned Shopping Center							CS	Planned Shopping Center	PSC	Planned Shopping Center
				IB	Industrial Buffer										
						PCO	Planned C Offices	PEP	Planned Employment Park						
								PF	Public Facilities			SU	Special Uses		
												SC	Senior Citizen Overlay	PCD	Planned Community Development
												NUP	Neighborhood Plan of Development		
												RUP	Residential Plan of Development		
												IUP	Industrial Plan of Development		
														R.O.W.	Right of Way
														P-1	Parking, Open
														P-2	Parking, Structures
														D.G	Dwelling Group

NOTES

* These values have been selected to fit many typical settings in Maricopa County. However, the engineer/hydrologist should ALWAYS evaluate the specific circumstances in any particular watershed for hydrological variations from these typical values.

** RTIMP = Percent Effective Impervious Area, Including R.O.W.

** Percent Veg. Cover = Percent vegetation cover for pervious area only

Table 4.3
Published Values of Uniform Loss Rates

Hydrologic Soil Group (1)	Uniform Loss Rate, Inches/hour		
	Musgrave (1955) (2)	USBR (1975)[1] (3)	USBR (1987)[2] (4)
A	0.30 - 0.45	0.40	0.30 - 0.50
B	0.15 - 0.30	0.24	0.15 - 0.30
C	0.05 - 0.15	0.12	0.05 - 0.15
D	0 - 0.05	0.08	0 - 0.05

[1] *Design of Small Dams*, Second Edition, 1975, Appendix A.
[2] *Design of Small Dams*, Third Edition, 1987.

Table 4.4
Initial Loss Plus Uniform Loss Rate Parameter Values for Bare Ground according to Hydrologic Soil Group

Hydrologic Soil Group (1)	Uniform Loss Rate CNSTL (2)	Initial Infiltration, Inches II[1]		
		Dry (3)	Normal (4)	Saturated (5)
A	0.4	0.6	0.5	0
B	0.25	0.5	0.3	0
C	0.15	0.5	0.3	0
D	0.05	0.4	0.2	0

[1] Selection of II:
Dry = Nonirrigated lands such as desert and rangeland;
Normal = Irrigated lawn, turf, and permanent pasture;
Saturated = Irrigated agricultural land.

Estimates of CN for the drainage area or subbasin should be made by referring to various publications of the SCS, particularly TR-55. Equation 4.5 should provide a fairly good estimate of STRTL in many cases, however, its use should be judiciously applied and carefully considered in all cases.

4.5 Procedure for Estimating Loss Rates

4.5.1 Green and Ampt Method

A. When soils data are available:

1. Prepare a base map of the drainage area delineating modeling subbasins, if used.

2. Delineate the subareas containing different soils (as determined from soil surveys, if available). Determine the soil texture for each soil type. Soils reports such as those of the Soil Conservation Service can be used, if available, or laboratory analysis of appropriate soil samples from the drainage area can be used if adequate documentation on the sampling and laboratory procedure is provided and approved. A soil texture classification triangle is provided in Appendix D.

3. If the watershed or subbasin contains soil of all one texture, then determine XKSAT, PSIF, and DTHETA from Table 4.2. Adjust XKSAT for vegetation cover using Figure 4.4, if appropriate.

4. If the watershed or subbasin is composed of soils of different textures, then area-weighted parameter values will be calculated:

   a. Determine the size (A_i) and the $XKSAT_i$ values for each soil subarea.

   b. Calculate the area-weighted value of $\overline{XKSAT}$ by using Equation 4.4.

   c. Select corresponding values of PSIF and DTHETA from Figure 4.3.

   d. Adjust the $\overline{XKSAT}$ value for vegetation cover using Figure 4.4, if appropriate. The adjustment factor may be area-weighted, if necessary.

5. Determine the land-use and/or soil cover for the drainage area and use Table 4.1 to estimate the surface retention loss (IA). Arithmetically area-weight average the values of IA if the drainage area or subbasin is composed of subareas of different IA.

6. Estimate the impervious area (RTIMP) for the drainage area or subbasin, and arithmetically area-weight average, if necessary.

7. Enter the area-weighted values of IA, DTHETA, PSIF, XKSAT, and RTIMP for the drainage area or each subbasin on the LG record of the HEC-1 input file.

B. Alternative methods:

As an alternative to the above procedures, Green and Ampt loss rate parameters can be estimated by reconstitution of recorded rainfall-runoff events on the drainage area or hydrologically similar watersheds, or parameters can be estimated by use of rainfall simulators in field experiments. Plans and procedures for estimating Green and Ampt loss rate parameters by either of these procedures should be approved by the Flood Control District and the local agency before initiating these procedures.

4.5.2 Initial Loss Plus Uniform Loss Rate Method

A. When soils data are available:

1. Prepare a base map of the drainage area delineating modeling subbasins, if used.

2. Delineate subareas of different infiltration rates (uniform loss rates) on the base map. Assign a land-use or surface cover to each subarea.

3. Determine the size of each subbasin and size of each subarea within each subbasin.

4. Estimate the impervious area (RTIMP) for the drainage area or each subarea.

5. Estimate the initial loss (STRTL) for the drainage area or each subarea by regional studies or calibration. Alternatively, Equation 4.5 or Tables 4.1 and 4.4 can be used to estimate or to check the value of STRTL.

6. Estimate the uniform loss rate (CNSTL) for the drainage area or each subarea by regional studies or calibration. Table 4.4 can be used, in certain situations, to estimate or to check the values of CNSTL.

7. Calculate the area-weighted values of RTIMP, STRTL, and CNSTL for the drainage area or each subbasin.

8. Enter the area-weighted values of RTIMP, STRTL, and CNSTL for the drainage area or each subbasin on the LU record of the HEC-1 input file.

5 Unit Hydrograph Procedures

5.1 General

Rainfall excess can be routed from a watershed to produce a storm discharge hydrograph at a downstream location (concentration point) by one of two methods: 1) hydraulic routing involving the complete or some simplified form of the equations of motion (i.e., the momentum equation plus the continuity equation); or 2) hydrologic routing involving the application of the continuity equation. Kinematic wave routing, as available in HEC-1, is an example of simplified hydraulic routing. Hydrologic routing is usually accomplished by either direct application of the equation of continuity (Equation 5.1), or a graphical procedure such as the application of the principles of the unit hydrograph.

$$I - O = \frac{dS}{dt} \tag{5.1}$$

Examples of hydrologic routing by direct application of the equation of continuity are the Clark Unit Hydrograph (Clark, 1945), the Santa Barbara Urban Hydrograph (Stubchaer, 1975), and the Single Linear Reservoir Model (Pedersen and others, 1980). Both the Santa Barbara Urban Hydrograph and the Single Linear Reservoir Model are simplified (one parameter) versions of the Clark Unit Hydrograph (three parameter) procedure (Sabol and Ward, 1985). Examples of unit hydrographs that require a graphical procedure are the SCS Dimensionless Unit Hydrograph, Snyder's Unit Hydrograph, S-graphs, and unit hydrographs that are derived directly from recorded runoff data. Graphical or tabular methods of routing rainfall excess by unit hydrographs are very amenable to hand-calculation methods commonly used before computers became readily available. Direct mathematical solution of the equation of continuity, such as the Clark Unit Hydrograph, is more efficiently conducted with computers and appropriate computer programs.

The recommended procedures for routing rainfall excess in Maricopa County are either the Clark Unit Hydrograph or the application of selected S-graphs; these two methods are collectively referred to as the Maricopa County Unit Hydrograph Procedure (MCUHP). The Clark Unit Hydrograph procedure, as described herein, is recommended for watersheds or subbasins less than about 5 square miles in size with an upper limit of application of 10 square miles. The application of S-graphs is recommended for use with major watercourses in Maricopa County.

A unit hydrograph is a graph of the time distribution of runoff from a specific watershed as the result of one inch of rainfall excess that is distributed uniformly over the watershed and that is produced during a specified time period (duration). The duration of rainfall excess is not generally equal to the rainfall duration, because a unit hydrograph is derived from or is to be representative of a specific watershed. A unit hydrograph is a lumped parameter and reflects all of the physical characteristics of the watershed that will affect the time rate at which rainfall excess will drain from the land surface.

The principles of the unit hydrograph were introduced by Sherman (1932) who observed that for a watershed all hydrographs resulting from a rain of the same duration have the same time base, and that ordinates of each storm hydrograph from the watershed are proportional to the volume of runoff if the time and areal distributions of the rainfalls are similar. The principles that are applied when using a unit hydrograph are:

1. For a watershed, hydrograph base lengths are equal for rainfall excesses of equal duration.

2. Hydrograph ordinates are proportional to the amount of rainfall excess.

3. A storm hydrograph can be developed by linear superposition of incremental hydrographs.

Application of these principles requires a linear relation between watershed outflow and storage within the watershed, $S = KO$. However, Mitchell (1962) has shown that nonlinear storage, $S = KO^x$, is a condition that occasionally occurs in natural watersheds. A method has been developed by Shen (1962) to evaluate the linearity of the storage-outflow relation for gaged watersheds. Mitchell (1972) developed the model hydrograph for use in watersheds that have nonlinear storage-outflow characteristics. Presently no method has been devised to evaluate the linearity of an ungaged watershed, and the assumption of linearity is a practical necessity in virtually all cases.

5.2 Clark Unit Hydrograph

Hydrologic routing by the Clark Unit Hydrograph method is analogous to the routing of an inflow hydrograph through a reservoir. This analogy is illustrated in Figure 5.1. The inflow hydrograph, called the translation hydrograph in the Clark method, is determined from the temporal and spatial distribution of rainfall excess over the watershed. The translation hydrograph is then routed by a form of the equation of continuity:

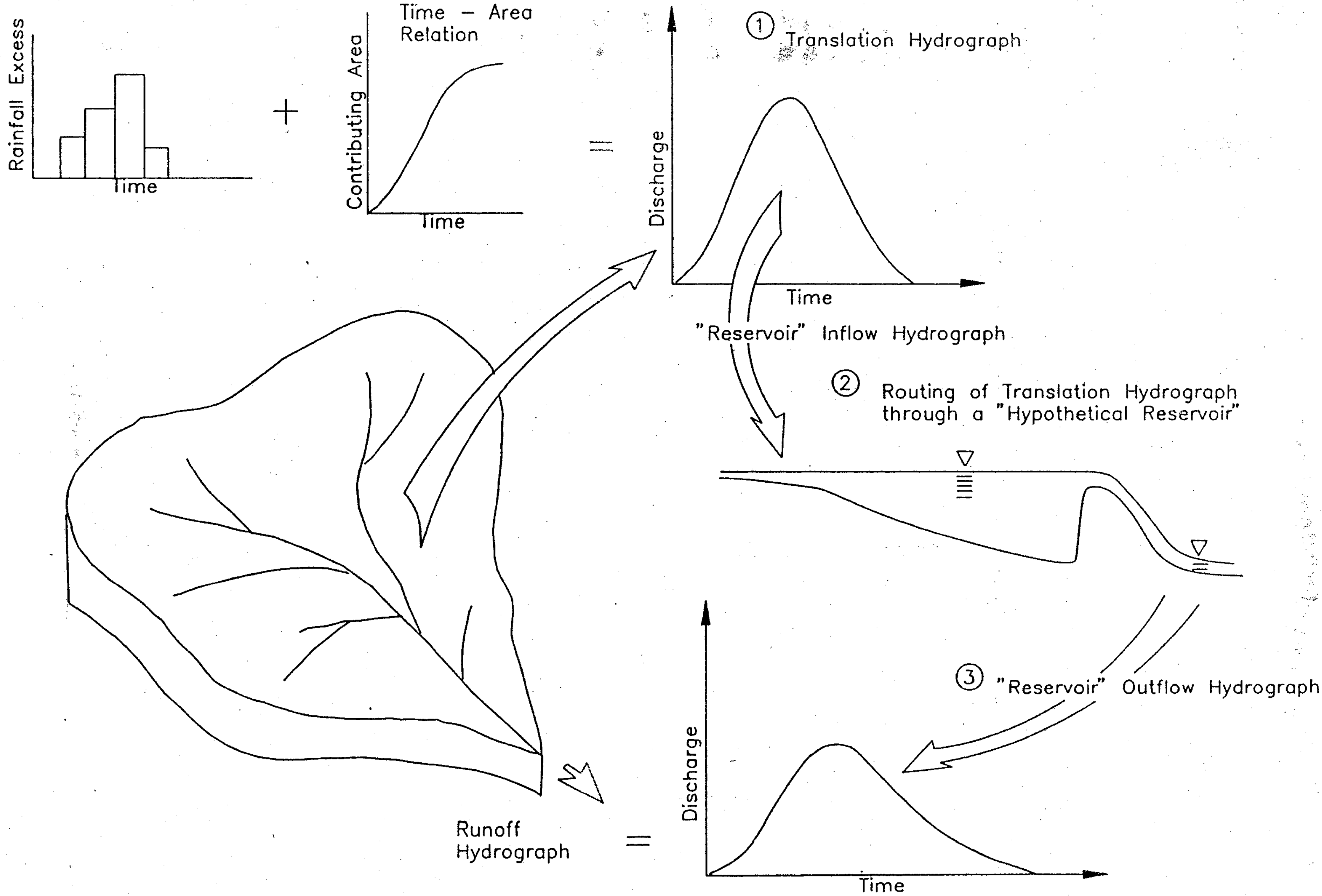


Figure 5.1
Conceptual Analogy of Linear Reservoir Routing to Generation of a Storm Hydrograph by the Clark Unit Hydrograph Method

$$O_i = CI_i + (1 - C)O_{i-1} \quad (5.2)$$

where

$$C = \frac{2\,\Delta t}{2R + \Delta t} \quad (5.3)$$

O_i is the instantaneous flow at the end of the time period; O_{i-1} is the instantaneous flow at the beginning of the time period; I_i is the ordinate of the translation hydrograph; Δt is the computation time interval; and R is the watershed storage coefficient. The Clark Unit Hydrograph of duration, Δt, is obtained by averaging two instantaneous unit hydrographs spaced Δt units apart:

$$U_i = 0.5(O_i + O_{i-1}) \quad (5.4)$$

where U_i = the ordinates of the Clark Unit Hydrograph.

The Clark method uses two numeric parameters, Tc and R, and a graphical parameter, the time-area relation. Clark (1945) defined Tc as the time from the end of effective rainfall over the watershed to the inflection point on the recession limb of the surface runoff hydrograph as shown in Figure 5.2. In practice, for ungaged watersheds this time is usually estimated by empirical equations since runoff hydrographs from the watershed are not often available.

The second parameter is the storage coefficient, R, which has the dimension of time. This parameter is used to account for the effect that temporary storage in the watershed has on the hydrograph. Several methods are available to estimate R from recorded hydrographs for a basin. As originally proposed by Clark (1945), this parameter can be estimated by dividing the discharge at the point of inflection of the surface runoff hydrograph by the rate of change of discharge (slope of the hydrograph) at the inflection point as shown in Figure 5.2.

Another technique for estimating R is to compute the volume remaining under the recession limb of the surface runoff hydrograph following the point of inflection and to divide the volume by the discharge at the point of inflection. Both of these methods require the ability to identify the inflection point on the recession limb of the runoff hydrograph. This is difficult if not impossible for complex hydrographs and flashy hydrographs such as occur from urban basins and natural watersheds in the Southwest. A method to estimate R by a graphical recession analysis of the hydrograph has been proposed (Sabol, 1988) and this method provides much more consistent results than do the previously described methods. The parameter, R, should be estimated by the analysis of several recorded events; however, in most cases recorded discharge hydrographs are not available and R must be estimated by empirical equations.

The time-area relation, a graphical parameter, is necessary to compute the translation hydrograph. The time-area relation specifies the accumulated area of the watershed that is contributing runoff to the outlet of the watershed at any point in time. Procedures to develop a time-area relation for a watershed are discussed in a later section of this manual.

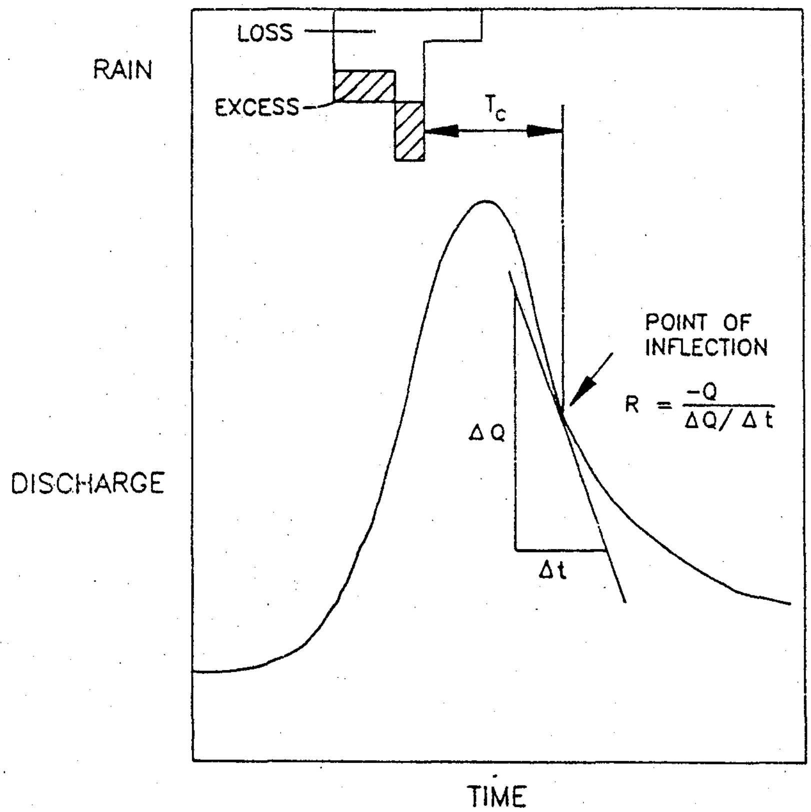
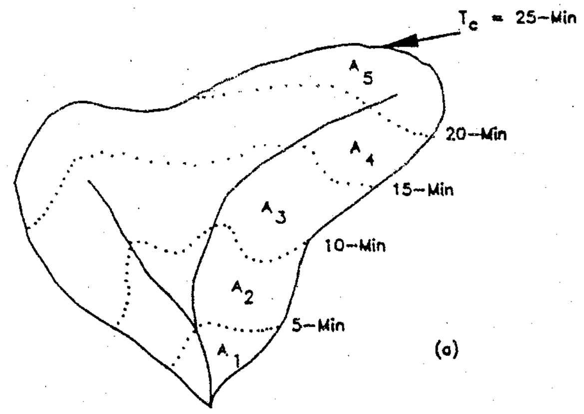


Figure 5.2
Definition Sketch of Clark Unit Hydrograph Parameters from hydrograph analysis

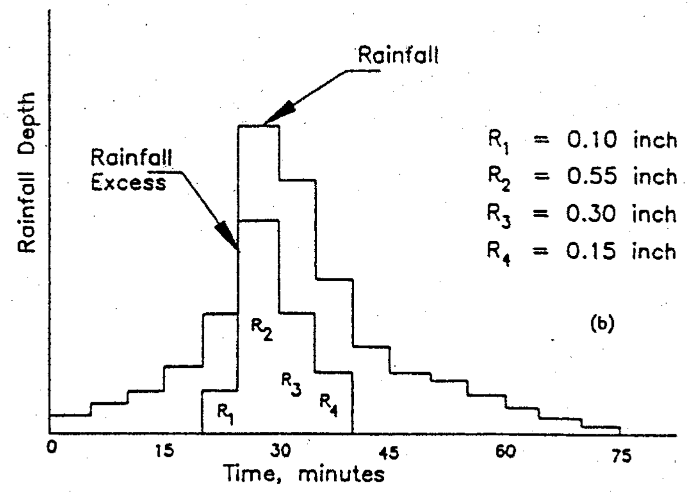
The application of the Clark Unit Hydrograph method is best described with a simple example. A watershed is shown in Figure 5.3(a), and a rainfall hyetograph and rainfall excess distribution are shown in Figure 5.3(b). For the example watershed and given intensity of rainfall excess, the time of concentration is estimated at 25 minutes. An isochrone interval of 5 minutes is selected and the watershed is divided into five zones by isochrones as shown in Figure 5.3(a). The areas within each isochrone zone are measured and the dimensionless time-area relation is developed as shown in the table and depicted in Figure 5.3(c). The translation hydrograph of the time rate of runoff is developed by considering each incremental unit of runoff production that would be available as inflow to a watershed routing model. For example, at the end of the first 5 minutes of rainfall excess the runoff that is available at the outlet of the watershed is the product of incremental area A_1, and the rainfall excess R_1.

$$I_1 = (A_1 R_1) \times \frac{c}{\Delta t}$$

where c = 60.5 cfs/acre-inch/minute



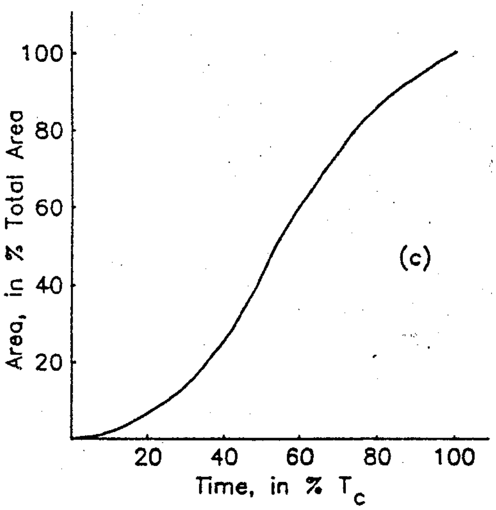
Watershed Map and Isochrones



Rainfall hydrograph and rainfall excess distribution

Table showing development of dimensionless time-area relation

Isochrone Zone (1)	Area Acres (2)	Accumulated Area (3)	Accumulated Area as % of Total Area (4)	Travel Time as % of T_c (5)
A_1	8	8	6.7	20
A_2	24	32	26.7	40
A_3	38	70	58.3	60
A_4	32	102	85.0	80
A_5	18	120	100.0	100



Dimensionless Time-Area Relation

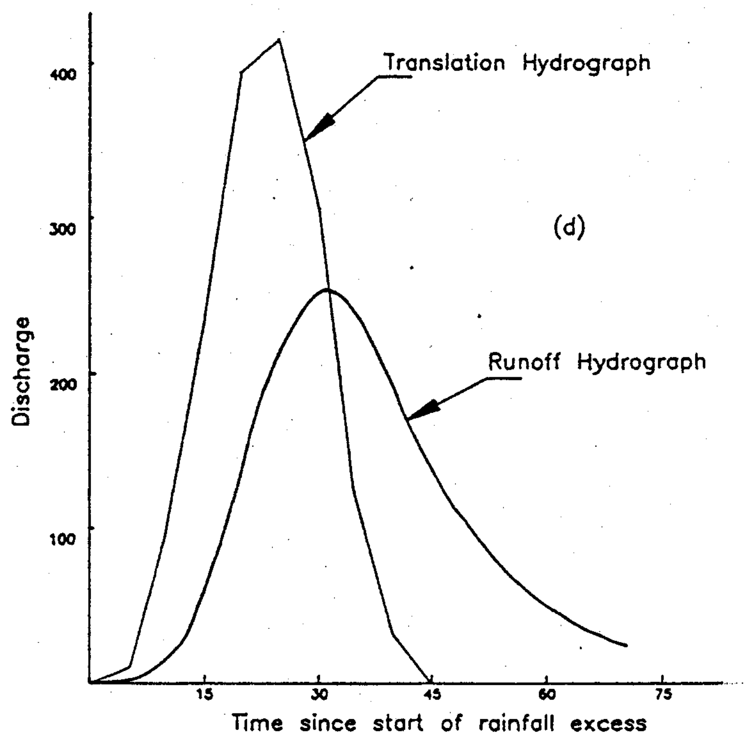


Figure 5.3

Example of Storm Hydrograph Generation using the Clark Unit Hydrograph Method

$\Delta t = 5$ minutes

$I_1 = (8 \text{ acres})(.10 \text{ inch})(60.5 \text{ cfs/acre-inch/minute})/(5 \text{ minutes})$

$= 9.7$ cfs

At the end of 10 minutes the available runoff is

$$I_2 = (A_1R_2 + A_2R_1) \times \frac{c}{\Delta t}$$
$$= [(8)(.55) + (24)(.10)] \times \frac{60.5}{5}$$
$$= 82.3 \; cfs$$

At the end of 15 minutes the available runoff is

$$I_3 = (A_1R_3 + A_2R_2 + A_3R_1) \times \frac{c}{\Delta t}$$
$$= [(8)(.30) + (24)(.55) + (38)(.10)] \times \frac{60.5}{5}$$
$$= 234.7 \; cfs$$

At the end of 20 minutes the available runoff is

$$I_4 = (A_1R_4 + A_2R_3 + A_3R_2 + A_4R_1) \times \frac{c}{\Delta t}$$
$$= [(8)(.15) + (24)(.30) + (38)(.55) + (32)(.10)] \times \frac{60.5}{5}$$
$$= 393.5 \; cfs$$

At the end of 25 minutes the available runoff is

$$I_5 = (A_1R_5 + A_2R_4 + A_3R_3 + A_4R_2 + A_5R_1) \times \frac{c}{\Delta t}$$
$$= [(8)(0) + (24)(.15) + (38)(.30) + (32)(.55) + (18)(.10)] \times \frac{60.5}{5}$$
$$= 416.2 \; cfs$$

Notice that, for this example, all incremental rainfalls equal 0.0 from R5 onward. At the end of 30 minutes the available runoff is

$$I_6 = (A_3R_4 + A_4R_3 + A_5R_2) \times \frac{c}{\Delta t}$$
$$= [(38)(.15) + (32)(.30) + (18)(.55)] \times \frac{60.5}{5}$$
$$= 304.9 \; cfs$$

At the end of 35 minutes the available runoff is

$$I_7 = A_4R_4 + A_5R_3) \times \frac{c}{\Delta t}$$
$$= [(32)(.15) + (18)(.30)] \times \frac{60.5}{5}$$
$$= 123.4\ cfs$$

At the end of 40 minutes the available runoff is

$$I_8 = (A_5R_4) \times \frac{c}{\Delta t}$$
$$= [(18)(.15)] \times \frac{60.5}{5}$$
$$= 32.7\ cfs$$

After 45 minutes (rainfall excess of 20 minutes plus travel time of 25 minutes) the available runoff is

$$I_9 = 0\ cfs$$

The translation hydrograph (I_i) is shown in Figure 5.3(d). This theoretical hydrograph has the correct volume of runoff from the watershed, however it does not reflect the effects of routing through the watershed. The translation hydrograph is then routed and averaged using Equations 5.2 through 5.4 resulting in the final runoff hydrograph. For this example, assume that R = 15 minutes, and the runoff hydrograph is shown in Figure 5.3(d). Notice that the Clark Unit Hydrograph itself was never developed per se but that the three principles of the unit hydrograph were applied directly (mathematically) to the rainfall excess without performing graphical superposition of ratios of a unit hydrograph. Computationally, this process can be completed very quickly and conveniently with a computer program such as is done with HEC-1.

5.3 Limitations and Applications

There are no theoretical limitations governing the application of the Clark Unit Hydrograph; however, there are some practical limitations that should be observed. The method that is used to estimate the parameters may dictate limitations in regard to the type or size of watershed that is being considered. If the parameters are estimated through an analysis or reconstitution of a recorded rainfall-runoff event, the parameters would be considered to be appropriate for that particular watershed, regardless of type or size. This is the preferred method of parameter estimation, but there will be limited opportunity for this approach because of the scarcity of instrumented watersheds in Maricopa County. The parameters could be estimated by indirect methods, such as a regional analysis of recorded data. In this case, application of the parameter estimation procedures should be applied only to those ungaged watersheds that are representative of the watersheds in the data base. Most often, the parameters are estimated by generalized relations that may have been developed from a relatively large and diverse data base. The parameter estimation procedures that are recommended herein are of this last category.

The Clark Unit Hydrograph parameter estimation procedures that are presented in this manual have been adopted, modified, or developed from an analysis of a large data base of instrumented watersheds, controlled experimental watersheds, and laboratory studies; therefore, the application of these procedures is considered to be appropriate for most conditions that occur in Maricopa County. The types of watersheds for which the procedures can be applied include urban, rangeland, developed and natural alluvial fans, agricultural, hillslopes, and mountains.

Watershed size should be 5 square miles or less, with an upper limit of application to a single basin of 10 square miles. Watersheds larger than 5 square miles should be divided into smaller sub-basins for modeling purposes. Many watersheds smaller than 5 square miles should also be divided into sub- basins depending on the drainage network and degree of homogeneity of the watershed. The subdivision of the watershed into near homogeneous units should result in improved accuracy. Subdivision may also be desirable or required to determine discharges at concentration points within the watershed.

5.4 Development of Parameter Estimators

The procedures for parameter estimation are based on available literature, research results, and analysis of original data. For example, the Tc equation is based on the recent research of Papadakis and Kazan (1987). A large data base of recorded rainfall-runoff data was compiled and analyzed in developing and testing the procedures. These data are for instrumented watersheds in Arizona, New Mexico, Colorado, and Wyoming. A discussion of the development and testing of these procedures is contained in the Documentation Manual that is a companion to the *Hydroloy Manual.*

5.5 Estimation of Parameters

The following procedures are recommended for the calculation of the Clark Unit Hydrograph parameters for use in Maricopa County. Other general procedures, as previously discussed, can be used, however, these should be approved by the jurisdictional agency prior to undertaking such procedures.

5.5.1 Time of Concentration

Time of concentration is defined as the travel time, during the corresponding period of most intense rainfall excess, for a floodwave to travel from the hydraulically most distant point in the watershed to the point of interest (concentration point). Note especially that Tc is not the travel time taken for a particle of water to move down the catchment, as is often cited in engineering texts. The catchment is in equilibrium when Tc is reached because the outlet then "feels" the inflow from every portion of the catchment (Bedient and Huber, 1988). Since a wave moves faster than a particle of water, the time of concentration (and catchment equilibrium) occurs sooner than if based on overland flow or channel water velocities. An empirical equation for time of concentration, Tc, has been adopted with some procedural modifications from Papadakis and Kazan (1987):

$$Tc = 11.4\, L^{0.50} K_b^{0.52} S^{-0.31} i^{-0.38} \qquad (5.5)$$

where Tc = time of concentration in hours

L = length of the flow path for Tc in miles

K_b = representative watershed resistance coefficient

S = watercourse slope in feet/mile and

i = the average rainfall excess intensity, during the time Tc, in inches/hour.

Watercourse slope, S, is the average slope of the flow path for the same watercourse that is used to define L. The magnitude of S can be calculated as the difference in elevation between the two points used to define L divided by the length, L. Watersheds in mountains can result in large values for S—which may result in an underestimation of Tc. This is because as slope increases in natural watersheds the runoff velocity does not usually increase in a corresponding manner. The slope of steep natural watercourses is often adjusted to reduce the slope, and the reduced slope is used in calculating runoff travel times. The slope of steep natural watercourses should be adjusted by using Figure 5.4.

The selection of a representative watershed resistance coefficient, K_b, similar in concept to *Manning's n* in open-channel flow, is very subjective and therefore a high degree of uncertainty is associated with its use. To diminish this uncertainty and to increase the reproducibility of the procedure, a graph is provided in Figure 5.5 for the selection of K_b based on watershed classification and watershed size. Interpolation can be used for a given watershed size and mixed classification. Equations for estimating K_b are given in Table 5.1.

The value of *i* in Equation 5.5 requires the knowledge of both the distribution of rainfall excess intensity and the time of concentration, which is, of course, unknown. Therefore, Equation 5.5 must be solved in a trial-and-error procedure. First, the time distribution of rainfall excess must be estimated for the design rainfall distribution and a graph of average rainfall excess intensity versus time prepared. Then a value of Tc is assumed and the corresponding value of i is read from the graph. Equation 5.5 is solved with that value of i. If the calculated value of Tc is reasonably close to the value that was assumed for i then the solution is finished; if not, then assume a new value of Tc, recalculate i, and recalculate Tc with Equation 5.5. The solution for Tc should converge within three trials.

A worksheet has been prepared that facilitates the calculation of Tc. Appendix E is a copy of this worksheet and the Examples section of this manual shows how it is used. Alternatively, program "MCUHP1" can be used which will also provide the necessary HEC-1 input file.

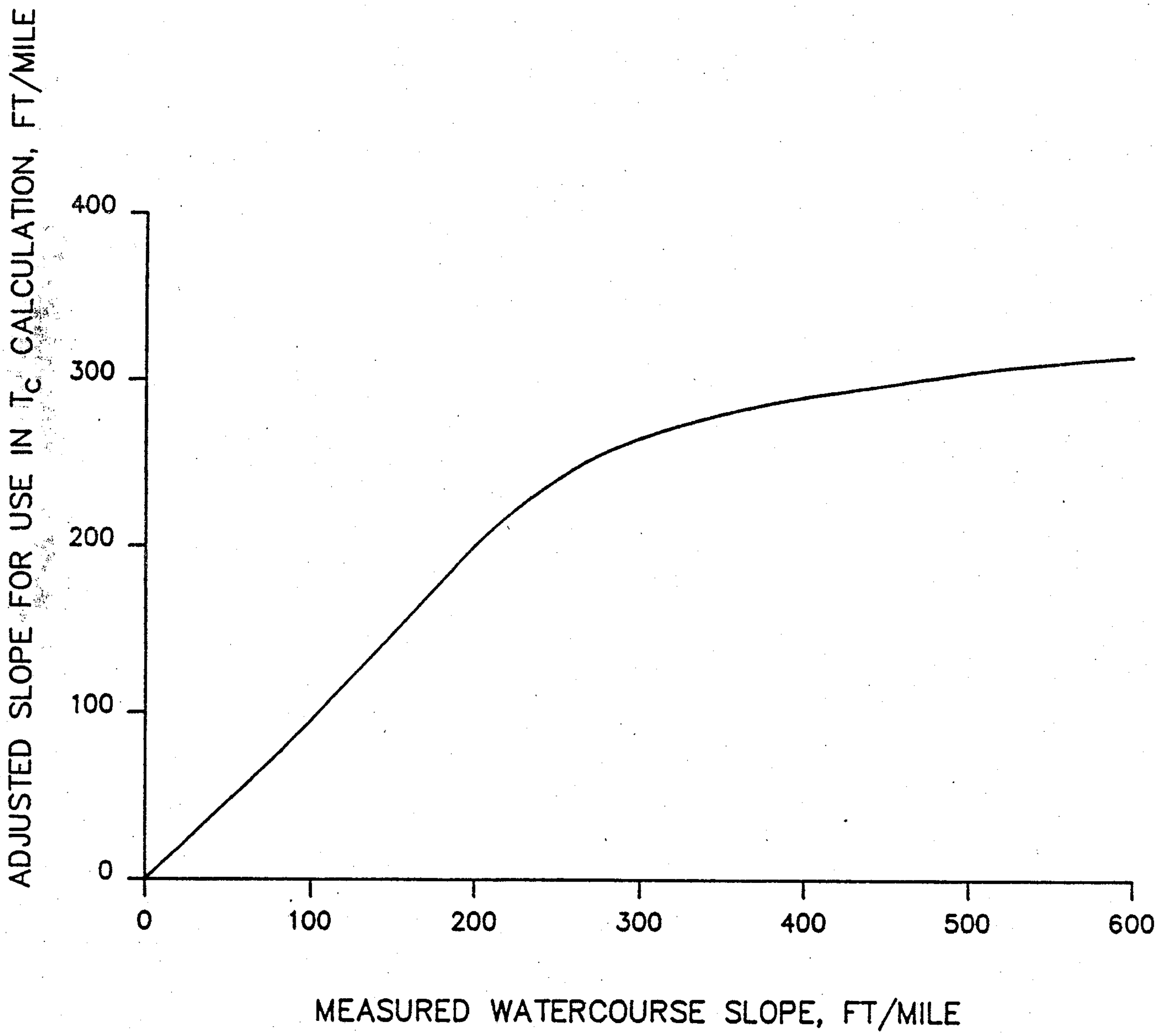


Figure 5.4
Slope Adjustment for Steep Watercourses in Natural Watersheds
(Source: *Drainage Criteria Manual*, Urban Drainage and Flood Control District, Colorado, May 1984.)

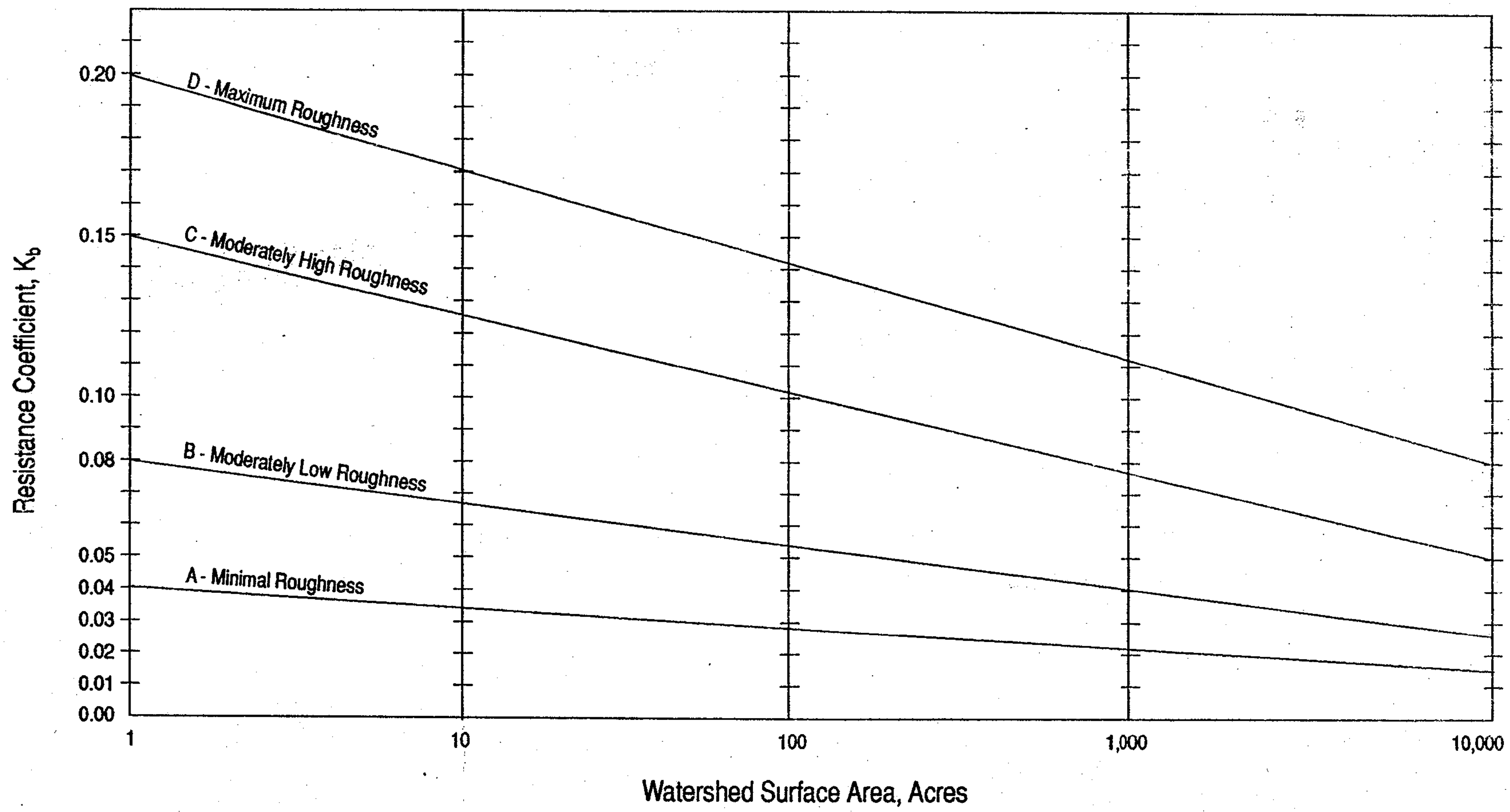


Figure 5.5

Resistance Coefficient "K_b" as a Function of Watershed Size and Surface Roughness Characteristics

Table 5.1
Equation for Estimating K_b in the Tc Equation

$K_b = m \log A + b$ Where A is drainage area, in acres				
Type	**Description**	**Typical Applications**	**Equation Parameters**	
			m	**b**
A	Minimal roughness: Relatively smooth and/or well graded and uniform land surfaces. Surface runoff is sheet flow.	Commercial/ industrial areas Residential area Parks and golf courses	–0.00625	0.04
B	Moderately low roughness: Land surfaces have irregularly spaced roughness elements that protrude from the surface but the overall character of the surface is relatively uniform. Surface runoff is predominately sheet flow around the roughness elements.	Agricultural fields Pastures Desert rangelands Undeveloped urban lands	–0.01375	0.08
C	Moderately high roughness: Land surfaces that have significant large- to medium-sized roughness elements and/or poorly graded land surfaces that cause the flow to be diverted around the roughness elements. Surface runoff is sheet flow for short distances draining into meandering drainage paths.	Hillslopes Brushy alluvial fans Hilly rangeland Disturbed land, mining, etc. Forests with underbrush	–0.025	0.15
D	Maximum roughness: Rough land surfaces with torturous flow paths. Surface runoff is concentrated in numerous short flow paths that are often oblique to the main flow direction.	Mountains Some wetlands	–0.030	0.20

5.5.2 Storage Coefficient

Very little literature exists on the estimation of the storage coefficient (R) for the Clark Unit Hydrograph. Clark (1945) had originally proposed a relation between Tc and R since they can both be defined by locating the inflection point of a runoff hydrograph (refer to Figure 5.2). The Corps of Engineers has discussed the development of regionalized relations for Tc and R as functions of watershed characteristics in *Training Document No. 15* (U.S. Army Corps of Engineers, 1982b). According to Corps procedures, Tc and R are estimated from relations of Tc + R and R/(Tc + R) as functions of watershed characteristics. These forms of empirical equations indicate an interrelation of Tc and R, and such dependence was observed in the data base, as discussed in the Documentation Manual. The equation for estimating R for Maricopa County is:

$$R = 0.37Tc^{1.11}A^{-0.57}L^{0.80} \tag{5.6}$$

where R = storage coefficient in hours

Tc = time of concentration in hours

A = drainage area in square miles, and

L = length of flow path in miles.

5.5.3 Time-Area Relation

Either a synthetic time-area relation must be adopted or the time-area relation for the watershed must be developed. If a synthetic time-area relation is not used, the time-area relation is developed by dividing the watershed into incremental runoff producing areas that have equal incremental travel times to the outflow location. This is a difficult task and well defined and reliable procedures for this are not available. The following general procedure is often used:

1. Use a topographic map of the watershed to trace along the flow path the distance from the hydraulically most distant point in the watershed to the outflow location; this defines L in both Equations 5.5 and 5.6.

2. Draw isochrones on the map to represent equal travel times to the outflow location. These isochrones can be established by considering the land surface slope and resistance to flow, and also whether the runoff would be sheet flow or would be concentrated in watercourses. A good deal of judgement and interpretation is required for this.

3. Measure and tabulate the incremental areas (in an upstream sequence) as well as the corresponding travel time for each area.

4. Prepare a graph of travel time versus contributing area (or a dimensionless graph of time as a percent of Tc versus contributing area as a percent of total area). The dimensionless graph is preferred because this facilitates the rapid development of new time-area relations should there be a need to revise the estimate of Tc.

Synthetic time-area relations can be used such as the default relation in the HEC-1 program:

$$A^* = 1.414(T^*)^{1.5} \qquad 0 \le T^* \le 0.5 \tag{5.7}$$

$$1 - A^* = 1.414(1 - T^*)^{1.5} \qquad 0.5 \le T^* \le 1.0$$

where A* = contributing area in percent of total area and

T* = time in percent of Tc.

Equation 5.7 is a symmetric relation and is not recommended for most watersheds in Maricopa County.

Two other dimensionless time-area relations have been developed during the reconstitution of recorded rainfall-runoff events as described in the Documentation Manual. These dimensionless relations for urban and natural watersheds are shown in Figures 5.6 and 5.7. Each of these figures show a synthetic time-area relation and a shaded zone where the time-area relation is expected to lie. For an urban watershed, the synthetic time-area relation of Figure 5.6 is recommended, and for a natural (undeveloped) watershed the synthetic time-area relation of Figure 5.7 is recommended. If a time-area relation is developed from the watershed map, which is generally recommended for unusually shaped watersheds, then the resulting relation should lie within the shaded zones in either Figures 5.6 or 5.7. The HEC-1 default time-area relation is shown for comparison in each figure. Tabulated values of the dimensionless time-area relations are shown in Table 5.2.

The computation interval (NMIN) on the IT record of HEC-1 must be selected to correspond to the time of concentration for the unit hydrograph. This requirement is necessary to adequately define the shape of the unit hydrograph. From Snyder's unit hydrograph theory, the unit rainfall duration for a unit hydrograph (computation interval) is equal to lag time divided by 5.5. For the SCS Dimensionless Unit Hydrograph, the unit rainfall duration is to equal 0.133Tc, and although small variation in the selection of computation interval is allowed, the SCS recommends that the duration not exceed 0.25 Tc. Although there is not a rigid theoretical limitation to how small the computation interval can be, from a practical standpoint, too small of a NMIN could result in excessive computer output. Therefore, as a general rule the computation interval should meet the following:

$$NMIN = 0.15Tc \tag{5.8}$$

Equation 5.8 is preferred, however, as a general requirement NMIN should fall in the range indicated in Equation 5.9.

$$0.10Tc \le NMIN \le 0.25Tc \tag{5.9}$$

NMIN is normally selected as a multiple of five minutes. This may require that watersheds with significantly different sub-basin sizes be modeled with some sub-basins run separately and the outflow hydrographs from these separate runs read directly into the multi-basin model.

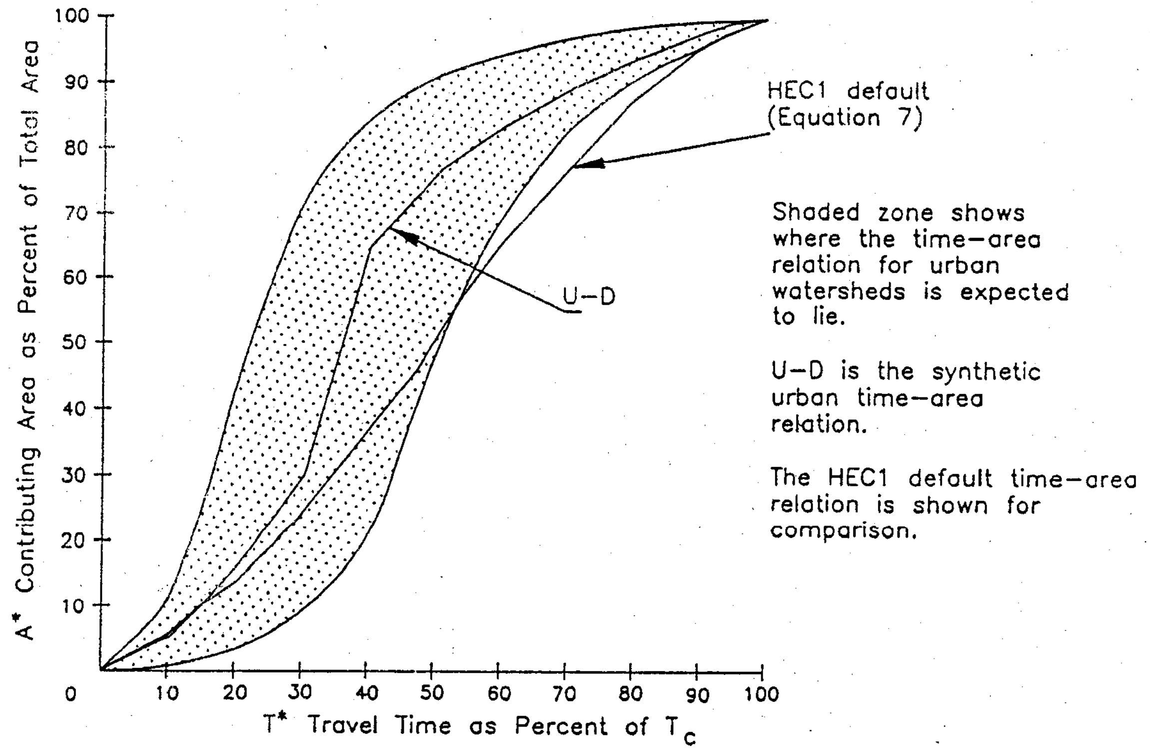


Figure 5.6
Synthetic Time-Area Relation for Urban Watershed

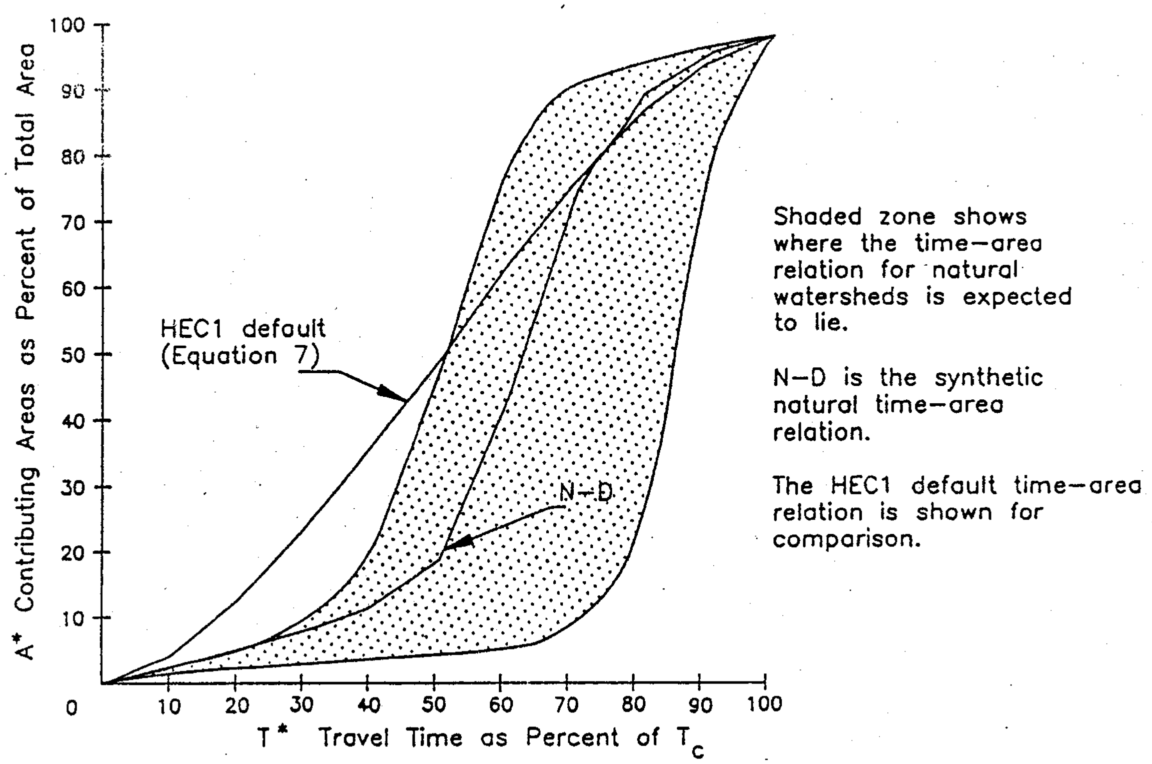


Figure 5.7
Synthetic Time-Area Relation for Natural Watersheds

Table 5.2
Values of the Synthetic Dimensionless Time-Area Relations for the Clark Unit Hydrograph

Time, as a percent of Time of Concentration (1)	Contributing Area, as a Percent of Total Area		
	Urban Watersheds (2)	Natural Watersheds (3)	HEC-1 Default (4)
0	0	0	0.0
10	5	3	4.5
20	16	5	12.6
30	30	8	23.2
40	65	12	35.8
50	77	20	50.0
60	84	43	64.2
70	90	75	76.8
80	94	90	87.4
90	97	96	95.5
100	100	100	100.0

5.6 S-Graphs

An S-graph is a dimensionless form of a unit hydrograph and it can be used in the place of a unit hydrograph in performing flood hydrology studies. The concept of the S-graph dates back to the development of the unit hydrograph itself, although the application of S-graphs has not been as widely practiced as that of the unit hydrograph. The use of S-graphs has been practiced mainly by the U.S. Army Corps of Engineers, Los Angeles District, and the U.S. Bureau of Reclamation (USBR).

An example of an S-graph from Design of Small Dams (USBR, 1987) is shown in Figure 5.8. The discharge scale is expressed as percent of ultimate discharge (Qult), and the time scale is expressed as percent lag. Lag is defined as the elapsed time, usually in hours, from the beginning of an assumed continuous series of unit rainfall excess increments over the entire watershed to the instant when the rate of resulting runoff equals 50 percent of the ultimate discharge. The intensity of rainfall excess is 1 inch per duration of computation interval (Δt). An equivalent definition of lag is the time for 50 percent of the total volume of runoff of a unit hydrograph to occur. It is to be noted that there are numerous definitions for lag in hydrology and the S-graph lag should not be calculated by methods that are not consistent with this definition.

Ultimate discharge is the maximum discharge that would be achieved from a particular watershed when subjected to a continuous intensity of rainfall excess of

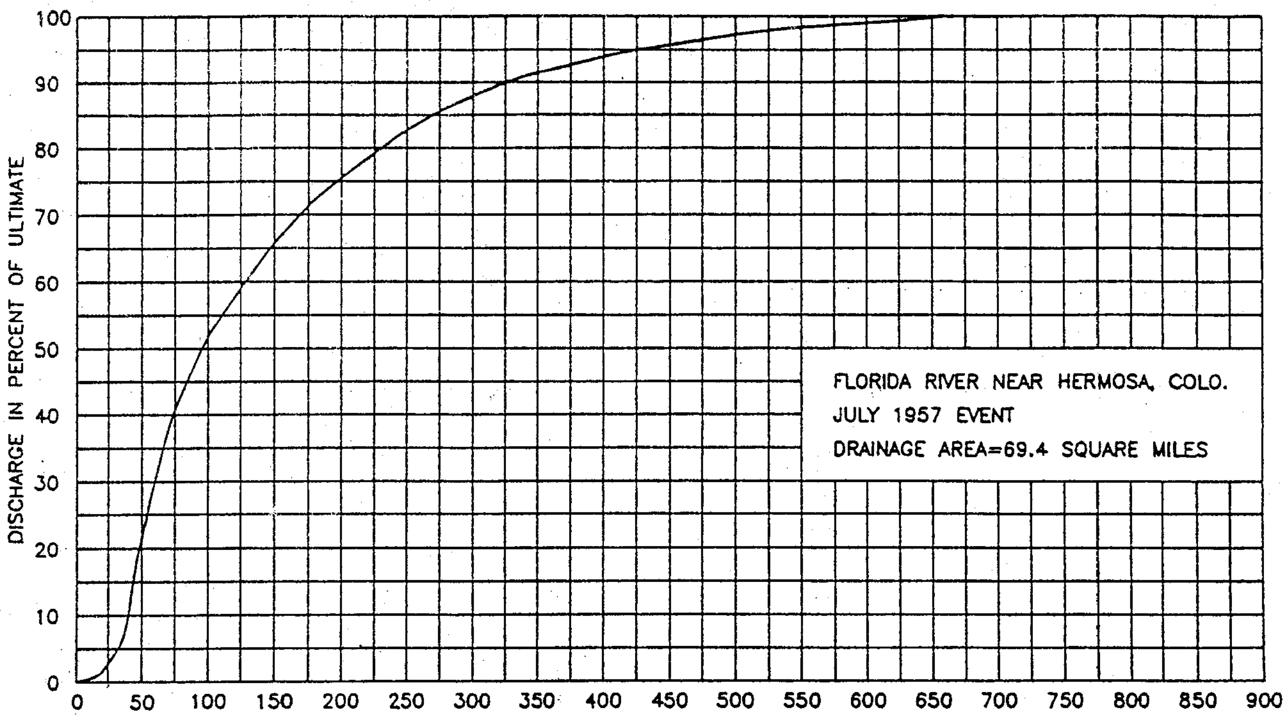


Figure 5.8
Example of an S-Graph from *Design of Small Dams* (USBR, 1987)

1 inch per duration (Δt) uniformly over the basin. Ultimate discharge (Qult), in cubic feet per second (cfs), can be calculated from Equation 5.10:

$$Qult = \frac{645.33A}{\Delta t} \qquad (5.10)$$

where A = drainage area in square miles, and

Δt = duration of the 1 inch of rainfall excess in hours.

S-graphs are developed by summing a continuous series of unit hydrographs, each lagged behind the previous unit hydrograph by a time interval that is equal to the duration of rainfall excess for the unit hydrograph (Δt). The resulting summation is a graphical distribution that resembles an S-graph except that the discharge scale is accumulated discharge and the time scale is in units of measured time. This graph is terminated when the accumulated discharge equals Qult which occurs at a time equal to the base time of the unit hydrograph less one duration interval. The basin lag can be determined from this graph at the time at which the accumulated discharge equals 50 percent of Qult. This summation graph is then converted to a dimensionless S-graph by dividing the discharge scale by Qult and the time scale by lag.

In practice, S-graphs have generally been developed by reconstituting observed floods to define a representative unit hydrograph and then converting this to an

S-graph. Prior to the advent of computerized models, such as HEC-1, flood reconstitution was a laborious task of rainfall and hydrograph separation along with numerous hand-cranked simulations to define the representative unit hydrograph. Modern S-graph development generally relies on use of optimization techniques, such as coded into HEC-1, to identify unit hydrograph parameters that best reproduce the observed flood.

Although an S-graph is completely dimensionless and does not have a duration of rainfall excess associated with it as does a unit hydrograph, its general shape and the magnitude of lag is influenced by the distribution of rainfall over the watershed and the time distribution of the rainfall. Therefore, the transposition of an S-graph from a gaged watershed to application in another watershed must be done with consideration of both the physiographic characteristics of the watersheds and the hydrologic characteristics of the rainfalls for the two watersheds.

5.6.1 Limitations and Applications

S-graphs are empirical, lumped parameters that represent runoff characteristics for the watershed for which the S-graph was developed. S-graphs that are developed from recorded runoff data from one watershed can be applied to another watershed only if the two watersheds are hydrologically and physiographically similar. In addition, a recent study for the Flood Control District of Maricopa County (Sabol, 1987) has demonstrated that the shape of S-graphs is significantly affected by storm characteristics, particularly the maximum intensity of the rainfall. Therefore, it may not be advisable to adopt S-graphs that have been developed from one hydrologic zone and to apply these to watersheds in other hydrologic zones because of possible differences in rainfall characteristics in the two zones that may affect the shape of the S-graph. Application of S-graphs requires the selection of an appropriate S-graph and the estimation of the one parameter, basin lag. Four S-graphs have been selected for use in Maricopa County and a method to estimate lag is provided.

The USBR has revised the Flood Hydrology Studies chapter of *Design of Small Dams* (USBR, 3rd Edition, 1987), and it has identified S-graphs for application in six generalized regional and physiographic type of watersheds. Recently, the USBR has issued a *Flood Hydrology Manual* (Cudworth, 1989) that contains extensive discussion of flood hydrology in general, and S-graphs in particular. Both of these references should be consulted before using S-graphs. The S-graph has been adopted as the unit hydrograph procedure by Orange County and San Bernardino County, California, and selected S-graphs are presented in the hydrology manuals for those counties. The S-graphs in those hydrology manuals have been selected primarily from S-graphs that previously had been defined by the U.S. Army Corps of Engineers, Los Angeles District from a rather long and extensive history of analyses of floods in California.

An S-graph can, in theory, be used in any application for which an unit hydrograph can be used. In practice an S-graph must be first converted to an unit hydrograph, and this can be done by one of two methods. First, The S-graph can be converted to an unit-hydrograph manually; or second, the S-graph can be converted to an unit hydrograph by use of the MCUHP2 program. The MCUHP2 program outputs the HEC-1 input file with the S-graph converted to an unit hydrograph, and the unit hydrograph is written to a HEC-1 input file using the UI (Given Unit Graph) record. The use of MCUHP2 greatly facilitates the use of S-graphs.

Although the S-graph is completely dimensionless and does not have a rainfall excess duration associated with it, the unit hydrograph does require the specification of a duration. In general, the same rules and recommendations apply to the S-graph as were made for the Clark Unit Hydrograph; that is, the duration (computation interval, NMIN) selected for the development of the unit hydrograph from a S-graph should equal about 0.15 times the lag. A duration (NMIN) in the range 0.10 to 0.25 times the lag is usually acceptable.

5.6.2 Sources of S-Graphs

S-graphs for Maricopa County have been selected from a compilation of S-graphs for the Southwestern United States (Sabol, 1987a) and an evaluation of S-graphs (Sabol, 1993a) used in the Unit Hydrograph Study (Sabol, 1987b). The sources of S-graphs for that compilation were reports and file data of the U.S. Army Corps of Engineers, Los Angeles District, and the USBR, as well as data collected for the Unit Hydrograph Study from gauged watersheds in Walnut Gulch, Tucson, Albuquerque, Denver, and Wyoming.

5.6.3 S-Graphs for Use in Maricopa County

The four S-graphs selected for use in flood hydrology studies in Maricopa County are the Phoenix Mountain, the Phoenix Valley, the Desert/Rangeland, and Agricultural S-graphs. The Phoenix Mountain S-graph is to be used in flood hydrology studies of watersheds that drain predominantly mountainous terrain, such as Agua Fria River above Rock Springs, New River above the Town of New River, the Verde River, Tonto Creek, and the Salt River above Phoenix. Although the Corps of Engineers developed a separate S-graph for Indian Bend Wash, it is nearly identical to the Phoenix Mountain S-graph which may also be appropriate for Indian Bend Wash.

The Phoenix Valley S-graph is appropriate for flood hydrology studies of watersheds that have little topographic relief and/or urbanized watersheds. However, the Clark method is still the preferred unit hydrograph method for use in urban areas in Maricopa County. The Desert/Rangeland S-graph is appropriate for use in natural areas with little to moderate relief, such as foothills, distributary flow areas, and other undeveloped desert areas. The Agricultural S-graph as the name suggests should be used for areas under agricultural crops like cotton, wheat, or vegetables. Table 5.4 summarizes the four S-graphs and describes their general areas of applicability.

The four S-graphs are shown in Figures 5.9, 5.10, 5.11, and 5.12 and the coordinates of the graphs listed in Table 5.3. The selection of S-graph should be made based on a comparison of the watershed of interest to the watershed(s) used to develop the various S-graphs.

