Drainage Design Manual

for Maricopa County, Arizona

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Acknowledgements

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 greatly appreciated.

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Comments

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Because of ongoing legal and technical changes in the field of stormwater management, revisions to this manual will be required from time to time. Such revisions will take place on an ongoing, as needed basis and will be posted on the FCDMC's Web page (www.fcd.maricopa.gov). A separate document available on the FCDMC's Web page will summarize revisions made after the release of this fourth edition.

Revisions

Because of ongoing technical and administrative changes in the field of stormwater management, revisions to this manual will be required from time to time. Such revisions will take place on an ongoing, as needed, basis and will be posted on the FCDMC's Web page (www.fcd.maricopa.gov). The dates of revision and an overview of changes made are listed below.

1st Edition	September 1, 1990
2nd Edition	June 1, 1992
3rd Edition	January 1, 1995
4th Edition	August 15, 2013

Overview of Changes Made in the Second Edition

Title - 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.

Adoption - 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 jurisdictions 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.

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

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.

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.

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.

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 $C = 24K_n$ instead of $C = 20K_n$). The MCUHPl and MCUHP2 computer programs were revised to reflect our change of address, some data inputs were added to facilitate revisions and an error was corrected in the 2-hour storm distribution (the program was underestimating T_c because of an incorrect summation of the first three rainfall excess values).

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

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

Overview of Changes Made in the Third Edition

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

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 2.1, 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.

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, . The revised program is supplied on the DDMS diskette available with this revision (see 6. below).

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.

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 K_n values for those S-graphs for estimation of basin lag time.

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.

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-I 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-I data file as a 15 minute distribution. Second, the two S-graphs added to Chapter 5 have been incorporated into the MCUHP2 program.

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

Overview of Changes Made For The Fourth Edition

All Chapters - Policies and standards were removed to a separate volume entitled *Policies and Standards for Maricopa County, Arizona,* 2003. This allows each jurisdictional entity to customize its policies and standards to meet its community's needs. Also all references to the MCUHP programs were changed to DDMSW.

Chapter 1 Introduction – In general, the contents were reformatted into a single section. Also, a brief discussion of the contents of each chapter was added.

Chapter 2 Rainfall – The table identifying design rainfall criteria is eliminated as this information is listed in the *Policies and Standards for Maricopa County, Arizona,* 2003. Procedures for determining the design rainfall criteria were expanded. NOAA Atlas 2 was dropped and NOAA Atlas 14 was officially adopted. The isopluvial figures were moved to Appendix A.

Chapter 3 Rational Method – The I-D-F graph was replaced with a new IDF based on NOAA Atlas 14 and then moved to Appendix B. A discussion of the computation of site specific intensities was added and is intended to replace the I-D-F graph. Procedures for determination of peak discharge at multiple points in a drainage network was added. A triangular hydrograph approach was added for combining and translating Rational Method peak discharges.

Chapter 4 Rainfall Losses – Procedures for the determination of the rainfall loss variables of the Green and Ampt equation were expanded.

Chapter 5 Unit Hydrograph – Procedures for the determination of the Clark unit hydrograph parameters and the S-Graph ordinates were expanded. The Clark unit hydrograph time of concentration procedure for estimating average rainfall excess intensity was revised.

Chapter 6 Multiple Frequency Modeling – This is an entirely new chapter.

Chapter 7 Channel Routing – The Channel Routing chapter was changed to Chapter 7. The contents of this chapter were reorganized.

Chapter 8 Indirect Methods – This is an entirely new chapter.

Chapter 9 Application – The Application chapter was changed to Chapter 9. The procedures presented in Chapters 2 through 8 were added. User notes regarding the procedures and application of the methodologies presented in this manual were added along with detailed examples specific to each chapter.

Fourth Edition Dates of Revisions

The following indicates the dates in which the fourth edition has been updated and summarizes revisions made after the release of this fourth edition.

01/07/2010 Corrected typographical error on page 9-22.

04/24/2013 Corrected typographical errors on Page 9-6.

05/09/2013 Corrected a typographical error on page B-2

08/15/2013 Finalized fourth edition.

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Approvals

APPROVAL BY CHIEF ENGINEER AND GENERAL MANAGER

The Drainage Design Manual for Maricopa County – Hydrology is hereby approved and accepted for use within Maricopa County, AZ as best available technical information. This manual has been submitted to various Flood Control District of Maricopa County (FCDMC) staff, other agencies, consultants and the Public for technical review. Review comments have been addressed and the document is hereby incorporated into FCDMC and County Policy. The Hydrology manual is only available in digital format and can be found on the FCDMC public web site at:

http://www.fcd.maricopa.gov/Pub/manuals/hydrology.aspx

Refer to the Revisions section of the manual for a history of the changes made.

The objective of the Drainage Design Manual, Hydrology, is to provide criteria and design guidance for estimation of peak discharges and runoff volumes for use in identifying flood hazards and design of drainage facilities in Maricopa County. This manual provides a convenient source of technical information that is specifically tailored to the unique hydrologic, environmental and social character of Maricopa County; and a consistent set of criteria that, when used by the local governing agencies and the land development community, will result in uniform drainage practices throughout the County.

This document is only advisory and, in conformance with A.R.S. 48-3641.6, is intended to inform the general public of the Flood Control District of Maricopa County's current approach or opinion to the requirements of the various federal, state and county floodplain and drainage related ordinances or regulations, including, where appropriate, the Flood Control District of Maricopa County's current recommended minimum practice, procedure or method of action based on that approach or opinion. This document is not intended to impose additional requirements or penalties on regulated parties or confidential information. Submissions made using other methodology shall be acceptable to the Flood Control District of Maricopa upon submission of scientific documentation and evidence showing that such methodology yields results that are consistent and in accordance with the requirements of the various ordinances and regulations. However, the burden of proof is on the applicant and may affect submittal review times.

Approved for use by:

5/2/13

Timothy S. Phillips, P.E.
Chief Engineer and General Manager
Flood Control District of Maricopa County

Date

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Table of Contents

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List of Tables

List of Figures

1 INTRODUCTION

2 RAINFALL

3 RATIONAL METHOD

4 RAINFALL LOSSES

5 UNIT HYDROGRAPH PROCEDURES

6 MULTIPLE FREQUENCY MODELING

7 CHANNEL ROUTING

8 INDIRECT METHODS

9 APPLICATION

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1 INTRODUCTION

TABLE OF CONTENTS

1.1 OVERVIEW

The objective of the *Drainage Design Manual for Maricopa County, Hydrology*, (hereinafter referred to as the *Hydrology Manual*) is to provide technical procedures for the estimation of flood discharges for the purposes of designing stormwater drainage facilities and regulating watercourses 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. 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 manual also provides indirect methods intended to be used as confidence checks and verification of the reasonableness of the results obtained from the two methodologies discussed above.

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- or 24-hour duration and that storm is to be used for the design of all stormwater drainage facilities except stormwater storage facilities. The criteria to be applied to the 2-hour storm is also provided in the *Hydrology Manual* for use in design of stormwater storage facilities, as a minimum recommended criteria for Maricopa County. The criteria for design of stormwater storage facilities in unincorporated areas of Maricopa County is the 100-year, 2-hour storm. Although this is the minimum recommended criteria for all of Maricopa County, the Policies and Standards manual for each jurisdictional entity should be referenced for specific guidance for incorporated areas.

The rainfall-runoff modeling procedures that are contained in the manual are 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 procedures are 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 and engineering 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, the anticipated uses, the consequences of error, and the 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 reasonable confidence 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 content 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 14, Arizona, which is currently the most comprehensive and authoritative source of such information.

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 19 August 1954 Queen Creek storm. The Corps' distribution has been modified somewhat to reflect the design rainfall criteria that are 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. This reflects 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 stormwater storage 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 areal reductions of point rainfall using NWS HYDRO-40 (Zehr and Myers, 1984).

Chapter 3 ***Rational Method*** - Use of the Rational Method is to be limited to an area of up to 160 acres. 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. An equation for the estimation of time of concentration is provided that 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 in this chapter.

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 5 square miles in size with an upper limit of application of 10 square miles. Procedures are provided for the estimation of the two numeric parameters: the time of concentration and the 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 *Multiple Storm Frequency Modeling* - Runoff hydrographs for the 2-, 5- and 10-year events are to be estimated by the application of ratios to the 100-year runoff hydrograph. Specific ratios for the 2-, 5- and 10-year events are provided in this chapter.

Chapter 7 *Channel Routing* - General guidance is provided for the use of Normal-Depth routing, Kinematic Wave routing, Muskingum routing and Muskingum-Cunge routing. Normal-Depth routing is the preferred approach and can be applied to both natural and artificial channels. Kinematic Wave routing can be applied to urbanized or artificial channels and closed conduits. Muskingum routing can be used for large natural channels where parameter calibration data exists. Muskingum-Cunge routing may be used in all other cases.

Chapter 8 *Indirect Methods* - Three methods for verification of peak discharge estimations are provided in this chapter. The three methods incorporate local and regional data for comparison as well as generalized, regional regression equations.

Chapter 9 *Application* - General guidelines and some specific aids in the use of the manual as well as detailed examples specific to each chapter are provided.

Chapter 10 *References* - A listing of all references is provided.

Appendices - Isopluvial maps, loss rate tables for soils in Maricopa County, Textural Class Diagram, selected blank figures, worksheets, and other supporting information are provided in Appendices A through D.

1.2 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 for both the County and municipalities when annexing County areas, and supplying equal and common protection from the hazards of stormwater drainage for all County residents. Additionally, developers would be benefited 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, Arizona* (herein referred to as the *Policies and Standards Manual*.)

- 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*.

1.3 SCOPE AND LIMITATION

When using the procedures detailed in this manual, it is important to keep three limitations 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 proven inappropriate. The purpose of this manual is to provide a means of assisting in the prediction of runoff that might result from a design storm of a given return interval.

Third, the typical design storm normally has no point of reference in terms of a singular historic event. Rather, it intends 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 that 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.

1.4 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 user of this manual is 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 and are provided in this manual. Failure to verify predictions may result in erroneous values.

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*.

1.5 APPLICATION

The contents of this manual, with the exception of Chapter 3 (Rational Method) and Chapter 8 (Indirect Methods), were prepared to supplement the most current version of HEC-1 User's Manual (U.S. Army Corps of Engineers). 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 facilitate the execution of the recommended procedures that are contained herein. The Flood Control District has written a HEC-1 interface program, Drainage Design Management System for Windows (DDMSW)', which enhances and simplifies the use of the HEC-1 program with the procedures of this manual. DDMSW is available on the district's website at www.fcd.maricopa.gov.

2 RAINFALL

TABLE OF CONTENTS

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 (July through September) and winter (December through March). Warm, moist tropical air can move into Arizona at any time 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 bands 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 in 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 20 square miles and less.

The 6-hour local storm for watersheds between 20 and 100 square miles may be the required design storm criteria, as discussed below. The general design storm for watershed areas between 20 and 500 square miles is the 24-hour storm.

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 cannot 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 that the general storm could result in the largest runoff volume.

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

Record floods for large drainage areas, similar to the Salt River Watershed 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 complexity of 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.

The design rainfall criteria to be used in the unincorporated areas of Maricopa County are summarized in the *Drainage Policies and Standards for Maricopa County.* The specific procedures that are needed to define the design rainfall for the 100-year, 2-hour storm, the 6-hour local storm and the 24-hour general storm are provided in the following sections. Refer to the Policies and Standards manual of the municipality for design rainfall criteria in the incorporated areas of Maricopa County.

2.2 RAINFALL DEPTH

The most commonly used descriptor of rainfall is the rainfall depth; however, for modeling purposes, two other 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, the 24-hour general storm, and the temporal distribution for the 100-year, 2-hour storm.

2.2.1 Data Source

The most comprehensive and available source of rainfall data analysis for Maricopa County is the NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, Volume 1: Semiarid Southwest (NOAA Atlas 14) (Arizona, Southeast California, Nevada, New Mexico, Utah) (Bonnin et al, 2004). The NOAA Atlas 14 is to be used for all drainage design purposes in Maricopa County. The District has elected to use the mean partial duration time series point precipitation values from NOAA Atlas 14 rather than the values for the upper or lower bound of the 90 percent confidence intervals. For critical projects that can significantly affect public safety, health and welfare, including floodplain delineation and dam safety studies, the engineer/hydrologist should check model results against indirect methods as defined in Chapter 8. These analyses should include performance of parameter sensitivity analyses, including the use of the upper bound of the 90 percent confidence interval point precipitation data, to ensure the model results are reasonable in comparison with available historic gage data for the watershed or hydrologically similar watersheds. As a result of such analyses, the engineer/hydrologist may elect to use the point precipitation values from the upper bound of the 90 percent confidence interval instead of the mean values, in order to better conform with available appropriate gage data. This application will be acceptable to the District. Use of the values for lower bound of the 90 percent confidence interval is not recommended.

The NOAA Atlas 14 data available through the NOAA Atlas 14 web site are not to be used for studies in Maricopa County. Instead, the NOAA Atlas 14 maps in Appendix A.1, the ESRI ASCII Grid data files available on the District’s web site, or the data supplied with the District’s DDMSW computer program are to be used. This data was taken from NOAA Atlas 14, Volume 1, Version 4.0, dated June 19, 2006. This is the version the District has reviewed and accepted for use in Maricopa County. Subsequent versions published by NOAA shall not be used until the District has reviewed the data, formally adopted its use by revising this document, or issued an addendum to this document, posted the new version on the District web site, and updated DDMSW.

As a historical study reference, point precipitation isopluvial maps generated using the mean NOAA Atlas 2 data are included in Appendix A.2 for reference when utilizing historical studies done using this data.

2.2.2 Depth-Duration-Frequency Statistics

The depth-duration-frequency (D-D-F) statistics in the NOAA Atlas 14 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 14 and these are contained in the *Hydrology Manual* (Figure A.1 through Figure A.60 of Appendix A.1). Areas immediately adjacent to Maricopa County are provided in the isopluvial maps; however, flood studies of certain large watersheds may require reference to ESRI ASCII Grid data available on the District's web site.

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 Figure A.1 through Figure A.60. In those situations, the ESRI ASCII Grid data available on the District's web site should be used.

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, the District's Engineering Division should be consulted.

2.3 DEPTH-AREA RELATION

The NOAA Atlas 14 rainfall depths from the isopluvial maps in Figure A.1 through Figure A.60 of Appendix A.1, 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 which has the effect of reducing the point rainfall value. The reduction reflects the greater non-homogeneity 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, indicated 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). For local storms (6-hour duration), the depth-area reduction curve that is to be used in Maricopa County is the curve developed by the U.S. Army Corps of Engineers for the 19 August 1954 Queen Creek Storm. That curve is shown in Table 2.1 and Figure 2.1. For the 24-hour general storm, the depth-area reduction curve that is to be used in Maricopa County is shown in Table 2.2 and Figure 2.2. This curve is taken from Figure 15 of the National Weather Service HYDRO-40 (Zehr and Myers, 1984).

Use these depth-area reduction values to adjust the point rainfall depths from the isopluvial maps (Figure A.1 through Figure A.60 of Appendix A.1). For the design of stormwater storage facilities, refer to the *Drainage Policies and Standards for Maricopa County* or the local jurisdiction for depth-area reduction values to adjust the point rainfall depth from the isopluvial map for the 100-year, 2-hour storm (Figure A.56 of Appendix A.1).

For design storms other than what is specified in this manual, the depth-area reduction and temporal distribution will need to be developed on a case-by-case basis depending on the purpose of the study, location of the watershed, and other meteorological and hydrological factors.

TABLE 2.1
DEPTH-AREA REDUCTION FACTORS FOR THE 6-HOUR DURATION RAINFALL

Area, sq. miles	**Depth-Area Reduction Factor (ratio to point rainfall)**
0.0	1.000
0.5	**0.994**
1.0	0.987
2.8	**0.975**
5.0	0.960
10.0	0.940
16.0	**0.922**
20.0	0.910
30.0	0.890
40.0	0.870
90.0	**0.810**
100.0	**0.800**

Note: Bold values correspond to the 6-hour design storm pattern numbers.

Figure 2.1
DEPTH-AREA REDUCTION CURVE FOR THE 6-HOUR DURATION RAINFALL

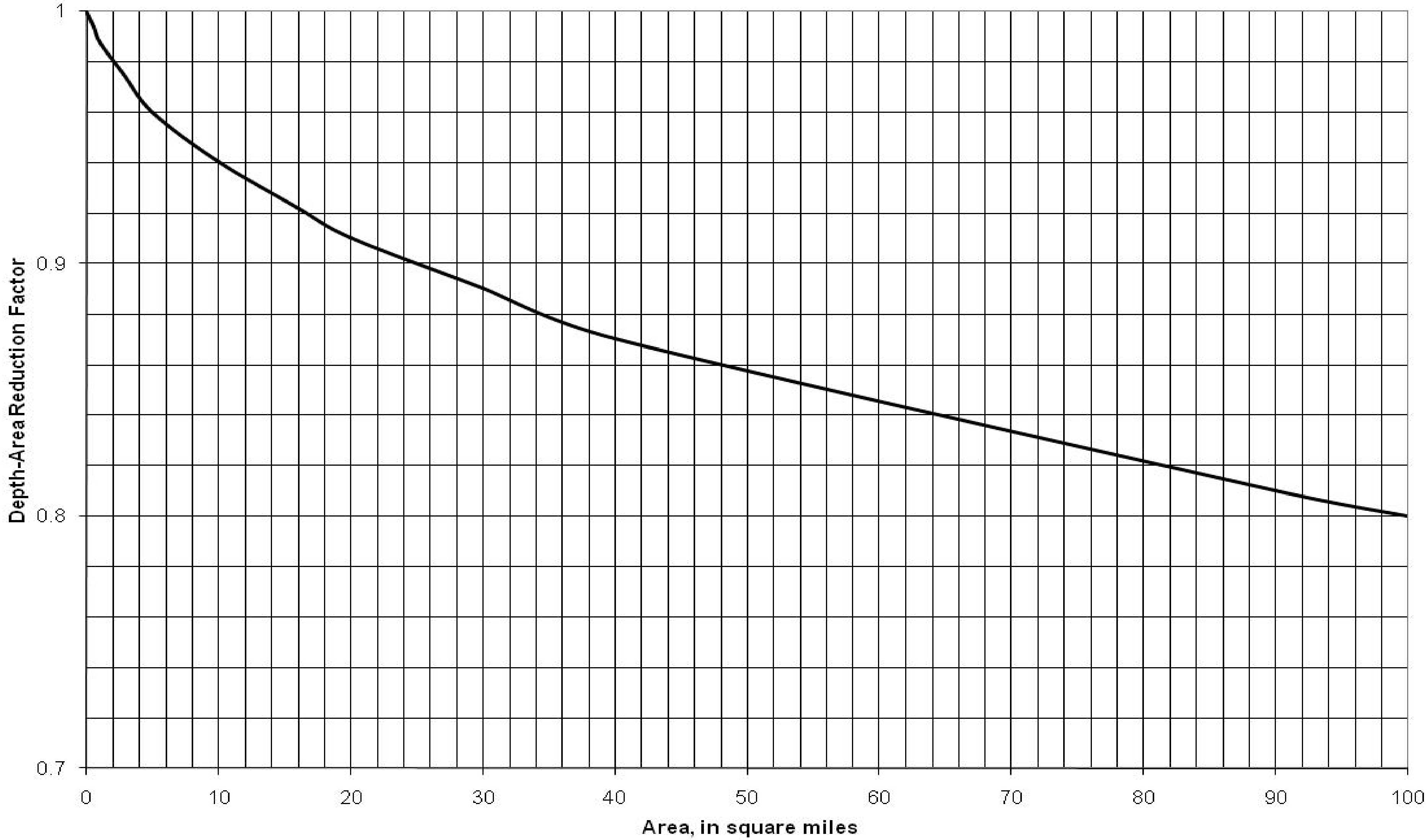
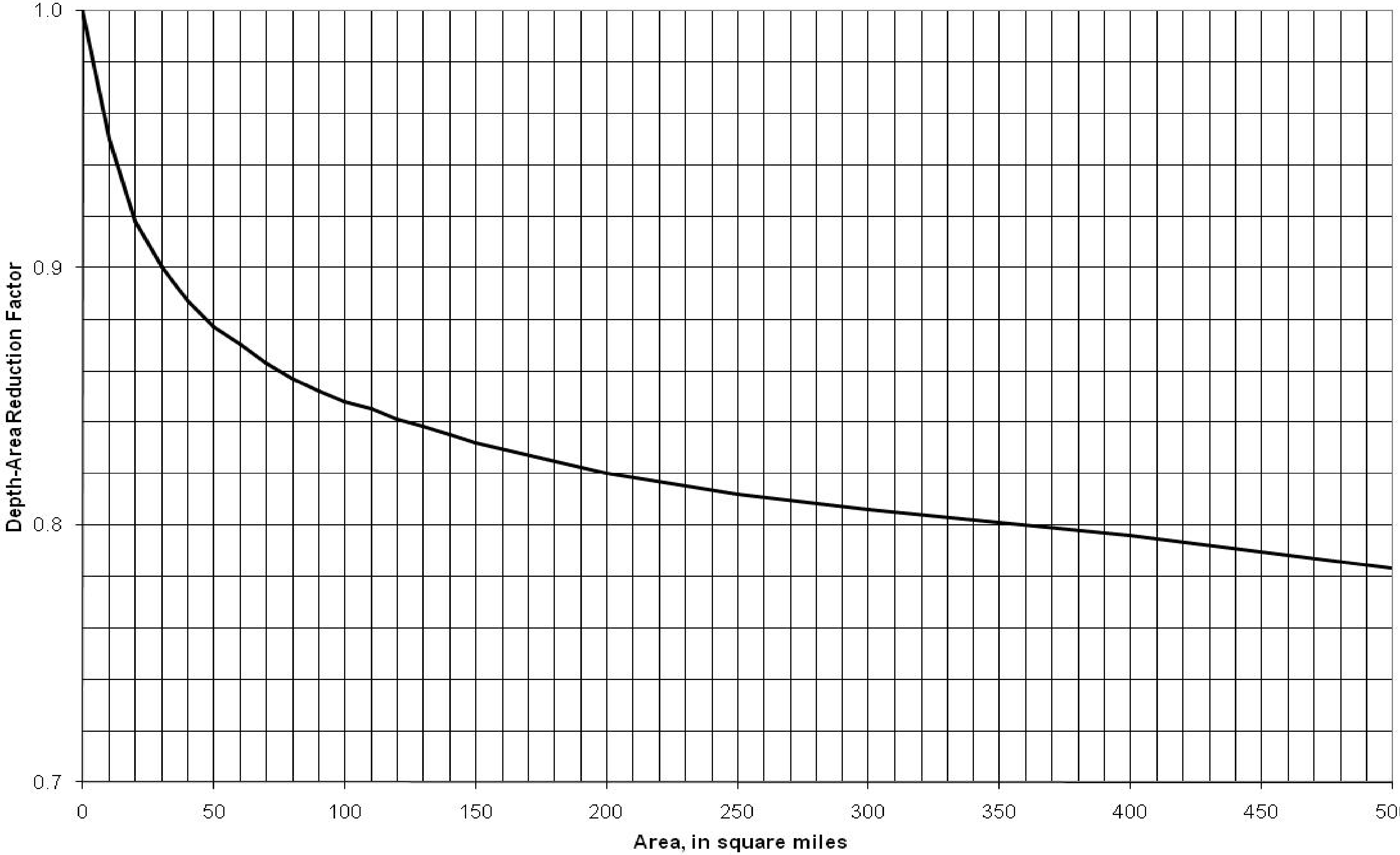


TABLE 2.2
DEPTH-AREA REDUCTION FACTORS FOR THE 24-HOUR DURATION RAINFALL

Area, sq. miles	Depth-Area Reduction Factor (ratio to point rainfall)
0	1.000
10	0.950
20	0.918
30	0.900
40	0.887
50	0.877
60	0.870
70	0.863
80	0.857
90	0.852
100	0.848
110	0.845
120	0.841
130	0.838
140	0.835
150	0.832
200	0.820
250	0.812
300	0.806
400	0.796
500	0.783

Figure 2.2
DEPTH-AREA REDUCTION CURVE FOR THE 24-HOUR DURATION RAINFALL



2.4 DESIGN STORM DISTRIBUTIONS

According to design rainfall criteria (*Policies and Standards Manual*), three types of design storm distributions are to be used in Maricopa County. These distributions are the 6-hour local storm, the 24-hour general storm and the 2-hour storm. 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

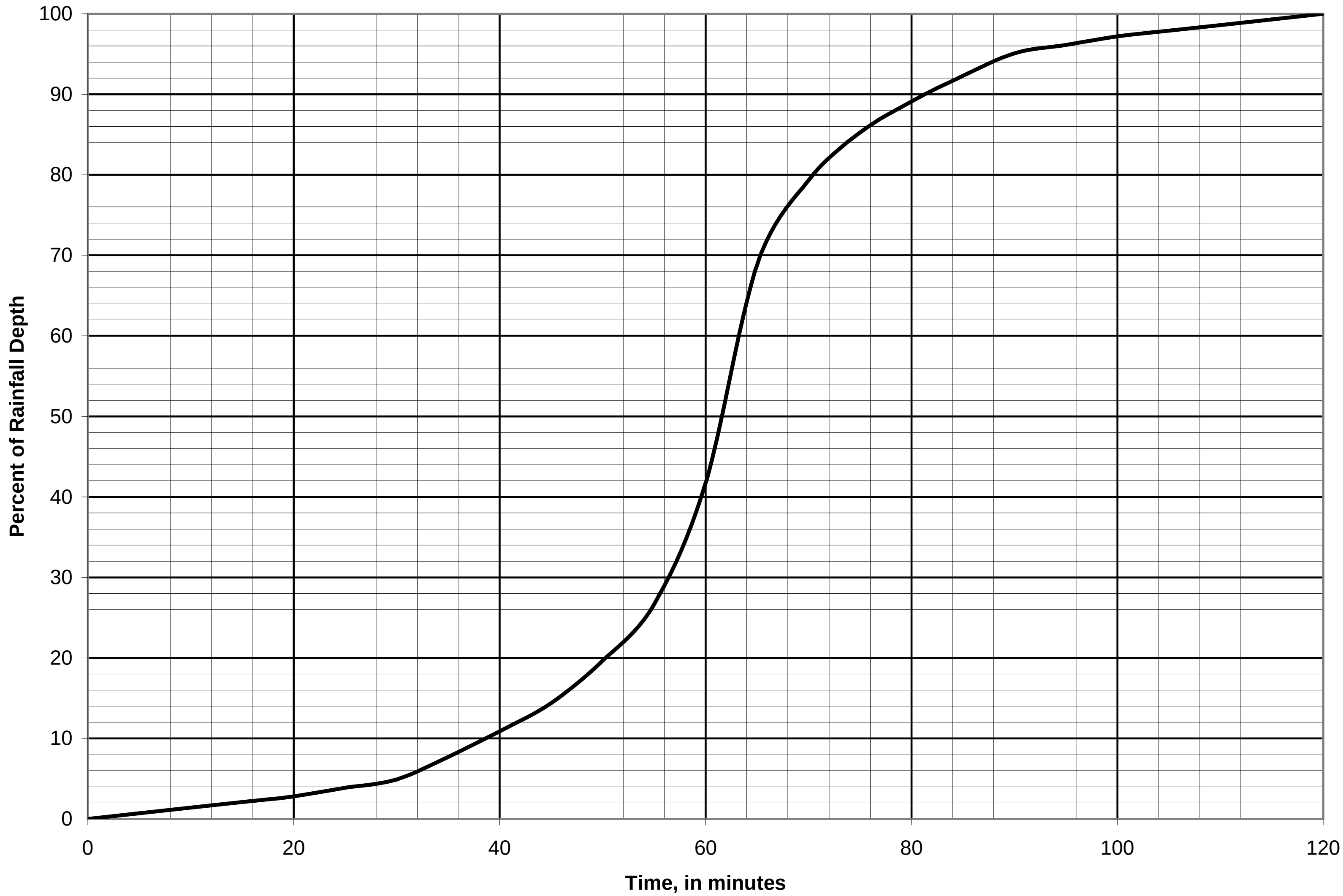
The 2-hour storm distribution is to be used for the design of stormwater storage facilities (see *Policies and Standards Manual*). The 2-hour distribution shown in Table 2.3 and Figure 2.3 is a dimensionless form of the 2-hour hypothetical distribution for the Phoenix Sky Harbor Airport location. This distribution can be applied throughout Maricopa County for the design of stormwater storage facilities.

Table 2.3
2-HOUR STORM DISTRIBUTION FOR STORMWATER STORAGE DESIGN

Time minutes	% Rainfall Depth
0	0.0
5	0.7
10	1.4
15	2.1
20	2.8
25	3.9
30	4.9
35	7.7
40	10.9
45	14.4
50	19.6
55	26.7
60	41.8

Time minutes	% Rainfall Depth
65	68.8
70	79.3
75	85.3
80	89.1
85	92.3
90	95.1
95	96.1
100	97.2
105	97.9
110	98.6
115	99.3
120	100.0

Figure 2.3
2-HOUR MASS CURVE FOR STORMWATER STORAGE DESIGN



2.4.2 6-hour Storm Distribution

The 6-hour storm distributions are used for flood studies and design of stormwater drainage facilities in Maricopa County of drainage areas less than 20 square miles, except for on-site stormwater storage facilities (see *Policies and Standards Manual*). 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 the NOAA Atlas for the Western United States, Arizona (Miller et al. 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 and Table 2.4.

Inspection of the storm patterns 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 2.5. As illustrated by Figure 2.5, 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.

Table 2.4
6-HOUR DISTRIBUTIONS

Time, in hours	Percent of Rainfall Depth				
	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5
0.00	0.0	0.0	0.0	0.0	0.0
0.25	0.8	0.9	1.5	2.1	2.4
0.50	1.6	1.6	2.0	3.5	4.3
0.75	2.5	2.5	3.0	5.1	5.9
1.00	3.3	3.4	4.8	7.1	7.8
1.25	4.1	4.2	6.3	8.7	9.8
1.50	5.0	5.1	7.6	10.5	11.9
1.75	5.8	5.9	9.0	12.5	14.1
2.00	6.6	6.7	10.5	14.3	16.2
2.25	7.4	7.6	11.9	16.0	18.6
2.50	8.7	8.7	13.5	17.9	21.2
2.75	9.9	10.0	15.2	20.1	23.9
3.00	11.8	12.0	17.5	23.2	27.1
3.25	13.8	16.3	22.2	28.1	32.1
3.50	21.6	25.2	30.4	36.4	40.8
3.75	37.7	45.1	47.2	50.0	51.5
4.00	83.4	69.4	67.0	65.8	62.7
4.25	91.1	83.7	79.6	77.3	73.5
4.50	93.1	90.0	86.8	84.1	81.4
4.75	95.0	93.8	91.2	88.8	86.4
5.00	96.2	95.0	94.6	92.7	90.7
5.25	97.2	96.3	96.0	94.5	93.0
5.50	98.3	97.5	97.3	96.4	95.4
5.75	99.1	98.8	98.7	98.2	97.7
6.00	100.0	100.0	100.0	100.0	100.0

Figure 2.4
6-HOUR MASS CURVES FOR MARICOPA COUNTY

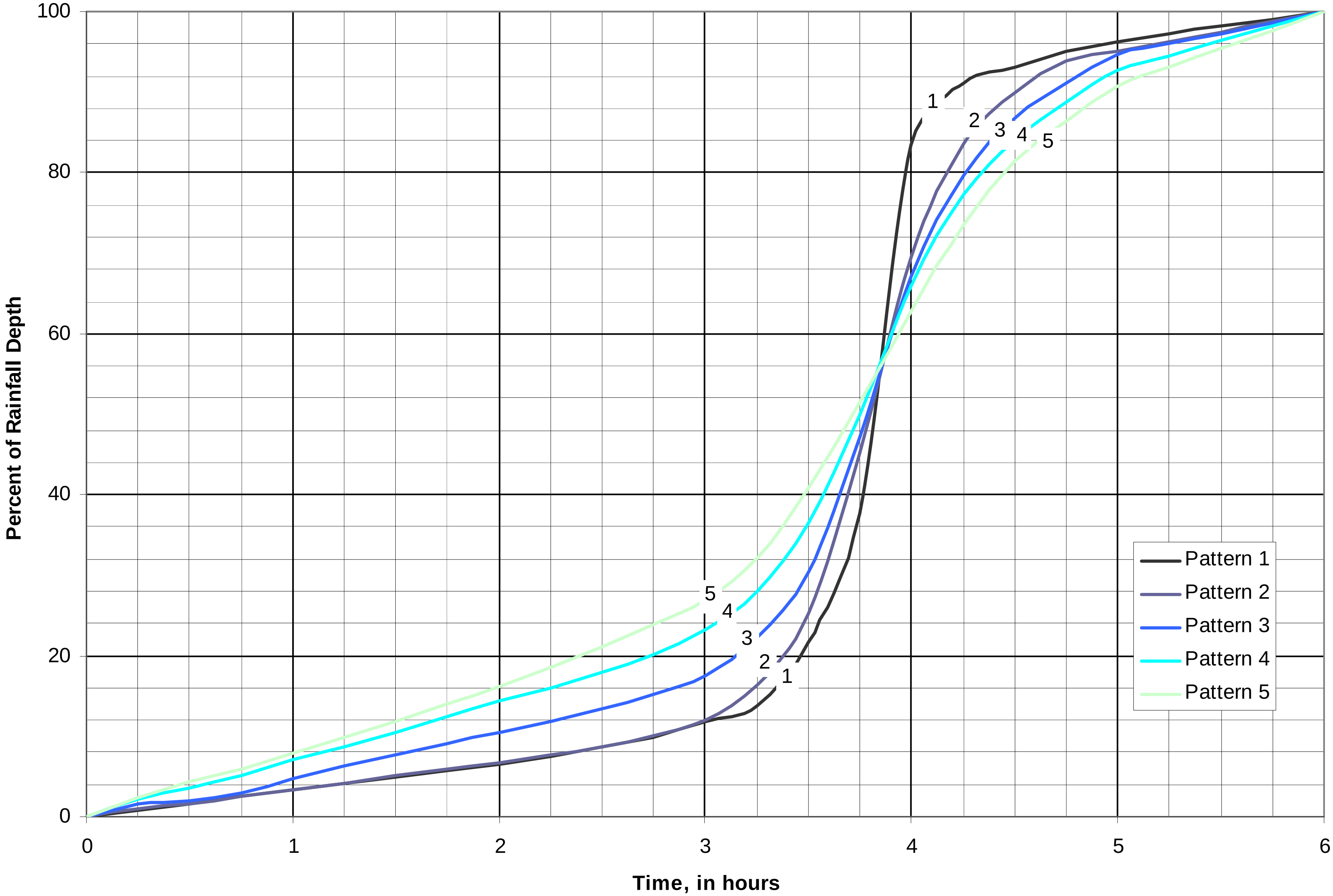
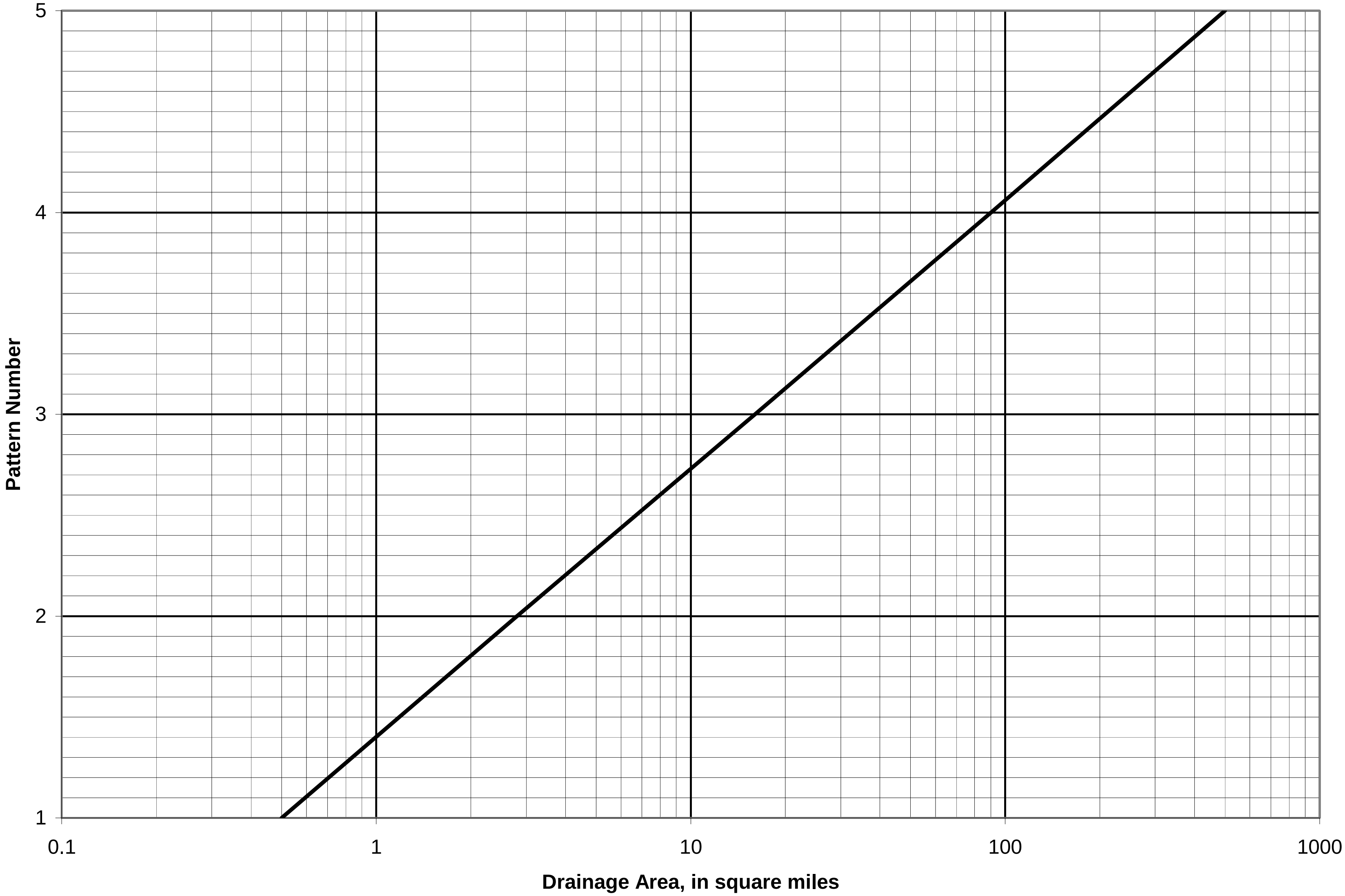


Figure 2.5
AREA VERSUS PATTERN NUMBER FOR MARICOPA COUNTY



2.4.3 24-hour Storm Distribution

The 24-hour storm distribution that is to be used for flood studies and design of stormwater drainage facilities in Maricopa County is the SCS Type II distribution. This distribution is shown in Table 2.5 and Figure 2.6. The 24-hour storm distribution is used for flood studies of drainage area larger than 100 square miles (see *Policies and Standards Manual*). This distribution is also to be used in combination with the 6-hour storm distribution for drainage areas between 20 and 100 square miles to determine whether a local storm or a general storm will produce the greatest flood peak discharges or the maximum flood volumes.

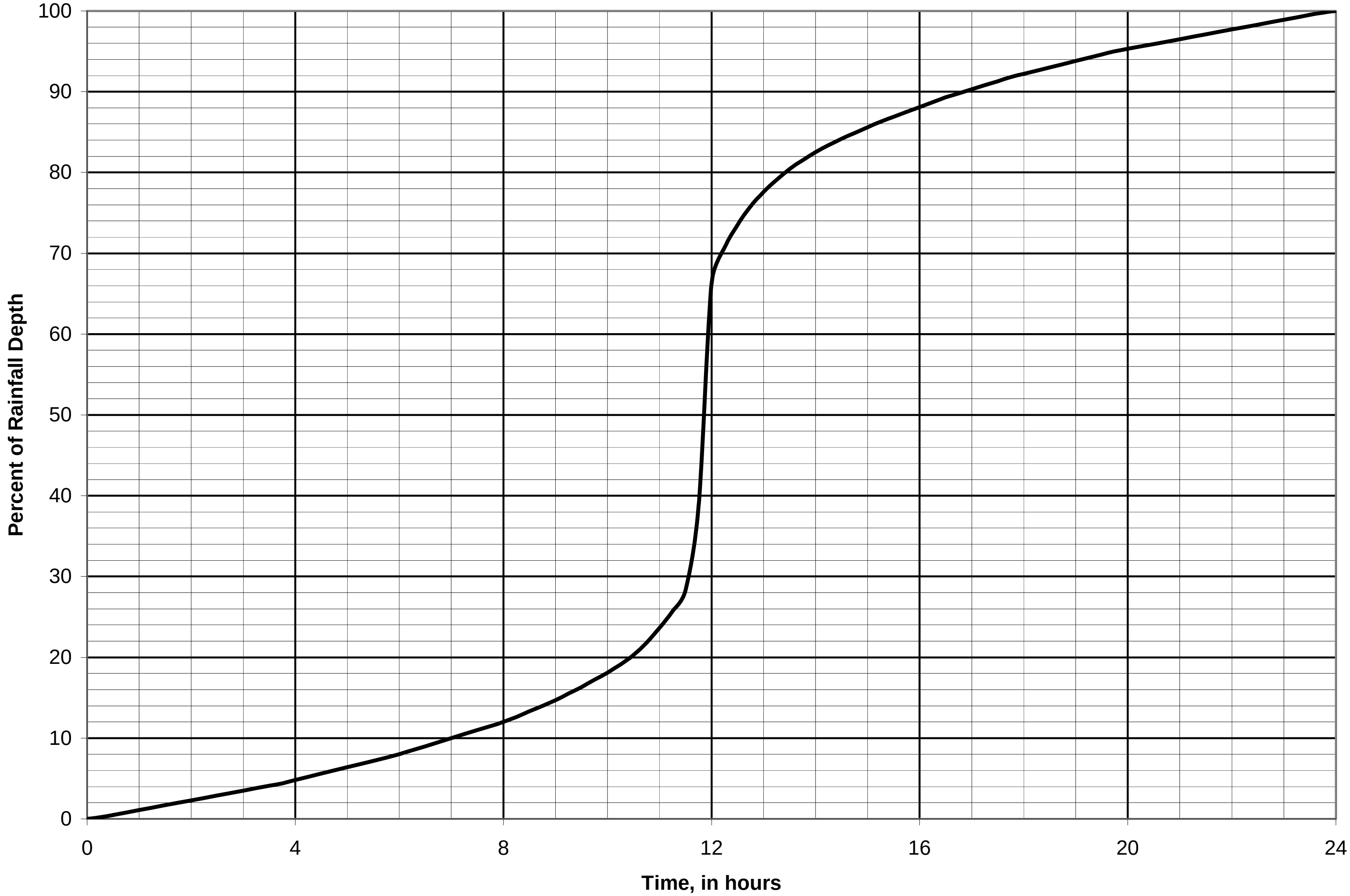
Table 2.5
24-HOUR DISTRIBUTION

Time hours	Rainfall Depth %
0.00	0.0
0.25	0.2
0.50	0.5
0.75	0.8
1.00	1.1
1.25	1.4
1.50	1.7
1.75	2.0
2.00	2.3
2.25	2.6
2.50	2.9
2.75	3.2
3.00	3.5
3.25	3.8
3.50	4.1
3.75	4.4
4.00	4.8
4.25	5.2
4.50	5.6
4.75	6.0
5.00	6.4
5.25	6.8
5.50	7.2
5.75	7.6
6.00	8.0
6.25	8.5
6.50	9.0
6.75	9.5
7.00	10.0
7.25	10.5
7.50	11.0
7.75	11.5
8.00	12.0

Time hours	Rainfall Depth %
8.25	12.6
8.50	13.3
8.75	14.0
9.00	14.7
9.25	15.5
9.50	16.3
9.75	17.2
10.00	18.1
10.25	19.1
10.50	20.3
10.75	21.8
11.00	23.6
11.25	25.7
11.50	28.3
11.75	38.7
12.00	66.3
12.25	70.7
12.50	73.5
12.75	75.8
13.00	77.6
13.25	79.1
13.50	80.4
13.75	81.5
14.00	82.5
14.25	83.4
14.50	84.2
14.75	84.9
15.00	85.6
15.25	86.3
15.50	86.9
15.75	87.5
16.00	88.1
16.25	88.7

Time hours	Rainfall Depth %
16.50	89.3
16.75	89.8
17.00	90.3
17.25	90.8
17.50	91.3
17.75	91.8
18.00	92.2
18.25	92.6
18.50	93.0
18.75	93.4
19.00	93.8
19.25	94.2
19.50	94.6
19.75	95.0
20.00	95.3
20.25	95.6
20.50	95.9
20.75	96.2
21.00	96.5
21.25	96.8
21.50	97.1
21.75	97.4
22.00	97.7
22.25	98.0
22.50	98.3
22.75	98.6
23.00	98.9
23.25	99.2
23.50	99.5
23.75	99.8
24.00	100.0

Figure 2.6
24-HOUR MASS CURVE FOR MARICOPA COUNTY (SCS TYPE II)



2.5 PROCEDURE FOR THE DEVELOPMENT OF THE DESIGN RAINFALL

The following is the procedure for the development of the design rainfall. Notes and general guidance on the application of this procedure and the methodologies presented in this chapter are provided along with a detailed example in 9.1 RAINFALL.

1. Determine the size of the drainage area.

2. Determine the point rainfall depth or the areally averaged point rainfall depth, from Figure A.1 through Figure A.60 of Appendix A.1, depending on the desired storm duration and frequency.

3. For a single storm analysis, determine the depth-area reduction factor using Table 2.1 or Figure 2.1 for a 6-hour local storm and Table 2.2 or Figure 2.2 for a 24-hour general storm.

   For a multiple storm analysis, determine the drainage areas at key points of interest in the watershed. For each drainage area, determine the depth-area reduction factor using Table 2.1 or Figure 2.1 for a 6-hour local storm and Table 2.2 or Figure 2.2 for a 24-hour general storm.

   As drainage area increases, the average depth of rainfall over that area decreases. For situations that require runoff magnitudes at only one point in the watershed, the effective rainfall over the watershed can be simulated by a single storm. The single storm approach can be applied regardless of the number of subbasins used to define the runoff characteristics of the watershed.

   For situations that require runoff magnitudes at multiple points within a drainage area, the effective rainfall depth at each of those points is simulated using a set of index storms. The drainage areas of the index storms and thus the rainfall depth adjustment factors are selected to be representative of the contributing drainage areas at the points of interest. This implies that the watershed will be delineated with multiple subbasins.

4. Multiply the point rainfall depth by the appropriate depth-area reduction factor(s).

5. For a 6-hour local storm, use Figure 2.5 to select the appropriate pattern number(s) (rounded to the nearest 0.1 pattern number).

6. For a 6-hour local storm, use the dimensionless rainfall distributions of or Table 2.4 to calculate the dimensionless distribution(s) by linear interpolation between the two bounding pattern numbers.

For a 24-hour general storm, use the dimensionless rainfall distribution of Figure 2.6 or Table 2.5.

Note: Steps 3 through 6 are performed automatically in DDMSW.

3 RATIONAL METHOD

TABLE OF CONTENTS

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 run-off 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. This is the required minimum criteria for unincorporated areas of Maricopa County. If the development involves channel routing, the procedures given in Chapters 4 through 6 should be used, since the peak discharge 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, in cfs, from a given area.

C = a coefficient relating the runoff to rainfall.

i = average rainfall intensity, in inches/hour, lasting for a T_c.

T_c = the time of concentration, in hours.

A = drainage area, in 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, T_c, 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):

$$T_c = 11.4L^{0.5}K_b^{0.52}S^{-0.31}i^{-0.38} \qquad (3.2)$$

where:

T_c = time of concentration, in hours.

L = length of the longest flow path, in miles.

K_b = watershed resistance coefficient (see Table 3.1 or Figure 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 the hydrologic characteristics of small, urban watersheds result in minimal rainfall loss. This is due to the extent of imperviousness associated with urban watersheds and to the fact that the time of concentration is usually very short.

Rational Method runoff coefficients for land uses are provided in Table 3.2.

Table 3.1
EQUATION FOR ESTIMATING K_B IN THE T_C EQUATION

$$K_b = m \log_{10} A + b$$

Where A is drainage area, in acres

Type	Description	Typical Applications	Equation Parameters	
			m	b
A	Minimal roughness: Land surfaces that are relatively smooth and/or well graded. Surface runoff is sheet flow.	Commercial/industrial areas Residential areas 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 are still 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 rangelands Disturbed lands, 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

Note: A is the area of the entire subbasin, not the area of the surface type A, B, C or D within the subbasin.

Figure 3.1
RESISTANCE COEFFICIENT K_b
AS A FUNCTION OF WATERSHED SIZE AND SURFACE ROUGHNESS CHARACTERISTICS

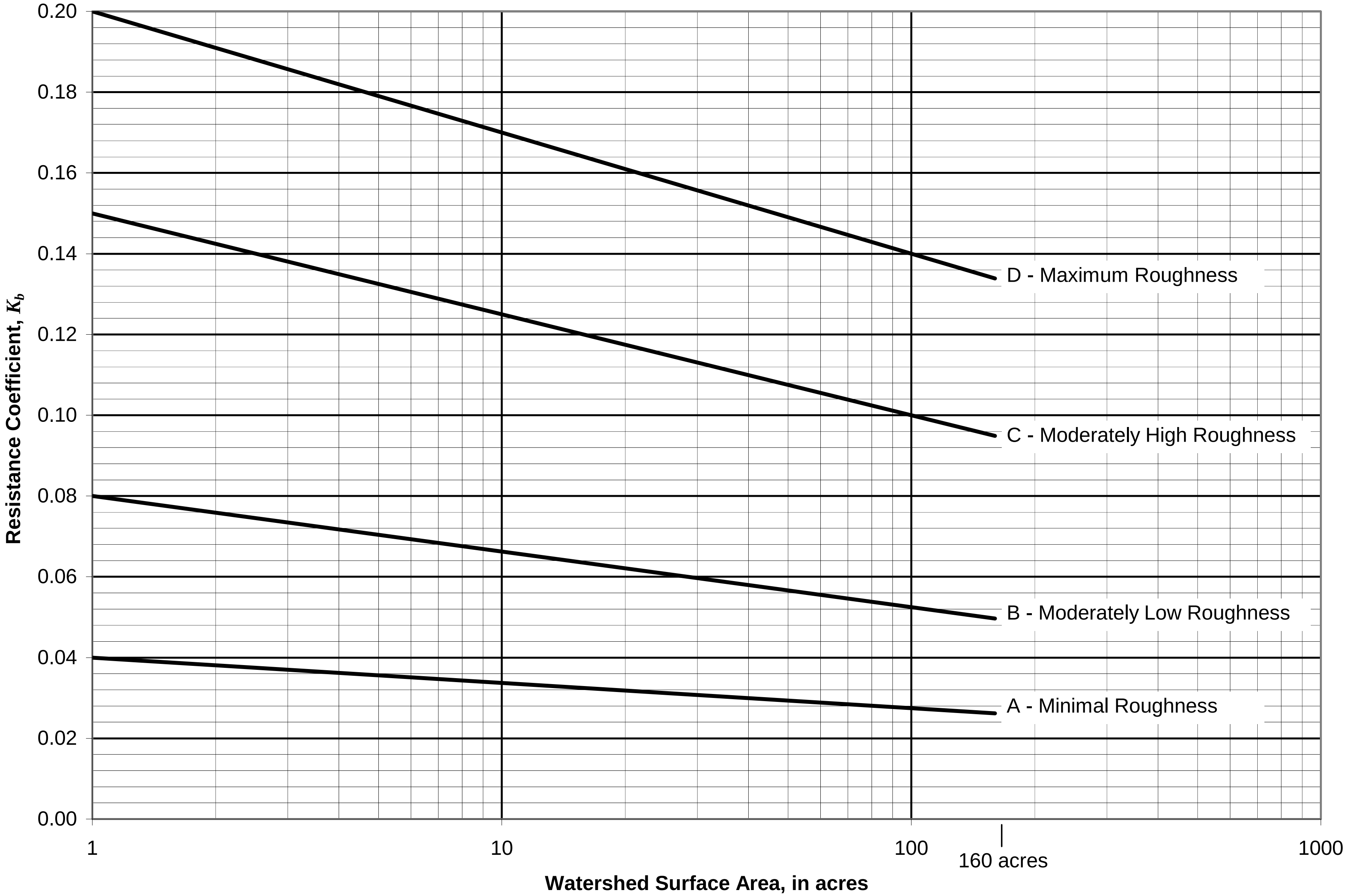


Table 3.2
RUNOFF COEFFICIENTS FOR MARICOPA COUNTY

Land Use Code	Land Use Category	Runoff Coefficients by Storm Frequency[1, 2]							
		2-10 Year		25 Year		50 Year		100 Year	
		min	max	min	max	min	max	min	max
VLDR	Very Low Density Residential[3, 4]	0.33	0.42	0.36	0.50	0.40	0.60	0.45	0.65
LDR	Low Density Residential[3, 4]	0.42	0.48	0.46	0.55	0.50	0.64	0.53	0.70
MDR	Medium Density Residential[3, 4]	0.48	0.65	0.53	0.72	0.58	0.78	0.60	0.80
MFR	Multiple Family Residential[3, 4]	0.65	0.75	0.72	0.83	0.78	0.90	0.82	0.94
I1	Industrial 1[3]	0.60	0.70	0.66	0.77	0.72	0.84	0.75	0.88
I2	Industrial 2[3]	0.70	0.80	0.77	0.88	0.84	0.95	0.88	0.95
C1	Commercial 1[3]	0.55	0.65	0.61	0.72	0.66	0.78	0.69	0.81
C2	Commercial 2[3]	0.75	0.85	0.83	0.94	0.90	0.95	0.94	0.95
P	Pavement and Rooftops	0.75	0.85	0.83	0.94	0.90	0.95	0.94	0.95
GR	Gravel Roadways & Shoulders	0.60	0.70	0.66	0.77	0.72	0.84	0.75	0.88
AG	Agricultural	0.10	0.20	0.11	0.22	0.12	0.24	0.13	0.25
LPC	Lawns/Parks/Cemeteries	0.10	0.25	0.11	0.28	0.12	0.30	0.13	0.31
DL1	Desert Landscaping 1	0.55	0.85	0.61	0.94	0.66	0.95	0.69	0.95
DL2	Desert Landscaping 2	0.30	0.40	0.33	0.44	0.36	0.48	0.38	0.50
NDR	Undeveloped Desert Rangeland	0.30	0.40	0.33	0.44	0.36	0.48	0.38	0.50
NHS	Hillslopes, Sonoran Desert	0.40	0.55	0.45	0.60	0.48	0.66	0.50	0.70
NMT	Mountain Terrain	0.50	0.70	0.65	0.80	0.70	0.90	0.75	0.90

Notes:

1. Runoff coefficients for 25-, 50- and 100-Year storm frequencies were derived using adjustment factors of 1.10, 1.20 and 1.25, respectively, applied to the 2-10 Year values with an upper limit of 0.95.

2. The ranges of runoff coefficients shown for urban land uses were derived from lot coverage standards specified in the zoning ordinances for Maricopa County.

3. Runoff coefficients for urban land uses are for lot coverage only and do not include the adjacent street and right-of-way, or alleys.

4, Values are based on the NDR terrain class. Values should be increased for NHS and NMT terrain classes by the difference between NHS (or NMT) and the NDR C values, up to a maximum of 0.95. Engineering judgement should be used.

5. Maricopa County has adopted specific values of C for each land use and storm frequency in the Drainage Policies and Standards for Maricopa County, Arizona (Maricopa County, 2007). These are the standard default values. The engineer/hydrologist may develop a computed composite value of C based on actual land uses, but must fully document the computations and assumptions and submit them to Maricopa County for approval. Many jurisdictions in Maricopa County may have adopted specific C coefficient values and procedures. The user should check with the appropriate agency before proceeding.

Table 3.3
RUNOFF COEFFICIENT DESCRIPTIONS FOR MARICOPA COUNTY

Land Use Code	Land Use Category Description
VLDR	40,000 sq. ft. and greater lot size
LDR	12,000 – 40,000 sq. ft. lot size
MDR	6,000 – 12,000 sq. ft. lot size
MFR	1,000 – 6,000 sq. ft. lot size
I1	Light and General
I2	General and Heavy
C1	Light, Neighborhood, Residential
C2	Central, General, Office, Intermediate
P	Asphalt and Concrete, Sloped Rooftops
GR	Graded and Compacted, Treated and Untreated
AG	Tilled Fields, Irrigated Pastures, slopes < 1%
LPC	Over 80% maintained lawn
DL1	Landscaping with impervious under treatment
DL2	Landscaping without impervious under treatment
NDR	Little topographic relief, slopes < 5%
NHS	Moderate topographic relief, slopes > 5%
NMT	High topographic relief, slopes > 10%

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.

5. The watershed should be of uniform land use. For example, sub-basins with both natural (undeveloped) and developed land uses should be broken into separate sub-basins where possible.

3.4 VOLUME CALCULATIONS

Volume calculations should be done by applying the following equation:

$$V = C\left(\frac{P}{12}\right)A \tag{3.3}$$

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 stormwater storage facility design, P equals the 100-year, 2-hour depth, in inches, as discussed in Section 2.2, and is determined from Figure A.56 of Appendix A.1.

3.5 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.

3.6 APPLICATION

The Rational Method can be used to calculate the generated peak discharge from drainage areas less than 160 acres. Procedures for calculating peak discharge are provided in the following sections. Notes and general guidance in the application of these procedures along with a detailed example are provided in Section 9.2.

3.6.1 Peak Discharge Calculation

1. Determine the area within the development boundaries.

2. Select the Runoff Coefficient C from Table 3.2. If the drainage subbasin contains subareas of different runoff characteristics, and thus different C coefficients, arithmetically area-weight the values of C.

3. Compile the site-specific depth-duration-frequency (D–D–F) and intensity-duration-frequency (I–D–F) statistics for the project site using NOAA Atlas 14 (see Section 2.2 and Section 9.1).

4. Calculate the time of concentration. This is to be done as an iterative process.

   a. Determine the K_b parameter from Table 3.1 or Figure 3.1. If the drainage subbasin contains subareas of different K_b values compute a K_b for each surface roughness class using the total area of the subbasin when applying Table 3.1 or Figure 3.1. Then arithmetically area-weight the values of K_b.

   b. Make an initial estimate of the duration and compute the intensity from the D–D–F data, or derive from the I–D–F curve for the desired frequency.

   c. Compute an estimated T_c using Equation (3.2). If the computed T_c is reasonably close to the estimated duration, then proceed to Step 5, otherwise repeat this step with a new estimate of the duration. The minimum T_c should not be less than 5-minutes.

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

6. As an alternative to the above procedure, the DDMSW program may be used to calculate peak discharge.

3.6.2 Multiple Basin Approach

The Rational Method can be used to compute peak discharges at intermediate locations within a drainage area less than 160 acres in size. A typical application of this approach is a local storm drain system where multiple subbasins are necessary to compute a peak discharge at each proposed inlet location. Consider the schematic example watershed shown in Figure 3.3. A peak discharge is needed for all three individual subbasins, subbasins A and B combined at Concentration Point 1 and subbasins A, B and C combined at Concentration Point 2. This can be accomplished using two different approaches: the combined watershed approach and the triangular hydrograph approach. The triangular hydrograph method is incorporated in the DDMSW computer program, but the combined hydrograph method is not. The combined hydrograph method is intended for use by engineers/hydrologists without access to a computer and DDMSW. Either method may be used but the engineer/hydrologist should receive prior approval from the jurisdiction before applying the combined watershed method. Steps for applying both approaches follow.

Combined Watershed Approach

1. Compute the peak discharge for each individual subbasin using steps 1 through 5 from Section 3.6.1.

2. Compute the arithmetically area-weighted value of C for subareas A and B.

3. Follow step 4 from Section 3.6.1 to calculate the T_c for the combined area of subbasins A and B at Concentration Point 1.

4. Compare the T_c values from subbasins A and B to the T_c value for the combined area at Concentration Point 1. Compute the peak discharge at Concentration Point 1 using the i for the combined subbasin T_c from step 3. If the combined peak discharge is less than the discharges for the individual subbasins, use the largest discharge as the peak discharge at Concentration Point 1. The design discharge should not decrease going downstream in a conveyance system unless storage facilities are used to attenuate peak flows.

   If there are more than two watersheds being combined, and the combined peak discharge is less than any of the individual subbasin peak discharges, another check needs to be made. A long narrow watershed having a long T_c may not be representative of the majority of the combined watershed and could be the reason the combined subbasin peak discharge is too low. A combination of the other subbasins may be more appropriate, using a computed T_c for the new combination.

5. Compute the arithmetically area-weighted value of C for combined subbasins A, B and C.

6. Calculate the T_c for the combined area of subbasins A, B and C at Concentration Point 2 using the following two methods:

   Method 1 - Follow step 4 from Section 3.6.1 to calculate the T_c for the single basin composed of all three subbasins.

   Method 2 - Compute the travel time from Concentration Point 1 to Concentration Point 2 using the Manning equation or other appropriate technique and hydraulic parameters for the conveyance path. Add the computed travel time for the conveyance path to the T_c from Concentration Point 1.

7. Using the T_c values from Methods 1 and 2 as well as the T_c from subbasin C, calculate the peak discharge at Concentration Point 2 as follows:

   a. If the T_c value from Method 1 is the longest, compute the total peak discharge using the Method 1 intensity, the arithmetically area-weighted value of C for all three subbasins and the total contributing drainage area at Concentration Point 2.

   b. If the T_c value from Method 2 is the longest, determine i directly from the D–D–F statistics or the I–D–F curve from step 3 of Section 3.6.1. Compute the total peak discharge at Concentration Point 2 using the arithmetically area-weighted value of C for all three subbasins and the total contributing drainage area at Concentration Point 2.

   c. If the T_c from subbasin C is the longest, compute the total peak discharge using the i for subbasin C, the arithmetically area-weighted value of C for all three subbasins and the total contributing drainage area at Concentration Point 2.

8. This method is not included in the DDMSW program.

Triangular Hydrograph Approach

1. Compute the peak discharge for each individual subbasin using steps 1 through 5 from Section 3.6.1.

2. Plot triangular hydrographs for subbasins A and B on a single sheet of graph paper using the dimensionless triangular hydrograph shown in Figure 3.2 as the model. The peak discharge occurs at time T_c and the hydrograph time base is $2.67T_c$.

3. Add the hydrograph ordinates from subbasins A and B to produce and plot a combined hydrograph at Concentration Point 1.

4. Compute the travel time from Concentration Point 1 to Concentration Point 2 using the Manning equation or other appropriate technique and hydraulic parameters for the conveyance path.

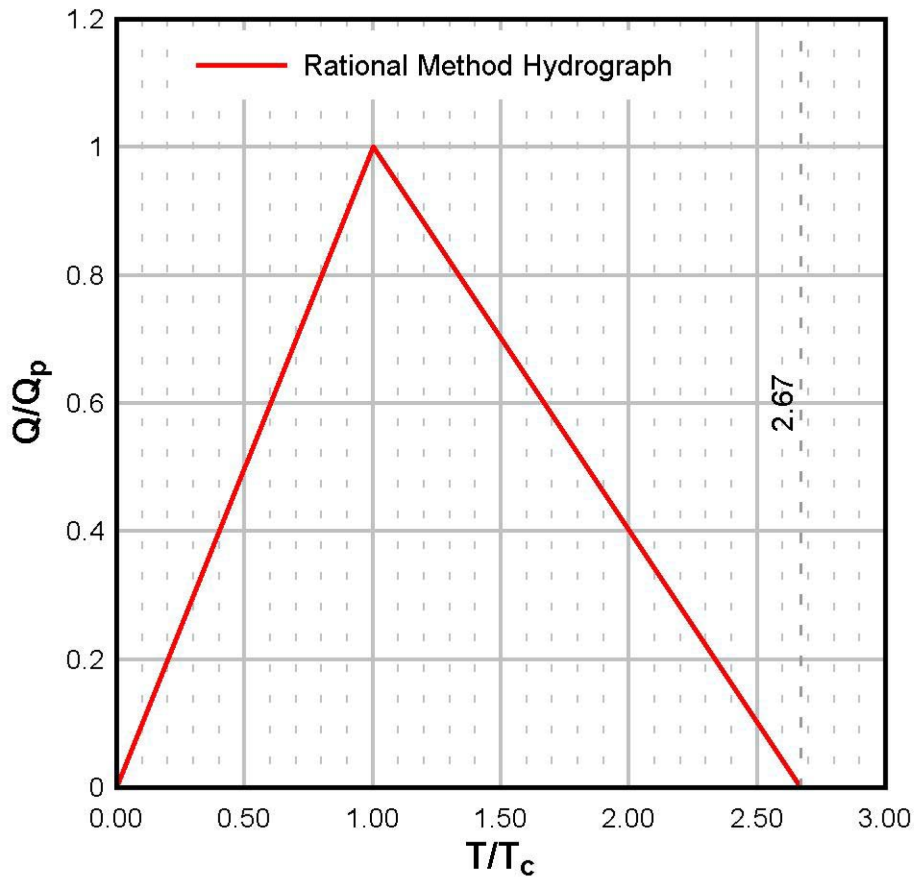
5. Plot the hydrograph for subbasin C on a new piece of graph paper, starting at time = 0.0. Plot the hydrograph for Concentration Point 1 starting at time = travel time from Concentration Point 1 to Concentration Point 2.

6. Add the hydrograph ordinates from Concentration Point 1 and subbasin C to produce and plot a combined hydrograph at Concentration Point 2.

Figure 3.2

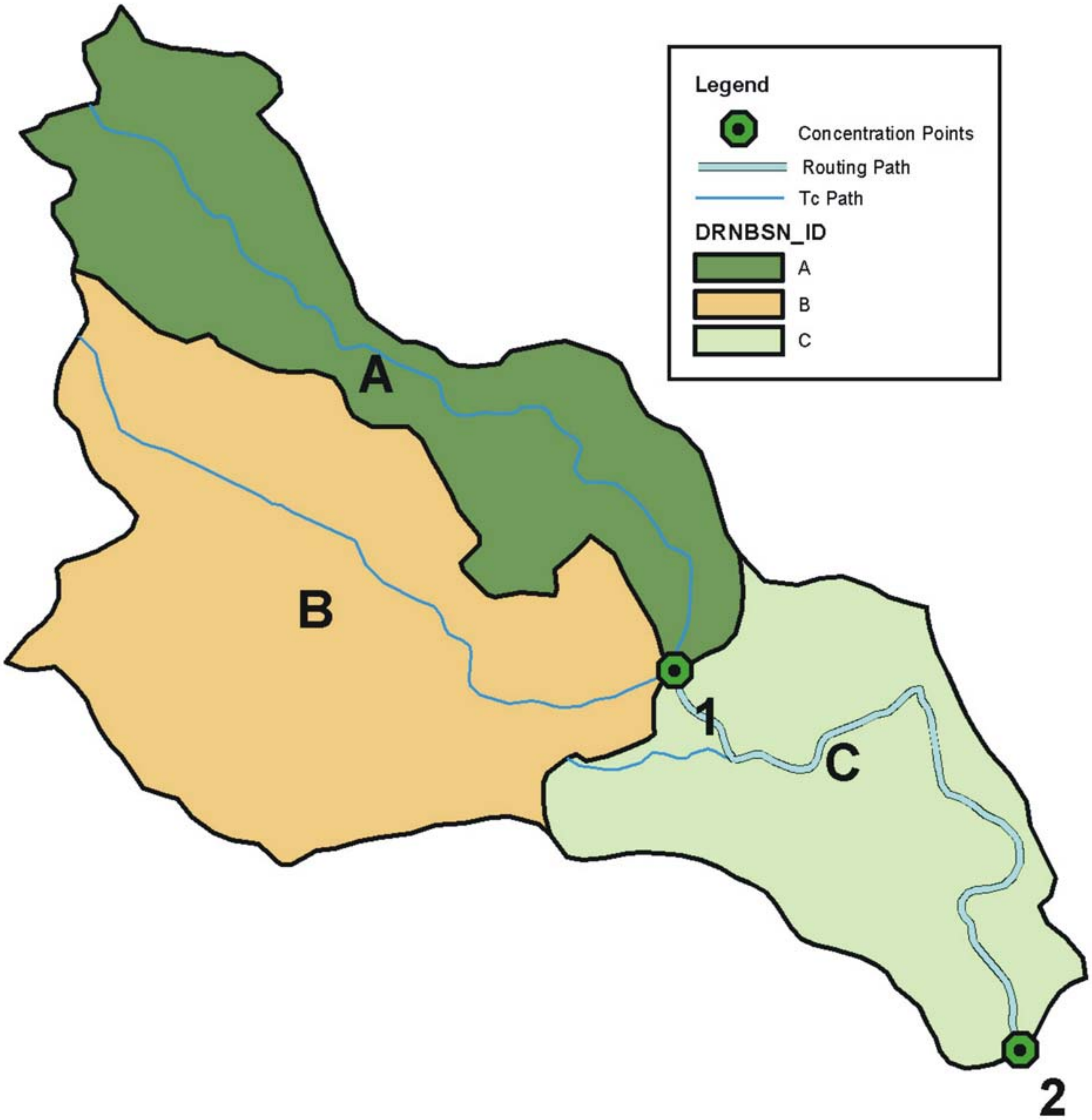
TRIANGULAR HYDROGRAPH FOR USE WITH THE RATIONAL METHOD

SOURCE: HIGHWAY HYDROLOGY (DERIVED FROM FHWA, 2002[1])



1. Receding limb of hydrograph set at $1.67T_c$ after review of representative measured urban runoff hydrographs from USGS flow gages in Mesa and Glendale, AZ.

Figure 3.3
SCHEMATIC EXAMPLE WATERSHED



4 RAINFALL LOSSES

TABLE OF CONTENTS

4.1 GENERAL

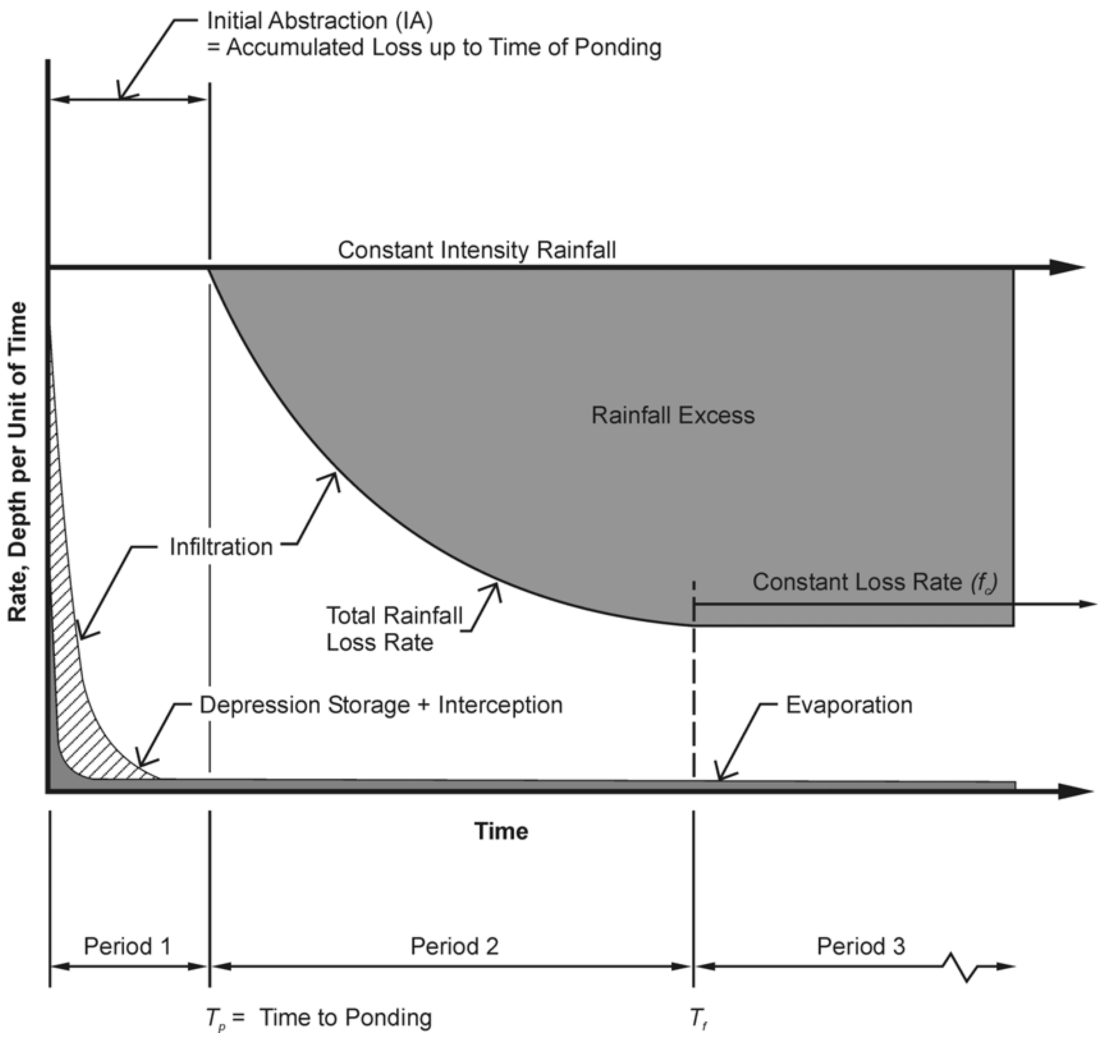
Rainfall excess is that portion of the total rainfall depth that drains directly from the land surface by overland flow. By a mass balance, rainfall excess plus rainfall loss equals precipitation. When performing a flood analysis using a rainfall-runoff model, the determination of rainfall excess is 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 the 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 et al. 1982), but little is known of the interception values for most hydrologic problems. Estimates of interception for various vegetation types (Linsley et al. 1982) are:

Vegetation Type	Interception, inches
Hardwood tree	0.09
Cotton	0.33
Alfalfa	0.11
Meadow grass	0.08

FIGURE 4.1
SCHEMATIC REPRESENTATION OF RAINFALL LOSSES FOR A UNIFORM INTENSITY RAINFALL



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 zero. Interception is considered for flood hydrology in Maricopa County, but for practical purposes an actual value is not assigned.

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.

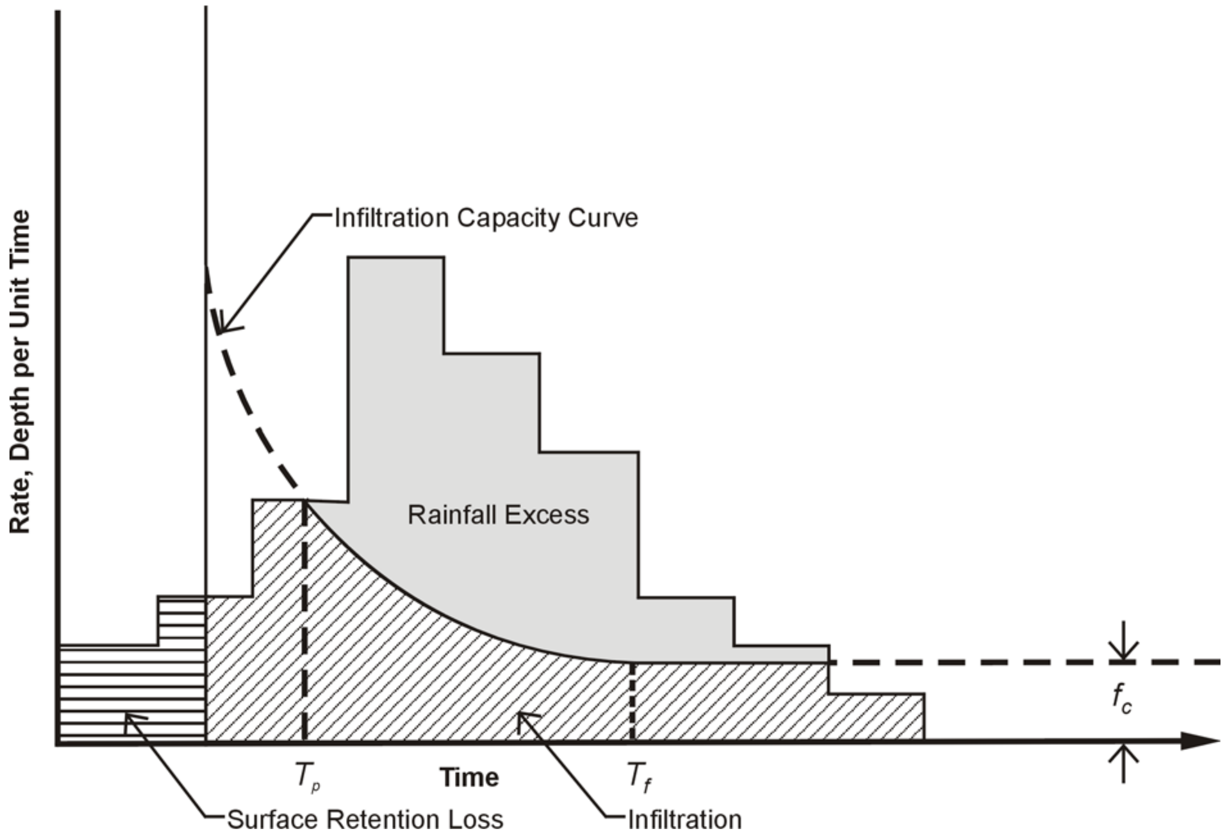
Three periods of rainfall losses are illustrated in Figure 4.1, and these must be understood and their implications appreciated before applying the procedures in this manual. First, there is a period of initial loss when no rainfall excess (runoff) is produced. During this initial period, the losses 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 (T_p). 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 (f_c). 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 (T_p) which signals the beginning of surface runoff. As illustrated in both Figure 4.1 and Figure 4.2, after the time of ponding the infiltration rate decreases exponentially and may reach steady-state, equilibrium rate (f_c). 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 the 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 part of the 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 surface 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 slopes 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 and 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 et al. 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 et al. 1982b). Surface retention losses for various land-uses and surface cover conditions in Maricopa County have been extrapolated from those reported estimates and these are shown in Table 4.2.

4.3 INFILTRATION

Infiltration is the movement of water from the land surface into the soil. Gravity and capillary are the two forces that drive infiltration by drawing water into and through the pore spaces of the soil matrix. 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. NRCS 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 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. NRCS 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 the 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 (f_c). 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 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 NRCS CN method previously was (pre-1990) the most extensively used rainfall loss rate method in Maricopa County and Arizona, and it had wide acceptance among many agencies, consulting engineering firms, and individuals throughout the community. However, because of both theoretical concerns and practical limitations, the NRCS 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 Section 4.4.1 and Section 4.4.2. The IL+ULR is a simplified model that is used extensively for flood hydrology and data often are available to estimate the two parameters for that method. The Green and Ampt infiltration equation is a physically based model that has been in existence since 1911, and is an option in HEC-1.

The preferred method, and the most theoretically accurate, is the Green and Ampt infiltration equation. That 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 C), 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/or the local regulatory agency.