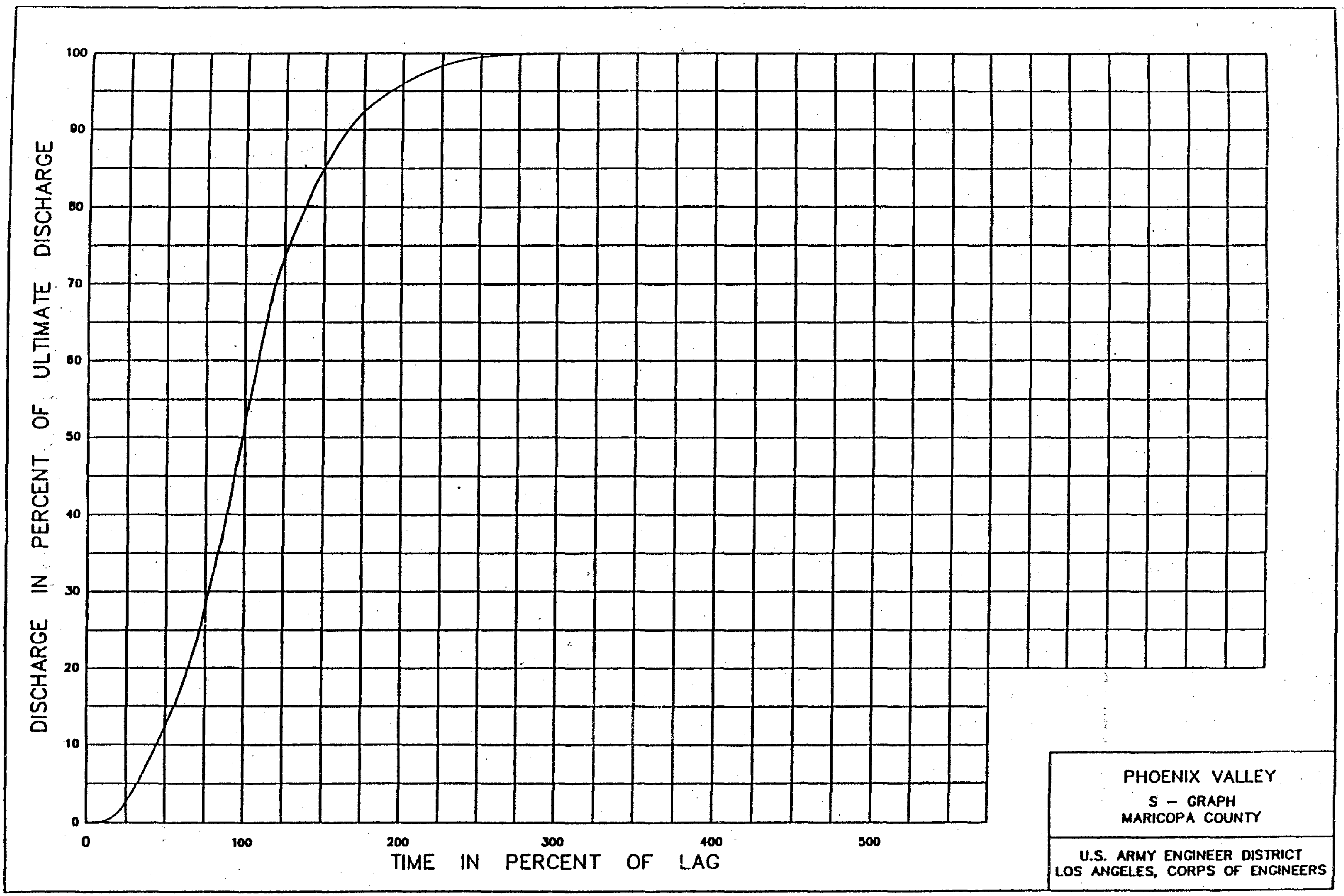
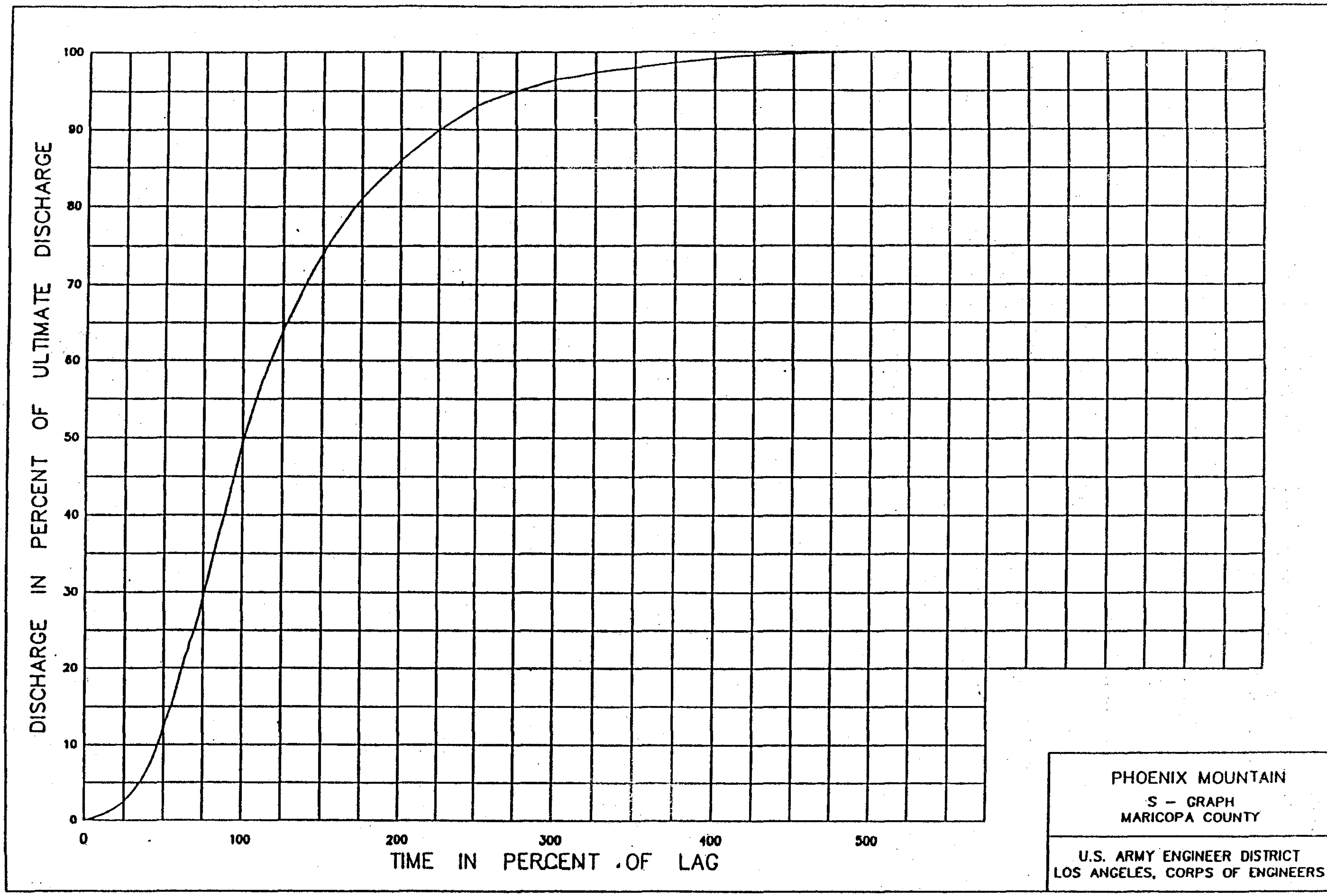

DISCHARGE IN PERCENT OF ULTIMATE DISCHARGE
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
TIME IN PERCENT OF LAG
PHOENIX VALLEY
S – GRAPH
MARICOPA COUNTY
U.S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS

Figure 5.9


DISCHARGE IN PERCENT OF ULTIMATE DISCHARGE
0
10
20
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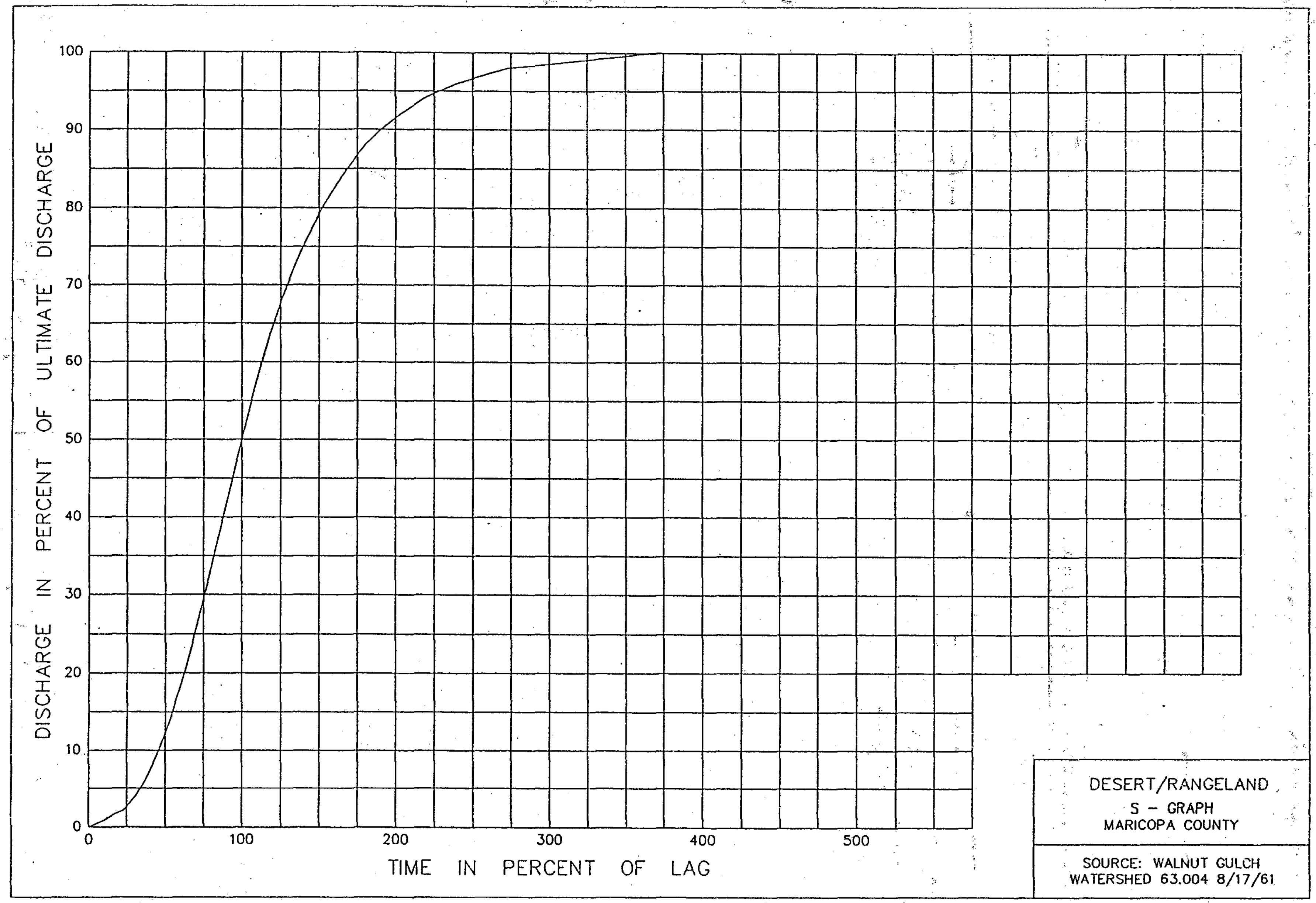
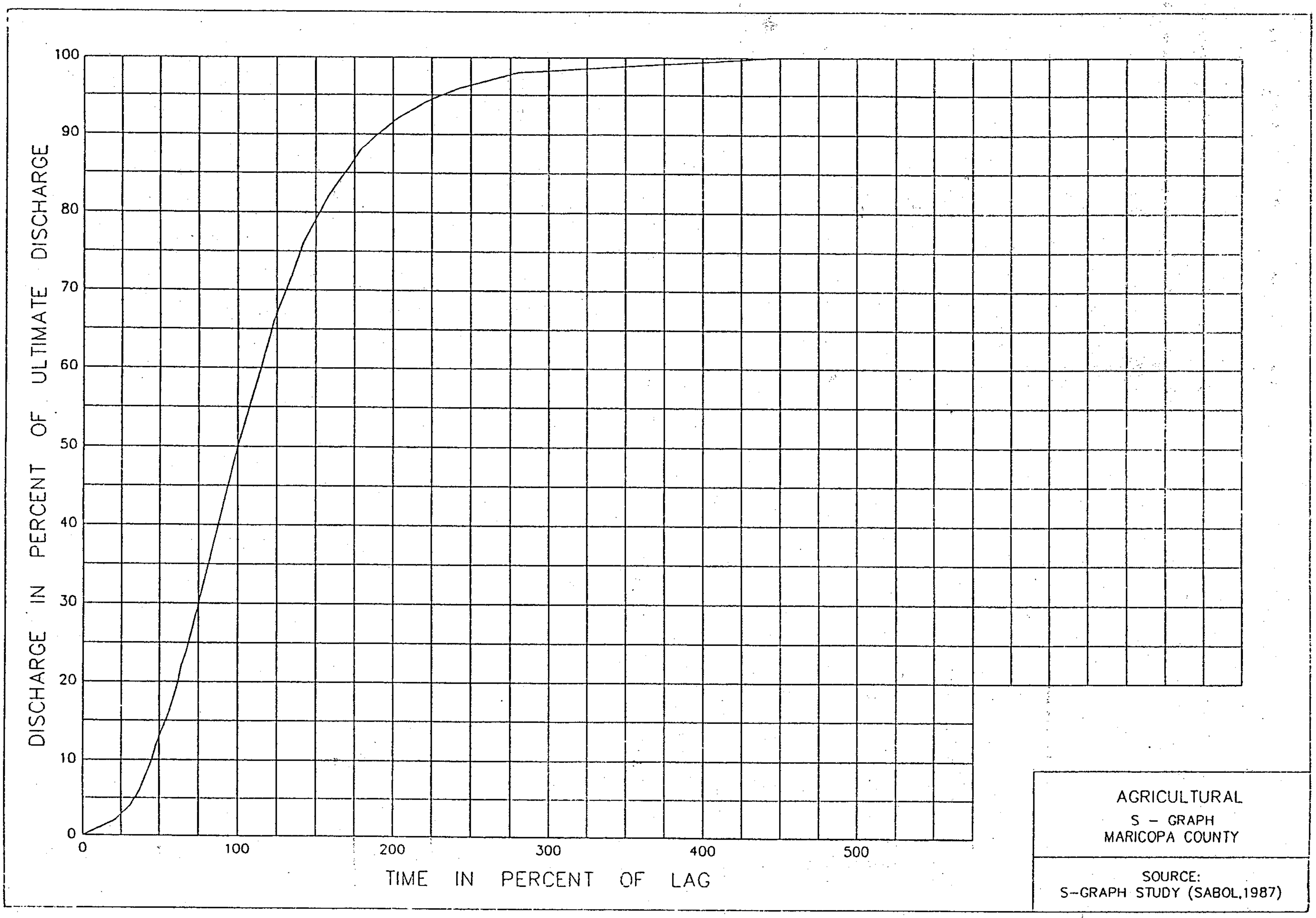
70
80
90
100
TIME IN PERCENT OF LAG
0
100
200
300
400
500
PHOENIX MOUNTAIN
S – GRAPH
MARICOPA COUNTY
U.S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS

Figure 5.10



DESERT/RANGELAND
S – GRAPH
MARICOPA COUNTY
SOURCE: WALNUT GULCH WATERSHED 63.004 8/17/61
DISCHARGE IN PERCENT OF ULTIMATE DISCHARGE
TIME IN PERCENT OF LAG
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500

Figure 5.11


DISCHARGE IN PERCENT OF ULTIMATE DISCHARGE
0
10
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60
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80
90
100
0
100
200
300
400
500
TIME IN PERCENT OF LAG
AGRICULTURAL
S – GRAPH
MARICOPA COUNTY
SOURCE:
S–GRAPH STUDY (SABOL,1987)

Figure 5.12

Table 5.3
Tabulation of Coordinates for S-graphs

Percent Ultimate Discharge	Time in Percent Lag			
	Phoenix Valley	Phoenix Mountain	Desert/Rangeland	Agricultural
0	0.0	0.0	0.0	0.0
2	23.0	23.0	23.0	21.0
4	30.0	31.0	31.0	31.0
6	36.0	37.0	36.9	37.0
8	41.0	42.0	41.7	41.0
10	45.7	46.0	45.9	45.0
12	50.0	49.8	49.7	48.0
14	54.1	53.4	53.2	52.0
16	58.0	56.8	56.4	56.0
18	61.7	60.0	59.7	59.0
20	65.2	63.1	62.5	62.0
22	68.5	66.1	65.3	64.0
24	71.6	69.0	68.0	67.5
26	74.6	71.8	70.6	70.0
28	77.5	74.4	73.2	72.5
30	80.2	76.8	75.7	75.0
32	82.7	79.1	78.3	77.5
34	85.0	81.2	80.7	80.0
36	87.2	83.2	83.1	82.5
38	89.0	85.1	85.5	85.0
40	91.1	86.8	87.9	87.5
42	92.9	88.8	90.3	90.0
44	94.6	91.0	92.7	92.5
46	96.3	93.8	95.1	95.0
48	98.1	96.8	97.5	97.5
50	100.0	100.0	100.0	100.0
52	102.0	103.4	102.5	103.0
54	104.1	107.0	105.1	106.0
56	106.3	110.8	107.6	109.0
58	108.6	114.7	110.3	112.0
60	111.0	118.7	113.0	115.0
62	113.5	122.9	115.9	117.5
64	116.1	127.3	119.0	120.5
66	118.8	131.9	122.3	123.0
68	121.6	136.7	125.6	127.0
70	124.5	141.7	129.3	131.0
72	127.5	147.1	133.2	135.0
74	130.7	152.8	137.4	138.6
76	134.1	158.8	141.9	142.0
78	137.7	165.5	146.8	147.0
80	141.5	172.9	152.1	152.5
82	145.5	181.6	158.0	158.0
84	149.9	191.0	164.5	165.0
86	154.6	201.0	172.0	172.5
88	159.6	212.0	180.4	179.0
90	165.6	226.0	190.7	190.0
92	173.6	244.0	202.9	203.0
94	186.6	265.0	217.9	220.0
96	200.6	295.0	239.6	243.0
98	223.6	342.0	273.2	280.0
100	298.6	462.0	367.7	448.0

5.6.4 Estimation of Lag

The application of an S-graph requires the estimation of the parameter, basin lag. A general relationship for basin lag as a function of watershed characteristics is given by Equation 5.11:

$$Lag = C\left(\frac{LL_{ca}}{S^p}\right)^m \tag{5.11}$$

where Lag=basin lag in hours

L	=	length of the longest watercourse in miles
Lca	=	length along the watercourse to a point opposite the centroid in miles
S	=	watercourse slope in feet per mile
C	=	coefficient and m & p = exponents.

The Corps of Engineers often uses C = 24Kn where Kn is the estimated mean Manning's n for all the channels within an area, and m = 0.38. The USBR (1987) has recommended that C = 26Kn and m = 0.33. Both sets of values in Equation 5.11 will often result in similar estimates for Lag. Traditionally the exponent, p, on the slope is equal to 0.5.

It should be noted that Kn is a measure of the hydraulic efficiency of the watershed and it is not necessarily a constant for a given watershed for all rainfall depths and rainfall intensities. As rainfall depth and/or rainfall intensity increases the efficiency of runoff increases and Kn decreases. Therefore, some adjustment in Kn should be made for use with rainfalls of different magnitudes (frequencies). Generally, Kn is the smallest for extreme floods such as PMFs and increases as the frequency of event increases.

5.6.4.1 Selection of Kn The selection of a representative Kn value for a particular watershed is an inherently subjective process. However, some guidelines are given for the selection of Kn in Maricopa County in conjunction with the four recommended S-graphs. Table 5.4 contains a summary of these guidelines. Additional guidance may be gleaned from the calculated Kn values for numerous watersheds provided in Appendix K. Care should be taken to keep in mind the limitations discussed above when selecting Kn for any given watershed.

Several graphical relations are available for estimating basin lag. One such relation (U.S. Army Corps of Engineers, 1982a) is shown in Appendix K. Several other relations that should be consulted when using S-graphs are contained in *Design of Small Dams* (USBR, 1987) and the USBR *Flood Hydrology Manual* (Cudworth, 1989).

When estimating basin lag the following steps should be used:

1. From an appropriate map of the watershed, measure drainage area (A), and the values of L, L_{ca}, and S.

2. Calculate the basin factor $LL_{ca}/(S^{0.5})$.

3. Use data in Appendix K *or* the tables in *Design of Small Dams* or the *Flood Hydrology Manual* to attempt to identify watersheds of the same physiographic type and similar drainage area and basin factor. Make a list of watersheds with similar drainage areas and basin factors, and tabulate the estimated value of Kn for those watersheds, and the measured lag.

4. Estimate Kn for the watershed by inspection of the tabulation, step 3.

5. Estimate lag by Equation 5.11. Use values of C and m corresponding to the source (U.S. Army Corps of Engineers or USBR) that was used to estimate Kn.

6. Compare the calculated lag with the measured lag for similar watersheds (step 3).

The use of measured values of Kn from hydrograph reconstitutions of similar watersheds will provide the most reliable estimates of Kn and basin lag.

Table 5-4
S-Graphs and Kn Values

S-Graph Type	Description	Kn Min	Kn Avg	Kn Max	Description
Phoenix Valley	Very shallow slopes and/or partially urbanized	0.015	---	0.15	variations dependent upon slope, degree of urbanization and connected impervious areas and development of organized drainage improvements; extreme high values may be appropriate in very flat areas with little or no drainage network
Phoenix Mountain	Mountain	0.045	0.05	0.055	quite rugged, with sharp ridges and narrow, steep canyons through which watercourses meander around sharp bends, over large boulders, and considerable devbris obstruction; grojnd cover, excluding small areas of rock outcrops, includes many trees and considerable underbrush; no drainage improvements
	Foothills	0.027	0.03	0.033	gently rolling, with rounded ridges and moderate side slopes; watercourses meander in fairly straight channels with some boulders and lodged debris; ground cover includes scattered brush, cactus and grasses; no drainage improvements
Desert/Rangeland	Gently sloping natural areas including distributary flow areas	0.020	0.025	0.03	variations from minimum to maximum roughness due to degree of definition of watercourses, extent of vegetation, and land surface hydraulic condition
Agricultural	Actively cultivated areas with crops	0.06	0.10	0.15	variations from minimum to maximum dependent upon slope, crop type and density

Note: The majority of Kn data upon which these values are based come from rainfall-runoff events of magnitude less than the 100-year event. Therefore, selected Kn values for a given design storm need to be evaluated for the purposes of modeling a particular watershed response to that design storm.

6

Channel Routing

6.1 General

Channel routing involves generation of an outflow hydrograph for a reach where an inflow hydrograph is specified. A reach is either an open channel with certain geometrical/structural specifications, or a pipe with open channel flow. This type of application assumes that the flow is not confined, and that surface configuration, flow pattern and pressure distribution within the flow depend on gravity. It also assumes that there is no movement of the bed or banks. In addition no backwater effects are considered.

A routing technique is normally required for a multi-basin design where flow is to be moved through time and space from one flow concentration point to the next. For the purposes of this manual, two types of open channels, natural and urbanized, are considered. Kinematic Wave Routing may be applied for urbanized channels since the routing process involves minimal attenuation. Non-pressurized pipe flow will also be through Kinematic Wave Routing procedures. Muskingum Routing may be used for natural, undeveloped channels since the method simulates outflow peak attenuation resulting from storage in the system. The Muskingum-Cunge Routing method may be used for both natural and man-made channels. However, since the 1992 revisions to the Drainage Design Manual, Volume I, some problems have been discovered with the use of Muskingum-Cunge routing in certain circumstances. For example, different results may occur if NMIN is changed. Also, peak discharges have been noted to increase through a routing reach. This problem appears to be especially acute when quickly rising hydrographs are routed through steep channel reaches. Another problem occurs with flat or null hydrographs. The lack of wave celerity in these flat hydrographs causes HEC-1 to fail to complete normal program execution (i.e. it crashes). Therefore, a third routing method is suggested as an alternative to Muskingum-Cunge routing, if a change is required or preferred by the engineer or hydrologist. This third method is the Normal-Depth routing method. All of these routing methods are options in HEC-1 which is again the principle modeling tool of the *Hydrology Manual*. The Modified Puls method which is typically used for routing through a structure or a detention basin is discussed in detail in the *Drainage Design Manual, Volume II, Hydraulics.*

6.2 Kinematic Wave Routing

The Kinematic Wave Routing as described in HEC-1 can be applied for routing of overland flow, collector channels and the main channel. However, for the purposes of this manual, the overland flow option of the Kinematic Wave will not be used. The overland flow analysis will be performed using the Maricopa County Unit Hydrograph Procedure (MCUHP), described in Chapter 5 of this manual. Once a hydrograph is generated through the MCUHP, it can be used as the inflow hydrograph for an urbanized open channel or a pipe where an outflow hydrograph is required. These reaches can be treated as collector channels or the main channel, as the case may be.

6.2.1 Collector Channel

Modeling of flow at a point where it becomes channel flow to a point where it enters the main channel is done as a collector channel element. It is assumed that the flow along the path of the channel is uniformly distributed. This is a proper assumption for a case when overland flow runs directly into a gutter. It is also a reasonable approximation of the flow as it passes through a storm drain system from a catch basin and the collector pipes along the collector channels.

6.2.2 Main Channel

The main channel element can be used to route inflow from an upstream subbasin or a combination of inflows from collector channels along a subbasin. The flow is assumed to be uniformly distributed, which appears to be a reasonable assumption when the flow is received from collector channels at several locations.

6.2.3 Parameter Selection

The data requirement for channel routing include surface drainage area, channel length and slope, channel shape and geometry, Manning's n, and the inflow hydrograph. The designer is referred to the HEC-1 manual for the proper selection of these parameters.

When working with the Kinematic Wave Method, it is important to be familiar with the computational procedures inherent in the model. In order to solve the governing equations which theoretically describe the Kinematic Wave Method, proper selection of time step and reach length are required. The designer will specify a channel reach length and a computational time step for the inflow hydrograph. This time step could very well be different from the one selected by the computer for computational purposes. Furthermore, the computer will use this information to select distance intervals based on the given reach length.

The computational process could unrealistically attenuate the outflow peak. It appears that a longer reach length would cause more attenuation. To overcome this problem, the September 1990 version of HEC-1 will calculate the outflow peak by applying both the time step selected by the designer as well as the one selected by the program. If the resulting peaks are not reasonably close, the designer can modify the selected time step or the reach length to improve the calculations. It should be noted that the program will compare peak flow values for the main channel and not the collector channels.

6.3 Muskingum Routing

Flow routing through natural channels can be accomplished by applying the Muskingum Routing technique. The main characteristic of natural channels with respect to routing is that the outflow peak can be drastically attenuated through storage loss, a process which is simulated by Muskingum routing.

6.3.1 Parameter Selection

Application of Muskingum Routing requires input values for parameters X and K. Parameter X has a range of values 0.0 to 0.5, where 0.0 represents routing through a linear reservoir and 0.5 indicates pure translation. Parameter K indicates the travel time of a floodwave through the entire routed reach. There are several methods which can be used to estimate K such as average flow velocity adjusted by a celerity factor, the time difference between peak inflow and peak outflow, or by using stage-discharge relationships. For more details the reader is referred to the HEC-1 manual and Chapter 7 of this manual. Once again, since the computational method within HEC-1 may result in an unstable solution, parameters K, X, and NSTPS (number of steps) must be checked to insure that an adequate number of subreaches is used.

In those rare situations that observed inflow *and* outflow hydrographs are available, K, X, and NSTPS can be calibrated by trial and error to enable reproduction of outflow hydrographs. Chapter 5 of the U.S. Bureau of Reclamation's *Flood Hydrology Manual* (Cudworth, 1989) is an excellent source of Muskingum routing information.

6.4 Muskingum-Cunge Routing

The Muskingum-Cunge routing method is based on the principle of hydraulic diffusivity, which simulates an attenuation of the flood peak through the routing reach. This method can be used for both man-made and natural channels where overbank flow is expected, provided the conveyance can be accurately described with an eight-point cross section. A complete description of Muskingum-Cunge applications and guidelines for parameter selection can be found in the September 1990, and later versions of the *HEC-1 Flood Hydrograph Package, User's Manual.*

6.4.1 Parameter Selection

Input data for Muskingum-Cunge routing include energy slope (or bed slope), reach length, and either the channel shape and a single Manning's "n" for a man-made channel, or an eight-point cross section with channel and overbank roughness coefficients for a natural channel. Example 8 provides guidance on both applications of Muskingum-Cunge routing.

6.5 Normal-Depth Routing

The Normal-Depth routing method uses the modified Puls routing method with storage and outflow data being computed by HEC-1 from channel characteristics entered by the user into the HEC-1 data file. This method allows the user to define a representative 8-point cross-section for the routing reach as well as overbank and main channel roughness values. For a complete description of the use and application of Normal-Depth routing in HEC-1 refer to the HEC-1 User's Manual.

7 Application

7.1 General

The methodologies presented in this Manual are, for the most part, standard procedures and practices commonly used in hydrologic analysis. However, the user of the manual may not always be familiar with these techniques because of a different previous experience or interest. A number of examples were developed to familiarize the user with the presented methods as well as the details of parameter estimation. In addition, this Chapter should provide some general suggestions to facilitate particular applications.

7.2 Notes on Design Rainfall

Some of the design rainfall criteria that are contained in Chapters 2 and 3 were based on the analysis of published rainfall statistics for the Phoenix metropolitan area. Specifically, the 2-hour storm distribution (Figure 2.15), Pattern No. 1 of the 6-hour storm distribution (Figure 2.16), and the intensity-duration-frequency relation (Figure 3.2), were all developed from rainfall statistics in NOAA Atlas 2 for the Phoenix Sky Harbor Airport location.

Those two storm distributions are dimensionless and therefore there may be little deviation between the use of those distributions and distributions that would be developed by the same procedure, but using site-specific rainfall statistics from NOAA Atlas 2. The 2-hour distribution and Pattern No. 1 of the 6-hour distribution are intended to be applicable throughout Maricopa County. However, there could be situations where site-specific distributions would be appropriate. In such cases, the distributions can be developed by the same procedures that were used to develop the distributions in this manual. The *Documentation Manual* should be consulted to obtain the details of the procedure. The use of the PREFRE program is encouraged in the development of the site-specific depth-duration-frequency statistics.

When using the Rational Method in Maricopa County, the intensity-duration-frequency (I-D-F) curve (Figure 3.2) is for the Phoenix metropolitan area. That I-D-F curve can be used throughout Maricopa County; however, there could be situations where a site-specific I-D-F curve would be appropriate. In such cases, the I-D-F curve can be developed from site-specific rainfall statistics from NOAA Atlas 2. The use of the PREFRE Program is encouraged when developing the site-specific depth-duration-frequency statistics. I-D-F graph paper is provided in Appendix G.

Before developing and using site-specific rainfall criteria (the 2-hour storm distribution, Pattern No. 1 of the 6-hour distribution, or the rainfall intensity-duration-frequency relation), this should be discussed with the Flood Control District and the local agency.

7.3 Notes on Calculating Loss Parameters

1. Since many of the soil groups contain horizons of different textures, the top horizon may or may not control the total volume and rate of infiltration. The decision of which soil layer controls the infiltration rate is based on soil texture, horizon thickness, and the accumulated depth of water during the initial low-intensity period of a design storm. As a general rule, sandy and loamy sand soils less than 2 inches thick will not act as the controlling horizon during a 100-year design storm.

2. Use caution when applying impervious cover percentages using the RTIMP variable. RTIMP will directly convert the assigned percentage of areal rainfall to runoff. If the SCS soil description lists a soil group as having 25 percent rock outcrop, 25 percent of the area will contribute direct runoff to the outlet only if the rock outcrop areas are hydraulically connected, which is rarely the case. This situation also exists in urban areas, where the impervious areas are streets and driveways rather than rock outcrop. Good judgement should be used to assess flowpaths and the infiltration characteristics of soils adjacent to impervious areas when using the RTIMP variable.

3. There are currently three Soil Survey volumes available for Maricopa County and adjoining areas, generally in the central, eastern, and northern regions. Copies of the Soil Surveys can be obtained from the Soil Conservation Service Field Offices.

4. Map unit values of XKSAT (bare ground) have been calculated based on individual soil textures, percentage of soil textures in a map unit, XKSAT values from Table 4.2, and a logarithmic area-weighting procedure. These map unit values of XKSAT are provided in Appendices A, B, and C. Those values can be used, in most cases, to calculate basin or subbasin average values of XKSAT.

5. The PSIF and DTHETA values are taken from Figure 4.3 as a function of the basin or subbasin average value of XKSAT (bare ground).

6. XKSAT (bare ground) is adjusted for the effects of vegetation cover by use of Figure 4.4. The PSIF and DTHETA values are not adjusted for vegetation cover.

7.4 Notes on the Application of the Clark Unit Hydrograph and the Calculation of Parameters

1. The Clark Unit Hydrograph procedure was developed from a database that includes both urban and natural (undeveloped) desert/rangeland watershed. Its primary application is for urban watersheds, but is applicable for desert/rangeland watersheds also. In general, it should not be applied to agricultural fields or steep mountain watersheds.

2. The size limitation for a watershed or modeling subbasin must be observed when using the Clark Unit Hydrograph procedure. The recommended size limit is 5 square miles with an upper limit of 10 square miles. In addition to that limit, the calculated Tc should not exceed the duration of rainfall excess. For example, a 4-square mile subbasin is being used for which the duration of rainfall excess is calculated to be 1.0 hour and the Tc is calculated as 1.5 hours. The Clark procedure should not be used and the modeler has two options: (1) subdivide the subbasin into two or more smaller subbasins so that none of the Tcs exceed the duration of rainfall excess; or (2) use another unit hydrograph procedure such as the S-graph.

3. Tc represents the time for a floodwave to travel from the hydraulically most distant point in the watershed to the outlet during the most intense period of rainfall excess. The flow path length (L) represents the hydraulic length corresponding to Tc. For a natural channel, L is the length of watercourse from the outlet to a point defining the hydraulically most distant point. For an urban basin where flow is mainly in streets and no primary channels exist, an average flow path should be selected, such as a line parallel to grade from the outlet to the upper watershed boundary.

4. Excess Rainfall Values: When developing the peak period of rainfall excess on the "Calculation of Tc & R" worksheet (Appendix E), start at the largest depth for the Δt used, choose the largest value above or below the peak, then the value above or below those two, and so on so that a contiguous grouping results. Do not list the depth values in a strictly descending order unless they are contiguous. Example:

Time	Excess(in)	Rank	Sorted
1415	0.21	6	0.40
1420	0.28	5	0.35
1425	0.35	2	0.32
1430	0.40	1	0.33
1435	0.32	3	0.28
1440	0.33	4	0.21
1445	0.18	7	0.18

Alternatively, program "MCUHP1" can be used to calculate Tc and R. This program will also construct the basin HEC-1 input file containing the appropriate Clark input (UC and UA records).

5. Worksheet: The worksheet allows a maximum of eight excess rainfall values to be entered, and this is sufficient in most cases. As a result, if $\Delta t = 5$ minutes (where Δt is hydrograph time step), then Tc should be less than (8*5)=40 minutes. For $\Delta t = 10$ minutes, Tc < 80 minutes, and so on. Remember that in no case should Tc be less than Δt for computational stability. The worksheet can be modified to allow calculation using any number of rainfall excess values. The worksheet is *not* needed if the MCUHP1 program is used.

6. Remember that Tc is a function of excess rainfall intensity and must be recalculated when the duration or frequency of a design storm is changed. If multiple frequencies are desired for a given duration, it may be acceptable to construct a graph of Tc vs. Frequency, when the peak producing portion of the distribution is maintained. In such a case, plot the 2, 10, and 100 year Tc values on semi-log paper, and interpolate intermediate values.

7. When calculating Tc for natural watersheds with overall slopes greater than 200 feet/mile, use Figure 5.4 to adjust the slope.

8. In cases where more than one basin roughness exists in a watershed, the basin roughness factor (Kb) should be weighted in the following manner:

   Say a 3.75 square mile watershed is 35 percent "moderately low roughness" (Type B) and 65 percent "moderately high roughness" (Type C). Calculate K_b separately for each roughness category, then weigh according to percentages, i.e.:

   Type B ——→ $-0.01375\ (\log 3.75 \times 640) + 0.08 = 0.034$

   Type C ——→ $-0.025\ (\log 3.75 \times 640) + 0.15 = 0.065$

   $$K_b = (0.35)(0.034) + (0.65)(0.065) = 0.054$$

7.5 Notes on the Application of S-graphs

1. The recommended S-graphs for Maricopa County, i.e., Phoenix Mountain, Phoenix Valley, Desert/Rangeland, and Agricultural S-graphs, should only be applied to large, natural watersheds. The Phoenix Valley S-graph can also be applied to large, urban basins. This is in part due to the fact that the original data base in Arizona applied the methodology to large watersheds. As a lower limit of application a watershed area of 5 square miles can be considered.

2. The Kn should be selected from the best available information. General guidance and some regional data are available from the U.S. Army Corps of Engineers (Figure 5.11). A broader range of data for watersheds in Maricopa County is provided in the U.S. Bureau of Reclamation, *Flood Hydrology Manual*

(Cudworth, 1989). The *S-Graph Study* (Sabol, 1987) contains Lag and watershed characteristics data that are not generally contained in other publications. These sources should be consulted when selecting K_n.

3. The manual discusses two slightly different forms of the Lag equation, one by the U.S. Army Corps of Engineers and one by the U.S. Bureau of Reclamation. The form of the equation that corresponds to the source used in selecting K_n should be used.

4. Program *MCUHP2* can be used to convert an S-graph into a unit-graph. This program, provides the necessary basin HEC-1 file with the appropriate rainfall pattern distribution.

5. The length to centroid (L_{ca}) is measured along L to a point on L that is essentially opposite (perpendicular to) the basin centroid. L_{ca} is not measured to the centroid unless the centroid happens to lie on the flow path line (L).

7.6 Notes on the Application of Kinematic Wave Routing

1. Kinematic Wave Routing is most appropriately used where peak attenuation and channel transmission losses are not expected to be significant. The usual applications are for defined urban channels and short, steep natural channels.

2. The computational procedure of the Kinematic Wave Routing Method may unrealistically attenuate the outflow peak. It appears that longer reach lengths cause more attenuation. To overcome this problem, the more recent versions of HEC-1 will calculate the outflow peak by applying both the time step selected by the designer as well as the one selected by the program. If the resulting peaks are not reasonably close, the designer can modify the selected time step or the reach length to improve the calculations. It should be noted that the program will compare peak flow values for the main channel and not the collector channels.

3. When working with Kinematic Wave Routing, channel capacity must be checked to assure proper conveyance of flow prior to the HEC-1 run. Otherwise, if the channel is undersized, the program will automatically extend channel boundaries to contain the flow.

4. The guidance, comments, and warnings in the HEC-1 User's Manual should be studied and carefully observed in applying the Kinematic Wave method.

7.7 Notes on the Application of Muskingum Routing

1. The Muskingum Routing method can be used where flood peak attenuation is expected. The best application of this method is for larger rivers with relatively flat slopes.

2. The parameters, K and X, are best determined by the analysis of streamgauge data, if available. Where such data are available, K and X can be determined by analytic methods as presented in many hydrology textbooks, or the HEC-1 parameter optimization option can be used. Other regional flood studies (by the U.S. Army Corps of Engineers and others) may contain the results of such analyses for larger rivers in the County.

3. The following parameter estimation procedures apply primarily to natural stream channels which convey a significant amount of flow in the overbank areas during design-frequency events.

4. NSTPS: The choice of a number of subreaches for a particular stream reach can be checked for computational stability using the following equation from the HEC-1 Manual:

$$\frac{1}{2\,(1-X)} \leq \frac{K}{NSTPS\Delta t} \leq \frac{1}{2\,(X)}$$

where K = the travel time through the entire reach in hours

X = Muskingum 'X'

Δt = the computational time step (hrs),

NSTPS = the integer number of subreaches.

5. K: K is the travel time of the floodwave peak through the entire reach. Calculation using Manning's equation is usually an appropriate method for estimating the floodwave velocity, *Vm*, with the following provisions:

   A. Use an average channel area and wetted perimeter for the reach—assume bankfull conditions.

   B. Choose an 'n' value representative of the main channel only—do not include the overbank roughness in a weighted average.

   C. Calculate an average flow velocity for the reach (*V*).

D. Use the following ratios (Cudworth, 1989) to estimate *Vm*, the velocity of the floodwave:

Channel Geometry	Vm/V
Wide rectangular	1.67
Wide parabolic	1.44
Triangular	1.33

The value of K is then estimated by dividing the reach length by *Vm*.

6. X: For wide, shallow channels with low to moderate slopes and significant overbank flow during the design flood being modeled, choose X = 0.15 to 0.25. For steep to very steep, narrow, deep channels with little overbank flow, choose X = 0.25 to 0.40.

7.8 Notes on the Application of Muskingum-Cunge Routing

Muskingum-Cunge routing (RD record) is an option in HEC-1 that often provides improved routing simulation over other routing options and it should be considered for most channel routing requirements. The advantages of Muskingum-Cunge routing are: (1) the parameters of the model are physically based, and (2) the method simulates unsteady flow routing over a wide range of flow conditions.

This option can be used with virtually any channel geometry, although for non-prismatic channels, a "representative" channel geometry must be selected that represents the actual channel geometry for the routing reach. For constructed channels and some natural channels, this routing option can be used by providing all input on the RD record only. This requires selection of a predetermined channel shape (see the HEC-1 User's Manual). Complex channel geometry and/or variable channel roughness (channel and overbank) can be modeled with the additional use of RC, RX, and RY records. An eight-point cross section is input on the RX and RY records to describe the representative channel geometry.

The Muskingum-Cunge option is encouraged in routing situations where flow attenuation due to routing is expected. This will occur in long, broad channels with relatively mild slopes. There is probably little advantage in using Muskingum-Cunge routing for short, relatively steep channels. In those cases, Kinematic Wave routing (RK record) may be adequate. For large rivers with gauging stations and recorded flood hydrographs, Muskingum routing (RM record) may be preferable. This is particularly true if recorded flood hydrographs are analyzed to estimate the Muskingum K and X parameters, and the HEC-1 optimization routine can be used for this purpose.

Several points, beyond those in the HEC-1 User's Manual, are noted when using the Muskingum-Cunge option:

1. Execution of the HEC-1 program may terminate with a math error message if the inflow to the routing reach is zero (no runoff generated from the upstream watershed). This may occur in situations that have either very low rainfall depth (intensities) or exceptionally high rainfall losses. Conversion of those RD records to RK (Kinematic Wave Routing) may provide an adequate solution while maintaining a routine operation in the model. Conversion back to RD would generally be advised if model input is revised such that runoff to the routing reach is produced.

2. The use of the Muskingum-Cunge routing option usually results in longer computation time in HEC-1. Run time may be increased appreciably when using the Depth/Area Storm option (JD record); however, this alone should not be a practical deterrent against using the Muskingum-Cunge method.

8

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Appendix A

Aguila-Carefree Loss Rate Parameters

Assumptions and criteria used in developing XKSAT tables in Appendices A, B, and C:

1. Soil textures determined in the SCS Soil Surveys were used as a basis for calculating XKSAT rather than individual soil sieve analyses.

2. If a soil texture was described as "gravelly," "very gravelly," "extremely gravelly," etc., its textural classification was bumped up one level in Table 4.2 to account for higher infiltration rates caused by increased biotic activity below surface gravels, and the decrease in areal pore clogging from falling raindrops. Example: a "gravelly loam" became a "sandy loam." Exception: sandy loams were not bumped to loamy sands unless they were described as "very gravelly" or "extremely gravelly." Conversely, "fine" and "very fine" sandy loams were bumped down to loams, due to their sieve analyses.

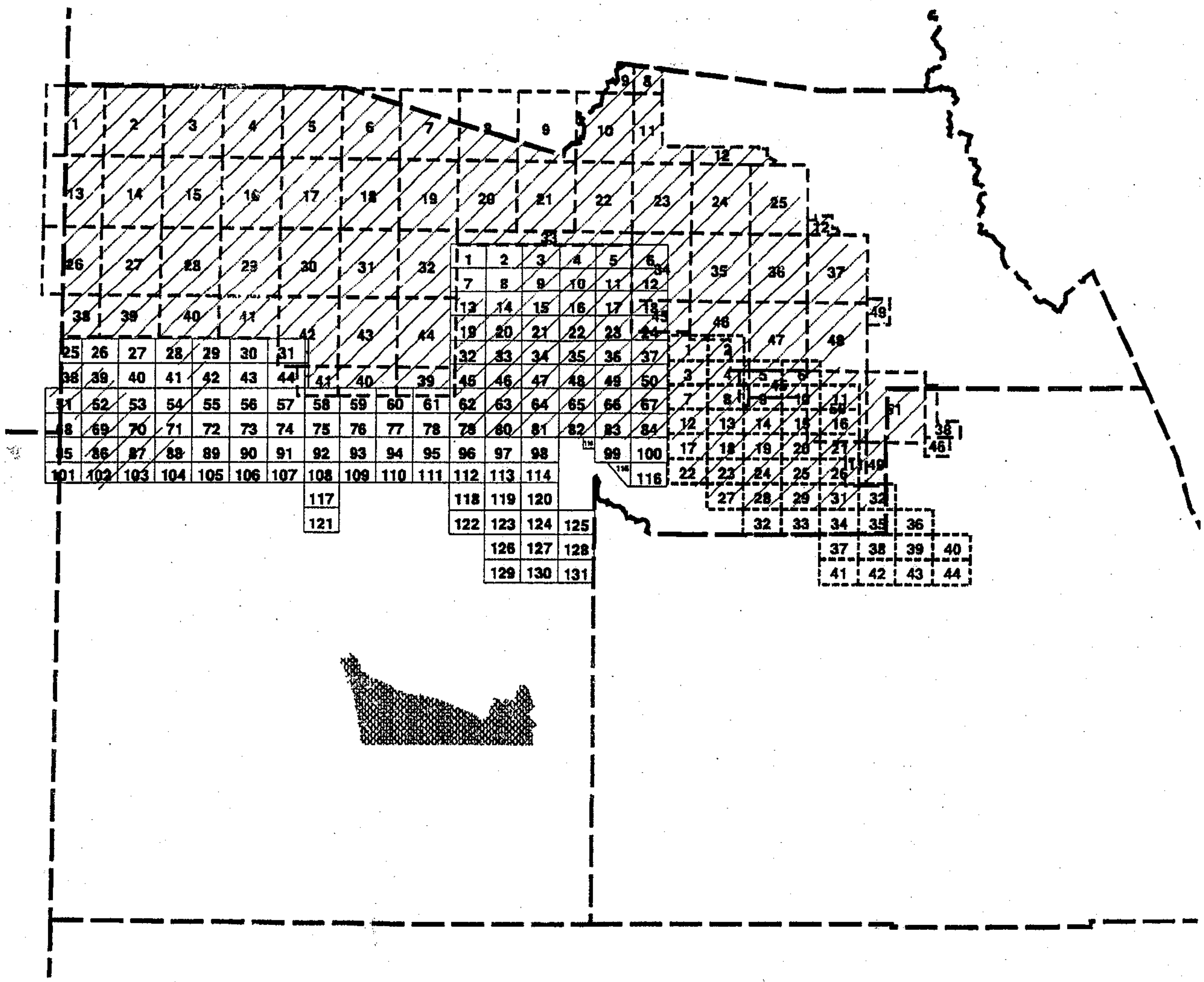
3. If a surface soil horizon was less than 3 inches deep, its XKSAT value was compared to the adjoining horizon, and the slower rate was reported in the table.

4. *Minor Soil Textures*: if more than one texture is assigned to a soil name in the map unit descriptions, then its minor soil designation was assigned as that which most closely matched the major soil(s) for the map unit in question. Each minor soil was given equal weight in determining the weighted map unit average XKSAT.

5. *Rock Outcrop*: Soil percentages within map units were normalized based on the percentage of rock outcrop stated in the soil surveys. Rock outcrop listed as a minor soil was ignored, since the chances are good that minor outcrop areas are not hydrologically connected to a subbasin concentration point.

6. *Maricopa Central Part Soil Survey*: In the few cases where a minor soil percentage was not given, 5 to 15% was assumed depending on percentages assigned to other soils in the series. In the Eastern Maricopa survey, minor soils were ignored since no percentages were given and because their textures generally match those of the major soils.

SOIL STUDY INDEX MAP



----- = Aguila-Carefree Area Parts of Maricopa and Pinal Counties

——— = Maricopa County, Central Part

--------- = Eastern Maricopa and Northern Pinal Counties Area

— — = County Lines

= S.C.S. Digital Soil Data Availability Area

= Unpublished S.C.S. Data Availability Area

Based on U.S.D.A. Soil Conservation Service Information

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT HYDROLOGY - 1992 UPDATE PAGE ____ OF ____

DETAIL ____ COMPUTED ____ DATE ____

____ CHECKED BY ____ DATE ____

EXAMPLES OF XKSAT CALCULATIONS USED TO CONSTRUCT TABLES IN APPENDICIES A, B, and C.

APPENDIX A

MAP UNIT No. 65: GREYEAGLE - CONTINENTAL - NICKEL ASSOCIATION

MAJOR SOILS:
- GREYEAGLE GRAVELLY LOAM AT 1 to 5 inches (45%)
- CONTINENTAL CLAY LOAM AT 2 to 5 inches (25%)
- NICKEL VERY GRAVELLY LOAM AT 0 to 5 inches (15%)

MINOR SOILS: (3% each)
- OHACO CLAY LOAM
- SUN CITY SANDY CLAY LOAM
- CAVE LOAM
- MOHAVE CLAY LOAM
- ARIZO LOAMY SAND

IN TABLE 4.2, GRAVELLY AND VERY GRAVELLY LOAMS (GREYEAGLE AND NICKEL) WILL BE ASSIGNED THE XKSAT VALUE FOR SANDY LOAM.

$$XKSAT = ALOG[.45(\log .40) + .25(\log .04) + .15(\log .40) + .03(\log .04) + .03(\log .06) + .03(\log .25) + .03(\log .04) + .03(\log 1.2)] = \underline{0.19 \text{ in/hr}}$$

APPENDIX B

MAP UNIT CO: CHERIONI - ROCK OUTCROP COMPLEX

MAJOR SOILS:
- CHERIONI VERY GRAVELLY LOAM AT 0-6 inches (50%)
- ROCK OUTCROP (20%)

MINOR SOILS: (30%)
- GACHADO VERY GRAVELLY CLAY LOAM
- PINAL LOAM
- GUNSIGHT LOAM
- RILLITO LOAM

SINCE THIS MAP UNIT CONTAINS ROCK OUTCROP, THE SOIL PERCENTAGES MUST BE NORMALIZED:

CHERIONI → 50/100-20 = 62.5%

MINOR SOILS → 30/80 = 37.5% /4 = 9.4% each

IN TABLE 4.2, VERY GRAVELLY LOAM (CHERIONI) WILL BE ASSIGNED THE XKSAT VALUE FOR SANDY LOAM; VERY GRAVELLY CLAY LOAM WILL BE ASSIGNED THE VALUE FOR SANDY CLAY LOAM.

$$XKSAT = ALOG[.625(\log .40) + .094(\log .06) + 3(.094)(\log .25)] = \underline{0.29 \text{ in/hr}}$$

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/ hour
1, 2	Antho	Sandy Loam	80	0-3	Sandy Loam	0.41
	Carrizo		4		Loamy Sand	
	Gilman		4		Loam	
	Maripo		4		Sandy Loam	
	Denure		4		Sandy Loam	
	Monoli		4		Sandy Loam	
3, 4	Antho	Sandy Loam	35	0-3	Sandy Loam	0.58
	Carrizo	Loamy Sand	30	0-28	Loamy Sand	
	Maripo	Sandy Loam	20	0-18	Sandy Loam	
	Brios		2.5		Loamy Sand	
	Gilman		2.5		Loam	
	Vint		2.5		Sandy Loam	
	Denure		2.5		Sandy Loam	
	Momoli		2.5		Sandy Loam	
	Carrizo		2.5		Loamy Sand	
5	Anthony	Sandy Loam	80	0-2	Sandy Loam	0.43
	Gila		10		Loam	
	Arizo		10		Loamy Sand	
6, 7	Antho	Sandy Loam	40	0-2	Sandy Loam	0.62
	Arizo	Very Gravelly Sandy Loam	40	1-8	Loamy Sand	
	Arizo	Sandy Loam	20		Sandy Loam	
8	Arizo	Very Cobbly Sandy Loam	80	1-8	Loamy Sand	0.96
	Stratified Sediment	—	20		Sandy Loam	
9	Beeline	Sandy Loam, Loam, Fine Sandy Loam	70	1-9	Loam	0.27
	Cipriano	Very Gravelly Loam	15	0-6	Sandy Loam	
	Ebon		2.5		Silty Clay Loam	
	Luke		2.5		Silty Clay Loam	
	Gunsight		2.5		Loamy Sand	
	Rillito		2.5		Loam	
	Antho		2.5		Sandy Loam	
	Carrizo		2.5		Loamy Sand	
10, 11	Brios	Loamy Sand	40	0-2	Loamy Sand	0.94
	Carrizo	Very Gravelly Sand	40	2-60	Loamy Sand	
	Antho		5		Sandy Loam	
	Gilman		5		Loam	
	Maripo		5		Sandy Loam	
	Vint		5		Sandy Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
12	Carefree	Clay	80	1-50	Clay	0.01
	Beardsley		4		Clay	
	Contine		4		Clay Loam	
	Ebon		4		Silty Clay Loam	
	Sun City		4		Clay Loam	
	Gadsden		4		Clay	
13	Carefree	Clay	50	1-50	Clay	0.01
	Beardsley	Clay	40	2-36	Clay	
	Antho		2		Sandy Loam	
	Carrizo		2		Loamy Sand	
	Contine		2		Clay Loam	
	Ebon		2		Silty Clay Loam	
	Sun City		2		Clay Loam	
14	Carrizo	Very Gravelly Sand	80	1-60	Loamy Sand	1.04
	Antho		6.7		Sandy Loam	
	Maripo		6.7		Sandy Loam	
	Brios		6.7		Loamy Sand	
15	Carrizo	Gravelly Sandy Loam	50	0-5	Sandy Loam	0.54
	Gunsight	Very Gravelly Sandy Loam	30	1-60	Loamy Sand	
	Brios		2.5		Loamy Sand	
	Carrizo		2.5		Loamy Sand	
	Denure		2.5		Sandy Loam	
	Cipriano		2.5		Sandy Loam	
	Chuckawalla		2.5		Silt	
	Momoli		2.5		Sandy Loam	
	Pinamt		2.5		Sand	
	Rillito		2.5		Loam	
16, 17	Cellar	Very Gravelly Fine Sandy Loam	76.5	0-3	Sandy Loam	0.44
	Rock Outcrop		15		—	
	Nickel		7.8		Sandy Loam	
	Eba		7.8		Sandy Loam	
	Arizo		7.8		Loamy Sand	
18	Cherioni	Extremely Gravelly Loam	71		Sandy Loam	0.33
	Rock Outcrop		15	1-10	—	
	Cipriano		7.25		Sandy Loam	
	Gachado		7.25		Silt	
	Gunsight		7.25		Loamy Sand	
	Sun City		7.25		Clay Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
19, 20	Chuckawala	Very Gravelly Sandy Clay Loam	45	2-14	Silt	0.19
	Gunsight	Very Gravelly Loam	35	0-3	Sandy Loam	
	Sal		2.857		Silt	
	Pinamt		2.857		Silt	
	Tremant		2.857		Sandy Loam	
	Rillito		2.857		Loam	
	Antho		2.857		Sandy Loam	
	Gilman		2.857		Loam	
	Maripo		2.857		Sandy Loam	
21	Cipriano	Very Gravelly Loam	80	0-6	Sandy Loam	0.38
	Cherioni		5		Sandy Loam	
	Gunsight		5		Sandy Loam	
	Sun City		5		Sandy Clay Loam	
	Carrizo		5		Loamy Sand	
22	Contine	Clay Loam	80	2-30	Clay Loam	0.04
	Carefree		6.67		Clay	
	Ebon		6.67		Silty Clay Loam	
	Mohall		6.67		Clay Loam	
23	Contine	Clay	80	0-12	Clay	0.01
	Carefree		6.67		Clay	
	Ebon		6.67		Silty Clay Loam	
	Mohall		6.67		Clay Loam	
24	Continental	Clay	80	1-60	Clay	0.02
	Eba		10		Sandy Loam	
	Mohave		10		Clay Loam	
25	Continental	Clay	80	0-60	Clay	0.02
	Eba		10		Sandy Loam	
	Mohave		10		Clay Loam	
26	Continental	Clay	85	2-60	Clay	0.01
	Ohaco		7.5		Clay Loam	
	Sun City		7.5		Sandy Clay Loam	
27	Continental	Clay	55	1-60	Clay	0.01
	Mohave	Clay Loam	20	2-20	Clay Loam	
	Guest		25		Clay	
28	Continental	Clay	70	2-60	Clay	0.02
	Ohaco	Clay Loam	20	2-27	Clay Loam	
	Eba		2.5		Sandy Loam	
	Sun City		2.5		Sandy Clay Loam	
	Anthony		2.5		Sandy Loam	
	Arizo		2.5		Loamy Sand	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT Inch/ hour
29, 30	Denure	Fine Sandy Loam	40	0-2	Loam	0.34
	Momoli	Gravelly Sandy Loam	30	0-10	Sandy Loam	
	Carrizo	Gravelly Sandy Loam	20	0-10	Sandy Loam	
	Gilman		3.33		Loam	
	Maripo		3.33		Sandy Loam	
	Carrizo		3.33		Loamy Sand	
31, 32	Dixaleta	Extremely Cobbly Sandy Loam	85	1-8	Sandy Loam	0.33
	Rock Outcrop		35		—	
	Ohaco		2.5		Clay Loam	
	Nickel		2.5		Sandy Loam	
	Cave		2.5		Loam	
	Eba		2.5		Sandy Loam	
	Gran		2.5		Clay Loam	
	Lehmans		2.5		Clay Loam	
33, 34, 35	Eba	Very Gravelly Loam	80	0-3	Sandy Loam	0.23
	Pinalena		10		Sandy Clay Loam	
	Continental		10		Clay	
36	Eba	Very Gravelly Loam	45	(0-3)	Sandy Loam	0.07
	Continental	Clay	35	(1-60)	Clay	
	Ohaco		5		Clay Loam	
	Pinaleno		5		Sandy Clay Loam	
	Sun City		5		Sandy Clay Loam	
	Tres Hermanos		5		Clay Loam	
37, 38	Eba	Very Gravelly Loam	40	(0-3)	Sandy Loam	0.13
	Continental	Clay	25	(1-60)	Clay	
	Cave	Loam	20	(1-14)	Loam	
	Anthony		2.5		Sandy Loam	
	Arizo		2.5		Loamy Sand	
	Greyeagle		2.5		Sandy Loam	
	Ohaco		2.5		Clay Loam	
	Nickel		2.5		Sandy Loam	
	Pinaleno		2.5		Sandy Clay Loam	
39	Eba	Very Gravelly Loam	30	0-3	Sandy Loam	0.29
	Nickel	Gravelly Loam	25	1-10	Sandy Loam	
	Cave	Loam	25	1-14	Loam	
	Arizo		4		Loamy Sand	
	Pinaleno		4		Sandy Clay Loam	
	Sun City		4		Sandy Clay Loam	
	Greyeagle		4		Sandy Loam	
	Ohaco		4		Clay Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
40, 42	Eba	Very Gravelly Loam	45	0-3	Sandy Loam	0.17
	Pinaleno	Gravelly Clay Loam	35	1-12	Sandy Clay Loam	
	Arizo		2.5		Loamy Sand	
	Anthony		2.5		Sandy Loam	
	Continental		2.5		Clay	
	Ohaco		2.5		Clay Loam	
	Greyeagle		2.5		Sandy Loam	
	Nickel		2.5		Sandy Loam	
	Vado		2.5		Sandy Loam	
	Tres Hermanos		2.5		Clay Loam	
41, 43	Eba	Very Gravelly Loam	45	0-3	Sandy Loam	0.17
	Pinaleno	Gravelly Clay Loam	35	1-12	Sandy Clay Loam	
	Ohaco		5		Clay Loam	
	Tres Harmanos		5		Clay Loam	
	Anthony		5		Sandy Loam	
	Arizo		5		Loamy Sand	
44, 45	Ebon	Very Gravelly Clay	80	1-43	Silty Clay	0.03
	Cipriano		2.857		Sandy Loam	
	Contine		2.857		Clay Loam	
	Beardsley		2.857		Clay	
	Luke		2.857		Silty Clay Loam	
	Gunsight		2.857		Loamy Sand	
	Mohall		2.857		Clay Loam	
	Pinamt		2.857		Silt	
46	Ebon	Very Gravelly Clay	45	1-43	Silty Clay	0.03
	Contine	Clay Loam	35	0-30	Clay Loam	
	Beardsley		3.33		Clay	
	Luke		3.33		Silty Clay Loam	
	Pinamt		3.33		Silt	
	Sun City		3.33		Sandy Clay Loam	
	Tremant		3.33		Sandy Loam	
	Carrizo		3.33		Loamy Sand	
47	Ebon	Very Gravelly Clay	35	1-43	Silty Clay	0.11
	Gunsight	Very Gravelly Sandy Loam	20	0-3	Loamy Sand	
	Cipriano	Very Gravelly Loam	20	0-8	Sandy Loam	
	Carrizo		6.25		Loamy Sand	
	Beardsley		6.25		Clay	
	Contine		6.25		Clay Loam	
	Luke		6.25		Silty Clay Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
48, 49	Ebon	Very Gravelly Clay	45	1-43	Silty Clay	0.06
	Pinamt	Very Gravelly Clay Loam	35	3-15	Silt	
	Carrizo		2.5		Loamy Sand	
	Antho		2.5		Sandy Loam	
	Contine		2.5		Clay Loam	
	Luke		2.5		Silty Clay Loam	
	Cipriano		2.5		Sandy Loam	
	Gunsight		2.5		Loamy Sand	
	Momoli		2.5		Sandy Loam	
	Tremant		2.5		Sandy Loam	
50	Estrella	Loam	80	0-21	Loam	0.26
	Gilman		6.67		Loam	
	Valencia		6.67		Sandy Loam	
	Mohall		6.67		Loam	
51	Gachado	Very Gravelly Sandy Clay Loam	50	2-8	Silt	0.24
	Lomitas	Very Gravelly Sandy Loam	25	2-17	Loamy Sand	
	Cherioni		3.571		Sandy Loam	
	Carrizo		3.571		Loamy Sand	
	Ebon		3.571		Silty Clay Loam	
	Contine		3.571		Clay Loam	
	Tremant		3.571		Sandy Loam	
	Denure		3.571		Sandy Loam	
	Gunsight		3.571		Loamy Sand	
52	Gachado	Very Gravelly Clay Loam	56	1-7	Sandy Clay Loam	0.16
	Lomitas	Very Gravelly Sandy Loam	25	0-10	Loamy Sand	
	Rock Outcrop		20		—	
	Carrizo		2.375		Loamy Sand	
	Cherioni		2.375		Sandy Loam	
	Cipriano		2.375		Sandy Loam	
	Ebon		2.375		Silty Clay Loam	
	Gunsight		2.375		Loamy Sand	
	Pinamt		2.375		Silt	
	Schenco		2.375		Sandy Loam	
	Vaiva		2.375		Sandy Loam	
53	Gadsden	Clay	80	0-3	Clay	0.02
	Contine		10		Clay Loam	
	Glenbar		10		Loam	
54	Gila	Fine Sandy Loam	80	0-2	Loam	0.29
	Anthony		6.67		Sandy Loam	
	Arizo		6.67		Loamy Sand	
	Gila		6.67		Loam	