4.4.1 Green and Ampt Infiltration Equation

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

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

$f = i$ for f P 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 et al. 1976) is:

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

where:

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

The average filtration rate is:

$$f = \frac{\Delta F}{\Delta t} \qquad (4.3)$$

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 abstraction (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 the first phase. 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 4.2. For example, about 0.35 inches of rainfall will not become 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 in 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 et al. 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 4.1. A best-fit plot of columns (2), (3), (4) and (5) is shown in Figure 4.3. Figure 4.3 should be used for selection of values of PSIF and DTHETA based on XKSAT. The values of XKSAT and PSIF from Table 4.1 or Figure 4.3 should be used if general soil texture classification of the drainage area is available. References used to create Table 4.1 can be found in the Documentation Manual available for review through the Engineering Division library at the FCDMC.

In Table 4.1, 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 Ampt method should be used with the parameter values for loamy sand or the IL+ULR method should be used with the appropriately determined values for the parameters.

Table 4.1
GREEN AND AMPT LOSS RATE PARAMETER VALUES FOR BARE GROUND

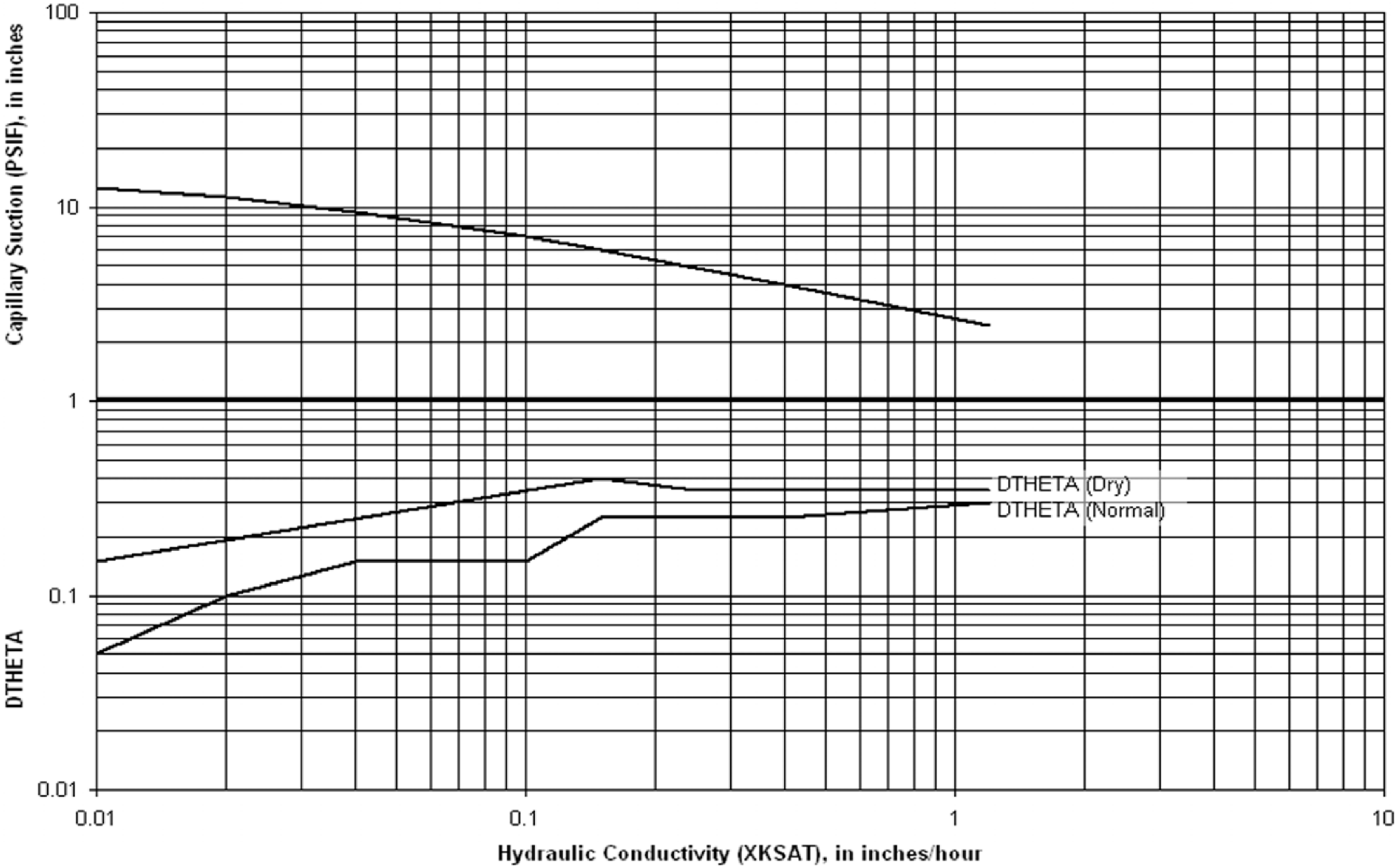
Soil Texture Classification (1)	XKSAT inches/hour (2)	PSIF inches (3)	DTHETA[1]		
			Dry (4)	Normal (5)	Saturated (6)
loamy sand & sand	1.20	2.4	0.35	0.30	0
sandy loam	0.40	4.3	0.35	0.25	0
loam	0.25	3.5	0.35	0.25	0
silty loam	0.15	6.6	0.40	0.25	0
silt	0.10	7.5	0.35	0.15	0
sandy clay loam	0.06	8.6	0.25	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

Notes:

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)



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 zero to the effective porosity. If the soil is effectively saturated at the start of rainfall then DTHETA equals zero; 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 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 zero 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 4.1. 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. However, judgement should be exercised when using a “Saturated” condition, particularly for large areas of irrigated land as it is unlikely that the entire area is being irrigated at the same time.

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 for 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 XKSAT value (and naturally occurring rock outcrop percentage) for each map unit as identified by the National Resources Conservation Service (NRCS) is provided in APPENDIX C. The data contained in this appendix covers the majority of the northern portion of Maricopa County. The values for XKSAT listed in the appendix are weighted based on the percentage of each unique soil texture present in the map unit. The weighted values take into consideration the horizon depth of the soil textures in regard to the expected depth of infiltration during the design storm duration. An example of the weighting procedure along with other assumptions and criteria used in developing the XKSAT values are provided at the front of APPENDIX C. The composite XKSAT is calculated by Equation (4.4):

$$\overline{XKSAT} = a\log_{10}\left(\frac{\Sigma A_i \log_{10} XKSAT_i}{A_T}\right) \quad (4.4)$$

where:

$\overline{XKSAT}$	=	composite subarea hydraulic conductivity, inches/hour
$XKSAT_i$	=	hydraulic conductivity of a map unit, inches/hour (from APPENDIX C)
A_i	=	size of subarea
A_T	=	size of the watershed or modeling subbasin

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

Procedures for Adjusting XKSAT for Vegetation Cover

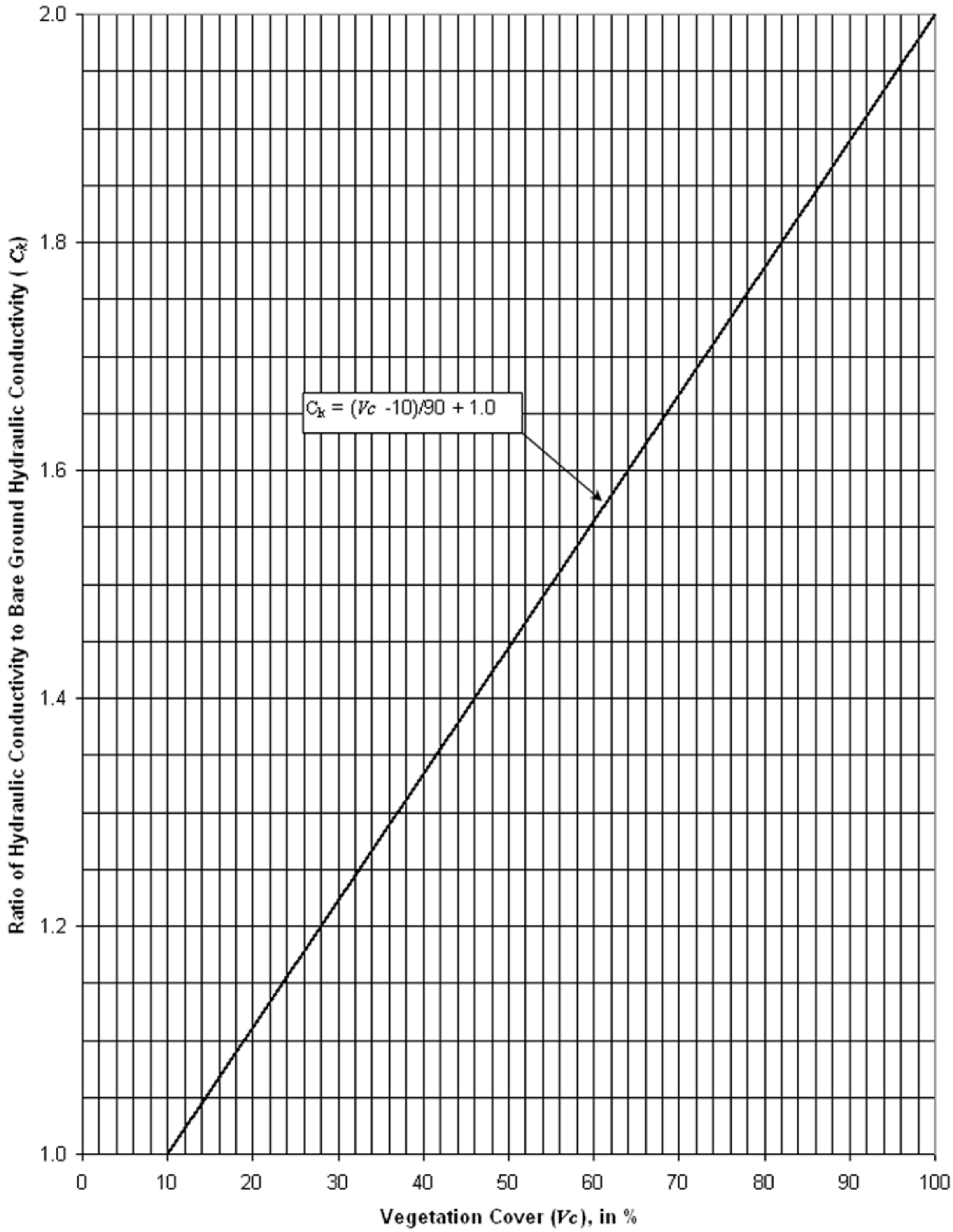
The hydraulic conductivity (XKSAT) can be affected by several factors besides soil texture. For example, hydraulic conductivity is reduced by soil crusting, increased by tillage, and increased by the influence of ground cover and canopy cover. The values of XKSAT that are presented for bare ground as 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 et al. 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 et al. 1964; Sabol et al. 1982a; Sabol et al. 1982b; Bach, 1984; Ward, 1986; Lane et al. 1987; Ward and Bolin, 1989). This correction factor can be used based on an estimate of vegetation cover as used by the NRCS in soil surveys; that is, vegetation cover is evaluated on basal area for grass and forbs, and is evaluated 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 and 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 adjustment to the infiltration parameters can be made, as necessary, for special flood studies such as reconstitution of storm events.

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



Selection of IA, RTIMP, and Percent Vegetation Cover for Urban Areas

Table 4.2 contains suggested values for IA, RTIMP, and percent vegetation cover for various natural conditions and urban land use types. The values in Table 4.2 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, 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 4.2
***IA*, *RTIMP*, AND VEGETATIVE CANOPY COVER FOR REPRESENTATIVE LAND USES IN MARICOPA COUNTY**

Land Use[1] Code	Land Use Category	Description	IA[2] inches	RTIMP[2,3] %	Vegetation Cover[2,4] %
VLDR	Very Low Density Residential[3]	40,000 sq. feet and greater lot size	0.30	5	30
LDR	Low Density Residential[3]	12,000 – 40,000 sq. feet lot size	0.30	15	50
MDR	Medium Density Residential[3]	6,000 – 12,000 sq. feet lot size	0.25	30	50
MFR	Multiple Family Residential[3]	1,000 – 6,000 sq. feet lot size (# du/ac)	0.25	45	50
I1	Industrial 1[3]	Light and General	0.15	55	60
I2	Industrial 2[3]	General and Heavy	0.15	55	60
C1	Commercial 1[3]	Light, Neighborhood, Residential	0.10	80	75
C2	Commercial 2[3]	Central, General, Office, Intermediate	0.10	80	75
P	Pavement and Rooftops	Asphalt and Concrete, Sloped Rooftops	0.05	95	0
GR	Gravel Roadways & Shoulders	Graded and Compacted, Treated and Untreated	0.10	5	0
AG	Agricultural	Tilled Fields, Irrigated Pastures, slopes < 1%	0.50	0	85
LPC	Lawns/Parks/Cemeteries	Over 80% maintained lawn	0.20	Varies[5]	80
DL1	Desert Landscaping 1	Landscaping with impervious under treatment	0.10	95	30
DL2	Desert Landscaping 2	Landscaping without impervious under treatment	0.20	0	30
NDR	Undeveloped Desert Rangeland	Little topographic relief, slopes < 5%	0.35	Varies[5]	Varies[6]
NHS	Hillslopes, Sonoran Desert	Moderate topographic relief, slopes > 5%	0.15	Varies[5]	Varies[6]
NMT	Mountain Terrain	High topographic relief, slopes > 10%	0.25	Varies[5]	Varies[6]

Notes:
1. Other land use or zoning classifications, such as Planned Area Development and Schools must be evaluated on a case by case basis.
2. 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 hydrologic variations from these typical values.
3. RTIMP = Percent Effective Impervious Area, including right-of-way. Effective means that all impervious areas are assumed to be hydraulically connected. The RTIMP values may need to be adjusted based on an evaluation of hydraulic connectivity.
4. Vegetation Cover = Percent vegetation cover for pervious areas only.
5. RTIMP values must be estimated on a case by case basis.
6. Vegetation Cover values must be estimated on a case by case basis.

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. Initially, all rainfall is prevented from becoming 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 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 Table 4.3 and Table 4.4. Table 4.4 was prepared based on the values in Table 4.3 and the hydraulic conductivities shown in Table 4.1. 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 initial infiltration (II) of Table 4.4 and surface retention loss (IA) of Table 4.2; 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 using the NRCS CN equations for estimated initial abstraction, written as:

$$STRTL = \frac{200}{CN} - 2 \tag{4.5}$$

Estimates for CN for the drainage area or subbasin should be made referring to various publications of the NRCS, particularly TR-55 (NRCS, 1986). 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.

FIGURE 4.5
REPRESENTATION OF RAINFALL LOSS
ACCORDING TO THE INITIAL LOSS PLUS UNIFORM LOSS RATE (IL + ULR)

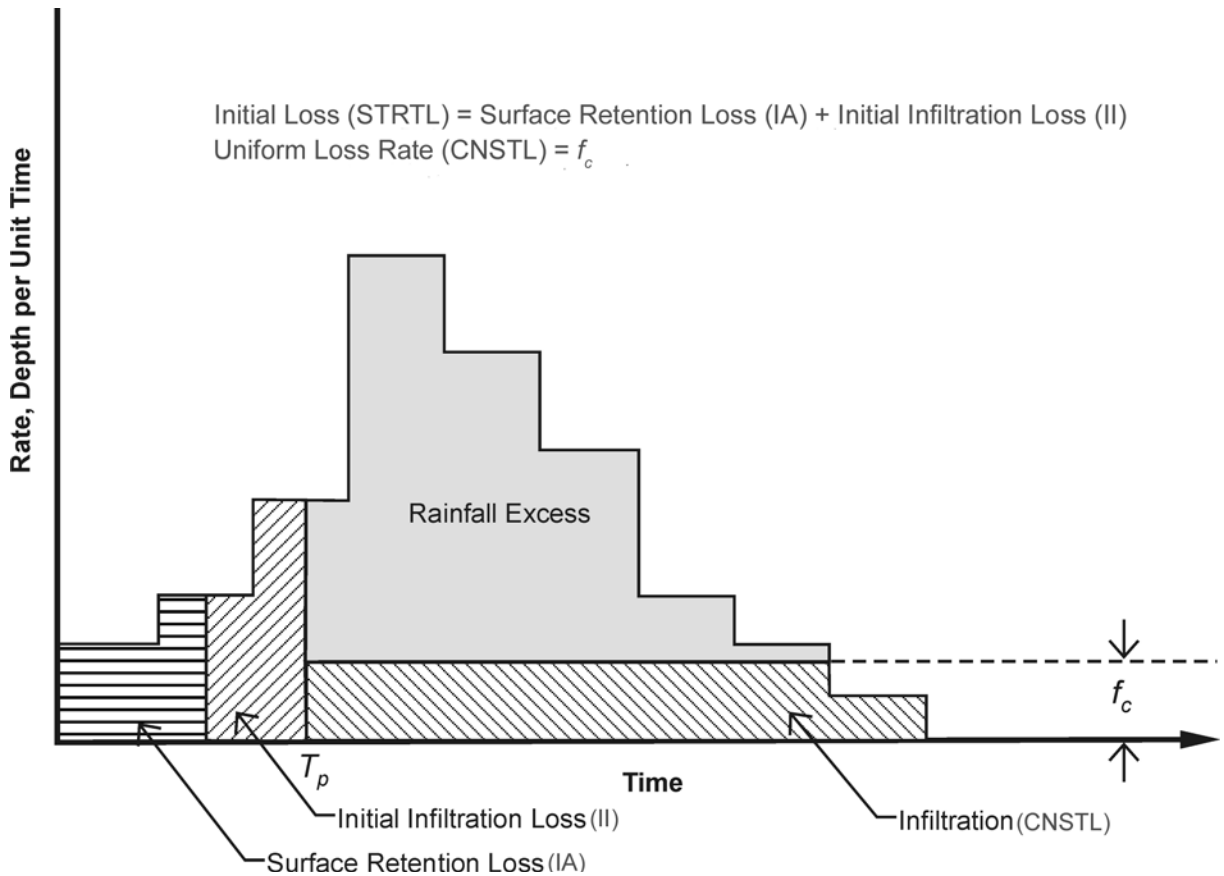


Table 4.3
PUBLISHED VALUES OF UNIFORM LOSS RATES

	Uniform Loss Rate, inches/hour		
Hydrologic Soil Group (1)	**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

Notes:
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

Notes:

1. Selection of II:

Dry = Nonirrigated lands, such as desert and rangeland.
Normal = Irrigated lawn, turf, and permanent pasture.
Saturated = Irrigated agricultural land.

4.5 PROCEDURE FOR ESTIMATING LOSS RATES

Procedures for estimating rainfall loss rates are provided in the following sections. Notes and general guidance on the application of these procedures are provided along with a detailed example using the Green and Ampt method in Section 9.3.

4.5.1 Green and Ampt Method

A. When soils data are available:

1. Prepare a base map of the drainage area delineating subbasins, if used.
2. Determine the location of the study area in regard to the limits of the soil surveys provided in APPENDIX C.
    a. If the study area is completely contained within these limits:
        i. Overlay the watershed limits on the soil survey maps from the appropriate soil survey report(s) and tabulate the map units present within the watershed. GIS or CAD coverages of the soil survey information are available from the District's GIS branch.
        ii. Cross reference the map units with those listed in APPENDIX C and tabulate the weighted value of XKSAT for each map unit and the corresponding percent imperviousness.

iii. Proceed to item (3) or (4).

b. If the study area is partly or entirely outside the limits of the soils surveys provided in APPENDIX C:

i. Refer to the figure showing the status of soil surveys in Arizona (at the front of APPENDIX C) for other sources of soils data. Other sources of soils data are:

- General soils surveys by county prepared by the NRCS.
- Other detailed soil surveys.
- Terrestrial Ecosystem Survey of Tonto National Forest.

ii. Using the data contained in the alternative source, follow the example procedure for determination of the weighted XKSAT value for each unique map unit that is included at the front of APPENDIX C

iii. Proceed to item (3) or (4).

3. If the watershed or subbasin contains only one soil texture, then use Figure 4.3 to select the value of PSIF and DTHETA.

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

a. Calculate the area-weighted value of XKSAT by using Equation (4.4).

b. Select the corresponding values of PSIF and DTHETA from Figure 4.3.

c. Calculate the arithmetically area-weighted value of naturally occurring RTIMP.

5. Select values of IA for each land use and/or soil cover using Table 4.2. Arithmetically area-weight the values of IA if the drainage area or subbasin is composed of subareas of different IA.

6. Select values of RTIMP for each land use using Table 4.2. Arithmetically area-weight the values of RTIMP if the drainage area or subbasin is composed of land use subareas of different RTIMP. Compute the weighted value of RTIMP based on the area-weighted land use and denote it as $RTIMP_L$. Arithmetically area-weight the rock outcrop percentages for all soil map units to obtain $RTIMP_N$. Estimate the effective percentage of rock outcrop for each soil map unit that is hydraulically connected. Arithmetically area-weight the effective percentage of rock outcrop for all soil map

units to obtain subbasin effective impervious area (EFF) in percent. Compute the final composite value of RTIMP using Equation (4.6).

$$RTIMP = RTIMP_L + \frac{EFF}{100}(RTIMP_N) \quad (4.6)$$

7. Estimate the vegetative cover (VC) for the natural portions of the drainage area or subbasin. Select values of VC for each land use using Table 4.2. Arithmetically area-weight the values of VC if the drainage area or subbasin is composed of land use subareas of different VC. Arithmetically average the natural VC and the area-weighted land use VC.

8. Adjust the XKSAT value for VC using Figure 4.4, if appropriate.

9. Arithmetically average $DTHETA_{dry}$ (natural portions of the drainage area or subbasin) and $DTHETA_{normal}$ (Developed portions of the drainage area or subbasin), if appropriate.

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/or the local agency before initiating the 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 Table 4.2 and Table 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 4.3 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.

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5 UNIT HYDROGRAPH PROCEDURES

TABLE OF CONTENTS

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.

$$I - O = \frac{dS}{dt} \qquad (5.1)$$

where:

I = Inflow

O = Outflow

$\frac{dS}{dt}$ = Change in storage per change in time.

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. 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 10 square miles and is the preferred procedure for urban watersheds. 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. A unit hydrograph is derived from or is representative of a specific watershed; therefore, a unit hydrograph is a lumped parameter that reflects all of the physical characteristics of the watershed that affect the time rate at which rainfall excess drains 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 though 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:

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

$$C = \frac{2\Delta t}{2R + \Delta t} \tag{5.3}$$

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:

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

where:

U_i = the ordinates of the Clark Unit Hydrograph.

The Clark method uses two numeric parameters, T_c and R, and a graphical parameter, the time-area relation. Clark (1945) defined T_c 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 hydrographs with steep rising and recession limbs 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.

A graphical parameter called the time area relation 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 5.1
CONCEPTUAL ANALOGY OF LINEAR RESERVOIR ROUTING TO THE GENERATION OF A STORM HYDROGRAPH BY THE CLARK UNIT HYDROGRAPH METHOD

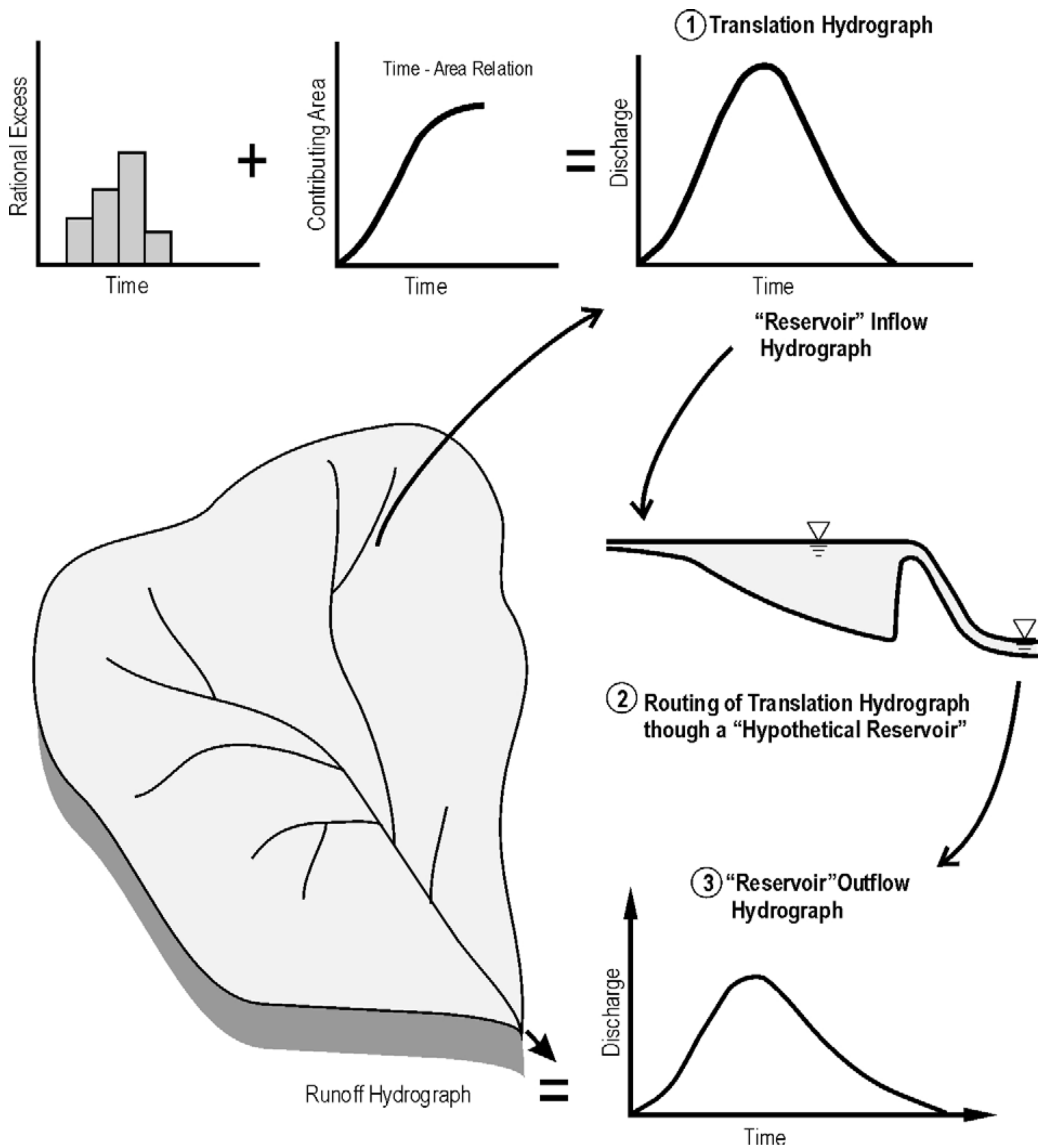
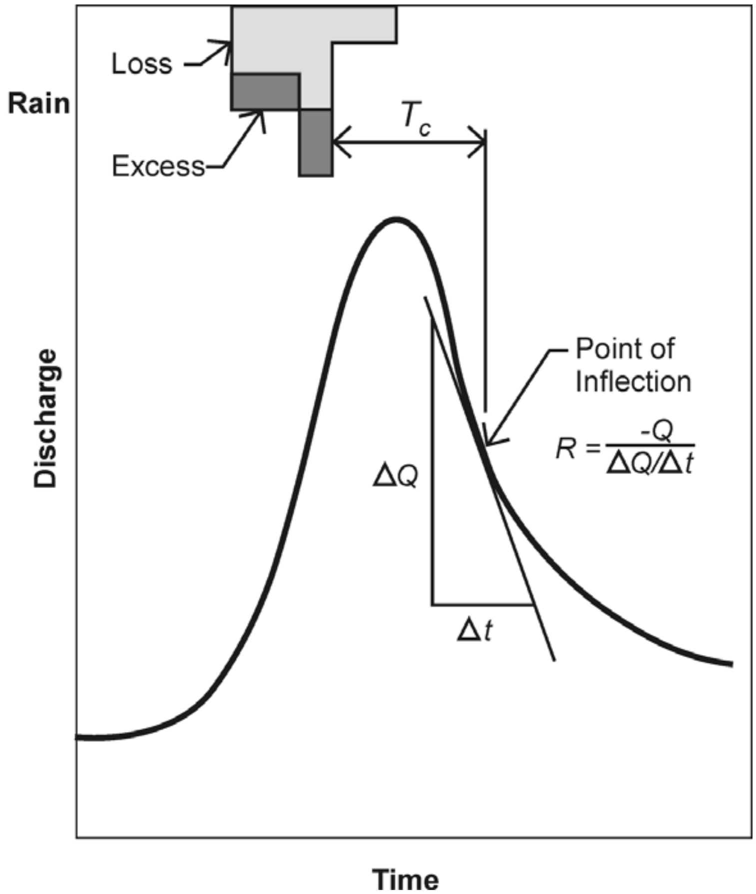


Figure 5.2
DEFINITION SKETCH OF CLARK UNIT HYDROGRAPH PARAMETERS FROM HYDROGRAPH ANALYSIS



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 area 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. The runoff that is available at the outlet of the watershed is the product of incremental area and rainfall excess.

At the end of the first 5 minutes of rainfall excess, the available runoff at the outlet of the watershed is:

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

where:

c = 60.5 cfs/acre-inch/minute

Δt = 5 minutes

I_1 = (8 acres)(0.10 inch)(60.5 cfs/acre-inch/minute)/(5 minutes)

= 9.7 cfs

At the end of 10 minutes the available runoff is:

$$I_2 = (A_1 R_2 + A_2 R_1) \frac{c}{\Delta t}$$

$$= [(8)(.55) + (24)(.10)] \times \frac{60.5}{5}$$

$$= 82.3\ cfs$$

At the end of 15 minutes the available runoff is:

$$I_3 = (A_1 R_3 + A_2 R_2 + A_3 R_1) \times \frac{c}{\Delta t}$$

$$= [(8)(.30) + (24)(.55) + (38)(.10)] \times \frac{60.5}{5}$$

$$= 234.7\ cfs$$

At the end of 20 minutes the available runoff is:

$$I_4 = (A_1 R_4 + A_2 R_3 + A_3 R_2 + A_4 R_1) \times \frac{c}{\Delta t}$$

$$= [(8)(.15) + (24)(.30) + (38)(.55) + (32)(.10)] \times \frac{60.5}{5}$$

$$= 393.3\ cfs$$

At the end of 25 minutes the available runoff is:

$$I_5 = (A_1 R_5 + A_2 R_4 + A_3 R_3 + A_4 R_2 + A_5 R_1) \times \frac{c}{\Delta t}$$

$$= [(8)(0) + (24)(.15) + (38)(.30) + (32)(.55) + (18)(.10)] \times \frac{60.5}{5}$$

$$= 416.2\ cfs$$

Notice that, for this example, all incremental rainfalls equal 0.0 from R_5 onward.

<u>At the end of 30 minutes the available runoff is:</u>

$$I_6 = (A_3R_4 + A_4R_3 + A_5R_2) \times \frac{c}{\Delta t}$$

$$= [(38)(.15) + (32)(.30) + (18)(.55)] \times \frac{60.5}{5}$$

$$= 304.9\ cfs$$

<u>At the end of 35 minutes the available runoff is:</u>

$$I_7 = (A_4R_4 + A_5R_3) \times \frac{c}{\Delta t}$$

$$= [(32)(.15) + (18)(.30)] \times \frac{60.5}{5}$$

$$= 123.4\ cfs$$

<u>At the end of 40 minutes the available runoff is:</u>

$$I_8 = (A_5R_4) \times \frac{c}{\Delta t}$$

$$= [(18)(.15)] \times \frac{60.5}{5}$$

$$= 32.7\ cfs$$

<u>After 45 minutes (rainfall excess of 20 minutes plus travel time of 25 minutes) the available runoff is:</u>

$$I_9 = 0\ cfs$$

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 Equation (5.2) through Equation (5.4) resulting in the final runoff hydrograph. For example, assume that R = 15 minutes, and the runoff hydrograph is shown in Figure 5.3(d).

Table 5.1
RUNOFF HYDROGRAPH

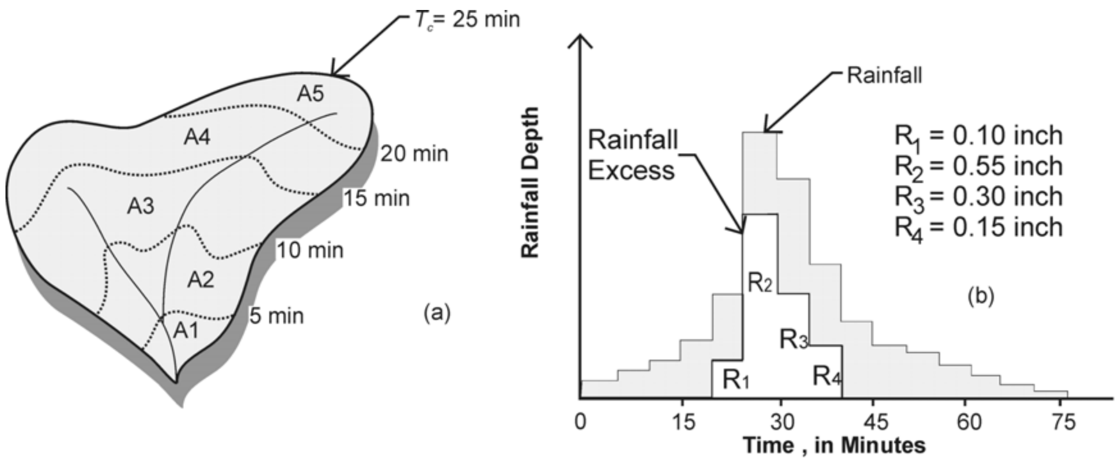
		Hydrograph		
		Translation,	Instantaneous,	Runoff,
Increment (1)	Time minutes (2)	(I) cfs (3)	(O) cfs (4)	(U) cfs (5)
1	5	9.7	2.8	1.4
2	10	82.3	25.9	14.3
3	15	234.7	86.4	56.1
4	20	393.3	175.4	131.9
5	25	416.2	245.2	210.3
6	30	304.9	262.6	253.9
7	35	123.4	222.2	242.4
8	40	32.7	167.2	194.7
9	45	0.0	118.7	143.0
10	50	0.0	84.3	101.5
11	55	0.0	59.9	72.1
12	60	0.0	42.5	51.2
13	65	0.0	30.2	36.3
14	70	0.0	21.4	25.8

Notes:

1. Δt = 5 minutes
2. R = 15 minutes
3. $C = 2\Delta t/(2R + \Delta t) = 0.29$
4. Assume O_{i-1} for increment 1 = 0.0

Notice that the Clark Unit Hydrograph itself was never developed per se, but 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 HEC-1.

Figure 5.3
EXAMPLE OF STORM HYDROGRAPH GENERATION USING THE CLARK UNIT HYDROGRAPH METHOD

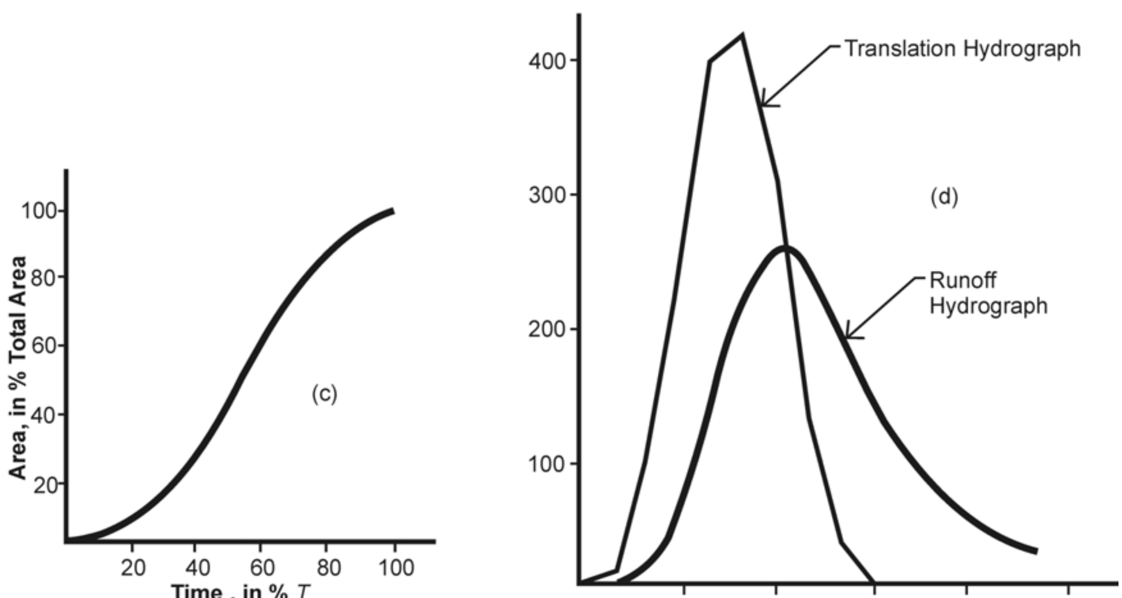


Watershed Map and Isochrones

Rainfall Hyetograph and Rainfall Excess Distribution

Table Showing Development of Dimensionless Time-Area Relation

Isochrone Zone	Area Acres	Accumulated Area	Accumulated Area as % of Total Area	Travel Time as % of *Tc*
(1)	(2)	(3)	(4)	(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	80
A_5	18	120	100	100



Dimensionless Time-Area Relation

Time Since Start of Rainfall Excess

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 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 database. Most often, the parameters are estimated by generalized relations that may have been developed from a relatively large and diverse database. The parameter estimation procedures that are recommended herein are of the 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, 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 T_c equation is based on the research of Papadakis and Kazan (1987). A large database 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 *Hydrology 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, those 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 T_c 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 T_c 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, T_c has been adopted with some procedural modifications from Papadakis and Kazan (1987).

$$T_c = 11.4L^{0.5}K_b^{0.52}S^{-0.31}i^{-0.38} \quad (5.5)$$

where:

T_c = time of concentration, in hours.

L = length of the hydraulically longest flow path, in miles.

K_b = watershed resistance coefficient (see Figure 5.5, or Table 5.3).

S = watercourse slope, in feet/mile.

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

L is the length of the flow path from the basin outlet to the hydraulically most distant point in the watershed. The hydraulically most distant point is not necessarily the longest path, but may be a shorter length with an appreciably flatter slope.

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 T_c. 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 of steep natural watercourses should be adjusted by using Table 5.2 or Figure 5.4.

Figure 5.4

SLOPE ADJUSTMENT FOR STEEP WATERCOURSES IN NATURAL WATERSHEDS

(SOURCE: DRAINAGE CRITERIA MANUAL, URBAN DRAINAGE AND FLOOD CONTROL DISTRICT, COLORADO, MAY 1984.)