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, Inch/ hour
55, 56	Gilman	Loam	80	0-5	Loam	0.27
	Antho		1.818		Sandy Loam	
	Carrizo		1.818		Loamy Sand	
	Estrella		1.818		Loam	
	Glenbar		1.818		Loam	
	Maripo		1.818		Sandy Loam	
	Valencia		1.818		Sandy Loam	
	Vint		1.818		Sandy Loam	
	Denure		1.818		Sandy Loam	
	Momoli		1.818		Sandy Loam	
	Carrizo		1.818		Sandy Loam	
	Gilman		1.818		Loam	
57	Gilman	Clay Loam	80	0-11	Clay Loam	0.06
	Glenbar		10		Loam	
	Vint		10		Sandy Loam	
58, 59	Gilman	Loam	40	0-2	Loam	0.34
	Momoli	Gravelly Sandy Loam	25	0-22	Sandy Loam	
	Denure	Gravelly Sandy Loam	20	0-9	Sandy Loam	
	Carrizo		3		Sandy Loam	
	Antho		3		Sandy Loam	
	Carrizo		3		Loamy Sand	
	Estrella		3		Loam	
	Maripo		3		Sandy Loam	
60	Glenbar	Loam	80	0-6	Loam	0.26
	Antho		4		Sandy Loam	
	Estrella		4		Loam	
	Gilman		4		Loam	
	Vint		4		Sandy Loam	
	Mohall		4		Loam	
61, 62	Gran	Extremely Gravelly Sandy Clay	40	1-12	Clay Loam	0.15
	Wickenburg	Gravelly Sandy Loam	35	0-1	Sandy Loam	
	Eba		8.33		Sandy Loam	
	Pinaleno		8.33		Sandy Clay Loam	
	Arizo		8.33		Loamy Sand	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT. inch/ hour
63, 64	Gran	Extremely Gravelly Sandy Clay	40	1-12	Clay Loam	0.14
	Wickenburg	Gravelly Sandy Loam	33	0-1	Sandy Loam	
	Rock Outcrop		25		—	
	Dixaleta		5.4		Sandy Loam	
	Lehmans		5.4		Clay Loam	
	Eba		5.4		Sandy Loam	
	Pinaleno		5.4		Sandy Clay Loam	
	Arizo		5.4		Loamy Sand	
65	Greyeagle	Gravelly Loam	45	1-5	Sandy Loam	0.19
	Continental	Clay Loam	25	2-5	Clay Loam	
	Nickel	Very Gravelly Loam	15	0-5	Sandy Loam	
	Ohaco		3		Clay Loam	
	Sun City		3		Sandy Clay Loam	
	Cave		3		Loam	
	Mohave		3		Clay Loam	
	Arizo		3		Loamy Sand	
66	Greyeagle	Very Gravelly Loam	55	1-5	Sandy Loam	0.23
	Sun City Variant	Gravelly Clay Loam	30	2-9	Sandy Clay Loam	
	Arizo		3.75		Loamy Sand	
	Cave		3.75		Loam	
	Ohaco		3.75		Clay Loam	
	Nickel		3.75		Sandy Loam	
67	Guest	Clay	85	0-2	Clay	0.01
	Anthony		5		Sandy Loam	
	Continental		5		Clay	
	Mohave		5		Clay Loam	
68, 69	Gunsight	Very Gravelly Sandy Loam	45	1-60	Loamy Sand	0.63
	Cipriano	Very Gravelly Loam	40	0-6	Sandy Loam	
	Gilman		3		Loam	
	Carrizo		3		Loamy Sand	
	Pinamt		3		Silt	
	Rillito		3		Loam	
	Tremant		3		Sandy Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/ hour
70, 71	Gunsight	Very Gravelly Loam	40	0-11	Sandy Loam	0.36
	Rillito	Gravelly Loam	40	0-12	Sandy Loam	
	Carrizo		2.22		Loamy Sand	
	Chuckawalla		2.22		Silt	
	Ebon		2.22		Clay Loam	
	Mohall		2.22		Loam	
	Pinamt		2.22		Silt	
	Tremant		2.22		Sandy Loam	
	Cipriano		2.22		Sandy Loam	
	Antho		2.22		Sandy Loam	
	Gilman		2.22		Loam	
72, 73	Lehmans	Clay Loam	64	0-2	Clay Loam	0.09
	Rock Outcrop		30		—	
	Arizo		7.2		Loamy Sand	
	Eba		7.2		Sandy Loam	
	Pinaleno		7.2		Sandy Clay Loam	
	Greyeagle		7.2		Sandy Loam	
	Nickel		7.2		Sandy Loam	
74	Luke	Very Gravelly Clay	45	1-28	Silty Clay	0.08
	Cipriano	Very Gravelly Loam	35	0-6	Sandy Loam	
	Beardsley		2.857		Clay	
	Contine		2.857		Clay Loam	
	Ebon		2.857		Silty Clay Loam	
	Pinamt		2.857		Silt	
	Sun City		2.857		Sandy Clay Loam	
	Gunsight		2.857		Loamy Sand	
	Carrizo		2.857		Loamy Sand	
75	Mohall	Loam	80	0-7	Loam	0.23
	Gilman		5		Loam	
	Glenbar		5		Loam	
	Contine		5		Clay Loam	
	Tremont		5		Sandy Loam	
76	Mohall	Loam	80	0-7	Loam	0.23
	Contine		3.33		Clay Loam	
	Mohall		3.33		Clay Loam	
	Tremant		3.33		Sandy Loam	
	Antho		3.33		Sandy Loam	
	Estrella		3.33		Loam	
	Valencia		3.33		Sandy Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
77	Mohall	Clay Loam	80	0-2	Clay Loam	0.05
	Gilman		5		Loam	
	Glenbar		5		Loam	
	Contine		5		Clay Loam	
	Tremant		5		Sandy Loam	
78	Mohall	Clay Loam	80	0-6	Clay Loam	0.05
	Contine		3.33		Clay Loam	
	Mohall		3.33		Clay Loam	
	Tremant		3.33		Sandy Loam	
	Antho		3.33		Sandy Loam	
	Estrella		3.33		Loam	
	Valencia		3.33		Sandy Loam	
79	Mohall	Clay	80	0-12	Clay	0.02
	Gilman		5		Loam	
	Glenbar		5		Loam	
	Contine		5		Clay Loam	
	Tremant		5		Sandy Loam	
80, 81	Mohall	Clay Loam	45	2-42	Clay Loam	0.08
	Tremant	Sandy Clay Loam	25	1-5	Sandy Clay Loam	
	Contine		3.75		Clay Loam	
	Pinamt		3.75		Silt	
	Sun City		3.75		Sandy Clay Loam	
	Gunsight		3.75		Loamy Sand	
	Rillito		3.75		Loam	
	Antho		3.75		Sandy Loam	
	Carrizo		3.75		Loamy Sand	
	Valencia		3.75		Sandy Loam	
82, 83	Mohave	Clay Loam	80	2-11	Clay Loam	0.04
	Gila		6.67		Loam	
	Continental		6.67		Clay	
	Tres Hermanos		6.67		Clay Loam	
84	Mohave	Clay Loam	85	2-28	Clay Loam	0.05
	Mohave		3		Loam	
	Continental		3		Clay	
	Tres Hermanos		3		Clay Loam	
	Anthony		3		Sandy Loam	
	Guest		3		Clay	
85	Mohave	Clay Loam	80	0-20	Clay Loam	0.04
	Gila		6.67		Loam	
	Continental		6.67		Clay	
	Tres Hermanos		6.67		Clay Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/ hour
86	Mohave	Clay Loam	85	2-15	Clay Loam	0.05
	Anthony		3		Sandy Loam	
	Gila		3		Loam	
	Tres Hermanos		3		Clay Loam	
	Mohave		3		Loam	
	Continental		3		Clay	
87	Mohave	Clay Loam	45	2-11	Clay Loam	0.04
	Mohave	Clay Loam	40	2-5	Clay Loam	
	Mohave		15		Clay Loam	
88	Mohave	Clay Loam	45	2-11	Clay Loam	0.02
	Guest	Clay	40	2-60	Clay	
	Mohave		7.5		Loam	
	Continental		7.5		Clay	
89	Mohave	Clay Loam	50	2-11	Clay Loam	0.06
	Tres Hermanos	Gravelly Clay Loam	30	2-20	Sandy Clay Loam	
	Arizo		5		Loamy Sand	
	Anthony		5		Sandy Loam	
	Continental		5		Clay	
	Pinaleno		5		Sandy Clay Loam	
90	Momoli	Gravelly Sandy Loam	70	0-3	Sandy Loam	0.39
	Carrizo		7.5		Loamy Sand	
	Maripo		7.5		Sandy Loam	
	Pinamt		7.5		Silt	
	Denure		7.5		Sandy Loam	
91, 92	Momoli	Very Gravelly Sandy Loam	45	1-60	Loamy Sand	0.93
	Carrizo	Very Gravelly Sandy Loam	35	0-11	Loamy Sand	
	Mohall		2.5		Loam	
	Tremant		2.5		Sandy Loam	
	Gunsight		2.5		Loamy Sand	
	Chuckawalla		2.5		Silt	
	Denure		2.5		Sandy Loam	
	Gilman		2.5		Loam	
	Maripo		2.5		Sandy Loam	
	Carrizo		2.5		Sandy Loam	
93, 94	Nickel	Gravelly Loam	50	1-10	Sandy Loam	0.33
	Cave	Loam	35	1-14	Loam	
	Arizo		3.75		Loamy Sand	
	Anthony		3.75		Sandy Loam	
	Pinaleno		3.75		Sandy Clay Loam	
	Greyeagle		3.75		Sandy Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT inch/ hour
95	Ohaco	Clay Loam	85	2-11	Clay Loam	0.04
	Continental		7.5		Clay	
	Sun City Variant		7.5		Sandy Clay Loam	
96, 97	Pinaleno	Gravelly Clay Loam	45	1-12	Sandy Clay Loam	0.07
	Tres Hermanos	Clay Loam	40	2-4	Clay Loam	
	Arizo		2.5		Loamy Sand	
	Mohave		2.5		Clay Loam	
	Greyeagle		2.5		Sandy Loam	
	Eba		2.5		Sandy Loam	
	Vado		2.5		Sandy Loam	
	Nickel		2.5		Sandy Loam	
98, 99	Pinamt	Very Gravelly Loam	45	1-3	Sandy Loam	0.37
	Tremant	Gravelly Loam	35	0-5	Sandy Loam	
	Carrizo		4		Loamy Sand	
	Chuckawalla		4		Silt	
	Ebon		4		Clay Loam	
	Gunsight		4		Loamy Sand	
	Rillito		4		Loam	
100	Quilotosa	Extremely Gravelly Loam	62.5	2-14	Sandy Loam	0.40
	Vaiva	Very Gravelly Loam	25	0-3	Sandy Loam	
	Rock Outcrop		20		—	
	Schenco		12.5		Sandy Loam	
101	Rillito	Loam	85	0-24	Loam	0.28
	Cipriano		3.75		Sandy Loam	
	Gunsight		3.75		Loamy Sand	
	Mohall		3.75		Loam	
	Tremant		3.75		Sandy Loam	
102	Rillito	Gravelly Loam	70	0-14	Sandy Loam	0.40
	Mohall		3.33		Loam	
	Pinamt		3.33		Silt	
	Tremant		3.33		Sandy Loam	
	Gunsight		3.33		Loamy Sand	
	Cipriano		3.33		Sandy Loam	
	Gilman		3.33		Loam	
	Antho		3.33		Sandy Loam	
	Maripo		3.33		Sandy Loam	
	Carrizo		3.33		Loamy Sand	
103	Rock Outcrop		65		—	0.10
	Gachado	Very Gravelly Clay Loam	71	1-7	Sandy Clay Loam	
	Lomitas		29		Sandy Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/hour
104, 105	Rock Outcrop		60		—	0.14
	Lehmans	Gravelly Clay Loam	50	2-15	Sandy Clay Loam	
	Arizo		16.67		Loamy Sand	
	Eba		16.67		Sandy Loam	
	Pinaleno		16.67		Sandy Clay Loam	
106, 107	Sal	Gravelly Clay Loam	50	2-7	Sandy Clay Loam	0.18
	Cipriano	Gravelly Sandy Loam	30	1-9	Sandy Loam	
	Gunsight		5		Loamy Sand	
	Rillito		5		Loam	
	Brios		5		Loamy Sand	
	Carrizo		5		Loamy Sand	
108	Schenco	Very Cobbly Loam	71	2-11	Sandy Loam	0.31
	Rock Outcrop		30		—	
	Antho		2.9		Sandy Loam	
	Beardsley		2.9		Clay	
	Cherioni		2.9		Sandy Loam	
	Cipriano		2.9		Sandy Loam	
	Ebon		2.9		Silty Clay Loam	
	Gunsight		2.9		Sandy Clay Loam	
	Sun City		2.9		Sandy Loam	
	Gachado		2.9		Silt	
	Quilotosa		2.9		Sandy Loam	
	Vaiva		2.9		Sandy Loam	
109	Schenco	Very Cobbly Loam	85	2-11	Sandy Loam	0.35
	Rock Outcrop		35		—	
	Beardsley		2.143		Clay	
	Cipriano		2.143		Sandy Loam	
	Ebon		2.143		Silty Clay Loam	
	Gunsight		2.143		Loamy Sand	
	Gachado		2.143		Silt	
	Quilotosa		2.143		Sandy Loam	
	Vaiva		2.143		Sandy Loam	
110	Sun City	Gravelly Clay Loam	55	1-9	Sandy Clay Loam	0.13
	Cipriano	Very Gravelly Loam	30	1-6	Sandy Loam	
	Carrizo		5		Loamy Sand	
	Beardsley		5		Clay	
	Gunsight		5		Loamy Sand	
111	Torriothents	—	100	0-60	Sandy Loam	0.40

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT. Inch/ hour
112	Tremant	Gravelly Sandy Loam	80	0-9	Sandy Loam	0.39
	Antho		2.22		Sandy Loam	
	Carrizo		2.22		Sandy Loam	
	Valencia		2.22		Sandy Loam	
	Carrizo		2.22		Loamy Sand	
	Denure		2.22		Sandy Loam	
	Mohall		2.22		Loam	
	Momoli		2.22		Loam	
	Pinamt		2.22		Silt	
	Rillito		2.22		Loam	
113	Tremant	Gravelly Sandy Loam	80	0-9	Sandy Loam	0.39
	Antho		1.818		Sandy Loam	
	Carrizo		1.818		Sandy Loam	
	Valencia		1.818		Sandy Loam	
	Carrizo		1.818		Loamy Sand	
	Denure		1.818		Sandy Loam	
	Momoli		1.818		Loam	
	Chuckawalla		1.818		Silt	
	Gunsight		1.818		Loamy Sand	
	Mohall		1.818		Loam	
	Pinamt		1.818		Silt	
	Rillito		1.818		Loam	
114	Tremant		80	0-9	Sandy Loam	0.39
	Antho		2.0		Sandy Loam	
	Carrizo		2.0		Sandy Loam	
	Valencia		2.0		Sandy Loam	
	Carrizo		2.0		Loamy Sand	
	Denure		2.0		Sandy Loam	
	Chuckawalla		2.0		Silt	
	Gunsight		2.0		Loamy Sand	
	Mohall		2.0		Loam	
	Pinamt		2.0		Silt	
	Rillito		2.0		Loam	
115	Tremant	Gravelly Sandy Loam	45	0-9	Sandy Loam	0.39
	Antho	Sandy Loam	35	0-3	Sandy Loam	
	Carrizo		4		Loamy Sand	
	Denure		4		Sandy Loam	
	Mohall		4		Loam	
	Momoli		4		Sandy Loam	
	Pinamt		4		Silt	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/hour
116, 117	Tremant	Gravelly Clay Loam	30	2-26	Sandy Clay Loam	0.23
	Gunsight	Very Gravelly Sandy Loam	20	0-10	Loamy Sand	
	Rillito	Gravelly Loam	20	0-60	Sandy Loam	
	Cipriano		3.75		Sandy Loam	
	Pinamt		3.75		Silt	
	Mohall		3.75		Clay Loam	
	Contine		3.75		Clay Loam	
	Antho		3.75		Sandy Loam	
	Carrizo		3.75		Loamy Sand	
	Gilman		3.75		Loam	
	Carrizo		3.75		Sandy Loam	
118	Tremant	Gravelly Sandy Loam	45	1-9	Sandy Loam	0.42
	Rillito	Gravelly Loam	30	0-12	Sandy Loam	
	Carrizo		5		Loamy Sand	
	Cipriano		5		Sandy Loam	
	Gunsight		5		Loamy Sand	
	Pinamt		5		Silt	
	Momali		5		Sandy Loam	
119	Tremant	Gravelly Loam	40	1-9	Sandy Loam	0.14
	Sun City	Clay Loam	30	2-12	Clay Loam	
	Gadsden		3.75		Clay	
	Cipriano		3.75		Sandy Loam	
	Beardsley		3.75		Clay	
	Gunsight		3.75		Loamy Sand	
	Mohall		3.75		Loam	
	Sal		3.75		Silt	
	Pinamt		3.75		Silt	
	Rillito		3.75		Loam	
120	Tres Hermanos	Clay Loam	80	2-6	Clay Loam	0.06
	Anthony		2.857		Sandy Loam	
	Mohave		2.857		Loam	
	Greyeagle		2.857		Sandy Loam	
	Nickel		2.857		Sandy Loam	
	Pinaleno		2.857		Sandy Clay Loam	
	Arizo		2.857		Loamy Sand	
	Guest		2.857		Clay	
121	Tres Hermanos	Clay Loam	50	2-6	Clay Loam	0.12
	Anthony	Gravelly Sandy Loam	35	2-40	Sandy Loam	
	Arizo		5		Loamy Sand	
	Pinaleno		5		Sandy Clay Loam	
	Nickel		5		Sandy Loam	

Aguila-Carefree Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
122	Vado	Gravelly Sandy Loam	75	0-2	Sandy Loam	0.33
	Anthony		6.25		Sandy Loam	
	Arizo		6.25		Loamy Sand	
	Pinaleno		6.25		Sandy Clay Loam	
	Tres Hermanos		6.25		Clay Loam	
123	Vaiva	Very Gravelly Loam	60	0-3	Sandy Loam	0.37
	Brias		4.44		Loamy Sand	
	Carrizo		4.44		Loamy Sand	
	Antho		4.44		Sandy Loam	
	Chuckawalla		4.44		Silt	
	Ebon		4.44		Sandy Clay Loam	
	Gunsight		4.44		Loamy Sand	
	Pinamt		4.44		Silt	
	Cipriano		4.44		Sandy Loam	
	Quilotosa		4.44		Sandy Loam	
124	Valencia	Sandy Loam	80	0-20	Sandy Loam	0.39
	Antho		4		Sandy Loam	
	Estrella		4		Loam	
	Gilman		4		Loam	
	Denure		4		Sandy Loam	
	Tremant		4		Sandy Loam	
125	Vint	Fine Loamy Sand	80	0-60	Sandy Loam	0.43
	Antho		4		Sandy Loam	
	Brios		4		Loamy Sand	
	Carrizo		4		Loamy Sand	
	Gilman		4		Loam	
	Maripa		4		Sandy Loam	

Appendix B

Maricopa County–Central Part Loss Rate Parameters

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/hour
Aa	Agualt	Loam	85	0-11	Loam	0.26
	Gilman	Loam	3		Loam	
	Maripo	Sandy Loam	3		Sandy Loam	
	Antho	Sandy Loam	3		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	3		Sandy Loam	
	Laveen	Loam	3		Loam	
AbA	Antho	Sandy Loam	85	0-13	Sandy Loam	0.38
	Maripo	Sandy Loam	2.143		Sandy Loam	
	Agualt	Loam	2.143		Loam	
	Valencia	Sandy Loam	2.143		Sandy Loam	
	Estrella	Loam	2.143		Loam	
	Gilman	Loam	2.143		Loam	
	Coolidge	Sandy Loam	2.143		Sandy Loam	
	Antho	Loam	2.143		Loam	
AbB	Antho	Sandy Loam	85	0-13	Sandy Loam	0.39
	Gilman	Loam	3.75		Loam	
	Maripo	Sandy Loam	3.75		Sandy Loam	
	Coolidge	Sandy Loam	3.75		Sandy Loam	
	Antho	Gravelly Sandy Loam	3.75		Sandy Loam	
Ac	Antho	Sandy Loam	80	0-13	Sandy Loam	0.39
	Valencia	Sandy Loam	4		Sandy Loam	
	Gilman	Loam	4		Loam	
	Laveen	Loam	4		Loam	
	Antho	Sandy Loam	4		Sandy Loam	
	Coolidge	Sandy Loam	4		Sandy Loam	
AdA	Antho	Gravelly Sandy Loam	85	0-13	Sandy Loam	0.40
	Antho	Sandy Loam	3.75		Sandy Loam	
	Maripo	Sandy Loam	3.75		Sandy Loam	
	Brios	Sandy Loam	3.75		Sandy Loam	
	Valencia	Gravelly Sandy Loam	3.75		Sandy Loam	
AdB	Antho	Gravelly Sandy Loam	85	0-13	Sandy Loam	0.40
	Valencia	Gravelly Sandy Loam	3.75		Sandy Loam	
	Rillito	Sandy Loam	3.75		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	3.75		Sandy Loam	
	Coolidge	Gravelly Sandy Loam	3.75		Sandy Loam	
Ae	Antho	Sandy Loam	45	0-13	Sandy Loam	0.39
	Brios	Sandy Loam	25	0-14	Sandy Loam	
	Maripo	Sandy Loam	20	0-34	Sandy Loam	
	Carrizo	Gravelly Sandy Loam	2.5		Sandy Loam	
	Gilman	Fine Sandy Loam	2.5		Loam	
	Agualt	Loam	2.5		Loam	
	Valencia	Sandy Loam	2.5		Sandy Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, Inch/ hour
AfA	Antho	Sandy Loam	50	0-13	Sandy Loam	0.38
	Carrizo	Gravelly Sandy Loam	30	0-5	Sandy Loam	
	Maripo	Sandy Loam	5		Sandy Loam	
	Valencia	Sandy Loam	5		Sandy Loam	
	Vint	Fine Sandy Loam	5		Loam	
	Gilman	Fine Sandy Loam	5		Loam	
AfB	Antho	Sandy Loam	40	0-13	Sandy Loam	0.40
	Carrizo	Gravelly Sandy Loam	25	0-5	Sandy Loam	
	Maripo	Sandy Loam	20	0-34	Sandy Loam	
	Valencia	Gravelly Sandy Loam	7.5		Sandy Loam	
	Rillito	Sandy Loam	7.5		Sandy Loam	
AGB	Antho	Sandy Loam	35	0-13	Sandy Loam	0.40
	Carrizo	Gravelly Sandy Loam	30	0-5	Sandy Loam	
	Maripo	Sandy Loam	20	0-34	Sandy Loam	
	Brios	Sandy Loam	5		Sandy Loam	
	Harqua	Gravelly Loam	5		Sandy Loam	
	Valencia	Sandy Loam	5		Sandy Loam	
AHC	Antho	Gravelly Sandy Loam	40	0-13	Sandy Loam	0.38
	Tremant	Gravelly Loam	30	0-10	Sandy Loam	
	Gunsight		3.33		Loam	
	Maripo		3.33		Sandy Loam	
	Rillito		3.33		Sandy Loam	
	Laveen		3.33		Loam	
	Carrizo		3.33		Sandy Loam	
	Mohall		3.33		Sandy Loam	
	Gilman		3.33		Loam	
	Valencia		3.33		Sandy Loam	
	Estrella		3.33		Loam	
AkB	Antho	Gravelly Sandy Loam	35	0-13	Sandy Loam	0.27
	Antho	Sandy Loam	15	0-13	Sandy Loam	
	Tremant	Gravelly Clay Loam	20	1-8	Sandy Clay Loam	
	Mohall	Gravelly Sandy Loam	15	0-10	Sandy Loam	
	Cacio/Torrio	—	5		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	5		Sandy Loam	
	Gilman	Fine Sandy Loam	5		Loam	
AL	Antho	Sandy Loam	55	0-13	Sandy Loam	0.40
	Antho	Gravelly Sandy Loam	30	0-13	Sandy Loam	
	Coolidge	Sandy Loam	3		Sandy Loam	
	Laveen	Sandy Loam	3		Sandy Loam	
	Valencia	Sandy Loam	3		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	3		Sandy Loam	
	Maripo	Sandy Loam	3		Sandy Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/hour
AM	Antho	Sandy Loam	40	0-13	Sandy Loam	0.39
	Valencia	Sandy Loam	40	0-10	Sandy Loam	
	Coolidge	Sandy Loam	6.67		Sandy Loam	
	Maripo	Sandy Loam	6.67		Sandy Loam	
	Gilman	Fine Sandy Loam	6.67		Loam	
An	Avonda	Clay Loam	75	0-13	Clay Loam	0.05
	Avondale	Clay Loam	6.25		Clay Loam	
	Glenbar	Clay Loam	6.25		Clay Loam	
	Agualt	Loam	6.25		Loam	
	Gilman	Loam	6.25		Loam	
Ao	Avondale	Clay Loam	85	0-12	Clay Loam	0.04
	Glenbar	Clay Loam	5		Clay Loam	
	Gilman	Loam	5		Loam	
	Trix	Clay Loam	5		Clay Loam	
Ap	Avondale	Clay Loam	85	0-12	Clay Loam	0.04
	Glenbar	Clay Loam	5		Clay Loam	
	Cashion	Clay	5		Clay	
	Gilman	Loam	5		Loam	
BE	Beardsley	Loam	90	0-3	Loam	0.24
	Vecont	Clay	2.5		Clay	
	Sun City	Very Gravelly Loam	2.5		Sandy Loam	
	Pinal	Gravelly Loam	2.5		Sandy Loam	
	Beardsley	Gravelly Loam	2.5		Sandy Loam	
Br	Brios	Loamy Sand	90	0-14	Loamy Sand	1.05
	Carrizo	Gravelly Sandy Loam	5		Sandy Loam	
	Vint	Fine Sandy Loam	5		Loam	
Bs	Brios	Sandy Loam	80	0-14	Sandy Loam	0.39
	Vint	Fine Sandy Loam	4		Loam	
	Carrizo	Gravelly Sandy Loam	4		Sandy Loam	
	Maripo	Sandy Loam	4		Sandy Loam	
	Anthô	Sandy Loam	4		Sandy Loam	
	Brios	Sandy Loam	4		Sandy Loam	
Bt	Brios	Loam	80	0-14	Loam	0.25
	Anthony	Sandy Loam	4		Sandy Loam	
	Maripo	Sandy Loam	4		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	4		Sandy Loam	
	Vint	Clay Loam	4		Clay Loam	
	Vint	Loam	4		Loam	
CA2	Calciorthids/ Torriorthents	Varies	80	0-60	Sandy Loam	0.38
	Gunsight	Loam	5		Loam	
	Pinal	Loam	5		Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
Cb	Carrizo	Gravelly Sandy Loam	85	0-5	Sandy Loam	0.40
	Maripo	Sandy Loam	3		Sandy Loam	
	Brios	Loamy Sand	3		Loamy Sand	
	Antho	Sandy Loam	3		Sandy Loam	
	Vint	Fine Sandy Loam	3		Loam	
	Agualt	Loam	3		Loam	
CeD	Carrizo	Gravelly Sandy Loam	60	0-5	Sandy Loam	0.19
	Ebon	Very Cobbly Clay Loam	30	2-13	Sandy Clay Loam	
	Tremant	Gravelly Clay Loam	10		Sandy Clay Loam	
CF	Carrizo	Sandy Loam	45	0-5	Sandy Loam	0.50
	Brios	Sandy Loam	35	0-14	Sandy Loam	
	Vint	Loamy Sand	20	0-60	Loamy Sand	
Cg	Casa Grande	Loam	85	1-3	Loam	0.24
	Laveen	Loam	3.75		Loam	
	Harqua	Gravelly Clay Loam	3.75		Sandy Clay Loam	
	Valencia	Sandy Loam	3.75		Sandy Loam	
	Tucson	Loam	3.75		Loam	
Ch	Casa Grande	Loam	85	0-3	Loam	0.24
	Laveen	Loam	3.75		Loam	
	Estrella	Loam	3.75		Loam	
	Harqua	Gravelly Clay Loam	3.75		Sandy Clay Loam	
	Tucson	Loam	3.75		Loam	
Ck	Casa Grande	Loam	75	0-3	Loam	0.30
	Laveen	Loam	8.33		Loam	
	Harqua	Gravelly Sandy Loam	8.33		Sandy Loam	
	Dune Land	Loamy Sand	8.33		Loamy Sand	
Cm	Casa Grande	Loam	40	1-3	Loam	0.26
	Laveen	Loam	40	0-15	Loam	
	Gilman	Loam	6.67		Loam	
	Coolidge	Sandy Loam	6.67		Sandy Loam	
	Estrella	Loam	6.67		Loam	
Cn	Cashion	Clay	80	0-27	Clay	0.01
	Gadsden	Clay	5		Clay	
	Avondale	Clay Loam	5		Clay Loam	
	Wintersburg	Clay Loam	5		Clay Loam	
	Glenbar	Clay Loam	5		Clay Loam	
CO	Cherioni	Very Gravelly Loam	62.5	0-6	Sandy Loam	0.29
	Rock Outcrop		20			
	Gachado	Very Gravelly Clay Loam	9.38		Sandy Clay Loam	
	Pinal	Loam	9.38		Loam	
	Gunsight	Loam	9.38		Loam	
	Rillito	Loam	9.38		Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
Cp	Coolidge	Sandy Loam	80	0-13	Sandy Loam	0.40
	Laveen	Sandy Loam	4		Sandy Loam	
	Antho	Sandy Loam	4		Sandy Loam	
	Rillito	Sandy Loam	4		Sandy Loam	
	Perryville	Sandy Loam	4		Sandy Loam	
	Valencia	Sandy Loam	4		Sandy Loam	
CrB	Coolidge	Gravelly Sandy Loam	85	0-13	Sandy Loam	0.40
	Rillito	Sandy Loam	5		Sandy Loam	
	Perryville	Sandy Loam	5		Sandy Loam	
	Antho	Gravelly Sandy Loam	5		Sandy Loam	
Cs	Coolidge	Gravelly Sandy Loam	50	0-12	Sandy Loam	0.19
	Tremant	Clay Loam	30	1-8	Clay Loam	
	Laveen	Loam	5		Loam	
	Perryville	Gravelly Loam	5		Sandy Loam	
	Antho	Sandy Loam	5		Sandy Loam	
	Rillito	Loam	5		Loam	
CV	Coolidge	Sandy Loam	40	0-13	Sandy Loam	0.39
	Laveen	Sandy Loam	40	0-15	Sandy Loam	
	Antho	Sandy Loam	6.667		Sandy Loam	
	Perryville	Gravelly Loam	6.667		Sandy Loam	
	Rillito	Loam	6.667		Loam	
Dn	Dune Land	Sand	100	0-60	Loamy Sand	1.20
EbD	Ebon	Very Cobbly Clay Loam	75	2-13	Sandy Clay Loam	0.10
	Pinamt	Gravelly Loam	8.333		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	8.333		Sandy Loam	
	Tremant	Gravelly Loam	8.333		Sandy Loam	
EPD	Ebon	Very Cobbly Clay Loam	40	2-13	Sandy Clay Loam	0.12
	Pinamt	Very Gravelly Sandy Loam	25	2-6	Sandy Loam	
	Tremant	Clay Loam	20	1-8	Clay Loam	
	Gunsight	Gravelly Loam	3.75		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	3.75		Sandy Loam	
	Rillito	Loam	3.75		Loam	
	Antho	Sandy Loam	3.75		Sandy Loam	
Es	Estrella	Loam	85	0-11	Loam	0.25
	Gilman	Loam	3.75		Loam	
	Valencia	Sandy Loam	3.75		Sandy Loam	
	Mohall	Loam	3.75		Loam	
	Laveen	Loam	3.75		Loam	
Et	Estrella	Loam	80	0-11	Loam	0.25
	Casa Grande	Loam	6.667		Loam	
	Laveen	Loam	6.667		Loam	
	Gilman	Loam	6.667		Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
GA	Gachado	Very Gravelly Clay Loam	66.67	0-1	Sandy Clay Loam	0.10
	Rock Outcrop	—	40		—	
	Cherioni	Very Gravelly Loam	8.333		Sandy Loam	
	Rillito	Loam	8.333		Loam	
	Pinal	Loam	8.333		Loam	
	Gunsight	Loam	8.333		Loam	
Gb	Gadsden	Clay Loam	80	0-14	Clay Loam	0.04
	Glenbar	Clay Loam	5		Clay Loam	
	Cashion	Clay	5		Clay	
	Avondale	Clay Loam	5		Clay Loam	
	Gadsden	Loam	5		Loam	
Gc	Gadsden	Clay	80	0-10	Clay	0.01
	Glenbar	Clay	5		Clay	
	Cashion	Clay	5		Clay	
	Avondale	Clay Loam	5		Clay Loam	
	Gadsden	Clay Loam	5		Clay Loam	
Gd	Gadsden	Clay	85	0-10	Clay	0.01
	Glenbar	Clay Loam	3.75		Clay Loam	
	Cashion	Clay	3.75		Clay	
	Avondale	Clay Loam	3.75		Clay Loam	
	Gadsden	Clay	3.75		Clay	
Ge	Gilman	Loam	80	0-5	Loam	0.26
	Antho	Sandy Loam	3.33		Sandy Loam	
	Agualt	Loam	3.33		Loam	
	Vint	Fine Sandy Loam	3.33		Loam	
	Estrella	Loam	3.33		Loam	
	Valencia	Sandy Loam	3.33		Sandy Loam	
	Laveen	Sandy Loam	3.33		Sandy Loam	
Gf	Gilman	Fine Sandy Loam	80	0-14	Loam	0.24
	Vint	Fine Sandy Loam	5		Loam	
	Antho	Sandy Loam	5		Sandy Loam	
	Avondale	Clay Loam	5		Clay Loam	
	Maripo	Sandy Loam	5		Sandy Loam	
GgA	Gilman	Loam	80	0-5	Loam	0.25
	Agualt	Loam	4		Loam	
	Antho	Sandy Loam	4		Sandy Loam	
	Estrella	Loam	4		Loam	
	Glenbar	Loam	4		Loam	
	Laveen	Loam	4		Loam	
GgB	Gilman	Loam	80	0-5	Loam	0.26
	Antho	Sandy Loam	6.667		Sandy Loam	
	Gilman	Loam	6.667		Loam	
	Laveen	Loam	6.667		Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/hour
Gh	Gilman	Loam	85	0-5	Loam	0.24
	Laveen	Loam	3.75		Loam	
	Antho	Sandy Loam	3.75		Sandy Loam	
	Estrella	Loam	3.75		Loam	
	Avondale	Clay Loam	3.75		Clay Loam	
GL	Gilman	Loam	40	0-5	Loam	0.25
	Gilman (other)	Loam	40	0-5	Loam	
	Antho	Sandy Loam	5	0-13	Sandy Loam	
	Gilman	Loam	5	0-5	Loam	
	Estrella	Loam	2.5		Loam	
	Carrizo	Gravelly Sandy Loam	2.5		Sandy Loam	
	Maripo	Sandy Loam	2.5		Sandy Loam	
	Harqua	Gravelly Clay Loam	2.5		Sandy Clay Loam	
GM	Gilman	Loam	50	0-5	Loam	0.29
	Antho	Sandy Loam	25	0-60	Sandy Loam	
	Agualt	Loam	10	0-11	Loam	
	Laveen	Loam	3.75		Loam	
	Maripo	Sandy Loam	3.75		Sandy Loam	
	Estrella	Loam	3.75		Loam	
	Carrizo	Gravelly Sandy Loam	3.75		Sandy Loam	
GN	Gilman	Loam	45	0-5	Loam	0.25
	Laveen	Loam	30	0-15	Loam	
	Estrella	Loam	20		Loam	
	Maripo	Loam	1.25		Loam	
	Tremant	Loam	1.25		Loam	
	Coolidge	Sandy Loam	1.25		Sandy Loam	
	Agualt	Loam	1.25		Loam	
Go3	Gilman	Loam	55	0-5	Loam	0.19
	Antho	Sandy Loam	25	0-60	Sandy Loam	
	Glenbar	Clay Loam	20	0-15	Clay Loam	
Gp	Gilman Variant	Loam	95	0-3	Loam	0.24
	Avondale	Clay Loam	1.667		Clay Loam	
	Gadsden	Clay Loam	1.667		Clay Loam	
	Gilman	Loam	1.667		Loam	
Gr	Glenbar	Loam	85	0-13	Loam	0.23
	Gilman	Loam	5		Loam	
	Avondale	Clay Loam	5		Clay Loam	
	Gilman Variant	Loam	5		Loam	
Gs	Glenbar	Loam	85	0-12	Loam	0.23
	Gilman	Loam	5		Loam	
	Estrella	Loam	5		Loam	
	Gadsden	Clay Loam	5		Clay Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT. Inch/ hour
Gt	Glenbar	Clay Loam	80	0-15	Clay Loam	0.04
	Avondale	Clay Loam	5		Clay Loam	
	Gilman	Loam	5		Loam	
	Trix	Clay Loam	5		Clay Loam	
	Gadsden	Clay Loam	5		Clay Loam	
Gu	Glenbar	Clay Loam	80	0-15	Clay Loam	0.04
	Avondale	Clay Loam	5		Clay Loam	
	Cashion	Clay	5		Clay	
	Gadsden	Clay	5		Clay	
	Gilman	Loam	5		Loam	
Gv	Glenbar	Clay	85	0-20	Clay	0.01
	Casion	Clay	5		Clay	
	Gadsden	Clay	5		Clay	
	Avondale	Clay Loam	5		Clay Loam	
GWD	Gunsight	Loam	40	1-3	Loam	0.35
	Pinal	Gravelly Loam	30	0-8	Sandy Loam	
	Pinamt	Very Gravelly Sandy Loam	12	2-6	Sandy Loam	
	Rillito	Gravelly Loam	6		Sandy Loam	
	Antho	Gravelly Sandy Loam	6		Sandy Loam	
	Carrizo	Very Gravelly Sand	6		Loamy Sand	
GxA	Gunsight	Loam	45	1-3	Loam	0.23
	Rillito	Fine Sandy Loam	45	2-10	Loam	
	Laveen	Loam	5		Loam	
	Harqua	Gravelly Clay Loam	5		Sandy Clay Loam	
GxB	Gunsight	Loam	45	1-3	Loam	0.24
	Rillito	Fine Sandy Loam	45	2-10	Loam	
	Laveen	Loam	2.5		Loam	
	Pinal	Loam	2.5		Loam	
	Coolidge	Gravelly Sandy Loam	2.5		Sandy Loam	
	Harqua	Gravelly Clay Loam	2.5		Sandy Clay Loam	
GYD	Gunsight	Loam	40	1-3	Loam	0.26
	Rillito	Fine Sandy Loam	40	2-10	Loam	
	Perryville	Gravelly Loam	3.33		Sandy Loam	
	Laveen	Loam	3.33		Loam	
	Pinal	Loam	3.33		Loam	
	Gilman	Loam	3.33		Loam	
	Antho	Gravelly Sandy Loam	3.33		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	3.33		Sandy Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/ hour
HAB	Harqua	Gravelly Clay Loam	85	0-1	Sandy Clay Loam	0.07
	Harqua	Gravelly Clay Loam	3		Sandy Clay Loam	
	Rillito	Gravelly Loam	3		Sandy Loam	
	Gunsight	Gravelly Loam	3		Sandy Loam	
	Casa Grande	Loam	3		Loam	
	Valencia	Sandy Loam	3		Sandy Loam	
HAC	Harqua	Gravelly Clay Loam	65	0-1	Sandy Clay Loam	0.05
	Harqua	Clay	20		Clay	
	Rillito	Gravelly Loam	5		Sandy Loam	
	Gunsight	Gravelly Loam	5		Sandy Loam	
	Laveen	Loam	5		Loam	
HLC	Harqua	Gravelly Clay Loam	40	0-1	Sandy Clay Loam	0.14
	Gunsight	Loam	35	1-3	Loam	
	Rillito	Loam	20	0-2	Loam	
	Rillito	Gravelly Loam	1.667		Sandy Loam	
	Gunsight	Gravelly Loam	1.667		Sandy Loam	
	Laveen	Loam	1.667		Loam	
HM	Harqua	Gravelly Clay Loam	40	0-1	Sandy Clay Loam	0.15
	Laveen	Fine Sandy Loam	35	0-15	Loam	
	Rillito	Loam	15		Loam	
	Gunsight	Gravelly Loam	5		Sandy Loam	
	Valencia	Sandy Loam	5		Sandy Loam	
HrB	Harqua	Clay Loam	50	0-1	Clay Loam	0.12
	Rillito	Gravelly Loam	20	0-2	Sandy Loam	
	Gunsight	Gravelly Loam	15	1-3	Sandy Loam	
	Gilman	Loam	2.143		Loam	
	Antho	Gravelly Sandy Loam	2.143		Sandy Loam	
	Laveen	Loam	2.143		Loam	
	Estrella	Loam	2.143		Loam	
	Valencia	Sandy Loam	2.143		Sandy Loam	
	Tremant	Gravelly Loam	2.143		Sandy Loam	
	Coolidge	Sandy Loam	2.143		Sandy Loam	
La	La Palma	Very Fine Sandy Loam	80	0-5	Loam	0.26
	Pinal	Loam	5		Loam	
	Casa Grande	Loam	5		Loam	
	Laveen	Loam	5		Loam	
	Harqua	Gravelly Loam	5		Sandy Loam	
Lb	Laveen	Sandy Loam	80	0-14	Sandy Loam	0.40
	Perryville	Sandy Loam	3.75		Sandy Loam	
	Coolidge	Sandy Loam	3.75		Sandy Loam	
	Valencia	Sandy Loam	3.75		Sandy Loam	
	Antho	Sandy Loam	3.75		Sandy Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
LcA	Laveen	Loam	85	0-6	Loam	0.25
	Gilman	Loam	3		Loam	
	Mohall	Loam	3		Loam	
	Estrella	Loam	3		Loam	
	Perryville	Gravelly Loam	3		Sandy Loam	
	Rillito	Loam	3		Loam	
LcB	Laveen	Loam	90	0-6	Loam	0.25
	Perryville	Gravelly Loam	3.33		Sandy Loam	
	Gilman	Loam	3.33		Loam	
	Rillito	Loam	3.33		Loam	
Ld	Laveen	Loam	80	0-6	Loam	0.25
	Casa Grande	Loam	4		Loam	
	Gilman	Loam	4		Loam	
	Estrella	Loam	4		Loam	
	Perryville	Loam	4		Loam	
	Laveen	Loam	4		Loam	
Le	Laveen	Clay Loam	85	0-14	Clay Loam	0.04
	Mohall	Clay Loam	3.75		Clay Loam	
	Tremant	Clay Loam	3.75		Clay Loam	
	Vecont	Clay	3.75		Clay	
	Tucson	Clay Loam	3.75		Clay Loam	
Lf	Laveen	Fine Sandy Loam	35	0-12	Loam	0.33
	Laveen	Sandy Loam	20	0-12	Sandy Loam	
	Antho	Sandy Loam	30	0-60	Sandy Loam	
	Coolidge	Sandy Loam	5		Sandy Loam	
	Gilman	Loam	5		Loam	
	Casa Grande	Sandy Loam	5		Sandy Loam	
Ma	Maripo	Sandy Loam	85	0-13	Sandy Loam	0.40
	Antho	Sandy Loam	5		Sandy Loam	
	Valencia	Sandy Loam	5		Sandy Loam	
	Coolidge	Sandy Loam	5		Sandy Loam	
Mo	Mohall	Sandy Loam	92	0-12	Sandy Loam	0.39
	Laveen	Sandy Loam	2		Sandy Loam	
	Coolidge	Sandy Loam	2		Sandy Loam	
	Valencia	Sandy Loam	2		Sandy Loam	
	Tremant	Loam	2		Loam	
Mp	Mohall	Loam	92	0-16	Loam	0.25
	Laveen	Loam	2		Loam	
	Estrella	Loam	2		Loam	
	Gilman	Loam	2		Loam	
	Tremant	Loam	2		Loam	

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Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/ hour
Mr	Mohall	Clay Loam	90	0-12	Clay Loam	0.05
	Laveen	Loam	2		Loam	
	Estrella	Loam	2		Loam	
	Tucson	Loam	2		Loam	
	Tremant	Loam	2		Loam	
	Vecont	Loam	2		Loam	
Ms	Mohall	Clay	80	0-19	Clay	0.01
	Trix	Clay Loam	2.857		Clay Loam	
	Glenbar	Clay	2.857		Clay	
	Cashion	Clay	2.857		Clay	
	Vecont	Clay	2.857		Clay	
	Avondale	Clay	2.857		Clay	
	Mohall	Clay Loam	2.857		Clay Loam	
	Mohall	Clay	2.857		Clay	
MTB	Mohall	Loam	40	0-12	Loam	0.15
	Mohall	Clay Loam	10	0-12	Clay Loam	
	Tremant	Clay	20	1-8	Clay Loam	
	Estrella	Loam	15	0-11	Loam	
	Rillito	Loam	5		Loam	
	Coolidge	Sandy Loam	5		Sandy Loam	
	Laveen	Loam	2.5		Loam	
	Gilman	Loam	2.5		Loam	
MV	Mohall	Clay Loam	25	0-12	Clay Loam	0.15
	Mohall	Loam	20	0-12	Loam	
	Laveen	Loam	20	0-15	Loam	
	Laveen	Sandy Loam	15	0-14	Sandy Loam	
	Estrella	Loam	6.667		Loam	
	Gilman	Loam	6.667		Loam	
	Tremant	Gravelly Clay Loam	6.667		Sandy Clay Loam	
Pa	Perryville	Sandy Loam	85	0-12	Sandy Loam	0.40
	Laveen	Sandy Loam	5		Sandy Loam	
	Coolidge	Sandy Loam	5		Sandy Loam	
	Rillito	Sandy Loam	5		Sandy Loam	
Pb	Perryville	Gravelly Loam	80	0-9	Sandy Loam	0.38
	Rillito	Loam	5		Loam	
	Laveen	Loam	5		Loam	
	Coolidge	Sandy Loam	5		Sandy Loam	
	Perryville	Gravelly Loam	5		Sandy Loam	
PeA	Perryville	Gravelly Loam	78	0-9	Sandy Loam	0.37
	Rillito	Loam	10		Loam	
	Tremant	Loam	4		Loam	
	Coolidge	Sandy Loam	4		Sandy Loam	
	Laveen	Loam	4		Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/hour
PeB	Perryville	Gravelly Loam	80	0-9	Sandy Loam	0.38
	Rillito	Loam	6.667		Loam	
	Laveen	Loam	6.667		Loam	
	Coolidge	Sandy Loam	6.667		Sandy Loam	
PRB	Perryville	Loam	35	0-9	Loam	0.28
	Rillito	Fine Sandy Loam	30	2-10	Loam	
	Perryville	Sandy Loam	10	0-9	Sandy Loam	
	Rillito	Fine Sandy Loam	10	2-10	Loam	
	Antho	Sandy Loam	3.75		Sandy Loam	
	Coolidge	Sandy Loam	3.75		Sandy Loam	
	Laveen	Sandy Loam	3.75		Sandy Loam	
	Gunsight	Gravelly Loam	3.75		Sandy Loam	
PsA	Pinal	Loam	85	0-8	Loam	0.25
	Pinal	Loam	3.75		Loam	
	LaPalma	Very Fine Sandy Loam	3.75		Loam	
	Toltec	Loam	3.75		Loam	
	Gunsight	Gravelly Loam	3.75		Sandy Loam	
PsB	Pinal	Loam	80	0-8	Loam	0.26
	Gunsight	Gravelly Loam	4		Sandy Loam	
	Coolidge	Gravelly Sandy Loam	4		Sandy Loam	
	LaPalma	Very Fine Sandy Loam	4		Loam	
	Rillito	Loam	4		Loam	
	Cherioni	Very Gravelly Fine Sandy Loam	4		Sandy Loam	
PT	Pinal	Gravelly Loam	85	0-8	Sandy Loam	0.40
	Gunsight	Gravelly Loam	7.5		Sandy Loam	
	Cherioni	Very Gravelly Loam	7.5		Sandy Loam	
PvB	Pinal	Loam	50	0-8	Loam	0.25
	LaPalma	Very Fine Sandy Loam	25	0-5	Loam	
	Toletec	Loam	15	0-12	Loam	
	Laveen	Loam	5		Loam	
	Pinal	Loam	5		Loam	
PWB	Pinal	Gravelly Loam	55	0-8	Sandy Loam	0.38
	Sun City	Gravelly Loam	35	0-3	Sandy Loam	
	Beardsley	Loam	5		Loam	
	Gunsight	Loam	5		Loam	
PYD	Pinamt	Very Gravelly Sandy Loam	40	0-6	Sandy Loam	0.20
	Tremant	Clay Loam	30	1-8	Clay Loam	
	Gunsight	Gravelly Loam	6		Sandy Loam	
	Antho	Gravelly Sandy Loam	6		Sandy Loam	
	Rillito	Gravelly Loam	6		Sandy Loam	
	Ebon	Gravelly Loam	6		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	6		Sandy Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/ hour
RaA	Rillito	Sandy Loam	80	0-12	Sandy Loam	0.39
	Coolidge	Sandy Loam	4		Sandy Loam	
	Laveen	Sandy Loam	4		Sandy Loam	
	Tremant	Loam	4		Loam	
	Perryville	Sandy Loam	4		Sandy Loam	
	Pinal	Loam	4		Loam	
RaB	Rillito	Sandy Loam	80	0-10	Sandy Loam	0.39
	Laveen	Sandy Loam	5		Sandy Loam	
	Coolidge	Gravelly Sandy Loam	5		Sandy Loam	
	Perryville	Gravelly Sandy Loam	5		Sandy Loam	
	Pinal	Loam	5		Loam	
RbA	Rillito	Loam	80	0-2	Loam	0.26
	Laveen	Loam	5		Loam	
	Perryville	Gravelly Loam	5		Sandy Loam	
	Coolidge	Sandy Loam	5		Sandy Loam	
	Tremant	Loam	5		Loam	
RbB	Rillito	Loam	80	0-10	Loam	0.25
	Laveen	Loam	6.667		Loam	
	Perryville	Gravelly Loam	6.667		Sandy Loam	
	Pinal	Loam	6.667		Loam	
RhB	Rillito	Loam	10	2-10	Loam	0.23
	Rillito	Loam	10	2-10	Loam	
	Rillito	Loam	10	2-10	Loam	
	Harqua	Gravelly Clay Loam	10	0-3	Sandy Clay Loam	
	Harqua	Gravelly Loam	10	0-3	Sandy Loam	
	Harqua	Loam	10	0-3	Loam	
	Gunsight	Loam	15	1-3	Loam	
	Gunsight	Loam	15	1-3	Loam	
	Gilman	Loam	1.25		Loam	
	Gilman	Fine Sandy Loam	1.25		Loam	
	Antho	Gravelly Sandy Loam	1.25		Sandy Loam	
	Antho	Sandy Loam	1.25		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	1.25		Sandy Loam	
	Valencia	Sandy Loam	1.25		Sandy Loam	
	Estrella	Loam	1.25		Loam	
	Estrella	Loam	1.25		Loam	
RpE	Rillito	Loam	15	2-10	Loam	0.29
	Rillito	Loam	15	2-10	Loam	
	Perryville	Gravelly Loam	30	0-9	Sandy Loam	
	Gunsight	Loam	7.5	1-3	Loam	
	Gunsight	Loam	7.5	1-3	Loam	
	Pinal	Gravelly Loam	15	0-8	Sandy Loam	
	Harqua	Gravelly Clay Loam	5		Sandy Clay Loam	
	Calcio/Torrio	Sandy Loam	5		Sandy Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
RS	Rock Outcrop	—	65	—		0.40
	Cherioni	Very Gravelly Loam	67	1-6	Sandy Loam	
	Gachado	Very Gravelly Loam	33		Sandy Loam	
Ta	Toltec	Loam	90	0-12	Loam	0.25
	Gilman	Loam	3.33		Loam	
	Laveen	Loam	3.33		Loam	
	Tucson	Loam	3.33		Loam	
TB	Torrifluvents	Sandy Loam	100	0-60	Sandy Loam	0.40
Tc	Torriorthents					
TD	Torripsamments	Loamy Sand	100	0-60	Loamy Sand	1.20
	Torrifluvents					
Te	Tremant	Loam	85	0-12	Loam	0.25
	Rillito	Loam	5		Loam	
	Laveen	Loam	5		Loam	
	Mohall	Loam	5		Loam	
TfA	Tremant	Gravelly Loam	85	0-12	Sandy Loam	0.37
	Tremant	Gravelly Sandy Loam	3		Sandy Loam	
	Laveen	Loam	3		Loam	
	Rillito	Gravelly Loam	3		Sandy Loam	
	Mohall	Loam	3		Loam	
	Harqua	Gravelly Clay Loam	3		Sandy Clay Loam	
TfB	Tremant	Gravelly Loam	85	0-12	Sandy Loam	0.36
	Harqua	Gravelly Clay Loam	3.75		Sandy Clay Loam	
	Rillito	Loam	3.75		Loam	
	Gunsight	Gravelly Loam	3.75		Sandy Loam	
	Laveen	Loam	3.75		Loam	
Tg	Tremant	Clay Loam	85	0-12	Clay Loam	0.04
	Mohall	Clay Loam	3		Clay Loam	
	Vecont	Clay	3		Clay	
	Laveen	Loam	3		Loam	
	Harqua	Gravelly Clay Loam	3		Sandy Clay Loam	
	Rillito	Loam	3		Loam	
Th	Tremant	Clay Loam	85	1-8	Clay Loam	0.04
	Rillito	Loam	3		Loam	
	Mohall	Clay	3		Clay	
	Laveen	Loam	3		Loam	
	Pinamt	Gravelly Clay Loam	3		Sandy Clay Loam	
	Harqua	Gravelly Clay Loam	3		Sandy Clay Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/hour
TPB	Tremant	Clay Loam	40	1-8	Clay Loam	0.12
	Tremant	Very Gravelly Loam	40	0-12	Sandy Loam	
	Mohall	Loam	4		Loam	
	Estrella	Loam	4		Loam	
	Pinamt	Gravelly Loam	4		Sandy Loam	
	Laveen	Loam	4		Loam	
	Gilman	Loam	4		Loam	
TrA	Tremant	Clay Loam	40	1-8	Clay Loam	0.11
	Rillito	Fine Sandy Loam	25	2-10	Loam	
	Gunsight	Loam	20	1-3	Loam	
	Laveen	Loam	5		Loam	
	Harqua	Gravelly Clay Loam	5		Sandy Clay Loam	
	Perryville	Gravelly Loam	5		Sandy Loam	
TrB	Tremant	Clay Loam	35	1-8	Clay Loam	0.13
	Rillito	Fine Sandy Loam	30	2-10	Loam	
	Gunsight	Loam	25	1-3	Loam	
	Laveen	Loam	2.5		Loam	
	Coolidge	Gravelly Loam	2.5		Sandy Loam	
	Perryville	Gravelly Loam	2.5		Sandy Loam	
	Harqua	Gravelly Clay Loam	2.5		Sandy Clay Loam	
TSC	Tremant	Clay Loam	35	1-8	Clay Loam	0.14
	Rillito	Fine Sandy Loam	30	2-10	Loam	
	Gunsight	Loam	20	1-3	Loam	
	Carrizo	Gravelly Sandy Loam	3.75		Sandy Loam	
	Laveen	Sandy Loam	3.75		Sandy Loam	
	Coolidge	Gravelly Sandy Loam	3.75		Sandy Loam	
	Perryville	Gravelly Loam	3.75		Sandy Loam	
Tt	Trix	Clay Loam	88	0-10	Clay Loam	0.04
	Avondale	Clay Loam	3		Clay Loam	
	Glenbar	Clay Loam	3		Clay Loam	
	Mohall	Clay Loam	3		Clay Loam	
	Laveen	Clay Loam	3		Clay Loam	
Tu	Tucson	Loam	85	0-14	Loam	0.25
	Casa Grande	Loam	3		Loam	
	Laveen	Loam	3		Loam	
	Gilman	Loam	3		Loam	
	Estrella	Loam	3		Loam	
	Tremant	Loam	3		Loam	
Tw	Tucson	Clay Loam	82	0-14	Clay Loam	0.05
	Casa Grande	Loam	3.6		Loam	
	Mohall	Clay Loam	3.6		Clay Loam	
	Laveen	Loam	3.6		Loam	
	Gilman	Loam	3.6		Loam	
	Estrella	Loam	3.6		Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, Inches	Table 4.2 Textural Class	XKSAT, inch/ hour
Va	Valencia	Sandy Loam	85	0-10	Sandy Loam	0.39
	Coolidge	Sandy Loam	5		Sandy Loam	
	Estrella	Loam	5		Loam	
	Mohall	Sandy Loam	5		Sandy Loam	
Vb	Valencia	Sandy Loam	70	0-10	Sandy Loam	0.39
	Casa Grande	Sandy Loam	7.5		Sandy Loam	
	Antho	Sandy Loam	7.5		Sandy Loam	
	Estrella	Loam	7.5		Loam	
	Coolidge	Sandy Loam	7.5		Sandy Loam	
Vc	Valencia	Gravelly Sandy Loam	80	0-30	Sandy Loam	0.39
	Antho	Gravelly Sandy Loam	6.67		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	6.67		Sandy Loam	
	Estrella	Loam	6.67		Loam	
Ve	Vecont	Loam	85	0-10	Loam	0.25
	Mohall	Loam	5		Loam	
	Gilman	Loam	5		Loam	
	Laveen	Loam	5		Loam	
Vf	Vecont	Clay	85	0-15	Clay	0.01
	Mohall	Clay Loam	5		Clay Loam	
	Estrella	Loam	5		Loam	
	Laveen	Loam	5		Loam	
Vg	Vint	Loamy Fine Sand	77	0-27	Loamy Sand	0.91
	Antho	Sandy Loam	4.6		Sandy Loam	
	Carrizo	Gravelly Sandy Loam	4.6		Sandy Loam	
	Brios	Sandy Loam	4.6		Sandy Loam	
	Maripo	Sandy Loam	4.6		Sandy Loam	
	Gilman	Fine Sandy Loam	4.6		Loam	
Vh	Vint	Fine Sandy Loam	80	0-14	Loam	0.27
	Antho	Sandy Loam	6.67		Sandy Loam	
	Brios	Sandy Loam	6.67		Sandy Loam	
	Maripo	Sandy Loam	6.67		Sandy Loam	
Vk	Vint	Loam	80	0-14	Loam	0.26
	Antho	Sandy Loam	5		Sandy Loam	
	Maripo	Sandy Loam	5		Sandy Loam	
	Gilman	Loam	5		Loam	
	Brios	Loam	5		Loam	
Vn	Vint	Clay Loam	80	0-14	Clay Loam	0.04
	Cashion	Clay	5		Clay	
	Avondale	Clay Loam	5		Clay Loam	
	Avonda	Clay Loam	5		Clay Loam	
	Brios	Loam	5		Loam	

Maricopa Central Soil Survey

Map Unit No.	Soil Name	USDA Soil Texture	% of Map Unit	Control Horizon Depth, inches	Table 4.2 Textural Class	XKSAT, inch/hour
Vr	Vint	Fine Sandy Loam	28	0-14	Loam	0.63
	Vint	Loamy Fine Sand	27	0-14	Loamy Sand	
	Carrizo	Gravelly Sandy Loam	15	0-5	Sandy Loam	
	Carrizo	Gravelly Sand	15	0-5	Loamy Sand	
	Brios	Loamy Sand	3.75		Loamy Sand	
	Antho	Sandy Loam	3.75		Sandy Loam	
	Torripsamments	Loamy Sand	3.75		Loamy Sand	
	Torrifluvents	Loamy Sand	3.75		Loamy Sand	
Wg	Wintersburg	Clay Loam	50	0-12	Clay Loam	0.03
	Wintersburg	Clay	35	0-18	Clay	
	Cashion	Clay	3.75		Clay	
	Avondale	Clay Loam	3.75		Clay Loam	
	Laveen	Loam	3.75		Loam	
	Wintersburg	Clay Loam	3.75		Clay Loam	

Appendix C

Eastern Maricopa/ Northern Pinal Counties Loss Rate Parameters

Eastern Soil Survey

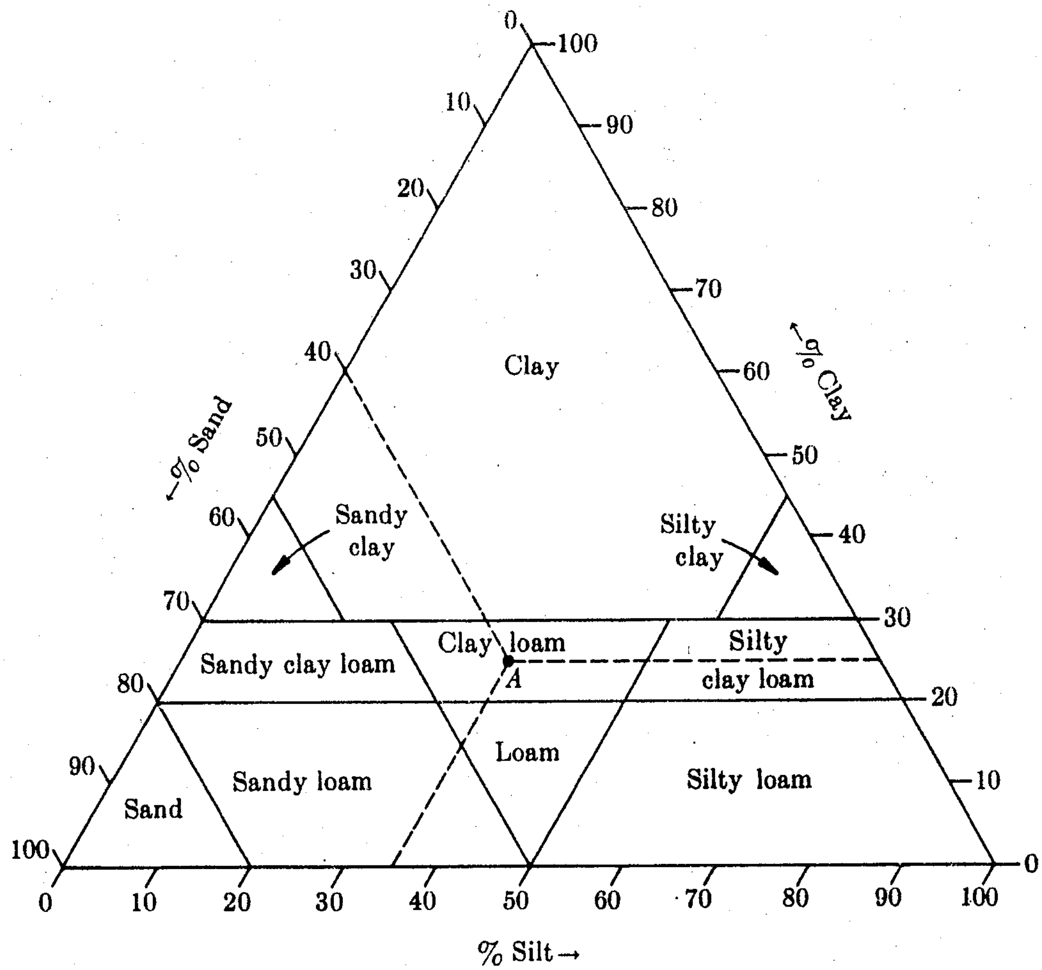
Map Unit No.	Soil Name	USDA Soil Texture	Control Horizon Depth, in	Table 4.2 Textural Class	XKSAT, in/hr
Af	Agualt	Fine Sandy Loam	0-17	Loam	0.25
Ag	Agualt	Loam	0-17	Loam	0.25
Am	Alluvial Land	Sand	0-60	Loamy Sand	1.20
AnA	Antho	Sandy Loam	0-17	Sandy Loam	0.40
AnB	Antho	Sandy Loam	0-17	Sandy Loam	0.40
AoB	Antho	Gravelly Sandy Loam	0-17	Sandy Loam	0.40
Av	Avondale	Clay Loam	0-13	Clay Loam	0.04
Ca	Carrizo	Gravelly Loamy Sand	0-15	Loamy Sand	1.20
Cb	Carrizo	Fine Sandy Loam	0-15	Loam	0.25
Cc	Cashion	Clay	0-12	Clay	0.01
CeC	Cavelt	Gravelly Loam	2-8	Sandy Loam	0.40
Co	Contine	Clay Loam	0-12	Clay Loam	0.04
Es	Estrella	Loam	0-15	Loam	0.25
Gf	Gilman	Fine Sandy Loam	0-13	Loam	0.25
Gm	Gilman	Loam	0-13	Loam	0.25
Gn	Glenbar	Clay Loam	0-14	Clay Loam	0.04
Gr	Gravelly Alluvial Land	Very Gravelly Sandy Loam, Loamy Sand	0-60	Loamy Sand	1.20
LaA	Laveen	Loam	0-14	Loam	0.25
LaB	Laveen	Loam	0-14	Loam	0.25
LeA	Laveen	Clay Loam	0-14	Clay Loam	0.04
Mo	Mohall	Sandy Loam	0-16	Sandy Loam	0.40
Mv	Mohall	Loam	0-15	Loam	0.25
Pm	Pimer	Clay Loam	0-15	Clay Loam	0.04
PnA	Pinal	Gravelly Loam	0-18	Sandy Loam	0.40
PnC	Pinal	Gravelly Loam	0-18	Sandy Loam	0.40
Po	Pinal Variant	Loam	0-13	Loam	0.25
PvA	Pinamt	Very Gravelly Loam	0-3	Sandy Loam	0.40
PvC	Pinamt	Very Gravelly Loam	0-3	Sandy Loam	0.40
RIA	Rillito	Gravelly Loam	0-13	Sandy Loam	0.40
RIB	Rillito	Gravelly Loam	0-13	Sandy Loam	0.40
Ro	Rock Land	Gravelly Loam - Clay Loam	—	Loam	0.25
Ru	Rough Broken Land	Varies	—	Sandy Loam	0.40
TrB	Tremant	Gravelly Sandy Clay Loam	1-5	Silt	0.10
Tx	Trix	Clay Loam	0-14	Clay Loam	0.04
Va	Valencia	Sandy Loam	0-13	Sandy Loam	0.40
Ve	Vecont	Clay	0-14	Clay	0.01
Vf	Vint	Loamy Fine Sand	0-12	Loamy Sand	1.20

Appendix D

Textural Classes

SOIL TEXTURE CLASSIFICATION

TRIANGLE



Definitions: Clay - mineral soil particles less than 0.002 mm in diameter.
Silt - mineral soil particles that range in diameter from 0.002 mm to 0.05 mm.
Sand - mineral soil particles that range in diameter from 0.05 mm to 2.0 mm.