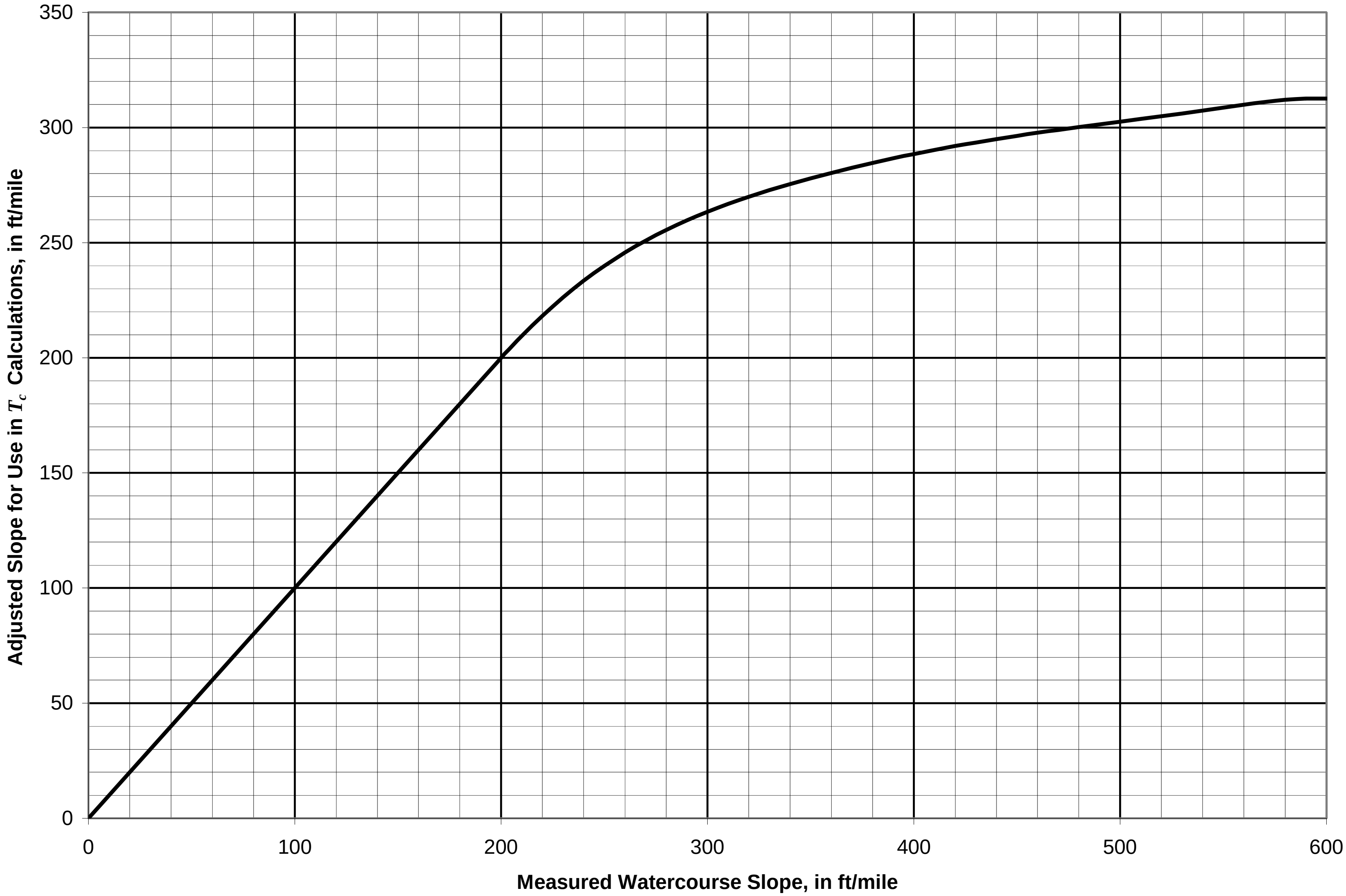


Table 5.2
SLOPE ADJUSTMENT FOR STEEP WATERCOURSES

Natural Slope (S)	Adjusted Slope (S_{adj})	Natural Slope (S)	Adjusted Slope (S_{adj})
200	200	410	290
210	209	420	292
220	218	430	294
230	226	440	295
240	233	450	296
250	240	460	298
260	246	470	299
270	251	480	300
280	255	490	301
290	260	500	303
300	263	510	304
310	267	520	305
320	270	530	306
330	273	540	307
340	275	550	309
350	278	560	310
360	280	570	311
370	283	580	312
380	285	590	313
390	287	600	313
400	288		

The adjusted slope is based on the following:

1. For $0 < S <= 200$, $S_{adj} = S$
2. For $200 < S <= 600$, $S_{adj} = a_0+a_1S+a_2S^2+a_3S^3+a_4S^4+a_5S^5+a_6S^6+a_7S^7$

   where:

   $a_0 =$ 6.725897827E+02
   $a_1 =$ -1.634093666E+01
   $a_2 =$ 1.739404649E-01
   $a_3 =$ -8.902683621E-04
   $a_4 =$ 2.552852266E-06
   $a_5 =$ -4.203532411E-09
   $a_6 =$ 3.721179614E-12
   $a_7 =$ -1.374400319E-15

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 on 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 5.2, along with general descriptions of land forms/use for which the equation applies.

To estimate T_c by Equation (5.5), the average rainfall excess intensity must be estimated. The average rainfall excess intensity can be estimated by the following method: Run an HEC-1 model using the FCDMC rainfall loss method to estimate the rainfall excess at each computational time interval (NMIN). Then, rank the rainfall excess values from the highest to the lowest. The average rainfall excess intensity (inch/hr) is estimated by summing up the first ten highest rainfall excess values and dividing the result by 10*NMIN/60. Then, T_c is obtained by directly solving Equation (5.5). The "ten" highest values method has been found to yield a reasonable time of concentration based on research of Maricopa County watersheds by FCDMC staff. An example of the procedure can be found in Section 9.4.4. Alternatively, the DDMSW program can be used to automate this process, which will also populate the HEC-1 input file with the required data.

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 0.133 T_c, and although small variation in the selection of computation interval is allowed, the SCS recommends that the duration not exceed 0.25 T_c. 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:

$$\text{NMIN} = 0.15\ T_c \tag{5.6}$$

Equation (5.6) is preferred; however, as a general requirement, NMIN should fall in the range indicated in Equation (5.7).

$$0.10\ T_c < \text{NMIN} < 0.25\ T_c \tag{5.7}$$

Figure 5.5

RESISTANCE COEFFICIENT K_b

AS A FUNCTION OF WATERSHED SIZE AND SURFACE ROUGHNESS CHARACTERISTICS

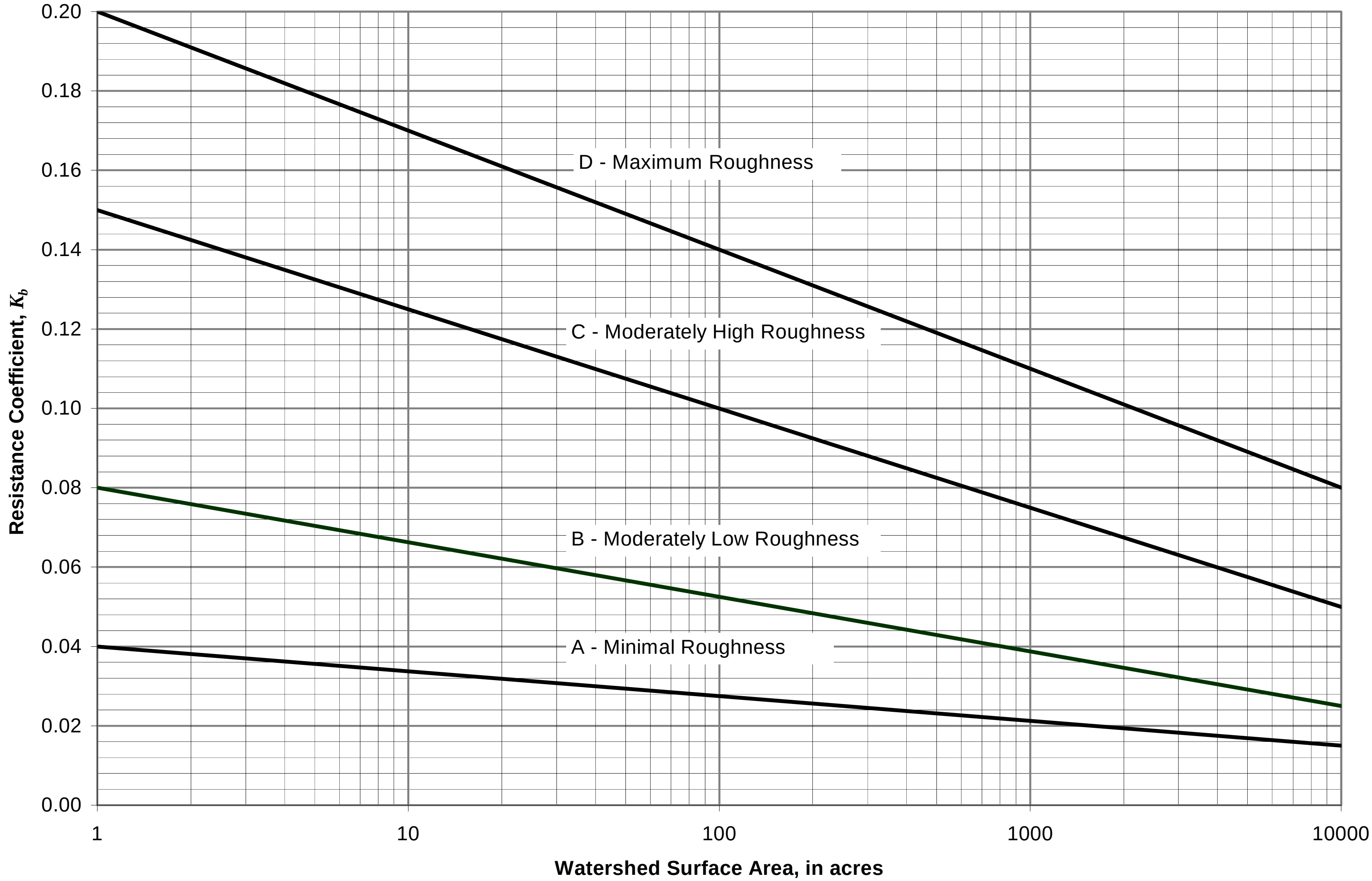


Table 5.3
EQUATION FOR ESTIMATING K_b IN THE T_c EQUATION

$K_b = m \log A + b$ Where A is drainage area, in acres				
			Equation Parameters	
Type	**Description**	**Typical Applications**	***m***	***b***
A	Minimal roughness: Relatively smooth and/or well graded and uniform land surfaces. Surfaces 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 tortuous 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
Note:	A is the area of the entire subbasin, not the area of the surface type A, B, C or D within the subbasin.			

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 T_c 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 discuss the development of regionalized relations for T_c and R as functions of watersheds characteristics in Training Document No. 15 (U.S. Army Corps of Engineers, 1982b). According to Corps procedures, T_c and R are estimated from relations of $T_c + R$ and $R / (T_c + R)$

as functions of watershed characteristics. These forms of empirical equations indicate an interrelation of T_c and R, and such dependence was observed in the database, as discussed in the Documentation Manual. The equation for estimating R for Maricopa County is:

$$R = 0.37 T_c^{1.11} A^{-0.57} L^{0.80} \quad (5.8)$$

where:

R = storage coefficient, in hours,

T_c = 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 a well defined and reliable procedure is currently 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 Equation (5.5) and Equation (5.8).

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 T_c 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 T_c.

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

$$A^* = 1.414\,(T^*)^{1.5} \qquad for\ 0 \le T^* \le 0.5 \qquad (5.9)$$

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

where:

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

T^* = time in percent of T_c.

Equation (5.9) 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 Figure 5.6 and Figure 5.7. Each of those figures show a synthetic time-area relation and 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 Figure 5.6 or Figure 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 5.4.

Figure 5.6
SYNTHETIC TIME-AREA RELATION FOR URBAN WATERSHED

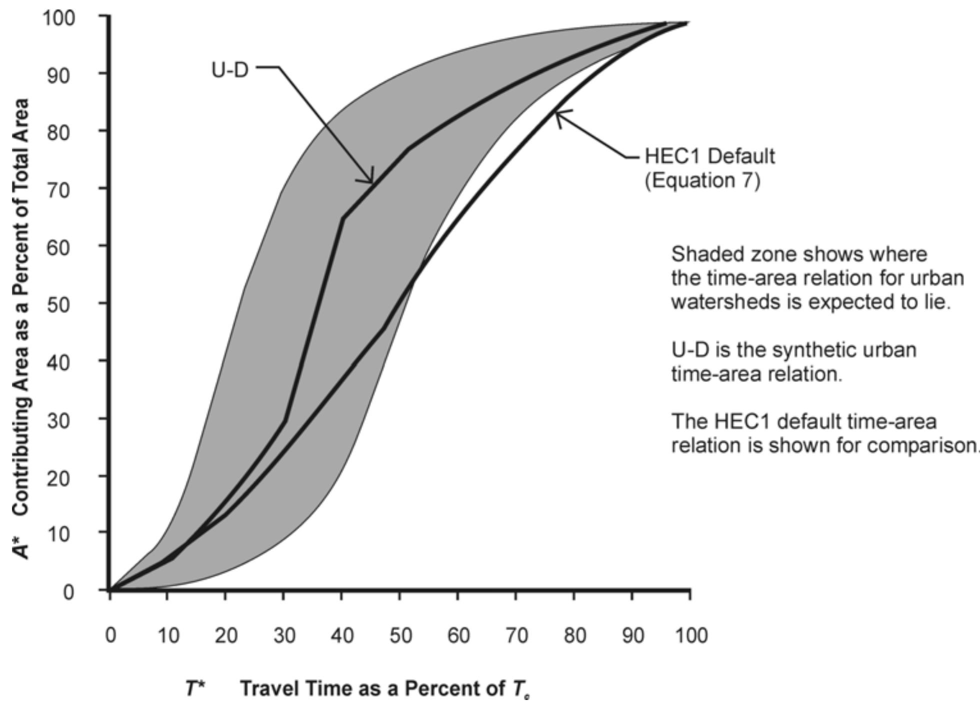


Figure 5.7
SYNTHETIC TIME-AREA RELATION FOR NATURAL WATERSHEDS

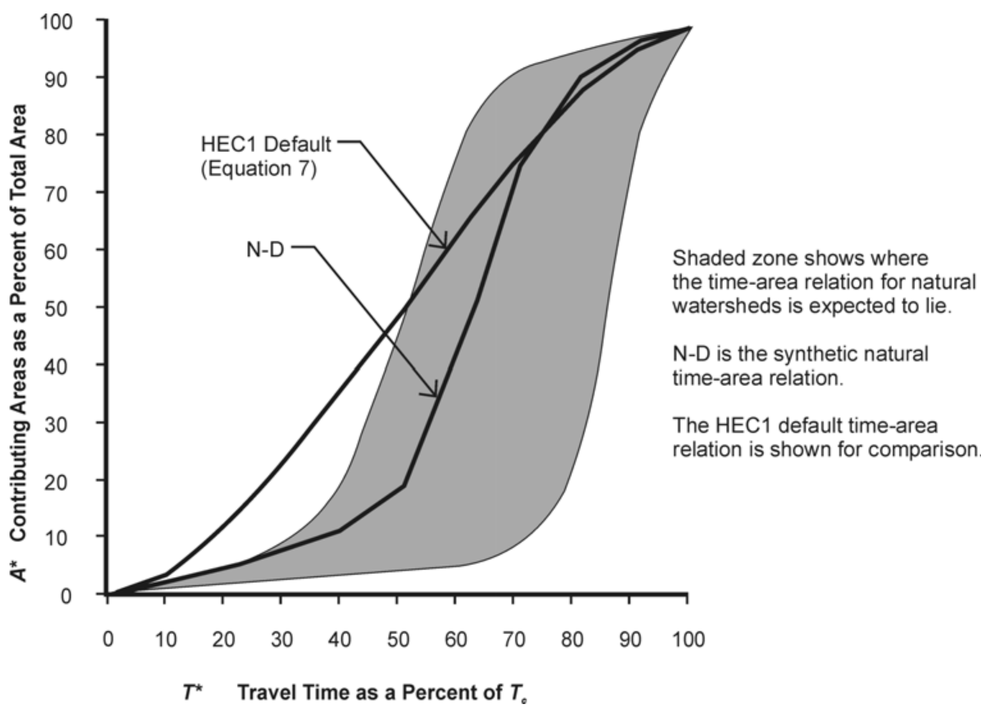


Table 5.4
VALUES OF THE SYNTHETIC DIMENSIONLESS TIME-AREA RELATIONS FOR THE CLARK UNIT HYDROGRAPH

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

$$Q_{ult} = \frac{645.33A}{\Delta t} \tag{5.10}$$

where:

A = drainage area, in square miles, and

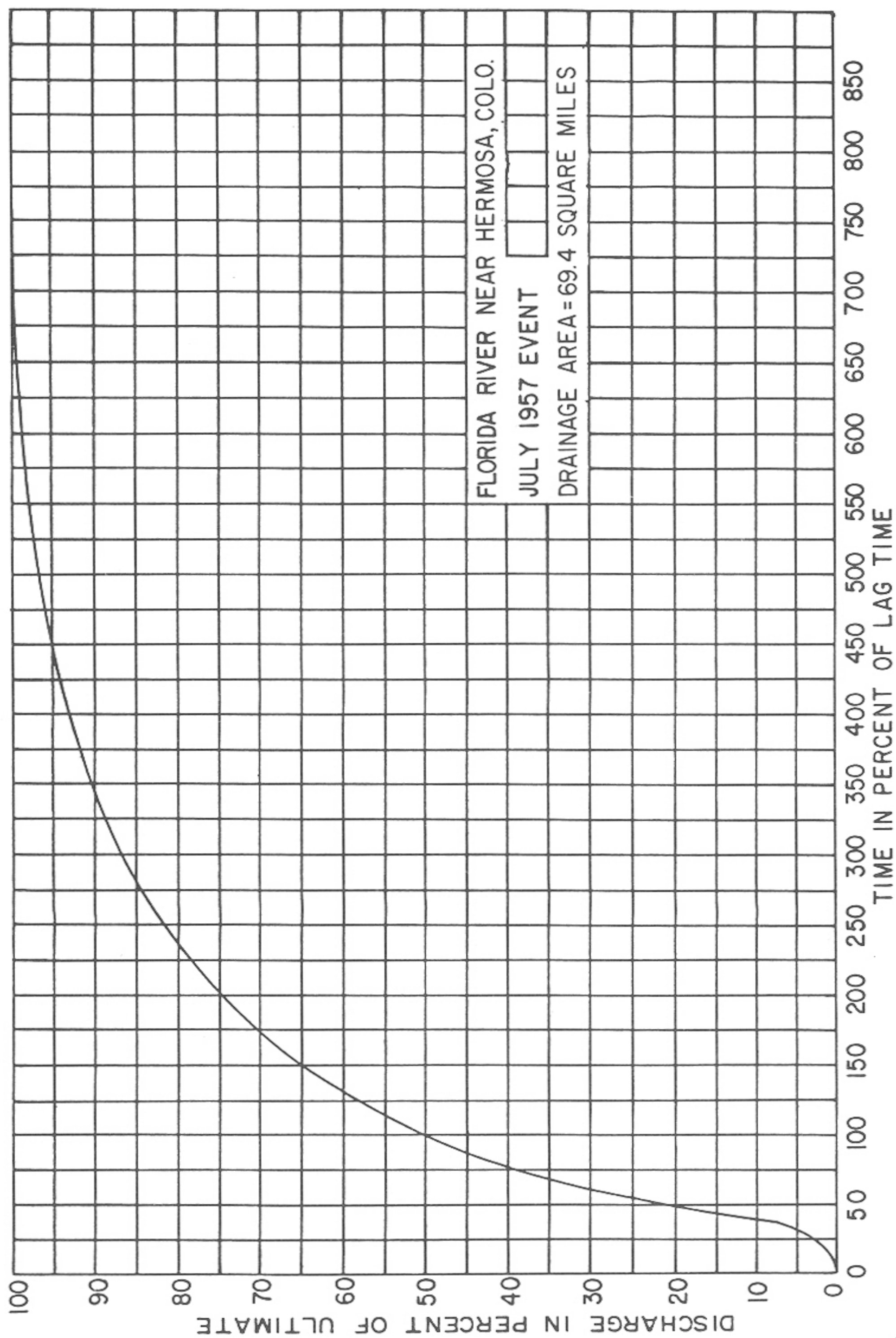
Δt = duration of the 1 inch of rainfall excess, in hours.

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 Q_{ult} 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 Q_{ult}. This summation graph is then converted to a dimensionless S-graph by dividing the discharge scale by Q_{ult} 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 manually calculated 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.

Figure 5.8
EXAMPLE OF AN S-GRAPH FROM DESIGN OF SMALL DAMS (USBR, 1987)



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 study for the Flood Control District of Maricopa County (Sabol, 1987) has demonstrated 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 those 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 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, 1987), and it has identified S-graphs for application in six generalized regional and physiographic type of watersheds. 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 Engineer, 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 a unit hydrograph, and this can be done by one of two methods. First, the S-graph can be converted to a unit-hydrograph manually; or second, the S-graph can be converted to an unit hydrograph by use of the DDMSW program. The DDMSW program outputs the HEC-1 input file with the S-graph converted to a unit hydrograph, and the unit hydrograph is written to a HEC-1 input file using the UI (given Unit Graph) record. The use of DDMSW 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 the 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 gaged 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 5.6 summarizes the four S-graphs and describes their general areas of applicability.

The four S-graphs are shown in Figure 5.9 and the coordinates of the graphs are listed in Table 5.5. 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.

Figure 5.9
S-GRAPHS FOR USE IN MARICOPA COUNTY

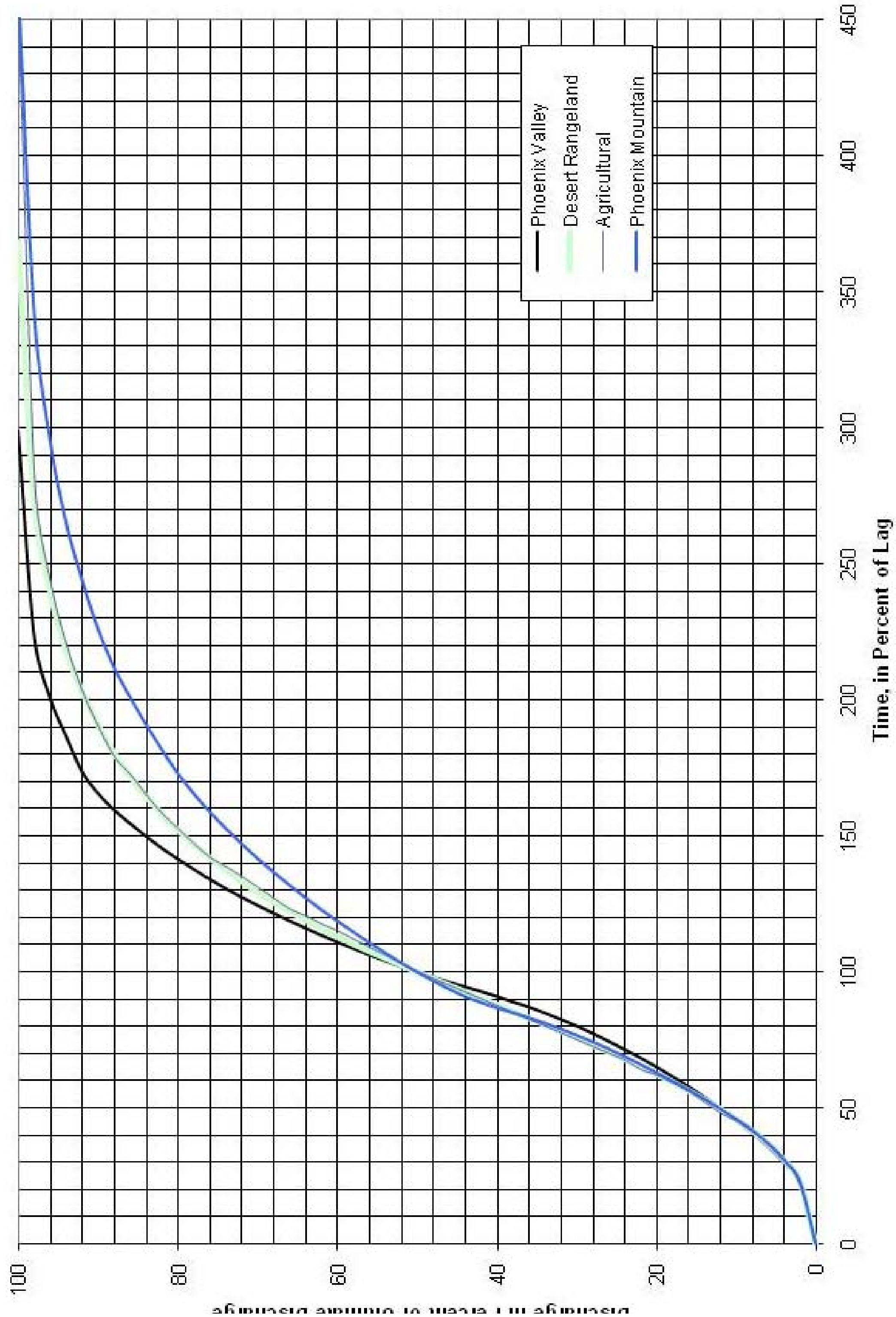


Table 5.5
TABULATION OF COORDINATES FOR S-GRAPHS

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,

L_{ca} = length along the watercourse to a point opposite the centroid, in miles,

S = watercourse slope, in feet per mile,

C = coefficient, and

m and p = exponents.

The Corps of Engineers often uses $C = 24K_n$, where K_n is the estimated mean Manning's n for all the channels within an area, and $m = 0.38$. The USBR (1987) has recommended that $C = 26K_n$ 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 K_n 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 K_n decreases. Therefore, some adjustment in K_n should be made for use with rainfalls of different magnitudes (frequencies). Generally, K_n is the smallest for extreme floods such as PMFs and increases as the frequency of event increases.

Selection of K_n

The selection of a representative K_n value for a particular watershed is an inherently subjective process. However, some guidelines are given for the selection of K_n in Maricopa County in conjunction with the four recommended S-graphs. Table 5.6 contains a summary of these guidelines. Additional guidance may be gleaned from the calculated K_n values for numerous watersheds provided in Appendix D.1. Care should be taken to keep in mind the limitations discussed above when selecting K_n 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 D.1. 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).

Table 5.6
S-GRAPHS AND K_n VALUES

S-Graph Type	Description	K_n Min	K_n Avg	K_n 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 debris obstruction; ground 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 K_n data upon which these values are based come from rainfall runoff events of magnitude less than the 100-year event. Therefore, selected K_n values for a given design storm need to be evaluated for the purposes of modeling a particular watershed response to that design storm.

5.7 PROCEDURES

Procedures for calculating the unit hydrograph parameters are provided in the following sections. Notes and general guidance on the application of these procedures and the methodologies presented in this chapter are provided along with a detailed example in Section 9.4.4.

5.7.1 Clark Unit Hydrograph

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

2. If S is greater than 200 ft/mi, adjust the slope using Table 5.2 or Figure 5.4.

3. Using either Figure 5.5 or Table 5.3, select a resistance coefficient (K_b) for the basin or subbasin based on a resistance classification and the drainage area (in acres). For a basin or subbasin of mixed classification;

    - A representative K_b can be interpolated from Figure 5.5, or
    - An arithmetically averaged K_b can be calculated based on the area of each unique K_b present in the basin or subbasin.

4. Calculate T_c as a function of i using Equation (5.5)

    a. Enter the following data into an HEC-1 input file:

    - Design rainfall per the methodology and procedures in Chapter 2.
    - Basin area.
    - Rainfall loss data per the methodologies and procedures in Chapter 4.
    - Clark unit hydrograph parameters (values set to zero).

    b. Run HEC-1 with the input file from Step 5 at an output level of zero for each subbasin. From the HEC-1 output file, find the rainfall excess at each time interval. Rank the values from the highest to the lowest. The average rainfall intensity is found by summing up the first ten highest rainfall excess values and dividing the result by the length of ten time intervals.

    c. Directly solve Equation (5.5) for T_c using the computed average rainfall intensity.

5. Calculate R using Equation (5.8).

6. Select the appropriate time-area relation for the basin or subbasin.

As an alternative to the above procedures, the DDMSW program will compute the rainfall excess directly and perform the necessary iterations to compute the T_c and R parameters.

5.7.2 S-Graph

1. From an appropriate map of the watershed, measure drainage area (A), L, L_{ca} and S.
2. Calculate the basin factor $\frac{LL_{ca}}{S^{0.5}}$.
3. Using the data in Appendix D.1 or the tables in the Design of Small Dams or the USBR Flood Hydrology Manual, attempt to identify watersheds of the same physiographic type and similar drainage area and basin factor. Make a list of the watersheds with similar drainage areas and basin factors and tabulate the estimated value of K_n for those watersheds and the measured lag.
4. Estimate K_n for the watershed by inspection of the tabulation from Step 3.
5. Calculate the coefficient (C) and select the value of the exponent (m) corresponding to the source (Corps of Engineers or USBR) that was used to estimate K_n. If the source of K_n is unknown, then use the Corps of Engineers version of Equation (5.11).
6. Using Equation (5.11), calculate the basin lag. Compare this value to the measured lags of watersheds from Step 3.
7. Select an appropriate computational time interval (NMIN) and compute Q_{ult} using Equation (5.10).
8. Select an appropriate S-Graph and tabulate the percent Q_{ult}, percent lag and the accumulated time.
9. Transform the S-Graph into an X-duration (NMIN) unit hydrograph using linear interpolation with Δt = NMIN.
10. Adjust the “tail” region of the S-Graph by lagging that portion by Δt and subtracting the ordinates.

As an alternative to the above procedure, the DDMSW will transform the S-Graph to a unit graph automatically.

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6 MULTIPLE FREQUENCY MODELING

TABLE OF CONTENTS

6.1 BACKGROUND

Originally, the *Hydrology Manual* was intended to be used for the development of flood discharges and runoff volumes resulting from infrequent storms, such as the 100-year rainfall. Data that were collected and used in the selection and development of the methods, techniques and parameters are representative of infrequent storms. While it was recognized that the application of the methods, techniques and procedures may not be appropriate for more frequent storms, this limitation was not perceived as a significant issue at that time.

Recently, there has been an increasing need for runoff magnitudes from more frequent storms, particularly in regard to the design of storm drains, but also for regulatory and planning purposes. However, use of the methods, techniques and parameters presented in the preceding chapters <u>may</u> result in the overestimation of runoff magnitudes for those types of events. The threshold at which this occurs often is the 10-year recurrence interval. Several different alternative approaches were considered that could be used in place of or to supplement the methods, techniques and parameters presented in the preceding chapters. Each alternative method was evaluated in regard to the three benchmarks (accuracy, practicality and reproducibility) that were used to evaluate the original methods, techniques and parameters. The alternative approach to be used in Maricopa County for the estimation of runoff for more frequent storms is a ratio that is applied to the 100-year runoff hydrographs.

6.2 APPROACH

Ratios for the 2-, 5- and 10-year recurrence intervals are based on analysis of USGS gage data for watersheds throughout the State of Arizona. That data reflects the wide range of hydrologic and physiographic characteristics that exist in Arizona. This variability was considered in the analysis in regard to the conditions that are specific to Maricopa County.

For reasons of practicality and to facilitate reproducibility, a single ratio for the 2-, 5- and 10-year recurrence intervals is provided that represents average conditions in Maricopa County. These values are listed in Table 6.1 and can be used for both local and general storms for drainage areas of any size, degree of development or other hydrologic and physiographic conditions.

Table 6.1
RATIOS TO 100-YEAR FLOOD HYDROGRAPHS
FOR THE 2-, 5- AND 10-YEAR RECURRENCE INTERVAL FLOODS

Recurrence Interval	Ratio %
2	10
5	25
10	35

This approach should be used when the results for the 2-, 5- and 10-year flood (peaks and volumes) using the methods, techniques and parameters in the preceding chapters are unreasonable. The reasonableness "test" applies to model results (peak discharges and runoff volumes) as well as to the HEC-1 input parameters, particularly for the unit hydrograph. This alternative method using the ratios from Table 6.1 does not preclude the use of another method or the use of different (site specific) ratios with prior approval from the Flood Control District, or local jurisdiction.

6.3 IMPLEMENTATION IN HEC-1

The ratio for the desired recurrence interval is coded into the 100-year HEC-1 model on field 3 of the subbasin area (BA) record for each subbasin. Alternatively, for a single storm analysis the ratio(s) can be coded into the 100-year HEC-1 model on the multiratio (JR) record. In addition to coding the ratio(s) on this record, the IRTIO variable in field 1 must be set to FLOW to ratio the runoff, not the precipitation. The JR record cannot be used for a multiple storm analysis due to a conflict with the JD record used to define the index areas.

7 CHANNEL ROUTING

TABLE OF CONTENTS

7.1 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. The preferred method for most applications in Maricopa County is Normal-Depth routing. Normal-Depth routing can be used for both natural and artificial channels in both urbanized and non-urbanized watersheds. Kinematic Wave routing may be used in urbanized watersheds and for natural channels where reductions in peak discharge due to attenuation is not anticipated. The Kinematic Wave method is limited to simple prismatic channel geometrics that include non-pressurized closed conduits. Muskingum routing may be used for large natural channels where parameter calibration data exists. The Muskingum-Cunge routing may be used for both natural and artificial channels.

Notes and general guidance on the parameter development and application of each of these methods are provided along with a detailed example in Section 9.5.

7.2 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 is physically based in that it simulates attenuation due to overbank storage.

7.2.1 Parameter Selection

Input data for Normal-Depth routing include the estimation of a representative eight-point cross section, the energy slope (or bed slope), reach length and Manning's n values for both the main channel and overbanks. In addition to those physical parameters, this method also requires the input of the number of routing steps (NSTPS) to be used in the computations. This is a calibration parameter that is directly related to the degree of attenuation introduced in the computations. This parameter is also a function of the model computational time interval, NMIN, as given by the following.

$$\mathrm{NSTPS} = \frac{((L)/V_{avg})}{\mathrm{NMIN}} \tag{7.1}$$

where:

$NSTPS$ = number of routing steps, a dimensionless integer.

L = reach length, in feet.

V_{avg} = velocity of flood wave, in ft per minute.

$NMIN$ = hydrograph computation time interval, in minutes.

For a complete description of the use and application of Normal-Depth routing, refer to the HEC-1 User's Manual. A second applicable reference is Hoggan (1989). Refer to Section 9.5 for guidance in the calibration of NSTPS.

7.3 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.

7.3.1 Collector Channel

Modeling of flow from 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 within the collector pipes.

7.3.2 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.

7.3.3 Parameter Selection

The data requirements for Kinematic Wave 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 results in more attenuation. To overcome this problem, 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.

7.4 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.

7.4.1 Parameter Selection

Application of Muskingum routing requires input values for parameters X and K. Parameter X has a range of values from 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 Section 9.5 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 simulation of known outflow hydrographs. Chapter 5 of the USBR's Flood Hydrology Manual (Cudworth, 1989) is an excellent source of Muskingum routing information.

7.5 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.

7.5.1 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.

8 INDIRECT METHODS

TABLE OF CONTENTS

8.1 GENERAL

The estimation of peak discharges by analytic methods (the Rational Method or by rainfall-runoff modeling using the HEC-1 program) is based on various assumptions, and in the case of HEC-1 modeling, requires the correct input of numerous parameters. Therefore, the resulting peak discharges that are computed by analytic methods should always be verified, to the extent possible, to guard against erroneous design discharges that can result from questionable assumptions and/or faulty model input.

Since the majority of discharge estimates are made for ungaged watersheds, usually only indirect methods can be used to check the discharge estimates obtained from either the Rational Method or rainfall-runoff modeling. When the watershed is gaged, or is near a gaging station, a flood-frequency analysis can be performed and the results of that analysis can be used for design or used to check the results from analytic methods. The results of flood-frequency analyses, because of variability of flooding in both the time and space regime, and because of uncertainties in the data and the analytic procedures, should also be checked by indirect methods.

True verification of design discharges cannot be made by any of the methods (analytic methods, flood-frequency analyses, or indirect methods) because for none of these methods is there “absolute assurance” that the discharges obtained are the “true” representations of the flood discharge for a given frequency of flooding. However, the results of the various methods, when compared against each other and when qualitatively evaluated, can provide a basis for either acceptance or rejection of specific estimates of design discharges for watersheds in Maricopa County.

In this chapter, three indirect methods are presented for “verifying” flood discharges that are obtained by analytic methods.

Those procedures are:

1. A graph of seven unit peak discharge versus drainage area curves,

2. Graphs of estimated 100-year discharges versus drainage area for gaged watersheds in Arizona, and

3. Regression equations and data graphs for flood regions in Maricopa County.

In general, all three procedures should be used when verifying the results of analytic methods.

8.2 INDIRECT METHOD NO. 1 - UNIT PEAK DISCHARGE CURVES

Figure 8.1 presents 7 unit peak discharge relations and envelope curves. A brief description of each of those curves follows:

A. An envelope curve, based on a compilation of unusual flood discharges in the United States and abroad (data prior to 1941), by Craeger and others (1945).

B. An envelope curve of extreme floods in Arizona and the Rocky Mountain region developed by Matthai and published by Roeske (1978).

C. An envelope curve of peak streamflow data developed for Arizona by Malvick (1980).

D. An envelope curve of peak streamflow data for the Little Colorado River basin in Northern Arizona developed by Crippen (1982).

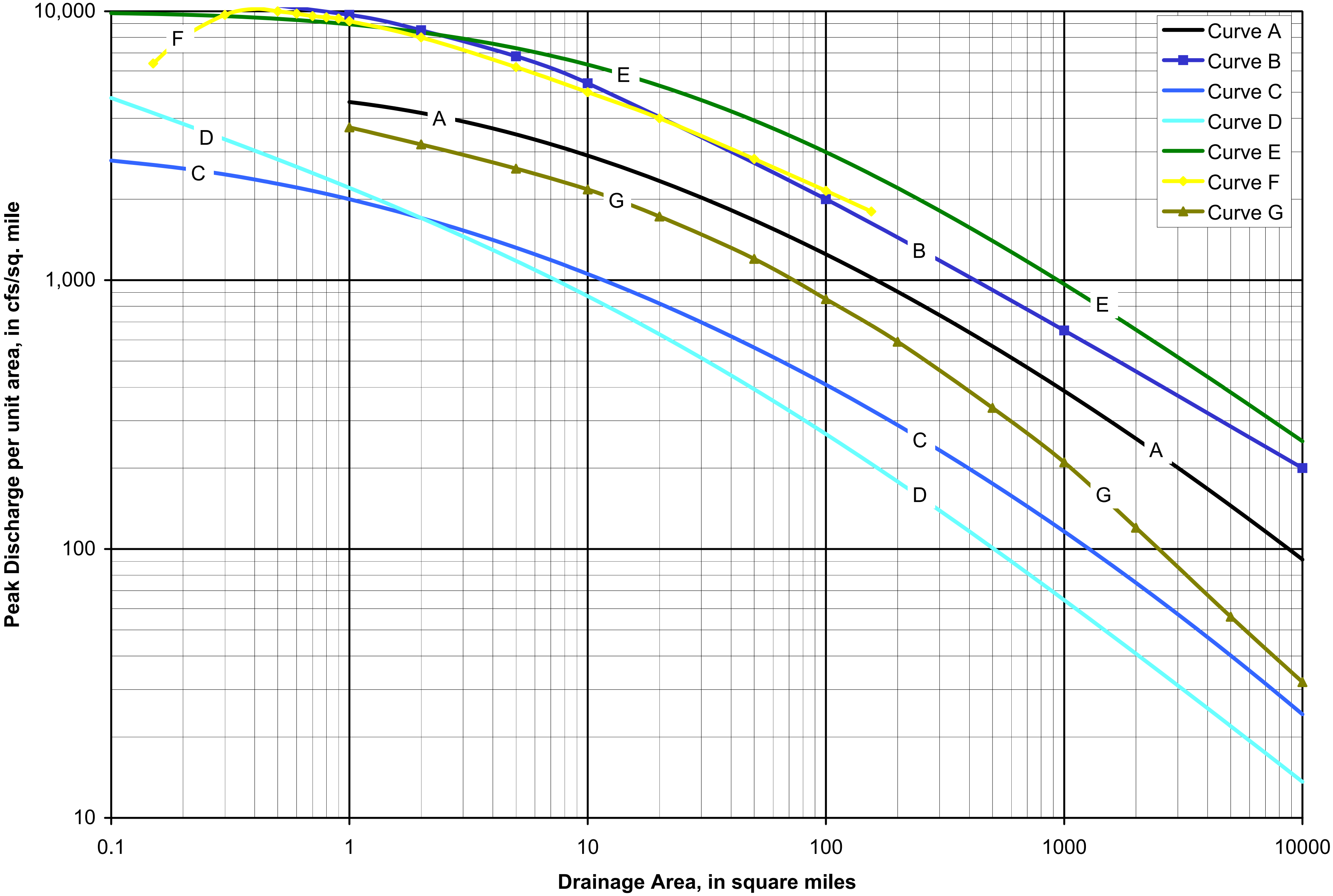
E. An envelope curve of peak streamflow data for Central and Southern Arizona developed by Crippen (1982).

F. An envelope curve of the largest floods in the semi-arid Western United States developed by Costa (1987).

G. An envelope curve of peak discharges for Arizona, Nevada and New Mexico developed by the U.S. Army Corps of Engineers (1988).

When using Figure 8.1, it must be noted that the curves represent envelopes of maximum observed flood discharges for different hydrologic regions.

Figure 8.1
UNIT PEAK DISCHARGE RELATIONS AND ENVELOPE CURVES



8.3 INDIRECT METHOD NO. 2 - USGS DATA FOR ARIZONA

The U.S. Geological Survey (USGS) provides streamflow and statistical data for 138 continuous-record streamflow-gaging stations and 176 partial-record gaging stations in Arizona (Garrett and Gellenbeck, 1991). The streamflow data were analyzed by the USGS by Log-Pearson Type 3 (LP3) analyses and flood magnitude-frequency statistics are provided in that report along with the maximum recorded discharge for each station. Figure 8.2 is a plot of the 100-year peak discharge (from LP3 analyses) versus drainage area (for stations with drainage areas smaller than 2,000 square miles). Lines were fit to the data by least-squares of the log-transformed data. The equation for the 100-year peak discharge (Q_{100}) line is:

$$Q_{100} = 850A^{0.54} \quad (8.1)$$

where:

A is the drainage area in square miles.

Figure 8.2 also shows 75 percent tolerance limit lines about the 100-year discharge line from Equation (8.1). The tolerance limits are a statistical measure of the spread of the data about that line.

As an aid to using Figure 8.2, that figure is reproduced with larger drainage area scales in Figure 8.3 and Figure 8.4. Those larger scale plots of the data also show 75 percent tolerance limit lines about the 100-year discharge line from Equation (8.1).

A listing of the data that was used to produce Figure 8.2 through Figure 8.4 is shown in Table 8.1. This table includes USGS streamflow-gaging station numbers, the associated drainage areas and the 100-year flood peak discharge estimates by LP3. Watershed characteristics for each of these gaging stations are provided in the USGS report (Garrett and Gellenbeck, 1991). A map of Arizona showing the locations of the gaging stations for this data compilation are shown in Figure 8.5.

Figure 8.2
100-YEAR PEAK DISCHARGE BY LP3 ANALYSIS
Source: 1989 USGS Basin Characteristic Report, Figure Adapted from the ADOT Hydrology Manual

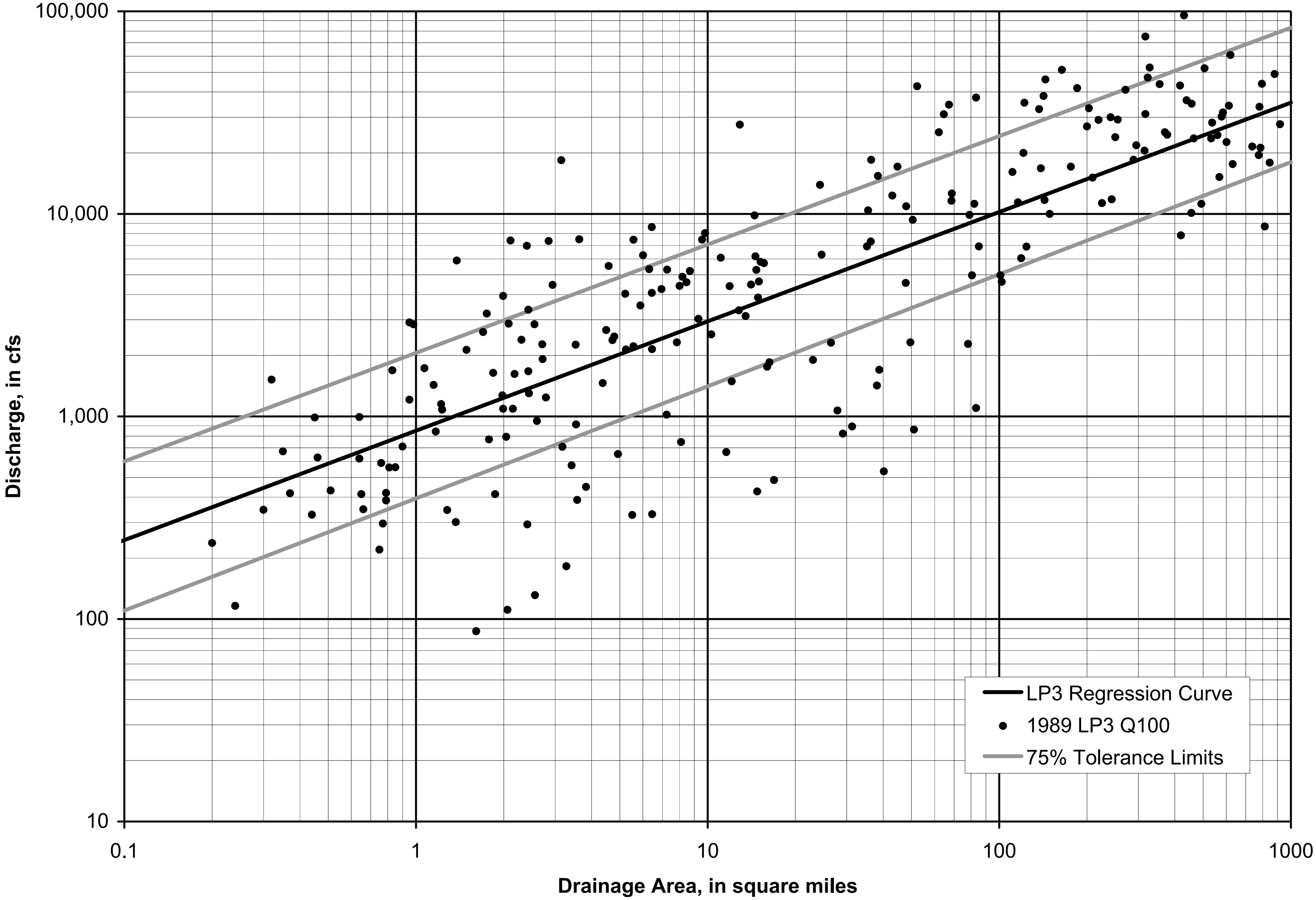


Figure 8.3
100-YEAR PEAK DISCHARGE BY LP3 ANALYSIS
Source: 1989 USGS Basin Characteristic Report, Figure Adapted from the ADOT Hydrology Manual

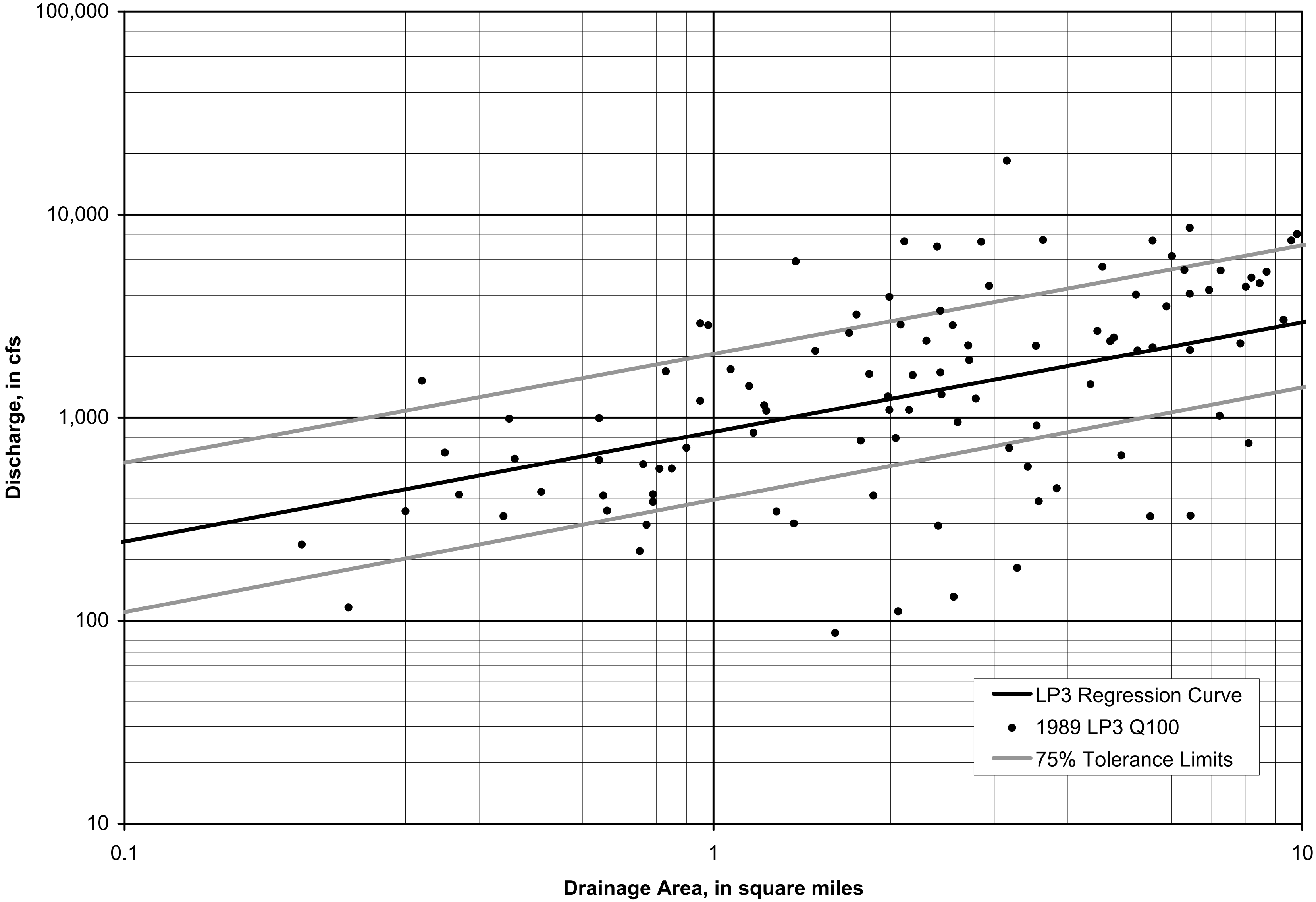


Figure 8.4
100-YEAR PEAK DISCHARGE BY LP3 ANALYSIS
Source: 1989 USGS Basin Characteristic Report, Figure Adapted from the ADOT Hydrology Manual

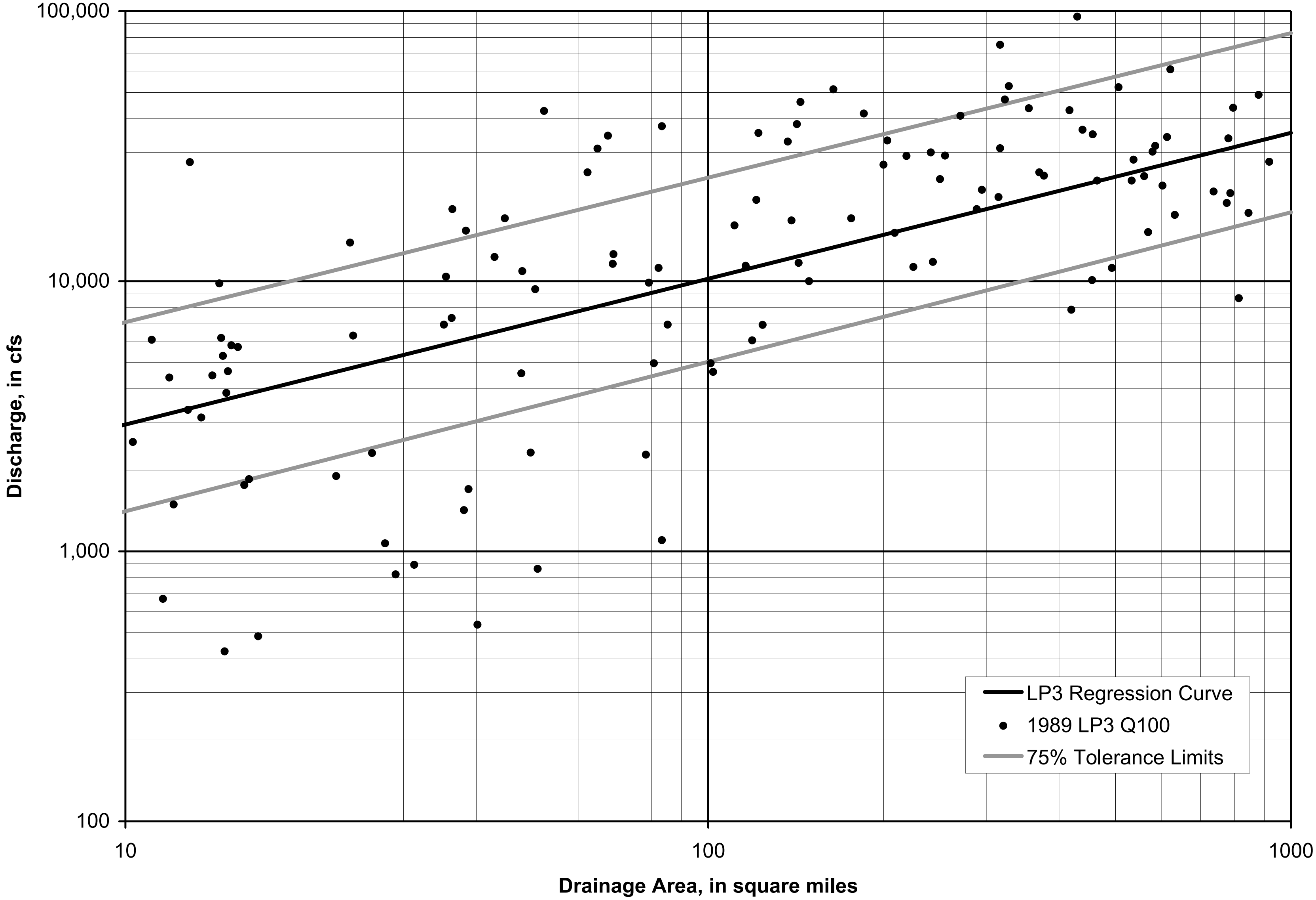


Table 8.1
USGS DATA LISTING FOR WATERSHEDS WITH DRAINAGE AREAS BETWEEN .1 AND 2,000 SQUARE MILES
(drainage area in ascending order)

Drainage Area	Gage No.	LP3 Q_{100}	Drainage Area	Gage No.	LP3 Q_{100}	Drainage Area	Gage No.	LP3 Q_{100}
0.20	9404310	237	1.23	9419590	1,080	2.72	9485550	1,920
0.24	9384200	116	1.28	9395100	345	2.79	9517200	1,240
0.30	9429510	346	1.37	9379060	301	2.85	9403800	7,350
0.32	9400200	1,520	1.38	9379100	5,880	2.94	9482480	4,460
0.35	9385800	672	1.49	9520230	2,130	3.15	9404350	18,400
0.37	9478600	417	1.61	9489080	87	3.18	9403930	708
0.44	9520110	327	1.70	9424430	2,610	3.28	9400910	182
0.45	9487140	987	1.75	9512200	3,220	3.42	9505600	573
0.46	9483040	627	1.78	9400560	770	3.53	9483045	2,260
0.51	9479200	431	1.84	9427700	1,640	3.54	9383020	913
0.64	9505900	619	1.87	9400680	413	3.57	9400530	387
0.64	9424700	993	1.98	9429150	1,270	3.63	9473200	7,490
0.65	9536350	413	1.99	9520400	3,930	3.83	9404050	449
0.66	9498600	348	1.99	9424410	1,090	4.37	9473600	1,460
0.75	9503740	220	2.04	9483200	793	4.49	9510100	2,670
0.76	9536100	589	2.06	9400660	111	4.58	9510070	5,530
0.77	9428545	296	2.08	9483250	2,870	4.72	9520130	2,380
0.79	9401245	419	2.11	9483030	7,390	4.79	9507700	2,480
0.79	9471600	385	2.15	9485950	1,090	4.93	9485900	652
0.81	9482330	560	2.18	9520160	1,620	5.22	9392800	4,030
0.83	9468300	1,690	2.30	9482950	2,390	5.25	9470900	2,140
0.85	9504100	561	2.40	9472400	6,960	5.52	9400700	326
0.90	9520300	710	2.41	9400740	293	5.57	9515800	7,450
0.95	9512420	2,910	2.43	9483025	3,360	5.57	9400580	2,220
0.95	9483010	1,210	2.43	9519600	1,670	5.88	9379560	3,530
0.98	9379980	2,850	2.44	9487400	1,300	6.01	9502700	6,250
1.07	9512700	1,730	2.55	9496800	2,850	6.31	9516600	5,330
1.15	9504400	1,430	2.56	9429400	131	6.44	9498900	4,070
1.17	9483042	842	2.60	9510170	950	6.44	9507600	8,600
1.22	9396400	1,150	2.71	9471700	2,270	6.45	9400565	2,150

TABLE 8.1 (CONTINUED)
USGS DATA LISTING FOR WATERSHEDS
WITH DRAINAGE AREAS BETWEEN .1 AND 2,000 SQUARE MILES
(drainage area in ascending order)

Drainage Area	Gage No.	LP3 Q_{100}
6.46	9484510	329
6.95	9424480	4,250
7.24	9482410	1,020
7.27	9415050	5,300
7.85	9400100	2,320
8.02	9472100	4,410
8.11	9400650	748
8.20	9483000	4,890
8.47	9423760	4,590
8.70	9520100	5,220
9.30	9400290	3,030
9.58	9485570	7,460
9.80	9510080	8,030
10.30	9481700	2,540
11.10	9513820	6,070
11.60	9444100	667
11.90	9487100	4,400
12.10	9520200	1,490
12.80	9488600	3,340
12.90	9519780	27,600
13.50	9424407	3,130
14.10	9484580	4,480
14.50	9503750	9,820
14.60	9428550	6,170
14.70	9423900	5,290
14.80	9489200	426
14.90	9503720	3,860
15.00	9456400	4,640
15.20	9510180	5,790
16.00	9371100	1,760

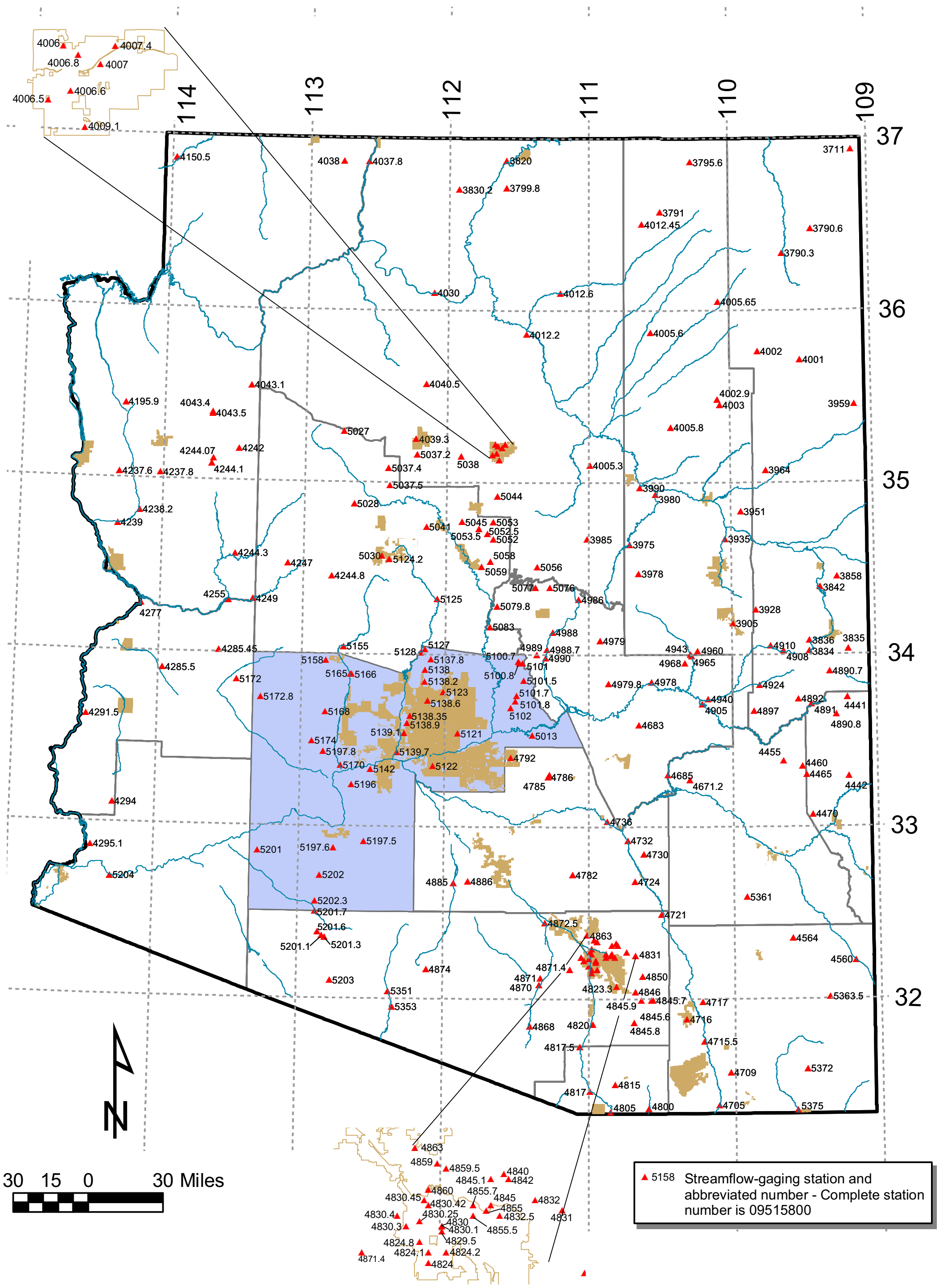
Drainage Area	Gage No.	LP3 Q_{100}
16.30	9484200	1,850
16.90	9383600	485
23.00	9482400	1,900
24.30	9501300	13,900
24.60	9505300	6,290
26.50	9482420	2,310
27.90	9397800	1,070
29.10	9383400	822
31.30	9423780	892
35.20	9467120	6,910
35.50	9484000	10,400
36.30	9503000	7,310
36.40	9508300	18,500
38.10	9489070	1,420
38.40	9484570	15,400
38.80	9492400	1,700
40.20	9490800	535
43.00	9483100	12,300
44.80	9485000	17,100
47.80	9517400	4,560
48.00	9505250	10,900
49.60	9400300	2,320
50.50	9484590	9,340
51.00	9400600	861
52.30	9510150	42,700
62.10	9497900	25,300
64.60	9513860	31,000
67.30	9513780	34,600
68.60	9390500	11,600
68.80	9519750	12,600

Drainage Area	Gage No.	LP3 Q_{100}
78.20	9491000	2,280
79.10	9537200	9,880
80.70	9379030	4,970
82.20	9480000	11,200
83.30	9513800	37,500
83.30	9383500	1,100
85.20	9517280	6,910
101.00	9403000	4,970
102.00	9445500	4,620
111.00	9505200	16,100
116.00	9519760	11,400
119.00	9489700	6,040
121.00	9512300	20,000
122.00	9498870	35,400
124.00	9503800	6,890
137.00	9516800	32,900
139.00	9512100	16,800
142.00	9505350	38,200
143.00	9424200	11,700
144.00	9478500	46,100
149.00	9446000	10,000
164.00	9510200	51,400
176.00	9481750	17,100
185.00	9513835	41,800
200.00	9497980	27,000
203.00	9496000	33,200
209.00	9481500	15,100
219.00	9484500	29,100
225.00	9494300	11,300
241.00	9505800	30,000

TABLE 8.1 (CONTINUED)
USGS DATA LISTING FOR WATERSHEDS
WITH DRAINAGE AREAS BETWEEN .1 AND 2,000 SQUARE MILES
(drainage area in ascending order)

Drainage Area	Gage No.	LP3 Q_{100}	Drainage Area	Gage No.	LP3 Q_{100}
243.00	9520170	11,800	1439.00	9425500	69,600
250.00	9486300	23,900	1470.00	9517000	49,200
255.00	9502800	29,200	1629.00	9401260	17,300
271.00	9397500	41,000	1682.00	9482000	36,500
289.00	9484560	18,500	1730.00	9471550	28,000
295.00	9497800	21,800			
315.00	9489100	20,500			
317.00	9513890	75,100			
317.00	9398500	31,100			
323.00	9513910	47,100			
328.00	9507980	52,800			
355.00	9504500	43,700			
370.00	9404340	25,300			
377.00	9446500	24,600			
417.00	9515500	43,000			
787.00	9423820	21,200			
796.00	9516500	43,900			
814.00	9456000	8,660			
846.00	9393500	17,900			
880.00	9513970	49,000			
918.00	9486000	27,700			
1023.00	9537500	5,750			
1026.00	9468500	54,500			
1028.00	9403780	7,140			
1110.00	9512800	182,000			
1128.00	9424900	37,900			
1170.00	9487250	12,500			
1232.00	9490500	97,900			
1250.00	9535300	7,250			
1410.00	9382000	20,200			

Figure 8.5
LOCATIONS OF USGS GAGING STATIONS



8.4 INDIRECT METHOD NO. 3 - REGIONAL REGRESSION EQUATIONS

An analysis was performed of streamflow data for a study area comprised of Arizona, Nevada, Utah, and parts of New Mexico, Colorado, Wyoming, Texas, Idaho, Oregon, and California (USGS Open File Report 93-419, 1994). That analysis resulted in sixteen sets of regional regression equations for the study area. Two of those regions (R12 and R13) are in Maricopa County as shown in Figure 8.6. These regional regression equations can be used to estimate flood magnitude-frequencies for watersheds in Maricopa County.

Regression equations are provided for both regions to estimate flood peak discharges for frequencies of 2-, 5-, 10-, 25-, 50-, and 100-years. Use of the regression equations is recommended only if the values of the independent variables (drainage area and mean basin elevation) for the watershed of interest are within the range of the database used to derive the specific regression equation.

The regression equations for both regions (R12 and R13) are functions of drainage area. In general, the equations are applicable to unregulated watersheds with drainage areas less than 200 square miles. The regression equation for Region 12 is also a function of mean basin elevation. Figure 8.7 is a scatter diagram of mean basin elevation versus drainage area for the database used to derive the regression equations as provided in USGS Open File Report 93-419.

The regression equations for Regions 12 and 13 are provided in Table 8.2 and Table 8.3, respectively.

Also provided for each set of regression equations are graphs, Figure 8.8 and Figure 8.9, of the 100-year LP3 discharge estimates versus drainage area for Flood Regions 12 and 13, respectively. A line depicting the relation between the 100-year peak discharge (computed from the regional regression equation) and drainage area is shown on each of those graphs. These graphs were recreated from the data provided in USGS Open File Report 93-419.

Figure 8.6
FLOOD REGIONS FOR MARICOPA COUNTY

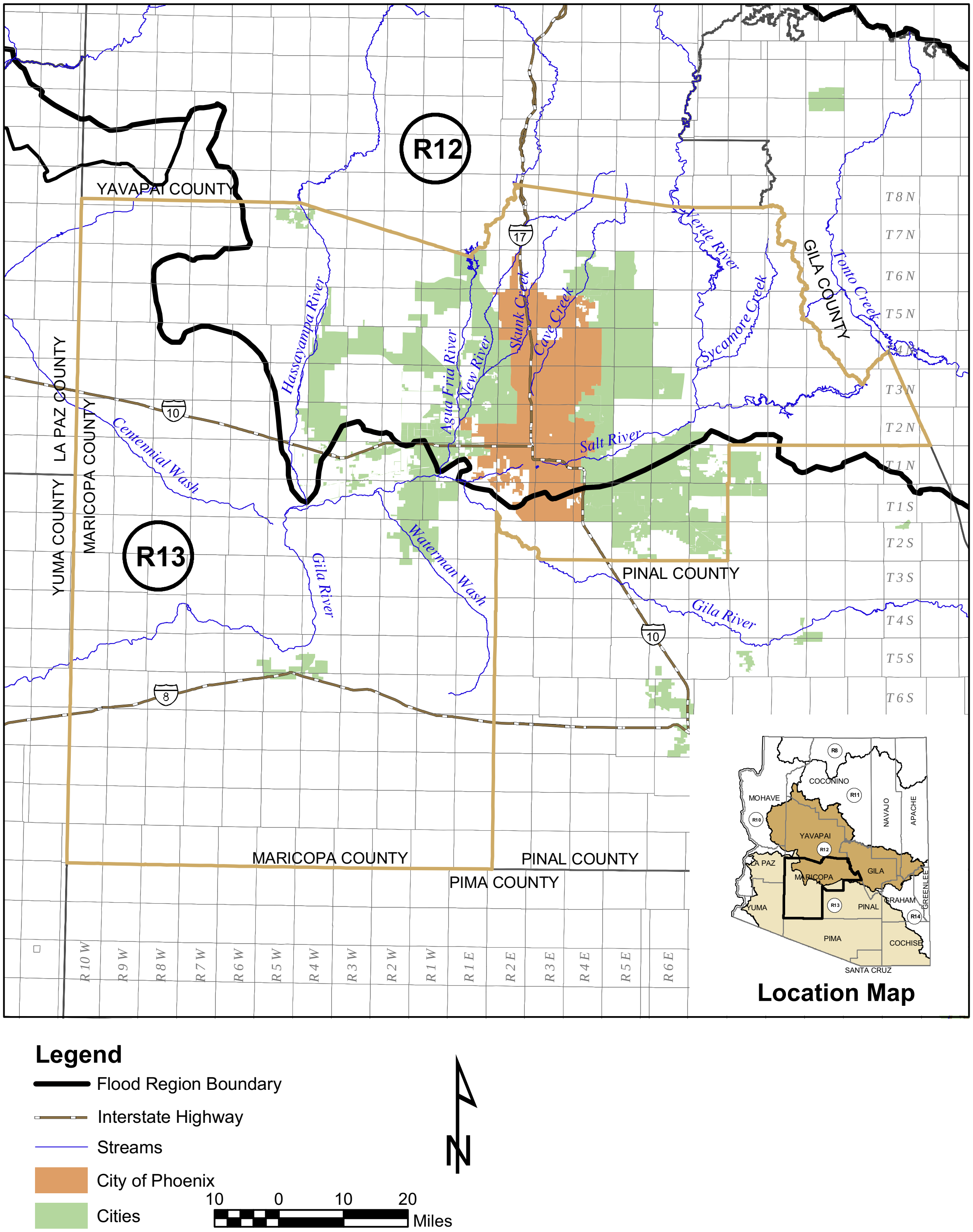


Table 8.2
FLOOD MAGNITUDE-FREQUENCY RELATIONS FOR THE CENTRAL AZ REGION (R12)

Equation: Q, peak discharge, in cubic feet per second; $AREA$, drainage area, in square miles; and $ELEV$, mean basin elevation, in feet divided by 1,000.

Recurrence interval, in years	Equation	Average standard error of model, in percent
2	$Q = 41.1\ AREA^{0.629}$	105
5	$Q = 238\ AREA^{0.687}\ ELEV^{-0.358}$	68
10	$Q = 479\ AREA^{0.661}\ ELEV^{-0.398}$	52
25	$Q = 942\ AREA^{0.630}\ ELEV^{-0.383}$	40
50	$LOG_{10}\ Q = 7.36 - 4.17\ AREA^{-0.08} - 0.440\ LOG_{10}\ ELEV$	37
100	$LOG_{10}\ Q = 6.55 - 3.17\ AREA^{-0.11} - 0.454\ LOG_{10}\ ELEV$	39

Figure 8.7

SCATTER DIAGRAM OF INDEPENDENT VARIABLES FOR FLOOD REGION 12

REGRESSION EQUATION: ADAPTED FROM DATA CONTAINED IN USGS OPEN FILE REPORT 93-419

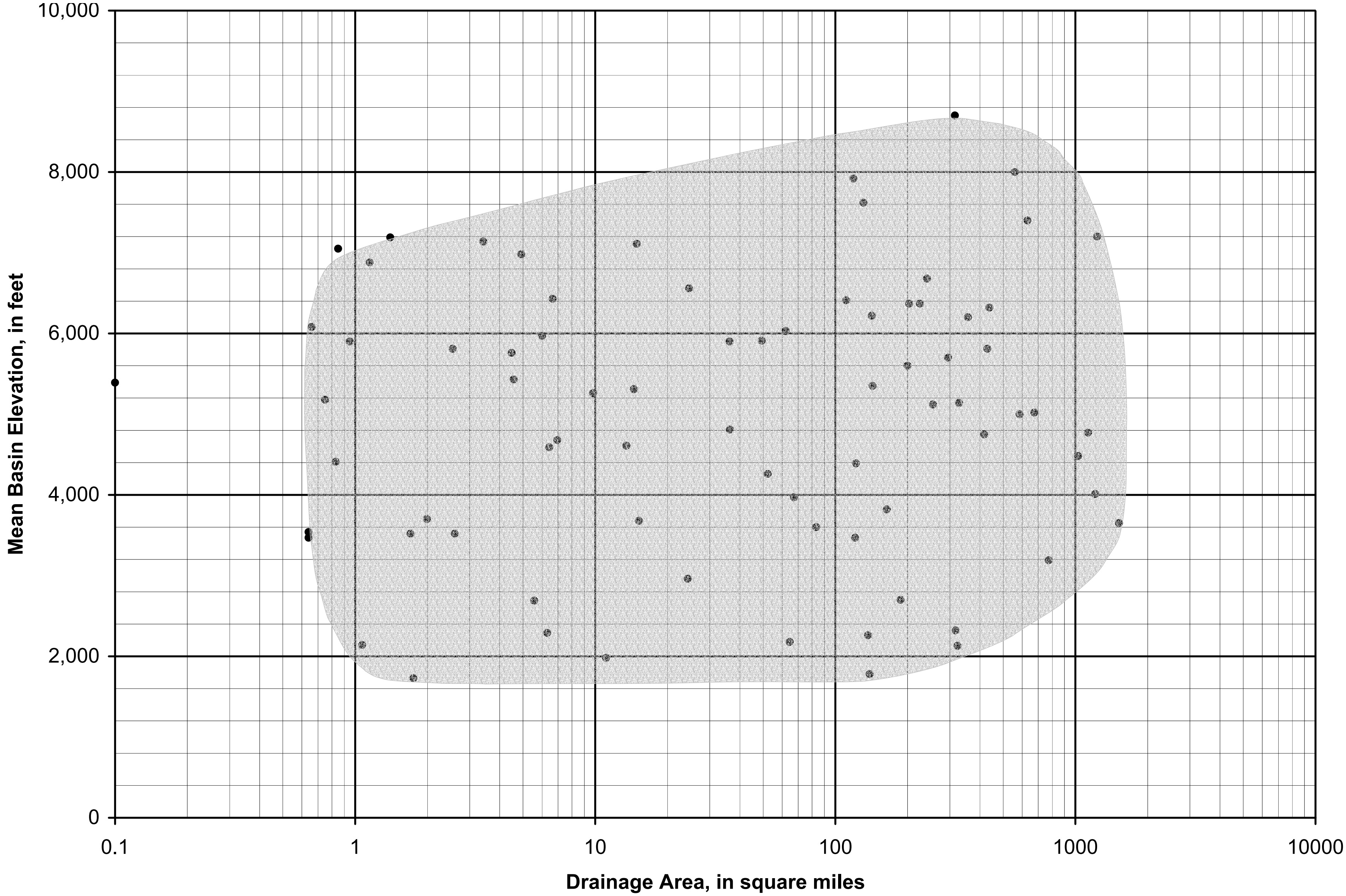


Figure 8.8
100-YEAR PEAK DISCHARGE RELATION FOR FLOOD REGION 12
Adapted from data contained in USGS Open File Report 93-419

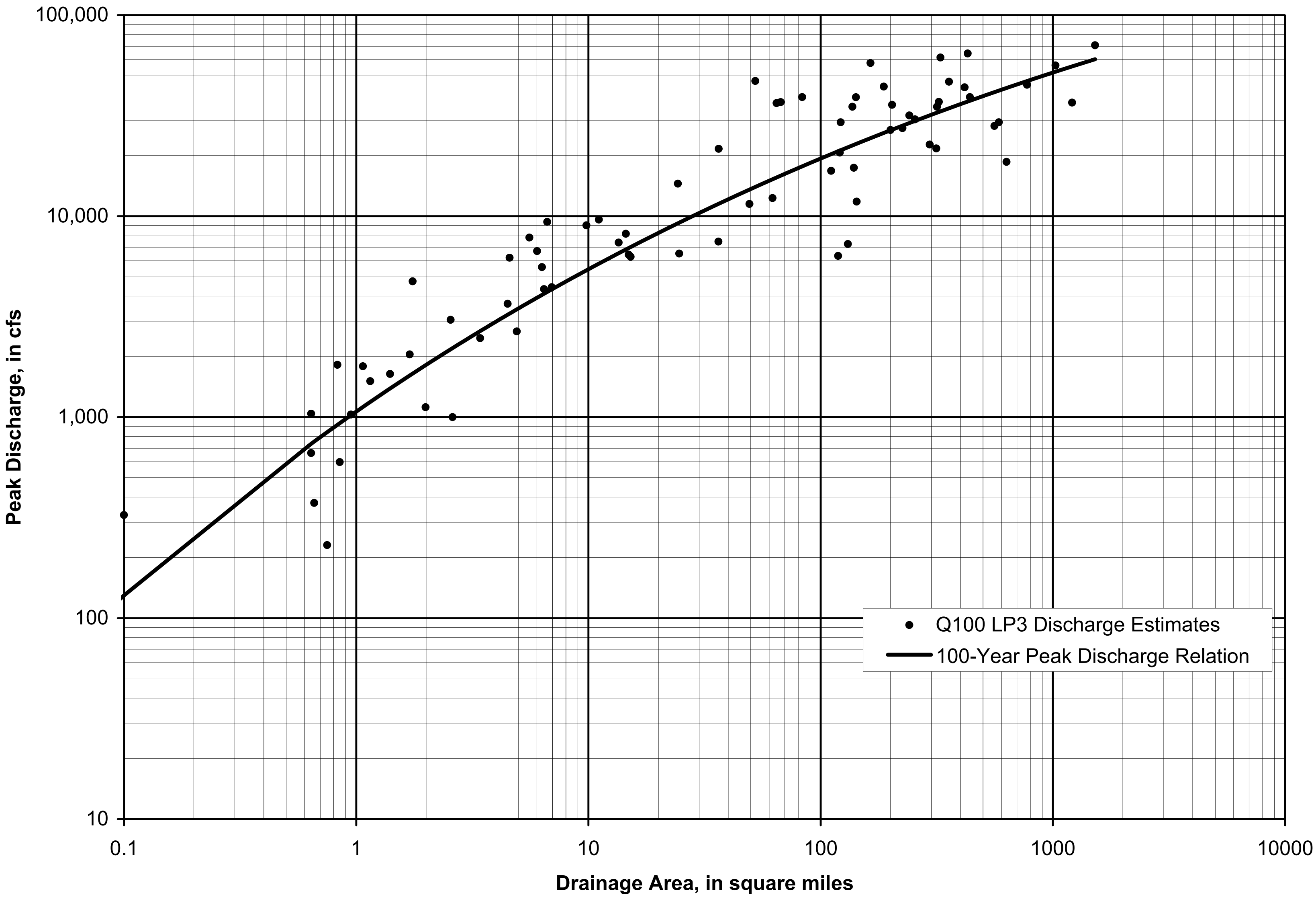


Table 8.3
FLOOD MAGNITUDE-FREQUENCY RELATIONS FOR THE SOUTHERN AZ REGION (R13)
EQUATIONS: Q, PEAK DISCHARGE, IN CUBIC FEET PER SECOND; AND $AREA$, DRAINAGE AREA, IN SQUARE MILES.