Example: Point A is a soil composed of 40% sand, 35% silt, and 25% clay. It is classified as a clay loam.

Appendix E

Tc and R Worksheet

CALCULATION OF Tc & R

Calculated by: ______________________________ Date: ____________

Checked by: ______________________________ Project: ____________

Watershed: ____

Rainfall Frequency: _____ - yr Duration: ________ - hr. Pattern #: ________

Rainfall Loss Method:
- [ ] Green & Ampt Method
- [ ] IL + ULR by soil texture
- [ ] IL + ULR by hydrologic soil group

Tabulate Period of Peak Rainfall Excess

Clock Time @ end of Increm.	Increm. Excess in.

Rearrange Incremental Excesses in Order of Decreasing Average Intensity

Accum. Time hr./min.	Increm. Excess in.	Accum. Excess in.	Avg. Excess Intensity in./hr.

A = __________ sq.mi.

L = __________ mi.

S = __________ ft/mi.

Kb = m [log(A * 640)]+ b

Kb = (   ) log (*640) + (   )

Kb = __________

$$Tc = 11.4\ L^{.50}\ Kb^{.52}\ S^{-.31}\ i^{-.38}$$

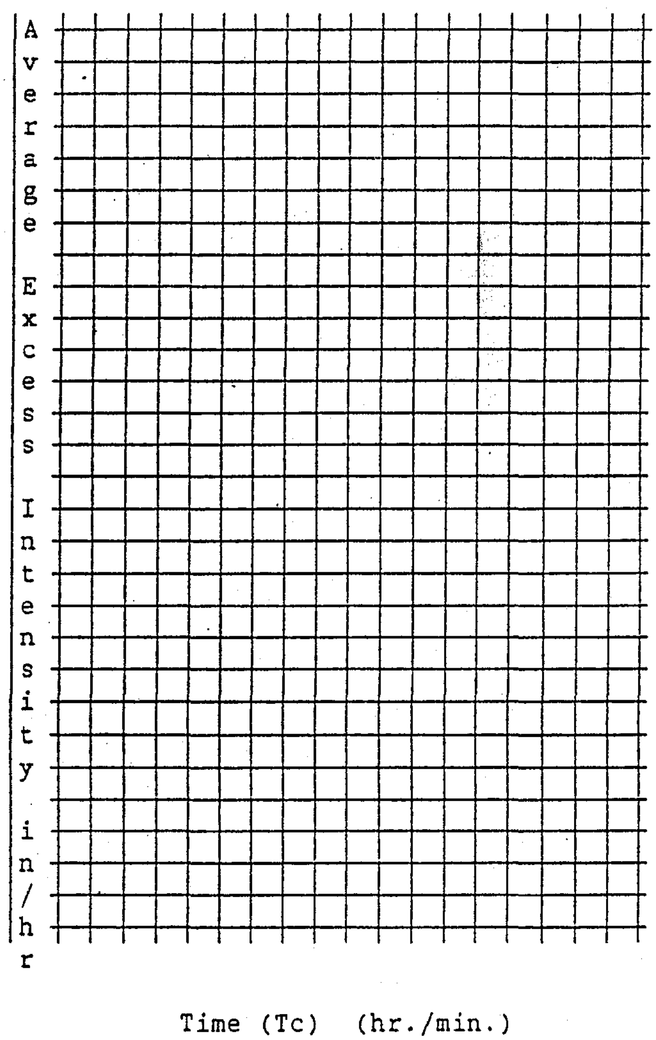
$$Tc = (\_\_\_\_\_\_\_)\ i^{-.38}$$

Trial Tc	i	Calc. Tc

Tc = hr.

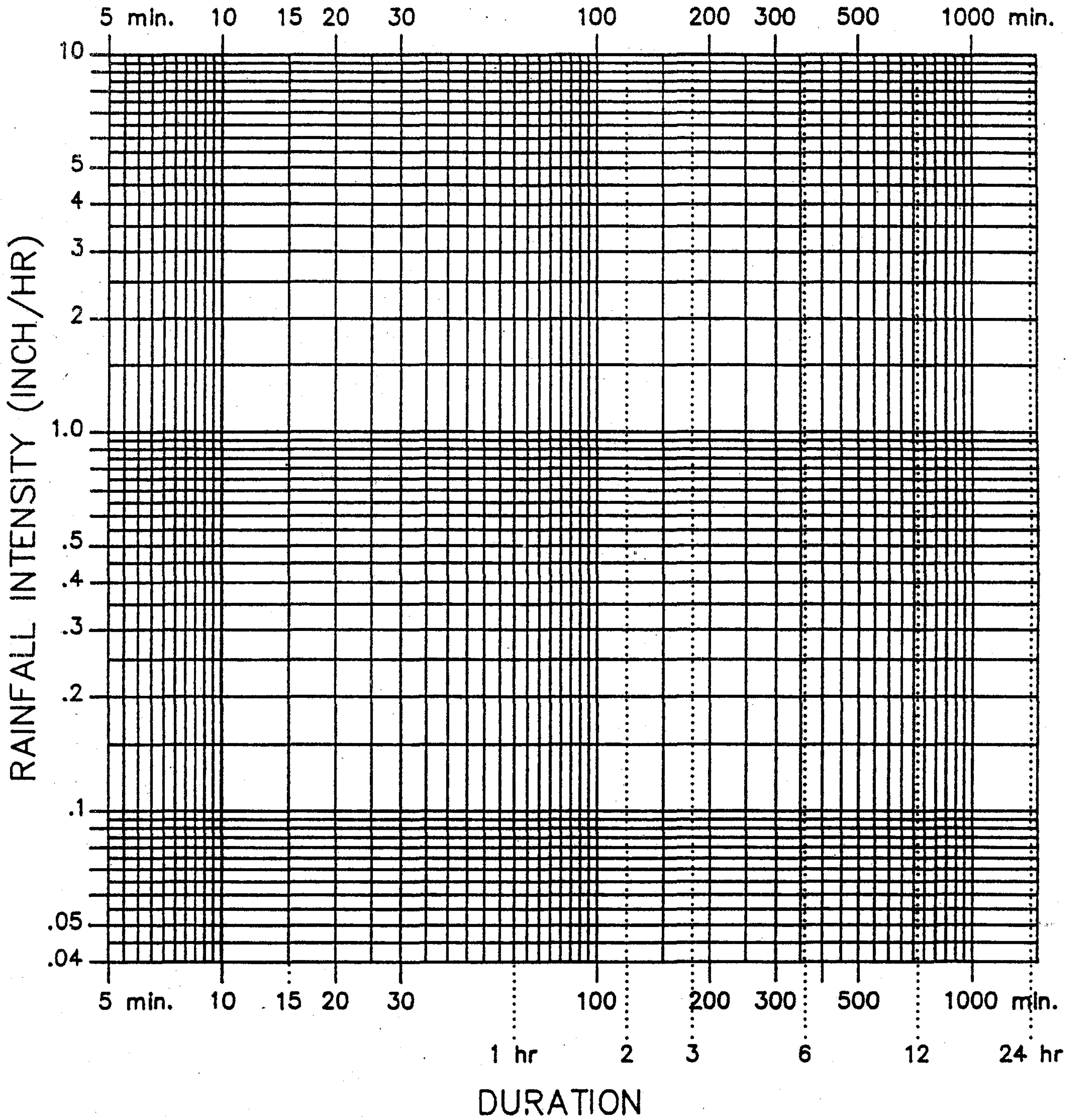
$$R = .37\ Tc^{1.11}\ A^{-.57}\ L^{.80}$$

R = hr.



Appendix F

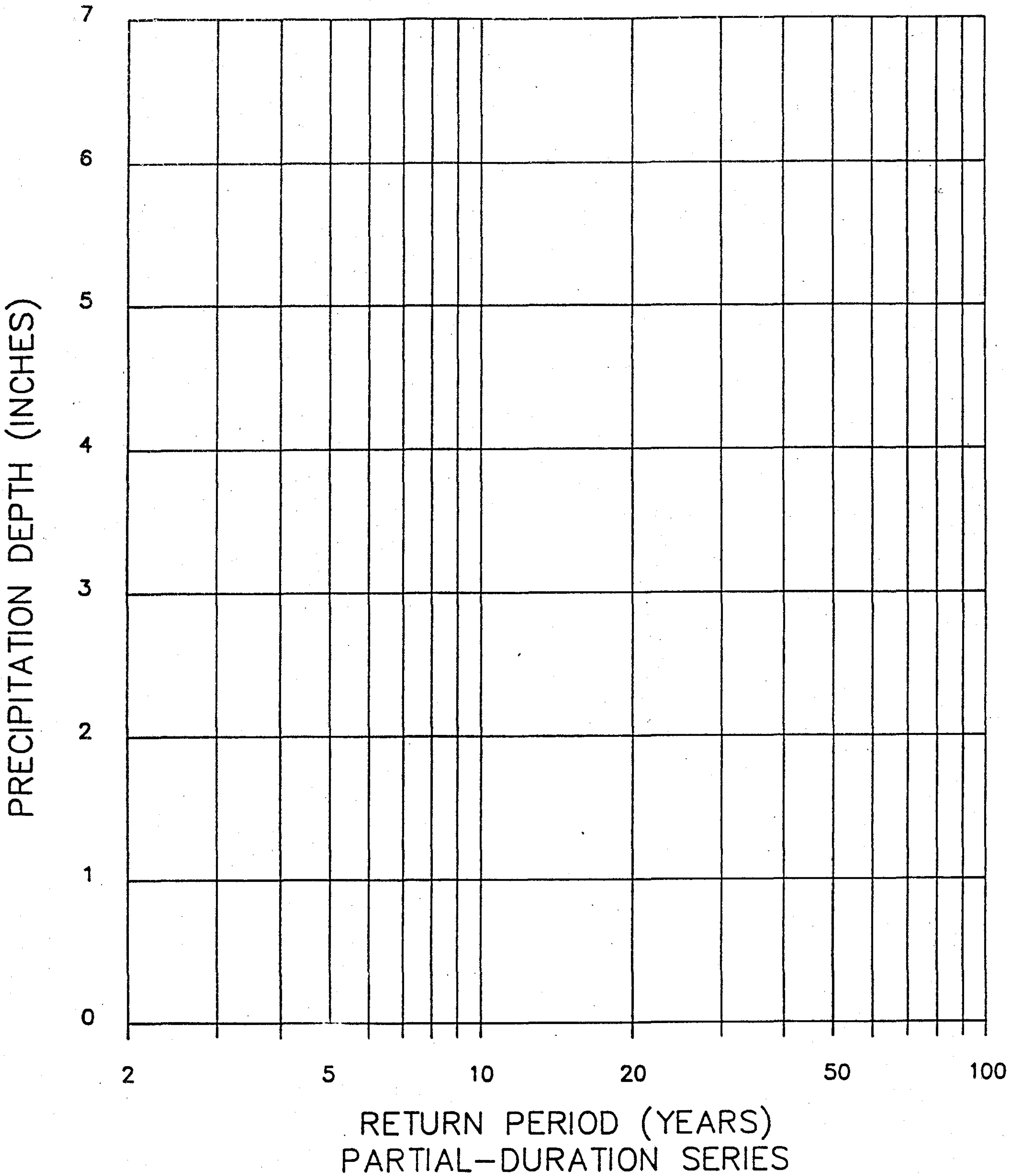
Precipitation Depth-Duration Diagram (6-24 hour)



RAINFALL INTENSITY–DURATION–FREQUENCY RELATION
FOR MARICOPA COUNTY, ARIZONA

Appendix G

Rainfall I-D-F Relation (blank)



Precipitation Depth versus Return Period for Partial-Duration Series

Appendix H

Method Comparison

The Flood Control District staff has conducted a comparison of different hydrologic methods for tutorial purposes. The results from these comparisons support a major objective for developing the *Drainage Design Manual of Maricopa County:* the standardization of drainage analyses. This helps alleviate problems that occur after a developed parcel is annexed. The comparisons are summarized below.

Two separate applications were considered for making a comparison of hydrologic analyses. The first looks at a small urbanized watershed using several different methodologies, but primarily the Rational Method, and is summarized in Table H-1.

Table H-1
Peak Discharge from a Small Urban Watershed

Tr* years	1 Maricopa Co. Rational, cfs	2 Phoenix Rational, cfs	3 Phoenix SCS***, cfs	4 Maricopa Co. UHP**, cfs	5 Phoenix Computer, cfs	6 Flood Frequency
2	37	29	7	12	20	16
5	60	41	17	24	44	31
10	75	48	26	39	61	48
25	108	57	42	58	86	83
50	140	67	53	89	105	126
100	173	74	68	113	126	190

*Tr = Return Frequency
**UHP = Unit Hydrograph Procedure
***SCS = Soil Conservation Service

The Maricopa Rational Method generates higher peak discharges than that being used by the City of Phoenix. However, in most instances, these figures are not overly conservative when compared to recorded data. The significance of this difference depends on which return frequency is used and for what purpose.

The second application compares retention requirements for various cities with those outlined in the *Hydrologic Design Manual,* and is summarized in Table H-2.

Table H-2
Comparison of Retention Requirements

City	City Method		Maricopa County Method	
	Q100 *, cfs	V**, ac-ft	Q100, cfs	V, ac-ft
Chandler	188	13.19	227	11.62
Glendale	109	7.74	237	10.88
Mesa	144***	11.34	231	11.49
Phoenix	138	7.74	243	12.41
Scottsdale	208	10.23	297	12.01
Tempe	138	15.80	231	11.18

*One-hundred Year Peak Discharge.
**Volume.
***Fifty Year Peak Discharge.

There is a 48 percent difference in discharge values between municipalities, as compared to a 24 percent difference using the *Hydrologic Design Manual;* and there is a 51 percent difference in volumes between cities, as compared to a 12 percent difference using the *Hydrologic Design Manual.* . The significance of the differences becomes important when the runoff from one jurisdiction impacts another.

If a further understanding of the results is needed before a decision is made on whether or not to accept the impacts from these differences, please contact us. The Flood Control District will make every attempt to present the *Drainage Design Manual* in a comprehendable format.

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT *METHOD COMPARISON* PAGE *1* OF *4*

DETAIL *YOUNGTOWN WATERSHED* COMPUTED ______ DATE ______

PEAK DISCHARGE FROM A SMALL URBAN WATERSHED CHECKED BY ______ DATE ______

THE YOUNGTOWN WATERSHED, AN URBAN WATERSHED NEAR 111TH AVE. AND PEORIA, IS DELINEATED ON FIGURE 1. IT IS THE ONLY SMALL URBAN WATERSHED IN THE COUNTY KNOWN TO HAVE A CONTINUOUS RUNOFF RECORD LONGER THAN 10 YEARS. SIX METHODS WILL BE USED IN THIS COMPARISON TO CALCULATE / ESTIMATE MULTI-FREQUENCY DISCHARGES AT THE GAUGE LOCATION:

1. THE MARICOPA COUNTY RATIONAL METHOD
2. THE CITY OF PHOENIX RATIONAL METHOD
3. THE MARICOPA COUNTY UNIT HYDROGRAPH PROCEDURE (CLARK UNIT HYDROGRAPH)
4. THE CITY OF PHOENIX / SCS METHOD
5. THE CITY OF PHOENIX COMPUTER GENERATED DRAINAGE ANALYSIS PROCEDURE
6. FLOOD FREQUENCY ANALYSIS USING USGS EXTREME LOG PAPER AND THE CUNAIN PLOTTING POSITION.

BASIN PARAMETERS:

LAND USE: Single Family RESIDENTIAL

AREA: $0.13\ mi^2$ or 83.2 acres

$L = 1.023\ mi = 5400\ ft$

$S = 5.8\ ft/mi = .0011\ ft/ft = 0.11\%$

① MARICOPA COUNTY RATIONAL METHOD

2-YEAR PEAK DISCHARGE

$Tc = 11.4\ L^{.5}\ K_b^{.52}\ S^{-.31}\ i^{-.38}$

$K_b = -.00625\ (\log 83.2) + .04 = .028$

$Tc = 11.4\ (1.023)^{.5}(.028)^{.52}(5.8)^{-.31}\ i^{-.38}$

$Tc = 1.042\ i^{-.38}$

TRY $Tc_2 = 1.00\ hr$: $i_2 = 0.93\ in/hr$, $Tc_2 = 1.042\ (.93)^{-.38} = 1.071$ → NO GOOD

TRY $Tc_2 = 1.10\ hrs$: $i_2 = 0.88\ in/hr$, $Tc_2 = 1.042\ (.88)^{-.38} = 1.094\ hr.$ → OK

$Q_2 = C_2\ i_2\ A = (.50)(.88)(83.2) =$ __37 cfs__

5-YEAR PEAK DISCHARGE

TRY $Tc_5 = .917\ hrs$: $i_5 = 1.45\ in/hr$; $Tc_5 = 1.042\ (1.45)^{-.38} = .905\ hrs$ → OK

$Q_5 = C_5\ i_5\ A = (.50)(1.45)(83.2) =$ __60 cfs__

10-YEAR PEAK DISCHARGE

TRY $Tc_{10} = .75\ hrs$: $i_{10} = 1.95\ in/hr$, $Tc_{10} = 1.042\ (1.95)^{-.38} = .808\ hr$ → No Good

TRY $Tc_{10} = .817\ hrs$: $i_{10} = 1.80\ in/hr$, $Tc_{10} = 1.042\ (1.80)^{-.38} = .833\ hr$ → OK

$Q_{10} = C_{10}\ i_{10}\ A = (.50)(1.80)(83.2) =$ __75 cfs__

25-YEAR PEAK DISCHARGE

TRY $Tc_{25} = .75\ hrs$: $i_{25} = 2.35\ in/hr$, $Tc_{25} = 1.042\ (2.35)^{-.38} = .753\ hr$ → OK

$Q_{25} = C_{25}\ i_{25}\ A = (.55)(2.35)(83.2) =$ __108 cfs__

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT *METHOD COMPARISON* PAGE 2 OF 4

DETAIL *YOUNGTOWN WATERSHED* COMPUTED ______ DATE ______

______ CHECKED BY ______ DATE ______

50-YEAR PEAK DISCHARGE

TRY Tc_{50} = .650 hrs: i_{50} = 2.95 in/hr, $Tc_{50} = 1.042\,(2.95)^{-.38} = .691$ hrs. → No Good

TRY Tc_{50} = .700 hrs: i_{50} = 2.80 in/hr, $Tc_{50} = 1.042\,(2.80)^{-.38} = .705$ hrs → OK

$$Q_{50} = C_{50}\, i_{50}\, A = (.60)(2.80)(83.2) = 140 \text{ cfs}$$

100-YEAR PEAK DISCHARGE

TRY Tc_{100} = .633 hrs: i_{100} = 3.40 in/hr, $Tc_{100} = 1.042\,(3.40)^{-.38} = 0.654$ hrs → No Good

TRY Tc_{100} = .667 hrs: i_{100} = 3.30 in/hr, $Tc_{100} = 1.042\,(3.30)^{-.38} = 0.662$ hrs → OK

$$Q_{100} = C_{100}\, i_{100}\, A = (.63)(3.30)(83.2) = 173 \text{ cfs}$$

② CITY OF PHOENIX RATIONAL METHOD

From: "STORM DRAIN DESIGN MANUAL", City of Phoenix, July, 1988.

BASIN PARAMETERS:

- AREA: 83.2 ac
- OVERLAND FLOW LENGTH (ALLEY TO STREET): 130'
- MAXIMUM GUTTER FLOW LENGTH: 5540' = L
- S = .11 %
- C = 0.45 (RESIDENTIAL AREA, AVERAGE ZONING)

CALCULATE Tc: Sum of Overland & Gutter Flow ($t_i + t_t$)

$$t_i = \frac{.04593\,(130)^{.77}}{(.11)^{.385}} = 4.6 \text{ min}$$

$t_t = L/60V$, V = 1.5 ft/s for S = .001 ft/ft and y = 0.5'

$= 5540/60(1.5) = 61.6$ min

$Tc = 4.6 + 61.6 = 66.2$ min or 1.103 hr.

$Q_{pk} = C\,i\,A$
$= 37.44\,i$

Tr (yrs)	i (in/hr)	Qpk (cfs)
2	.78	29
5	1.09	41
10	1.29	48
25	1.52	57
50	1.78	67
100	1.98	74

③ CITY OF PHOENIX / SCS METHOD

$$Q_p = \frac{484\,A\,Q}{T_p}$$

where
- Q_p = Peak Discharge (cfs)
- A = Drainage Area (mi²)
- Q = Storm Runoff (in)
- T_p = Time to Peak (hr)

BASIN PARAMETERS:

- $A = 0.13\ mi^2 = 83.2$ ac
- L = 5650'
- S = 0.01 ft/ft (min. on p.21)
- W = (43,560×83.2)/5650 = 641'
- W_f = 1.10
- Tc = 1.04 hr (p.21)
- Soil Group B, CN = 84 (R
- $T_p = Tc(W_f) = 1.144$ hr

Tr (yrs)	2	5	10	25	50	100
P_1^{Tr} (in)	.88	1.30	1.61	2.02	2.35	2.66
Q^{Tr} (in)	.12	.31	.48	.77	.97	1.23
Q_{pk}^{Tr} (cfs)	7	17	26	42	53	68

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT METHOD COMPARISON PAGE 3 OF 4

DETAIL YOUNGTOWN WATERSHED COMPUTED ________ DATE ________

________ CHECKED BY ________ DATE ________

(4) MARICOPA COUNTY UNIT HYDROGRAPH PROCEDURE

BASIN PARAMETERS:

$A = .13\ mi^2$
$S = 5.8\ ft/mi$
$L = 1.023\ mi$
$Kb = 0.028$
Time - Area Curve: URBAN
Runoff: Clark Unit Hydrograph
Losses: Green - Ampt Method

LOSSES: Soil Map Units → LcA (50%), PeA (35%), Vf (15%)
FROM APPENDIX C, XKSAT VALUES ARE: LcA → .25 in/hr
PeA → .37 in/hr
Vf → .01 in/hr

Basin Average XKSAT:

$\overline{XKSAT} = ALOG[.50(\log .25) + .35(\log .37) + .15(\log .01)] = .18$ in/hr

FROM FIG. 4.3, $\overline{PSIF}$ = 5.7 in and $\overline{DTHETA}$ (DRY) = 0.38 in

IA = .50(.20) + .50(.10) = 0.15 in (50% Desert Landscaping & 50% lawns)

RTIMP = 25% (connected imperviousness)

HEC-1 RUNS USING 6-HOUR RAINFALL DEPTHS (adjusted), 6-HOUR PATTERN No. 1, AND Tc & R CALCULATIONS FROM MCUHP1.EXE. :

Tr (yrs)	2	5	10	25	50	100
RAINFALL (in)	1.11	1.60	1.95	2.31	2.80	3.15
Tc (hr)	1.50	1.33	1.12	.96	.82	.75
R (hr)	1.89	1.65	1.36	1.15	.96	.87
Qpk (cfs)	12	24	39	58	89	113

(5) CITY OF PHOENIX "COMPUTER GENERATED ANALYSIS PROCEDURE"

CURVE NUMBER: 85% B SOIL, 15% D SOIL → .85(84) + .15(90) = 85

LAG TIME: $T_L = 0.6\ T_c$
T_c = 66.3 min from Rational Method Calcs. in (2)
T_L = 0.6 (66.3) = 39.8 min = 0.663 hr

RAINFALL: 24-Hour Depths and Distribution from p. 16 of the "Storm Drain Design Manual".

RUNOFF MODEL: HEC-1

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT METHOD COMPARISON

DETAIL YOUNGTOWN WATERSHED COMPUTED ______ DATE ______

CHECKED BY ______ DATE ______

RESULTS:

Tr (years)	RAINFALL DEPTH (in)	PEAK DISCHARGE (cfs)
2	1.44	20
5	2.10	44
10	2.53	61
25	3.12	86
50	3.57	105
100	4.04	126

SUMMARY TABLE: PEAK DISCHARGES IN CFS

Tr (years)	MARICOPA Co. RATIONAL METHOD	CITY OF PHX. RATIONAL METHOD	CITY OF PHX. SCS	MARICOPA Co. U.H.P.	CITY OF PHX. COMPUTER	FLOOD FREQUENCY
2	37	29	7	12	20	16
5	60	41	17	24	44	31
10	75	48	26	39	61	48
25	108	57	42	58	86	83
50	140	67	53	89	105	126
100	173	74	68	113	126	190

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT METHOD COMPARISON PAGE ____ OF ____

DETAIL YOUNGTOWN WATERSHED COMPUTED ____________ DATE ______

________________________ CHECKED BY ____________ DATE ______

RECORDED DATA

The U.S.G.S. operated a stream/precipitation gauge* at the outlet of the Youngtown Watershed during the period 1961 - 1973. Using the Cunane plotting position, a summary of the data and the statistical analysis follows:

WATER YEAR	Q_p (cfs)	RANK (m)	$P = \frac{m-.4}{N+.2}$	RETURN PERIOD (years)
1965	73	1	.0455	22.00
1970	47	2	.1212	8.25
1973	39	3	.1970	5.08
1971	36	4	.2727	3.67
1966	21	5	.3485	2.87
1964	17	6	.4242	2.36
1972	17	7	.5000	2.00
1963	16	8	.5758	1.74
1969	15	9	.6515	1.55
1961	8.8	10	.7273	1.38
1968	7.8	11	.8030	1.25
1967	6.6	12	.8788	1.14
1962	5.7	13 = N	.9545	1.05

* Gauge # 9-5137: Agua Fria Tributary at Youngtown, Az.

9-179b
Extreme log data plot
April 1955

UNITED STATES DEPARTMENT OF THE INTERIOR

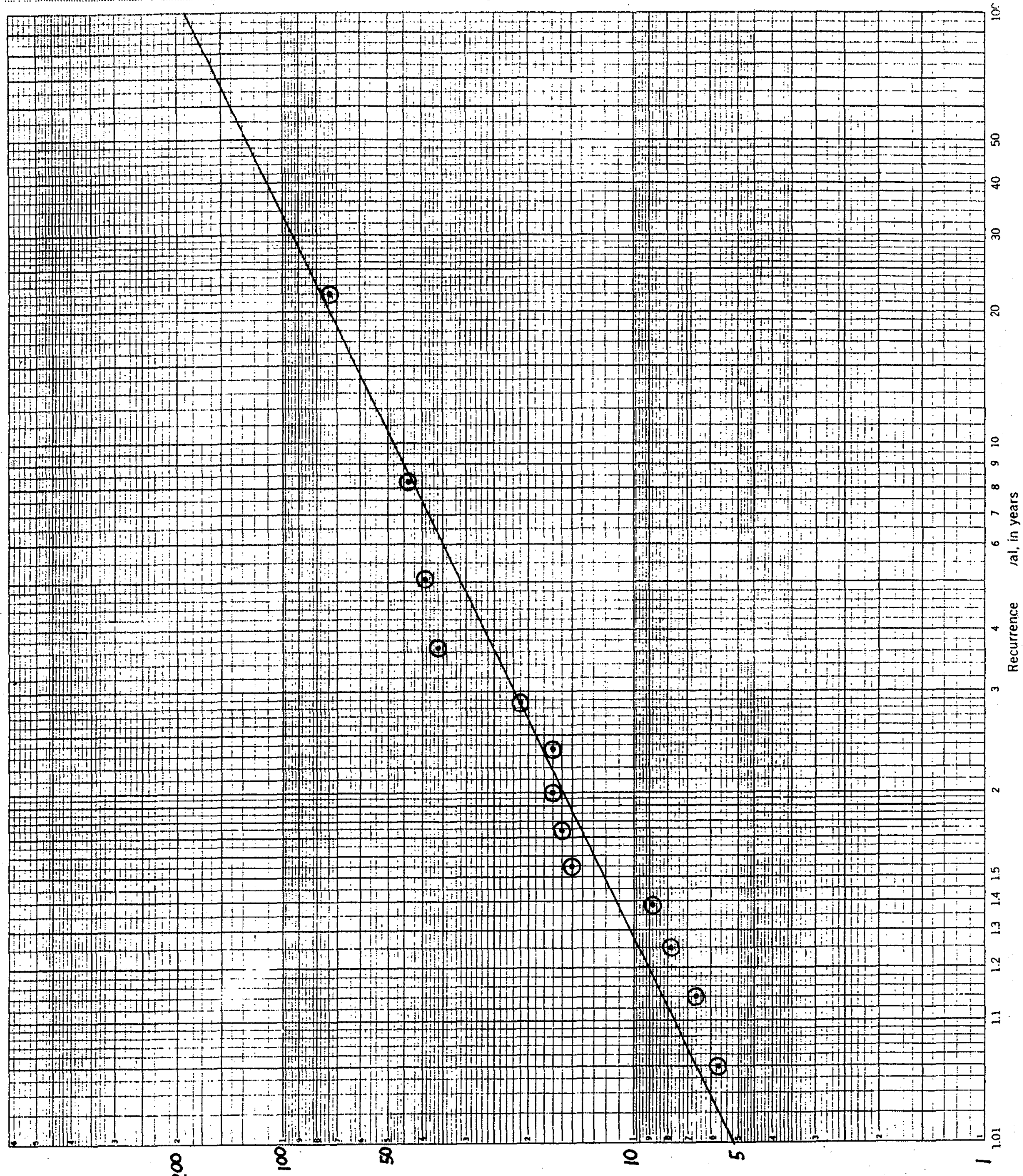
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

File ....

Magnitude and frequency of AGUA FRIA TRIB. @ YOUNGTOWN, AZ. on ....

Drainage area 0.13 sq. mi. Period 1961 - 1973



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GPO 863751

FIGURE 1

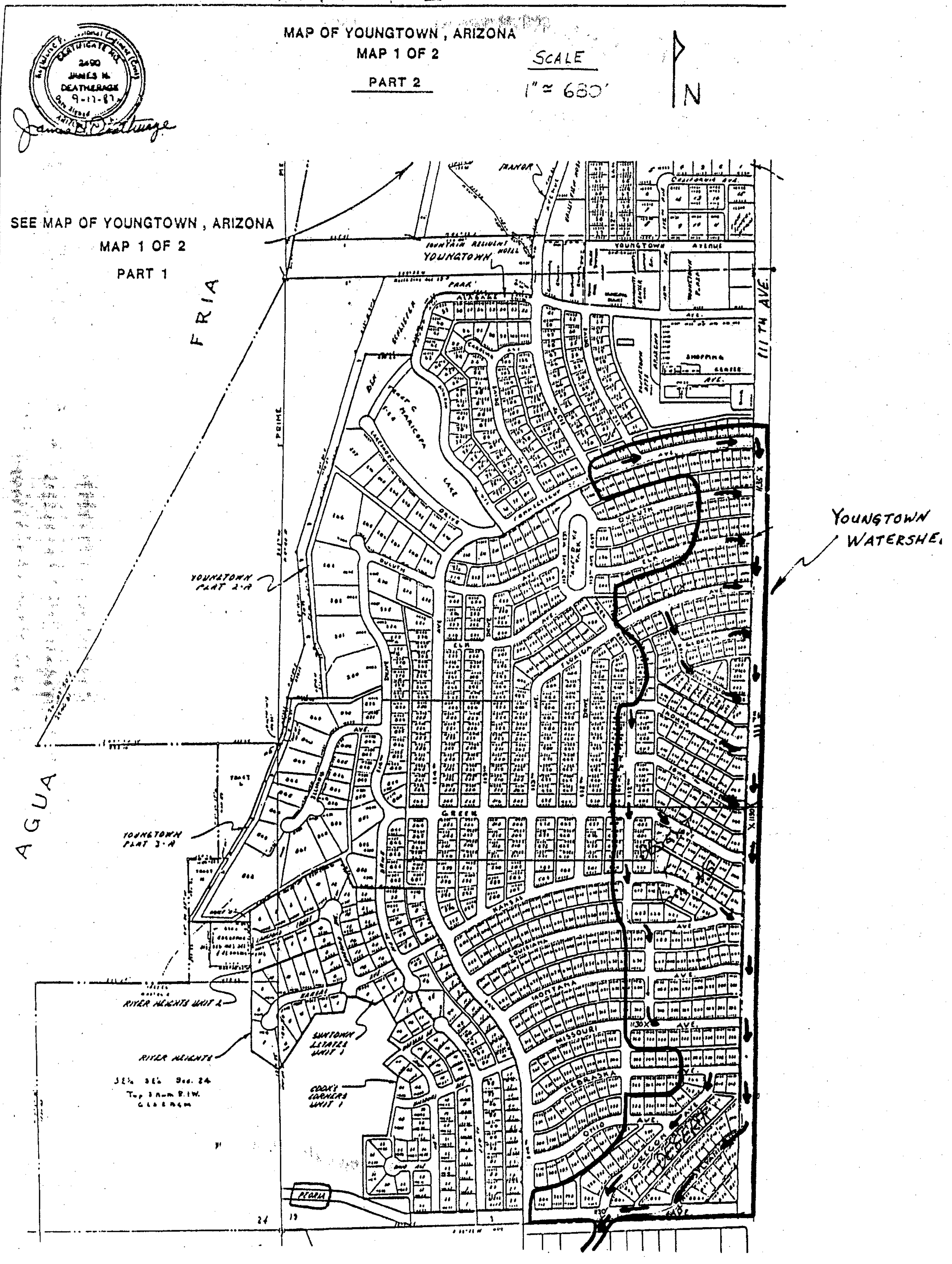
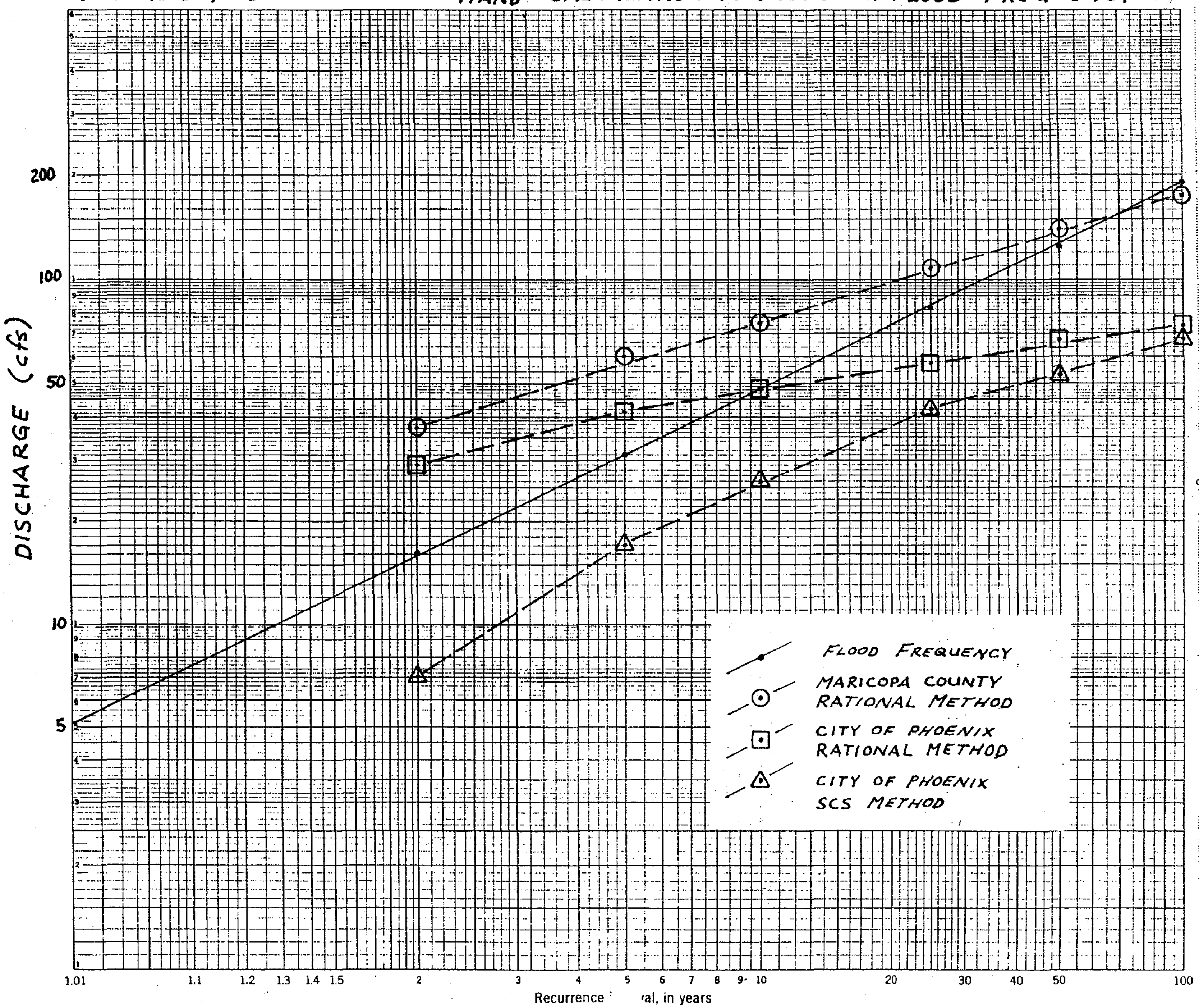

MAP OF YOUNGTOWN, ARIZONA
MAP 1 OF 2
PART 2
SCALE
1" ≈ 680'
N
JAMES N. DEATHERAGE
9-17-87
SEE MAP OF YOUNGTOWN, ARIZONA
MAP 1 OF 2
PART 1
AGUA
FRIA
YOUNGTOWN AVENUE
YOUNGTOWN PARK
111 TH AVE.
SHOPPING CENTER
YOUNGTOWN PLAT 2-A
YOUNGTOWN PLAT 3-A
RIVER HEIGHTS UNIT 2
RIVER HEIGHTS
SUNTOWN ESTATES UNIT 1
COOK'S CORNERS UNIT 1
PEORIA
DULUTH
ELM
GREEN
KANSAS
LOUISIANA
MONTANA
MISSOURI
NEBRASKA
OHIO
OREGON
ALABAMA
CONNECTICUT
FLORIDA
YOUNGTOWN WATERSHED

FIGURE 2, COMPARISON OF "HAND" CALCULATION METHODS VS. FLOOD FREQUENCY



9-179b
Extreme log data plot
April 1955

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Magnitude and frequency of YOUNGTOWN (AGUA FRIA TRIB.) on
Drainage area 0.13 sq. mi. Period

File

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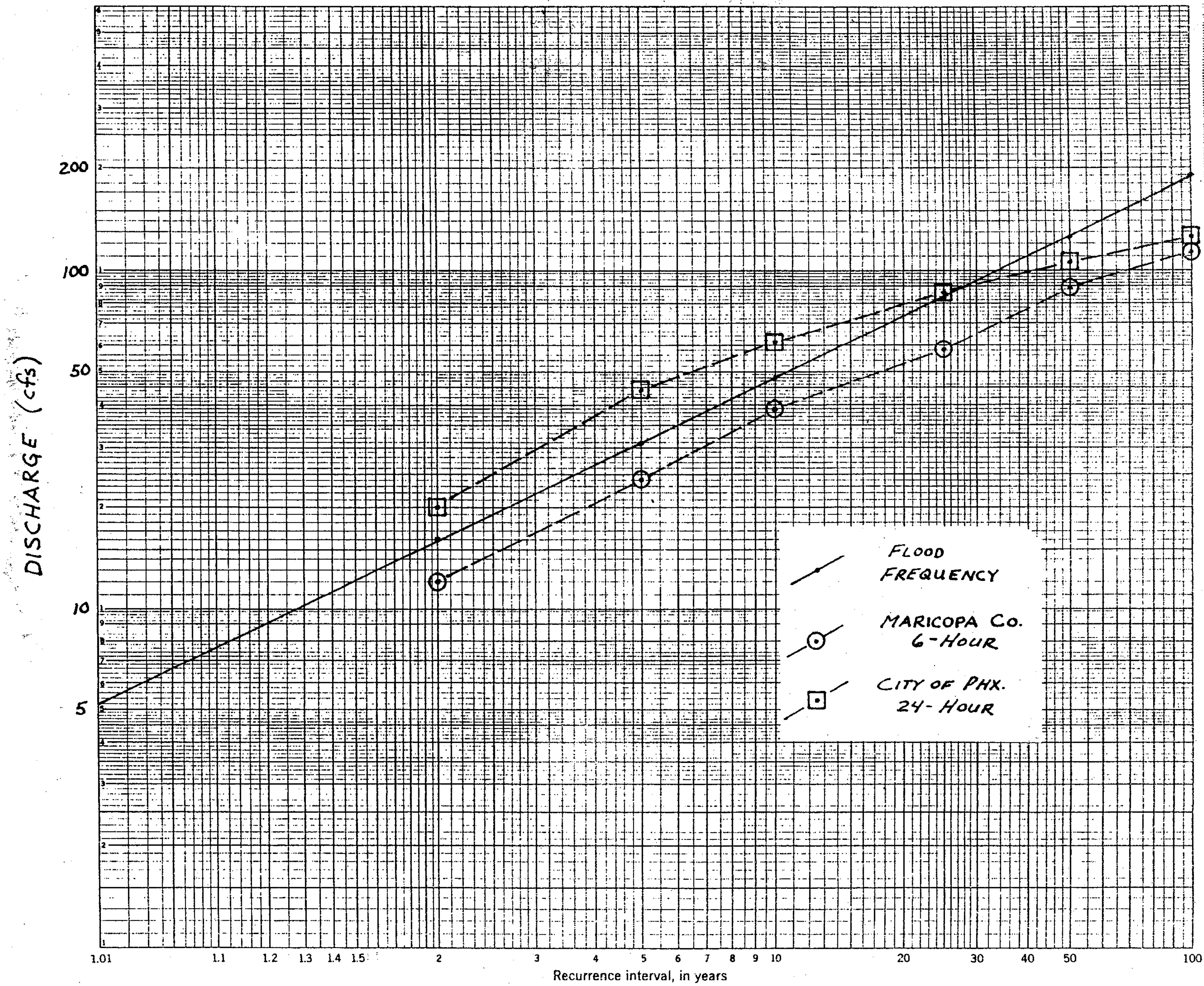
GPO 863751

FIGURE 3, COMPARISON OF "COMPUTER" METHODS VS. FLOOD FREQUENCY



9-179b
Extreme log data plot
April 1955

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Magnitude and frequency of YOUNGTOWN (AGUA FRIA TRIB.) on ....
Drainage area 0.13 sq. mi. Period ....

File ....

Sheet No. ...... of ...... Sheets. Prepared by .... Date .... Checked by .... Date ....

GPO 863751

```
ID  MARICOPA COUNTY UNIT HYDROGRAPH PROCEDURE
ID  YOUNGTOWN WATERSHED:  6HR - 100 YR RAINFALL, CLARK UNIT HYDROGRAPH,
ID  GREEN & AMPT LOSSES, URBAN TIME/AREA CURVE
IT     5                        100
IO     0
KK  SUB1
BA   .13
IN    15
KM 6-HOUR RAINFALL, PATTERN NO. 1.00 WAS USED TO FING TC & R FOR THIS BASIN
KM THIS BASIN USED A RAINFALL REDUCTION FACTOR OF .998
PC  .000     .008     .016     .025     .033     .041     .050     .058     .066     .074
PC  .087     .099     .118     .138     .216     .377     .834     .911     .931     .950
PC  .962     .972     .938     .991    1.000
LG   .15      .38      5.7      .18     25.0
UA     0        5       16       30       65       77       84       90       94       97
UA   100
UC  0.82     0.96
ZZ
```

```
ID MULTI-FREQUENCY RUN FOR YOUNGTOWN WATERSHED
ID USING CRITERIA ESTABLISHED IN THE CITY OF PHOENIX
ID STORM DRAIN DESIGN MANUAL
IT     10                       250
IO      3
JP      6
KK YOUNG
BA    .13
IN     30
PB   1.44
PC      0    .004     .008     .013     .018     .022     .026     .031     .035     .040
PC   .044    .048     .053     .057     .062     .066     .071     .075     .080     .093
PC   .107    .120     .140     .170      .50     .830     .860     .880     .893     .907
PC   .920    .924     .928     .933     .937     .942     .947     .951     .956     .960
PC   .964    .969     .973     .978     .982     .987     .991     .995     1.00     1.00
LS             85
UD   .663
KP      2
PB    2.1
KP      3
PB   2.53
KP      4
PB   3.12
KP      5
PB   3.57
KP      6
PB   4.04
ZZ
```

<u>FIGURE 4</u>

<u>HEC-1 SAMPLE PROGRAMS FOR</u>

<u>MARICOPA COUNTY UNIT HYDROGRAPH PROCEDURE AND CITY OF PHOENIX METHOD</u>

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

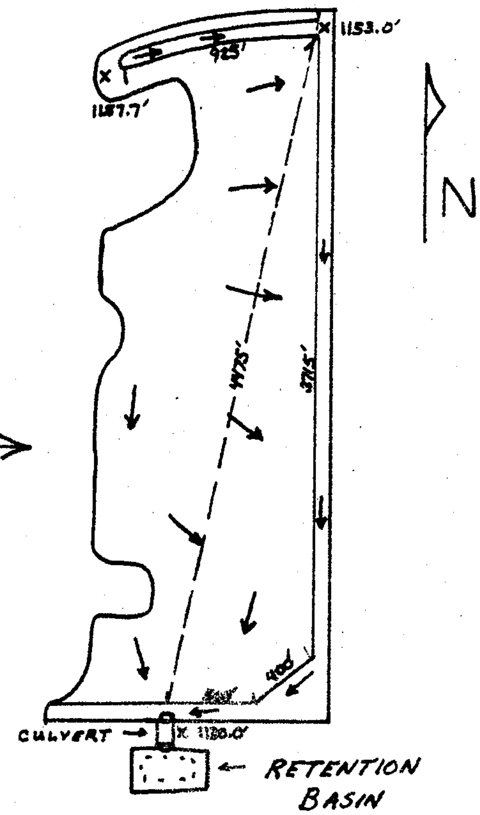
PROJECT *METHOD COMPARISON*

DETAIL *RETENTION REQUIREMENTS* COMPUTED ______ DATE ______

CHECKED BY ______ DATE ______

FOLLOWING IS A COMPARISON OF THE METHODOLOGIES USED BY SIX DIFFERENT CITIES IN MARICOPA COUNTY TO CALCULATE RETENTION VOLUMES, AND THE MARICOPA COUNTY METHOD AS APPLIED TO SPECIFIC LOCATIONS IN EACH CITY. A BASIN INLET CULVERT WILL ALSO BE SIZED USING THE 100-YEAR FREQUENCY STORM FOR EACH JURISDICTION WHERE POSSIBLE.

FOR EASE OF COMPARISON, THE YOUNGTOWN WATERSHED WILL BE USED IN SLIGHTLY MODIFIED FORM: →



$A = 0.13\ mi^2 = 83.2\ ac$

ZONING: R1-6 (PHX), R1-7 (Scottsdale)

LAND USE: ROOFS – 10%
PAVEMENT – 10%
DESERT LANDSCAPE – 40%
LAWNS – 30%
BARE GROUND – 10%

SOIL TYPE: VARIES WITH LOCATION

AVERAGE OVERLAND FLOW LENGTH: 130'

① CITY OF CHANDLER

SOURCE: CITY OF CHANDLER TECHNICAL DESIGN MANUAL #3 – STORM DRAINAGE SYSTEM DESIGN 1987

CITY METHOD: RATIONAL EQUATION

BASIN OUTLET LOCATION: WARNER RD. AT ARIZONA AVE

$C = 0.65$ (DETACHED SINGLE FAMILY)

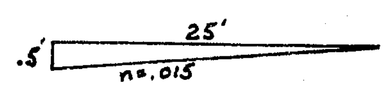
RAINFALL SOURCE: USWB MAPS IN ADOT DRAINAGE MANUAL

$P_{100}^{6} = 3.00\ in$

$P_{100}^{24} = 3.40\ in \rightarrow P_{100}^{1} = .494 + .755 \frac{(P_{100}^{6})^2}{P_{100}^{24}} = 2.49\ in$

$T_c = t_i + t_t \qquad t_i = \frac{.04593\,(130)^{.77}}{(.5)^{.385}} = 2.55\ min$

t_t: Use Mannings' EQ.



$A = .5(25)½ = 6.25\ ft^2$

$P = .5 + \sqrt{.5^2 + 25^2} = 25.505\ ft$

$R = A/P = .245$

$V = \frac{1.49}{.015}(.245)^{.67}(.005)^{.5} = 2.75\ ft/s$

$t_t = L/60V = 5540/60(2.75) = 33.58\ min$

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT *Method Comparison* PAGE 2 OF 6

DETAIL *Retention Requirements* COMPUTED ______ DATE ______

CHECKED BY ______ DATE ______

CITY OF CHANDLER (cont.)

$T_c = t_i + t_t = 36.13$ min

AT $T_c = 36.13$ min. and $P_{100}^{1} = 2.49$ in., $i = 3.48$ in/hr

THEN $Q_{100} = (.65)(3.48)(83.2) =$ <u>188 cfs</u>

VOLUME: $V = 1.10\left[CA\,\frac{P_{100}^{2}}{12}\right]$

$P_{100}^{2} = .341\,(P_{100}^{6}) + .659\,(P_{100}^{1}) = 2.66$ in

$V = 1.10[(.65)(83.2)(2.66/12) =$ <u>13.19 ac-ft</u>

MARICOPA METHOD FOR CHANDLER

$C = 0.63$

$L = 1.023$ mi

$K_b = -.00625\,(\log 83.2) + .04 = .028$

$S = 27.08$ ft/mi

$P_{100}^{6} = 1.87$ in

$T_c = 11.4\,L^{.50}\,K_b^{.52}\,S^{-.31}\,i^{-.38}$

$T_c = 0.646\,i^{-.38}$

TRY $T_c = 20$ min., $i_p = 5.1$ in/hr, $i_{100} = (5.1)(1.87)/2.07 = 4.61$ in/hr

$T_c = .646\,(4.61)^{-.38} = 21.69$ min ⟶ NO GOOD

TRY $T_c = 22$ min., $i_p = 4.8$ in/hr, $i_{100} = (4.8)(1.87)/2.07 = 4.34$ in/hr

$T_c = .646\,(4.34)^{-.38} = 22.2$ min ⟶ OK

$Q_{100} = (.63)(4.34)(83.2) =$ <u>227 cfs</u>

VOLUME: $V = CA\,(P_{100}^{2}/12)$; $P_{100}^{2} = .341\,(P_{100}^{6}) + .659\,(P_{100}^{1}) = 2.66$ in

$V_{100} = (.63)(83.2)(2.66/12) =$ <u>11.62 ac-ft</u>

---

(2) CITY OF GLENDALE

SOURCE: City of Glendale Design Guidelines for Site Development and Infrastructure Construction - 1990

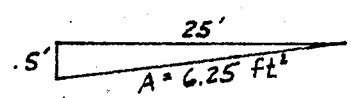
Basin Outlet Location: Northern & 67TH AVE.

CITY METHOD: RATIONAL METHOD

$T_c = t_t + 10$ min

$C = 0.45$ (from City of Phoenix Manual)

$t_t =$ $Q = .56\left(\frac{50}{.015}\right)(.005)^{1/2}(.5)^{8/3} = 20.78$ cfs



$V = Q/A = 3.33$ ft/s

$t_t = L/60V = 5540'/60(3.33) = 27.73$ min

THEN $T_c = 27.73 + 10 = 37.73$ min

AT $T_c = 37.73$ min, $i_{100} = 2.9$ in/hr (USWB / City of Phoenix Manual)

$Q_{100} = (.45)(2.9)(83.2) =$ <u>109 cfs</u>

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT *Method Comparison*

DETAIL *Retention Requirements* COMPUTED ______ DATE ______

CHECKED BY ______ DATE ______

CITY OF GLENDALE (Cont.)

VOLUME : $V_r = 7200\ A_a C I$, where $C = .45$, $A_a = 83.2\ ac$, $I = 1.25\ in/hr$

$$V_r = \frac{7200(83.2)(.45)(1.25)}{43{,}560\ ft^2/ac}$$

$V_r = 7.74$ ac-ft

MARICOPA COUNTY METHOD FOR CITY OF GLENDALE

$T_c = 11.4\,(1.023)^{.5}\,(.028)^{.52}\,(27.08)^{-.31}\, i^{-.38} = .646\, i^{-.38}$, $P_{10}^{6} = 1.95$ in

Try $T_c = 22$ min, $i_p = 4.8$ in/hr, $i_{100} = (4.8)(1.95)/2.07 = 4.52$ in/hr

$T_c = .646\,(4.52)^{-.38} = 21.85$ min → OK

$Q_{100} = (0.63)(4.52)(83.2) = 237$ cfs

VOLUME : $P_{100}^{1} = .494 + .755\,(2.95)\left(\frac{2.95}{3.75}\right) = 2.25$ in; $P_{100}^{6} = 2.95$ in, $P_{100}^{24} = 3.75$ in

$P_{100}^{2} = .341\,(2.95) + .659\,(2.25) = 2.49$ in

$V = CA\left(\frac{P_{100}^{2}}{12}\right) = (.63)(83.2)\quad(2.49/12) = 10.88$ ac-ft

---

(3) CITY OF MESA

SOURCE: Mesa Engineering Procedure Manual, June 1983, Aug. 1989.
BASIN OUTLET LOCATION: McDOWELL & RECKER Rd.
CITY METHOD: RATIONAL EQUATION (50-year)

C : 10% ROOFS (.85), 10% PAVEMENT (.85), 40% Desert Landscape (.70), 10% Bare Ground (.50?), 30% Grass Landscape (.15)

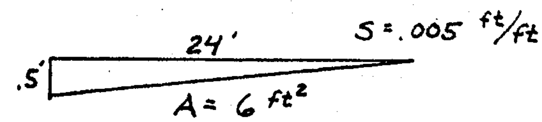
$C = .20(.85) + .40(.70) + .10(.50) + .30(.15) = 0.545$

T_c : $T_c = t_i + t_t$

$$t_i = \frac{.04593\,(130)^{1.77}}{(.5)^{.385}} = 2.55\ min$$

t_t :

$Q = 17.5$ cfs per side (nomograph)



$V = Q/A = 2.92$ ft/s, $t_t = 5540/60\,(2.92) = 31.62$ min

$T_c = 2.55 + 31.62 = 34.2$ min

AT $T_c = 34.2$ min, $i_{50} = 3.17$ in/hr (No 100-yr curve presented)

$Q_{50} = (.545)(3.17)(83.2) = 144$ cfs

VOLUME = $(.25)\,CA = (.25)(.545)(83.2) = 11.34$ ac-ft

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT *METHOD COMPARISON* PAGE 4 OF 6

DETAIL *RETENTION REQUIREMENTS* COMPUTED ______ DATE ______

______ CHECKED BY ______ DATE ______

MARICOPA COUNTY METHOD FOR CITY OF MESA

$P_{10}^{6} = 1.90$ in
$P_{100}^{6} = 3.00$ in
$P_{100}^{24} = 3.50$ in

$Tc = 11.4 (1.023)^{.5} (.028)^{.52} (27.08)^{-.31} i^{-.38}$

$Tc = .646\ i^{-.38}$

TRY $Tc = 22$ min, $i_p = 4.8$ in/hr, $i_{100} = (4.8)(1.90)/2.07 = 4.41$ in/hr

$Tc = .646 (4.41)^{-.38} = 22.05$ min → OK

$Q_{100} = (.63)(4.41)(83.2) =$ 231 cfs

VOLUME:

$P_{100}^{1} = .494 + .755 (3.00)^2/3.50 = 2.44$ in

$P_{100}^{2} = .341 (3.00) + .659 (2.44) = 2.63$ in

$V = CA \left(\frac{P_{100}^{2}}{12} \right) = (.63)(83.2)(2.63/12) =$ 11.49 ac-ft

---

(4) CITY OF PHOENIX

SOURCE: City of Phoenix Storm Drain Design Manual, July, 1988
BASIN OUTLET LOCATION: RAY Rd. & 40TH ST.
CITY METHOD: SCS

$C = .45$ (R1-6 Zoning)
$S = .005$ ft/ft ; Hydrologic Soil Group B ; CN = 84
$W = A/L = 43,560 \times 82.3 / 5540 = 654'$; $Wf = 1.10$

$Tc = t_i + t_t$ $\quad t_i = \frac{.04593 (130)^{.77}}{(.5)^{.385}} = 2.55$ min

t_t: $V = 3.25$ ft/s (from p.33), $t_t = L/60V = 5540/60(3.25) = 28.41$ min

$Tc = 2.55 + 28.41 = 31.0$ min, $Tp = Tc \times Wf = 34.1$ min $= 0.568$ hr.

For $P_{100}^{1} = 2.66$ in, $Q = 1.25$ in $\quad Q_p = \frac{484 (.13)(1.25)}{.568} =$ 138 cfs

VOLUME: $V = 7200\,CIA$, where $C = .45$, $I = 1.25$ in/hr, $A = 83.2$ ac

$V = [7200 (.45)(1.25)(83.2)/43,560] =$ 7.74 ac-ft

MARICOPA COUNTY METHOD FOR CITY OF PHOENIX

$P_{10}^{6} = 2.00$ in
$P_{100}^{6} = 3.30$ in
$P_{100}^{24} = 3.90$ in

$Tc = 11.4 (1.023)^{.5} (.028)^{.52} (27.08)^{-.31} i^{-.38} = .646\ i^{-.38}$

TRY $Tc = 22$ min., $i_p = 4.8$ in/hr, $i_{100} = (2.00)(4.8)/2.07 = 4.64$ in/hr

$Tc = .646 (4.64)^{-.38} = 21.63$ min → OK

$Q_{100} = (.63)(4.64)(83.2) =$ 243 cfs

CITY OF PHOENIX (cont.)

VOLUME: $V = CA\left(\frac{P_{100}^{2}}{12}\right)$

$P_{100}^{1} = .494 + .755\ (3.30)^2/3.90 = 2.60$ in

$P_{100}^{2} = .341\ (3.30) + .659\ (2.60) = 2.84$ in

$V = (.63)(83.2)(2.84/12) = \underline{12.41 \text{ ac-ft}}$

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(5) CITY OF SCOTTSDALE

SOURCE: City of Scottsdale Design Procedures and Criteria, Section 2, July, 1985

BASIN OUTLET LOCATION: Jomax Rd. & 136TH ST.

CITY METHOD: RATIONAL METHOD

ZONING: R1-7; Hydrologic Soil Group B, CN = 92, $C_D = 0.65$

$T_c = t_i + t_t$: $t_i = \frac{.04593\ (130)^{.77}}{(.5)^{.385}} = 2.55$ min ; $V = 545^{1/2}$ (6" curb) = 3.82 ft/s

$t_t = 24.17$ min , $T_c = 2.55 + 24.17 = 26.72$ min

At $T_c = 27$ min and $P_{100}^{1} = 2.27$ in , $i_{100} = 3.85$ in/hr

$Q_{100} = (.65)(3.85)(83.2) = \underline{208 \text{ cfs}}$

$V = C_D A\left(\frac{P_{100}^{1}}{12}\right) = (.65)(83.2)(2.27/12) = \underline{10.23 \text{ ac-ft}}$

OPTIONAL METHOD FOR SCOTTSDALE: Techniques used in the "General Drainage Plan for North Scottsdale, Ariz."

AN HEC-1 MODEL USING THE FOLLOWING INPUT GENERATED A PEAK DISCHARGE OF 225 cfs AND A RUNOFF VOLUME OF 18.4 ac-ft.

IT	5			200		
IO	3					
KK						
PB	4.5					
PC	...	SCS TYPE IIA				
LS		74			95	
UK	130	.005	.200	65		
UK	50	.01	.075	35		
RK	620.	.005	.020	.0108	TRAP	40.
RK	4615.	.005	.025	.13	TRAP	50.
ZZ						

MARICOPA COUNTY METHOD FOR CITY OF SCOTTSDALE

$P_{10}^{6} = 2.30$ in

$P_{100}^{6} = 3.42$ in

$P_{100}^{24} = 4.55$ in

$T_c = 11.4\ (1.023)^{.5}(.028)^{.52}(27.08)^{-.31}\, i^{-.38}$; $T_c = .646\ i^{-.38}$

TRY $T_c = 22$ min., $i_p = 4.8$ in/hr, $i_{100} = 4.8\ (2.3/2.07) = 5.33$ in/hr

$T_c = .646\ (5.33)^{-.38} = 20.52$ min → NO GOOD

TRY $T_c = 20$ min., $i_p = 5.1$ in/hr, $i_{100} = 5.67$ in/hr, $T_c = .646\ (5.67)^{-.38} = 20.05$ min. → OK

$Q_{100} = (.63)(5.67)(83.2) = \underline{297 \text{ cfs}}$

CITY OF SCOTTSDALE (Cont.)