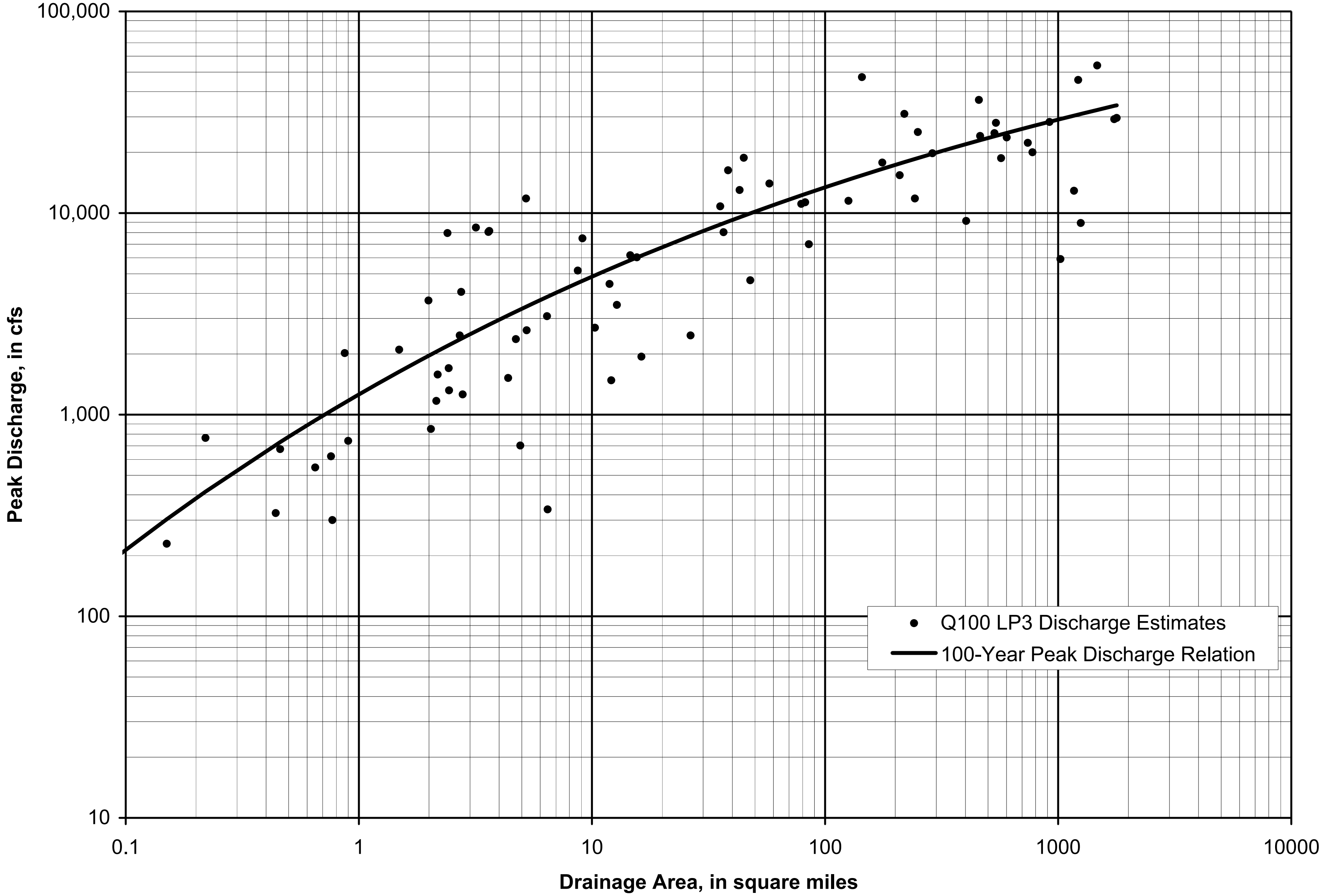
.

Recurrence interval, in years	Equation	Average standard error of model, in percent
2	$LOG_{10}\ Q = 6.38 - 4.29\ AREA^{-0.06}$	57
5	$LOG_{10}\ Q = 5.78 - 3.31\ AREA^{-0.08}$	40
10	$LOG_{10}\ Q = 5.68 - 3.02\ AREA^{-0.09}$	37
25	$LOG_{10}\ Q = 5.64 - 2.78\ AREA^{-0.10}$	39
50	$LOG_{10}\ Q = 5.57 - 2.59\ AREA^{-0.11}$	43
100	$LOG_{10}\ Q = 5.52 - 2.42\ AREA^{-0.12}$	48

Figure 8.9

100-YEAR PEAK DISCHARGE RELATION FOR FLOOD REGION 13

Adapted from data contained in USGS Open File Report 93-419



8.5 APPLICATIONS AND LIMITATIONS

The three indirect methods can be applied to any watershed gaged or ungaged in Maricopa County. Limitations exist for the use of the Regional Regression Equations based on values of the watershed characteristics as compared to the values of watershed characteristics that were used to derive these regional regression equations. The interpretation and evaluation of the results of these methods must be conducted with awareness of several factors.

1. It must be noted that these are empirical methods and the results are only applicable to watersheds that are hydrologically similar to the database used to derive the particular method.

2. The majority of the data in all three of these methods are for undeveloped, unregulated watersheds. Urbanized watersheds can have significantly higher discharges than the results that are predicted by any of these methods.

3. These methods (other than envelope curves) produce discharge values that are statistically based averages for watersheds in the database. Conditions can exist in any watershed that would produce flood discharges, either larger than or smaller than, those indicated by these methods. Watershed characteristics that should be considered when comparing the results of indirect methods to results by analytic methods and/or flood-frequency analysis are:

    a. The occurrence and extent of rock outcrop in the watershed.

    b. Watershed slopes that are either exceptionally flat or steep.

    c. Soil and vegetation conditions that are conducive to low rainfall losses, such as clay soils, thin soil horizons underlain by rock or clay layers, denuded watersheds (forest and range fires), and disturbed land.

    d. Soil and vegetation conditions that are conducive to high rainfall losses, such as sandy soil, tilled agricultural land, and irrigated turf.

    e. Land-use, especially urbanization, but also mining, large scale construction activity, and over-grazing.

    f. Transmission losses that may occur in the watercourses.

    g. The existence of distributary flow areas.

    h. Upstream water regulation or diversion.

8.6 PROCEDURES

The following instructions should be followed as confidence checks on the validity of peak discharges that are derived by analytic methods, (Rational Method or rainfall-runoff modeling). These procedures are typically applied for floodplain delineation studies, dam safety designs and studies, and where the hydrologic model results are to be used for defining high hazard areas or for design of facilities used to provide protection in high flood risk areas. Watersheds with an area of less than one square mile are exempt. The agency may require application of these procedures for larger watersheds depending on the intended application.

A. Confidence Check using Unit Peak Discharge Curves:

1. For a given watershed of drainage area (A), in square miles, divide the 100-year primary peak discharge estimate by A.

2. Plot the unit peak discharge on a copy of Figure 8.1. Note the location of the plotted point in relation to the various curves in that figure.

B. Confidence Check using USGS Data for Arizona:

1. Calculate the 100-year peak discharge estimate by Equation (8.1)

2. Select Figure 8.3 or Figure 8.4 according to watershed drainage area size, and plot the 100-year peak discharge estimate on a copy of that figure.

3. Using watershed drainage area as a guide, identify gaged watersheds of the same approximate size from Table 8.1. Tabulate the peak discharge statistics and watershed characteristics for those gaged watersheds by using the USGS report (Garrett and Gellenbeck, 1991). Compare these to the computed peak discharge estimates and watershed characteristics for the watershed of interest.

C. Confidence Check using Regional Regression Equations:

1. Determine the flood region (Figure 8.6).

2. Calculate the regression equation variables, such as mean basin elevation ($ELEV$) for Region 12. This can be done by placing a transparent grid over the largest scale topographic map available. The grid spacing should be selected such that at least 20 elevation points are sampled. The elevation at each grid point is determined and the elevations are then averaged.

3. Check the drainage area using the appropriate scatter diagram to determine if the values are in the “cloud of common values.” Proceed with the analysis regardless of the

outcome, but clearly note if the variable values are not within the "cloud of common values."

4. Calculate the peak discharge estimates using the applicable regression equations for the flood region within which the project site is located.

5. Plot the 100-year peak discharge estimate on a copy of the appropriate Q_{100} data points and 100-year peak discharge relation graph (Figure 8.8 or Figure 8.9).

D. For all three Indirect Methods:

1. Quantitatively and qualitatively analyze the results of the primary and the secondary peak discharge estimates. Address watershed characteristics that may explain differences between the primary and secondary estimates.

2. Prepare a summary of results by all methods and a qualitative evaluation of the results. The qualitative evaluation should provide a description of the findings from step D.1 and assess whether the model results make logical sense when compared with the available indirect method data. If there is reason to doubt the model results based on the indirect method comparisons, the engineer/hydrologist should reexamine the model input parameters for reasonableness and adjust them where appropriate. If there is no reason to doubt the model results based on the indirect method comparisons, it should be so stated.

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9 APPLICATION

TABLE OF CONTENTS

9.1 RAINFALL

9.1.1 Procedure for the Development of the Design Rainfall

9.1.1.1 Procedure for the Rational Method

1. Determine the size of the drainage area.

2. Locate the drainage area and determine the point rainfall depth for every duration, and all frequencies of interest from Figure A.1 through Figure A.60 of Appendix A.1. Summarize in a Depth-Duration-Frequency (D-D-F) table.

3. Create an Intensity-Duration-Frequency (I-D-F) table by dividing the individual rainfall depth values from Step 2 by the duration associated with the rainfall depth. The units should be in terms of inches per hour.

4. Plot the results for each frequency on log-log paper and examine the results to be sure they plot as smooth curves. Any anomalies should be checked against Appendix A.1 to be sure the correct depth value was read.

   Note: Steps 2 through 4 are performed automatically in DDMSW.

9.1.1.2 Procedure for the Unit Hydrograph Method.

1. Determine the size of the drainage area.

2. Determine the point rainfall depth or the areally averaged point rainfall depth, from Figure A.1 through Figure A.60 of Appendix A.1, depending on the desired storm duration and frequency.

3. For a single storm analysis, determine the depth-area reduction factor using or Table 2.1 for a 6-hour local storm and Table 2.2 or Figure 2.2 or a 24-hour general storm.

   For a multiple storm analysis, determine the drainage areas at key points of interest in the watershed. For each drainage area, determine the depth-area reduction factor using or Table 2.1 for a 6-hour local storm and Table 2.2 or Figure 2.2 for a 24-hour general storm.

4. Multiply the point rainfall depth by the appropriate depth-area reduction factor(s).

5. For a 6-hour local storm, use Figure 2.5 to select the appropriate pattern number(s) (rounded to the nearest 0.1 pattern number).

6. For a 6-hour local storm, use the dimensionless rainfall distributions of Table 2.4, or Figure 2.4 and Figure 9.7 or to calculate the dimensionless distribution(s) by linear interpolation between the two bounding pattern numbers.

   For a 24-hour general storm, use the dimensionless rainfall distribution of Table 2.5 or Figure 2.6.

   Note: Steps 2 through 6 are performed automatically in DDMSW.

9.1.2 User Notes

1. For a multiple storm analysis, areal reduction is accomplished in the HEC-1 program using the JD record option. The use of this record in conjunction with diversion simulations may cause an error at hydrograph combine operations downstream of the diversion. The error is that the model "looses track" of all the upstream tributary area after a diversion. Consequently the peak discharge at hydrograph combines downstream of the diversion are overestimated due to the "loss" of area. This error can be corrected by hard coding the total drainage area on the HC record of the hydrograph combine operation downstream of the diversion.

2. Use of the JD record option prohibits the use of the JR (job ratio) record option.

3. The DDMSW program automatically computes areal reduction factors and the corresponding precipitation mass curves for the 6-hour storm for a multiple storm analysis at predefined intervals. These intervals should be inspected for reasonableness in regard to the study watershed. The JD/PC record sets for storm areas greater than the next largest storm area over the total watershed area can be removed.

4. Precipitation records (PI and PC records) are coded into the HEC-1 program at the time interval specified on the IN record. The DDMSW program automatically populates these records at a time interval of 15 minutes. All other time dependent input data, such as input hydrographs (QI records) will be read into the program at the previously specified time interval unless a new time interval is specified.

9.1.3 Rainfall Examples

9.1.3.1 Rainfall for the Rational Method

A watershed to be modeled using the Rational Method has its centroid located at 33° 42' 40" N and 112° 14' 50" W. Use Figure A.1 through Figure A.60 of Appendix A.1 to develop D-D-F and I-D-F tables and an I-D-F curve for all storm frequencies and durations. The resulting D-D-F data is shown in Table 9.1.

Table 9.1
EXAMPLE DEPTH-DURATION-FREQUENCY STATISTICS FROM FIGURES
(Source: NOAA Atlas 14 Arizona, Figures in Appendix A.1)
Point Rainfall DepthData in inches

Duration	Storm Frequency, years					
	2	5	10	25	50	100
5-min	0.30	0.40	0.43	0.53	0.61	0.70
10-min	0.41	0.54	0.68	0.82	0.93	1.06
15-min	0.52	0.70	0.83	1.02	1.17	1.31
30-min	0.70	0.93	1.12	1.38	1.58	1.78
1-hour	0.86	1.17	1.40	1.70	1.95	2.20
2-hours	0.98	1.32	1.58	1.92	2.20	2.46
3-hour	1.02	1.35	1.61	1.96	2.23	2.50
6-hour	1.20	1.52	1.79	2.13	2.42	2.70
12-hour	1.34	1.70	1.96	2.35	2.61	2.90
24-hour	1.55	1.99	2.34	2.84	3.22	3.62

To obtain I-D-F data, divide each rainfall depth value from Table 9.1 by the corresponding duration using Equation (9.1):

$$i_j^k = \frac{P_j^k}{D^k} \tag{9.1}$$

where:

i_j^k = Rainfall intensity in in/hr for duration j in hours and frequency k in years.

P_j^k = Point rainfall depth in inches for duration j and frequency k.

D^k = Rainfall duration in hours for frequency k.

Consider the 2-year frequency storm of 5-minute duration:

$$j_{0.083}^{2} = \frac{0.30}{5/60} = 3.60\ inches/hour$$

Apply Equation (9.1) for all storm durations and frequencies to create the data in Table 9.2.

Table 9.2
EXAMPLE COMPUTED INTENSITY-DURATION-FREQUENCY DATA
(using Table 9.1)
Point Rainfall Intensity Data in inches/hr

Duration	Storm Frequency, years					
	2	**5**	**10**	**25**	**50**	**100**
5-min	3.60	4.80	5.16	6.36	7.32	8.40
10-min	2.46	3.24	4.08	4.92	5.58	6.36
15-min	2.08	2.80	3.32	4.08	4.68	5.24
30-min	1.40	1.86	2.24	2.76	3.16	3.56
1-hour	0.86	1.17	1.40	1.70	1.95	2.20
2-hours	0.49	0.66	0.79	0.96	1.10	1.23
3-hour	0.34	0.45	0.54	0.65	0.74	0.83
6-hour	0.20	0.25	0.30	0.36	0.40	0.45
12-hour	0.11	0.14	0.16	0.20	0.22	0.24
24-hour	0.06	0.08	0.10	0.12	0.13	0.15

9.1.3.2 Rainfall for the Unit Hydrograph Method

Problem:

For the 22.87 square mile watershed shown on Figure 9.1, determine the following for a 100-year multiple storm analysis:

1. Point rainfall depth,
2. Depth-area reduction factors, and
3. Rainfall distributions.

Solution:

Given the watershed size, both the local storm (6-hour) and the general storm (24-hour) are to be considered (refer to Section 2.1.2).

1. Point Rainfall Depth: From Figure A.58 and Figure A.60 of APPENDIX A,

$$P_6^{100} = 2.70 \text{ inches}$$

$$P_{24}^{100} = 3.62 \text{ inches}$$

2. Depth - Area Reduction Factors: Inspection of Figure 9.1 yields the following:

   - Subbasin areas range from 0.83 to 22.87 square miles
   - Drainage areas at concentration points (CP) range from 0.44 to 22.9 square miles
   - Selected index areas and corresponding depth-area reduction factors from Table 2.1 or Figure 2.1 for the 6-hour storm, and Table 2.2 or Figure 2.2 for the 24-hour storm are:

6-hour		**24-hour**	
Area sq. miles	**Depth-Area Reduction Factors**	**Area sq. miles**	**Depth-Area Reduction Factors**
0.01	1.000	0.01	1.000
0.50	0.994	0.50	0.998
2.80	0.975	2.00	0.990
16.00	0.922	10.00	0.950
25.00	0.900	25.00	0.909

Rainfall Distribution

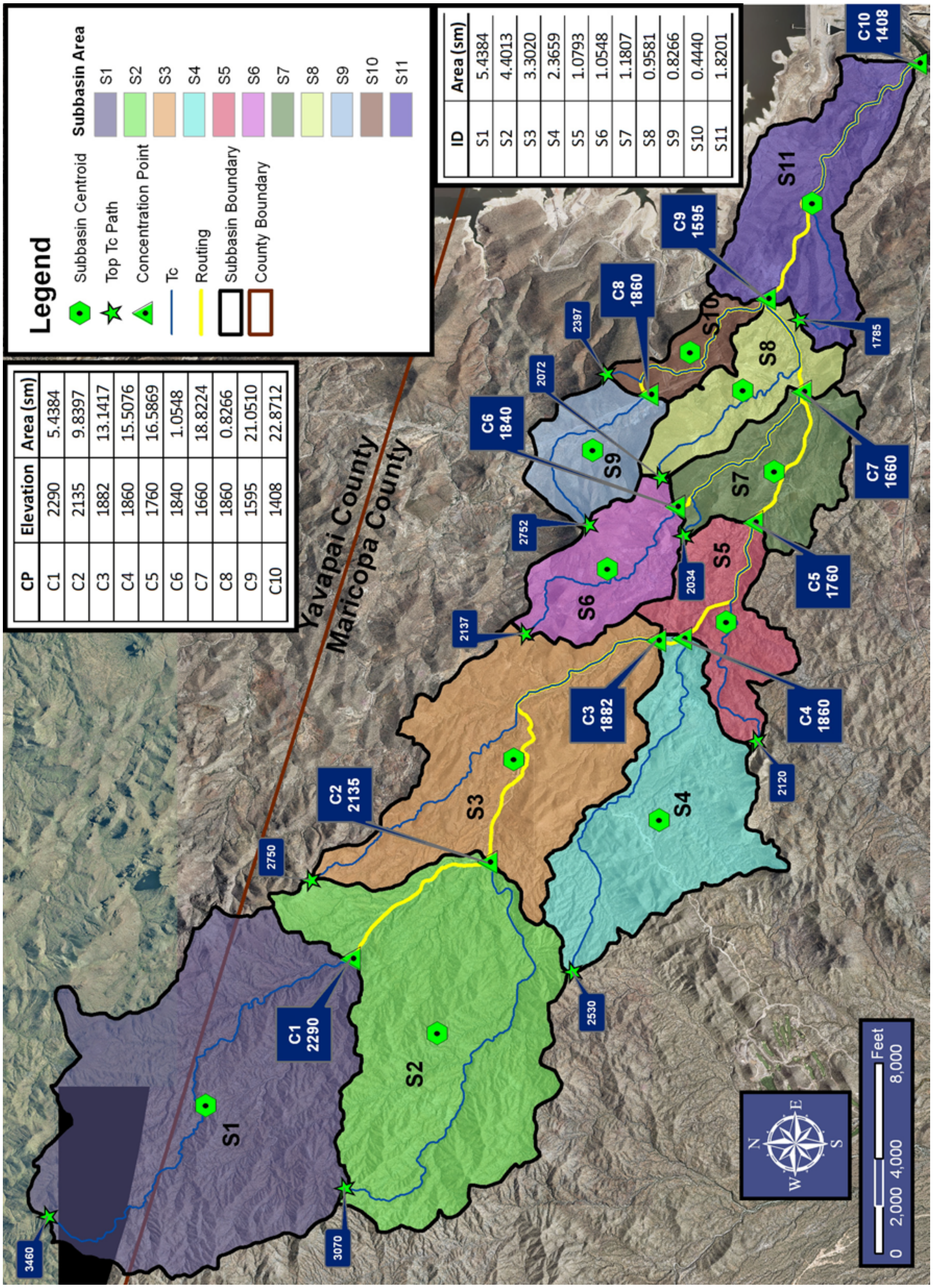
3. The 6-hour pattern numbers corresponding to the selected index areas are 1, 2, 3 and 3.3.

   Dimensionless rainfall distributions for pattern numbers 1, 2 and 3 are taken directly from Table 2.4. The distribution for pattern number 3.3 is determined by linear interpolation between pattern numbers 3 and 4 as listed in Table 2.4. The dimensionless distribution for pattern number 3.3 is:

Time hours	Pattern 3.3	Time hours	Pattern 3.3	Time hours	Pattern 3.3
0:00	0.0	2:15	13.1	4:30	86.0
0:15	1.7	2:30	14.8	4:45	90.5
0:30	2.5	2:45	16.7	5:00	94.0
0:45	3.6	3:00	19.2	5:15	95.6
1:00	5.5	3:15	24.0	5:30	97.0
1:15	7.0	3:30	32.2	5:45	98.6
1:30	8.5	3:45	48.0	6:00	100.0
1:45	10.1	4:00	66.6		
2:00	11.6	4:15	78.9		

For the 24-hour storm, the SCS Type II distribution is taken directly from Table 2.5 and is not a function of area.

Figure 9.1
EXAMPLE WATERSHED MAP



CP	Elevation	Area (sm)
C1	2290	5.4384
C2	2135	9.8397
C3	1882	13.1417
C4	1860	15.5076
C5	1760	16.5869
C6	1840	1.0548
C7	1660	18.8224
C8	1860	0.8266
C9	1595	21.0510
C10	1408	22.8712

ID	Area (sm)
S1	5.4384
S2	4.4013
S3	3.3020
S4	2.3659
S5	1.0793
S6	1.0548
S7	1.1807
S8	0.9581
S9	0.8266
S10	0.4440
S11	1.8201

9.2 RATIONAL METHOD

9.2.1 Procedures for the Peak Discharge Calculation

1. Determine the area within the development boundaries.

2. Select the Runoff Coefficient, C from Table 3.2. If the drainage area contains subareas of different runoff characteristics, and thus different C coefficients, arithmetically area-weight the values of C.

3. Tabulate the depth-duration-frequency (D-D-F) statistics for the project site using Figure A.1 through Figure A.60 (see Section 9.1.3.1) for an example. If many subbasins for the same area are to be analyzed, compute an I-D-F table and prepare an I-D-F graph to more efficiently select rainfall intensities. Refer to APPENDIX B for an example I-D-F table and graph. Alternatively, if the project site lies within the Phoenix Metro area, the I-D-F graph in APPENDIX B can be used to compute intensity, but a site-specific I-D-F is preferred.

4. Calculate the time of concentration. This is to be done as an iterative process.

   a. Determine the K_b parameter from Figure 3.1 or Table 3.1. If the drainage area contains subareas of different K_b values, arithmetically area-weight the values of K_b.

   b. Make an initial estimate of the duration and compute the intensity from the site-specific I-D-F for the desired frequency.

   c. Compute an estimated T_c using Equation (3.2). If the computed T_c is reasonably close to the estimated duration, then proceed to Step 5, otherwise repeat this step with a new estimate of the duration. The minimum T_c should not be less than 5-minutes.

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 DDMSW program may be used to calculate peak discharges.

9.2.2 Procedures for Volume Calculations

Volume calculations should be done by applying the following equation:

$$V = C\left(\frac{P}{12}\right)A \qquad (3.3)$$

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 stormwater storage facility design, P equals the 100-year, 2-hour depth, in inches, as discussed in Section 2.2, and is determined from Figure A.56 of Appendix A.1.

9.2.3 Procedures for the Multiple Basin Approach

The Rational Method can be used to compute peak discharges at intermediate locations within a drainage area less than 160 acres in size. A typical application of this approach is a local storm drain system where multiple subbasins are necessary to compute a peak discharge at each proposed inlet location. Consider the schematic example watershed shown in Figure 9.2. A peak discharge is needed for all three individual subareas, subareas A and B combined at Concentration Point 1 and subareas A, B and C combined at Concentration Point 2.

There are two accepted methods for computing peak discharges for multiple basins using the Rational Method. The first method is the traditional approach that relies upon combining the subbasin areas into a single watershed, computing a new T_c, an arithmetically area-weighted value of C for combined sub-basins, and then computing the peak discharge. This approach is referred to as the “Combined Watershed Method.” The second method is the “Triangular Hydrograph Method.” For this method, a triangular hydrograph is created for each sub-basin where the time-to-peak is assumed equal to T_c and the hydrograph time base is equal to 2.67T_c, as shown on Figure 3.2. Referring to Figure 9.2, the ordinates of hydrographs A and B at CP 1 are added to obtain the total flow hydrograph. That hydrograph is then lagged downstream to CP 2 by the estimated travel time in the roadway, pipe, or channel. The lagged hydrograph is then added to the sub-basin C hydrograph to obtain the peak discharge at CP 2. The triangular hydrograph method is incorporated in the DDMSW computer program, but the combined hydrograph method is not. The combined hydrograph method is intended for use by engineers/hydrologists without access to a computer and DDMSW. Either method may be used but the engineer/hydrologist should receive prior approval from the jurisdiction before applying the combined watershed method.

The procedures for the Combined Hydrograph Method are as follows:

1. Compute the peak discharge for each individual subarea using steps 1 through 5 from Section 9.2.1.
2. Compute the arithmetically area-weighted value of C for subareas A and B.
3. Follow step 4 from Section 9.2.1 to calculate the T_c for the combined area of subareas A and B at Concentration Point 1.
4. Compare the T_c values from subareas A and B to the T_c value for the combined area at Concentration Point 1. Compute the peak discharge at Concentration Point 1 using the i for the longest T_c from step 3. If the combined peak discharge is less than the discharges for the individual subareas, use the largest discharge as the peak discharge at Concentration Point 1. The design discharge SHOULD NOT DECREASE going downstream in a conveyance system unless storage facilities are used to attenuate peak flows.
5. Compute the arithmetically area-weighted value of C for subareas A, B and C.
6. Calculate the T_c for the combined area at Concentration Point 2 using the following two methods:

   Method 1 - Follow step 4 from Section 9.2.1 to calculate the T_c for the single basin composed of all three subareas.

   Method 2 - Compute the travel time from Concentration Point 1 to Concentration Point 2 using the Manning equation or other appropriate technique and hydraulic parameters for the conveyance path. Add the computed travel time for the conveyance path to the T_c from Concentration Point 1.

7. Compare the T_c values from Methods 1 and 2 as well as the T_c from subarea C and calculate the peak discharge at Concentration Point 2 as follows:

   a. If the T_c value from Method 1 is the longest, compute the total peak discharge using the Method 1 intensity, the arithmetically area-weighted value of C for all three subareas and the total contributing drainage area at Concentration Point 2.

   b. If the T_c value from Method 2 is the longest, determine i directly from the I-D-F statistics from step 3 of Section 9.2.1. Compute the total peak discharge at Concentration Point 2 using the arithmetically area-weighted value of C for all three subareas and the total contributing drainage area at Concentration Point 2.

c. If the T_c from subarea C is the longest, compute the total peak discharge using the i for subarea C, the arithmetically area-weighted value of C for all three subareas and the total contributing drainage area at Concentration Point 2.

The procedures for theTriangular Hydrograph Method are as follows:

1. Compute the peak discharge for each individual sub-basin using steps 1 through 5 from Section 9.2.1.
2. Plot triangular hydrographs for sub-basins A and B on a single sheet of graph paper using the dimensionless triangular hydrograph shown in Figure 3.2 as the model. The peak discharge occurs at time T_c and the hydrograph time base is $2.67T_c$.
3. Add the hydrograph ordinates from sub-basins A and B to produce and plot a combined hydrograph at CP 1.
4. Compute the travel time from CP 1 to CP 2 using the continuity equation or other appropriate technique and hydraulic parameters for the conveyance path.
5. Plot the hydrograph for sub-basin C on a new piece of graph paper, starting at time = 0.0. Plot the hydrograph for CP 1 starting at time = travel time from CP 1 to CP 2.
6. Add the hydrograph ordinates from CP 1 and sub-basin C to produce and plot a combined hydrograph at CP 2.

As an alternative to the above procedure, the DDMSW program may be used to calculate the peak discharge at intermediate locations.

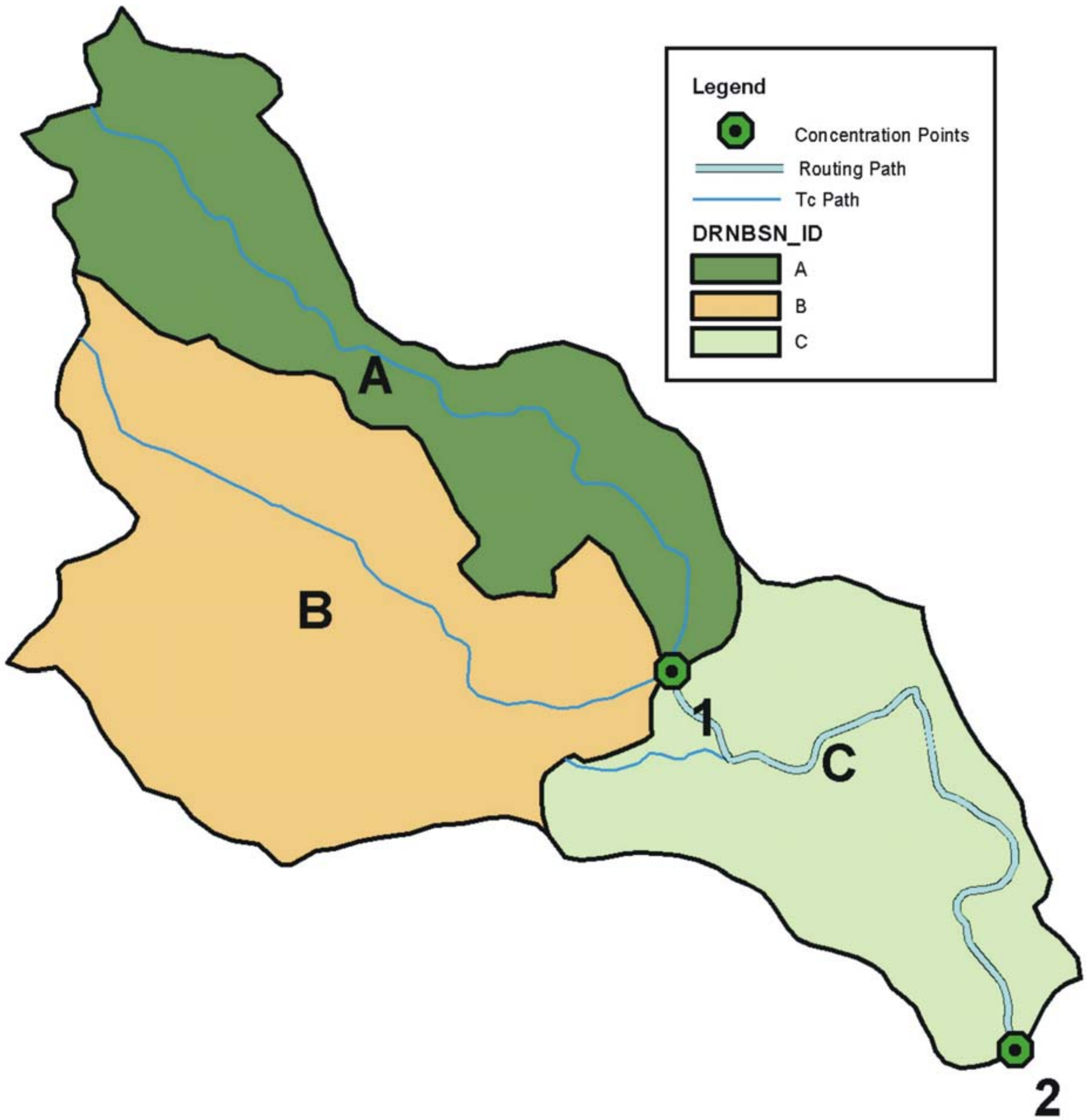
9.2.4 User Notes

1. The Rational Method is appropriate for watersheds less than 160 acres in size.
2. For drainage areas greater than 160 acres or for situations where hydrograph routing is desired, the procedures described in Chapters 4 through 7 should be used.
3. The duration of T_c should not be longer than 2 hours and normally it will be less than 1 hour.

4, The minimum duration of T_c should not be less than 5 minutes, but is normally set to a minimum of 10 minutes.

5. For a multiple basin analysis, judgement must be used in the calculation of travel time, particularly in regard to velocity.

Figure 9.2
SCHEMATIC EXAMPLE WATERSHED



9.2.5 Rational Method Example

A 35.06-acre mixed use residential development is planned for the tract of land as shown on Figure 9.3. Off-site runoff is to be conveyed through the site in a new storm drain.

Determine the 100-year, post-development peak discharge at concentration point C1 (storm drain inlet) and C2. Also determine the total required stormwater storage volume.

- Time of concentration physical data for each subbasin are listed in Table 9.3.
- Rainfall D-D-F statistics are listed in Table 9.1 and Table 9.4 and I-D-F statistics in Table 9.2 and Table 9.5 and on Figure 9.4 for the manual and DDMSW GIS methods of obtaining NOAA Atlas 14 data. Note that these two methods produce comparable results, but there can be inaccuracies, particularly for the shortest durations.
- Resistance coefficients for the off-site area can be characterized as moderately high for subarea S1 and moderately low for subarea S2.
- Developed areas are as follows:

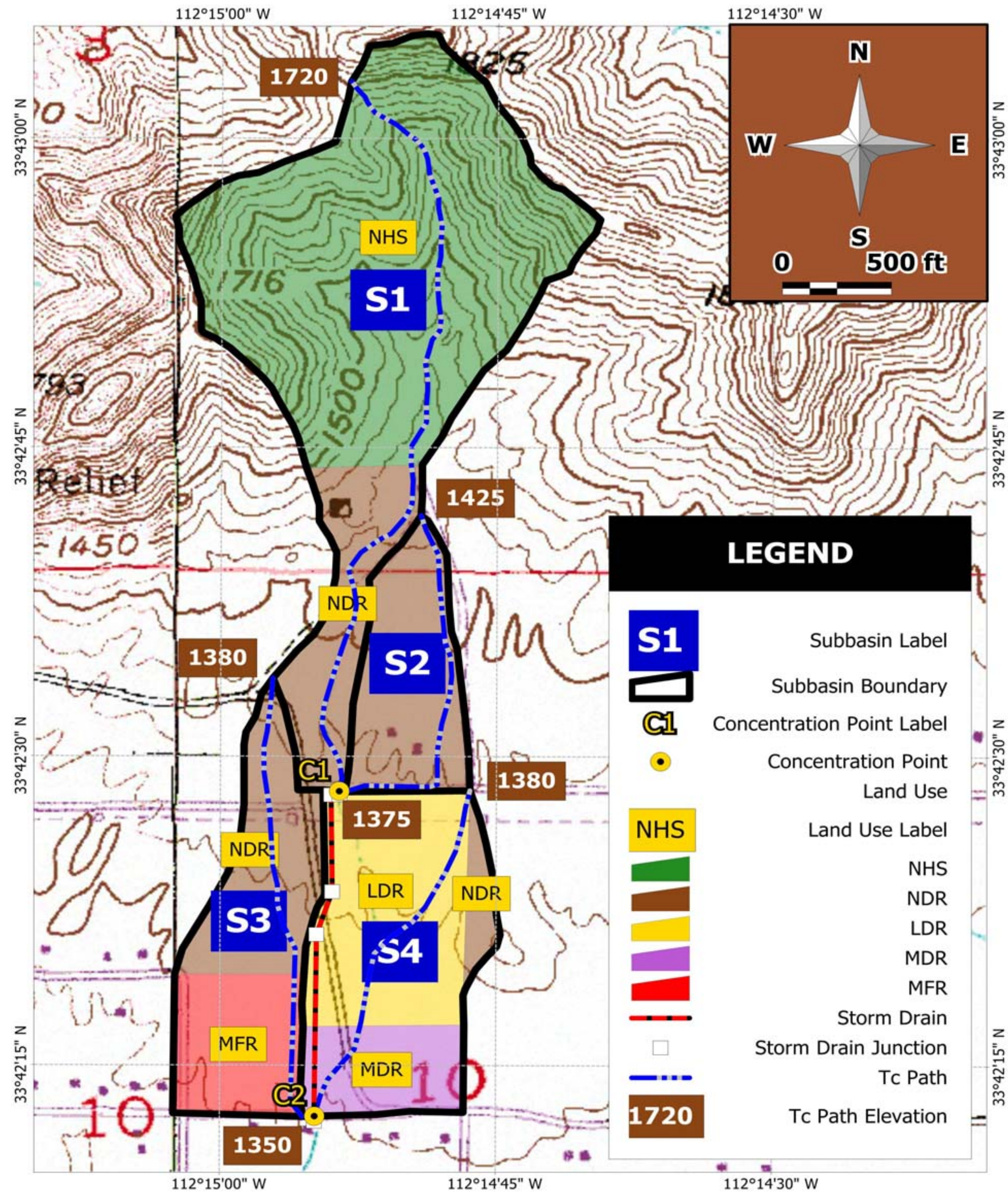
  Low Density Residential = 16.50 acres
  Medium Density Residential = 6.64 acres
  Multiple Family Residential = 8.39 acres
  Pavement = 3.53 acres

- The maximum permissible velocity in the storm drain is 6 fps and the storm drain length = 1,653 feet.
- Assume that 10 percent of the developed area will be needed for the local and collector roadway system.

Table 9.3
TIME OF CONCENTRATION PHYSICAL DATA

Subbasin ID	Flow Path		Land Use Area, acres						Total Drainage Area acres
	Length miles	Slope ft/mi	NHS	NDR	LDR (130)	MDR (140)	MFR (170)	P (2002)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
S1	0.729	473.0	54.72	11.27	0.00	0.00	0.00	0.00	65.99
S2	0.337	148.9	0.00	12.60	0.00	0.00	0.00	0.00	12.60
S3	0.415	72.2	0.00	11.85	0.00	0.00	8.39	0.94	21.18
S4	0.341	87.9	0.00	2.07	16.50	6.64	0.00	2.59	27.80
								Total:	127.57

Figure 9.3
RATIONAL METHOD EXAMPLE WATERSHED MAP



Solution:

1. Select Runoff Coefficients (C) for each land use from the range of values in Table 3.2. This watershed is within unincorporated Maricopa County. Therefore, the following values are from the Drainage Policies and Standards for Maricopa County, Arizona (2007).

Hillslopes, Sonoran Desert	(NHS)	C = 0.69
Undeveloped Desert Rangeland	(NDR)	C = 0.50
Low Density Residential	(LDR, 130)	C = 0.60
Medium Density Residential	(MDR, 140)	C = 0.71
Multiple Family Residential	(MFR, 170)	C = 0.94
Pavement	(P, 2002)	C = 0.95

Compute the arithmetically area-weighted C value for subbasins S1 through S4.