VOLUME: $P_{100}^1 = .494 + .755\,(3.42)^2/4.55) = 2.435$ in

$P_{100}^2 = .341\,(3.42) + .659\,(2.435) = 2.77$ in

$V = (.63)(83.2)(2.77/12) = \underline{12.01 \text{ ac-ft}}$

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(6) CITY OF TEMPE: SOURCE: TEMPE PUBLIC WORKS DEPT. - PRIVATE DEVELOPMENT DESIGN CRITERIA; June, 1987.
BASIN OUTLET LOCATION: PRICE & SOUTHERN
CITY METHOD: RATIONAL METHOD

C: 10% ROOFS (.95), 10% PAVEMENT (.95), 40% DESERT LANDSCAPING (.70), 10% BARE GROUND (.25), 30% AVERAGE SLOPED LAWNS (.20)

$C = .20(.95) + .40(.70) + .10(.25) + .30(.20) = 0.56$

$T_c = t_i + t_t$ $\quad t_i = \frac{KL^{.37}}{S^{.2}} = \frac{1.57\,(130')^{.37}}{(.5)^{.2}} = 10.9$ min

t_t: $V = 2.74$ ft/s ; $t_t = L/60V = 5540'/60(2.74) = 33.7$ min

$T_c = 10.9 + 33.7$ min $= 44.6$ min ; $i = 2.97$ in/hr

$Q_{100} = (.56)(2.97)(83.2) = \underline{138 \text{ cfs}}$; $V = (D/12)AC = (2.4/12)(83.2)(.95) = \underline{15.80 \text{ ac-ft}}$

MARICOPA COUNTY METHOD FOR CITY OF TEMPE

$T_c = 11.4\,(1.023)^{.5}(.028)^{.52}(27.08)^{-.31}\,i^{-.38} = 0.646\,i^{-.38}$

$P_{10}^6 = 1.90$ in
$P_{100}^6 = 3.00$ in
$P_{100}^{24} = 3.70$ in

Try $T_c = 22$ min, $i_p = 4.8$ in/hr, $i_{100} = 4.8(1.9)/2.07 = 4.41$ in/hr

$T_c = .646\,(4.41)^{-.38} = 22.05$ min → OK

$Q_{100} = (.63)(4.41)(83.2) = \underline{231 \text{ cfs}}$

VOLUME: $P_{100}' = .494 + .755\,(3.00)^2/3.70 = 2.33$ in ; $P_{100}^2 = .341(3.0) + .659(2.33) = 2.56$ in

$V = CA\,(P_{100}^2/12) = (.63)(83.2)(2.56/12) = \underline{11.18 \text{ ac-ft}}$

SUMMARY TABLE

CITY	CITY METHODS Q_{100} (cfs)	CITY METHODS V (ac-ft)	MARICOPA Co. METHOD Q_{100} (cfs)	MARICOPA Co. METHOD V (ac-ft)
1. CHANDLER	188	13.19	227	11.62
2. GLENDALE	109	7.74	237	10.88
3. MESA	144 *	11.34	231	11.49
4. PHOENIX	138	7.74	243	12.41
5. SCOTTSDALE	208	10.23	297	12.01
6. TEMPE	138	15.80	231	11.18

* denotes Q_{50}

APPENDIX I

DRAINAGE DESIGN MENU SYSTEM
USER'S GUIDE

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY
January 1, 1995

TABLE OF CONTENTS

I. About the Drainage Design Menu System

The Drainage Design Menu System was developed by Sandra Towers with direction of Ted Lehman of the Flood Control District of Maricopa County (FCDMC). The menu system's main purpose was to bring together several programs currently used by the District in conjunction with design hydrology using the methods in the Drainage Design Manual, Volume I Hydrology (1992). The menu system was intended to facilitate the input and management of data used in the development of design hydrology according to the Drainage Design Manual. The menu system makes use of previously existing programs which have been recommended for use with the Manual, such as PREFRE, MCUHP1 and MCUHP2, and HEC-1. Among the main improvements over the previous procedures, the new menu system allows for easy creation of MCUHP input files and automatic merging of MCUHP output and HEC-1 data files. It is hoped that the menu system will make for easier, more efficient and cost effective development of design hydrology for engineers and hydrologists working with the Drainage Design Manual.

II. Hardware and Software Requirements

The Drainage Design Menu System (DDMS) requires at least a 386 IBM compatible computer with a math coprocessor. These are the same requirements as those for the MCUHP programs. A 486 computer is recommended to process data at a speed acceptable to most users.

The program must be run from the DOS prompt. Much of the program will run in a DOS prompt window from Windows but HEC-1 will not execute.

The DDMS comes with PREFRE, MCUHP1, MCUHP2, and RATIONAL executable programs. HEC-1 is not provided with the DDMS. Users are responsible for obtaining their own copies of HEC-1. However, the DDMS as packaged assumes that the user will be using HEC-1 through the MENU-1 interface.

III. Using the Manual

Users of the DDMS should be familiar with the procedures outlined in the Drainage Design Manual, Volume I. The DDMS is not a replacement for the Manual rather a tool to facilitate the use of the methodologies outlined in it.

IV. Installation Procedure From Distribution Diskette

To install the DDMS first insert the diskette containing the software into a floppy disk drive, change to that drive and type INSTALL. However, before installation read the following instructions completely. Those persons downloading the software from the WWW use the installation instructions found in the acompanying README11.TXT file available on the Web.

The installation program will ask the user to define the source drive (A: or B:) and a target drive (C: , D: , or E: are possible) and a target directory. The default (and suggested) target directory is HECEXE. The target directory will be created if it does not already exist.[1] The installation program will then 1) copy the executable programs for the DDMS, MCUHP1, MCUHP2, PREFRE, and RATIONAL into the target directory, 2) create a subdirectory to the target directory called CONTROL, and 3) copy the additional files needed by the DDMS into the CONTROL directory. The entire DDMS package with all its associated files will take approximately 1 Mb of hard disk space.

Once installed, the target directory must be added to your path. If you already have HEC-1 installed, the HECEXE directory should already be in your path. Addtionally, if HEC-1 is not already installed on your computer you need to do so before all of the DDMS functions will be complete. The user may also have to increase the number of files defined in the CONFIG.SYS. If HEC-1 is already installed and working correctly the CONFIG.SYS will not require modification. For information on HEC-1 software and installation refer to your HEC-1 installation diskettes and/or your official Corps software distributor. The DDMS also requires the DOS directory to be in the path. This is generally already the case for most users.

V. Getting Started

So long as the DDMS has been installed in a directory which is included in your DOS path, the DDMS may be executed from any directory *other than the root directory* by typing DDMS at the DOS prompt. The DDMS will not execute all functions properly from the root directory. Also, it is *strongly* recommended that DDMS never be initiated or operated from within the HECEXE or CONTROL directories. This will prevent inadvertant overwriting or deleting of default files and make for easier file management in the long run. See your DOS manual for help with use of the DOS path if you are unfamiliar with the use of the DOS path command. It is therefore recommended that the user create a new directory for use of DDMS for a given study.

Any time a new analysis is begun, the user must first define a file family name for the files to be created during the analysis. The file family is an important concept used in the DDMS. Essentially, the file family name tells the DDMS how to name the files for a given analysis. The file family name becomes the first part of the DOS file name for each file created using the DDMS so long as the current file family remains the same. To establish a new file family, move to the Family menu and select New Family. Enter a name for the new file family and press [Enter]. The DDMS will then set up the new file family and return the user to the main menu. The user can

[1] If an alternate target drive or directory is selected (e.g. other than C:\HECEXE), the file DDMS.CTL will need to be manually edited to change the PARAMS_DIR variable to the installed target path. See the README.TXT file for additional information.

verify that the new file family has been established by checking the top status line. It should show the current working directory and file family. If the status line does not appear to have the correct information, return to the Family menu and try again. In all likelihood a simple typing error was the cause of the problem. For more discussion of file families and use of the Family menu, see section VII. under Family.

VI. Keyboard Techniques

Window Movement Keystrokes
Keystrokes to move around a window

When any window is displayed, the following keystrokes may be used:

[Alt][F1]........................ Display and move into Help Index Menu
[F1]................................ Display current help topic screen

Additionally, if the window text occupies more than one display box or "screen" of text in length or width, the following keystrokes may be used:

[Home]........................ Display the first screen of the text
[End] .... Display the last screen of the text
[Up Arrow] .... Display text starting one line up
[Down Arrow] .... Display text starting one line down
[Page Up].................... Display text starting one page up
[Page Dn].................... Display text starting one page down
[Left Arrow]................ Display text starting one column to left
[Right Arrow] .... Display text starting one column to right

Finally, if the window is a help window, the following keystrokes may also be used:

[Ctrl][Page Dn] .... Display next help topic screen in current help topic "stack"
[Ctrl][Page Up] .... Display previous help topic screen in current help topic "stack"

Menu Movement Keystrokes
Keystrokes to move around a menu

When any menu is displayed, the current item is displayed in a bar of contrasting color. "Hot Keys" are shown in another contrasting color. Making a selection using the "Hot Key" depends on the menu being used.

In a Strip menu, across the top of the screen, press [Alt] and the "Hot Key" character. The Strip menu item will be selected, making a menu drop down below the item. This is a normal menu, and a selection may be made from it as with any other menu.

In all other menus, simply press the "Hot Key" character. If the "Hot Key" is unique, the item will be selected. If it is NOT unique, the highlight bar will be moved to the next item with the "Hot Key" that is pressed.

To move the highlight bar to a new item, the following keystrokes may be used:

[Enter] .... Select the current menu item
[Home] .... Move to the first menu item
[End] .... Move to the last menu item
[Up Arrow] .... Move to the item one line up from the current item
[Down Arrow] .... Move to the item one line down from the current item
[Left Arrow] .... Move to the item on the left of the current item
[Right Arrow] .... Move to the item on the right of the current item
[Alt][F1] .... Display and move into Help Index Menu
[F1] .... Display help for the current item, if there is any, otherwise, the most current help topic screen

Additionally, if the menu text occupies more than one display box or "screen" of text in length or width, the following keystrokes may be used:

[Page Up] .... Move to the item one page up from the current item
[Page Dn] .... Move to the item one page down from the current item

If multiple items may be chosen from a menu, pressing [Enter] on an item will not cause an automatic exit from the menu. In this case the following keystrokes may be used:

[Enter] .... Select current item if unselected, or deselect it if already selected
[F8] .... Select all items in the menu and exit

Finally, to exit from a menu use the following keystrokes:

[Alt][F10] .... Exit menu, use all selected items in multiple choice menu. Use current item in single choice menu
[Esc] .... Exit menu, ignore any choices made

Form Movement Keystrokes
Keystrokes to move around a form

When a form is first displayed, the cursor is moved to the first field, in the first section. That field is highlighted and the cursor blinks at the end of any characters in the field. There will also be a strip menu at the top of the screen which provides further options for use of the data displayed in the form.

To change values in the field, use the following keystrokes:

[BackSpace] .... Backspace and clear the character before the cursor
[Ctrl][BackSpace] .... Clear the field
[Page Up] .... Toggle to the previous value in a field with a defined a toggle menu
[Page Dn] .... Toggle to the next value in a field with a defined a toggle menu
[Insert] .... Enter "Field Edit" mode

In the insert mode, characters may be inserted before the cursor position or deleted at the cursor position. The left and right arrow keys move the cursor only within the field. To exit the insert mode press [Enter]. Any other character will be added to the end of the field.

To move to another field, use the following keystrokes:

[Enter] .... Move to the next field in numerical order
[Left Arrow] .... Move to the nearest field to the left on the same line
[Right Arrow] .... Move to the nearest field to the right on the same line
[Up Arrow] .... Move to the nearest field above this field
[Down Arrow] .... Move to the nearest field below this field
[Home] .... Move to the first field in numerical order
[End] .... Move to the last field in numerical order

To move to another section or access the next data set in a file, use the following keystrokes:

[Tab] .... Move to the next form section
[Ctrl][Page Dn] .... Access the next data set in the file
[Ctrl][Page Up] .... Access the previous data set in the file

To Zoom the section window, use:

[F5] .... Increase the size of the standard section window to the position and
.... size specified in the form specification. Pressing [F5] again, or leaving the section, reduces the size to the standard size again.

To access the strip menu, use the following keystrokes:

[F10]........................... go to the strip menu
[Alt]........................... with any valid Hot Key (i.e. one of those highlighted in the strip menu, takes you to that strip menu item)

Other form keystrokes use commands analogous to those used in the U.S. Army Corps of Engineers CoEditor which is used by MENU-1. Hence, commands like [Shift][F3] clears a field, [Alt][F10] saves and quits a form, [Ctrl][F10] quits a form without saving, [F3] deletes a line and [F4] inserts a line.

An extension of the CoEd logic was also made to the commands where [Ctrl][F3] deletes a data set (e.g. set of form data for one subbasin) and [Ctrl][F4] inserts a new data set below the current data set. These two commands are especially helpful in the Subbasin Preparation and MCUHP forms. For more discussion on Subbasin Preparation and MCUHP form keyboard techniques see their respective sections in section VI. Functions.

VII. Functions

This section discusses each of the menus and menu items in the Drainage Design Menu System. Each bold heading reflects a menu name in the DDMS main menu. Subsequent headings are primarily menu items available under each main menu.

Programs

The Programs menu contains the main programs used by the DDMS in putting together a flood hydrology model and its related data. Generally, upon beginning the creation of an HEC-1 model using the DDMS each menu item (except Rational) should be performed in the order they appear in the menu listing. Normally only one MCUHP option will be used per file family. To select a program menu item simply scroll down to the item so that it becomes highlighted and press [Enter]. The selection of a menu item will cause the DDMS to open a form for entering input to the program menu item program selected. The form essentially facilitates the creation of ASCII input files used by each of the programs for proper execution. Once a complete set of files has been created for a given file family, changes in storm, land use, or soil loss characteristics can easily be made and the MCUHP and HEC-1 programs can be rerun to obtain the new results.

PREFRE

When selected, the PREFRE menu item loads a form into which the rainfall statistics may be entered. For each input field the status line at the bottom of the screen provides a short help message reminding the user what do for the current field. For more description of the field press the [F1] key. Once all the necessary input fields have been filled in, just save and execute the form (or use [Alt][F10]) to create the depth-duration-frequency (DDF) table for the study area. The PREFRE menu item returns the user to the PREFRE form after execution so that the user may examine the DDF table before proceeding to the next menu item. Once PREFRE has been run satisfactorily, the user may escape out of the form or quit the form by pressing [Esc] or [Alt]-File-Quit or [Ctrl][F10]. For more discussion on the use of the Help or form movement keystrokes see section V. Keyboard Techniques.

Land Types

The Land Types menu item loads the file family land use table to be used in the Subbasin Preparation form for the association of land use types and loss parameter characteristics such as IA, RTIMP, and percent vegetation cover. By default, the program uses the land use table shipped with the DDMS. However, this should not be construed as a recommendation for the sole use of these land use types or associated parameters for every flood hydrology study in Maricopa County. The hydrologist is expected to evaluate the land use types and their associated parameters for each flood hydrology study. The land use table defined for the current file family will be used for every subbasin entered into the Subbasin Preparation form. However, the Subbasin Preparation form does allow for exceptions to the file family land use table for any given subbasin. See the Subbasin Preparation menu item section below for more discussion. As is the case throughout the DDMS, the status line at the bottom of the screen provides a short reminder message as to the nature of the contents of each field. Likewise, more help is available for each field by pressing the [F1] key. Once the user is satisfied with the land use types and their associated parameters, the table may be saved and the form exited.

NOTE: Once data from the file family land use table has been merged into the Subbasin Preparation form and saved, deleting a land use type from the file family land use table in the Land Types form and reentering the Subbasin Preparation form will cause data in the land use section of the Subbasin Preparation form to become mismatched. The reason is that the merge of the land use table into the land use section of the Subbasin Preparation form assumes that a given land use type (and its associated parameters) occur on the same line in both places. Therefore, it behooves the user to determine the land use types to be used for a given study BEFORE the subbasin data is entered into the Subbasin Preparation form. This does NOT prevent the user from changing parameters for a given land use type after the subbasin data has been entered into the Subbasin Preparation form. This is in fact the main purpose and advantage of using this portion of the DDMS. If the user does need to add new land use types after data has been entered into the Subbasin Preparation form, do so by adding the new types to the bottom of the file family land use table using [Crtl-F4] at the end of the table from the Land Types menu item. This will prevent mismatches resulting from the merge.

Subbasin Prep (Subbasin Preparation)

The Subbasin Preparation form acts in similar fashion to the spreadsheet program previously available from the FCDMC. The form starts by opening a blank form for the first subbasin data set to be entered. Again the form may be navigated using the keyboard techniques describe in section V. Keyboard Techniques. Basically, fields within a form section may be moved into using the arrow keys, while each new form section is accessed with the [Tab] key. Backward movement through the form sections may be accomplished with use of [Shift][Tab]. The form sections are differentiated by a double-lined boundary. As is the case throughout the DDMS, the status line at the bottom of the screen provides a short reminder message as to the nature of the contents of each field. More help may be obtained for each field by pressing the [F1] key.

Once the first subbasin data set is completed, a new data set can be added by using the insert command [Ctrl][F4]. This will create a new blank "spreadsheet" for the next subbasin data set. Each new data set or subbasin to be added can be done by use of the insert command [Ctrl][F4]. When multiple data sets have been created, the other data sets may be accessed by use of the [Crtl][Page Up] and [Crtl][Page Dn] keys. Another method to move between data sets is to move to the Subbasin Name field in the first form section and activate the lookup menu by typing [Alt] (to activate the strip menu) and then 'L' for the lookup menu. The [F10] key may alternatively be used to activate the strip menu. Once the lookup menu has been selected, a long narrow window will appear on the right-hand side of the screen containing a list of the data sets for the Subbasin Preparation form for the current file family. To move to the desired data set, simply scroll down the list to the data set you wish to move to and press [Enter].

Calculations resulting from input fields will not be performed until either the user moves the active cursor to another form section by tabbing (or Shift-tabbing), or by saving the file ([Alt]-File-Save or [Shift][F10]), or by saving and exiting the file ([Alt][F10] or [Alt]-File-Save and Execute).

Custom land use types, either different land use types or different parameters for a default land use type, may be given for any subbasin data set. To designate a given land use type as a custom land use simply fill an asterisk (*) into the field in the column headed by an asterisk. This will prevent this line in the data set from automatically being updated from the file family land use table if and when new default land use parameters are defined and saved into the file family land use table from the Land Types form. By default, all unmarked lines in the land use section of every data set will be updated with the new land use table parameters if the land use table is newer than the subbasin preparation file when the Subbasin Preparation form is loaded. This allows for easy, quick updating or parameter sensitivity analyses of land use related parameter assumptions. For example, RTIMP values for any or all land use types could be changed in the Land Types form and saved. Then the Subbasin Preparation form could be loaded to calculate the new average subbasin RTIMP values for every subbasin. Next, MCUHP could be loaded which will merge the newly calculated subbasin RTIMP values into the MCUHP input file. Then by saving and executing MCUHP, new subbasin KK blocks will be generated. Finally, the new KK blocks may be merged into the existing HEC-1 data file by selecting the HEC-1 menu item from the programs menu. Rerun HEC-1 with these new data and compare the results.

MCUHP1 and MCUHP2

The MCUHP1 and MCUHP2 menu items behave quite similarly. Essentially these menu items load forms which can merge in subbasin data from the subbasin preparation file and create a properly formatted MCUHP input file. Upon saving and executing the MCUHP form, MCUHP1 or MCUHP2 is run with the formatted input file to create an HEC-1 skeleton file. When the HEC-1 menu item is subsequently selected, the subbasin KK blocks from the MCUHP created HEC-1 skeleton file are merged into the existing HEC-1 data file (if one already exists). If no HEC-1 data file exists, the skeleton file is merged with an empty file to create the new HEC-1 data file.

The mechanics of using the MCUHP forms are similar to those of the other DDMS forms. Fields in the form sections may be filled in and moved through using the arrow keys. The user may move between form sections by use of the [Tab] and [Shift][Tab] keys. Help is available in both the status line at the bottom of the screen with additional help found through use of the [F1] key.
The MCUHP forms consist of two sections. The first section defines the design storm information, while the second section consists of multiple data sets containing the subbasin parameters to be used by the selected MCUHP program. When entering the first section field information, the user does not need to fill out the Storm Size field until the subbasin data sets have been filled into section two. Since the design storm size is usually coincident with the total area of all subbasins, the user may fill in all subbasin data sets first and then refer to the Total Area field in section one to help decide the area value to be placed in the Storm Size field. The Total Area field is taken as the sum of all individual subbasin areas from the data sets in section two. Therefore, the Total Area field is not "correct" until all subbasin data sets have been completed.

The second form section may be completed in a couple of different ways. First, if the user is not utilizing the Subbasin Preparation portion, input fields may be entered manually. Once the first data set is complete, use [Ctrl][F4] to insert a new blank second section for the second data set. Repeat this insert process until all data sets have been entered. Then [Shift][Tab] back to section one and complete the Storm Size field. Finally, save and execute the form using [Alt][F10] or [Alt]-File-Save and Execute. The DDMS will then create a properly formatted MCUHP input file and display a window asking to run MCUHP# < FileFamily.M#I. Answering yes to this prompt will cause the MCUHP program selected to execute with input taken from the input file created with the form. During execution, MCUHP will send information to the screen. Once it has finished running, a message will appear saying "Run completed -- press any key to return to menus ...". Pressing any key will return the user to the Main Menu. Now the user is ready to select the HEC-1 menu item from the Programs menu.

The other method of using the MCUHP forms differs in the use of the second form section. If the Subbasin Preparation form has been used to calculate the subbasin parameters, the user may move to the Subbasin Name field in section two. Then by activating the Lookup menu, [Alt]-L, a list of the subbasin data sets available from the Subbasin Preparation file is displayed. Subbasin data sets that are to be entered into MCUHP can be selected from the menu by scrolling to the desired data set name and pressing [Enter]. Use the [Enter] key to select the data sets to be entered into MCUHP. To exit the lookup menu with the selected data sets, use [Alt][F10]. This will cause the selected data sets to be loaded into the MCUHP form section two. Then all that remains to be entered by the user in the MCUHP form are the high and low elevations, subbasin length, slope, and the UA record type or S-Graph type depending on whether MCUHP1 or MCUHP2 is being used. The default loss method is the Green and Ampt method. These parameters will automatically be filled into section two when the lookup menu is exitted. If the Initial and Uniform Loss method is being used, the Loss Method field must be changed from 1 to 2 and the STRTL and CNSTL values entered manually by the user. If the user wishes to have all data sets from the Subbasin Preparation file loaded, activate the lookup menu from the Subbasin Name field in the blank section two and press [F8]. This will exit the lookup menu and cause all subbasin data sets from the Subbasin Preparation file to be loaded into the MCUHP form.

Once any data sets have been loaded into the MCUHP form, the user may move from one data set to another using the [Crtl][Page Up] and [Ctrl][Page Dn] keys or by entering the Subbasin Name field in a loaded data set in section two and using the lookup menu. Activating the lookup menu on the Subbasin Name field in a loaded data set will cause DDMS to display a menu of data sets already loaded in the MCUHP form.

If a data set needs to be deleted from the MCUHP form, move to section two to the data set to be deleted and press [Ctrl][F3]. This will cause the current data set to be deleted from the MCUHP form. If a new data set needs to be inserted, move to section two and press [Ctrl][F4]. This will cause a blank data set to be inserted. The user may then complete the data set by filling it in manually, or if the new data set has a corresponding data set in the Subbasin Preparation file, use the lookup menu on the Subbasin Name field to display data sets that have not yet been loaded into MCUHP but which do exist in the Subbasin Preparation file.

The order in which data sets appear in the Subbasin Preparatation form or MCUHP form is not critical but perhaps helpful. The reason the order is not critical is that the subbasin KK blocks created by MCUHP will be merged into the HEC-1 data file in the order in which the KK blocks occur in an existing HEC-1 data file. Thus, a "schematic" file may be created and named FileFamily.DAT containing the KK records and ids matching those used in MCUHP. This will cause the MCUHP output KK blocks to be merged into the HEC-1 .DAT file in the order they appear in they appear in the HEC-1 data file. However, if no "schematic" is created before the merge is performed (by selecting the HEC-1 menu item from the Programs menu), the KK blocks from the MCUHP output file will be merged into the empty HEC-1 data file in the order which they occur in the MCUHP output file which is the order they were entered in the MCUHP input form.

NOTE: The insertion of new data sets in the MCUHP forms occurs after the the current data set from which [Ctrl][F4] was pressed. Therefore, the form does not allow the user to insert a new subbasin data set as the very first data set. The problem this creates is that for the single storm option, the precipitation cards for the HEC-1 input file are put into the first subbasin KK block by MCUHP. To correct this problem the user could insert the new data set anywhere and then move the KK block manually in the resulting HEC-1 input file along with the precipitation cards. If the user should desire to insert a new data set as the first data set and avoid the editing of the HEC-1 input file, the user can edit the FileFamily.M#I file inserting a block for the new data set within the .M#I file. The subbasin data used by MCUHP can then be entered directly into the .M#I file or if the Subbasin Preparation form has already been used to enter data for this new first data set, add the ID name for the new data set to the "basin name" line in the newly inserted block in the .M#I file and save. Then return to the Subbasin Preparation form, save it to update its time stamp, and enter the MCUHP form. This should cause the new data set information to be loaded from the Subbasin Preparation file into the MCUHP form as the new first data set. After running the MCUHP program, entry to HEC-1 will perform a new merge and the precipitation cards and new first subbasin should be in the correct place. Also, the old first subbasin KK block containing the precipitation cards should be updated with the new KK block from the MCUHP output file which no longer contains the precipitation cards.

HEC-1

The HEC-1 menu item causes the HEC-1 form to be loaded with the HEC-1 data file (FileFamily.DAT). If the MCUHP output file is newer than the HEC-1 data file, the MCUHP output file KK blocks will be merged into the HEC-1 data file by matching KK names in the two files. Duplicate KK block ids will cause all but the first KK block with the duplicated id to be dropped from the HEC-1 data file. Therefore, the user should follow a convention of unique naming of KK blocks both for subbasin blocks as well as any other KK blocks in the HEC-1 input file. In the HEC-1 form, the HEC-1 input may be reviewed to ensure that the merge has taken place as expected.

The form consists of two sections. The first contains the IDs and job control lines. The second contains the KK blocks. Each KK block is displayed one at a time much like the data sets in the Subbasin Preparation or MCUHP forms. Once the form has been loaded and the user is comfortable that the merge has taken place correctly, the form may be saved and executed. This will cause a window to appear which asks if the HEC-1 data file should be saved as merged and whether to start MENU1. Answering yes to this window will save the merged file as FileFamily.DAT and start MENU1 with the input, output and DSS files already defined for the current file family. From MENU1 the input file may be edited, run, and displayed as normal in MENU1. The only exception is that MENU1 selection number 5, Exit to DOS, will return the user to the DDMS main menu.

Rational

The Rational menu item in the Programs menu will cause a form to be loaded into which data is entered for the FCDMC RATIONAL.EXE program. Again the form serves to facilitate input to the program and in addition to the previous use of RATIONAL.EXE, program input and output may be saved to a file. The primary limitation in the DDMS implementation of the RATIONAL program is that only one RATIONAL data set may be defined per file family. The Rational form may be navigated similarly to other forms in the DDMS.

Reports

The Reports menu from the DDMS Main Menu contains two categories of reports which may be generated from DDMS files. One set is for input summary reports and the other provides reports from HEC-1 output. In order for the output reports to function properly, HEC-1 must have been run at output level 3. Each report menu item when selected will open a form which will load data from the appropriate input or output file and display that information in the form. The user may either review the data in the form or save and execute the form which will cause an ASCII report file to be generated. These report files may then be viewed or printed from the DDMS or loaded into the user's favorite word processor to be included in their flood hydrology study report.

Input Summaries

Selecting the Input Summaries menu item activates a submenu which contains various reports which may be generated from the Subbasin Preparation and MCUHP input files.

Subbasin Summary

The Subbasin Summary report produces an ASCII file which contains a report for each subbasin of the data entered in the Subbasin Preparation form. The report format is similar to that produced by the previously available FCDMC Loss Parameter Spreadsheet.

MCUHP1 Summary

The MCUHP1 Summary report produces an ASCII file which contains a columnar summary of the subbasin names, areas, loss parameters, and calculated Tc and R parameters for the Clark Unit Hydrograph method.

MCUHP2 Summary

The MCUHP2 Summary report produces an ASCII file which contains a columnar summary of the subbasin names, areas, loss parameters, and subbasin lag time.

MCUHP2 Lag Time Summary

The MCUHP2 Lag Time Summary report produces an ASCII file which contains a columnar summary of the subbasin names, S-Graph type, length, Lca, Kn, slope, and lag times for each subbasin entered in the MCUHP2 form.

Output Extract

The Output Extract reports work just like the Input Summaries except that the reports are taken from the HEC-1 output file. Again, the reports assume that HEC-1 has been run with output level 3 defined on the IO record.

Discharge Report

The discharge report produces an ASCII file which contains a columnar summary of KK names, rainfall, losses, rainfall excess, peak discharge, time to peak discharge, volume of runoff, and area. The default file extension for the discharge report is .DIS.

JD Discharge Report

The JD discharge report produces an ASCII file containing a summary of discharge and related results for an HEC-1 run using the JD multiple storm option. The default file extension for the JD discharge report is .JD.

Unit Hydrograph Volume Report

The unit hydrograph volume report produces an ASCII file which contains a columnar summary of subbasin names and unit hydrograph volumes from HEC-1 output files which have used MCUHP2 to generate UI records for unit hydrographs. The default file extension for the unit hydrograph volume report is .RUV.

Unit Hydrograph Report

The unit hydrograph report produces an ASCII file which contains a summary of subbasin names and unit hydrograph volumes as well as the UI records used as the unit hydrographs for each subbasin. Like the unit hydrograph volume report, the HEC-1 output files must have used MCUHP2 to generate the UI records for unit hydrographs. The default file extension for the unit hydrograph report is .RUI.

Kinematic Wave Stream Routing Report

The Kinematic wave stream routing report produces an ASCII file which contains a summary of Kinematic wave routing parameters used in channel routings in a level 3 HEC-1 output file. The default file extension is .RKW.

Storage Routing Reports

The storage routing reports produce ASCII files which contain summaries of the various storage routings used in a level 3 HEC-1 output file. The form will create separate report files for four different types of storage routings. One, storage reservoir routings using SV records (default file extension .RTS); two, storage reservoir routings using SA and SE records (default file extension .SAE); three, storage reservoir routings using the spillway option (default file extension .SPL); and four, Normal Depth channel storage routings (default file extension .RND). Upon saving and executing this report form, the program will ask the user whether each of the four files should be written out. Use the summary of the number of KK blocks found containing each of the various report types in the first form section as a guide to deciding which files to write.

Muskingum-Cunge Reports

The Muskingum-Cunge reports produce ASCII files which contain summaries of the routing parameters used in the channel routings using the Muskingum-Cunge routing method. The form will create separate report files for Muskingum-Cunge routings using the RD record alone and those using the RC, RX, RY option. The default file extension for the RD only report is .RMC while the file extension for the RC, RX, RY option is .RMD.

Diversion Report

The diversion report produces an ASCII file which contains a summary of diversions in a level 3 HEC-1 output file. The default file extension for the diversion report is .RDV.

Hydrograph Combination Report

The hydrograph combination report produces an ASCII file which contains a columnar summary of hydrograph combination KK ids, number of hydrographs combined, peak discharge, time to peak discharge, volume of runoff, and area. The default file extension for the hydrograph combination report is .RHC.

Clark Subbasin Report

The Clark Subbasin report generates a report for each subbasin using the Clark Unit Hydrograph method. The report contains Tc and R and the UA array for each subbasin using the Clark method in the HEC-1 output file. The default file extension for the Clark subbasin report is .RCK.

Rational Report

The Rational Report menu item opens a form which when saved and executed produces an ASCII report file summarizing the input and output from a rational analysis for the current file family. The default file extension for the Rational Report generated by this form is .RTR.

Utilities

The Utilities menu provides access to several commonly used programs which can be used in conjuction with the DDMS to improve its overall use.

Editor

The Editor menu item provides access to the editor defined under the Options menu as the default editor. As shipped, the Editor menu item uses the DOS editor EDIT. When the Editor menu item is selected, a form is loaded into which the filename of the file to be edited should be entered. A lookup menu is also accessable by use of the [Alt]-L keys. The lookup menu allows the user to select the file to be edited from the menu. Exiting from the DOS editor returns the user to the main menu.

CoEditor

The CoEditor menu item behaves similarly to the Editor menu item except that the U.S. Army Corps of Engineers' CoEditor is invoked rather than the DOS editor once the file to be edited has been defined by the user.

List File

The List File menu item works like the other Utilities menu items except that the LIST.COM program is used to open up the selected file for viewing. The LIST.COM program is the same program used by MENU1 in its display option number 4.

Print

The Print menu item asks for a file to be printed which can be looked up using the lookup menu to select the file to be printed. Once the file is defined, the Print menu item sends the selected file to the port defined in the Options form using the print command also defined in the Options form. By default the DDMS uses the DOS PRINT command and sends the file to LPT1.

Family

About File Families

The File Family concept is an important concept used by the DDMS in managing the files generated by the various forms. It is important that the user of the DDMS understands the idea of File Families to take greatest advantage of the DDMS. The File Family refers to the name given to all files related to a given set of analyses using the DDMS. The File Family name is used as the first part of the DOS filename given to every file generated with the DDMS while the current File Family remains the same. The files associated with the various DDMS functions are differentiated by the DOS file extensions assigned by the DDMS forms. For example, if a new file family is named STUDY1, then every file generated by the DDMS while this file family is the current file family (which is always displayed in the top status line of the DDMS) will be given the name STUDY1.extension where the extension provides the unique filename identifier. Therefore, the PREFRE input and output files will become STUDY1.PFI and STUDY1.PFO respectively. Likewise, the Subbasin Preparation file is called STUDY1.SUB and the MCUHP1 files STUDY1.M1I and STUDY1.M1O, and so forth. Report file names are assigned similarly differentiated only by the file extension. This file naming convention using the File Family concept allows the File Family Copy, Delete, Archive, etc. functions to find all the files associated with the current file family very easily and neatly. This also allows the user to easily identify files associated with a given analysis.

Caution should be taken however when examining various storm or parameter assumptions and rerunning various portions of the analysis. An example would be when the hydrologist wishes to compare the results of the 6-hour storm with the 24-hour storm. If the storm information in MCUHP is modified and rerun without changing the file family name, the files associated with the first storm will be overwritten. To avoid this mistake, use the File Family Copy command to copy all the files to a new file family name and then perform the analysis using the new design storm information. Then the two sets of output files or report files can be compared without the danger of overwriting files the user intended to keep. Prudent use of the File Family naming convention and a little forethought can prevent unwanted rework. However, the ease with which the DDMS allows for these types of changes also means inadvertant mistakes can be quickly and easily performed.

New

The New File Family menu item establishes a new file family. When selected, a form will appear where the user should fill in the name of the new file family to establish. Saving and executing the form with the new file family name creates a default land use table for the new file family (FileFamily.LDF) and changes the status line to show the new file family as the current file family. Single field forms like the New Family form may be saved and executed by use of the [Enter] key alone. The Options form is also updated to reflect the change to a new file family. The new file family may be created in a directory other than the current working directory. If the new file family is created in a directory other than the current working directory, the current working directory will also be changed. However, the directory must exist first for this to work.

Move to

The Move to menu item allows the user to move to an existing file family from the current (or blank) file family. The lookup menu may be used to select a file from the file family to be moved to. File extensions will be ignored using this selection process. Again since the Move to form is a single field form, saving and executing may be accomplished by use of the [Enter] key or by use of [Alt][F10].

Move

The Move menu item performs a renaming of the current file family to a new family name (and working directory if so specified). Since this form is a multiple field form, saving and executing the form must be performed using [Alt]-File-Save and Execute or [Alt][F10]. Saving and executing the Move form will cause the DDMS to copy the current file family to the newly specified file family name and delete the current file family. In addition, the DDMS will change the current file family to be the newly defined file family.

Copy

The Copy menu item does just that. It makes a copy of the current file family to the newly specified file family name and changes the current file family to the new file family name.
Delete

The Delete menu item can be used to delete an entire file family or just certain specified files within the file family. The lookup menu can be used to select a file from the file family to be deleted. Pressing [Enter] will activate another menu window from which the files to be deleted can be selected in a manner similar to the multiple selection menus used in the Subbasin Preparation and MCUHP forms. When this second menu appears all files beginning with the file family name will be listed and highlighted. If all highlighted files are to be deleted, saving and executing the form will cause the delete to be performed. If certain files are not to be deleted, scroll down to those files one at a time and press [Enter] to unselect them from the list of files to be deleted. Saving and executing will then delete only the highlighted files.

Archive

The File Family Archive menu item, by default, assumes the use of the PKZIP utility to compress all current file family files into one zip file called FileFamily.ZIP (or whatever extension is defined as the archive extension in the Options form. The archive menu item creates the archive file but does not delete the uncompressed files. To delete the uncompressed copies use the File Family Delete menu item. The .ZIP file will not be deleted using the Delete function unless it is specifically highlighted in the delete list. By default the .ZIP file will not automatically be highlighted. However, if the default archive file extension is changed in the Options form, the .ZIP files will be highlighted automatically but files ending with the archive extension defined in the Options form will not automatically be highlighted.

If a compression utility other than PKZIP is to be used, the FAMARCH.FRM ASCII file in the control directory (C:\HECEXE\CONTROL by default) must be changed. The COMMAND line must be altered to contain the new compression utility to be used along with the proper syntax for the use of the new command. The existing COMMAND line may be used as a guide.

Retrieve

The File Family Retrieve menu item, by default, uncompresses an archive file using the PKUNZIP utility. Upon finishing the uncompression, the DDMS returns the user to the main menu with the uncompressed file family as the current file family. Use of an uncompression utility other than PKUNZIP will require a change to the COMMAND line in the FAMRETR.FRM similar to the change needed for the archive form.

Options

The Options menu item contains only one submenu item, Change Control Parameters.

Change Control Parameters

The Change Control Parameters form, sometimes referred to elsewhere in this document simply as the Options form, contains the definitions which control many DDMS functions and display appearances. The fields in the Change Control Parameters form all have additional help which explains the purpose and use of each of the fields. The current file family may be changed from this form. Changing the current file family in this form is equivalent to the Move to function on the Family menu. The Change Control Parameters form also contains fields for changing the control directory and for providing an alternate control directory. The control directory will only need to be changed if the DDMS is installed to a drive and/or directory different than C:\HECEXE\CONTROL. The alternate control directory may be used to store customized menus, forms, or other default files. The colors used for any of the various menus and forms may be changed in the Change Control Parameters form as well. The list of possible colors for each display type field may be accessed by use of the lookup menu or by toggling through the list using the [Page Up] and [Page Dn] keys. Color combinations which cause text not to be seen etc. are not allowed. The DDMS will prompt the user with an appropriate error should the user select an unallowable color combination. Finally, the Change Control Parameters form contains fields which define the default strings for use in the Editor, Print, and Archive functions discussed elsewhere.

Help

The Help menu item provides access to a list of help topics which discuss the use of various DDMS functions. To access the list simply select the help menu, then select the Help Index.

Help Index

The Help Index is a list of help topics available in the DDMS. These are in addition to the field help for each field in every form. To view a help topic simply scroll to the help item of interest and press [Enter].

Exit

The main menu Exit item provides two types of exiting from the DDMS.

Quit

The Quit menu item quits the DDMS altogether and returns the user to the startup directory in DOS.

Exit to DOS

The Exit to DOS menu item dumps the user out to DOS to perform any DOS functions desired. To return to the DDMS type EXIT and [Enter] from the DOS prompt.

VIII. Error Messages

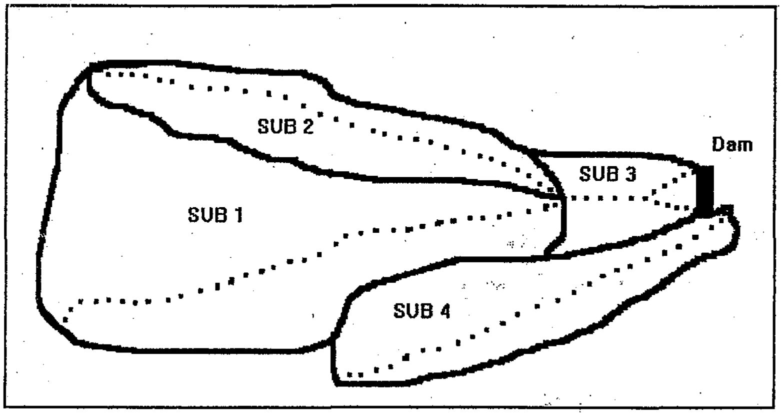
The DDMS will display error messages in red boxes. Most of these errors are self explanatory and relate to form data entry mistakes or omissions. Press [Esc] to clear any error message. If the error is a data entry problem the DDMS should return the user to the offending field. One common error message the user will see is the "No control file found. Use default. C:\HECEXE\DDMS.CTL". This message simply means that the startup directory does not already contain a DDMS.CTL control file. The program then copies the default control file into the startup directory.

IX. Who to Call

If the user should encounter problems associated with the use of the DDMS or should the user have any constructive suggestions, please contact Ted Lehman at the Flood Control District of Maricopa County, 506 - 1501, 506 - 4601 FAX, 2801 W. Durango Street, Phoenix, AZ 85009.

X. Sample Problems

The following sample problems are provided to help get the new user of DDMS up to speed more quickly. The sample problems follow the procedure outlined in the accompanying flow chart. The figure to the right is a representation of the watershed(s) used in the sample problems. Subbasin 4 is used in Sample Problems #3 and #4.



Not to scale

Sample Problem #1

1) From DOS create a new directory in which to run the sample problem.

2) Change to the new directory and start DDMS by typing DDMS from the DOS prompt.

3) Define a new file family by using the arrow keys to move over to the Family menu item or by pressing the letter 'a'. Once the Family menu is activated use the arrow keys to move down to New Family and press [Enter] or press the letter 'N' to select the New Family menu item. A new "window" should appear into which the user should type in the name of the new file family, say SAMPLE1. Press enter to create the new file family or alternately use [Alt-F10].

4) Next, select the Programs menu item from the main menu by using the arrow keys to move over to it or pressing the letter 'P'.

5) Select the PREFRE menu item from the Programs menu by using the arrow keys to move down to the PREFRE line and pressing [Enter] or pressing the letter 'P'. A new empty form will appear for entry of the input data necessary for PREFRE. Complete the form with the following point rainfall data. Use the [Tab] and [Shift-Tab] to move from one form section to the next. For help on any given field refer to the status line at the bottom of the screen or press [F1] for more help.

Point rainfall data for PREFRE for Sample Problem #1		
Frequency	6-hour	24-hour
2-year	1.4	3.4
100-year	3.4	4.2

Once the form has been filled out, save and execute PREFRE by pressing [Alt-F10] or Alt-File-Save and Execute. DDMS will return the user to the PREFRE form to review the output which is displayed in the third form section. If the program appears to have executed successfully, quit the PREFRE form by pressing [Esc], [Ctrl-F10], or Alt-File-Quit.

6) Next select the Land Types menu item from the Programs menu. This will cause the default land use table to be displayed. At this point the user could modify the land use defaults as desired for the study being undertaken. However, for the purposes of this sample, simply save and execute the form without making any changes.

7) Select the Subbasin Preparation menu item from the Programs menu. Use the following data to complete the form. Once the first subbasin data has been entered, press [Ctrl-F4] to insert a blank form for entry of the second subbasin data set. Repeat for the third subbasin. Once the data for all three subbasins has been entered, save and execute the Subbasin Preparation form by pressing [Alt-F10] or Alt-File-Save and Execute.

Special points to be noted in the data entry process: First, remember that the ability of DDMS to transfer data from one program file to the next depends on the subbasin ID. Therefore, chose a format (such as all caps) to ensure proper data transfer. Second, toggle and lookup menus have been added to many fields to facilitate the data entry process. Fields with available toggle or lookup menus should be labelled as such in the status line shown at the bottom of the screen when the field is active (i.e. the cursor is located in the field). Toggle menus can be toggled through by using the [PageUp] and [PageDn] keys. Finally, to move from one subbasin data set to another use [Ctrl-PageUp] and [Ctrl-PageDn].

Subbasin Preparation Data for Sample Problem #1					
Soil Data					
Soil Survey = Aguila/Carefree					
SUB1		SUB2		SUB3	
Map Unit	Area (mi^2)	Map Unit	Area (mi^2)	Map Unit	Area (mi^2)
3	0.443	94	0.357	73	0.064
62	0.346	73	0.056	62	0.038
73	0.227	17	0.054	7	0.018
109	0.186	33	0.032		
38	0.086	62	0.001		
94	0.023				
17	0.019				
Percent Effectiveness for Rock Outcrop = 50 %					
Land Use Data					
Land Use Type	Area (mi^2)	Land Use Type	Area (mi^2)	Land Use Type	Area (mi^2)
Desert	1.33	Desert	0.5	L.D.R.	0.114
				Commercial	0.006

8) Select MCUHP1 from the Programs menu. The first field is optional but may be used to enter some helpful descriptive information. This information is written to an ID record in the HEC-1 data file.

Move to the second field and select the single storm option (1).

Skip the storm size field and move to the storm duration field. The storm size can be filled in later once the subbasin data has been entered. For the purposes of Sample Problem #1, select the 6-hour storm duration (1). This can be accomplished by typing a 1 into the field or by use of the toggle menu using the [PageUp] and [PageDn] keys.

Move to the point rainfall depth field. Use the lookup menu to select the 100-year 6-hour point rainfall depth. To accomplish this press Alt-L to activate the lookup menu. Then arrow across to the 100-year depth and press enter to place this value into the MCUHP1 form field.

Tab to the second form section. Once in the subbasin name field, activate the lookup menu with Alt-L. A small menu should appear containing the names of the subbasins entered into the Subbasin Preparation form (i.e. for Sample Problem #1 the subbasin names in the menu should be SUB1, SUB2, and SUB3). Press F8 to load the data from all subbasins into the MCUHP form. Alternately, each subbasin name may be selected (it will become highlighted) by pressing the [Enter] key on each subbasin name and then use [Alt-F10] to exit the lookup menu and load the selected subbasin data sets into the MCUHP form. The pertinent data from the Subbasin Preparation file should now be loaded into the MCUHP1 form. This may be checked by scrolling through the subbasin data sets using the [Ctrl-PageUp] and [Ctrl-PageDn] keys. Also the counter at the bottom left corner of the second form section should read "Set # of 3" where # is the number of the data set currently active. This # should change as the user scrolls between data sets.

Complete the remaining fields in the second form section for each subbasin data set using the following data.

Additional Subbasin Data for MCUHP1			
	SUB1	SUB2	SUB3
High Elev.	1250 ft	1350 ft	1050 ft
Low Elev.	1000 ft	1000 ft	900 ft
Length	2.37 miles	1.7 miles	0.76 miles
UA	2	2	1

Once these data have been entered, [Shift-Tab] back to section one and move to the storm size field. Consult the Total Area field to select the storm size. The storm size field takes the area to the nearest square mile. The user may enter a decimal value, but it will be rounded to the nearest whole square mile.

When all data have been entered, save and execute the form. If all required data has not been entered DDMS should give a red error message stating that some required data has not been entered. DDMS will then return the user to the missing field. Complete the missing field and save and execute again. A small "window" should appear at the bottom of the screen asking if it is okay to run MCUHP1 < FileFamily.M1I. Answer yes to this prompt to run MCUHP1 using an input file created from the data entered into the MCUHP1 form. MCUHP1 will then echo some information to the screen as it runs. Once it has completed, a line will appear asking the user to press any key to continue. Doing so will return the user to DDMS.

9) Select HEC-1 from the Programs menu. This will cause the MCUHP1 output file to be merged with the HEC-1 data file (if one already exists). In this case, no HEC-1 data file exists, so the MCUHP1 output file is merged into an empty HEC-1 data file. The HEC-1 data file may be reviewed in the form to confirm that MCUHP ran correctly and that the merge was performed as expected. The HEC-1 form consists of two sections. The first section contains the ID records and the IT and IO records along with any comment lines added to the file. To enter the second section use the [Tab] key. In the second section each HEC-1 KK block is treated as a data set. To move between data sets in the second section use the [Ctrl-PageUp] and [Ctrl-PageDn] keys.

To save the merge and start MENU1, save and execute the HEC-1 form using [Alt-F10] or Alt-File-Save and Execute. Another small "window" should appear asking if it is okay to run MENU1. Answering yes to this prompt will start MENU1 with the FileFamily.DAT file already selected as the input file.

10) Once in MENU1, select option 2 (Create or edit input file). For the purposes of Sample Problem #1 change the output level to level 3 and add the following routing and combination data to the input file. The *DIAGRAM option may also be added to provide an HEC-1 created diagram of the model if desired.

Combine runoff hydrographs for subbasins SUB1 and SUB2.

```
KK    HC2
KM       COMBINE HYDROGRAPHS FROM SUB1 AND SUB2
HC      2
```

Route the combined hydrographs

```
KK   R2-3
KM         ROUTE HYDROGRAPH HC2 THROUGH SUB3
RS      1     FLOW       -1
RC 0.030   0.015   0.030    4000   0.0373
RX      0       0      10      10      40      40      50      50
RY      5       1      .5       0       0      .5       1       5
```

Combine the routed hydrograph from R2-3 with the runoff hydrograph from SUB3

```
KK    HC3
KM       COMBINE HYDROGRAPH R2-3 WITH RUNOFF HYDROGRAPH FROM SUB3
HC      2
```

Route the combine flow through the following reservoir.

```
KK    RR3
KM   RESERVOIR ROUTING
RS      1     STOR        0
SA      0       10       36       50       73       98
SE    900      902      904      905      906      907
SQ      0        0        0       50      150      350
```

Once these changes and additions have been made save the file and run HEC-1. When HEC-1 has finished running successfully, exit MENU1 to return to DDMS.

11) Select the Output Extracts menu item from the Reports menu on the main menu. Select the Discharge report from the Output Extracts submenu. A form will load with data retrieved from the HEC-1 level three output file. Save and execute the report form to create the ASCII report file. DDMS will then return the user to the main menu.

12) To view the report file created, select List File from the Utilities menu. The List File menu item uses the LIST.COM program used by MENU1 to view files. In the "window" that opens, use the lookup menu to see a list of file family files for Sample Problem #1. Scroll down to the FileFamily.DIS file, press [Enter] to select this file. Then press [Enter] again to view the file. Another small "window" will appear asking if the user really wants to view the selected file. Answer yes to view the report file.

13) Experiment with other reports as desired.

Sample Problem #2

Sample Problem #2 modifies Sample Problem #1 to demonstrate the quick, simple manner in which a file family can be modified and the effects of the changes can be implemented and evaluated.

1) Copy the Sample Problem #1 file family to a new file family name using the Copy function on the Family menu. To accomplish this properly, start with Sample Problem #1 as the current file family. Select the family Copy function from the Family menu. A window will appear containing two lines. The first should contain the path and file

family name for Sample Problem #1. In the second line enter a new file family name for Sample Problem #2 (such as SAMPLE2). To perform the copy, save and execute the form using [Alt-F10]. DDMS will perform a DOS copy command of the first file family (e.g. SAMPLE1.*) to the second file family name (e.g. SAMPLE2.*). Once the copy is complete, the user will be returned to the DDMS main menu with the newly defined file family as the new current file family.

2) Select Land Types from the Programs menu. Change the DTHETA condition for the Desert and OPEN land use categories from NORMAL to DRY. This may be most easily accomplished using the toggle menu (i.e. [PageUp] and [PageDn]). Also change the RTIMP value for the Commercial category from 80 to 85 percent. Save and execute the file to record these changes into the Sample Problem #2 land use table.

3) Select Subbasin Preparation from the Programs menu. This will merge the new land use table with the changed DTHETA and RTIMP values into the existing subbasin data sets and recalculate the subbasin average parameters. The merge and recalculation may be verified by looking through the land use section of the form for each data set. Save and execute the form to record the new values.

4) Select MCUHP1 from the Programs menu. This will merge the new data from the Subbasin Preparation file into the MCUHP1 form. Again the merge may be verified by looking at the subbasin data set information displayed in the form. Save and execute the MCUHP1 form and run MCUHP1 (i.e. answer yes to the prompt in the blue window asking if it is okay to execute MCUHP1 < SAMPLE2.M1I).

5) Upon returning to DDMS, select HEC-1 from the Programs menu. This will merge the new subbasin KK blocks from the new MCUHP1 output file into the existing HEC-1 data file. Confirm the success of the merge in the HEC-1 form. The new subbasin KK blocks from the MCUHP1 output file should have replaced the old blocks from SAMPLE1. The asterisk line preceeding each subbasin KK block should now read "Updated". The routing and combination blocks should remain unaffected. The asterisk lines preceeding these KK blocks should read "Preserved". Save and execute the HEC-1 form and run MENU1.

   Once in MENU1 run the newly updated HEC-1 file and return to DDMS.

6) Run the Discharge Report from the Output Extracts submenu of the Reports menu.

7) List the new discharge report (SAMPLE2.DIS) and compare with the Sample Problem #1 results.

Sample Problem #3

Sample Problem #3 demonstrates how a new subbasin data set may be added to an existing file family to create a new HEC-1 model. For the purposes of this example, this new model will be put together as a new file family. However, the same process could be applied to modify an existing file family without creating a new file family. This sample problem will also demonstrate how to ensure that the new subbasin can be placed into the desired location in the HEC-1 data file independent of the order in which the data sets occur in the Subbasin Preparation file or MCUHP file.

1) Copy the Sample Problem #2 file family to a new file family name (such as SAMPLE3).

2) Select Subbasin Preparation from the Programs menu. Once the form has loaded, use [Crtl-F4] to insert a space for the new subbasin. At this point it is not required that the insert be performed in the logical place where the new subbasin belongs. However, the user may chose to insert the new subbasin in its "correct" place for other reasons (such as the preservation of the numerical order of the basins in the Subbasin Preparation file or the MCUHP file). For the purposes of this example the new subbasin will logically occur after the reservoir routing and will be called SUB4. However, in order to demonstrate the capablilities of the DDMS merge functions, insert the new subbasin in the Subbasin Preparation form from the data set for SUB1.

Complete the new subbasin data set with the following information.

Subbasin Preparation Data for Sample Problem #3	
Soil Data	
Soil Survey = Aguila/Carefree	
SUB4	
Map Unit	Area (mi^2)
32	0.128
68	0.146
87	0.236
Percent Effectiveness for Rock Outcrop = 50 %	
Land Use Data	
Land Use Type	Area (mi^2)
Desert	0.51

Save and execute the Subbasin Preparation form to save the newly added data set into the Subbasin Preparation file.

3) Select the CoEditor from the Utilities menu. In the file to edit field enter SAMPLE3.DAT. In the CoEditor, go to the end of the file. Insert a line immediately prior to the ZZ record. On this line add "KK SUB4" where the string SUB4 starts in the fifth column (i.e. so that is aligned as it would be if the user tabbed to the first field on the KK line in the CoEditor in MENU1). The placement of this line in this position in the HEC-1 data file will cause the data set KK block for SUB4 to be loaded in this location. Save the file and return to DDMS.

4) Select MCUHP1 from the Programs menu. Tab to the second form section. Again to demonstrate the independence of location in the merge capability, [Crtl-PageDn] to the second data set and insert a space for the new data set using [Ctrl-F4]. Once the blank space has been inserted, use the lookup menu on the subbasin name field to display the data sets in the Subbasin Preparation file which have not yet been added to the MCUHP file. The lookup menu should contain SUB4. To load the data for SUB4 into the MCUHP1 form press [Enter] to select the data set and then [Alt-F10] to exit the lookup menu and perform the load.

Complete the data set for SUB4 with the following data.

Additional Subbasin MCUHP1 Data for SUB4	
	SUB4
High Elev.	925 ft
Low Elev.	800 ft
Length	0.68 miles
UA	2

Once these data have been added to the data set for SUB4, [Shift-Tab] to the first form section and modify the storm size field based on the new total area.

Save and execute MCUHP1.

5) Select HEC-1 from the Programs menu. This will cause the MCUHP1 output file to be merged with the existing HEC-1 data file. In order for the merge to occur the MCUHP output file must be newer than the HEC-1 data file. If the HEC-1 file is newer than the MCUHP file then no merge is performed. This would be the case if the addition of the new KK line to the HEC-1 data file had been performed after step 4. If this should occur, simply rerun MCUHP to create an output file newer than the HEC-1 data file. Verify that the KK block for SUB4 has been added as the last data set. Save and execute the HEC-1 form and run MENU1.

Once in MENU1, edit the input file to add the following KK block to combine the runoff from SUB4 with the outflow from RR3.

```
KK   HC4
KM  COMBINE RUNOFF FROM SUBBASIN 4 WITH ROUTED RESERVOIR OUTFLOW
HC     2
```

Save the file, run HEC-1, and return to DDMS.

6) Run the Discharge Report to see the effects of the addition of SUB4 to the model.

Sample Problem #4

Sample Problem #4 demonstrates the ease with which different rainfall durations can be examined with DDMS.

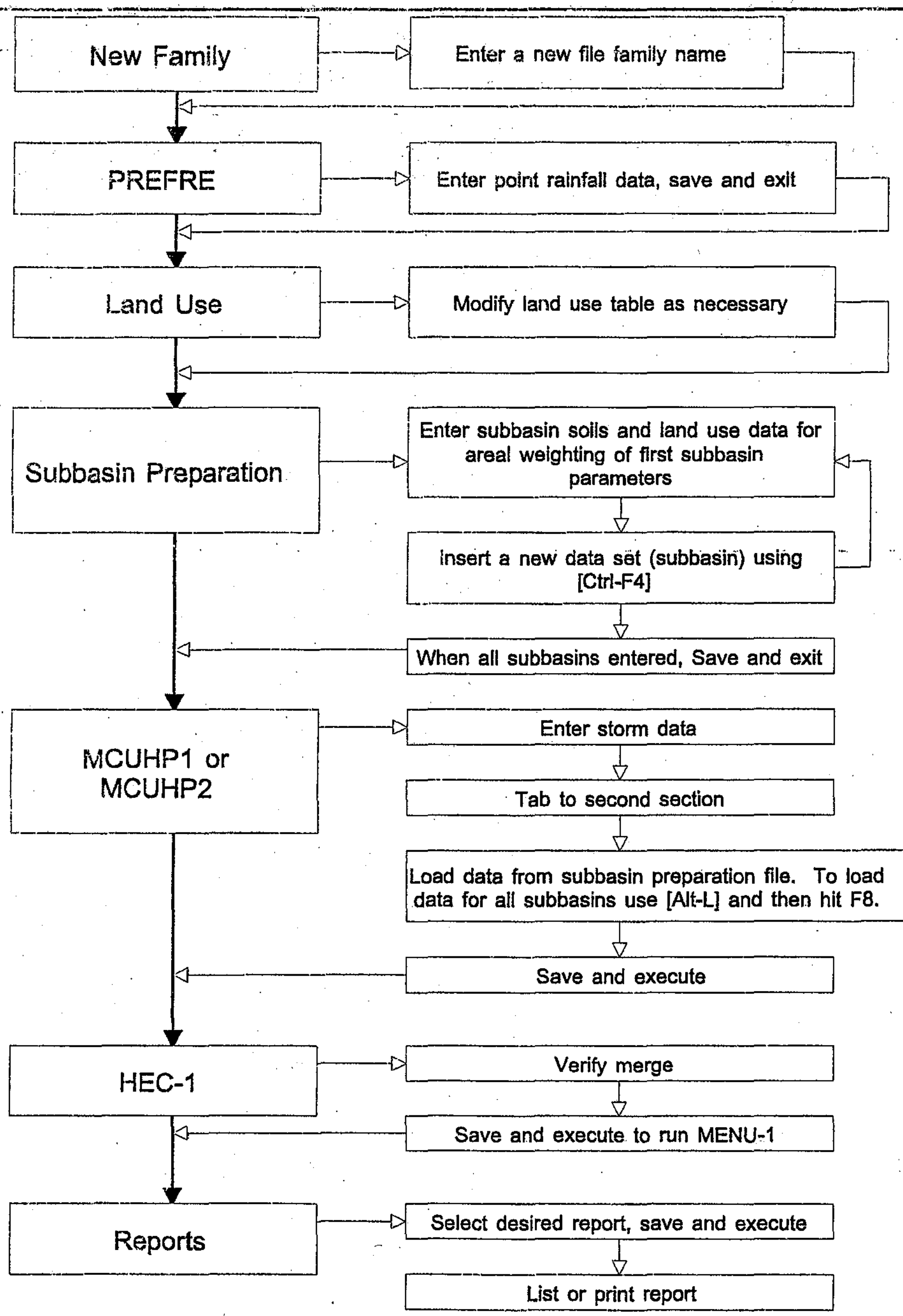
1) Copy the file family for Sample Problem #3 to a new file family name (such as SAMPLE4).

2) Select MCUHP1 from the Programs menu. In the first form section move to the storm duration field. Change this field to select the 24-hour storm (3) and press [Enter]. Notice how the areal reduction factor has been filled in automatically based on the storm size field. Next move to the storm depth field. Use the lookup menu to select the 100-year 24-hour storm depth. Once the 24-hour depth has been selected and the lookup menu exitted, save and execute MCUHP1.

3) Select HEC-1 from the Programs menu. Verify the merge then save and execute the HEC-1 form and run MENU1. Run HEC-1 and return to DDMS.

4) Run the Discharge report and compare the results to the 6-hour storm (e.g. SAMPLE3.DIS).

XI. Flow Chart



NOTE: RATIONAL is a separate program which is not used by DDMS in the development of an HEC-1 model.

XII. Fortran Programs:MCUHP1 and MCUHP2

Maricopa County Unit Hydrograph Procedures 1 and 2, Programs MCUHP1 and MCUHP2, were developed to facilitate the use of the methodologies outlined in the *Drainage Design Manual for Maricopa County, Volume I, Hydrology*. They are provided along with the Drainage Design Menu System (DDMS). However, it is not required that they be run exclusively in conjunction with the DDMS. Both MCUHP1 and MCUHP2 may be run independently from the DDMS by typing MCUHP1 or MCUHP2 from the DOS prompt. Both programs are installed by the DDMS installation program into the C:\HECEXE directory by default.

MCUHP1 provides the necessary parameters for the Clark Unit Hydrograph option of HEC-1. These parameters include time of concentration, Tc, and the storage coefficient, R. In addition, the program also provides a rainfall distribution pattern. MCUHP1 will provide all of the required information in the form of a HEC-1 input file for immediate application.

MCUHP2 provides the required parameters when working with the S-graph techniques as outlined in this manual. MCUHP2 develops the necessary basin unit graph from the indicated S-graph. It will also provide the required rainfall distribution pattern. All calculations will be provided in the form of a HEC-1 input file for immediate application. MCUHP2 has been revised for the October 1, 1994 *Manual* to include the two new S-graphs, Desert/Rangeland and Agricultural, as S-graph choices in the program.

Both MCUHP1 and MCUHP2 contain corrected temporal distributions for the SCS Type II 24-hour design storm. Also, the programs write this distribution to the HEC-1 input file as 15 minute distributions rather than the 30 minute increment used in the earlier versions of MCUHP1 and MCUHP2.

The user is encouraged to read the *Drainage Design Manual, Volume I, Hydrology* before using these programs. Follow these directions to run MCUHP1 and MCUHP2 independent from DDMS:

- If using the Clark Unit Hydrograph method, type MCUHP1. If using the S-graph method, type MCUHP2. Respond to each prompt with the appropriate information. Remember that in either case, a HEC-1 file will be built for your immediate use.

- The constructed input file can be viewed or edited as desired like any other HEC-1 file. All you need to do is to go to your MENU1 of HEC-1 and recall your input file.

Appendix J

PREFRE User's Manual

* P R E F R E *

COMPUTATION OF PRECIPITATION FREQUENCY-DURATION VALUES

IN THE WESTERN UNITED STATES

PROGRAM USER MANUAL

FLOOD SECTION
SURFACE WATER BRANCH
EARTH SCIENCES DIVISION
BUREAU OF RECLAMATION

DENVER, COLORADO

AUGUST 1988

USER MANUAL FOR PROGRAM PREFRE

--

COMPUTATION OF PRECIPITATION FREQUENCY-DURATION VALUES IN THE WESTERN UNITED STATES

1. Introduction.

The PREFRE computer program was written to compute the precipitation frequency values for each of 10 durations and for each of 7 return periods. This document describes how to prepare the input data, how to execute the program, and gives an example of the output.

The PREFRE program computes frequency values for 5-, 10-, 15-, and 30-minute and 1-, 2-, 3-, 6-, 12-, and 24-hour durations for return periods of 2, 5, 10, 25, 50, 100, and 500 years for areas in the 11 western states and presents the results in tabular form. It uses as input the precipitation frequency values taken from the NOAA Atlas 2 (11 volumes). The PREFRE program also duplicates the values in Weather Bureau Technical Paper No. 40 for the six Plains states within the Bureau's area of operations not included in the NOAA Atlas 2 volumes.

NOAA Atlas 2 reflects the effects of topography on precipitation frequencies, but it contains isohyetal maps for return periods of 2, 5, 10, 25, 50, and 100 years but only for 6- and 24-hour durations. For other durations, it is necessary to use the nomograms and equations included in the atlas.