Subbasin S1:

$$C_w = \frac{(0.69)(54.72) + (0.50)(11.27)}{(65.99)} = 0.66$$

Subbasin S2:

$$C_w = 0.50$$

Subbasin S3:

$$C_w = \frac{(0.50)(11.85) + (0.94)(8.39) + (0.95)(0.94)}{(21.18)} = 0.69$$

Subbasin S4:

$$C_w = \frac{(0.50)(2.07) + (0.60)(16.50) + (0.71)(6.64) + (0.95)(2.59)}{27.80} = 0.65$$

The runoff coefficients for each subbasin are:

S1: C = 0.66

S2: C = 0.50

S3: C = 0.69

S4: C = 0.65

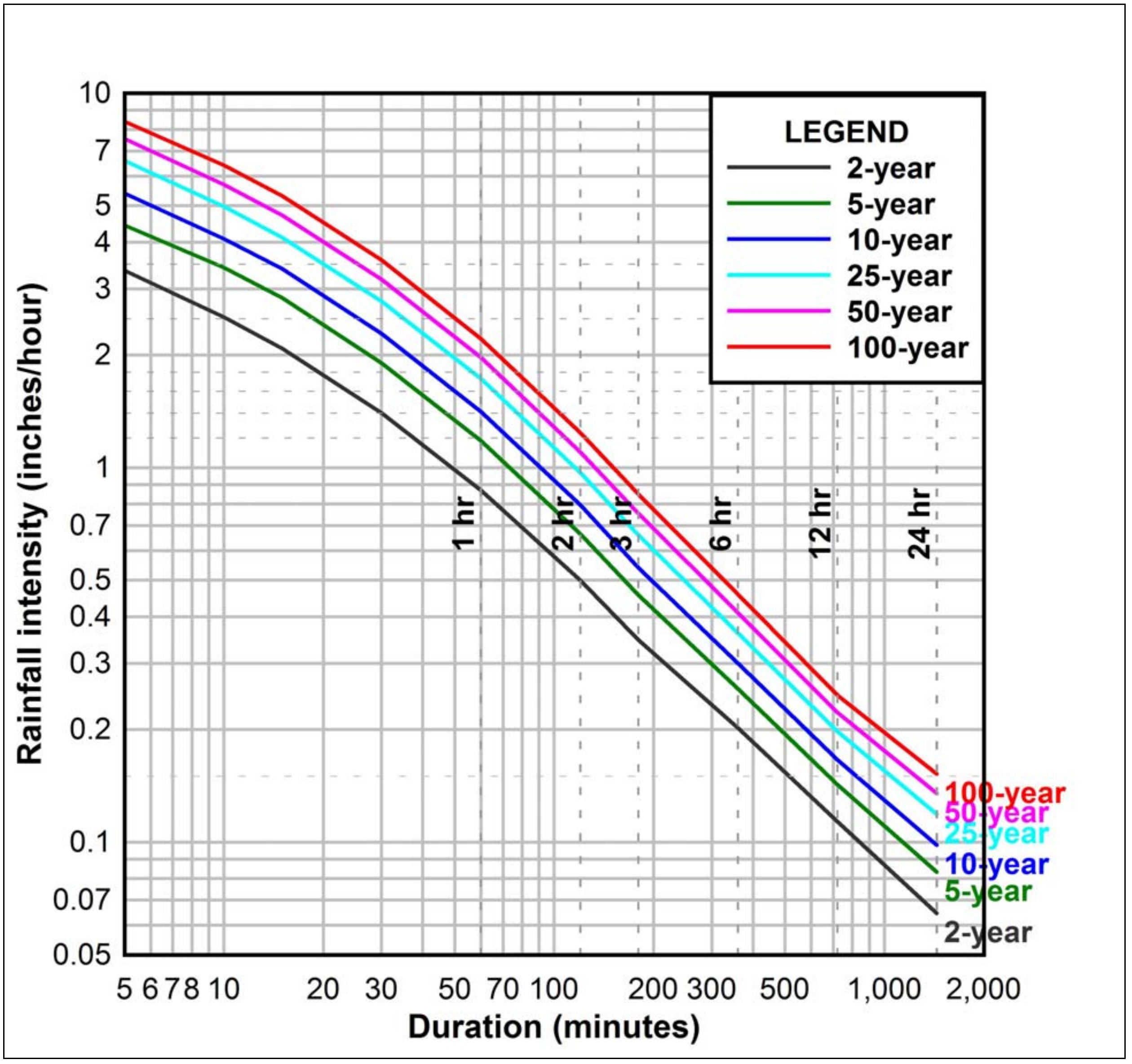
Table 9.4
EXAMPLE DEPTH-DURATION-FREQUENCY STATISTICS FROM GIS
(Source: NOAA Atlas 14 Arizona, DDMSW GIS Method)
Point Rainfall Depth Data in inches

Duration	Storm Frequency, years					
	2	5	10	25	50	100
5-min	0.274	0.370	0.445	0.544	0.620	0.698
10-min	0.417	0.564	0.677	0.828	0.943	1.062
15-min	0.517	0.699	0.839	1.026	1.169	1.316
30-min	0.696	0.941	1.130	1.382	1.575	1.773
1-hour	0.862	1.165	1.398	1.710	1.949	2.194
2-hours	0.992	1.322	1.576	1.919	2.180	2.451
3-hour	1.030	1.354	1.608	1.960	2.237	2.529
6-hour	1.189	1.519	1.781	2.143	2.425	2.718
12-hour	1.338	1.689	1.967	2.338	2.624	2.918
24-hour	1.540	1.989	2.342	2.831	3.219	3.624

Table 9.5
EXAMPLE COMPUTED INTENSITY-DURATION-FREQUENCY DATA
(using Table 9.4)
Point Rainfall Intensity Data in inches/hr

Duration	Storm Frequency, years					
	2	5	10	25	50	100
5-min	3.29	4.44	5.34	6.53	7.44	8.38
10-min	2.50	3.38	4.06	4.97	5.66	6.37
15-min	2.07	2.80	3.36	4.10	4.68	5.26
30-min	1.39	1.88	2.26	2.76	3.15	3.55
1-hour	0.86	1.17	1.40	1.71	1.95	2.19
2-hours	0.50	0.66	0.79	0.96	1.09	1.23
3-hour	0.34	0.45	0.54	0.65	0.75	0.84
6-hour	0.20	0.25	0.30	0.36	0.40	0.45
12-hour	0.11	0.14	0.16	0.19	0.22	0.24
24-hour	0.06	0.08	0.10	0.12	0.13	0.15

Figure 9.4
EXAMPLE INTENSITY-DURATION-FREQUENCY GRAPH
(using Table 9.5)



2. Compile a D-D-F table of point precipitation data and compute I-D-F data. Prepare an I-D-F graph. Refer to Table 9.1, Table 9.5, and Figure 9.4.

3. Compute the Resistance Coefficient (K_b) for each subbasin using Table 3.1.

   Subbasin S1, using K_b type C for the Hillslope area and K_b type B for the desert/rangeland area:

$$K_{b(NHS)} = (-0.025)\log_{10}(65.99) + 0.15 = 0.105$$

$$K_{b(NDR)} = (-0.01375)\log_{10}(65.99) + 0.08 = 0.055$$

$$K_{b(weighted)} = \frac{(0.105)(54.72) + (0.055)(11.27)}{65.99} = 0.096$$

Subbasin S2, using K_b type B:

$$K_b = (-0.01375)\log_{10}(12.60) + 0.08 = 0.065$$

Subbasin S3, using K_b type B for the desert/rangeland area and K_b type A for the developed area:

$$K_{b(NDR)} = (-0.01375)\log_{10}(21.18) + 0.08 = 0.062$$

$$K_{b(Dev)} = (-0.00625)\log_{10}(21.18) + 0.04 = 0.032$$

$$K_{b(weighted)} = \frac{(0.062)(11.85) + (0.032)(9.33)}{21.18} = 0.049$$

Subbasin S4, using K_b type B for the desert/rangeland area and K_b type A for the developed area:

$$K_{b(NDR)} = (-0.01375)\log_{10}(27.80) + 0.08 = 0.060$$

$$K_{b(Dev)} = (-0.00625)\log_{10}(27.80) + 0.04 = 0.031$$

$$K_{b(weighted)} = \frac{(0.060)(2.07) + (0.031)(25.73)}{27.80} = 0.033$$

The K_b values for each subbasin are:

S1: $K_b = 0.096$

S2: $K_b = 0.065$

S3: $K_b = 0.049$

S4: $K_b = 0.033$

4. Compute the Time of Concentration (T_c) and Intensity (i) for each subbasin using Equation (3.2) and the data from Table 9.5 based on the 100 year event. Use a log interpolation to compute i.

Subbasin S1:

$$T_c = 11.4L^{0.5}K_b^{0.52}S^{-0.31}i^{-0.38}$$

$$= 11.4(0.729)^{0.5}(0.096)^{0.52}(473.0)^{-0.31}i^{-0.38}$$

$$T_c = 0.426i^{-0.38}$$

Start with an initial estimate for T_c of 15 minutes.

- From Table 9.5, i = 5.26 inches/hour for a 15-minute duration.

$$T_c = 0.426(5.26)^{-0.38} = 0.227 \text{ hours} = 13.6 \text{ min}$$

Recompute i for T_c of 13.6 minutes.

- From Table 9.5, i = 5.26 inches/hour for 15 minutes, and i = 6.37 inches/hour for 10-minutes

$$i = 10^{(((13.6-10)/(15-10))(\log_{10}5.26 - \log_{10}6.37) + \log_{10}6.37)} = 5.55 \text{ inches/hour}$$

$$T_c = 0.426(5.55)^{-0.38} = 0.222 \text{ hours} = 13.3 \text{ min}$$

Recompute i for T_c of 13.3 minutes.

$$i = 10^{(((13.3-10)/(15-10))(\log_{10}5.26 - \log_{10}6.37) + \log_{10}6.37)} = 5.61 \text{ inches/hour}$$

$$T_c = 0.426(5.61)^{-0.38} = 0.221 \text{ hours} = 13.3 \text{ min}$$

Recompute i for T_c of 13.3 minutes.

$$i = 10^{(((13.3-10)/(15-10))(\log_{10}5.26 - \log_{10}6.37) + \log_{10}6.37)} = 5.61 \text{ inches/hour}$$

$$T_c = 0.426(5.61)^{-0.38} = 0.221 \text{ hours} = 13.3 \text{ min}$$

Difference is less than 2%. Round T_c to nearest minute and recomput i. Use T_c = 13 min, and i = 5.68 inches/hour

NOTE: There may be slight differences in results when DDMSW is used to perform these calculations due to numerical rounding.

Using the above procedure, the T_c and i for each subbasin are:

Subbasin	**T_c, min**	***i*, in/hr**
S1	13	5.68
S2	10	6.37
S3	12	5.90
S4	10	6.37

5. Compute the peak discharge for each subbasin using Equation (3.1):

Subbasin S1: $Q = (0.66)(5.68)(65.99) = 247 \text{ cfs}$

Subbasin S2: $Q = (0.50)(6.37)(12.60) = 40 \text{ cfs}$

Subbasin S3: $Q = (0.69)(5.90)(21.18) = 86 \text{ cfs}$

Subbasin S4: $Q = (0.65)(6.37)(27.80) = 115 \text{ cfs}$

6. Compute the peak discharge for concentration point C1 using the Combined Watershed Method.

The combined area of subbasins S1 and S2 is 78.59 acres.

The area-weighted C coefficient is:

C1: $$C_w = \frac{(0.66)(65.99) + (0.50)(12.60)}{(78.59)} = 0.63$$

The area-weighted K_b is:

C1: $$= \frac{(0.096)(65.99) + (0.065)(12.60)}{(78.59)} = 0.091$$

Use the length, L, and slope, S, from subbasin S1 since both subbasins S1 and S2 join at C1 and subbasin S1 has the longer T_c flow path.

C1: L = 0.729 miles

C1: S = 473.0 feet/mile

Compute the Time of Concentration (T_c) and Intensity (i) for concentration point C1 using Equation (3.2) and the data from Table 9.5. Use a log interpolation to compute i.

Concentration Point C1:

$$T_c = 11.4L^{0.5}K_b^{0.52}S^{-0.31}i^{-0.38}$$

$$= 11.4(0.729)^{0.5}(0.091)^{0.52}(473.0)^{-0.31}i^{-0.38}$$

$$T_c = 0.415^{-0.38}$$

Start with an initial estimate for T_c of 15 minutes.

- From Table 9.5, i = 5.26 inches/hour for a 15-minute duration.

$$T_c = 0.415(5.26)^{-0.38} = 0.221 \text{ hours} = 13.3 \text{ min}$$

Recompute i for T_c of 13.3 minutes.

- From Table 9.5, i = 5.26 inches/hour for 15 minutes, and i = 3.55 inches/hour for 30-minutes

$$i = 10^{(((13.3-15)/(30-15))(\log_{10}3.55 - \log_{10}5.26) + \log_{10}5.26)} = 5.50 \text{ inches/hour}$$

$$T_c = 0.415(5.50)^{-0.38} = 0.217 \text{ hours} = 13.0 \text{ min}$$

Difference is less than 1%. Use T_c = 13.0 min, i = 5.50 inches/hour

Compute the peak discharge at C1:

Concentration Point C1: $Q = (0.63)(5.50)(78.59) = 272$ cfs

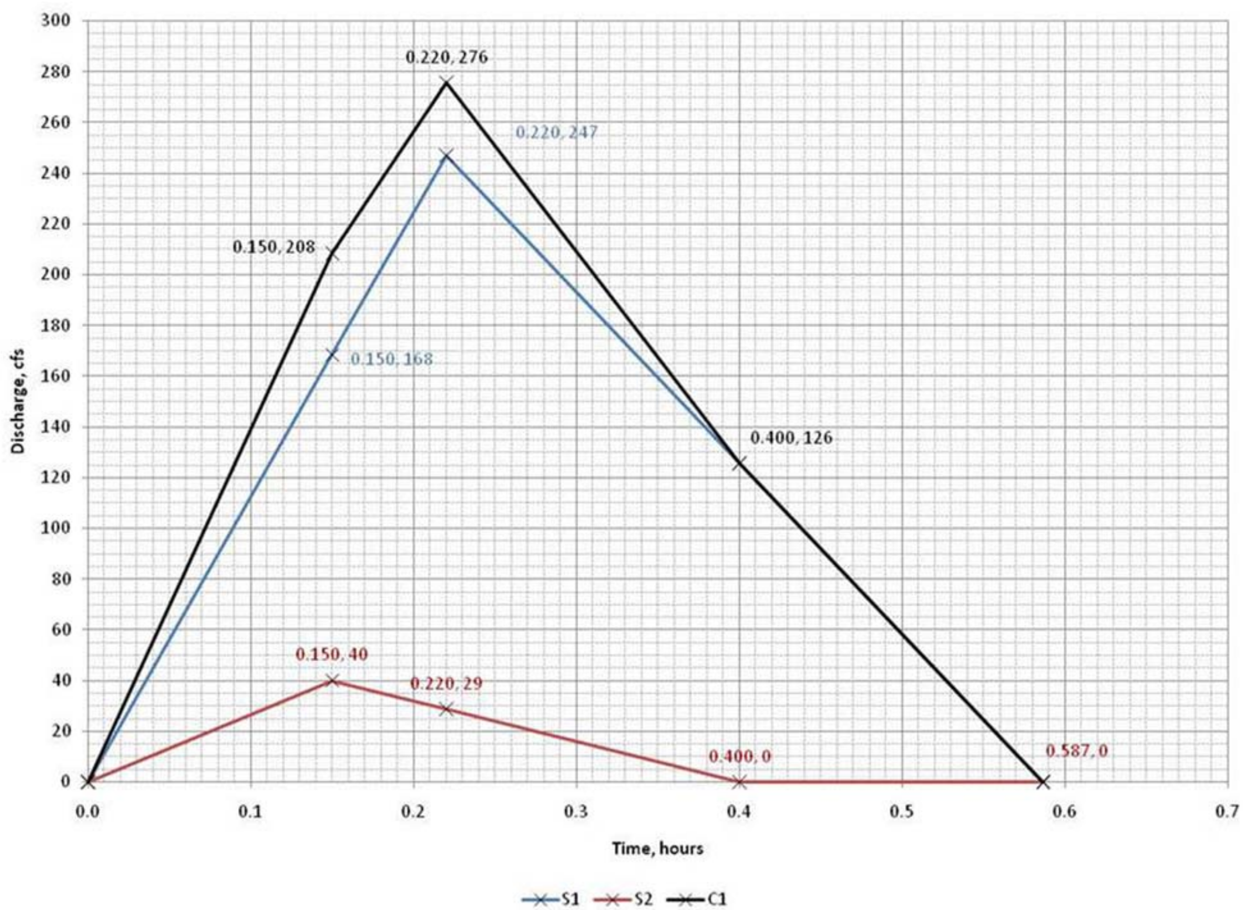
7. The peak discharge at concentration point C2 can be computed in a similar manner. Keep in mind that the Combined Watershed Method is not implemented in DDMSW.

8. Compute the peak discharge for concentration points C1 and C2 using the Triangular Hydrograph Method.

Concentration Point C1:

Plot triangular hydrographs for subbasin S1 and subbasin S2 using the template shown on Figure 3.2. Add the hydrograph ordinates to create a total flow hydrograph at concentration point C1. Refer to Figure 9.5.

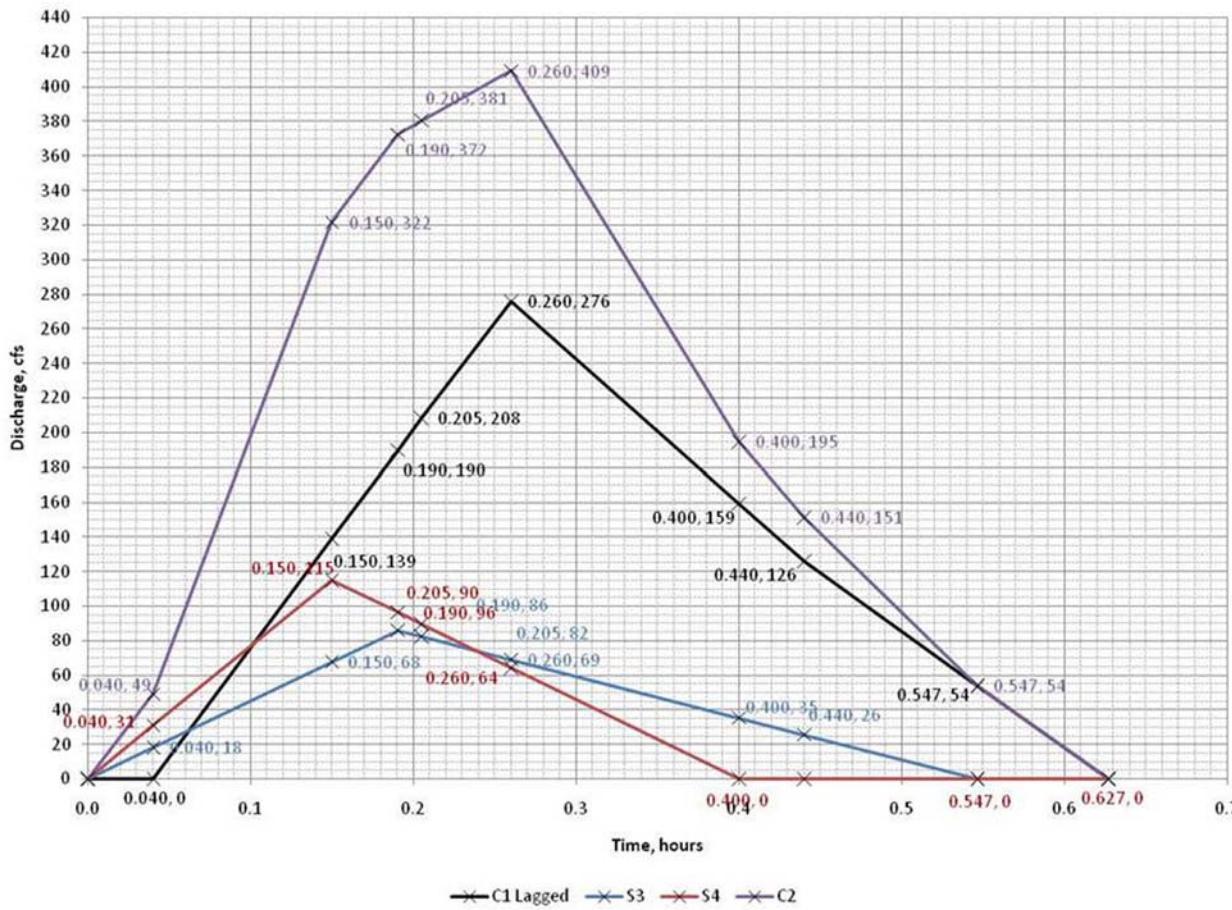
Figure 9.5
RATIONAL METHOD HYDROGRAPHS AT CONCENTRATION POINT C1



Concentration Point C2:

Plot triangular hydrographs for concentration point C1, subbasin S3 and subbasin S4 using the template shown on Figure 3.2. Add the hydrograph ordinates to create a total flow hydrograph at concentration point C2. Refer to Figure 9.6.

Figure 9.6
RATIONAL METHOD HYDROGRAPHS AT CONCENTRATION POINT C2



The Triangular Hydrograph Method is implemented in the current version of DDMSW.

9.3 RAINFALL LOSSES

9.3.1 Procedures for the Green and Ampt Method

A. When soils data are available:

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

2. Determine the location of the study area in regard to the limits of the soil surveys provided in APPENDIX C.

   a. If the study area is completely contained within these limits:

      i. Overlay the watershed limits on the soil survey maps from the appropriate soil survey report(s) and tabulate the map units present within the watershed.

      ii. Cross reference the map units with those listed in APPENDIX C and tabulate the weighted value of XKSAT for each map unit and the corresponding percent imperviousness.

      iii. Proceed to item (3) or (4).

   b. If the study area is partly or entirely outside the limits of the soils surveys provided in APPENDIX C:

      i. Refer to the figure showing the status of soil surveys in Arizona (at the front of APPENDIX C) for other sources of soils data. Other sources of soils data are:

         - General soils surveys by county prepared by the NRCS.
         - Other detailed soil surveys.
         - US Forest Service Terrestrial Ecosystem Reports.

      ii. Using the data contained in the alternative source, follow the example procedure for determination of the weighted XKSAT value for each unique map unit that is included at the front of APPENDIX C.

      iii. Proceed to item (3) or (4).

3. If the watershed or subbasin contains only one soil texture, then determine XKSAT, PSIF and DTHETA from Table 4.1.

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

   a. Calculate the area-weighted value of XKSAT by using Equation (4.4).

   b. Select the corresponding values of PSIF and DTHETA from Figure 4.3.

   c. Calculate the arithmetically area-weighted value of naturally occurring RTIMP.

5. Select values of IA for each land use and/or soil cover using Table 4.2. Arithmetically area-weight the values of IA if the drainage area or subbasin is composed of subareas of different IA.

6. Select values of RTIMP for each land use using Table 4.2. Arithmetically area-weight the values of RTIMP if the drainage area or subbasin is composed of land use subareas of different RTIMP. Compute the weighted value of RTIMP based on the area-weighted land use and denote it by $RTIMP_L$. Arithmetically area-weight the rock outcrop percentages for all soil map units to obtain $RTIMP_N$. Estimate the effective percentage of rock outcrop for each soil map unit that is hydraulically connected. Arithmetically area-weight the effective percentage of rock outcrop for all soil map units to obtain EFF. Compute the final composite value of RTIMP using Equation (4.6).

   $$RTIMP = RTIMP_L + EFF\,(RTIMP_N)$$

7. Estimate the vegetative cover (VCD) for the natural portions of the drainage area or subbasin. Select values of VC for each land use using Table 4.2. Arithmetically area-weight the values of VCD if the drainage area or subbasin is composed of land use subareas of different VCD. Arithmetically average the natural VCD and the area-weighted land use VCD.

8. Adjust the XKSAT value for VC using Figure 4.4, if appropriate.

9. Arithmetically average $DTHETA_{dry}$ (natural portions of the drainage area or subbasin) and $DTHETA_{normal}$ (Developed portions of the drainage area or subbasin), if appropriate.

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/or the local agency before initiating the procedures.

9.3.2 Procedures for the 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 Table 4.2 and Table 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 4.3 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.

9.3.3 User Notes

1. There are currently six soil survey volumes available for Maricopa County and adjoining areas. Five of these are published by the National Resource Conservation Service (NRCS). A figure showing the status and extent of each NRCS survey is provided at the front of APPENDIX C. Copies of these survey reports can be obtained from the NRCS field offices. Data from three of these surveys have been summarized and are included in APPENDIX C, Appendix C.2, Appendix C.3 and Appendix C.4 along with map unit values of XKSAT and rock outcrop percentages. The sixth soil survey is published by the Forest Service and is entitled Tonto National Forest Terrestrial Ecosystem Survey. A copy of this survey can also be obtained from the Forest Service field office.

2. Map unit values of XKSAT (bare ground) are calculated based on individual soil textures in a map unit, percentages of soil textures in a map unit, XKSAT values from Table 4.1, and a logarithmic area-weighting procedure. Since many of the soil groups contain horizons of different textures, the top texture 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.

3. Impervious cover percentages, applied in an HEC-1 model using the RTIMP variable, directly converts the assigned percentage of areal rainfall to runoff. This assumes that the impervious area is hydraulically connected to the outlet. Impervious cover percentages (i.e. rock outcrop) listed in the soil surveys may or may not be hydraulically connected to the outlet. Judgement should be exercised in the assignment of the effectiveness of impervious cover percentages based on the soil surveys.

4. The PSIF and DTHETA values are taken from Figure 4.3 as a function of the basin or subbasin average value of XKSAT (bareground) not for each map unit value of *XKSAT.*

5. XKSAT (bareground) is adjusted for the effects of vegetation cover by use of Figure 4.4. The PSIF and DTHETA values are not a function of the adjusted XKSAT value and are not adjusted for vegetation cover.

6. For a partially developed basin or subbasin, DTHETA dry and DTHETA normal can be readily averaged based on the percentages of the natural and developed areas.

7. The DTHETA “Saturated” condition should be used only if the entire area is under irrigation simultaneously.

9.3.4 Rainfall Losses Example

Compute the area-weighted Green and Ampt rainfall loss parameters for each subbasin shown in Figure 9.1 (see Section 9.1.1). Soil map units as they occur within the watershed are shown in Figure 9.7. The majority of the watershed lies within the limits of the Soil Survey of Aguila-Carefree and Parts of Maricopa and Pinal Counties, Arizona. The remaining portion of the watershed lies within the limits of the Soil Survey of Yavapai County, Arizona, Western Part. Soil characteristics for each map unit are provided in Table 9.6. The area of each map unit present within each subbasin is provided in Table 9.7 along with the corresponding soil characteristics. Vegetation cover for all natural portions of the watershed is estimated to be 26 percent. Developed areas within the watershed are shown in Figure 9.8. Land use characteristics are provided in Table 9.8. The area of each land use type present within each subbasin is provided in Table 9.9 along with the corresponding land use characteristics.

Solution:

1. Compute the log-averaged bare ground XKSAT for each subbasin using Equation (4.4) and the data from Table 9.7:

   Subbasin S1: $A_T = 3480.4\ acres$

   Log-averaged $XKSAT = 10^a$; where:

$$a = \left[\frac{\begin{array}{l}5.6\log_{10}0.96 + (167.2 + 873.3)\log_{10}0.44 \\ +1{,}723.5\log_{10}0.33 + (50.6 + 2.4 + 137.1)\log_{10}0.09 \\ +(3.0 + 67.3 + 340.3 + 72.5)\log_{10}0.14 + (36.0 + 1.6)\log_{10}0.01\end{array}}{3{,}480.4}\right]$$

$$a = \frac{-1,887.43}{3,480.4} = -0.54$$

$$\text{Log-averaged } XKSAT = 10^{-0.54} = 0.29\ in/hr$$

   Using the above procedure, the log-averaged XKSAT for each subbasin is shown in the table in Step 2.

2. From Figure 4.3, select the values for DTHETA (both dry and normal) and PSIF for each subbasin corresponding to the computed XKSAT from Step 1.

Subbasin ID	Log-Averaged Bare Ground XKSAT in/hr	DTHETA		PSIF inches
		Dry	Normal	
S1	0.29	0.35	0.25	4.55
S2	0.33	0.35	0.25	4.35
S3	0.20	0.38	0.25	5.30
S4	0.30	0.35	0.25	4.50
S5	0.32	0.35	0.25	4.40
S6	0.14	0.39	0.23	6.20
S7	0.23	0.36	0.25	5.00
S8	0.21	0.37	0.25	5.20
S9	0.11	0.36	0.17	6.80
S10	0.13	0.38	0.21	6.40
S11	0.24	0.36	0.25	4.90

3. Compute the arithmetically area-weighted surface retention loss (IA) for each subbasin using the data in Table 9.9:

Subbasin S2: $A_T = 2,816.9\ acres$

$$IA = \left[\frac{(1189.8)(0.30) + (1627.1)(0.15)}{2,816.9}\right]$$

$$IA = \frac{601.00}{2,816.9} = 0.21\ inches$$

Using the above procedure, the area-weighted IA values for each subbasin are as follows:

Subbasin ID	IA inches
S1	0.15
S2	0.21
S3	0.28
S4	0.28
S5	0.26

Subbasin ID	IA inches
S6	0.27
S7	0.24
S8	0.21
S9	0.27
S10	0.30
S11	0.17

4. Compute the arithmetically area-weighted percent impervious (RTIMP) for each subbasin for natural conditions using the data in Table 9.7:

   Subbasin S1: $A_T = 3,480.4\ acres$

$$RTIMP_N = \left[\frac{(5.6)(0) + (873.3 + 167.2)(15) + (1723.5)(35) + (50.6 + 2.4 + 137.1)(30) + (3.0 + 67.3 + 340.3 + 72.5)(60) + (36.0 + 1.6)(50)}{3,480.4}\right]$$

$$RTIMP_N = \frac{112,499}{3,480.4} = 32\%$$

   Using the above procedure, the area-weighted RTIMP for each subbasin is shown in the table in Step 5.

5. Compute the arithmetically area-weighted RTIMP for each subbasin for developed conditions:

   Subbasin S3: $A_D = 2,113.3\ acres$

$$RTIMP_D = \left[\frac{(106.9)(80) + (742.5)(15) + (81.3)(30) + (1,103.1)(5) + (79.6)(0)}{2,113.3}\right]$$

$$RTIMP_D = \frac{27,644}{2,113.3} = 13\%$$

Using the above procedure, the area-weighted RTIMP for the developed portion of each subbasin is shown in the following table. The total RTIMP for each subbasin is estimated by adding $RTIMP_N$ and $RTIMP_D$.

Subbasin ID	$RTIMP_N$ %	$RTIMP_D$ %	Total RTIMP %
S1	32	0	32
S2	35	6	41
S3	33	13	46
S4	34	21	55
S5	34	13	47
S6	55	7	62
S7	21	15	36
S8	22	24	46
S9	39	5	44
S10	37	15	52
S11	3	5	8

6. Compute the arithmetically area-weighted vegetation cover (*VC*) for each subbasin:

Subbasin S3: $A = 2,113.3\ acres$

$$VC = \left[\frac{(106.9)(65) + (742.5 + 81.3)(50) + (1,103.1)(30) + (79.6)(26)}{2113.3}\right]$$

$$VC = \frac{83,301}{2,113.3} = 39\%$$

Using the above procedure, the area weighted *VC* for each subbasin is as follows:

Subbasin ID	VC %
S1	26
S2	36
S3	39
S4	50
S5	42
S6	35
S7	44

Subbasin ID	VC %
S8	44
S9	30
S10	49
S11	30

7. Compute the average value of DTHETA using Table 9.9 for each subbasin based on the percent developed and percent natural areas, from item #2 on pgs. 9-30.

Subbasin S2: $A_T = 2,816.9\ acres$

$$Natural\,Area = \frac{1,627.1}{2,816.9} = 58\%$$

$$Developed\,Area = \frac{1,189.8}{2,816.9} = 42\%$$

$$\begin{aligned} DTHETA_{AVG} &= ((58)DTHETA_{Dry} + (42)DTHETA_{Normal})/100 \\ &= ((58)(0.35) + (42)(0.25))/100 \\ &= 0.31 \end{aligned}$$

Using the above procedures, the average values of DTHETA each subbasin are as follows:

Subbasin ID	DTHETA
S1	0.35
S2	0.31
S3	0.25
S4	0.25
S5	0.27
S6	0.26
S7	0.28
S8	0.29
S9	0.21
S10	0.21
S11	0.33

8. Compute the vegetation cover correction factor using Figure 4.4 and the adjusted XKSAT for each subbasin from Figure 4.4:

$$C_k = \frac{VC - 10}{90} + 1.0$$

Subbasin ID	VC%	Bare Ground XKSAT	Correction Factor	Adjusted XKSAT in/hr
S1	26	0.29	1.18	0.34
S2	36	0.33	1.29	0.43
S3	39	0.20	1.32	0.26
S4	50	0.30	1.44	0.43
S5	42	0.32	1.36	0.44
S6	35	0.14	1.28	0.18
S7	44	0.23	1.38	0.32
S8	44	0.21	1.38	0.29
S9	30	0.11	1.22	0.13
S10	49	0.13	1.43	0.19
S11	30	0.24	1.22	0.29

9. The area-weighted Green and Ampt rainfall loss parameters for each subbasin are summarized as follows:

Subbasin ID	IA inches	DTHETA	PSIF inches	XKSAT in/hr	RTIMP %
S1	0.15	0.35	4.55	0.34	32
S2	0.21	0.31	4.35	0.43	41
S3	0.28	0.25	5.30	0.26	46
S4	0.28	0.25	4.50	0.43	55
S5	0.26	0.27	4.40	0.44	47
S6	0.27	0.26	6.20	0.18	62
S7	0.24	0.28	5.00	0.32	36
S8	0.21	0.29	5.20	0.29	46
S9	0.27	0.21	6.80	0.13	44
S10	0.30	0.21	6.40	0.19	52
S11	0.17	0.33	4.90	0.29	8

Table 9.6
RAINFALL LOSS CHARACTERISTICS FOR EACH SOIL MAP UNIT

Map Unit ID (1)	Description (2)	XKSAT[1] in/hr (3)	RTIMP[1] % (4)	IA[3] inches (5)
8	Very cobbly sandy loam	0.96	0	0.35
10	Loamy sand	0.94	0	0.35
16	Very gravelly fine sandy loam	0.44	15	0.25
21	Very gravelly loam	0.38	0	0.35
31	Extremely cobbly sandy loam	0.33	35	0.25
33	Very gravelly loam	0.23	0	0.35
41	Very gravelly loam	0.17	0	0.25
45	Very gravelly clay	0.03	0	0.25
48	Very gravelly clay	0.06	0	0.15
51	Very gravelly sandy clay loam	0.24	0	0.15
52	Very gravely clay loam	0.16	20	0.25
66	Very gravely loam	0.23	0	0.35
68	Very gravely sandy loam	0.63	0	0.35
70	Very gravely loam	0.36	0	0.25
72	Clay loam	0.09	30	0.25
93	Gravelly loam	0.33	0	0.25
95	Clay loam	0.04	0	0.35
103	Very gravelly clay loam	0.10	65	0.25
104	Gravelly clay loam	0.14	60	0.25
108	Very cobbly loam	0.31	30	0.25
109	Very cobbly loam	0.35	35	0.25
CmD[2]	Very gravelly sandy loam	0.44	15	0.25
Le[2]	Gravelly clay loam	0.09	30	0.25
Lh[2]	Extremely rocky clay loam	0.14	60	0.25
Rr[2]	Rock outcrop	0.01	50	0.25

Notes:

1. Values for the soil map units within the limits of the Soil Survey of Aguila-Carefree and Parts of Maricopa and Pinal Counties, Arizona are taken from Appendix C, Section 1.
2. Values for the soil map units within the limits of the Soil Survey of Yavapai County, Arizona, Western Part are based on the soil texture descriptions from that soil survey.
3. Values are based on the descriptions in the soil surveys and the use of Table 4.2.

Table 9.7
SUMMARY OF SOILS CHARACTERISTICS FOR EACH SUBBASIN

Subbasin ID	NRCS Soil Map Unit	DDMSW Soil ID	Area acres	Area sq. mi.	VC %	XKSAT Bare Ground in/hr	XKSAT Adjusted in/hr	Natural RTIMP %
S1	Rr	6371	36.0	0.0562		0.01		50
S1	Rr	6372	1.6	0.0025		0.01		50
S1	Le	6373	50.6	0.0791		0.09		30
S1	Le	6374	2.4	0.0038		0.09		30
S1	Lh	6375	3.0	0.0048		0.14		60
S1	Lh	6376	67.3	0.1051		0.14		60
S1	CmD	6377	873.3	1.3646		0.44		15
S1	Lh	6378	340.3	0.5317		0.14		60
S1	8	6458	5.6	0.0088		0.96		0
S1	16	64516	167.2	0.2613		0.44		15
S1	31	64531	1723.5	2.6929		0.33		35
S1	72	64572	137.1	0.2143		0.09		30
S1	104	645104	72.5	0.1133		0.14		60
Totals and Area-Weighted Values:			**3480.4**	**5.4384**	**26**	**0.29**	**0.34**	**32**
S2	8	6458	68.5	0.107		0.96		0
S2	31	64531	2623.9	4.0999		0.33		35
S2	41	64541	18.7	0.0292		0.17		0
S2	104	645104	105.7	0.1652		0.14		60
Totals and Area-Weighted Values:			**2816.9**	**4.4013**	**36**	**0.33**	**0.43**	**35**
S3	8	6458	130.4	0.2038		0.96		0
S3	31	64531	948.4	1.4818		0.33		35
S3	33	64533	29.6	0.0462		0.23		0
S3	41	64541	12.3	0.0192		0.17		0
S3	72	64572	734.7	1.148		0.09		30
S3	95	64595	0.2	0.0004		0.04		0
S3	104	645104	257.7	0.4027		0.14		60
Totals and Area-Weighted Values:			**2113.3**	**3.3021**	**39**	**0.20**	**0.26**	**33**
S4	8	6458	11.3	0.0176		0.96		0
S4	10	64510	0.1	0.0001		0.94		0
S4	31	64531	795.3	1.2426		0.33		35
S4	72	64572	162.4	0.2537		0.09		30
S4	104	645104	0.9	0.0015		0.14		60
S4	109	645109	544.2	0.8503		0.35		35
Totals and Area-Weighted Values:			**1514.2**	**2.3658**	**50**	**0.30**	**0.43**	**34**

Table 9.7
SUMMARY OF SOILS CHARACTERISTICS FOR EACH SUBBASIN

Subbasin ID	NRCS Soil Map Unit	DDMSW Soil ID	Area		VC	XKSAT		Natural RTIMP
						Bare Ground	Adjusted	
			acres	sq. mi.	%	in/hr	in/hr	%
S5	8	6458	5.4	0.0084		0.96		0
S5	10	64510	43.5	0.0679		0.94		0
S5	31	64531	5.7	0.0088		0.33		35
S5	51	64551	3.8	0.006		0.24		0
S5	52	64552	7.2	0.0113		0.16		20
S5	72	64572	14.1	0.022		0.09		30
S5	104	645104	80.7	0.126		0.14		60
S5	108	645108	119.9	0.1874		0.31		30
S5	109	645109	410.5	0.6414		0.35		35
Totals and Area-Weighted Values:			**690.8**	**1.0792**	**42**	**0.32**	**0.43**	**34**
S6	31	64531	25.7	0.0402		0.33		35
S6	72	64572	90.6	0.1416		0.09		30
S6	104	645104	558.7	0.873		0.14		60
Totals and Area-Weighted Values:			**675.0**	**1.0548**	**35**	**0.14**	**0.18**	**55**
S7	10	64510	54.1	0.0845		0.94		0
S7	21	64521	33.2	0.0519		0.38		0
S7	48	64548	11.9	0.0186		0.06		0
S7	51	64551	171.1	0.2673		0.24		0
S7	52	64552	183.6	0.2869		0.16		20
S7	68	64568	16.9	0.0263		0.63		0
S7	70	64570	15.3	0.0239		0.36		0
S7	103	645103	38.9	0.0608		0.1		65
S7	104	645104	92.0	0.1437		0.14		60
S7	108	645108	93.0	0.1453		0.31		30
S7	109	645109	45.7	0.0715		0.35		35
Totals and Area-Weighted Values:			**755.7**	**1.1807**	**44**	**0.23**	**0.32**	**21**
S8	10	64510	29.8	0.0465		0.94		0
S8	21	64521	0.0	0.0001		0.38		0
S8	51	64551	309.9	0.4842		0.24		0
S8	52	64552	59.7	0.0933		0.16		20
S8	72	64572	0.6	0.001		0.09		30
S8	93	64593	11.2	0.0175		0.33		0
S8	104	645104	202.0	0.3156		0.14		60
Totals and Area-Weighted Values:			**613.2**	**0.9582**	**44**	**0.21**	**0.29**	**22**
S9	66	64566	27.0	0.0422		0.23		0
S9	72	64572	125.4	0.1959		0.09		30
S9	93	64593	20.5	0.032		0.33		0
S9	95	64595	79.1	0.1236		0.04		0
S9	104	645104	277.0	0.4329		0.14		60
Totals and Area-Weighted Values:			**529.0**	**0.8266**	**30**	**0.11**	**0.13**	**39**

Table 9.7
SUMMARY OF SOILS CHARACTERISTICS FOR EACH SUBBASIN

Subbasin ID	NRCS Soil Map Unit	DDMSW Soil ID	Area		VC	XKSAT		Natural RTIMP
			acres	sq. mi.	%	Bare Ground in/hr	Adjusted in/hr	%
S10	10	64510	0.4	0.0007		0.94		0
S10	51	64551	47.9	0.0748		0.24		0
S10	52	64552	2.1	0.0033		0.16		20
S10	72	64572	106.3	0.1661		0.09		30
S10	93	64593	3.0	0.0046		0.33		0
S10	95	64595	5.4	0.0085		0.04		0
S10	103	645103	16.0	0.0251		0.1		65
S10	104	645104	103.1	0.161		0.14		60
Totals and Area-Weighted Values:			**284.2**	**0.4441**	**49**	**0.13**	**0.19**	**37**
S11	10	64510	69.3	0.1083		0.94		0
S11	45	64545	1.7	0.0027		0.03		0
S11	51	64551	908.9	1.4201		0.24		0
S11	52	64552	181.5	0.2836		0.16		20
S11	103	645103	3.5	0.0054		0.1		65
Totals and Area-Weighted Values:			**1164.9**	**1.8201**	**30**	**0.24**	**0.29**	**3**

Table 9.8
RAINFALL LOSS CHARACTERISTICS FOR EACH LAND USE

Land Use Code (1)	Land Use ID (2)	Description (3)	IA inches (4)	RTIMP % (5)	Effective Vegetation Cover[2] % (6)
220	C1	Commercial - light	0.10	80	15
200	C2	Commercial - general	0.10	80	15
130	LDR	Low density residential	0.30	15	43
140	MDR	Medium density residential	0.25	30	35
NHS	NHS	Hillslopes, Sonoran Desert [1]	0.00	0	0
110	VLDR	Very low density residential	0.30	5	29

Notes:

1 The NHS land use classification is representative of all natural conditions in the watershed. Rainfall loss parameters for these areas are accounted for under the soil map units.