The computer program was originally developed by Mr. Ralph Frederick, Office of Hydrology, NWS (National Weather Service). The program was extensively revised to fit Bureau of Reclamation needs in 1975 by Mr. James Mumford of what was then the Flood and Sedimentation Section, Engineering and Research Center. It was further revised in 1988 by Mr. Richard Eddy of the Flood Section to incorporate updated information for short-duration values.

The program is written in FORTRAN V for the Bureau's CYBER mainframe computer. This version has also been converted to FORTRAN 77 for use with personal computers (IBM compatible).

2. Input Data.

The following data are required for the program input file:

a. Site name.

b. Primary zone number identifying where the site is located, obtained from the map included as appendix A in this manual. The zone boundaries correspond to those found in NOAA Atlas 2, but the numbers may be different. It is advisable to identify the location of a site from the zone map in the atlas volume and refer to appendix A for the zone number used in PREFRE.

c. Zone number for short-duration values (appendix B).

d. Site latitude and longitude (required for primary zones 3, 9, and 11; optional for other primary zones).

e. Site elevation (required for primary zones 1, 2, and 6; optional for other primary zones).

f. NOAA Atlas 2 precipitation values (note that Atlas values are in tenths of inches).

(1) Standard: Enter the values of 2-year and 100-year return periods for durations of 6 hours and 24 hours.

(2) Option: The original NWS program was designed to input 12 precipitation frequency values. This format has been retained as an option. The 2-, 5-, 10-, 25-, 50-, and 100-year values for durations of 6 hours and 24 hours must be used as input for this option. The program uses the six return-period values and develops a line of best fit to the points read from the NOAA Atlas 2 maps. It then uses this line of best fit to recompute the return-period values and uses these computed values in all subsequent computations.

The input data format is presented in appendixes C1 through C3. Each field in a line must be separated from the next field by either a blank or a comma, and an entry is required for each field (i.e., enter zeroes if latitude, longitude, and elevation are omitted). Input data can be all metric, if desired.

3. Output Data.

The site name, zone numbers, and latitude, longitude, and elevation (if included in the input data) are printed as a heading. A table is then given showing the precipitation values for 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods for durations of 5, 10, 15, and 30 minutes and 1, 2, 3, 6, 12, and 24 hours. Output units are the same as the input units. The PC version also prints the input data for reference. Appendix D1 is a sample output from the CYBER version of PREFRE. Appendix D2 is the standard PC output. Appendix D3 is the output when the site is in primary zone 7; it prints a note regarding revised depth-area values for Arizona and New Mexico. Appendix D4 is the output when the option to input 12 precipitation values is selected.

4. Program Execution.

Execution of program PREFRE depends on the computer system being used. Appendix E describes the steps of execution for both the Bureau of Reclamation CYBER mainframe and the IBM PC/AT and compatibles.

Sometimes the site will be very near the boundary between two zones, a situation in which a weighting of calculated frequency values among neighboring zones may provide a more appropriate answer. In these cases, it can be helpful to make more than one run, using the neighboring zone's values. Edit the input file to change the zone number (and other data as needed) and re-run the program.

5. Method of Derivation.

The program follows procedures outlined in NOAA Atlas 2 to derive the precipitation frequency values. The 2-year and 100-year input figures for 6-hour and 24-hour durations are used to derive these same return frequency values for 1-, 2-, and 3-hour durations. The relationships among the 6-hour and 24-hour values and the 1-, 2-, and 3-hour values were determined by the NWS and are dependent on the zone in which the site is located. The 12-hour values are derived by taking the midpoint between the 6-hour and 24-hour input values for the 2-year and 100-year return periods. The 5-, 10-, 15-, and 30-minute duration values for 2-year and 100-year events are determined by multiplying the 1-hour values by a set of factors. These factors are dependent on the short-duration zone in which the site is located. <u>It is important to note that the short-duration zones are different from the primary (longer duration) zones.</u> The program then computes the values for the remaining return periods by fitting the precipitation values to a Gumbel distribution. The 2-year values for all durations are first adjusted from a partial duration series (input values) to an annual series. Then the 5-, 10-, 25-, 50-, and 500-year frequency values for all durations are calculated from their respective relationship to the 2-year and 100-year values in a Gumbel distribution. The 2-, 5-, and 10-year values are then converted back to a partial duration series, which correspond to the NOAA Atlas 2 map values. All output values are for point locations.

NOTE: Areal values of precipitation frequency are often needed. Because program PREFRE does not provide this information, it is necessary to follow the procedure found in the appropriate NOAA Atlas 2 volume. When areal values are required for Arizona and New Mexico, use the information found in the 1984 NOAA Technical Memorandum NWS HYDRO-40.

6. Comments.

It was decided in 1975 to change the program from the procedure originally used by the NWS to a more simplified approach using only the four key precipitation values for input. This allows for quicker setup of the input data and facilitates the use of the program. No loss of accuracy in the calculated values occurs as the 2-year 6-hour, 2-year 24-hour, 100-year 6-hour, and 100-year 24-hour maps are the key maps initially derived in the NWS studies. The maps in NOAA Atlas 2 for return periods of 5, 10, 25, and 50 years were derived from the 2- and 100-year maps in the same manner that the PREFRE program computes these values.

In the original program, only one set of national factors was used to determine 5-min to 30-min values from 1-hour values. Papers by Fredrick and Miller and Arkell and Richards presented sets of factors that depended on the location of the site. These values were used for sites west of the 105th meridian; the old factors were retained for the Plains states east of the 105th meridian.

The 1975 version of the program allowed the user to specify two zones in the event that the site was near a zonal boundary. The current version does not offer that option because two types of zones (the original long-duration zone and the new short-duration zone) are now required and major revisions to the program would be required to accommodate various combinations of multiple runs. The only way to get runs for two adjacent zones is to edit the input file after the first run (a quick and simple procedure) and execute the program again.

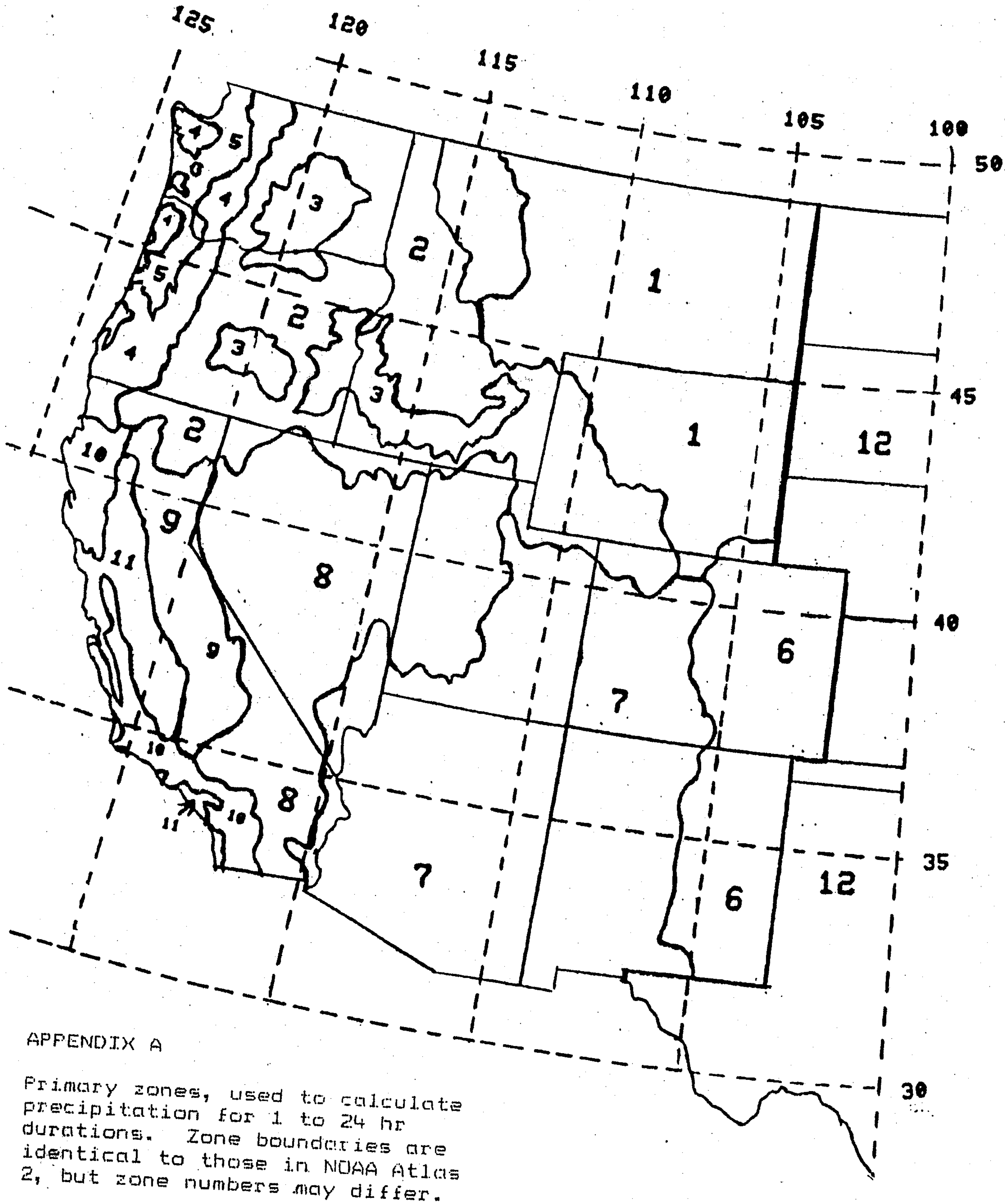
7. References.

Arkell, R. E., and F. Richards, "Short Duration Rainfall Relations for the Western United States," Preprint, Conference on Climate and Water Management-A Critical Era and Conference on the Consequences of 1985's Climate, August 4-7, 1986, Asheville, NC, Amer. Meteorol. Soc., Boston, 1986.

Frederick, R. H., and J. F. Miller, "Short Duration Rainfall Frequency Relations for California," Preprint, Third Conference on Hydrometeorology, August 20-24, 1979, Bogota, Colombia, Amer. Meteorol. Soc., Boston, 1979.

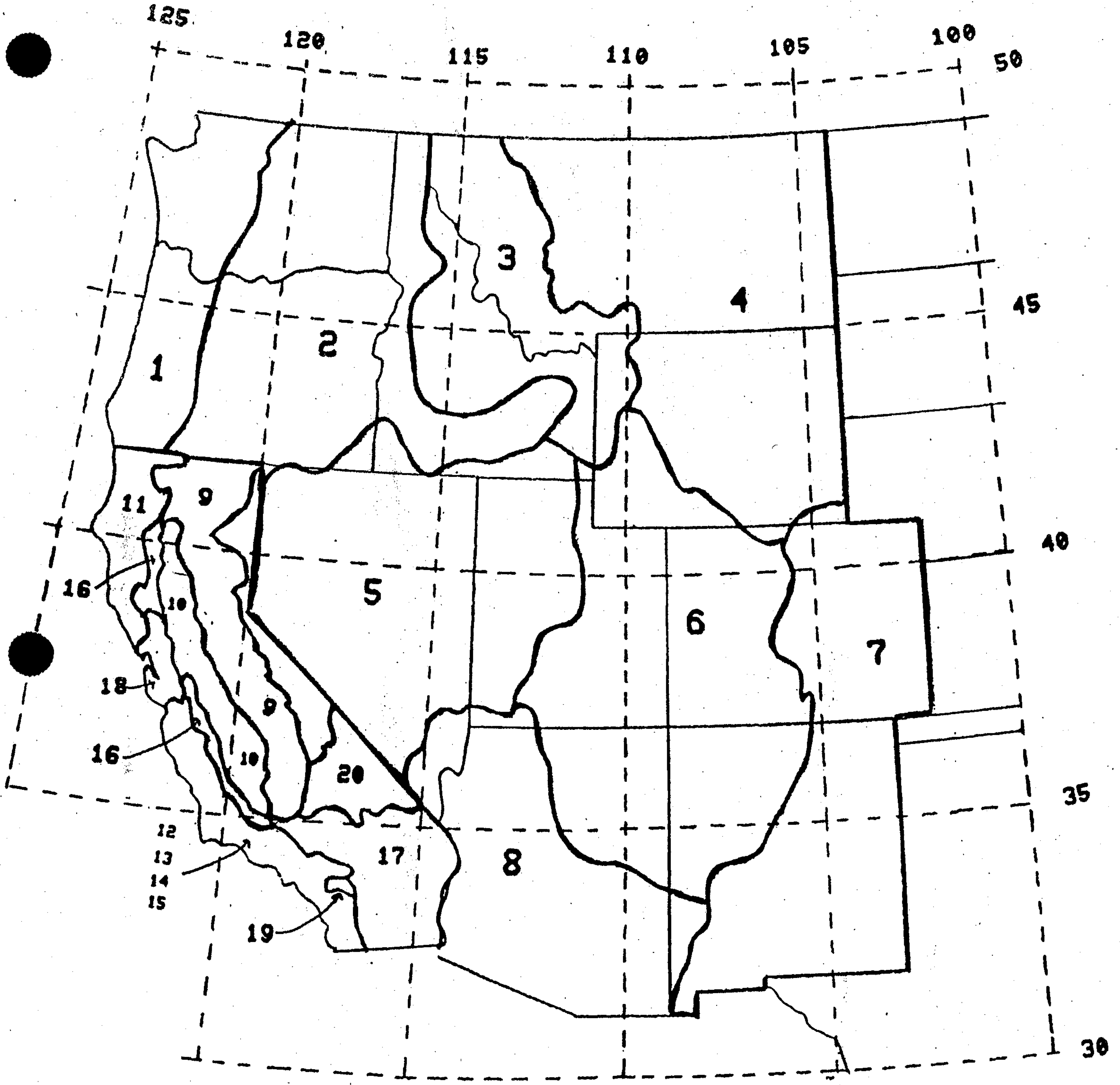
Miller, J. F., R. H. Frederick, and R. J. Tracy, "NOAA Atlas 2 - Precipitation-Frequency Atlas of the Western United State," 11 volumes, National Weather Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, Silver Spring, Maryland, 1973.

Zehr, R. M., and V. A. Myers, "Depth-Area Ratios in the Semi-Arid Southwest United States," NOAA Technical Memorandum NWS HYDRO-40, Office of Hydrology, National Weather Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, Silver Spring, Maryland, August 1984.



APPENDIX A

Primary zones, used to calculate precipitation for 1 to 24 hr durations. Zone boundaries are identical to those in NOAA Atlas 2, but zone numbers may differ.



APPENDIX B

Short-duration zones, used to calculate 5 to 30 min durations.

APPENDIX C1

INPUT FORMAT - FOUR PRECIPITATION VALUES

Line 1:
Field 1. Title of study or site name, up to 32 characters

Line 2 (fields separated by blanks or commas):
Field 1. Primary zone number (appendix A)
Field 2. Short-duration zone number (appendix B) *
Field 3. Latitude, degrees and decimals (or 0)
Field 4. Longitude, degrees and decimals (or 0)
Field 5. Elevation (or 0)
Field 6. 0 (number zero)

Line 3 (fields separated by blanks or commas):
Field 1. 2-yr 6-hr precipitation value from NOAA Atlas 2
Field 2. 100-yr 6-hr precipitation value
Field 3. 2-yr 24-hr precipitation value
Field 4. 100-yr 24-hr precipitation value

Line 4 (optional):
Field 1. ENDRUN (alpha characters)

NOTE: Actual latitude and longitude values are required for sites in primary zones 3, 9, and 11, and elevation data are required for sites in primary zones 1, 2, and 6. For other primary zones, enter either zeroes or the latitude, longitude, and elevation values. Elevation may be entered in meters, if precipitation is also metric.

* Short-duration zones 12 through 15 are all for the Southern Pacific Coast. Zone 12 is for sites with elevation greater than 700 ft. Zone 13 is for sites with elevation between 500 and 700 ft. Zone 14 is for sites with elevation less than 500 ft. Zone 15 represents an average of all elevations within the boundaries of the Southern Pacific Coast.

APPENDIX C2

INPUT FORMAT - TWELVE PRECIPITATION VALUES

Line 1: same as for four precipitation values

Line 2:
Fields 1 through 5: same as for four precipitation values
Field 6. 2

Line 3:
Field 1. 2-yr 6-hr precipitation value from NOAA Atlas 2
Field 2. 5-yr 6-hr precipitation value
Field 3. 10-yr 6-hr precipitation value
Field 4. 25-yr 6-hr precipitation value
Field 5. 50-yr 6-hr precipitation value
Field 6. 100-yr 6-hr precipitation value
Field 7. 2-yr 24-hr precipitation value
Field 8. 5-yr 24-hr precipitation value
Field 9. 10-yr 24-hr precipitation value
Field 10. 25-yr 24-hr precipitation value
Field 11. 50-yr 24-hr precipitation value
Field 12. 100-yr 24-hr precipitation value

Line 4 (optional):
Field 1. ENDRUN (alpha characters)

APPENDIX C3

SAMPLE INPUT - FOUR PRECIPITATION VALUES

Fields separated by blanks	QUARTZ HILL, COLORADO 6 7 39.80 105.52 8900 0 1.19 2.85 1.78 4.21 ENDRUN
Fields separated by commas	LEADVILLE, COLORADO 7,6,39.27,106.31,0,0 .79,1.85,1.00,2.79 ENDRUN

SAMPLE INPUT - 12 PRECIPITATION VALUES

```
KUTCH (NW), COLORADO
7 6 39.00 104.00 6100 2
1.04 1.20 2.00 2.25 2.40 2.50 1.39 1.75 1.90 2.25 2.60 3.30
ENDRUN
```

APPENDIX D1

SAMPLE OUTPUT - CYBER

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR QUARTZ HILL, COLORADO
PRIMARY ZONE NO.= 6 SHORT-DURATION ZONE NO.= 7
LATITUDE 39.80N LONGITUDE 105.52W ELEVATION 8900 FEET

POINT VALUES

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.26	.34	.39	.47	.53	.59	.73	5-MIN
10-MIN	.40	.53	.62	.74	.84	.93	1.16	10-MIN
15-MIN	.48	.66	.78	.94	1.07	1.20	1.49	15-MIN
30-MIN	.65	.90	1.06	1.29	1.47	1.65	2.05	30-MIN
1-HR	.78	1.09	1.30	1.59	1.81	2.03	2.54	1-HR
2-HR	.92	1.26	1.50	1.82	2.06	2.31	2.88	2-HR
3-HR	1.03	1.39	1.64	1.99	2.25	2.52	3.13	3-HR
6-HR	1.19	1.60	1.87	2.26	2.55	2.85	3.53	6-HR
12-HR	1.49	1.98	2.32	2.80	3.16	3.53	4.37	12-HR
24-HR	1.78	2.37	2.78	3.34	3.78	4.21	5.21	24-HR

INPUT DATA

PROJECT NAME-QUARTZ HILL, COLORADO
ZONE- 6 SHORT-DURATION ZONE- 7
LATITUDE= 39.80 LONGITUDE= 105.52 ELEVATION= 8900
2-YR, 6-HR PCPN= 1.19 100-YR, 6-HR PCPN= 2.85
2-YR, 24-HR PCPN= 1.78 100-YR, 24-HR PCPN= 4.21

```
AAAAAAAAAAAAAA
A            A
A END OF RUN A
A            A
AAAAAAAAAAAAAA
```

APPENDIX D2

SAMPLE OUTPUT - PC

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR QUARTZ HILL, COLORADO
PRIMARY ZONE NUMBER= 6
SHORT-DURATION ZONE NUMBER= 7

LATITUDE 39.80N   LONGITUDE 105.52W   ELEVATION 8900 FEET

POINT VALUES

RETURN PERIOD

DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.26	.34	.39	.47	.53	.59	.73	5-MIN
10-MIN	.40	.53	.62	.74	.84	.93	1.16	10-MIN
15-MIN	.48	.66	.78	.94	1.07	1.20	1.49	15-MIN
30-MIN	.65	.90	1.06	1.29	1.47	1.65	2.05	30-MIN
1-HR	.78	1.09	1.30	1.59	1.81	2.03	2.54	1-HR
2-HR	.92	1.26	1.50	1.82	2.06	2.31	2.88	2-HR
3-HR	1.03	1.39	1.64	1.99	2.25	2.52	3.13	3-HR
6-HR	1.19	1.60	1.87	2.26	2.55	2.85	3.53	6-HR
12-HR	1.49	1.98	2.32	2.80	3.16	3.53	4.37	12-HR
24-HR	1.78	2.37	2.78	3.34	3.78	4.21	5.21	24-HR

INPUT DATA

PROJECT NAME=QUARTZ HILL, COLORADO
ZONE= 6   SHORT-DURATION ZONE= 7
LATITUDE= 39.80   LONGITUDE= 105.52   ELEVATION= 8900
2-YR, 6-HR PCPN= 1.19   100-YR, 6-HR PCPN= 2.85
2-YR, 24-HR PCPN= 1.78   100-YR, 24-HR PCPN= 4.21

* * * * E N D   OF   R U N * * * *

APPENDIX D3

SAMPLE OUTPUT - PC (PRIMARY ZONE 7)

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR LEADVILLE, COLORADO
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 6

LATITUDE 39.27N   LONGITUDE 106.31W   ELEVATION 10200 FEET

POINT VALUES

DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
			RETURN PERIOD					
5-MIN	.20	.26	.30	.36	.41	.45	.56	5-MIN
10-MIN	.31	.41	.47	.57	.64	.71	.88	10-MIN
15-MIN	.37	.50	.58	.70	.79	.88	1.09	15-MIN
30-MIN	.48	.64	.75	.91	1.03	1.15	1.43	30-MIN
1-HR	.58	.78	.92	1.12	1.27	1.42	1.77	1-HR
2-HR	.65	.87	1.03	1.24	1.40	1.57	1.94	2-HR
3-HR	.70	.93	1.09	1.32	1.49	1.66	2.06	3-HR
6-HR	.79	1.05	1.22	1.47	1.66	1.85	2.29	6-HR
12-HR	.89	1.25	1.49	1.81	2.07	2.32	2.90	12-HR
24-HR	1.00	1.45	1.75	2.16	2.48	2.79	3.52	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=LEADVILLE, COLORADO
ZONE= 7   SHORT-DURATION ZONE= 6
LATITUDE= 39.27   LONGITUDE= 106.31   ELEVATION=10200
2-YR, 6-HR PCPN= .79   100-YR, 6-HR PCPN= 1.85
2-YR, 24-HR PCPN= 1.00   100-YR, 24-HR PCPN= 2.79

* * * * E N D   O F   R U N * * * *

APPENDIX D4

SAMPLE OUTPUT - PC (12 PRECIP VALUES)

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR KUTCH (NW), COLORADO
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 6

OPTION NUMBER 2 --- INPUT OF 12 PRECIP VALUES
LATITUDE 39.00N LONGITUDE 104.00W ELEVATION 6100 FEET

POINT VALUES

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.29	.40	.47	.57	.65	.72	.90	5-MIN
10-MIN	.45	.61	.73	.89	1.01	1.13	1.41	10-MIN
15-MIN	.54	.75	.90	1.09	1.25	1.40	1.75	15-MIN
30-MIN	.68	.97	1.16	1.42	1.63	1.83	2.30	30-MIN
1-HR	.82	1.18	1.42	1.75	2.01	2.26	2.84	1-HR
2-HR	.91	1.28	1.53	1.87	2.14	2.40	3.01	2-HR
3-HR	.96	1.34	1.60	1.95	2.22	2.49	3.12	3-HR
6-HR	1.06	1.46	1.73	2.10	2.38	2.67	3.33	6-HR
12-HR	1.17	1.58	1.86	2.25	2.56	2.86	3.55	12-HR
24-HR	1.28	1.71	2.00	2.41	2.73	3.05	3.78	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=KUTCH (NW), COLORADO
ZONE= 7 SHORT-DURATION ZONE= 6
LATITUDE= 39.00 LONGITUDE= 104.00 ELEVATION= 6100
12-VALUE PRECIPITATION OPTION
PRECIPITATION VALUE:

1.04	1.20
2.00	2.25
2.40	2.50
1.39	1.75
1.90	2.25
2.60	3.30

* * * * E N D   O F   R U N * * * *

APPENDIX E

EXECUTION OF PROGRAM PREFRE

CYBER

The following steps are used to execute program PREFRE on the Bureau of Reclamation CYBER mainframe computer:

1. Create an input file, using any convenient name, following the format presented in appendix C. This becomes a permanent file on the CYBER. Purge it when it is no longer needed.

2. Enter OLD,PREFREB [the binary (executable) form]
then GET,INPUT=your input file name
then PREFREB

3. The output information is sent to the screen. It can also be printed; use the procedures appropriate for the hardware available to you.

Personal Computer

PREFRE is the executable version of the program. It may be stored on the hard disk or it may be on a floppy disk. The following steps are used to execute the program on an IBM PC/AT or compatible (a FORTRAN compiler must be available on the particular PC being used):

1. Create an input file, using any convenient name, following the format presented in appendix C. This is a permanent file on the hard disk or floppy disk.

2. For hard disk, enter PREFRE filename1 filename2
(e.g., PREFRE PREIN1 PREOUT1)
For floppy disk, enter A:PREFRE filename1 filename2
(e.g., A:PREFRE A:PREIN1 A:PREOUT1)

Filename1 (including device ID and name extension) is the name of your input file and filename2 (including device ID and name extension) is the name of the file you wish the output information written. Either or both files may be on the hard disk or they may be on a floppy disk in device A. If they are on a floppy disk, the filename must be preceded by A:. The output file will be created by the program. If you fail to enter the file names at this point, the program will prompt you to enter those names. Messages will appear on the screen, but the output data are written to the file.

3. Enter PRINT filename2

APPENDIX E (continued)

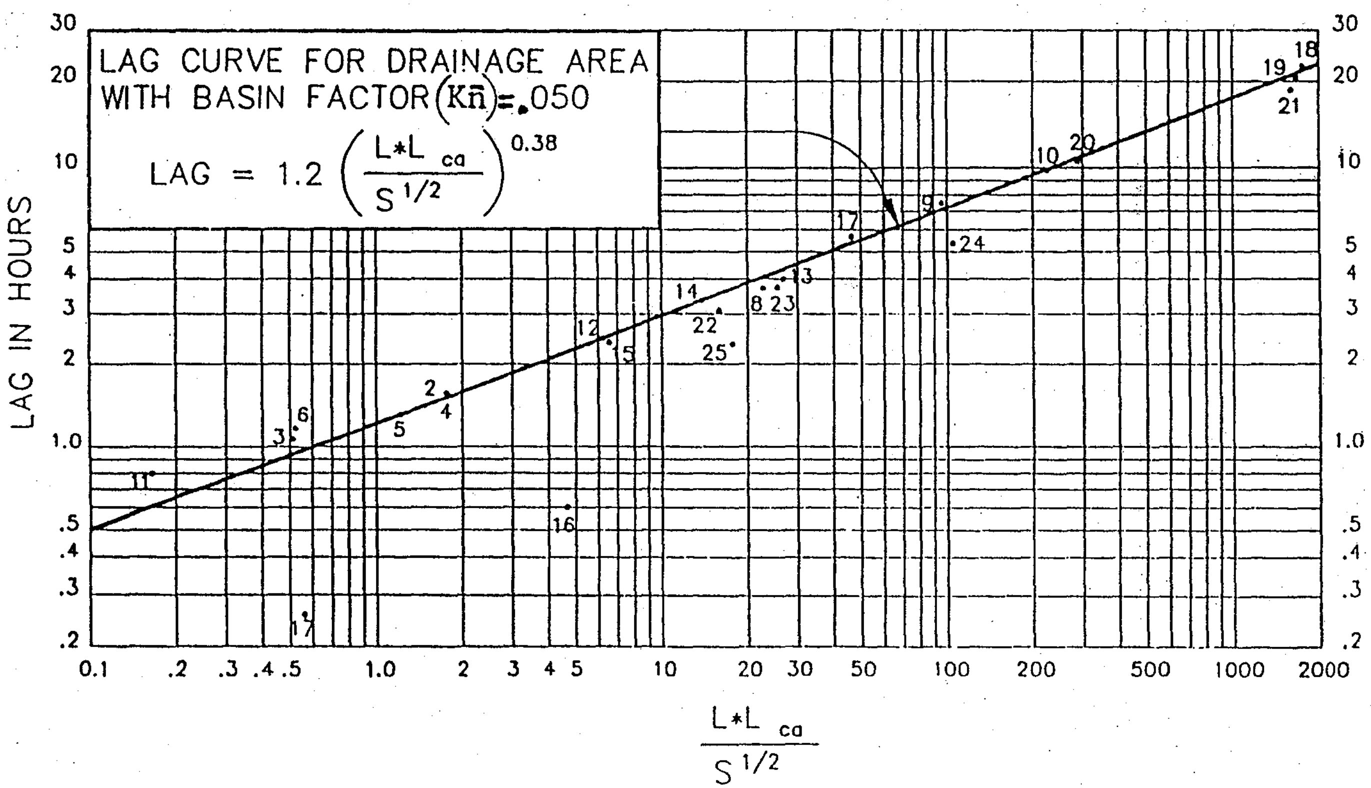
The output data will be listed at the printer. If you directed the output file to be written to the floppy disk (in device A), enter PRINT A:filename2. The output file is also a permanent file on the hard disk or floppy disk.

Appendix K

Kn Values for Various Rainfall-Runoff Events

This appendix contains tables of data showing estimated Kn values for various rainfall-runoff events for different watersheds. The first set of data is Figure 5.11 from the Drainage Design Manual, Volume I (1992). This figure was simply moved to Appendix K for the 1995 revisions. The remaining data comes from a compilation of data collected by George V. Sabol Consulting Engineers, Inc. for the *S-Graph Kn Study* performed for the FCDMC in March 1993 (Sabol, 1993b). These data are provided to serve as a comparative set of information, which engineers and hydrologists may consult when selecting Kn values for calculating basin lag times, using the U. S. Army Corps of Engineers lag equation with one of the four recommended S-graphs for use in Maricopa County (see Chapter 5). When examining these Kn data, one should keep in mind that the derived Kn values in these tables were reconstructed from actual rainfall-runoff events and, therefore, the values are storm (as well as watershed) dependent. Thus, a great deal of judgement is still necessary when evaluating these data for assistance in the selection of Kn values, for the purposes of modeling a particular watershed response to a given design storm.

		CONTRIBUTING AREA SQ. MI.	L MILES	L_{ca} MILES	S FT./MI.	LAG HOURS	ESTIMATED $K\bar{n}$
1.	SAN GABRIEL RIVER AT SAN GABRIEL DAM, CA	162.0	23.2	11.6	350	3.3	0.050
2.	WEST FORT SAN GABRIEL RIVER AT COGSWELL DAM, CA	40.4	9.3	4.3	450	1.6	.050
3.	SAN ANITA CREEK AT SANTA ANITA DAM, CA	10.8	5.8	2.5	690	1.1	.050
4.	SAN DIMAS CREEK AT SAN DIMAS DAM, CA	16.2	8.8	4.8	440	1.5	.050
5.	EATON WASH AT EATON WASH DAM, CA	9.5	7.3	4.4	600	1.3	.050
6.	SAN ANTONIO CREEK NEAR CLAREMONT, CA	16.9	5.9	3.0	1017	1.2	.055
7.	SANTA CLARA RIVER NEAR SAUGAS, CA	355.0	36.0	15.8	140	5.6	.050
8.	TEMECULA CREEK AT PAUBA CANYON, CA	166.0	26.0	11.3	150	3.7	.050
9.	SANTA MARGARITA RIVER NEAR FALLBROOK, CA	645.0	46.0	22.0	105	7.3	.055
10.	SANTA MARGARITA RIVER AT YSIDORA, CA	740.0	61.2	34.3	85	9.5	.055
11.	LIVE OAK CREEK AT LIVE OAK DAM, CA	2.3	2.9	1.5	700	0.8	.070
12.	TUJUNGA CREEK AT BIG TUJUNGA DAM, CA	81.4	15.1	7.3	290	2.5	.050
13.	MURRIETA CREEK AT TEMECULA, CA	220.0	27.2	10.3	95	4.0	.050
14.	LOS ANGLES RIVER AT SEPULVEDA DAM, CA	152.0	19.0	9.0	145	3.5	.050
15.	PACOIMA WASH AT PACOIMA DAM, CA	27.8	15.0	8.0	315	2.4	.050
16.	ALHAMBRA WASH ABOVE SHORT STREET, CA	14.0	9.5	4.8	85	0.6	.015
17.	BROADWAY DRAIN ABOVE RAYMOND DIKE, CA	2.5	3.4	1.7	100	0.28	.015
18.	GILA RIVER AT CONNOR NO. 4 DAM SITE, AZ	2840.0	131.0	71.0	29	21.5	.050
19.	SAN FRANCISCO RIVER AT JUNCTION WITH BLUE RIVER, AZ	2000.0	30.0	74.0	32	20.6	.050
20.	BLUE RIVER NEAR CLIFTON, AZ	790.0	77.0	37.0	65	10.3	.050
21.	SALT RIVER NEAR ROOSEVELT, AZ	4310.0	160.0	66.0	45	18.6	.050
22.	NEW RIVER AT ROCK SPRINGS, AZ	67.3	20.2	9.7	141	3.1	.045
23.	NEW RIVER AT NEW RIVER, AZ	85.7	23.2	13.6	145	3.7	.045
24.	NEW RIVER AT BELL ROAD, AZ	187.0	47.8	20.7	83	5.3	.037
25.	SKUNK CREEK NEAR PHOENIX, AZ	64.6	17.6	10.0	89	2.4	.033



GUIDE FOR ESTIMATING BASIN FACTOR $K\bar{n}$

$K\bar{n}$ = 0.200: DRAINAGE AREAS HAS COMPARATIVELY UNIFORM SLOPES AND SURFACE CHARACTERISTICS SUCH THAT CHANNELIZATION DOES NOT OCCUR. GROUND COVER CONSISTS OF CULTIVATED CROPS OR SUBSTANTIAL GROWTHS OF GRASS AND FAIRLY DENSE SMALL SHRUBS, CACTI, OR SIMILAR VEGETATION. NO DRAINAGE IMPROVEMENTS EXIST IN THE AREA.

$K\bar{n}$ = 0.050: DRAINAGE AREA IS QUITE RUGGED, WITH SHARP RIDGES AND NARROW, STEEP CANYONS THROUGH WHICH WATERCOURSES MEANDER AROUND SHARP BENDS, OVER LARGE BOULDERS, AND CONSIDERABLE DEBRIS OBSTRUCTION. THE GROUND COVER, EXLUDING SMALL AREAS OF ROCK OUTCROPS, INCLUDES MANY TREES AND CONSIDERABLE UNDERBRUSH, NO DRAINAGE IMPROVEMENTS EXIST IN THIS AREA.

$K\bar{n}$ = 0.030: 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.

$K\bar{n}$ = 0.015: DRAINAGE AREA HAS FAIRLY UNIFORM GENTLE SLOPES WITH MOST WATERCOURSES EITHER IMPROVED OR ALONG PAVED STREETS. GROUND COVER CONSISTS OF SOME GRASSES WITH APPRECIABLE AREAS DEVELOPED TO THE EXTENT THAT A LARGE PERCENTAGE OF THE AREA IS IMPERVIOUS.

TERMINOLOGY

- L — LENGTH OF LONGEST WATERCOURSE (mi)
- L_{ca} — LENGTH ALONG LONGEST WATERCOURSE, MEASURED UPSTREAM TO POINT OPPOSITE CENTER CENTER OF AREA. (mi)
- S — OVER-ALL SLOPE OF LONGEST WATERCOURSE BETWEEN HEADWATER AND COLLECTION POINT.
- LAG — ELAPSED TIME FROM BEGINNING OF UNIT PRECIPITATION TO INSTANT THAT SUMMATION HYDROGRAPH REACHES 50% OF ULTIMATE DISCHARGE.
- $K\bar{n}$ — VISUALLY ESTIMATED MEAN OF THE n (MANNING'S FORMULA) VALUES OF ALL THE CHANNELS WITHIN AN AREA.

NOTE: TO OBTAIN THE LAG (IN HOURS) FOR ANY AREA, MULTIPLY THE LAG OBTAINED FROM THE CURVE BY:

$$20(K\bar{n})$$

or $\frac{1}{.05}(K\bar{n})$

Figure 5.11

LAG RELATIONSHIPS

U.S. ARMY CORPS OF ENGINEERS (1982)

Lag and Kn Data for Mountain and Foothill Watersheds
(Kn values sorted in ascending order)

Reference and I.D. No. B	C	D	F	Watershed	Location	A (sq. miles)	L (miles)	Lca (miles)	S (ft/mi)	$\frac{L*Lca}{S^{.5}}$	Lag (hrs)	kn
		48		West Fork San Gabriel River	at Cogswell Dam (No. 2), CA	40.40	11.40	3.90	400.00	2.2230	a	b
		39		Santa Anita Creek (general storm)	at Santa Anita Dam, CA	10.80	5.10	2.10	898.00	0.3574	a	b
		44		San Gabriel River	at San Gabriel Dam No. 1, CA	162.00	23.20	11.60	350.00	14.3851	a	b
		46		West Fork San Gabriel River	at Cogswell Dam (No. 2), CA	40.40	11.40	3.90	400.00	2.2230	a	b
		40		Santa Anita Creek (local storm)	at Santa Anita Dam, CA	10.80	5.10	2.10	898.00	0.3574	a	b
		51		Trinity River	near Loulston, CA	a	a	a	a	b	a	b
		41		San Dieguito River	CA	a	a	a	a	b	a	b
		37		Colma Creek Basin	CA	a	a	a	a	b	a	b
		49		San Jose Creek	CA	a	a	a	a	b	a	b
		50		Verdugo Wash (LACDA)	CA	26.80	11.40	5.70	310.00	3.6906	0.840	0.0150
	21	33		San Jose Creek	at Workman Mill Rd., CA	81.30	23.70	9.10	75.00	24.9034	2.400	0.0272
		15		New River (Sept., 1970)	at New River, AZ	85.70	26.20	12.40	121.60	29.4618	2.720	0.0289
	20	32		East Fullerton Creek	at Fullerton Dam, CA	3.10	3.20	1.70	140.00	0.4598	0.600	0.0310
		13		New River (Sept., 1970)	near Rock Springs, AZ	67.30	20.20	9.70	141.40	16.4778	2.500	0.0332
		12		New River (Dec., 1967)	near Rock Springs, AZ	67.30	20.20	9.70	141.00	16.5011	2.590	0.0343
	37	2		New River (Sept., 1970)	at Bell Road near Phoenix, AZ	187.00	47.60	20.70	83.40	107.8932	5.360	0.0349
		53		Buckhorn Creek	near Masonville, CO	6.90	6.40	3.40	312.00	1.2319	1.000	0.0355
	24			Deep Creek	near Hesperia, CA	137.00	a	a	a	28.1000	2.800	0.0360
	2			Verde River	below Jerome, AZ	3190.00	110.00	47.00	46.40	758.9821	12.000	0.0371
		22		Agua Fria R. (Sept., 1970)	at Avondale, AZ	718.00	61.00	27.20	68.90	199.8891	7.800	0.0401
	1			Salt River	at Roosevelt,AZ	4341.00	145.00	60.00	47.00	1269.0254	16.000	0.0407
20				Sevier River	near Kingston, UT	1110.00	82.00	40.00	49.00	468.5714	11.000	0.0409
	35			New River	at Rock Springs, AZ	67.30	20.20	9.70	141.40	16.4778	3.100	0.0411
	36			New River	at New River, AZ	85.70	23.20	13.60	145.00	26.2025	3.700	0.0411
		20		New River (Sept., 1970)	near Glendale, AZ	323.00	55.50	20.60	73.60	133.2666	6.900	0.0414
		52		Animas River	at Farmington, NM	1360.00	106.30	55.20	72.40	689.6092	12.900	0.0414
	12	28		Temecula Creek	at Pauba Canyon, CA	168.00	26.00	11.30	150.00	23.9887	3.700	0.0425
	28			Blue River	near Clifton, AZ	790.00	77.00	37.00	65.00	353.3750	10.300	0.0426
	17	25		Murrieta Creek	at Temecula, CA	220.00	27.20	10.30	95.00	28.7438	4.000	0.0429
	4			Agua Fria R.	near Mayer, AZ	590.00	42.00	14.00	87.10	63.0040	5.400	0.0430
	8	30		San Dimas Creek	at San Dimas Dam, CA	16.20	8.60	4.80	440.00	1.9679	1.500	0.0446
	19			Pacoima Wash	at Pacoima Dam, CA	27.80	15.00	8.00	315.00	6.7612	2.400	0.0447
18				Coal Cr.	near Cedar City, UT	92.00	16.50	7.10	310.00	6.6537	2.400	0.0449
	9	31		Eaton Wash	at Eaton Wash Dam, CA	9.50	7.30	4.40	600.00	1.3113	1.300	0.0451
		14		New River (Dec., 1967)	at New River, AZ	85.70	26.20	12.40	121.60	29.4618	4.250	0.0452
	5	45		San Gabriel River	at San Gabriel Dam, CA	162.00	23.20	11.60	350.00	14.3851	3.300	0.0461
	14	26		Santa Margarita River	at Ysidora, CA	740.00	61.20	34.30	85.00	227.6859	9.500	0.0464
	27			San Francisco River	at Jct. with Blue River, AZ	2000.00	130.00	74.00	32.00	1700.5918	20.600	0.0469
	16	29		Tujunga Creek	at Big Tujunga Dam, CA	81.40	15.10	7.30	290.00	6.4729	2.500	0.0473
19				Sevier River	near Hatch, UT	260.00	29.00	14.00	100.00	40.6000	5.100	0.0480
	6	47		West Fork San Gabriel River	at Cogswell Dam, CA	40.40	9.30	4.20	450.00	1.8413	1.600	0.0488
	13	27		Santa Margarita River	near Fallbrook, CA	645.00	46.00	22.00	105.00	98.7611	7.300	0.0490
	18			Los Angeles River	at Sepulveda Dam, CA	152.00	19.00	9.00	145.00	14.2008	3.500	0.0491
	11	36		Santa Clara River	near Saugus, CA	355.00	36.00	15.80	140.00	48.0724	5.600	0.0494
		5		Cave Creek (Dec., 1967)	Phoenix, AZ	70.00	26.00	11.80	75.90	35.2155	4.990	0.0496
		42		Santa Barbara (Mission Creek)	at Los Olivos Street, CA	7.70	a	a	a	b	a	0.0500

NOTE: a - unknown, b - cannot calculate
References and ID No.s available in the
Documentation And Verification Manual at the FCDMC.

Lag and Kn Data for Urban Watersheds
(Kn values sorted in ascending order)

Reference and I.D. No. A	D	E	Watershed	Location	A (sq. miles)	L (miles)	Lca (miles)	S (ft/mi)	RTIMP (%)	L*Lca / S^.5	Lag (hrs)	kn
		D3	Concourse D	Denver, CO	0.150	0.97	0.43	a	a	b	0.24	b
14			Southwest Outfall	Louisville, KY	7.500	6.50	2.70	18.5	33.0	4.0803	0.50	0.0113
1	34		Alhambra Wash above Short St.	Monterey Park, CA	14.000	9.50	4.60	85.0	40.0	4.7399	0.60	0.0128
6			Brays Bayou	Houston, TX	88.400	23.30	10.40	4.1	40.0	119.6733	2.10	0.0131
3	35		Broadway Drain at Raymond Dike	L.A., CA	2.500	3.40	1.70	100.0	45.0	0.5780	0.30	0.0142
13			Southern Outfall	Louisville, KY	6.400	6.40	2.50	13.0	48.0	4.4376	0.70	0.0153
12			Northwest Trunk	Louisville, KY	1.900	3.00	1.10	19.0	50.0	0.7571	0.40	0.0171
		Q1	Villa Del Oso	Albuquerque, NM	0.052	0.54	0.27	111.0	16.4	0.0138	0.09	0.0176
10			Beargrass Cr.	Louisville, KY	9.700	5.60	2.50	6.3	70.0	5.5777	0.90	0.0180
7			White Oak Bayou	Houston, TX	92.000	23.10	12.80	5.0	35.0	132.2321	3.10	0.0186
		Q5	Taylor Ranch	Albuquerque, NM	0.136	0.55	0.23	25.0	9.6	0.0253	0.12	0.0187
		Q4	Academy Acres	Albuquerque, NM	0.124	0.90	0.53	100.0	16.3	0.0477	0.16	0.0196
11			17th Street Sewer	Louisville, KY	0.200	0.90	0.30	48.0	93.0	0.0390	0.15	0.0198
5			Ballomna Cr. at Sawtelle Blvd.	L.A., CA	88.600	11.80	5.60	64.0	40.0	8.2600	1.20	0.0207
		D5	Sand Creek	Denver, CO	0.290	0.84	0.21	41.0	24.0	0.0275	0.14	0.0211
		D1	116 Ave & Claude Ct.	Denver, CO	0.260	1.16	0.49	69.0	13.3	0.0684	0.21	0.0224
		D6	Sand Creek	Denver, CO	0.290	0.84	0.21	41.0	24.0	0.0275	0.15	0.0226
		T2	High School Wash	Tucson, AZ	0.950	1.60	0.75	58.0	10.7	0.1576	0.30	0.0233
15			Beargrass Cr.	Louisville, KY	6.300	4.00	1.80	4.5	20.0	3.3941	1.00	0.0242
21			Walker Avenue Drain	Baltimore, MD	0.200	1.00	0.40	83.0	33.0	0.0439	0.20	0.0252
		Q2	Villa Del Oso	Albuquerque, NM	0.052	0.54	0.27	111.0	16.4	0.0138	0.13	0.0254
		T4	Arcadia	Tucson, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.75	0.0258
19			Little Pimmit Run	Arlington, VA	2.300	2.20	1.00	77.0	20.0	0.2507	0.40	0.0260
2	33		San Jose Cr. at Workman Mill Rd	Whittier, CA	81.300	23.70	9.10	75.0	35.0	24.9034	2.40	0.0272
		T6	Arcadia, Part 2	Tucson, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.81	0.0279
8			Boneyard Cr.	Austin, TX	4.500	2.80	1.30	9.5	37.0	1.1810	0.80	0.0289
		T5	Arcadia, Part 1	Tucson, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.84	0.0289
4			Compton Cr. below Hooper Ave Storm Drain	L.A., CA	19.500	8.80	4.20	14.6	60.0	9.6729	1.80	0.0292
		T3	Arcadia	Tucson, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.90	0.0310
18			Four Mile Run	Alexandria, VA	14.400	7.80	3.50	43.0	20.0	4.1632	1.40	0.0313
17			Tripps Run	Falls Church, VA	1.800	2.30	1.00	79.0	25.0	0.2588	0.50	0.0321
		D2	Villa Italia	Denver, CO	0.120	0.67	0.33	100.0	77.0	0.0221	0.20	0.0327
		T1	High School Wash	Tucson, AZ	0.950	1.60	0.75	58.0	10.7	0.1576	0.43	0.0334
9			Waller Cr.	Austin, TX	4.100	5.20	1.90	48.0	27.0	1.4261	1.00	0.0336
16			Tripps Run	near Falls Church, VA	4.600	4.10	1.90	52.0	28.0	1.0803	0.90	0.0336
		Q3	Academy Acres	Albuquerque, NM	0.124	0.90	0.53	100.0	16.3	0.0477	0.29	0.0354
20			Piney Branch	Vienna, VA	0.300	0.50	0.20	87.0	30.0	0.0107	0.20	0.0431
		T8	Railroad	Tucson, AZ	2.300	2.30	1.48	46.0	17.0	0.5019	0.89	0.0445
		T7	Railroad	Tucson, AZ	2.300	2.30	1.48	46.0	17.0	0.5019	1.10	0.0550
		D4	Goose Creek	Denver, CO	1.340	1.34	0.60	74.0	15.4	0.0935	0.63	0.0596
		T9	Atterbury	Tucson, AZ	4.970	6.67	3.87	26.0	3.0	5.0623	3.42	0.0710
	10		Aqua Fria R. trib. (Sept, 1970)	Phoenix, AZ	0.130	0.77	0.39	16.0	25.0	0.0751	0.96	0.0988
	11		Aqua Fria R. trib. (Sept, 1970)	Phoenix, AZ	0.130	0.77	0.39	16.0	25.0	0.0751	1.00	0.1029
				Maximum	92.000	23.70	12.80	111.0	93.0	132.2321	3.42	0.1029
				Minimum	0.052	0.50	0.20	4.1	3.0	0.0107	0.09	0.0113
				Mean	11.071	4.57	2.16	51.0	29.1	8.0720	0.81	0.0313
				Standard Deviation	25.179	5.88	2.75	32.3	19.1	27.0547	0.77	0.0200

NOTE: a - unknown value, b - cannot calculate

References and ID No.s available in the Documentation And Verification Manual at the FCDMC

Lag and Kn Data for Mountain and Foothill Watersheds
(Kn values sorted in ascending order)

Reference and I.D. No. B	C	D	F	Watershed	Location	A (sq. miles)	L (miles)	Lca (miles)	S (ft/mi)	L*Lca / S^.5	Lag (hrs)	kn
	3			Tonto Creek	above Gun Cr., AZ	678.00	41.00	16.50	104.60	66.1458	6.500	0.0508
	22			San Vincente Creek	at Foster, CA	75.00	a	a	a	12.8000	3.200	0.0530
	7	38		Santa Anita Creek	at Santa Anita Dam, CA	10.80	5.80	2.50	690.00	0.5520	1.100	0.0530
			Y9	Medicine Bow River	WY	3.01	3.79	1.92	550.00	0.3103	0.890	0.0534
	33			White River	near Watson, UT	4020.00	a	a	a	1473.0000	15.700	0.0540
		21		Agua Fria R. (Dec., 1967)	at Avondale, AZ	718.00	61.00	27.20	68.90	199.8891	10.680	0.0549
	25			Bill Williams River	at Planet, AZ	4730.00	a	a	a	1476.0000	16.200	0.0560
		1		New River (Dec., 1967)	at Bell Road near Phoenix, AZ	187.00	47.60	20.70	83.40	107.8932	8.850	0.0575
	10			San Antonio Creek	near Claremont, CA	16.90	5.90	3.00	1017.00	0.5550	1.200	0.0577
		6		Cave Creek (Sept., 1970)	Phoenix, AZ	70.00	26.00	11.80	75.90	35.2155	5.880	0.0584
	34			Paria River	at Lees Ferry, AZ	1570.00	a	a	a	296.0000	10.200	0.0600
			Y4	West Fork Dry Cheyenne Creek Trib.	WY	1.85	2.39	1.27	356.00	0.1609	0.790	0.0606
24				Dolores River	near McPhee, CO	793.00	a	a	a	193.0000	9.000	0.0610
	15	43		Live Oak Creek	at Live Oak Dam, CA	2.30	2.90	1.50	700.00	0.1644	0.800	0.0611
1				Purgatoire River	at Trinidad, CO	742.00	44.00	20.00	159.00	69.7885	8.000	0.0613
		19		New River (Dec., 1967)	near Glendale, AZ	323.00	55.50	20.60	73.60	133.2666	10.590	0.0635
8				North Fk Big Thompson River	near Glen Haven, CO	1.30	1.90	1.30	709.00	0.0928	0.700	0.0665
7				Rabbit Gulch	near Estes Park, CO	3.40	3.30	1.50	480.00	0.2259	1.000	0.0677
	32			Plateau Creek	near Cameo, CO	604.00	a	a	a	89.9000	7.900	0.0690
6				Dry Gulch	near Estes Park, CO	2.10	2.70	1.00	295.00	0.1572	0.900	0.0699
	23			San Diego River	near Santee, CA	380.00	a	a	a	95.4000	9.200	0.0780
			Y2	West Fork Dry Cheyenne Creek	WY	0.69	1.93	0.88	240.00	0.1098	0.910	0.0811
			Y3	West Fork Dry Cheyenne Creek Trib.	WY	1.85	2.39	1.27	356.00	0.1609	1.060	0.0816
21				Centerville Cr.	near Centerville, UT	3.90	a	a	a	0.4000	2.400	0.1240
22				Parrish Cr.	near Centerville, UT	2.00	a	a	a	0.3000	2.200	0.1260
13				Madison River	near Three Forks, MT	2511.00	a	a	a	2060.0000	50.000	0.1550
15				Surface Cr.	at Cedaredge, CO	43.00	a	a	a	11.3000	11.300	0.1950
14				Gallatin River	at Logan, MT	1795.00	a	a	a	443.0000	38.000	0.1960
17				Piney Cr.	at Kearney, WY	106.00	a	a	a	29.0000	16.500	0.2090
12				Weiser River	above Craney Cr. near Weiser, ID	1160.00	a	a	a	310.0000	37.000	0.2140
5				Uncompaghre River	at Delta, CO	1110.00	a	a	a	216.0000	36.000	0.2350
10				South Fk. Payette River	near Garden Valley, ID	779.00	a	a	a	123.0000	30.000	0.2360
4				San Miguel River	at Naturita, CO	1080.00	a	a	a	174.0000	34.000	0.2380
2				Wood River	near Meeteetse, WY	194.00	a	a	a	41.9000	21.500	0.2410
11				Malheur River	near Drewsy, OR	910.00	a	a	a	114.0000	30.000	0.2420
23				Florida River	near Hermosa, CO	69.40	a	a	a	12.5000	15.500	0.2590
16				South Piney Cr.	at Willow Park, WY	28.90	a	a	a	3.8000	10.500	0.2600
3				Grey Bull River	near Meeteetse, WY	681.00	a	a	a	68.3000	34.000	0.3240
9		54		Uintah River	near Neola, UT	181.00	a	a	a	59.0000	32.000	0.3240
25				Los Pinos River	near Bayfield, CO	284.00	a	a	a	35.0000	28.500	0.3390
					Maximum	4730.00	145.00	74.00	1017.00	2060.00	50.000	0.3390
					Minimum	0.69	1.90	0.88	32.00	0.09	0.600	0.0150
					Mean	542.77	31.55	14.56	264.81	178.59	9.920	0.0893
					Standard Deviation	956.60	32.81	15.75	243.35	398.21	11.178	0.0817

NOTE: a - unknown, b - cannot calculate

References and ID No.s available in the Documentation And Verification Manual at the FCDMC.

Not representative of Maricopa County mountain and foothill watersheds.

Lag and Kn Data for Desert/Rangeland Watersheds
(Kn values sorted in ascending order)

Reference and I.D. No. C	D	F	Watershed	Location	A (sq. miles)	L (miles)	Lca (miles)	S (ft/mi)	L*Lca / S^.5	Lag (hrs)	kn
	55		Arbuckle Creek and Dam	OK	a	a	a	a	b	a	b
		X6	Walnut Gulch 63.011	Tombstone, AZ	3.180	4.02	1.780	117.00	0.6615	0.510	0.0230
		X12	Walnut Gulch 63.111	Tombstone, AZ	0.220	0.95	0.480	150.00	0.0372	0.200	0.0269
		X11	Walnut Gulch 63.111	Tombstone, AZ	0.220	0.95	0.480	150.00	0.0372	0.210	0.0282
38	4		Skunk Creek (Sept., 1970)	near Phoenix, AZ	64.600	17.60	9.900	101.90	17.2608	2.190	0.0285
		X1	Walnut Gulch 63.004	Tombstone, AZ	0.880	2.10	1.040	112.00	0.2064	0.470	0.0329
29	23		Moencopi Wash	near Tuba City, AZ	2490.000	84.50	36.300	42.10	472.7399	9.200	0.0341
		X9	Walnut Gulch 63.103	Tombstone, AZ	0.013	0.22	0.094	195.00	0.0015	0.075	0.0343
		X7	Walnut Gulch 63.015	Tombstone, AZ	9.240	4.25	2.500	60.00	1.3717	1.070	0.0365
		X8	Walnut Gulch 63.103	Tombstone, AZ	0.013	0.22	0.094	195.00	0.0015	0.082	0.0375
	3		Skunk Creek (Dec., 1967)	near Phoenix, AZ	64.600	17.60	9.900	101.90	17.2608	2.950	0.0384
		X2	Walnut Gulch 63.004	Tombstone, AZ	0.880	2.10	1.040	112.00	0.2064	0.550	0.0385
30	24		Clear Creek	near Winslow, AZ	607.000	78.00	46.800	41.00	570.0967	11.200	0.0386
26			Gila River	at Conner No. 4 Damsite, AZ	2840.000	131.00	71.000	29.00	1727.1523	21.500	0.0487
31			Puerco River	near Admana, AZ	2760.000	a	a	a	1225.0000	15.900	0.0580
	9		Queen Creek Tributary (Sept., 1970)	Phoenix, AZ	0.510	1.50	0.750	67.00	0.1374	0.790	0.0646
	7		Queen Creek Tributary (Dec., 1967)	Phoenix, AZ	0.510	1.50	0.750	67.00	0.1374	0.860	0.0703
	8		Queen Creek Tributary (Sept., 1970)	Phoenix, AZ	0.510	1.50	0.750	67.00	0.1374	0.950	0.0777
				Maximum	2840.000	131.00	71.000	195.00	1727.1523	21.500	0.0777
				Minimum	0.013	0.22	0.094	29.00	0.0015	0.075	0.0230
				Mean	520.140	21.75	11.479	100.49	237.2027	4.042	0.0422
				Standard Deviation	1050.622	39.57	21.056	51.88	504.7440	6.448	0.0161

NOTE: a - unknown value, b - cannot calculate

References and ID No.s available in the Documentation And Verification Manual at the FCDMC.

Lag and Kn Data for Distributary Flow Area Watersheds
(Kn values sorted in ascending order)

Ref. and I.D. No D	G	Watershed	Location	A (sq. miles	L (miles)	Lca (miles)	S (ft/mi)	L*Lca / S^.5	Lag (hrs)	kn
	Q12	N. Camino Arroyo Trib.	Albuquerque, NM	0.210	2.12	1.05	196.0	0.1590	0.27	0.0209
	Q9	Camino Arroyo Trib.	Albuquerque, NM	0.089	0.93	0.40	177.0	0.0280	0.15	0.0225
	Q11	N. Camino Arroyo Trib.	Albuquerque, NM	0.210	2.12	1.05	196.0	0.1590	0.31	0.0240
18		Indian Bend Wash (June, 1972)	near Scottsdale, AZ	142.000	27.70	13.60	64.2	47.0166	3.10	0.0276
	Q6	La Cueva Arroyo Trib.	Albuquerque, NM	0.090	0.76	0.40	432.0	0.0146	0.15	0.0287
	Q10	Camino Arroyo Trib.	Albuquerque, NM	0.089	0.93	0.40	177.0	0.0280	0.34	0.0509
	Q7	La Cueva Arroyo Trib.	Albuquerque, NM	0.090	0.76	0.40	432.0	0.0146	0.27	0.0517
17		Indian Bend Wash (Sept., 1970)	near Scottsdale, AZ	142.000	27.70	13.60	64.2	47.0166	7.31	0.0651
16		Indian Bend Wash (Dec., 1967)	near Scottsdale, AZ	142.000	27.70	13.60	64.2	47.0166	8.02	0.0714
	Q8	La Cueva Arroyo Trib.	Albuquerque, NM	0.090	0.76	0.40	432.0	0.0146	0.39	0.0747
			Maximum	142.000	27.70	13.60	432.0	47.0166	8.02	0.0747
			Minimum	0.089	0.76	0.40	64.2	0.0146	0.15	0.0209
			Mean	42.687	9.15	4.49	223.5	14.1468	2.03	0.0437
			Standard Deviation	68.533	12.81	6.29	153.6	22.6824	3.10	0.0215

References and ID No.s available in the Documentation And Verification Manual at the FCDMC.

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Examples

Index

1. **Rational Method**
   The Rational Method is used to determine the peak discharge and runoff volume from a hypothetical 140-acre urban watershed.

2. **Green and Ampt Losses**
   Loss parameters for input to the Green and Ampt method are calculated for Subbasin No. 4 of the Example Watershed.

3. **Clark Unit Hydrograph (Urban)**
   Clark Unit Hydrograph parameters are developed for Subbasin No. 2 of the Example Watershed using the worksheet (manual) method. The results are input to an example HEC-1 input file, and output is provided.

4. **Clark Unit Hydrograph (Natural)**
   Clark Unit Hydrograph parameters are developed for Subbasin No. 4 of the Example Watershed using the worksheet (manual) method. The results are input to an example HEC-1 input file, and output is provided.

5. **S-Graph Applications**
   The Phoenix Mountain S-Graph is used to manually develop an unit hydrograph for a hypothetical watershed. An HEC-1 input file example is provided.

6. **Kinematic Wave Routing**
   Flow is routed along a trapezoidal channel using the Kinematic Wave Routing option. HEC-1 input and output file examples are provided.

7. **Muskingum Routing**
   Flow is routed along a hypothetical natural stream using the Muskingum Routing option. HEC-1 input and output file examples are provided.

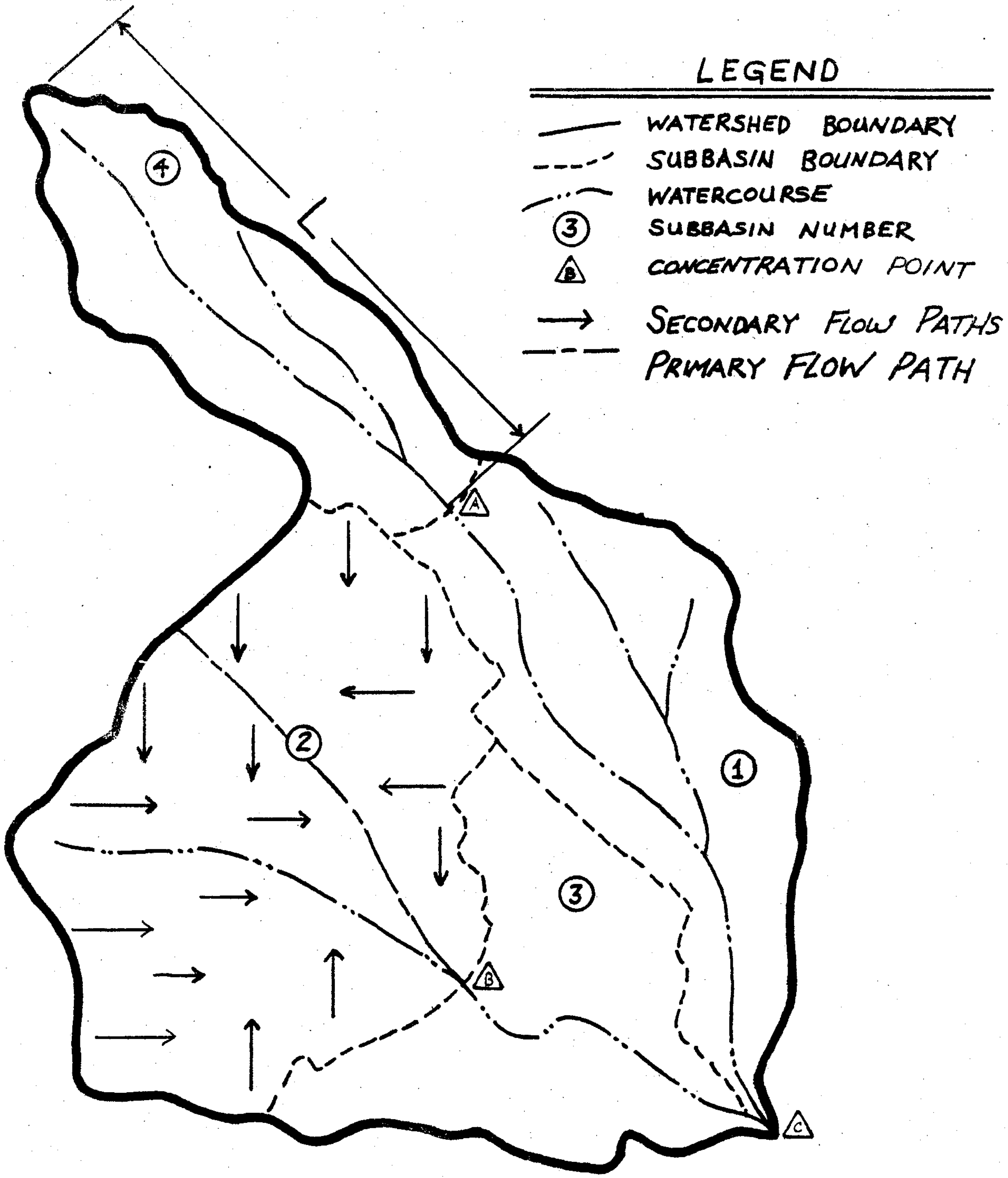
8. **Muskingum-Cunge Routing**
   Flow is routed along a hypothetical channel using the Muskingum-Cunge Routing option. Examples are provided for both the simplified and 8-point cross-section options. HEC-1 input and output file examples are provided.

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT *HYDROLOGIC DESIGN MANUAL* PAGE 1 OF 2

DETAIL *EXAMPLE WATERSHED* COMPUTED ______ DATE ______

CHECKED BY ______ DATE ______



SUBBASIN CHARACTERISTICS

SUBBASIN #	AREA (mi²)	IMPERVIOUSNESS (%)	FLOW PATH LENGTH (mi)	SLOPE (ft/mi)	LAND USE
1	1.52	33	2.65	170.	40% MULTI-UNIT AREAS 60% APARTMENT AREAS
2	2.17	21	1.85	30.5	100% SINGLE FAMILY RESIDENTIAL
3	0.96	42	1.13	104.	50% LIGHT INDUSTRIAL 50% DOWNTOWN AREAS
4	0.86	9	1.49	537.	100% UNDEVELOPED Desert MOUNTAIN

WATERCOURSES

SUBBASIN #	DESCRIPTION	GEOMETRY	AVE. BOTTOM WIDTH (ft)	AVE. DEPTH (ft)	SIDE SLOPE	MANNINGS 'n'
1	SOIL CEMENT LINED	TRAP.	25	5	2:1	.018
2	DREDGED EARTH	Rect.	15	4	—	.022
3	CONCRETE LINED	TRAP.	35	4	3:1	.015
4	NATURAL DESERT STREAM	TRAP.	15	2	2:1	.040

SCENARIO: USE THE RATIONAL METHOD TO DETERMINE THE 100-YEAR PEAK DISCHARGE AND RUNOFF VOLUME FROM AN URBAN WATERSHED WITH THE FOLLOWING PHYSICAL CHARACTERISTICS:

LOCATION → CAREFREE, AZ. T6N - R4E - Sec. 6
DRAINAGE AREA → 140 acres
FLOW PATH LENGTH → 1.236 mi.
AVERAGE SLOPE → 33 ft/mi
LAND USE → 70% SINGLE FAMILY RESIDENTIAL
30% LIGHT INDUSTRIAL

STEP 1: DETERMINE THE RUNOFF COEFFICIENT C (TABLE 3.)

SINCE OUR RETURN PERIOD IS 100-YEAR, USE COLUMN (4).

RESIDENTIAL (70%) → $C_1 = 0.63$
LIGHT INDUSTRIAL (30%) → $C_2 = 0.82$

$$C_{100} = (.70)(.63) + (.30)(.82) = \underline{\underline{0.69}}$$

STEP 2: CALCULATE T_c USING Equation 3.2

$$T_c = 11.4\, L^{.50}\, K_b^{.52}\, S^{-.31}\, i_{100}^{-.38}$$

where $L = 1.236$ mi.
$S = 33$ ft/mi
$K_b = -.00625\,(\log 140) + .04 = 0.027$ (TABLE 3.1 & 3.2)

PLUG IN THE KNOWN VARIABLES:

$$T_c = 11.4\,(1.236)^{.5}\,(.027)^{.52}\,(33)^{-.31}\,(i)^{-.38}$$

$$T_c = 0.655\, i_{100}^{-.38}$$

SINCE THE EQUATION CONTAINS TWO UNKNOWNS, IT MUST BE SOLVED BY AN ITERATIVE PROCESS. WE'LL CHOOSE 30 min. as a FIRST GUESS AT T_c. AT T_c = 30 min., THE 100-YEAR RAINFALL INTENSITY IS 4.00 in/hr. (FIG. 3.3). BECAUSE THE WATERSHED IS OUTSIDE THE PHOENIX AREA, THE INTENSITY VALUES MUST BE ADJUSTED USING EQUATION 3.3:

$$i_{100} = i_p\left(\frac{P_{10}^{6}}{2.07}\right)$$

where i_p is the rainfall intensity value for Phoenix (FIG 3.3), and $P_{10}^{6}/2.07$ is the ratio of the 6-hour, 10-year rainfall depth (FIG. 2.4) for our area to that for Phoenix.

FOR THIS CASE: $i_p = 4.00$ in/hr, $P_{10}^{6} = 2.3$ in

$$i_{100} = 4.00\left(\frac{2.3}{2.07}\right) = 4.44 \text{ in/hr}$$

AT $i_{100} = 4.44$ in/hr, $T_c = 0.655\,(4.44)^{-.38} = 22.3$ min — No Good

TRY $T_c = 20$ min.

$i_p = 5.1$ in/hr, $i_{100} = 5.1\left(\frac{2.3}{2.07}\right) = 5.67$ in/hr

$T_c = 0.655\,(5.67)^{-.38} = 20.3$ min — OK

SO $T_{c_{100}} = 20$ min, $i_{100} = 5.67$ in/hr

STEP 3: CALCULATE PEAK DISCHARGE USING EQUATION 3.1

$$Q_{pk} = C_{100}\, i_{100}\, A = (0.69)(5.67)(140) = 548 \text{ cfs}$$

STEP 4: CALCULATE RETENTION VOLUME (V)

$$V = C_{100}\left(\frac{P_{100}^{2}}{12}\right)A$$

where P_{100}^{2} is the 2-hour, 100-year point rainfall depth (in). The P_{100}^{2} can be read from FIG. 3.2, or calculated using the equations in Section 2.4.4.

For this case, we will read P_{100}^{2} from Figure 3.2. At T6N-R4E-Section 6, the approximate value is 2.75 in.

THEN: $$V = 0.69\left(\frac{2.75}{12}\right)140 = 22.14 \text{ ac-ft}$$

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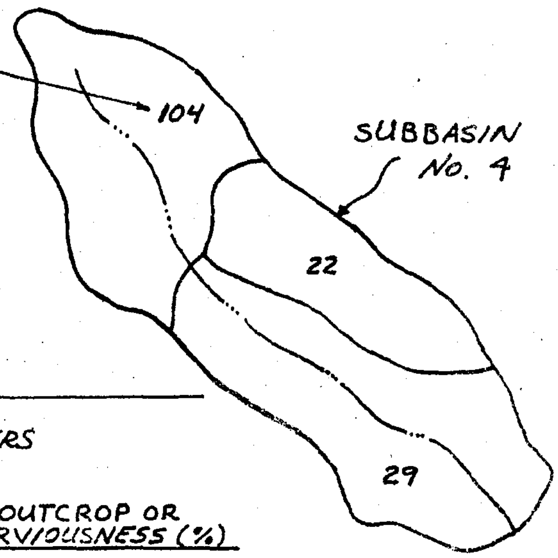
PROJECT HYDROLOGIC DESIGN MANUAL PAGE 1 OF 1

DETAIL EXAMPLE No. 2 COMPUTED ______ DATE ______

GREEN & AMPT LOSSES CHECKED BY ______ DATE ______

SCENARIO: CALCULATE THE GREEN AND AMPT LOSS PARAMETERS FOR SUBBASIN No. 4 OF THE EXAMPLE WATERSHED. ASSUME THAT THE WATERSHED IS LOCATED WITHIN THE BOUNDARIES OF THE "SOIL SURVEY OF AGUILA-CAREFREE AREA, PARTS OF MARICOPA AND PINAL COUNTIES, ARIZONA." ASSUME THE DESIGN STORM TO BE A 6-HOUR, 100-YEAR EVENT OF 3.5 to 4.0 INCHES.

NUMBERS ARE FOUND ON THE SOIL SURVEY MAPS AND DENOTE SOIL MAP UNITS.



STEP 1: PLANIMETER MAP UNIT AREAS WITHIN THE SUBBASIN. ASSUME FOR THIS CASE:

MAP UNIT No. 22 —— A = 25%
29 —— A = 35%
104 —— A = 40%

STEP 2: LOOK UP XKSAT & RTIMP PARAMETERS IN APPENDIX A:

MAP UNIT No.	XKSAT (in/hr)	ROCK OUTCROP OR IMPERVIOUSNESS (%)
22	.04	0
29	.34	0
104	.14	60

STEP 3: CALCULATE A LOG-WEIGHTED XKSAT FOR THE SUBBASIN:

$$\overline{XKSAT} = ALOG[.25(\log .04) + .35(\log .34) + .40(\log .14)] = 0.14 \text{ in/hr}$$

STEP 4: DETERMINE VALUES OF PSIF AND DTHETA FROM FIGURE 4.3 USING THE XKSAT VALUE IN STEP 3:

PSIF = 6.2 in
DTHETA (DRY) = 0.39

STEP 5: USE FIGURE 4.4 To Adjust XKSAT BASED ON VEGETATION: FOR THIS EXAMPLE, ASSUME THAT MAP UNITS 22 & 29 AVERAGE 20% VEGETATION COVER, AND UNIT 104 AVERAGES 30%.

$$\overline{XKSAT} = [.60(1.11) + .40(1.22)].14 = 0.16 \text{ in/hr}$$

STEP 6: CALCULATE IA AND RTIMP: FOR THIS EXAMPLE, ASSUME MAP UNIT 104 IS ROUGH MOUNTAINS AND UNITS 22 & 29 ARE HILLSLOPE AREAS:

$$IA = (.40 \times .25) + (.60 \times .15) = 0.19 \text{ in}$$

RTIMP: ASSUME 75% CONNECTED IMPERVIOUSNESS FOR MAP UNIT 104:

$$.75(60) = 45\%$$

$$RTIMP = .40(45\%) = 18\%$$

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT HYDROLOGIC DESIGN MANUAL PAGE 1 OF ______

DETAIL EXAMPLE No. 3 COMPUTED ______ DATE ______

CLARK UNIT HYDROGRAPH (URBAN) CHECKED BY ______ DATE ______

SCENARIO: DEVELOP THE CLARK UNIT HYDROGRAPH INPUT PARAMETERS FOR SUBBASIN No. 2 OF THE EXAMPLE WATERSHED.

STEP 1: ASSEMBLE PHYSICAL BASIN CHARACTERISTICS:

AREA = 2.17 mi^2 = 1389 ac.

FLOW PATH (L) = 1.85 mi

SLOPE (S) = 30.5 ft/mi

IMPERVIOUSNESS = 21 %

STEP 2: CALCULATE THE BASIN RESISTANCE COEFFICIENT K_b USING Fig. 5.5, TABLES 5.1 & 5.2, AND THE "T_c & R WORKSHEET" (Appendix E).

SINCE THIS IS AN URBAN BASIN: m = −.00625 and b = .04

$$K_b = m(\log A) + b = -.00625(\log 1389) + .04 = .020$$

STEP 3: REDUCE T_c to a function of intensity (i):

NOTE: REFER TO THE WORKSHEET DURING THE REMAINING STEPS.

$$T_c = 11.4\, L^{.50} K_b^{.52} S^{-.31} i^{-.38}; \quad T_c = 11.4(1.85)^{.50}(.020)^{.52}(30.5)^{-.31} i^{-.38} = .703\, i^{-.38}$$

STEP 4: ENTER RAINFALL, LOSS, AND CLARK PARAMETER DATA INTO AN HEC-1 INPUT FILE, WITH T_c & R SET TO ZERO. RUN THE PROGRAM WITH THE IO CARD = 0 TO GENERATE A RAINFALL - LOSS - EXCESS TABLE.

STEP 5: USING THE WORKSHEET AND THE RESULTS OF STEP 4, TABULATE THE PERIOD OF PEAK RAINFALL EXCESS AND COMPUTE THE AVERAGE INTENSITIES TO A TIME GREATER THAN THE EXPECTED T_c.

STEP 6: CONSTRUCT THE GRAPH OF AVERAGE EXCESS INTENSITY VS. TIME.

STEP 7: CALCULATE T_c BY ITERATION. INTENSITY (i) VALUES ARE READ FROM THE GRAPH. CALCULATE R.

STEP 8: ENTER THE T_c & R VALUES INTO THE HEC-1 FILE; SAVE; AND RUN. A SAMPLE HEC-1 INPUT AND OUTPUT FILE IS PROVIDED.

ALTERNATE METHOD

Program MCUHP1 can be used to complete steps 3 − 8. See APPENDIX I FOR INSTRUCTIONS.

CALCULATION OF Tc & R

Calculated by: ______________________ Date: __________
Checked by: ______________________ Project: EXAMPLE No. 3

Watershed: EXAMPLE WATERSHED - SUBBASIN No. 2
Rainfall Frequency: 100 - yr Duration: 6 - hr. Pattern #: 1.85

Rainfall Loss Method:
[X] Green & Ampt Method
[ ] IL + ULR by soil texture
[ ] IL + ULR by hydrologic soil group

Tabulate Period of Peak Rainfall Excess

Clock Time @ end of Increm.	Increm. Excess in.
0335	.17
0340	.17
0345	.17
0350	.26
0355	.26
0400	.26
0405	.11
0410	.11

Rearrange Incremental Excesses in Order of Decreasing Average Intensity

Accum. Time hr./min.	Increm. Excess in.	Accum. Excess in.	Avg. Excess Intensity in./hr.
5	.26	.26	3.12
10	.26	.52	3.12
15	.26	.78	3.12
20	.17	.95	2.85
25	.17	1.12	2.69
30	.17	1.29	2.58
35	.11	1.40	2.40
40	.11	1.51	2.27

A = 2.17 sq.mi.
L = 1.85 mi.
S = 30.5 ft/mi.

$Kb = m [\log(A * 640)] + b$

$Kb = (-.00625) \log (2.17 * 640) + (.04)$

$Kb = .020$

$Tc = 11.4\ L^{.50}\ Kb^{.52}\ S^{-.31}\ i^{-.38}$

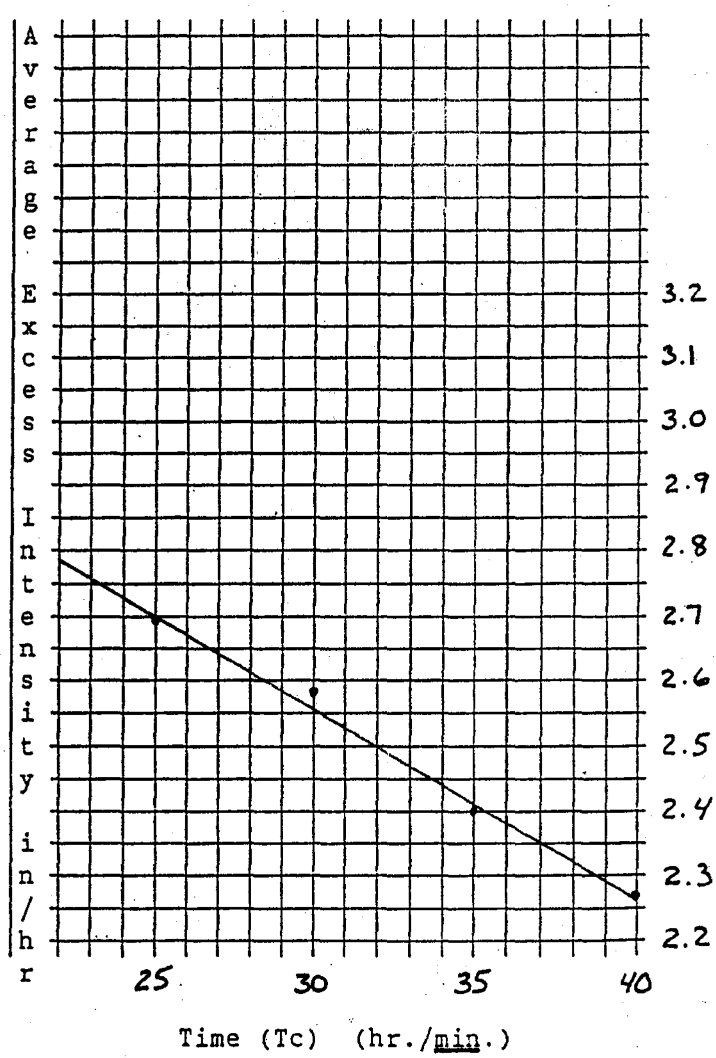
$Tc = (0.703)\ i^{-.38}$

Trial Tc	i	Calc. Tc
.417	2.70	.482
.483	2.58	.490
.500	2.56	.492

Tc = .492 hr.

$R = .37\ Tc^{1.11}\ A^{-.57}\ L^{.80}$

R = .177 hr.



```
LINE      ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1       ID   SAMPLE HEC-1 INPUT USING TECHNIQUES OUTLINED IN THE
  2       ID   HYDROLOGIC DESIGN MANUAL FOR MARICOPA COUNTY
          * ***************************************************************************
  3       ID   EXAMPLE NO. 3 - CLARK UNIT HYDROGRAPH (URBAN)
          * ***************************************************************************
  4       ID       RAINFALL: 6-HR, 100-YEAR POINT RAINFALL DEPTH OF 3.25 INCHES
  5       ID       HYDROGRAPH: CLARK - TC & R FROM WORKSHEET
  6       ID       URBAN TIME-AREA CURVE
  7       ID       LOSSES: GREEN AND AMPT METHOD
  8       ID       BASIN AREA: 2.17 SQUARE MILES, RAINFALL PATTERN NO. 1.85
          * ***************************************************************************
  9       IT       5                      85
 10       IO       0
          * ***************************************************************************

 11       KK  BASIN2
 12       KM   COMPUTE DISCHARGE AT THE OUTLET OF SUBBASIN NO. 2
 13       KM   6-HOUR RAINFALL, PATTERN NO. 1.85 WAS USED TO FIND TC & R FOR THIS BASIN
 14       KM   THIS BASIN USED RAINFALL REDUCTION FACTOR OF .979
 15       BA   2.170
 16       IN      15
 17       KM   RAINFALL DEPTH OF 3.25 WAS SPACIALLY REDUCED AS SHOWN BY THE PB RECORD
 18       PB   3.182
 19       KM   THE FOLLOWING PC RECORD USED A 6-HOUR STORM WITH A PATTERN No. OF 1.85
 20       PC    .000    .009    .016    .025    .034    .042    .051    .059    .067    .076
 21       PC    .087    .100    .120    .159    .247    .440    .715    .848    .905    .940
 22       PC    .952    .964    .976    .988   1.000
 23       LG    .150    .350   7.500    .100  21.000
 24       UC    .492    .177
 25       UA       0       5      16      30      65      77      84      90      94      97
 26       UA     100
 27       ZZ
```

HYDROGRAPH AT STATION BASIN2

DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q
1		0000	1	.00	.00	.00	0.
1		0005	2	.01	.01	.00	1.
1		0010	3	.01	.01	.00	4.
1		0015	4	.01	.01	.00	10.
1		0020	5	.01	.01	.00	17.
1		0025	6	.01	.01	.00	21.
1		0030	7	.01	.01	.00	24.
1		0035	8	.01	.01	.00	26.
1		0040	9	.01	.01	.00	27.
1		0045	10	.01	.01	.00	28.
1		0050	11	.01	.01	.00	30.
1		0055	12	.01	.01	.00	31.
1		0100	13	.01	.01	.00	32.
1		0105	14	.01	.01	.00	33.
1		0110	15	.01	.01	.00	33.
1		0115	16	.01	.01	.00	32.
1		0120	17	.01	.01	.00	32.
1		0125	18	.01	.01	.00	31.
1		0130	19	.01	.01	.00	32.
1		0135	20	.01	.01	.00	32.
1		0140	21	.01	.01	.00	32.
1		0145	22	.01	.01	.00	32.
1		0150	23	.01	.01	.00	31.
1		0155	24	.01	.01	.00	31.
1		0200	25	.01	.01	.00	30.
1		0205	26	.01	.01	.00	30.
1		0210	27	.01	.01	.00	30.
1		0215	28	.01	.01	.00	31.
1		0220	29	.01	.01	.00	32.
1		0225	30	.01	.01	.00	33.
1		0230	31	.01	.01	.00	35.
1		0235	32	.01	.01	.00	37.
1		0240	33	.01	.01	.00	39.
1		0245	34	.01	.01	.00	42.
1		0250	35	.02	.02	.00	44.
1		0255	36	.02	.02	.00	49.
1		0300	37	.02	.02	.00	54.
1		0305	38	.04	.03	.01	62.
1		0310	39	.04	.03	.01	74.
1		0315	40	.04	.03	.01	90.
1		0320	41	.09	.05	.04	120.
1		0325	42	.09	.05	.05	191.
1		0330	43	.09	.04	.05	316.
1		0335	44	.20	.04	.17	507.
1		0340	45	.20	.04	.17	822.
1		0345	46	.20	.03	.17	1281.
1		0350	47	.29	.03	.26	1783.
1		0355	48	.29	.03	.26	2294.
1		0400	49	.29	.03	.26	2843.
1		0405	50	.14	.03	.11	3273.
1		0410	51	.14	.03	.11	3387.
1		0415	52	.14	.03	.11	3184.
1		0420	53	.06	.03	.03	2826.
1		0425	54	.06	.03	.04	2412.
1		0430	55	.06	.02	.04	1938.
1		0435	56	.04	.02	.01	1500.
1		0440	57	.04	.02	.01	1155.
1		0445	58	.04	.02	.01	863.
1		0450	59	.01	.01	.00	636.
1		0455	60	.01	.01	.00	468.
1		0500	61	.01	.01	.00	331.
1		0505	62	.01	.01	.00	226.
1		0510	63	.01	.01	.00	155.
1		0515	64	.01	.01	.00	111.
1		0520	65	.01	.01	.00	83.
1		0525	66	.01	.01	.00	65.
1		0530	67	.01	.01	.00	56.
1		0535	68	.01	.01	.00	51.
1		0540	69	.01	.01	.00	48.
1		0545	70	.01	.01	.00	46.
1		0550	71	.01	.01	.00	45.
1		0555	72	.01	.01	.00	45.
1		0600	73	.01	.01	.00	45.
1		0605	74	.00	.00	.00	44.
1		0610	75	.00	.00	.00	39.
1		0615	76	.00	.00	.00	31.
1		0620	77	.00	.00	.00	22.
1		0625	78	.00	.00	.00	15.
1		0630	79	.00	.00	.00	10.
1		0635	80	.00	.00	.00	6.
1		0640	81	.00	.00	.00	4.
1		0645	82	.00	.00	.00	2.
1		0650	83	.00	.00	.00	1.
1		0655	84	.00	.00	.00	1.
1		0700	85	.00	.00	.00	0.

TOTAL RAINFALL = 3.18, TOTAL LOSS = 1.11, TOTAL EXCESS = 2.07

PEAK FLOW	TIME		MAXIMUM AVERAGE FLOW			
			6-HR	24-HR	72-HR	7.00-HR
+ (CFS)	(HR)					
		(CFS)				
+ 3387.	4.17		479.	412.	412.	412.
		(INCHES)	2.054	2.059	2.059	2.059
		(AC-FT)	238.	238.	238.	238.

CUMULATIVE AREA = 2.17 SQ MI

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

	OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD			BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
+					6-HOUR	24-HOUR	72-HOUR			
	HYDROGRAPH AT									
+		BASIN2	3387.	4.17	479.	412.	412.	2.17		

*** NORMAL END OF HEC-1 ***

SCENARIO: DEVELOP THE CLARK UNIT HYDROGRAPH INPUT PARAMETERS FOR SUBBASIN No. 4 OF THE EXAMPLE WATERSHED.

STEP 1: ASSEMBLE PHYSICAL BASIN CHARACTERISTICS:

AREA = 0.86 mi^2 = 550.4 acres

FLOW PATH LENGTH (L) = 1.49 mi

SLOPE (S) = 310 ft/mi (ADJUSTED USING FIG. 5.4)

IMPERVIOUSNESS = 18%

STEP 2: CALCULATE THE BASIN RESISTANCE COEFFICIENT K_b USING FIG. 5.5, TABLES 5.1 & 5.2, AND THE "Tc & R WORKSHEET" (APPENDIX E). ASSUME THAT THIS SUBBASIN IS 50% "HILLSLOPE" AND 50% "MOUNTAIN".

$$-.025(\log 550.4) + 0.15 = .081$$
$$-.030(\log 550.4) + 0.20 = .118$$
$$.50(.081) + .50(.118) = 0.100 = \overline{K_b}$$

STEP 3: REDUCE Tc TO A FUNCTION OF EXCESS INTENSITY (i):

NOTE: REFER TO THE WORKSHEET DURING THE REMAINING STEPS

$$T_c = 11.4\,L^{.5} K_b^{.52} S^{-.31} i^{-.38}\ ;\quad T_c = 11.4(1.49)^{.5}(.100)^{.52}(310)^{-.31} i^{-.38} = 0.710\, i^{-.38}$$

STEP 4: ENTER RAINFALL, LOSS, AND CLARK PARAMETER DATA INTO AN HEC-1 INPUT FILE, WITH Tc & R SET TO ZERO. RUN THE MODEL WITH THE IO CARD = 0 TO GENERATE A RAINFALL - LOSS - EXCESS TABLE.

STEP 5: USING THE WORKSHEET AND THE RESULTS OF STEP 4, TABULATE THE PERIOD OF PEAK RAINFALL EXCESS AND COMPUTE THE AVERAGE EXCESS INTENSITIES TO A TIME GREATER THAN THE EXPECTED Tc.

STEP 6: CONSTRUCT THE GRAPH OF AVERAGE EXCESS INTENSITY VS. TIME

STEP 7: CALCULATE Tc BY ITERATION. INTENSITY (i) VALUES ARE READ FROM THE GRAPH. CALCULATE R.

STEP 8: ENTER THE Tc & R VALUES INTO THE HEC-1 FILE; SAVE; AND RUN. SAMPLE HEC-1 INPUT AND OUTPUT FILES ARE PROVIDED.

ALTERNATE METHOD:

PROGRAM MCUHP1 CAN BE USED TO COMPLETE STEPS 3-8. SEE APPENDIX I FOR INSTRUCTIONS.

CALCULATION OF Tc & R

Calculated by: ______________________ Date: __________
Checked by: ______________________ Project: __________

Watershed: EXAMPLE No. 4, SAMPLE WATERSHED No. 4
Rainfall Frequency: 100 - yr Duration: 2 - hr. Pattern #: N.A.

Rainfall Loss Method:
- [X] Green & Ampt Method
- [ ] IL + ULR by soil texture
- [ ] IL + ULR by hydrologic soil group

Tabulate Period of Peak Rainfall Excess

Clock Time @ end of Increm.	Increm. Excess in.
0055	.06
0100	.19
0105	.68
0110	.33
0115	.27
0120	.05
0125	.03
0130	.02

Rearrange Incremental Excesses in Order of Decreasing Average Intensity

Accum. Time hr./min.	Increm. Excess in.	Accum. Excess in.	Avg. Excess Intensity in./hr.
5	.68	.68	8.16
10	.33	1.01	6.06
15	.27	1.28	5.12
20	.19	1.47	4.41
25	.06	1.53	3.67
30	.05	1.58	3.16
35	.03	1.61	2.76
40	.02	1.63	2.45

A = 0.86 sq.mi.
L = 1.49 mi.
S = 310. ft/mi.

Kb = m [log(A * 640)]+ b
Kb = (   ) log (*640) + (   )
Kb = .100

$$Tc = 11.4\ L^{.50}\ Kb^{.52}\ S^{-.31}\ i^{-.38}$$

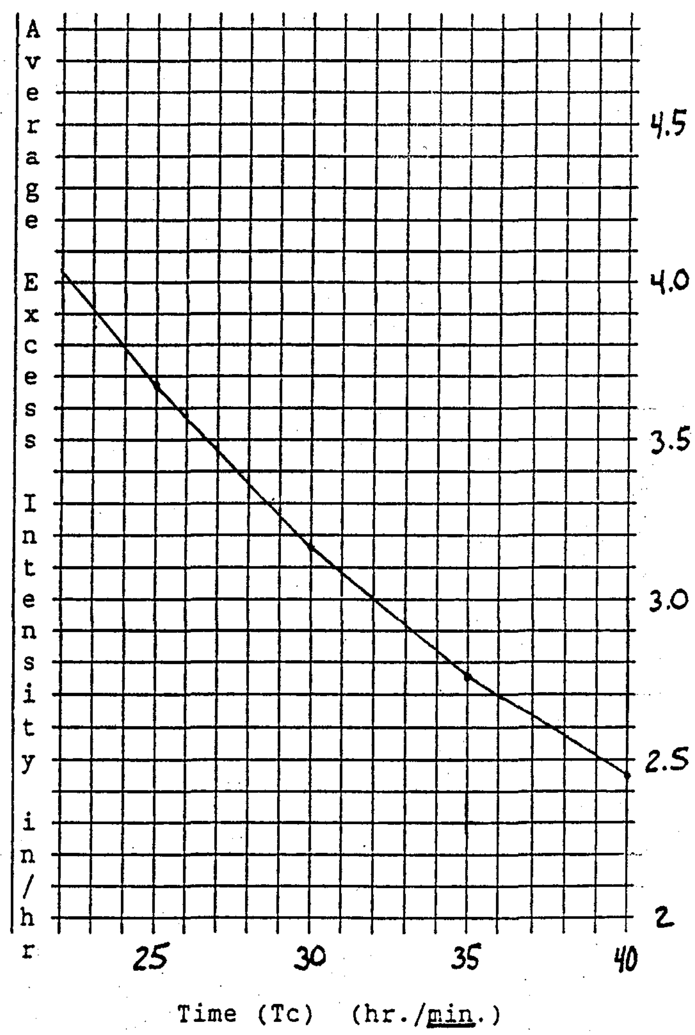
$$Tc = (.710)\ i^{-.38}$$

Trial Tc	i	Calc. Tc
.500	3.16	.459
.450	3.47	.443
.433	3.57	.438

Tc = .438 hr.

$$R = .37\ Tc^{1.11}\ A^{-.57}\ L^{.80}$$

R = .222 hr.



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LINE        ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1         ID        SAMPLE HEC-1 RUN USING TECHNIQUES PRESENTED IN THE
  2         ID        HYDROLOGIC DESIGN MANUAL FOR MARICOPA COUNTY
            * ****************************************************************************
  3         ID        EXAMPLE NO. 4 - CLARK UNIT HYDROGRAPH, UNDEVELOPED BASIN
            * ****************************************************************************
  4         ID        RAINFALL: 2-HR, 100-YR POINT RAINFALL DEPTH OF 2.70 INCHES
  5         ID        HYDROGRAPH: CLARK - Tc & R FROM WORKSHEET, NATURAL TIME-AREA CURVE
  6         ID        LOSSES: GREEN & AMPT
  7         ID        SUBBASIN AREA: 0.86 SQUARE MILES
            * ****************************************************************************
  8         IT        5 03JAN92    0000      40
  9         IO        0
            * ****************************************************************************

 10         KK  BASIN4
 11         KM   COMPUTE DISCHARGE AT OUTLET OF SUBBASIN NO. 4
 12         KM   2-HOUR RAINFALL DISTRIBUTION WAS USED TO FIND TC & R FOR THIS BASIN
 13         KM   THIS BASIN USED RAINFALL REDUCTION FACTOR OF1.000
 14         BA     .860
 15         IN        5
 16         KM   RAINFALL DEPTH OF 2.70 WAS SPACIALLY REDUCED AS SHOWN BY THE PB RECORD
 17         PB   2.700
 18         KM   THE FOLLOWING PC RECORD USED A 2-HOUR RAINFALL DISTRIBUTION
 19         PC     .000    .011    .018    .023    .028    .032    .046    .071    .100    .137
 20         PC     .176    .232    .327    .601    .743    .863    .901    .930    .954    .962
 21         PC     .970    .979    .982    .992   1.000
 22         LG     .190    .390   6,200    .160  18.000
 23         UC     .438    .222
 24         UA        0       3       5       8      12      20      43      75      90      96
 25         UA      100
 26         ZZ
```

HYDROGRAPH AT STATION BASIN4

DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q
3	JAN	0000	1	.00	.00	.00	0.	3	JAN	0140	21	.02	.02	.00	1131.
3	JAN	0005	2	.03	.02	.01	0.	3	JAN	0145	22	.02	.02	.00	829.
3	JAN	0010	3	.02	.02	.00	1.	3	JAN	0150	23	.01	.01	.00	592.
3	JAN	0015	4	.01	.01	.00	3.	3	JAN	0155	24	.03	.02	.00	417.
3	JAN	0020	5	.01	.01	.00	8.	3	JAN	0200	25	.02	.02	.00	293.
3	JAN	0025	6	.01	.01	.00	13.	3	JAN	0205	26	.00	.00	.00	207.
3	JAN	0030	7	.04	.03	.01	15.	3	JAN	0210	27	.00	.00	.00	148.
3	JAN	0035	8	.07	.06	.01	16.	3	JAN	0215	28	.00	.00	.00	108.
3	JAN	0040	9	.08	.06	.01	19.	3	JAN	0220	29	.00	.00	.00	77.
3	JAN	0045	10	.10	.08	.02	27.	3	JAN	0225	30	.00	.00	.00	53.
3	JAN	0050	11	.11	.09	.02	40.	3	JAN	0230	31	.00	.00	.00	35.
3	JAN	0055	12	.15	.09	.06	59.	3	JAN	0235	32	.00	.00	.00	18.
3	JAN	0100	13	.26	.07	.19	88.	3	JAN	0240	33	.00	.00	.00	10.
3	JAN	0105	14	.74	.06	.68	166.	3	JAN	0245	34	.00	.00	.00	4.
3	JAN	0110	15	.38	.06	.33	335.	3	JAN	0250	35	.00	.00	.00	3.
3	JAN	0115	16	.32	.05	.27	692.	3	JAN	0255	36	.00	.00	.00	2.
3	JAN	0120	17	.10	.05	.05	1268.	3	JAN	0300	37	.00	.00	.00	1.
3	JAN	0125	18	.08	.05	.03	1690.	3	JAN	0305	38	.00	.00	.00	1.
3	JAN	0130	19	.06	.04	.02	1718.	3	JAN	0310	39	.00	.00	.00	0.
3	JAN	0135	20	.02	.02	.00	1477.	3	JAN	0315	40	.00	.00	.00	0.

TOTAL RAINFALL = 2.70, TOTAL LOSS = .96, TOTAL EXCESS = 1.74

	EAK FLOW	TIME		MAXIMUM AVERAGE FLOW			
				6-HR	24-HR	72-HR	3.25-HR
+	(CFS)	(HR)					
			(CFS)				
+	1718.	1.50		297.	297.	297.	297.
			(INCHES)	1.736	1.736	1.736	1.736
			(AC-FT)	80.	80.	80.	80.

CUMULATIVE AREA = .86 SQ MI

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

	OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD			BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
+					6-HOUR	24-HOUR	72-HOUR			
	HYDROGRAPH AT									
+		BASIN4	1718.	1.50	297.	297.	297.	.86		

*** NORMAL END OF HEC-1 ***

APPLICATION OF S-GRAPHS

SCENARIO: DEVELOP THE APPROPRIATE UNIT-GRAPH AND DISCHARGE FOR THE FOLLOWING BASIN.

STEP 1: LIST PHYSICAL CHARACTERISTICS:

AREA (A) = 5.19 mi^2

LENGTH OF WATER COURSE (L) = 5.2 mi
(FROM THE OUTLET TO THE DRAINAGE BOUNDRY)

LENGTH OF WATER COURSE TO A POINT OPPOSITE TO CENTROID (L_{ca}) = 3.0 mi

$$SLOPE\ (S) = \frac{\Delta H}{L} = \frac{2900-1500}{5.2} = 269\ ft/mi$$

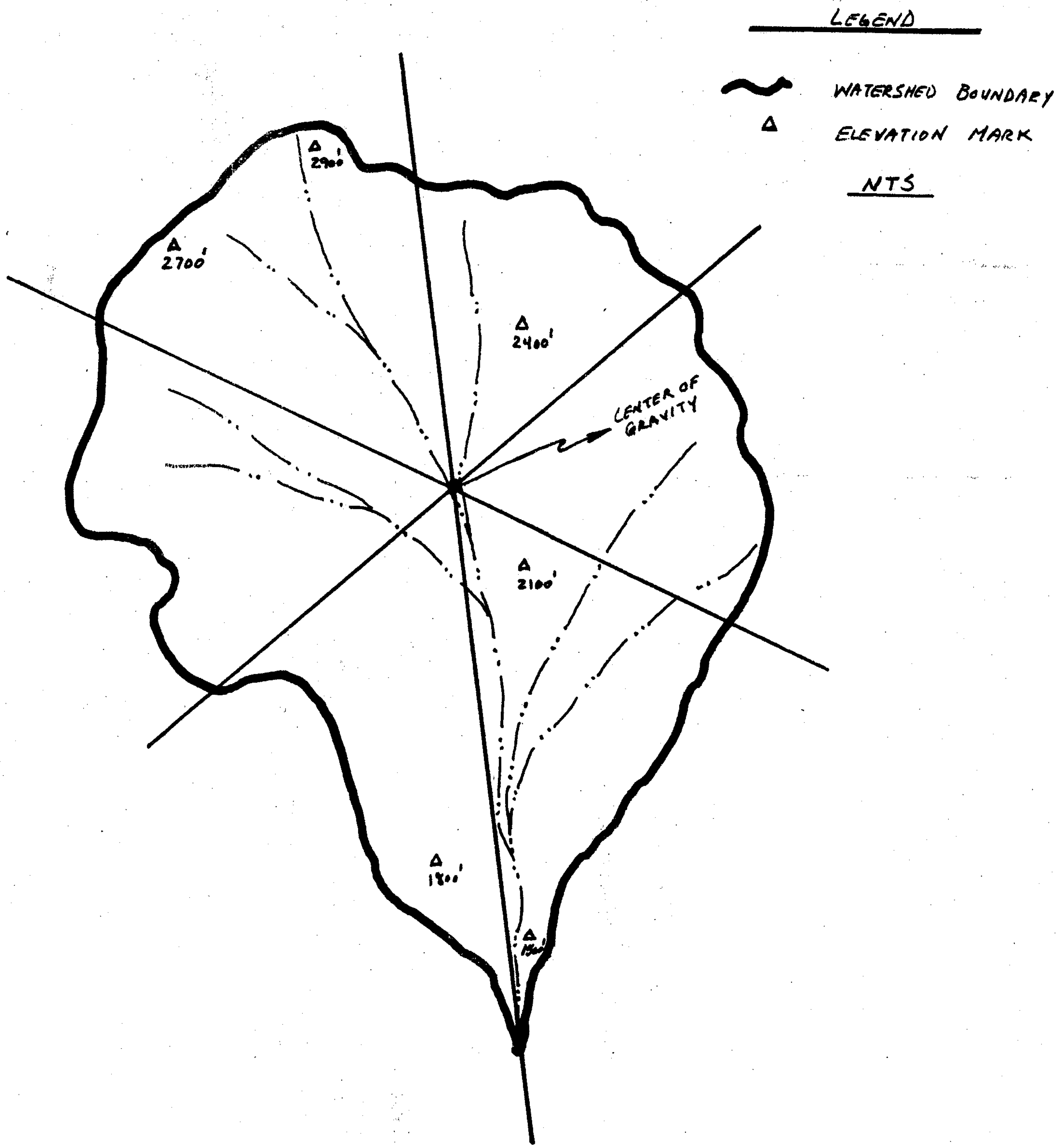
$$CALCULATE: \frac{LL_{ca}}{S^{1/2}} = \frac{(5.2)(3.0)}{269^{1/2}} = .95$$

STEP 2: COMPARE WITH HYDROLOGICALLY SIMILAR WATER SHEDS. IN PARTICULAR, COMPARE WITH THE $LL_{ca}/S^{1/2}$ OF FIGURE 5.11 IN THE HYDROLOGIC DESIGN MANUAL. THIS STEP IS INTENDED TO HELP WITH K_n SELECTION.

No.	NAME	A	L	Lca	S	$LL_{ca}/S^{1/2}$
5	EATON WASH	9.5	7.3	4.4	600	1.3

SINCE $LL_{ca}/S^{1/2}$ ARE RELATIVELY CLOSE, THESE TWO BASINS ARE CONSIDERED "HYDROLOGICALLY SIMILAR". EATON WASH HAS A K_n VALUE OF .05.

USE FIELD OBSERVATIONS ON THE HYDRAULIC FEATURES OF THE MAIN WATER COURSE, AND REALIZING THE SIGNIFICANCE OF K_n = .05 ESTABLISH IF .05 IS APPROPRIATE FOR YOUR BASIN.


LEGEND
WATERSHED BOUNDARY
ELEVATION MARK
NTS
2900'
2700'
2400'
CENTER OF GRAVITY
2100'
1800'
1500'

ASSUMING THAT THE MAIN WATER COURSE IS A WELL-DEFINED CHANNEL WITH ONLY MINIMAL VEGETATION, A $K_{\bar{n}}$ VALUE OF 0.04 IS SELECTED IN THIS CASE.

STEP 3: CALCULATE THE LAG. THE FOLLOWING LAG RELATION BY THE CORPS OF ENGINEERS IS USED:

$$LAG = 24(K_{\bar{n}})(L\,L_{ca}/S^{1/2})^{.38} = 24(.04)(.95)^{.38} = 0.94 \text{ HOURS}$$

STEP 4: SELECT THE APPROPRIATE TIME STEP:

THE COMPUTATIONAL TIME STEP SHOULD BE WITHIN THE RANGE OF $(.10 \rightarrow .25) \times (\text{LAG TIME})$ AS SUGGESTED IN THE MANUAL. NOTE THAT THIS COMPUTATIONAL TIME STEP IS THE SAME AS THE ONE USED ON THE "IT" CARD IN HEC-1. THIS VALUE IS SELECTED TO BE 10 MINUTES.

STEP 5: AT THIS POINT ALL OF THE NECESSARY PARAMETERS ARE FOUND. THEN, A UNIT-GRAPH CAN BE DEVELOPED BY USING THE "MCUHP2" PROGRAM. ALTERNATIVELY, A UNIT-GRAPH CAN BE DEVELOPED MANUALLY, WHICH IS EXPLAINED NEXT.

MANUAL CONSTRUCTION OF A 10-MINUTE UNIT HYDROGRAPH FROM THE PHOENIX MOUNTAIN DIMENSIONLESS S-GRAPH

CONSIDER THE PREVIOUSLY DESCRIBED BASIN WITH THE FOLLOWING PARAMETERS:

$$A = 5.19 \text{ mi}^2$$

$$LAG = 0.94 \text{ HOURS}$$

$$Q_{ULT} = \frac{645.33\,A}{D} = \frac{645.33(5.19)}{(10/60)} = 20{,}096 \text{ CFS}$$

WHERE: Q_{ULT} = ULTIMATE DISCHARGE (CFS);

A = DRAINAGE AREA (mi^2);

D = DURATION OF RAINFALL EXCESS, SAME AS THE TIME STEP PREVIOUSLY CALCULATED (HOURS).

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT HYDROLOGIC DESIGN MANUAL

DETAIL S-GRAPH APPLICATIONS COMPUTED ______ DATE ______

EXAMPLE # 5 CHECKED BY ______ DATE ______

(1) CONSTRUCT A TABLE LIKE THE FOLLOWING BY READING OFF THE VALUES ON % QULT AND % LAG FROM THE DIMENSIONLESS S-GRAPH TABLES (PHOENIX MOUNTAIN OR PHOENIX VALLEY) IN THE HYDROLOGIC DESIGN MANUAL.

ORDINATE	% Qult	DISCHARGE (cfs)	% LAG	TIME (hours)
0	0	0	0.0	0.000
1	2	402	23.0	0.216
2	4	804	31.0	0.291
3	6	1206	37.0	0.345
4	8	1608	42.0	0.395
5	10	2010	46.0	0.432
6	12	2411	49.8	0.468
7	14	2813	53.4	0.502
8	16	3215	56.8	0.534
9	18	3617	60.0	0.564
10	20	4019	63.1	0.593
11	22	4421	66.1	0.621
12	24	4823	69.0	0.649
13	26	5225	71.8	0.675
14	28	5627	74.4	0.699
15	30	6029	76.8	0.722
16	32	6431	79.1	0.744
17	34	6832	81.2	0.763
18	36	7234	83.2	0.782
19	38	7636	85.1	0.800
20	40	8038	86.8	0.816
21	42	8440	88.8	0.835
22	44	8842	91.0	0.855
23	46	9244	93.8	0.882
24	48	9646	96.8	0.910
25	50	10048	100.0	0.940
26	52	10450	103.4	0.972
27	54	10852	107.0	1.006
28	56	11254	110.8	1.052
29	58	11655	114.7	1.078
30	60	12057	118.7	1.116
31	62	12459	122.9	1.155
32	64	12861	127.3	1.197
33	66	13263	131.9	1.240
34	68	13655	136.7	1.285
35	70	14067	141.7	1.332
36	72	14469	147.1	1.383
37	74	14871	152.8	1.436
38	76	15273	158.8	1.493
39	78	15675	165.5	1.559
40	80	16076	172.9	1.625
41	82	16478	181.6	1.707
42	84	16880	191.0	1.795
43	86	17282	201.0	1.889
44	88	17684	212.0	1.993
45	90	18086	226.0	2.124
46	92	18488	244.0	2.294
47	94	18890	265.0	2.491
48	96	19292	295.0	2.773
49	98	19694	342.0	3.215
50	100	20096	462.0	4.343

(2) TRANSFORM THE S-GRAPH INTO A <u>10-MINUTE</u> UNIT-GRAPH. USE LINEAR INTERPOLATION IN 10-MINUTE INCREMENTS FOR TIME AND DISCHARGE VALUES.

ORDINATE	TIME (HOURS)	Q_{S1} (CFS)	Q_{S2} (CFS) (*)	Q_{UG} (CFS) ▼
1	0.000	0	0	0
2	0.167	311	0	311
3	0.333	1117	311	806
4	0.500	2789	1117	1672
5	0.677	5101	2789	2312
6	0.833	8398	5105	3297
7	1.000	10781	8398	2383
8	1.167	12574	10781	1793
9	1.333	14075	12574	1500
10	1.500	15316	14075	1241
11	1.667	16282	15316	966
12	1.833	17043	16282	761
13	2.000	17705	17043	662
14	2.167	18188	17705	483
15	2.333	18568	18188	380
16	2.500	18900	18568	332
17	2.667	19160	18900	260
18	2.833	19370	19160	210
19	3.000	19520	19370	150
20	3.167	19665	19520	145
21	3.333	19745	19665	80
22	3.500	19805	19745	60
23	3.667	19865	19805	60
24	3.833	19925	19865	60
25	4.000	19985	19925	60
26	4.167	20045	19985	60
27	4.333	20096	20045	51
28	4.500	20096	20096	0

(*) 10-MINUTE LAG

▼ $Q_{UG} = Q_{S1} - Q_{S2}$

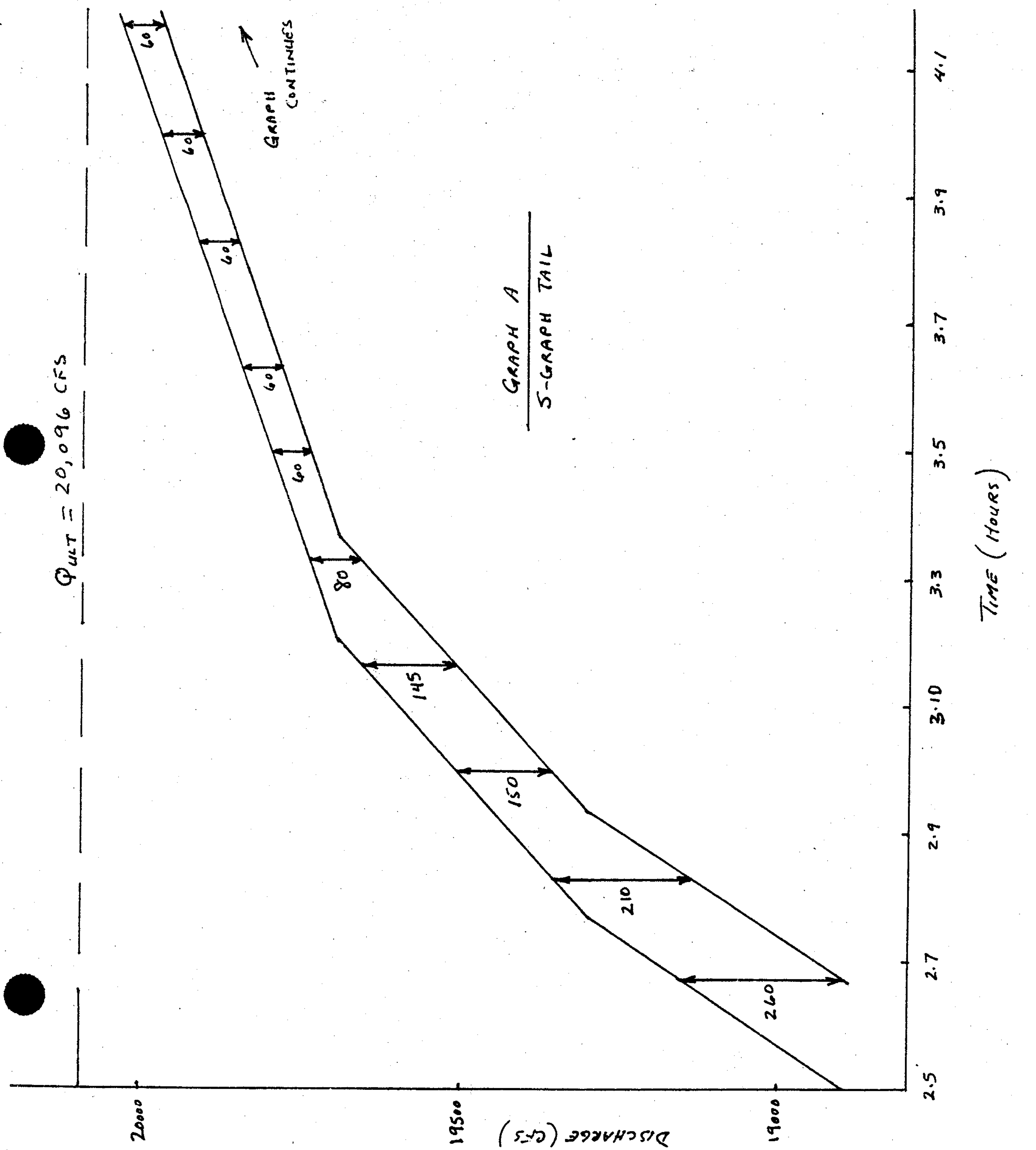
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT: HYDROLOGIC DESIGN MANUAL — PAGE 6 OF 7

DETAIL: S-GRAPH APPLICATIONS — COMPUTED ______ DATE ______

EXAMPLE # 5 — CHECKED BY ______ DATE ______



FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT HYDROLOGIC DESIGN MANUAL PAGE 7 OF 7

DETAIL S-GRAPH APPLICATIONS COMPUTED ______ DATE ______

EXAMPLE # 5 CHECKED BY ______ DATE ______

NOTICE THE BEHAVIOR OF THE UNIT-GRAPH VALUES AFTER TIME = 2.5 HOURS ON. THIS IS DUE TO THE LONGER TIME INCREMENT AT THE END OF THE S-GRAPH. TO CORRECT THIS, CONSTRUCT A GRAPH OF THE "TAIL" REGION OF THE S-GRAPH, LAG IT BY THE APPROPRIATE TIME DURATION, AND SUBTRACT THE ORDINATES (SEE GRAPH OF NEXT PAGE).

FINAL 10-MINUTE UNIT GRAPH

TIME (HOURS)	DISCHARGE (CFS)
0.000	0
0.167	311
0.333	806
0.500	1672
0.667	2312
0.833	3297
1.167	2383
1.333	1793
1.500	1500
1.667	1241
1.833	966
2.000	761
2.167	662
2.333	483
2.500	380
2.667	332
2.833	260
3.000	210
3.167	150
3.333	145
3.500	80
3.667	60
3.833	60
4.000	60
4.167	60
4.333	60
4.500	57
	0

THE ABOVE UNIT-GRAPH SHALL BE USED AS THE "UI" CARD IN HEC-1.

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*****************************************
*                                       *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *
*            SEPTEMBER 1990             *
*              VERSION 4.0              *
*                                       *
*  RUN DATE  06/19/1991  TIME  14:45:00 *
*                                       *
*****************************************
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*****************************************
*                                       *
*     U.S. ARMY CORPS OF ENGINEERS      *
*     HYDROLOGIC ENGINEERING CENTER     *
*           609 SECOND STREET           *
*        DAVIS, CALIFORNIA 95616        *
*          (916) 756-1104 *             *
*                                       *
*****************************************
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X     X  XXXXXXX   XXXXX          X
X     X  X        X     X        XX
X     X  X        X               X
XXXXXXX  XXXX     X        XXXXX  X
X     X  X        X               X
X     X  X        X     X         X
X     X  XXXXXXX   XXXXX         XXX
```

THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

```
ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

ID     SAMPLE HEC-1 RUN USING TECHNIQUES OUTLINED IN THE
ID     HYDROLOGIC DESIGN MANUAL FOR MARICOPA COUNTY
* ***********************************************************************
ID     EXAMPLE #5 S-GRAPH APPLICATIONS
* ***********************************************************************
IT      10                   300
IO       5

KK
KM    BASIN BAS-A
KM     THE FOLLOWING PARAMETERS WERE PROVIDED FOR THIS BASIN
KM     L=  27456.0  Lca=  15840.0   S=  269.0  Kn= .040  LAG=   56.5
KM     PHOENIX MOUNTAIN S-GRAPH WAS USED FOR THIS BASIN
BA     5.19
IN      15
KM    RAINFALL DEPTH OF 3.40 WAS SPACIALLY REDUCED AS SHOWN BY THE PB RECORD
KM    AN AREAL REDUCTION COEFFICIENT OF .959 WAS USED
PB     3.26
KM    THE FOLLOWING PC RECORD USED A 6-HOUR RAINFALL WITH PATTERN NO. 2.35
PC     .000    .011    .017    .027    .039    .049    .060    .070    .080    .091
PC     .104    .118    .139    .184    .270    .458    .685    .822    .889    .929
PC     .949    .962    .974    .988   1.000
LG      .25     .35    3.50     .25   10.00
UI     309.    790.   1682.   2302.   3300.   2382.   1788.   1508.   1244.    963.
UI     763.    666.    482.    383.    336.    237.    208.    151.    151.     89.
UI      59.     59.     59.     59.     59.     59.      0.      0.      0.      0.
UI       0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
ZZ
```

****

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD			BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
				6-HOUR	24-HOUR	72-HOUR			
HYDROGRAPH AT									
		3618.	4.67	908.	229.	111.	5.19		

*** NORMAL END OF HEC-1 ***

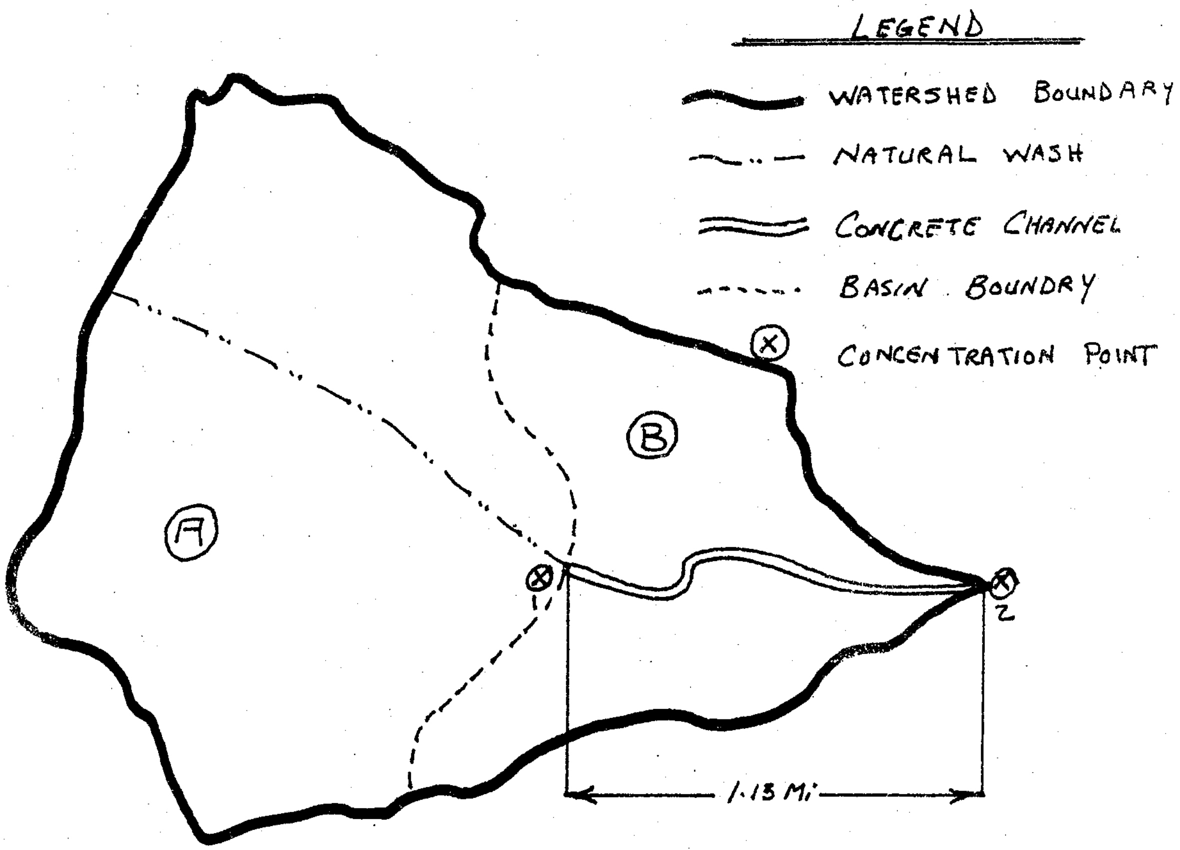
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT HYDROLOGIC DESIGN MANUAL PAGE 1 OF 2

DETAIL EXAMPLE # 6 COMPUTED ______ DATE ______

KINEMATIC WAVE ROUTING CHECKED BY ______ DATE ______

KINEMATIC WAVE ROUTING



SCENARIO: THE GENERATED PEAK DISCHARGE FROM BASIN (A) IS TO BE ROUTED THROUGH THE 1.13 MI CHANNEL, FROM CONCENTRATION POINT ⊗1 TO ⊗2.

PROCEDURE: COLLECT THE NECESSARY DATA AND PLOT SCHEMATIC OF THE CHANNEL CROSS SECTION.

CHANNEL TYPE = CONCRETE, TRAPOZOIDAL

CHANNEL LENGTH = 1.13 Mi = 5966.4 FEET

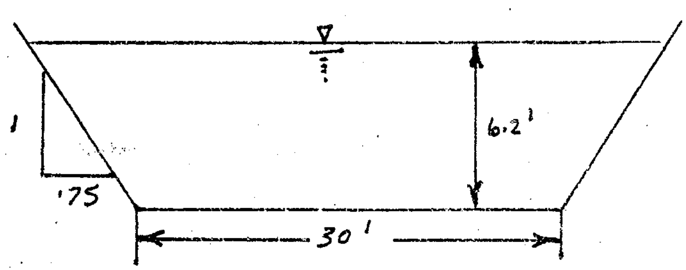
AVERAGE DEPTH = 6.2 FEET

SIDE SLOPE = 0.75 : 1.00

MANNING'S = .015

BOTTOM WIDTH = 30 FEET

CHANNEL SLOPE = .0008 ft/ft



(OVER)

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT HYDROLOGIC DESIGN MANUAL PAGE 2 OF 2

DETAIL EXAMPLE # 6 COMPUTED ______ DATE ______

KINEMATIC WAVE ROUTING CHECKED BY ______ DATE ______

(*) PRIOR TO RUNNIG THE HEC-1 MODEL, CHANNEL CAPACITY MUST BE CHECKED TO ASSURE THAT THE DEPTH AND THE SIDE SLOPE ARE PROPERLY SELECTED FOR FLOW CONVEYANCE. OTHERWISE, THE KINEMATIC WAVE PROCEDURE WILL AUTOMATICALLY EXTEND THE CHANNEL BOUNDRIES TO CONTAIN THE FLOW.

(*) THE MORE RECENT VERSIONS OF HEC-1 (1988 AND BEYOND) ACCOUNT FOR THE PROPER SELECTION OF THE COMPUTATIONAL TIME STEP. THIS IS DONE BY COMPARING THE SELECTED TIME STEP BY THE USER WITH THE COMPUTED TIME STEP. THE USER MAY NEED TO CHANGE THE SELECTED TIME STEP TO AVOID UNREALISTIC ATTENUATION OF THE ROUTED PEAK DISCHARGE. THE ENCLOSED HEC-1 PRINTOUT INCLUDES THE EVALUATION OF THE TIME STEP.

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****************************************
*                                      *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *
*            SEPTEMBER 1990            *
*             VERSION 4.0              *
*                                      *
* RUN DATE  06/19/1991  TIME  12:42:11 *
*                                      *
****************************************
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****************************************
*                                      *
*   U.S. ARMY CORPS OF ENGINEERS       *
*   HYDROLOGIC ENGINEERING CENTER      *
*        609 SECOND STREET             *
*     DAVIS, CALIFORNIA 95616          *
*        (916) 756-1104                *
*                                      *
****************************************
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X     X  XXXXXXX   XXXXX          X
X     X  X        X     X        XX
X     X  X        X               X
XXXXXXX  XXXX     X       XXXXX   X
X     X  X        X               X
X     X  X        X     X         X
X     X  XXXXXXX   XXXXX         XXX
```

THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
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DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

```
LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1           ID     SAMPLE HEC-1 RUN USING TECHNIQUES OUTLINED IN THE
  2           ID     HYDROLOGIC DESIGN MANUAL
              * ******************************************************************************
  3           ID     EXAMPLE # 6 - KINEMATIC WAVE ROUTING
              * ******************************************************************************
  4           IT       5                     100
  5           IO       5
              * ******************************************************************************

  6           KK     BAS-A
  7           KM     COMPUTE PEAK DISCHARGE AT THE OUTLET OF BASIN-A
  8           KM     6-HOUR RAINFALL, PATTERN NO. 1.89 WAS USED TO FIND TC & R FOR THIS BASIN
  9           KM     ABOVE PATTERN NO. BASED ON A TOTAL WATERSHED AREA OF 2.3 SQ. MILES.
 10           KM     THIS BASIN USED RAINFALL REDUCTION FACTOR OF .98
 11           BA     1.800
 12           IN        15
 13           KM     RAINFALL DEPTH OF 3.40 WAS SPACIALLY REDUCED AS SHOWN BY THE PB RECORD
 14           PB     3.326
 15           KM     THE FOLLOWING PC RECORD USED A 6-HOUR STROM WITH A PATTERN No. OF 1.89
 16           PC      .000    .009    .016    .025    .034    .042    .051    .059    .067    .076
 17           PC      .087    .100    .120    .160    .248    .443    .710    .845    .904    .939
 18           PC      .951    .964    .976    .988   1.000
 19           LG      .170    .280   7.000    .300  12.000
 20           UC      .817    .440
 21           UA         0       3       5       8      12      20      43      75      90      96
 22           UA       100
              * ******************************************************************************
 23           KK     ROUTE
 24           KM     ROUTE THROUGH BASIN-B USING KINEMATIC WAVE ROUTING
 25           KO         1       2
 26           RK    5966.4   .0008    .015            TRAP      30     .75
 27           ZZ
```

*** ***

COMPUTED KINEMATIC PARAMETERS
VARIABLE TIME STEP
(DT SHOWN IS A MINIMUM)

ELEMENT	ALPHA	M	DT (MIN)	DX (FT)	PEAK (CFS)	TIME TO PEAK (MIN)	VOLUME (IN)	MAXIMUM CELERITY (FPS)
MAIN	.36	1.58	2.76	1988.80	1673.94	281.12	1.56	12.66

CONTINUITY SUMMARY (AC-FT) - INFLOW= .1499E+03 EXCESS= .0000E+00 OUTFLOW= .1499E+03 BASIN STORAGE= .2637E+00 PERCENT ERROR= -.2

INTERPOLATED TO SPECIFIED COMPUTATION INTERVAL

MAIN	.36	1.58	5.00		1670.00	280.00	1.56

****

```
                                                  STATION   ROUTE

                        (I) INFLOW,   (O) OUTFLOW
             0.       200.      400.      600.      800.     1000.     1200.     1400.     1600.     1800.        0.        0.  0.
DAHRMN PER
 10000  1I---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.
 10225  30.I        .         .         .         .         .         .         .         .         .         .         .
 10230  31.I        .         .         .         .         .         .         .         .         .         .         .
 10235  32.I        .         .         .         .         .         .         .         .         .         .         .
 10240  33.I        .         .         .         .         .         .         .         .         .         .         .
 10245  34.I        .         .         .         .         .         .         .         .         .         .         .
 10250  35.I        .         .         .         .         .         .         .         .         .         .         .
 10255  36.I        .         .         .         .         .         .         .         .         .         .         .
 10300  37.I        .         .         .         .         .         .         .         .         .         .         .
 10305  38.I        .         .         .         .         .         .         .         .         .         .         .
 10310  39.I        .         .         .         .         .         .         .         .         .         .         .
 10315  40.I        .         .         .         .         .         .         .         .         .         .         .
 10320  41.I        .         .         .         .         .         .         .         .         .         .         .
 10325  42.I        .         .         .         .         .         .         .         .         .         .         .
 10330  43.OI       .         .         .         .         .         .         .         .         .         .         .
 10335  44.OI       .         .         .         .         .         .         .         .         .         .         .
 10340  45.O I      .         .         .         .         .         .         .         .         .         .         .
 10345  46.O   I    .         .         .         .         .         .         .         .         .         .         .
 10350  47. O    I  .         .         .         .         .         .         .         .         .         .         .
 10355  48.  O      I         .         .         .         .         .         .         .         .         .         .
 10400  49.   O     .    I    .         .         .         .         .         .         .         .         .         .
 10405  50.       O .         .   I     .         .         .         .         .         .         .         .         .
 10410  51.         .     O   .         .     I   .         .         .         .         .         .         .         .
 10415  52.         .         .       O .         .       I .         .         .         .         .         .         .
 10420  53.         .         .         .         .  O      .         .  I      .         .         .         .         .
 10425  54.         .         .         .         .         .        O.         .    I    .         .         .         .
 10430  55.         .         .         .         .         .         .         .   O     .  I      .         .         .
 10435  56.         .         .         .         .         .         .         .         . O  I    .         .         .
 10440  57.         .         .         .         .         .         .         .         .  I O    .         .         .
 10445  58.         .         .         .         .         .         .         .      I  .  O      .         .         .
 10450  59.         .         .         .         .         .         .         I       O .         .         .         .
 10455  60.         .         .         .         .         .         I         O         .         .         .         .
 10500  61.         .         .         .         .         .I        .O        .         .         .         .         .
 10505  62.         .         .         .         .  I      .  O      .         .         .         .         .         .
 10510  63.         .         .         .      I  .     O   .         .         .         .         .         .         .
 10515  64.         .         .         .I       O.         .         .         .         .         .         .         .
 10520  65.         .         .     I   .   O     .         .         .         .         .         .         .         .
 10525  66.         .         . I      O.         .         .         .         .         .         .         .         .
 10530  67.         .       I .    O    .         .         .         .         .         .         .         .         .
 10535  68.         .    I    .O        .         .         .         .         .         .         .         .         .
 10540  69.         .  I    O .         .         .         .         .         .         .         .         .         .
 10545  70.         .I   O    .         .         .         .         .         .         .         .         .         .
 10550  71.        I.  O      .         .         .         .         .         .         .         .         .         .
 10555  72.       I .O        .         .         .         .         .         .         .         .         .         .
 10600  73.      I  O         .         .         .         .         .         .         .         .         .         .
 10605  74.     I O .         .         .         .         .         .         .         .         .         .         .
 10610  75.    I O  .         .         .         .         .         .         .         .         .         .         .
 10615  76.   I O   .         .         .         .         .         .         .         .         .         .         .
 10620  77.   I O   .         .         .         .         .         .         .         .         .         .         .
 10625  78.  I O    .         .         .         .         .         .         .         .         .         .         .
 10630  79.  IO     .         .         .         .         .         .         .         .         .         .         .
 10635  80. I O     .         .         .         .         .         .         .         .         .         .         .
 10640  81. IO      .         .         .         .         .         .         .         .         .         .         .
 10645  82.I O      .         .         .         .         .         .         .         .         .         .         .
 10650  83.I O      .         .         .         .         .         .         .         .         .         .         .
 10655  84.IO       .         .         .         .         .         .         .         .         .         .         .
 10700  85.IO       .         .         .         .         .         .         .         .         .         .         .
 10705  86I O       .         .         .         .         .         .         .         .         .         .         .
 10710  87IO        .         .         .         .         .         .         .         .         .         .         .
 10715  88IO        .         .         .         .         .         .         .         .         .         .         .
 10720  89IO        .         .         .         .         .         .         .         .         .         .         .
 10725  90IO        .         .         .         .         .         .         .         .         .         .         .
 10730  91IO        .         .         .         .         .         .         .         .         .         .         .
 10735  92IO        .         .         .         .         .         .         .         .         .         .         .
 10740  93IO        .         .         .         .         .         .         .         .         .         .         .
 10745  94I         .         .         .         .         .         .         .         .         .         .         .
 10750  95I         .         .         .         .         .         .         .         .         .         .         .
```

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
HYDROGRAPH AT	BAS-A	1682.	4.58	301.	220.	220.	1.80		
ROUTED TO	ROUTE	1670.	4.67	301.	220.	220.	1.80		

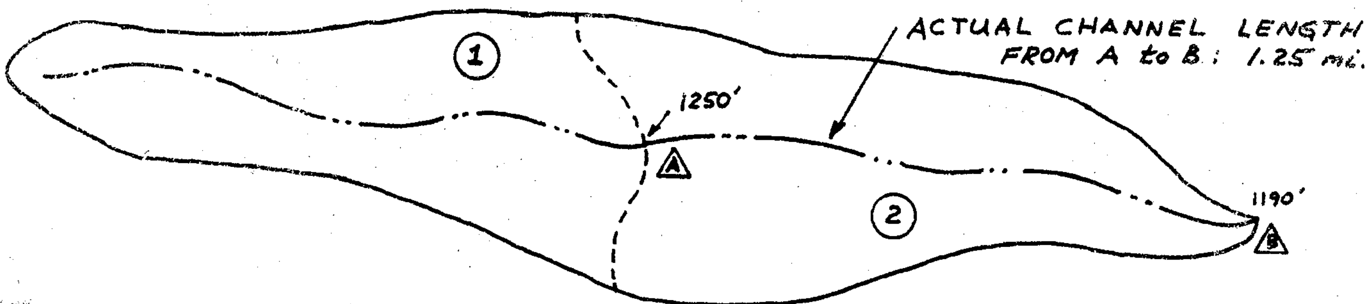
SUMMARY OF KINEMATIC WAVE - MUSKINGUM-CUNGE ROUTING
(FLOW IS DIRECT RUNOFF WITHOUT BASE FLOW)

ISTAQ	ELEMENT	DT (MIN)	PEAK (CFS)	TIME TO PEAK (MIN)	VOLUME (IN)	INTERPOLATED TO COMPUTATION INTERVAL DT (MIN)	PEAK (CFS)	TIME TO PEAK (MIN)	VOLUME (IN)
ROUTE	MANE	2.76	1673.94	281.12	1.56	5.00	1670.00	280.00	1.56

CONTINUITY SUMMARY (AC-FT) - INFLOW= .1499E+03 EXCESS= .0000E+00 OUTFLOW= .1499E+03 BASIN STORAGE= .2637E+00 PERCENT ERROR= -.2

*** NORMAL END OF HEC-1 ***

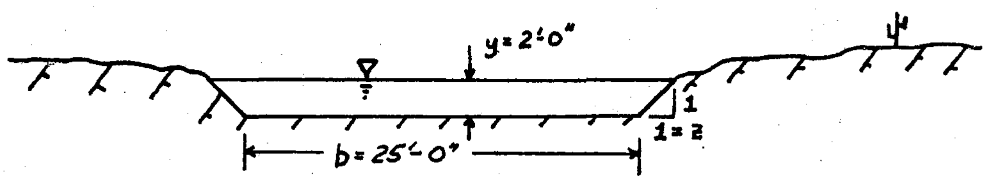
MUSKINGUM ROUTING



SCENARIO: DEVELOP MUSKINGUM ROUTING PARAMETERS FOR THE PRIMARY CHANNEL IN SUBBASIN # 2, USE HEC-1 TO GENERATE A FLOOD HYDROGRAPH AT CONCENTRATION POINT A, THEN ROUTE IT FROM POINT A TO POINT B.

STEP 1 : DEVELOP MUSKINGUM PARAMETERS

ASSUME AN AVERAGE CHANNEL X-SECTION FOR THE PRIMARY CHANNEL IN SUBBASIN # 2:



A. CALCULATE THE AVERAGE VELOCITY USING MANNING'S EQN:

$$A = (b + zy)y = (25 + (1)(2))2 = 54 \ ft^2$$

$$P = b + 2y(1 + z^2)^{1/2} = 25 + (2)(2)(1 + 1^2)^{1/2} = 30.66 \ ft$$

$$R = A/p = 54 \ ft^2 / 30.66 \ ft = 1.761 \ ft.$$

$$S = (1250' - 1190') / (1.25 \ mi \times 5280 \ ft/mi) = 0.0091 \ ft/ft$$

$$n = 0.040$$

$$V = \frac{1.49}{n} R^{2/3} S^{1/2} = \left(\frac{1.49}{.040}\right)(1.761)^{2/3}(.0091)^{1/2} = \underline{5.18 \ ft/s}$$

B. ESTIMATE FLOODWAVE VELOCITY (V_m):

SINCE A WIDE TRAPEZOIDAL CHANNEL IS BEST APPROXIMATED BY A WIDE RECTANGULAR CHANNEL, CHOOSE $V_m/V = 1.67$ FROM THE TABLE IN SECTION 7.6.D.

$$V_m = 1.67\,V = 1.67\,(5.18\ ft/s) = \underline{8.65\ ft/s}$$

C. CALCULATE K:

$$K = 1.25\ mi \times 5280\ \frac{ft}{mi} \times \frac{1}{8.65}\ \frac{s}{ft} \times \frac{1}{3600}\ \frac{hr}{s} = \underline{0.212\ hr.}$$

D. ESTIMATE X:

SINCE THIS IS A WIDE, SHALLOW CHANNEL WITH A LOW SLOPE, CHOOSE $X = 0.20$

E. CHECK NSTPS:

NSTPS MUST BE WITHIN THE FOLLOWING LIMITS:

$$\frac{1}{2(1-X)} \le \frac{(AMSKK \times 60)}{(NMIN \times NSTPS)} \le \frac{1}{2X}, \quad NMIN = 5\ MINUTES$$

TRY NSTPS = 1: $\frac{1}{2(1-.2)} \le \frac{.212 \times 60}{(5)(1)} \le \frac{1}{2(.2)}$

$$.625 \le 2.54 \le 2.5 \longrightarrow \text{NO GOOD!}$$

TRY NSTPS = 2: $\frac{.212 \times 60}{5 \times 2} = 1.27$, $.625 \le 1.27 \le 2.5$, OK!

STEP 2: ENTER THE CALCULATED MUSKINGUM PARAMETERS INTO AN HEC-1 FILE ON THE RM CARD, AS IN THE FOLLOWING EXAMPLE. HAND CALCULATION PROCEDURES FOR THIS METHOD CAN BE FOUND IN MOST HYDROLOGY TEXTBOOKS.

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*****************************************
*                                       *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *
*            SEPTEMBER 1990             *
*             VERSION 4.0               *
*                                       *
* RUN DATE  08/28/1991  TIME  13:13:09 *
*                                       *
*****************************************
```

```
*****************************************
*                                       *
*     U.S. ARMY CORPS OF ENGINEERS      *
*    HYDROLOGIC ENGINEERING CENTER      *
*          609 SECOND STREET            *
*       DAVIS, CALIFORNIA 95616         *
*           (916) 756-1104              *
*                                       *
*****************************************
```

```
X     X  XXXXXXX   XXXXX           X
X     X  X        X     X         XX
X     X  X        X                X
XXXXXXX  XXXX     X         XXXXX  X
X     X  X        X                X
X     X  X        X     X          X
X     X  XXXXXXX   XXXXX          XXX
```

THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

```
LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1          ID   SAMPLE HEC-1 RUN USING TECHNIQUES OUTLINED IN THE
   2          ID   HYDROLOGIC DESIGN MANUAL FOR MARICOPA COUNTY
              * ******************************************************************************
   3          ID   EXAMPLE # 7 - MUSKINGUM ROUTING
              * ******************************************************************************
   4          IT       5                  300
   5          IO       5

   6          KK   INFLOW
   7          KM   SUB-BASIN A, COMPUTE INFLOW HYDROGRAPH
   8          KM   6-HOUR RAINFALL, PATTERN NO. 1.99 WAS USED TO FIND TC & R FOR THIS BASIN
   9          KM   THIS BASIN USED RAINFALL REDUCTION FACTOR OF .975
  10          BA   2.750
  11          IN      15
  12          KM   RAINFALL DEPTH OF 3.50 WAS SPACIALLY REDUCED AS SHOWN BY THE PB RECORD
  13          PB   3.413
  14          KM   THE FOLLOWING PC RECORD USED A 6-HOUR STROM WITH A PATTERN No. OF 1.99
  15          PC    .000    .009    .016    .025    .034    .042    .051    .059    .067    .076
  16          PC    .087    .100    .120    .163    .252    .450    .695    .838    .900    .938
  17          PC    .950    .963    .975    .988   1.000
  18          LG    .200    .350   4.300    .250   6.500
  19          UC    .400    .205
  20          UA       0       3       5       8      12      20      43      75      90      96
  21          UA     100
              * ******************************************************************************

  22          KK   ROUTE
  23          KM   ROUTE INFLOW HYDROGRAPH THROUGH THE ROUTING REACH
  24          KO       1       2
  25          RM       2    .212     .20
  26          ZZ
```

```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
          ***************
          *             *
  6 KK    *    INFLOW   *
          *             *
          ***************
                          COMPUTE INFLOW HYDROGRAPH

  8 BA          SUBBASIN CHARACTERISTICS
                      TAREA        2.75  SUBBASIN AREA

                PRECIPITATION DATA

 10 PB                STORM        3.41  BASIN TOTAL PRECIPITATION

 14 LG          GREEN AND AMPT LOSS RATE
                      STRTL         .20  STARTING LOSS
                        DTH         .35  MOISTURE DEFICIT
                       PSIF        4.30  WETTING FRONT SUCTION
                      XKSAT         .25  HYDRAULIC CONDUCTIVITY
                      RTIMP        6.50  PERCENT IMPERVIOUS AREA

 15 UC          CLARK UNITGRAPH
                         TC         .40  TIME OF CONCENTRATION
                          R         .20  STORAGE COEFFICIENT

 16 UA          ACCUMULATED-AREA VS. TIME,  11 ORDINATES
                      .0       3.0       5.0       8.0      12.0      20.0      43.0      75.0      90.0      96.0
                   100.0
                                                    ***
                                         UNIT HYDROGRAPH PARAMETERS
                                    CLARK   TC=   .40 HR,       R=   .20 HR
                                   SNYDER   TP=   .34 HR,      CP=   .88

                                              UNIT HYDROGRAPH
                                         16 END-OF-PERIOD ORDINATES
             189.      605.     2046.     4185.     4534.     3290.     2178.     1442.      955.      632.
             419.      277.      184.      122.       81.       53.

*****************************************************************************************************************

    TOTAL RAINFALL =    3.41, TOTAL LOSS =    1.69, TOTAL EXCESS =    1.72

   PEAK FLOW      TIME                          MAXIMUM AVERAGE FLOW
                                        6-HR       24-HR       72-HR      6.17-HR
 +   (CFS)        (HR)
                            (CFS)
 +    3835.       4.25                  505.        492.        492.        492.
                          (INCHES)     1.709       1.709       1.709       1.709
                           (AC-FT)      251.        251.        251.        251.

                           CUMULATIVE AREA =     2.75 SQ MI
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
              **************
              *            *
18 KK         *    ROUTE   *
              *            *
              **************
```

ROUTE INFLOW HYDROGRAPH THROUGH A ROUTING REACH

20 KO OUTPUT CONTROL VARIABLES

IPRNT	1	PRINT CONTROL
IPLOT	2	PLOT CONTROL
QSCAL	0.	HYDROGRAPH PLOT SCALE

HYDROGRAPH ROUTING DATA

21 RM MUSKINGUM ROUTING

NSTPS	2	NUMBER OF SUBREACHES
AMSKK	.21	MUSKINGUM K
X	.20	MUSKINGUM X

HYDROGRAPH AT STATION ROUTE

DA MON HRMN	ORD	FLOW	DA MON HRMN	ORD	FLOW	DA MON HRMN	ORD	FLOW	DA MON HRMN	ORD	FLOW
12 JUL 0000	1	0.	12 JUL 0135	20	13.	12 JUL 0310	39	20.	12 JUL 0445	58	2419.
JUL 0005	2	0.	12 JUL 0140	21	13.	12 JUL 0315	40	23.	12 JUL 0450	59	1941.
12 JUL 0010	3	0.	12 JUL 0145	22	13.	12 JUL 0320	41	26.	12 JUL 0455	60	1502.
12 JUL 0015	4	0.	12 JUL 0150	23	13.	12 JUL 0325	42	32.	12 JUL 0500	61	1124.
12 JUL 0020	5	1.	12 JUL 0155	24	13.	12 JUL 0330	43	40.	12 JUL 0505	62	814.
12 JUL 0025	6	2.	12 JUL 0200	25	13.	12 JUL 0335	44	57.	12 JUL 0510	63	575.
12 JUL 0030	7	4.	12 JUL 0205	26	13.	12 JUL 0340	45	93.	12 JUL 0515	64	398.
12 JUL 0035	8	6.	12 JUL 0210	27	13.	12 JUL 0345	46	178.	12 JUL 0520	65	270.
12 JUL 0040	9	8.	12 JUL 0215	28	13.	12 JUL 0350	47	355.	12 JUL 0525	66	181.
12 JUL 0045	10	9.	12 JUL 0220	29	13.	12 JUL 0355	48	685.	12 JUL 0530	67	121.
12 JUL 0050	11	10.	12 JUL 0225	30	13.	12 JUL 0400	49	1184.	12 JUL 0535	68	82.
12 JUL 0055	12	11.	12 JUL 0230	31	13.	12 JUL 0405	50	1775.	12 JUL 0540	69	56.
12 JUL 0100	13	12.	12 JUL 0235	32	13.	12 JUL 0410	51	2375.	12 JUL 0545	70	40.
12 JUL 0105	14	12.	12 JUL 0240	33	14.	12 JUL 0415	52	2925.	12 JUL 0550	71	31.
12 JUL 0110	15	13.	12 JUL 0245	34	15.	12 JUL 0420	53	3348.	12 JUL 0555	72	25.
12 JUL 0115	16	13.	12 JUL 0250	35	15.	12 JUL 0425	54	3550.	12 JUL 0600	73	22.
12 JUL 0120	17	13.	12 JUL 0255	36	16.	12 JUL 0430	55	3499.	12 JUL 0605	74	21.
12 JUL 0125	18	14.	12 JUL 0300	37	17.	12 JUL 0435	56	3254.	12 JUL 0610	75	20.
12 JUL 0130	19	13.	12 JUL 0305	38	18.	12 JUL 0440	57	2879.			

PEAK FLOW	TIME		MAXIMUM AVERAGE FLOW			
			6-HR	24-HR	72-HR	6.17-HR
+ (CFS)	(HR)					
		(CFS)				
+ 3550.	4.42		505.	491.	491.	491.
		(INCHES)	1.706	1.706	1.706	1.706
		(AC-FT)	250.	250.	250.	250.

CUMULATIVE AREA = 2.75 SQ MI

STATION ROUTE

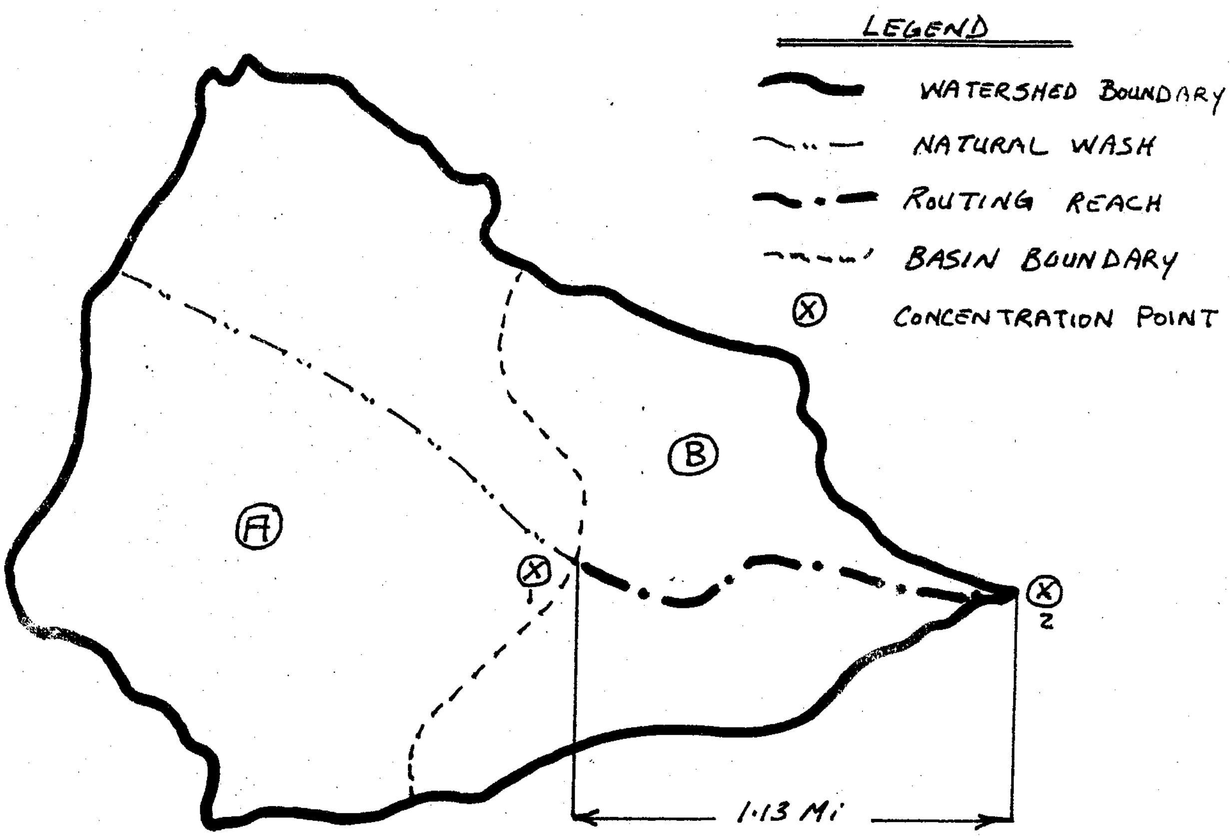
```
                         (I) INFLOW,   (O) OUTFLOW
            0.       500.      1000.      1500.      2000.      2500.      3000.      3500.      4000.         0.         0.         0.         0.
 DAHRMN PER
 120000   1I---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.
 120315  40OI        .         .         .         .         .         .         .         .         .         .         .         .
 120320  41.I. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
 120325  42.I        .         .         .         .         .         .         .         .         .         .         .         .
 120330  43.OI       .         .         .         .         .         .         .         .         .         .         .         .
 120335  44.O  I     .         .         .         .         .         .         .         .         .         .         .         .
 120340  45. O    I  .         .         .         .         .         .         .         .         .         .         .         .
 120345  46.   O     .   I     .         .         .         .         .         .         .         .         .         .         .
 120350  47.     O   .         .        I .        .         .         .         .         .         .         .         .         .
 120355  48.         .  O      .         .         . I       .         .         .         .         .         .         .         .
 120400  49.         .         .  O      .         .         .    I    .         .         .         .         .         .         .
 120405  50.         .         .         .     O   .         .         .    I    .         .         .         .         .         .
 120410  51. . . . . . . . . . . . . . . . . . . . . . . . . O . . . . . . . . . . . . . . I . . . . . . . . . . . . . . . . . . . . . . .
 120415  52.         .         .         .         .         .       O.        .   I     .         .         .         .         .
 120420  53.         .         .         .         .         .         .     O   . I     .         .         .         .         .
 120425  54.         .         .         .         .         .         . I       .O      .         .         .         .         .
 120430  55.         .         .         .         .         .    I    .        O        .         .         .         .         .
 120435  56.         .         .         .         . I       .         .    O    .         .         .         .         .         .
 120440  57.         .         .         . I       .         .      O  .         .         .         .         .         .         .
 120445  58.         .         .  I      .         .         O .       .         .         .         .         .         .         .
 120450  59.         .      I  .         .      O. .         .         .         .         .         .         .         .         .
 120455  60.         . I       .         O         .         .         .         .         .         .         .         .         .
 120500  61. . . I . . . . . . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
 120505  62.     I   .      O  .         .         .         .         .         .         .         .         .         .         .
 120510  63.  I      .O        .         .         .         .         .         .         .         .         .         .         .
 120515  64. I     O .         .         .         .         .         .         .         .         .         .         .         .
 120520  65. I  O    .         .         .         .         .         .         .         .         .         .         .         .
 120525  66.I  O     .         .         .         .         .         .         .         .         .         .         .         .
 120530  67.IO       .         .         .         .         .         .         .         .         .         .         .         .
 120535  68.IO       .         .         .         .         .         .         .         .         .         .         .         .
 120540  69IO        .         .         .         .         .         .         .         .         .         .         .         .
 120545  70IO        .         .         .         .         .         .         .         .         .         .         .         .
 120550  71IO. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
 120555  72IO        .         .         .         .         .         .         .         .         .         .         .         .
 120600  73I         .         .         .         .         .         .         .         .         .         .         .         .
 120605  74I         .         .         .         .         .         .         .         .         .         .         .         .
 120610  75I---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.
```

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
HYDROGRAPH AT	INFLOW	3835.	4.25	505.	492.	492.	2.75		
ROUTED TO	ROUTE	3550.	4.42	505.	491.	491.	2.75		

*** NORMAL END OF HEC-1 ***

MUSKINGUM - CUNGE ROUTING



SCENARIO: THE GENERATED PEAK DISCHARGE FROM BASIN (A) IS TO BE ROUTED THROUGH THE 1.13 Mi CHANNEL, FROM CONCENTRATION POINT ⊗1 TO ⊗2 BY FIRST ASSUMING AN URBANIZED CHANNEL AND THEN A NATURAL CHANNEL.

PROCEDURE FOR THE URBANIZED CHANNEL: COLLECT THE NECESSARY DATA AND ALSO PROVIDE THE SCHEMATIC OF THE CHANNEL CROSS SECTION.

CHANNEL TYPE: CONCRETE, TRAPOZOIDAL

CHANNEL LENGTH: 1.13 Mi = 5966.4 FEET

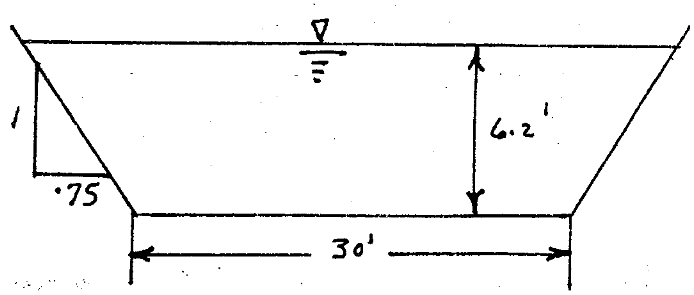
AVERAGE DEPTH: 6.2 FEET

SIDE SLOPE : 0.75 : 1.00

MANNING'S : .015

BOTTOM WIDTH : 30 FEET

CHANNEL SLOPE : .0008 FEET/FEET



(OVER)

(*) PRIOR TO RUNNING THE HEC-1 MODEL, CHANNEL CAPACITY MUST BE CHECKED TO ASSURE THAT THE DEPTH AND THE SIDE SLOPE ARE PROPERLY SELECTED FOR FLOW CONVEYANCE. OTHERWISE, THE MUSKINGUM-CUNGE PROCEDURE WILL AUTOMATICALLY EXTEND THE CHANNEL BOUNDARIES TO CONTAIN THE FLOW.

(*) THE HEC-1 PROCEDURES DO ACCOUNT FOR THE PROPER SELECTION OF THE COMPUTATIONAL TIME STEP. THIS IS DONE BY COMPARING THE SELECTED TIME STEP BY THE USER WITH THE COMPUTED TIME STEP. IF UNREALISTIC ATTENUATION IS EXPERIENCED, THE TIME STEP CAN BE ADJUSTED FOR A MORE REALISTIC VALUE. THE ENCLOSED HEC-1 PRINTOUT INCLUDES THE EVALUATION OF THE TIME STEP.

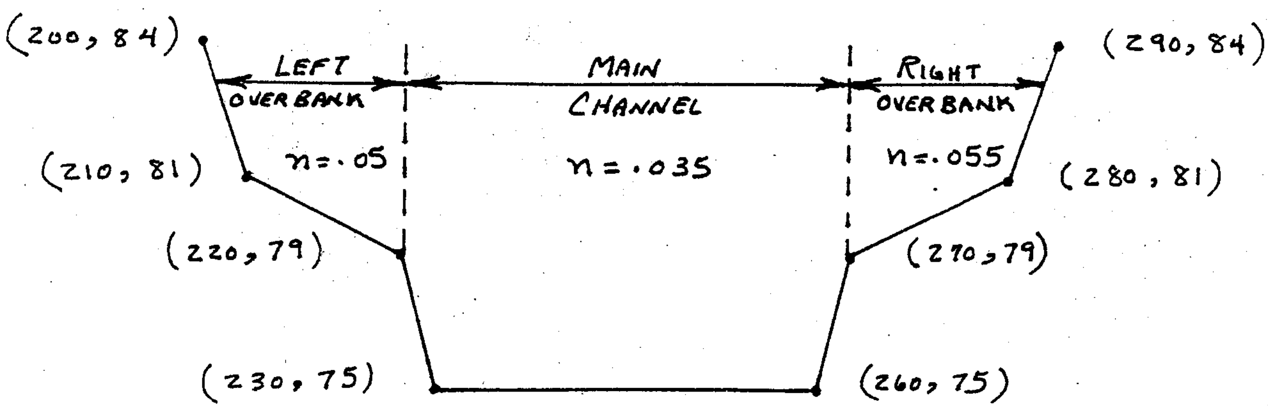
PROCEDURE FOR THE NATURAL CHANNEL: COLLECT THE NECESSARY DATA, AND ALSO PROVIDE THE SCHEMATIC OF THE CHANNEL CROSS SECTION.

CHANNEL TYPE: NATURAL WITH SOME VEGETATION AND BANK STORAGE

CHANNEL LENGTH: 1.13 Mi = 5966.4 FEET

AVERAGE DEPTH: 8 FEET

CHANNEL SLOPE: .0008 FEET/FEET



(*) IF SUFFICIENT CAPACITY IS NOT PROVIDED FOR FLOW CONVEYANCE, THE HEC-1 MODEL WILL PRINT A WARNING INDICATING THAT CHANNEL BOUNDARIES ARE EXTENDED FOR PROPER CONVEYANCE.

```
*****************************************          ***************************************
*                                       *          *                                     *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *          *   U.S. ARMY CORPS OF ENGINEERS      *
*            SEPTEMBER 1990             *          *   HYDROLOGIC ENGINEERING CENTER     *
*             VERSION 4.0               *          *         609 SECOND STREET           *
*                                       *          *      DAVIS, CALIFORNIA 95616        *
* RUN DATE  06/19/1991  TIME  14:30:15  *          *          (916) 756-1104             *
*                                       *          *                                     *
*****************************************          ***************************************
```

```
X     X  XXXXXXX   XXXXX         X
X     X  X        X     X       XX
X     X  X        X              X
XXXXXXX  XXXX     X      XXXXX   X
X     X  X        X              X
X     X  X        X     X        X
X     X  XXXXXXX   XXXXX        XXX
```

THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

```
LINE        ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1         ID     SAMPLE HEC-1 RUN USING TECHNIQUES OUTLINED IN THE
  2         ID     HYDROLOGIC DESIGN MANUAL
            * ***************************************************************************
  3         ID     EXAMPLE # 8 - MUSKINGUM-CUNGE ROUTING (URBANIZED CHANNEL)
            * ***************************************************************************
  4         IT       5                    100
  5         IO       5
            * ***************************************************************************
  6         KK   BAS-A
  7         KM   COMPUTE PEAK DISCHARGE AT THE OUTLET OF BASIN-A
  8         KM   6-HOUR RAINFALL, PATTERN NO. 1.89 WAS USED TO FIND TC & R FOR THIS BASIN
  9         KM   ABOVE PATTERN NO. BASED ON A TOTAL WATERSHED AREA OF 2.3 SQ. MILES.
 10         KM   THIS BASIN USED RAINFALL REDUCTION FACTOR OF .98
 11         BA   1.800
 12         IN      15
 13         KM   RAINFALL DEPTH OF 3.40 WAS SPACIALLY REDUCED AS SHOWN BY THE PB RECORD
 14         PB   3.326
 15         KM   THE FOLLOWING PC RECORD USED A 6-HOUR STROM WITH A PATTERN No. OF 1.89
 16         PC    .000    .009    .016    .025    .034    .042    .051    .059    .067    .076
 17         PC    .087    .100    .120    .160    .248    .443    .710    .845    .904    .939
 18         PC    .951    .964    .976    .988   1.000
 19         LG    .170    .280   7.000    .300  12.000
 20         UC    .817    .440
 21         UA       0       3       5       8      12      20      43      75      90      96
 22         UA     100
            * ***************************************************************************
 23         KK   ROUTE
 24         KM   ROUTE THROUGH BASIN-B USING MUSKINGUM-CUNGE ROUTING
 25         KO       1       2
 26         RD  5966.4   .0008    .015            TRAP      30     .75
 27         ZZ
```

*** ***

COMPUTED MUSKINGUM-CUNGE PARAMETERS

ELEMENT	ALPHA	M	COMPUTATION TIME STEP DT (MIN)	DX (FT)	PEAK (CFS)	TIME TO PEAK (MIN)	VOLUME (IN)	MAXIMUM CELERITY (FPS)
MAIN	.36	1.58	5.00	2983.20	1595.11	285.00	1.55	9.81
INTERPOLATED TO SPECIFIED COMPUTATION INTERVAL								
MAIN	.36	1.58	5.00		1595.11	285.00	1.55	

CONTINUITY SUMMARY (AC-FT) - INFLOW= .1499E+03 EXCESS= .0000E+00 OUTFLOW= .1490E+03 BASIN STORAGE= .1894E+00 PERCENT ERROR= .4

****

STATION ROUTE

```
                          (I) INFLOW,  (O) OUTFLOW
          0.       200.      400.      600.      800.     1000.     1200.     1400.     1600.     1800.       0.        0.  0.
DAHRMN PER
10000  1I-------------------------------------------------------------------------------------------------------------------------
10225  30.I
10230  31.I
10235  32.I
10240  33.I
10245  34.I
10250  35.I
10255  36.I
10300  37.I
10305  38.I
10310  39.I
10315  40.I
10320  41.I
10325  42.I
10330  43.OI
10335  44.OI
10340  45.O I
10345  46. O  I
10350  47. O    I
10355  48.  O       I
10400  49.   O           I
10405  50.      O                 I
10410  51.           O                       I
10415  52.                    O                          I
10420  53.                                 O                           I
10425  54.                                                O                        I
10430  55.                                                             O                   I
10435  56.                                                                        O          I
10440  57.                                                                              O  I
10445  58.                                                                           I   O
10450  59.                                                                    I       O
10455  60.                                                           I           O
10500  61.                                                  I             O
10505  62.                                          I              O
10510  63.                                    I            O
10515  64.                              I            O
10520  65.                         I           O
10525  66.                     I          O
10530  67.                 I         O
10535  68.              I        O
10540  69.            I       O
10545  70.          I      O
10550  71.        I     O
10555  72.       I    O
10600  73.      I    O
10605  74.     I   O
10610  75.    I   O
10615  76.   I  O
10620  77.   I O
10625  78.  I O
10630  79.  I O
10635  80. I O
10640  81. IO
10645  82.I O
10650  83.IO
10655  84.IO
10700  85.IO
10705  86IO
10710  87IO
10715  88IO
10720  89IO
10725  90I
10730  91I
10735  92I
10740  93I
10745  94I
10750  95I
```

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
HYDROGRAPH AT	BAS-A	1682.	4.58	301.	220.	220.	1.80		
ROUTED TO	ROUTE	1595.	4.75	299.	219.	219.	1.80		

SUMMARY OF KINEMATIC WAVE - MUSKINGUM-CUNGE ROUTING
(FLOW IS DIRECT RUNOFF WITHOUT BASE FLOW)

ISTAQ	ELEMENT	DT (MIN)	PEAK (CFS)	TIME TO PEAK (MIN)	VOLUME (IN)	INTERPOLATED TO COMPUTATION INTERVAL DT (MIN)	PEAK (CFS)	TIME TO PEAK (MIN)	VOLUME (IN)
ROUTE	MANE	5.00	1595.11	285.00	1.55	5.00	1595.11	285.00	1.55

CONTINUITY SUMMARY (AC-FT) - INFLOW= .1499E+03 EXCESS= .0000E+00 OUTFLOW= .1490E+03 BASIN STORAGE= .1894E+00 PERCENT ERROR=

*** NORMAL END OF HEC-1 ***

```
LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1           ID     SAMPLE HEC-1 RUN USING TECHNIQUES OUTLINED IN THE
  2           ID     HYDROLOGIC DESIGN MANUAL
              * ******************************************************************************
  3           ID     EXAMPLE # 8 - MUSKINGUM-CUNGE ROUTING (NATURAL CHANNEL)
              * ******************************************************************************
  4           IT       5                  100
  5           IO       5
              * ******************************************************************************

  6           KK    BAS-A
  7           KM    COMPUTE PEAK DISCHARGE AT THE OUTLET OF BASIN-A
  8           KM    6-HOUR RAINFALL, PATTERN NO. 1.89 WAS USED TO FIND TC & R FOR THIS BASIN
  9           KM    ABOVE PATTERN NO. BASED ON A TOTAL WATERSHED AREA OF 2.3 SQ. MILES.
 10           KM    THIS BASIN USED RAINFALL REDUCTION FACTOR OF .98
 11           BA    1.800
 12           IN       15
 13           KM    RAINFALL DEPTH OF 3.40 WAS SPACIALLY REDUCED AS SHOWN BY THE PB RECORD
 14           PB    3.326
 15           KM    THE FOLLOWING PC RECORD USED A 6-HOUR STROM WITH A PATTERN No. OF 1.89
 16           PC     .000    .009    .016    .025    .034    .042    .051    .059    .067    .076
 17           PC     .087    .100    .120    .160    .248    .443    .710    .845    .904    .939
 18           PC     .951    .964    .976    .988   1.000
 19           LG     .170    .280   7.000    .300  12.000
 20           UC     .817    .440
 21           UA        0       3       5       8      12      20      43      75      90      96
 22           UA      100
              * ******************************************************************************
 23           KK    ROUTE
 24           KM    ROUTE THROUGH BASIN-B USING MUSKINGUM-CUNGE ROUTING
 25           KO       1       2
 26           RD
 27           RC      .05    .035    .055  5966.4   .0008    83.0
 28           RX      200     210     220     230     260     270     280     290
 29           RY       84      81      79      75      75      79      81    83.5
 30           ZZ
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

                                  CROSS-SECTION DATA
                         --- LEFT OVERBANK --- + ------ MAIN CHANNEL ------- + --- RIGHT OVERBANK ---
 29 RY     ELEVATION    84.00    81.00    79.00    75.00    75.00    79.00    81.00    83.50
 28 RX     DISTANCE    200.00   210.00   220.00   230.00   260.00   270.00   280.00   290.00

                          COMPUTED STORAGE-OUTFLOW-ELEVATION DATA

     STORAGE        .00     1.79     3.70     5.74     7.89    10.17    12.57    15.09    17.73    20.49
     OUTFLOW        .00     8.62    27.65    54.97    89.89   132.07   181.39   237.79   301.29   371.94
   ELEVATION      75.00    75.42    75.84    76.26    76.68    77.11    77.53    77.95    78.37    78.79

     STORAGE      23.39    26.51    29.88    33.49    37.35    41.43    45.69    50.13    54.74    59.54
     OUTFLOW     455.95   554.26   661.44   777.84   903.73  1039.76  1185.64  1341.30  1506.83  1682.33
   ELEVATION      79.21    79.63    80.05    80.47    80.89    81.32    81.74    82.16    82.58    83.00

                       COMPUTED MUSKINGUM-CUNGE PARAMETERS
                              COMPUTATION TIME STEP
      ELEMENT     ALPHA      M        DT        DX       PEAK    TIME TO    VOLUME    MAXIMUM
                                                                   PEAK               CELERITY
                                    (MIN)      (FT)     (CFS)     (MIN)      (IN)      (FPS)

        MAIN                         5.00    1491.60   1287.13    295.00     1.51       4.44

                        INTERPOLATED TO SPECIFIED COMPUTATION INTERVAL

        MAIN                         5.00              1287.13    295.00     1.51

CONTINUITY SUMMARY (AC-FT) - INFLOW= .1499E+03 EXCESS= .0000E+00 OUTFLOW= .1452E+03 BASIN STORAGE= .5683E+00 PERCENT ERROR=   2.7
*******************************************************************************************************************************
```

STATION   ROUTE

```
                              (I) INFLOW,   (O) OUTFLOW
          0.        200.      400.      600.      800.      1000.     1200.     1400.     1600.     1800.      0.         0.  0.
DAHRMN PER
10000   1I---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.
10225  30.I         .         .         .         .         .         .         .         .         .         .         .  .
10230  31.I . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
10235  32.I         .         .         .         .         .         .         .         .         .         .         .  .
10240  33.I         .         .         .         .         .         .         .         .         .         .         .  .
10245  34.I         .         .         .         .         .         .         .         .         .         .         .  .
10250  35.I         .         .         .         .         .         .         .         .         .         .         .  .
10255  36.I         .         .         .         .         .         .         .         .         .         .         .  .
10300  37.I         .         .         .         .         .         .         .         .         .         .         .  .
10305  38.I         .         .         .         .         .         .         .         .         .         .         .  .
10310  39.I         .         .         .         .         .         .         .         .         .         .         .  .
10315  40.I         .         .         .         .         .         .         .         .         .         .         .  .
10320  41.I . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
10325  42.I         .         .         .         .         .         .         .         .         .         .         .  .
10330  43.OI        .         .         .         .         .         .         .         .         .         .         .  .
10335  44.OI        .         .         .         .         .         .         .         .         .         .         .  .
10340  45.O I       .         .         .         .         .         .         .         .         .         .         .  .
10345  46.O   I     .         .         .         .         .         .         .         .         .         .         .  .
10350  47.O     I   .         .         .         .         .         .         .         .         .         .         .  .
10355  48.O        I.         .         .         .         .         .         .         .         .         .         .  .
10400  49.O         .   I     .         .         .         .         .         .         .         .         .         .  .
10405  50.O         .         .  I      .         .         .         .         .         .         .         .         .  .
10410  51. O . . . . . . . . . . . . . . . . I . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
10415  52.     O    .         .         .         .      I  .         .         .         .         .         .  .
10420  53.          . O       .         .         .         .         .I        .         .         .         .         .  .
10425  54.          .         . O       .         .         .         .         .  I      .         .         .         .  .
10430  55.          .         .         .  O      .         .         .         .         .I        .         .         .  .
10435  56.          .         .         .         .  O      .         .         .         .  I      .         .         .  .
10440  57.          .         .         .         .         . O       .         .         .I        .         .         .  .
10445  58.          .         .         .         .         .       O  .         .    I    .         .         .         .  .
10450  59.          .         .         .         .         .         . O     I .         .         .         .         .  .
    5  60.          .         .         .         .         .        I.  O      .         .         .         .         .  .
    0  61. . . . . . . . . . . . . . . . . . . . . . . . . .I. . . . . . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
10505  62.          .         .         .         . I       .         .O        .         .         .         .         .  .
10510  63.          .         .         .     I   .         .      O  .         .         .         .         .         .  .
10515  64.          .         .         .I        .         .  O      .         .         .         .         .         .  .
10520  65.          .         .    I    .         .       O .         .         .         .         .         .         .  .
10525  66.          .         .I        .         .   O     .         .         .         .         .         .         .  .
10530  67.          .      I  .         .        O.         .         .         .         .         .         .         .  .
10535  68.          .   I     .         .   O     .         .         .         .         .         .         .         .  .
10540  69.          . I       .         .O        .         .         .         .         .         .         .         .  .
10545  70.          .I        .     O   .         .         .         .         .         .         .         .         .  .
10550  71. . . . .I. . . . . . . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
10555  72.       I  .         .O        .         .         .         .         .         .         .         .         .  .
10600  73.      I   .        O.         .         .         .         .         .         .         .         .         .  .
10605  74.     I    .     O   .         .         .         .         .         .         .         .         .         .  .
10610  75.    I     .   O     .         .         .         .         .         .         .         .         .         .  .
10615  76.   I      .  O      .         .         .         .         .         .         .         .         .         .  .
10620  77.   I      . O       .         .         .         .         .         .         .         .         .         .  .
10625  78.  I       O         .         .         .         .         .         .         .         .         .         .  .
10630  79.  I      O.         .         .         .         .         .         .         .         .         .         .  .
10635  80. I     O  .         .         .         .         .         .         .         .         .         .         .  .
10640  81. I . .O. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
10645  82.I     O   .         .         .         .         .         .         .         .         .         .         .  .
10650  83.I    O    .         .         .         .         .         .         .         .         .         .         .  .
10655  84.I   O     .         .         .         .         .         .         .         .         .         .         .  .
10700  85.I   O     .         .         .         .         .         .         .         .         .         .         .  .
10705  86I   O      .         .         .         .         .         .         .         .         .         .         .  .
10710  87I   O      .         .         .         .         .         .         .         .         .         .         .  .
10715  88I  O       .         .         .         .         .         .         .         .         .         .         .  .
10720  89I  O       .         .         .         .         .         .         .         .         .         .         .  .
10725  90I  O       .         .         .         .         .         .         .         .         .         .         .  .
10730  91I O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
10735  92I O        .         .         .         .         .         .         .         .         .         .         .  .
10740  93I O        .         .         .         .         .         .         .         .         .         .         .  .
       94IO         .         .         .         .         .         .         .         .         .         .         .  .
       95IO         .         .         .         .         .         .         .         .         .         .         .  .
```

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

	OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
+	HYDROGRAPH AT									
+		BAS-A	1682.	4.58	301.	220.	220.	1.80		
+	ROUTED TO									
+		ROUTE	1287.	4.92	291.	213.	213.	1.80		

SUMMARY OF KINEMATIC WAVE - MUSKINGUM-CUNGE ROUTING
(FLOW IS DIRECT RUNOFF WITHOUT BASE FLOW)

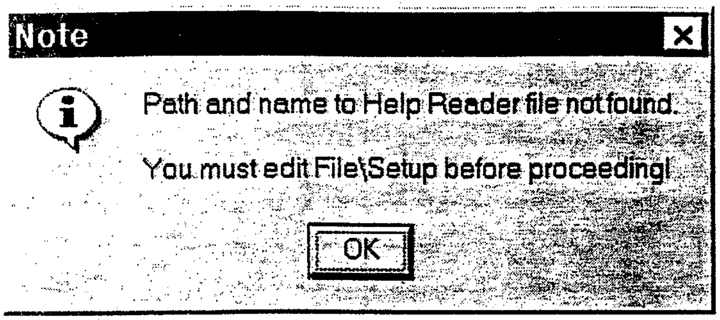
						INTERPOLATED TO COMPUTATION INTERVAL			
ISTAQ	ELEMENT	DT	PEAK	TIME TO PEAK	VOLUME	DT	PEAK	TIME TO PEAK	VOLUME
		(MIN)	(CFS)	(MIN)	(IN)	(MIN)	(CFS)	(MIN)	(IN)
ROUTE	MANE	5.00	1287.13	295.00	1.51	5.00	1287.13	295.00	1.51

CONTINUITY SUMMARY (AC-FT) - INFLOW= .1499E+03 EXCESS= .0000E+00 OUTFLOW= .1452E+03 BASIN STORAGE= .5683E+00 PERCENT ERROR= 2.7

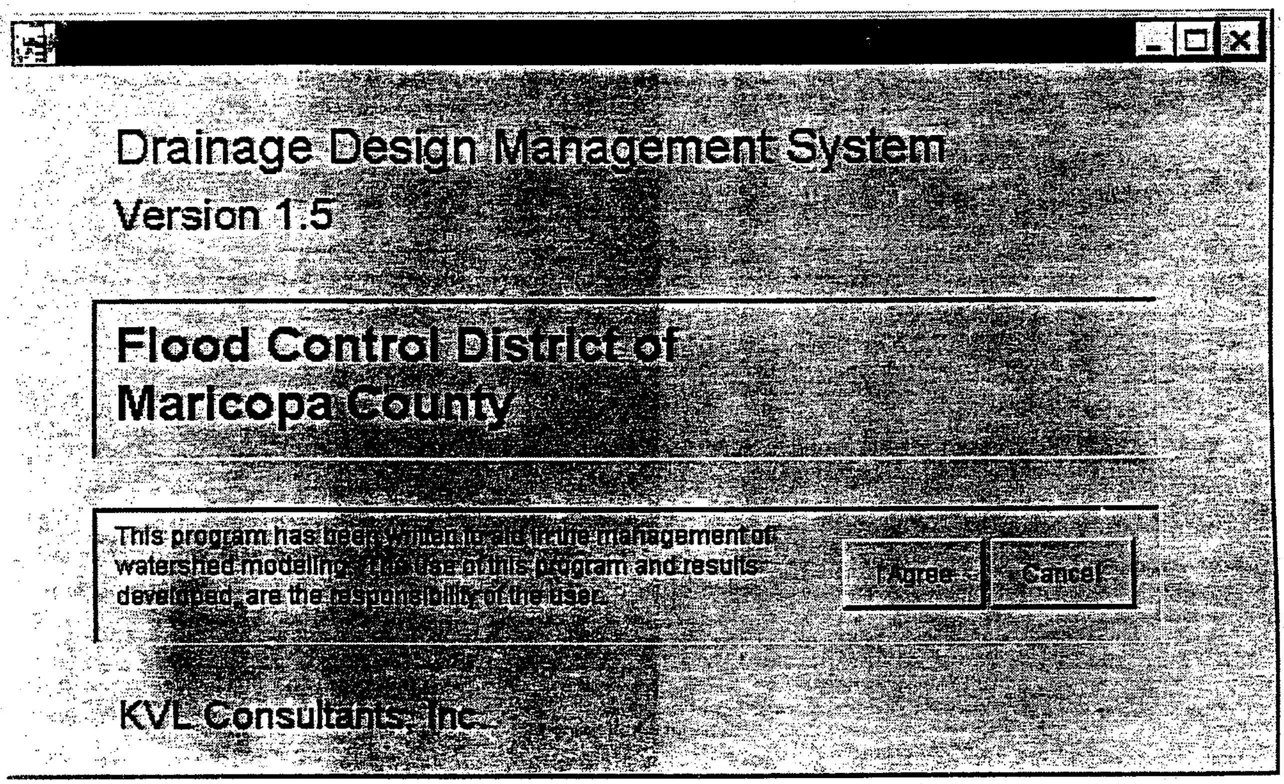
*** NORMAL END OF HEC-1 ***

Drainage Design Management System for Windows, Version 1.5
Installation Instructions

1) Insert the DDMSW CD in the CD drive (here denoted as X:). The CD contains an autorun file and installation should begin automatically. If not, from the Start menu, type X:\DDMSW\Setup at the RUN command (substitute your CD drive letter for X).
2) Follow the instructions on the screen. Once installation has finished, start the program by double-clicking on the DDMSW icon. You will receive the following message:

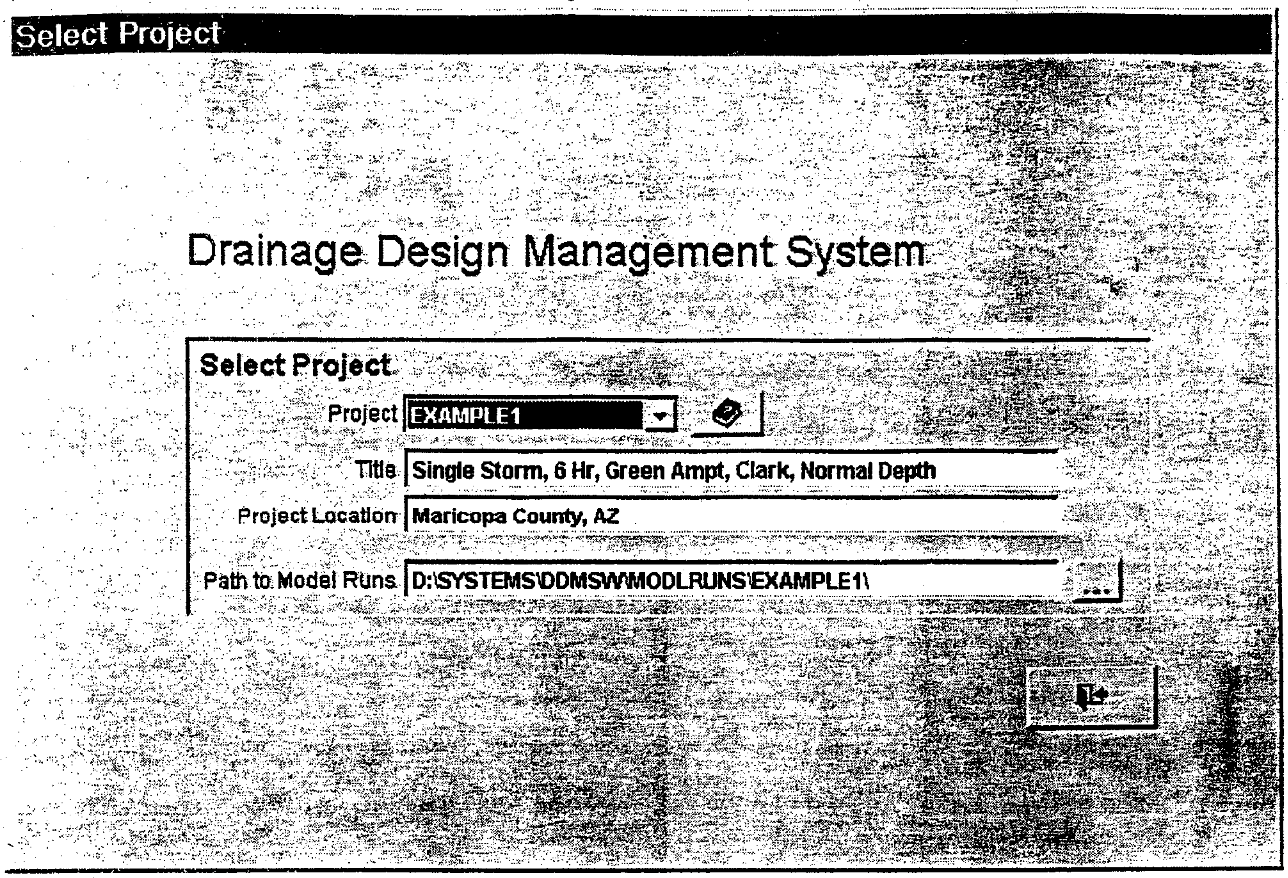


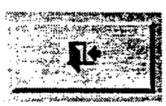
3) Click OK.
4) Next, you will see the following screen:



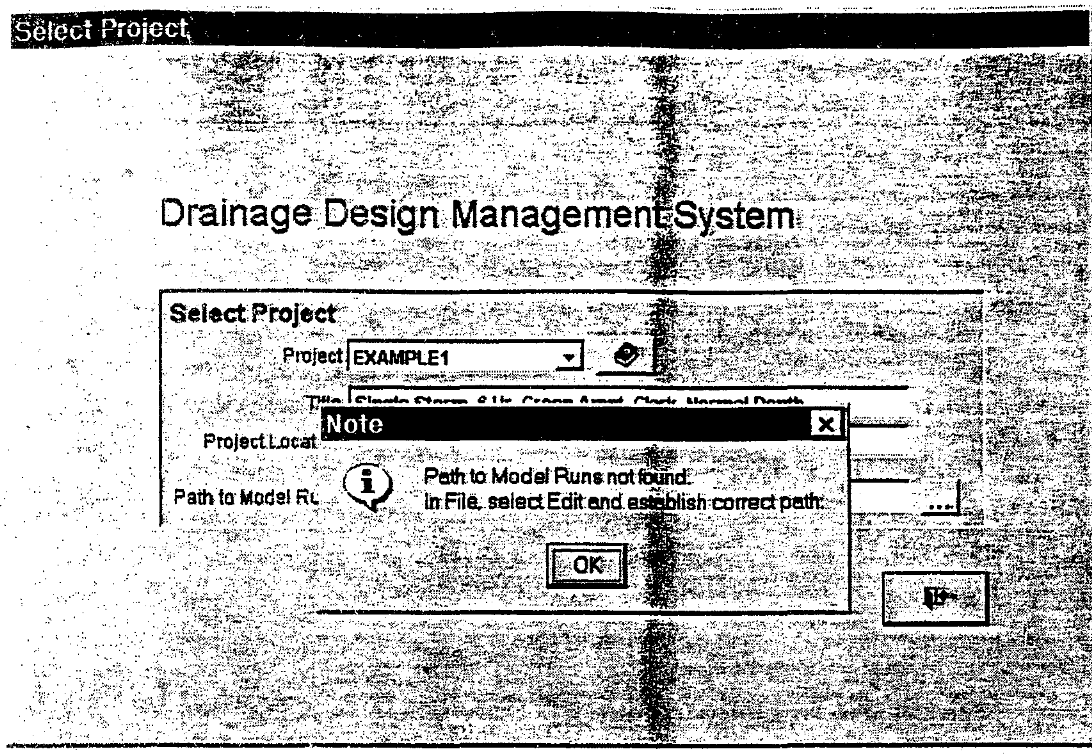
5) Click "I Agree".

6) Next, you will see the following screen:

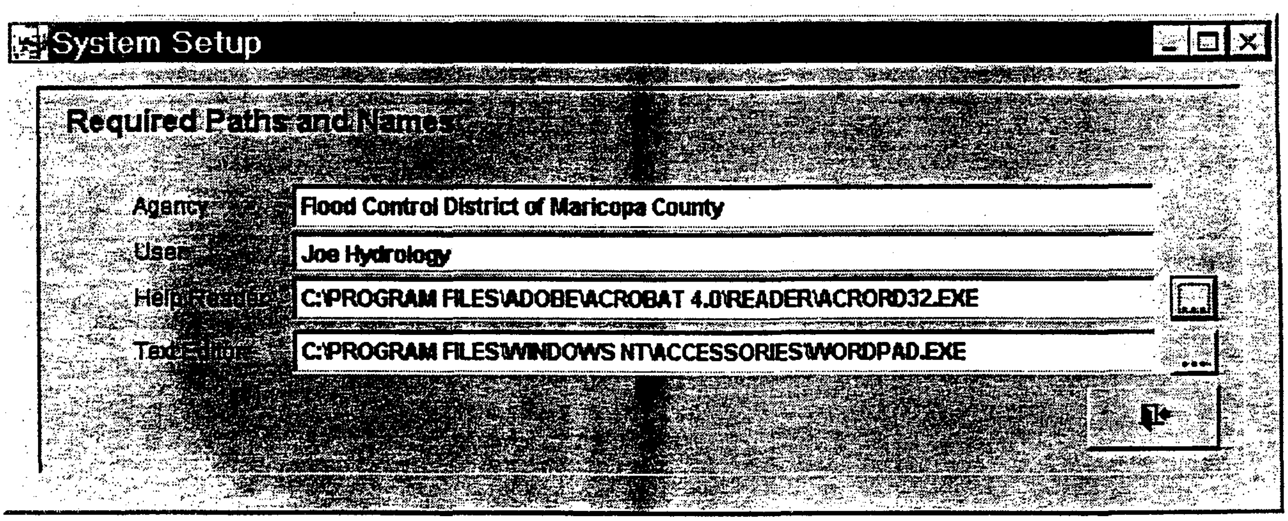


7) Click the Exit  button.

8) Next, you will see the following screen:



9) Click OK.
10) From the pulldown menus at the top of the main DDMSW screen, choose FILE | SETUP. You should see the following screen:



11) To use the DDMSW help files, you must have Adobe Acrobat installed on your system. Included in the DDMSW installation is the setup file for Adobe Acrobat 4.0, or you access the free download from www.adobe.com.

12) **If you do not have the Adobe Acrobat Reader,** you can use the installation file that was included in the setup. Go to C:\DDMSW\ADOBE\ and run the setup file "rs40eng.exe" Once Acrobat is installed, type C:\PROGRAM FILES\ADOBE\ACROBAT 4.0\READER\ACRORD32.EXE in the Help Reader block, as shown in the above screenshot. Note: The exact path may differ from what is shown. If so, type in the correct path, or use the Browse option (the button with three dots) to find the correct path.
13) **If you already have Adobe Acrobat Reader installed on your system,** type in the correct file path in the "Help Reader" block, or use the Browse option (the button with three dots) to find the correct path.
14) Similarly, you must also define which text editor DDMSW should use (usually NotePad or WordPad) by typing the correct file path in the "Text Editor" block, or using the Browse button to locate the correct file. See above screenshot for example of using WordPad under Windows NT.
15) For detailed instructions on using the program, please see the User's Manual, which can be accessed through the HELP pull-down menu, or opened directly from C:\DDMSW\HELP\MANUAL.PDF.

The following is a list of all the confirmed bugs found so far. KVL is working to resolve these issues and we will post the patch on our website as soon as possible. In the meantime, please be aware of these items (especially 1, 2, 7 and 9) and pass this along to anyone you know who is using the program.

Chris Perry, P.E.
Flood Control District of Maricopa County
602-506-4001 Phone
602-506-4601 Fax
http://www.fcd.maricopa.gov/

1) The program allows the user to duplicate a current Project ID when creating a "new" project under the File pull-down menu.
2) If a project includes subbasins that use the Desert/Rangeland S-graph, DDMSW issues the error message, "CSGRAPH not found" when the user chooses the "Develop Draft Model Data" command from the HEC-1 pull-down menu. DDMSW then creates an incorrect HEC-1 model.
3) When importing soils data, the map units do not show up in "Detail" tab of the Soil Data editor. Similar problems when importing land uses. This does not affect the data updates or creation/update of HEC-1 model. The only "problem" is that you don't see the map unit label in the detail tab.
4) Cannot import from latest Excel version - the first record (row) is deleted during the process. User has to save in Excel version 5.0 format for import to work correctly.
5) Program locks up when it encounters a non-default map unit while updating soils data. You cannot choose a "non-default" map unit from the pull-down, but you can enter one in the List tab. After that, you can't do anything else in the program. This is essentially a nuisance issue that results from a typo or other input mistake.
6) If the user specifies different methods for Basin and Reach Routing, there are errors in the HEC-1 model routing cards created by DDMSW.
7) Kb calculated incorrectly in the Rational Method module.
8) DDMSW does not allow user to change the number of ordinates on the IT card - always forces 2000.
9) DDMSW does not update the HEC-1 file with changes to basin area (BA).