2 Effective vegetation cover is the average vegetation cover for the land use area, including the impervious area.

Table 9.9
SUMMARY OF LAND USE CHARACTERISTICS FOR EACH SUBBASIN

Subbasin ID	Land Use Code	Area acres	Area sq. mi.	IA in	Developed RTIMP %	VC %	RTIMP Natural %	RTIMP Total %
S1	NHS	3480.6	5.4384	0.15	0	26		
		3480.6	**5.4384**	**0.15**	**0**	**26**	**32**	**32**
S2	130	1189.8	1.8590	0.30	15	50		
S2	NHS	1627.1	2.5423	0.15	0	26		
		2816.9	**4.4013**	**0.21**	**6**	**36**	**35**	**41**
S3	110	1103.1	1.7236	0.30	5	30		
S3	130	742.5	1.1601	0.30	15	50		
S3	140	81.3	0.1270	0.25	30	50		
S3	220	106.9	0.1670	0.10	80	65		
S3	NHS	79.6	0.1243	0.15	0	26		
		2113.3	**3.3020**	**0.28**	**13**	**39**	**33**	**47**
S4	110	16.2	0.0253	0.30	5	30		
S4	130	1063.6	1.6619	0.30	15	50		
S4	140	387.7	0.6058	0.25	30	50		
S4	220	46.7	0.0729	0.10	80	65		
		1514.2	**2.3659**	**0.28**	**21**	**50**	**34**	**55**
S5	110	84.1	0.1314	0.30	5	30		
S5	130	358.3	0.5599	0.30	15	50		
S5	140	94.0	0.1469	0.25	30	50		
S5	220	2.9	0.0046	0.10	80	65		
S5	NHS	151.4	0.2365	0.15	0	26		
		690.7	**1.0793**	**0.26**	**13**	**42**	**34**	**47**
S6	110	374.1	0.5846	0.30	5	30		
S6	130	178.1	0.2783	0.30	15	50		
S6	NHS	122.8	0.1919	0.15	0	26		
		675.0	**1.0548**	**0.27**	**7**	**35**	**55**	**62**
S7	130	472.3	0.7380	0.30	15	50		
S7	200	56.2	0.0878	0.10	80	60		
S7	NHS	227.1	0.3549	0.15	0	26		
		755.6	**1.1807**	**0.24**	**15**	**44**	**21**	**37**
S8	130	120.1	0.1877	0.30	15	50		
S8	140	230.1	0.3595	0.25	30	50		
S8	200	75.6	0.1182	0.10	80	60		
S8	NHS	187.3	0.2927	0.15	0	26		
		613.1	**0.9581**	**0.21**	**24**	**44**	**22**	**46**
S9	110	395.5	0.6180	0.30	5	30		
S9	130	27.3	0.0426	0.30	15	50		
S9	NHS	106.2	0.1660	0.15	0	26		
		529.0	**0.8266**	**0.27**	**5**	**30**	**39**	**43**

Table 9.9
SUMMARY OF LAND USE CHARACTERISTICS FOR EACH SUBBASIN

Subbasin ID	Land Use Code	Area		IA	Developed RTIMP	VC	RTIMP	
		acres	sq. mi.	in	%	%	Natural %	Total %
S10	110	8.4	0.0131	0.30	5	30		
S10	130	261.7	0.4089	0.30	15	50		
S10	140	14.1	0.0220	0.25	30	50		
		284.2	**0.4440**	**0.30**	**15**	**49**	**37**	**52**
S11	130	19.9	0.0311	0.30	15	50		
S11	140	191.7	0.2996	0.25	30	50		
S11	NHS	953.2	1.4894	0.15	0	26		
		1164.8	**1.8201**	**0.17**	**5**	**30**	**3**	**9**

Figure 9.7
EXAMPLE WATERSHED SOILS MAP

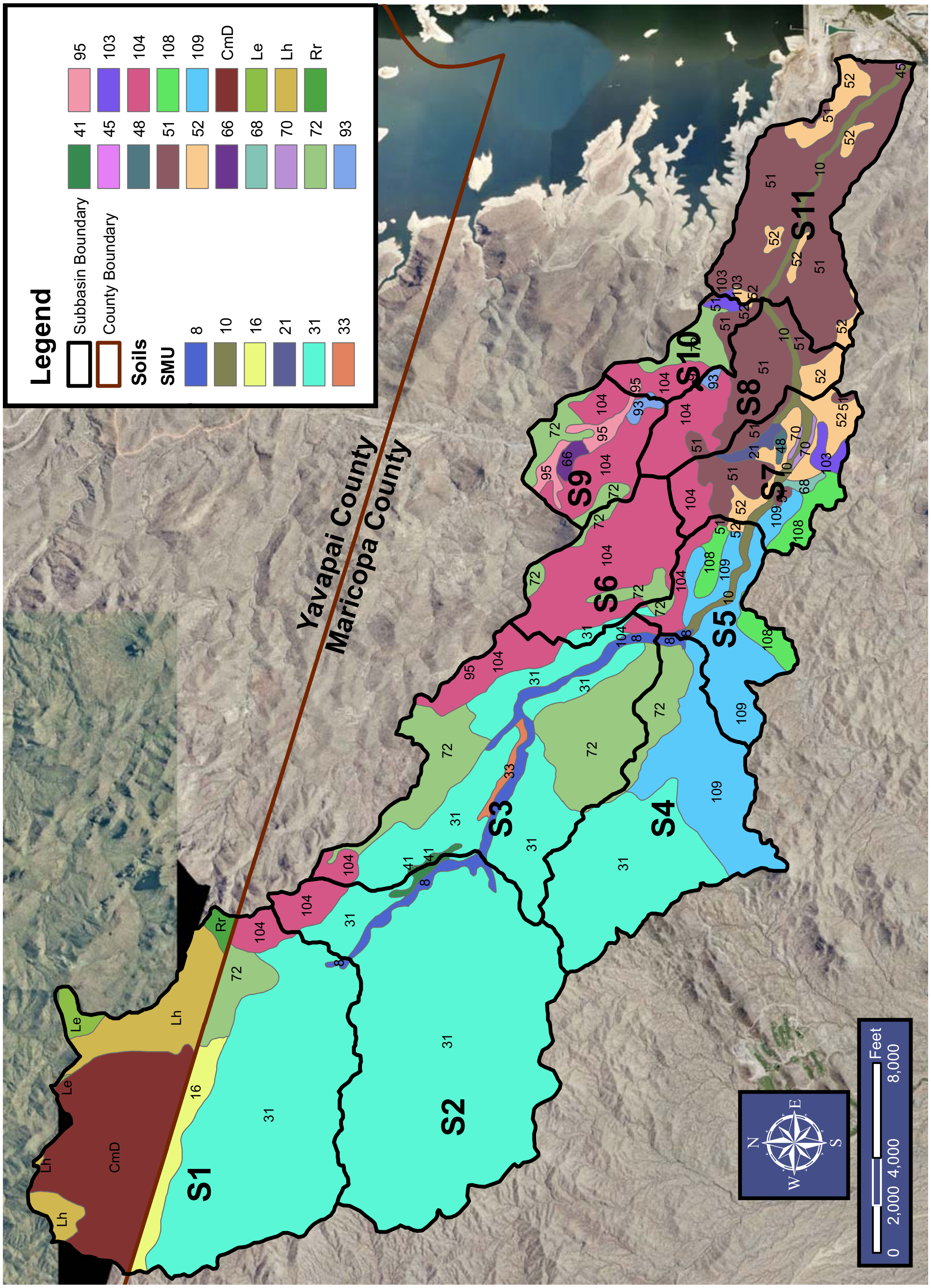
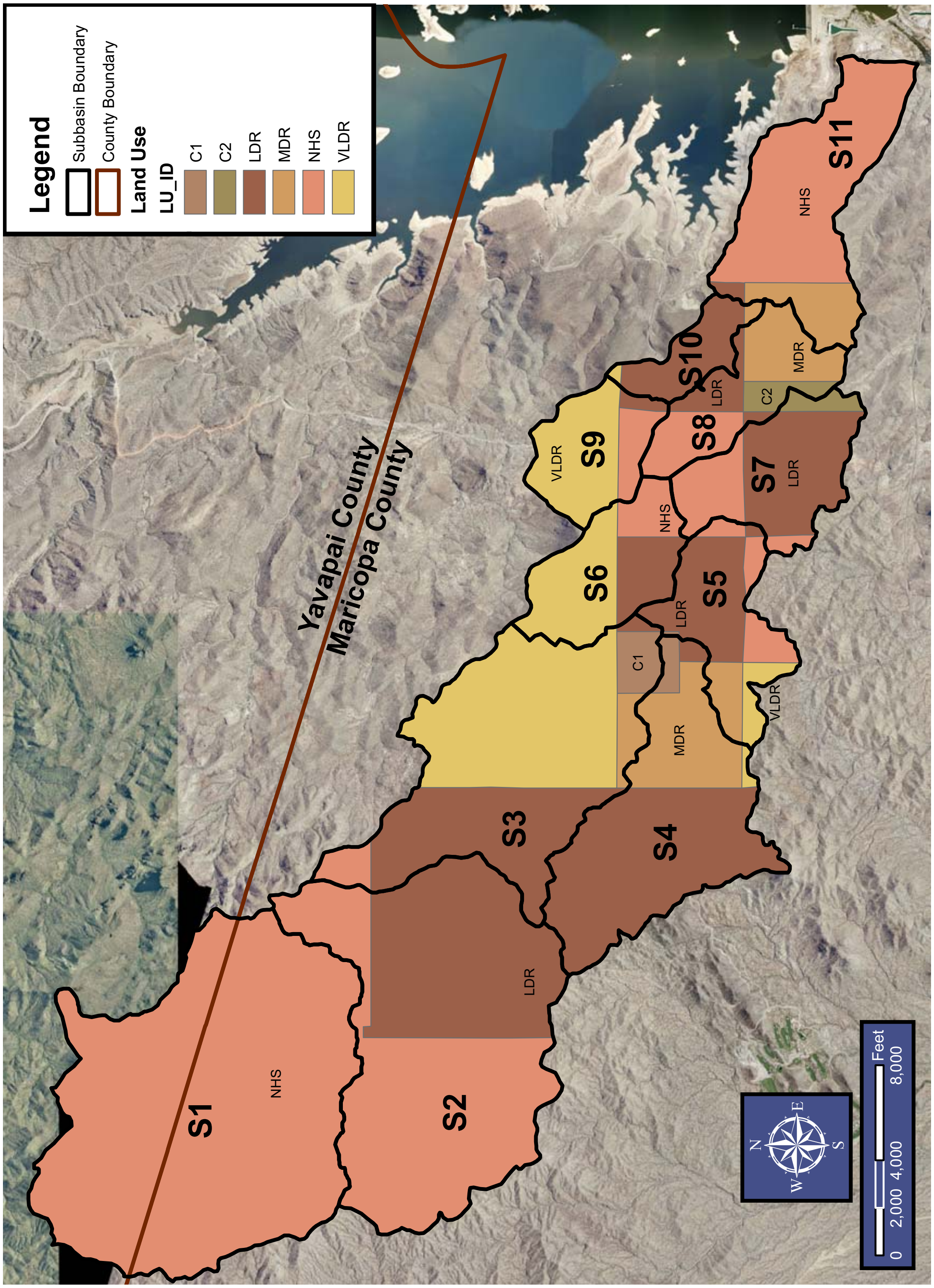


Figure 9.8
EXAMPLE WATERSHED LAND USE MAP



9.4 UNIT HYDROGRAPH

9.4.1 Procedures for the Clark Unit Hydrograph

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

2. If S is greater than 200 ft/mi, adjust the slope using Table 5.2 or Figure 5.4.

3. Using Figure 5.5 and Table 5.3, select a resistance coefficient (K_b) for the basin or subbasin based on a resistance classification and the drainage area (in acres). For a basin or subbasin of mixed classification;

   - A representative K_b can be interpolated from Figure 5.5, or
   - An arithmetically averaged K_b can be calculated based on the area of each unique K_b present in the basin or subbasin.

4. Calculate T_c as a function of i using Equation (5.5)

5. Enter the following data into an HEC-1 input file:

   - Design rainfall per the methodology and procedures in Chapter 2;
   - Basin area;
   - Rainfall loss data per the methodologies and procedures in Chapter 4; and
   - Clark unit hydrograph parameters (values set to zero).

6. Run HEC-1 with the input file from Step 5 at an output level of zero for each subbasin. Rank the incremental rainfall excess values from smallest to highest for each subbasin and sum the ten (10) highest values. Compute the average rainfall intensity, *i*, by dividing the sum by the total of ten (10) computation time intervals and convert to units of hours (total of 10 highest rainfall excess values/(10(NMIN/60)).

7. Compute T_c using the equation from Step 4 above.

8. Calculate R using Equation (5.8).

9. Select the appropriate time-area relation for the basin or subbasin.

As an alternative to the above procedures, the DDMSW program will compute the rainfall excess directly and perform the necessary iterations to compute the T_c and R parameters.

9.4.2 Procedures for the S-Graph

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

2. Calculate the basin factor $\frac{LL_{ca}}{S^{0.5}}$.

3. Using the data in Appendix D.1 or the tables in the Design of Small Dams or the USBR Flood Hydrology Manual, attempt to identify watersheds of the same physiographic type and similar drainage area and basin factor. Make a list of the watersheds with similar drainage areas and basin factors and tabulate the estimated value of K_n for those watersheds and the measured lag.

4. Estimate K_n for the watershed by inspection of the tabulation from Step 3.

5. Calculate the coefficient (C) and select the value of the exponent (m) corresponding to the source (Corps of Engineers or USBR) that was used to estimate K_n. If the source of K_n is unknown, then use the Corps of Engineers version of Equation (5.11).

6. Using Equation (5.11), calculate the basin lag. Compare this value to the measured lags of watersheds from Step 3.

7. Select an appropriate computational time interval (NMIN) and compute Q_{ult} using Equation (5.10).

8. Select an appropriate S-Graph and tabulate the percent Q_{ult}, percent lag and the accumulated time.

9. Transform the S-Graph into an X-duration (NMIN) unit hydrograph using linear interpolation with Δt = NMIN.

10. Adjust the "tail" region of the S-Graph by lagging that portion by Δt and subtracting the ordinates.

As an alternative to the above procedure, the DDMSW will transform the S-Graph to a unit graph automatically.

9.4.3 User Notes

9.4.3.1 Clark Unit Hydrograph

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

2. The following limitations apply to the Clark Unit Hydrograph procedure.

    a. The recommended drainage area limit is 5 square miles with a maximum of 10 square miles.

    b. The calculated T_c should not exceed the duration of rainfall excess.

    c. The calculated T_c should not be longer than 1.5 hours.

    If a drainage basin does not meet any or all of the preceding limitations, then the following options are available:

    - Subdivide the drainage area into smaller subbasins such that all of these subbasins satisfy the limitations.
    - Use the S-Graph method, provided the drainage basin satisfies the limitations of that method.
    - Justify the use of an alternative approach.

3. Time of concentration as defined in this manual is the travel time, during the corresponding period of the most intense portion of rainfall excess, for a floodwave to travel from the hydraulically most distant point in the watershed to the point of interest. The determination of the hydraulically most distant point is made in regard to both length and slope. In other words, the hydraulically most distant point is not necessarily the longest length, but may be a shorter length with an appreciably flatter slope.

4. When calculating the T_c for a natural watershed, with slopes greater than 200 ft/mile, use Figure 5.4 to adjust the slope. The use of the adjusted slope should be considered when determining the T_c of the hydraulically most distant point.

5. T_c is a function of rainfall excess and must be recalculated for each desired frequency or design storm duration.

6. If hand calculating the T_c, perform the following:

   a. Compute incremental rainfall excess for each time step using HEC-1. Rank the rainfall excess values by ordering from largest to smallest.

   b. The average rainfall excess intensity, i, is estimated by summing the first ten (10) largest rainfall excess values and dividing the result by 10 times the time interval, NMIN, in hours.

7. If a time-area relation is not specified in the HEC-1 model, then the HEC-1 default time-area relation is used which, in general, is not recommended for use in Maricopa County.

9.4.3.2 S-Graph

1. The recommended S-Graphs for Maricopa County (i.e. Phoenix Mountain, Phoenix Valley, Desert/Rangeland, and Agricultural) should only be applied to large natural watersheds. The Phoenix Valley S-Graph is also applicable to large urban watersheds. This is, in part, due to the fact that the original database 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. K_n should be selected from the best available information. General guidance and some regional data is available from the U.S. Army Corps of Engineers (Appendix D.1). A broader range of data for watersheds in Maricopa County is provided in the USBR 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 (Equation (5.11)), one by the U.S. Army Corps of Engineers and one by the USBR. The form of the equation that corresponds to the source used in the selection of K_n should be used.

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

5. The transformation of an S-Graph to a unit graph is a function of the selected computational time interval (NMIN). If a new NMIN is desired a new unit graph must be recalculated.

6. The slope as applied in the calculation of basin lag is not adjusted, regardless of the value.

9.4.4 Unit Hydrograph Example

Compute the 6-hour unit hydrograph parameters for each subbasin shown in Figure 9.9 and Table 9.7 using rainfall data and rainfall loss data from the examples in Chapters 2 and 4, respectively and the following data:

Subbasin ID	Drainage Area, sq. miles	Flow Path Length, miles	Flow Path L_{ca}, miles	Flow Path Unadjusted Slope, ft/mi	Unit Hydrograph Method
S1	5.438	4.59	2.30	254.8	S-Graph
S2	4.401	4.11	---	227.8	Clark
S3	3.302	3.91	---	222.3	Clark
S4	2.366	3.40	---	197.0	Clark
S5	1.079	2.29	---	157.5	Clark
S6	1.055	2.06	---	144.2	Clark
S7	1.181	1.74	---	215.2	Clark
S8	0.958	2.36	---	201.8	Clark
S9	0.827	1.66	---	537.3	Clark
S10	0.444	1.83	---	438.3	Clark
S11	1.820	2.98	---	126.3	Clark

Solution:

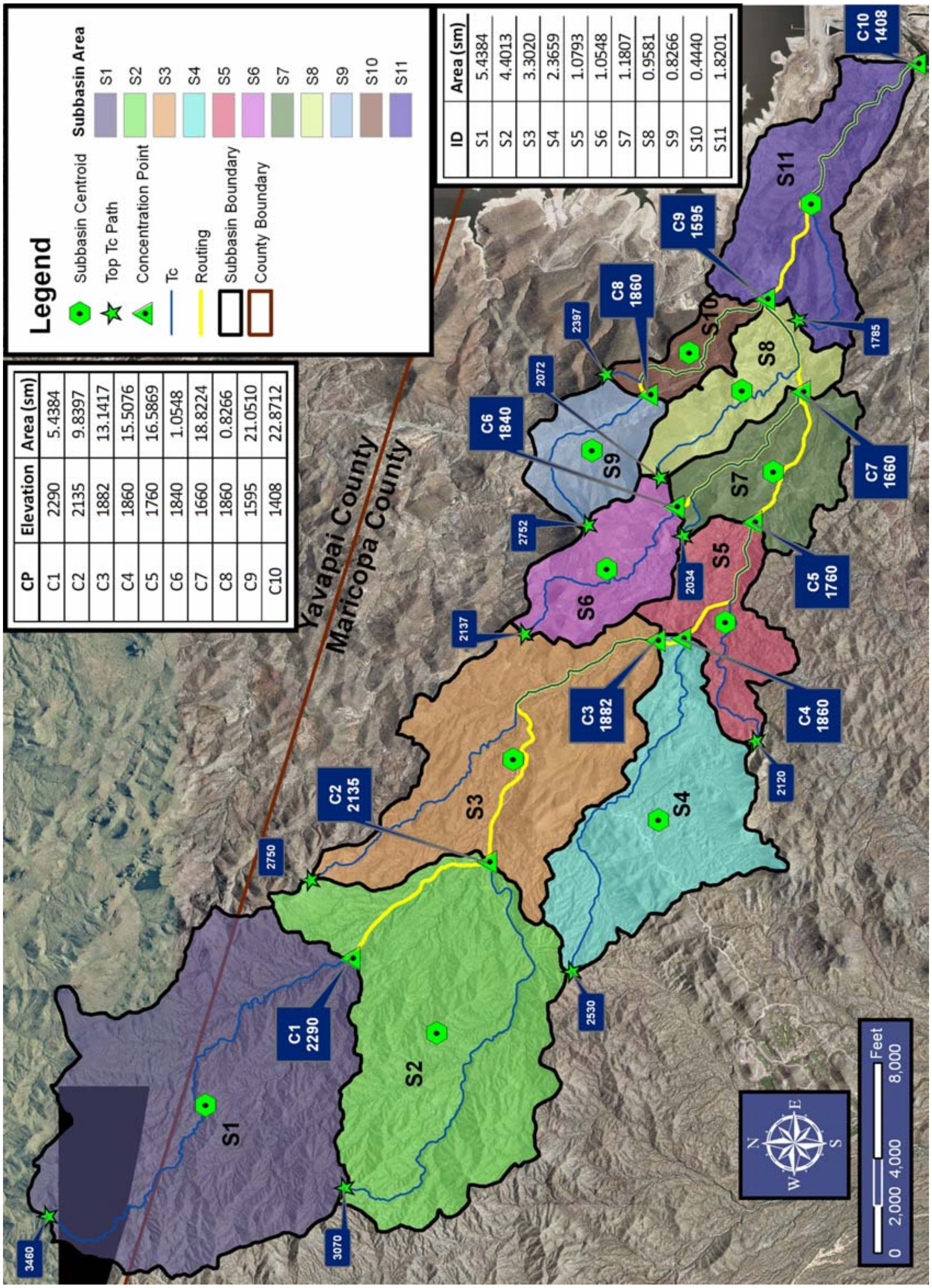
1. Select the appropriate unit hydrograph method for each subbasin

   For subbasin S1, the Phoenix Mountain S-graph is selected because the watershed is natural and has mountainous characteristics. For all other subbasins, the Clark unit hydrograph is selected because they are developed.

2. Develop the unit hydrograph for subbasin S1

   a. Compute the basin factor $\left(\frac{LL_{ca}}{S^{0.5}}\right)$

Figure 9.9
UNIT HYDROGRAPH METHOD EXAMPLE SUBBASIN MAP



CP	Elevation	Area (sm)
C1	2290	5.4384
C2	2135	9.8397
C3	1882	13.1417
C4	1860	15.5076
C5	1760	16.5869
C6	1840	1.0548
C7	1660	18.8224
C8	1860	0.8266
C9	1595	21.0510
C10	1408	22.8712

ID	Area (sm)
S1	5.4384
S2	4.4013
S3	3.3020
S4	2.3659
S5	1.0793
S6	1.0548
S7	1.1807
S8	0.9581
S9	0.8266
S10	0.4440
S11	1.8201

$$\frac{LL_{ca}}{S^{0.5}} = \frac{(4.59)(2.30)}{255^{0.5}} = 0.66$$

b. Select a value for K_n

From Appendix D, Section 2 for mountain and foothill watersheds, the Santa Anita Creek and Medicine Bow River watersheds were found to have similar physical characteristics to Subbasin S1. The K_n values for those watersheds are 0.053 and 0.0534, respectively with lagtimes of 1.10 and 0.89 hours, respectively. Comparison of the K_n values for these two watersheds to the general values of K_n for the Phoenix Mountain S-graph, provided in Table 5.6, indicate that a value for K_n of 0.053 is appropriate.

$$K_n = 0.053$$

c. Compute the lag time using Equation (5.11)

The source of the K_n values for the two similar watersheds is unknown, therefore use the Corps of Engineers version of the lag equation.

$$C = 24K_n = (24)(0.053) = 1.272$$

$$m = 0.38$$

$$Lag = C\left(\frac{LL_{ca}}{S^{0.5}}\right)^m = 1.272(0.66)^{0.38} = 1.09\ hours$$

The lag of 1.09 hours compares favorably to the lag times of the similar watersheds used for the selection of K_n.

d. Compute Q_{ult} using Equation (5.10)

$$Q_{ult} = \frac{645.33A}{\Delta t}$$

$\Delta t = 0.15\ lag = (0.15)(1.09) = 0.164\ hours$, therefore

use $\Delta t = 10\ minutes$

$$Q_{ult} = \frac{(645.33)(5.44)}{(10/60)} = 21{,}064 \text{ cfs}$$

e. Compute the discharge and lag corresponding to the values for percent Q_{ult} and percent lag in Table 5.5.

Percent Q_{ult} (1)	Discharge cfs (2)	Percent Lag (3)	Lag hours (4)
0	0	0.0	0.00
2	421	23.0	0.25
4	843	31.0	0.34
6	1264	37.0	0.40
8	1685	42.0	0.46
10	2106	46.0	0.50
12	2528	49.8	0.54
14	2949	53.4	0.58
16	3370	56.8	0.62
18	3792	60.0	0.65
20	4213	63.1	0.69
22	4634	66.1	0.72
24	5055	69.0	0.75
26	5477	71.8	0.78
28	5898	74.4	0.81
30	6319	76.8	0.84
32	6740	79.1	0.86
34	7162	81.2	0.89
36	7583	83.2	0.91
38	8004	85.1	0.93
40	8426	86.8	0.95
42	8847	88.8	0.97
44	9268	91.0	0.99
46	9689	93.8	1.02
48	10111	96.8	1.06
50	10532	100.0	1.09

Percent Q_{ult} (1)	Discharge cfs (2)	Percent Lag (3)	Lag hours (4)
52	10953	103.4	1.13
54	11375	107.0	1.17
56	11796	110.8	1.21
58	12217	114.7	1.25
60	12638	118.7	1.29
62	13060	122.9	1.34
64	13481	127.3	1.39
66	13902	131.9	1.44
68	14324	136.7	1.49
70	14745	141.7	1.54
72	15166	147.1	1.60
74	15587	152.8	1.67
76	16009	158.8	1.73
78	16430	165.5	1.80
80	16851	172.9	1.88
82	17272	181.6	1.98
84	17694	191.0	2.08
86	18115	201.0	2.19
88	18536	212.0	2.31
90	18958	226.0	2.46
92	19379	244.0	2.66
94	19800	265.0	2.89
96	20221	295.0	3.22
98	20643	342.0	3.73
100	21064	462.0	5.04

Notes:

(1) = From Table 5.5 (2) = (1) * Q_{ult}

(3) = From Table 5.5 (4) = (3) * Lag

f. Transform the S-graph into a 10-minute Unit Hydrograph

Time hours (1)	Q_1 cfs (2)	Q_2 cfs (3)	Q_{ult} cfs (4)
0.000	0.0	0.0	0
0.167	281.2	0.0	281
0.333	823.2	281.2	542
0.500	2,106.4	823.2	1,283
0.667	3,977.3	2,106.4	1,871
0.833	6,286.7	3,977.3	2,309
1.000	9,417.5	6,286.7	3,131
1.167	11,415.4	9,417.5	1,998
1.333	13,031.9	11,415.4	1,617
1.500	14,432.4	13,031.9	1,401
1.667	15,625.9	14,432.4	1,194
1.833	16,608.6	15,625.9	983
2.000	17,379.5	16,608.6	771
2.167	18,045.1	17,379.5	666
2.333	18,616.3	18,045.1	571
2.500	19,051.8	18,616.3	436
2.667	19,406.2	19,051.8	354
2.833	19,712.9	19,406.2	307
3.000	19,954.8	19,712.9	242
3.167	20,170.6	19,954.8	216
3.333	20,325.7	20,170.6	155
3.500	20,463.4	20,325.7	138
3.667	20,601.1	20,463.4	138
3.833	20,679.8	20,601.1	79
4.000	20,733.7	20,679.8	54
4.167	20,787.7	20,733.7	54
4.333	20,841.3	20,787.7	54
4.500	20,895.3	20,841.3	54
4.667	20,949.2	20,895.3	54
4.833	21,002.8	20,949.2	54
5.000	21,056.8	21,002.8	54
5.167	21,064.0	21,056.8	7
5.333	21,064.0	21,064.0	0

Notes:

(2) = Linear interpolation from previous Table, column 2

(3) = (2) lagged 10-minutes

(4) = (2) - (3)

3. Calculate the Clark unit hydrograph parameters for subbasins S2 through S11

   a. Using Table 5.2 or Figure 5.4, determine the adjusted slope for subbasins S2, S3, S7, S8, S9 and S10 (subbasins with average slopes greater than 200 ft/mi).

Subbasin ID	Slope	
	Average ft/mi	**Adjusted ft/mi**
S2	227.8	224.5
S3	222.3	220.1
S7	215.2	214.1
S8	201.8	201.6
S9	537.3	307.0
S10	438.3	294.8

   b. Compute the Resistance Coefficient (K_b) using Table 5.3 and area values from Table 9.9. Surface type C is selected for the natural areas, and type A is selected for the urban areas. Note that A in the K_b equation is the total subbasin area in acres.

Subbasin S2:

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

$$K_b^N = -0.025 \log(2,816.8) + 0.15 = 0.064$$

$$K_b^D = -0.00625 \log(2,816.8) + 0.04 = 0.018$$

$$K_b^W = (0.58)(0.064) + (0.42)(0.018) = 0.045$$

Using the above procedure, the K_b for each of the Clark subbasins is as follows:

Subbasin ID	Drainage Area acres	Percent Natural	Percent Developed	K_b		
				Natural	Developed	Weighted
S2	2816.8	57.76	42.24	0.064	0.018	0.045
S3	2113.3	3.76	96.24	0.067	0.017	0.019
S4	1514.1	0.00	100.00	---	0.020	0.020
S5	690.8	21.91	78.09	0.079	0.022	0.035
S6	675.0	18.19	81.81	0.079	0.022	0.033
S7	755.7	30.06	69.94	0.078	0.022	0.039
S8	613.2	30.55	69.45	0.080	0.023	0.040
S9	529.0	20.08	79.92	0.082	0.023	0.035
S10	284.2	0.00	100.00	---	0.025	0.025
S11	1164.9	81.83	18.17	0.073	0.021	0.064

c. Compute Time of Concentration (T_c) as a function of Intensity (i) using Equation (5.5)

Subbasin S2:

$$T_c = 11.4L^{0.5}K_b^{0.52}S^{-0.31}i^{-0.38}$$

$$T_c = (11.4)(4.11)^{0.5}(0.045)^{0.52}(224.5)^{-0.31}i^{-0.38}$$

$$T_c = 0.860i^{-0.38}$$

Using the above procedure, T_c as a function of i for each of the Clark subbasins is as follows:

Subbasin ID	Length miles	K_b Weighted	Adjusted Slope ft/mi	T_c as a Function of i
S2	4.11	0.045	224.5	0.860
S3	3.91	0.021	220.1	0.568
S4	3.40	0.020	197.0	0.534
S5	2.29	0.035	157.5	0.629
S6	2.06	0.033	144.2	0.595
S7	1.74	0.039	214.1	0.527
S8	2.36	0.040	201.6	0.634
S9	1.66	0.035	307.0	0.435
S10	1.83	0.025	294.8	0.389
S11	2.98	0.064	126.3	1.051

d. Develop a subbasin-only HEC-1 model using the 6-hour rainfall data, the procedures and example from Section 9.1, and the rainfall loss parameters from the procedures and example in Section 9.3 to compute rainfall excess (HEC-1 output for subbasin S2 follows). Use an estimate for T_c. The purpose of the model is to compute rainfall excess, not peak discharge.

Note: For the purpose of this example, only the HEC-1 model for subbasin S2 is provided.

e. Sort the incremental rainfall excess values from the HEC-1 output from highest to lowest and tabulate the ten (10) highest values as follows:

Time, hours & minutes	Incremental Excess Rainfall, inches
0:00	0.15
0:05	0.15
0:10	0.15
0:15	0.11
0:20	0.11
0:25	0.11

Time, hours & minutes	Incremental Excess Rainfall, inches
0:30	0.08
0:35	0.08
0:40	0.08
0:45	0.03
Total:	**1.05**

f. Compute the average intensity, i, for subbasin S2:

$$i = \frac{E_T}{T} = \frac{1.05}{10(5/60)} = \frac{1.05}{0.83} = 1.27 \text{ in/hr}$$

where:

E_T = Sum of the ten (10) highest incremental rainfall excess values.

T = Total time associated with E_T, in hours.

g. Compute T_c and R for subbasin S2, using the relation from Step 3c above to compute T_c, and Equation (5.8) to compute R.

$$T_c = 0.86 i^{-0.38} = 0.86(1.27^{-0.38}) = 0.786 \text{ hours}$$

$$R = 0.37 T_c^{1.11} A^{-0.57} L^{0.80}$$

$$R = 0.37(0.786)^{1.11}(4.401)^{-0.57}(4.11)^{0.80}$$

$$R = 0.377 \text{ hours}$$

Using the above procedure, T_c and R for each of the Clark subbasins are as follows:

Subbasin ID	T_c hours	**R** hours
S2	0.786	0.377
S3	0.489	0.252
S4	0.467	0.259

Subbasin ID	T_c hours	**R** hours
S5	0.563	0.363
S6	0.494	0.292
S7	0.470	0.227
S8	0.553	0.390
S9	0.364	0.201
S10	0.326	0.275
S11	1.002	0.632

h. Select the time-area relation for each subbasin.

The majority of the land in subbasins S2 and S11 is undeveloped, therefore use the natural time-area relation. Use the urban time-area relation for all other Clark subbasins.

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*****************************************                                                         ***************************************
*                                       *                                                         *                                     *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                         *    U.S. ARMY CORPS OF ENGINEERS     *
*             JUN   1998                *                                                         *    HYDROLOGIC ENGINEERING CENTER    *
*           VERSION 4.1                 *                                                         *          609 SECOND STREET          *
*                                       *                                                         *       DAVIS, CALIFORNIA 95616       *
*  RUN DATE   04MAY09  TIME  16:56:01   *                                                         *           (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


                                          HEC-1 INPUT                                              PAGE  1

          LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

            1           ID       Flood Control District of Maricopa County
            2           ID       DDM UH EX GIS - DDM Unit Hydrograph Example GIS Method
            3           ID       100 YEAR
            4           ID       6 Hour  Storm
            5           ID       Unit Hydrograph: Clark
            6           ID       05/04/2009
            7           IT       5       0       0     300
            8           IN      15
            9           IO       5
                        *
                        *

           10           KK      S2   BASIN
           11           KO       1                              21
           12           BA   4.401
           13           PB   2.983
           14           PC   0.000   0.015   0.021   0.031   0.049   0.064   0.077   0.092   0.107   0.121
           15           PC   0.137   0.154   0.178   0.225   0.307   0.473   0.669   0.795   0.867   0.911
           16           PC   0.945   0.959   0.973   0.987   1.000
           17           LG    0.21    0.31    4.35    0.42      41
           18           UC   0.785   0.376
           19           UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
           20           UA     100
                        *

           21           KK      S3   BASIN
           22           KO       3                              21
           23           BA   3.302
           24           LG    0.28    0.25    5.30    0.26      47
           25           UC   0.489   0.252
           26           UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
           27           UA     100
                        *

           28           KK      S4   BASIN
           29           KO       3                              21
           30           BA   2.366
           31           LG    0.28    0.25    4.50    0.42      55
           32           UC   0.467   0.259
           33           UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
           34           UA     100
                        *

           35           KK      S5   BASIN
           36           KO       3                              21
           37           BA   1.079
           38           LG    0.26    0.27    4.40    0.43      47
           39           UC   0.563   0.363
           40           UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
           41           UA     100
                        *
                                          HEC-1 INPUT                                              PAGE  2
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      LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

        42          KK  CLEAN1 COMBINE
        43          KO       5                               21
        44          HC       4
                    *

        45          KK      S6   BASIN
        46          KO       3                               21
        47          BA   1.055
        48          LG    0.27    0.26    6.20    0.18      62
        49          UC   0.494   0.292
        50          UA       0
5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
        51          UA     100
                    *

        52          KK      S7   BASIN
        53          KO       3                               21
        54          BA   1.181
        55          LG    0.24    0.28    5.00    0.31      37
        56          UC   0.470   0.227
        57          UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
        58          UA     100
                    *

        59          KK      S8   BASIN
        60          KO       3                               21
        61          BA   0.958
        62          LG    0.21    0.29    5.20    0.29      46
        63          UC   0.553   0.390
        64          UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
        65          UA     100
                    *

        66          KK      S9   BASIN
        67          KO       3                               21
        68          BA   0.827
        69          LG    0.27    0.21    6.80    0.13      43
        70          UC   0.364   0.201
        71          UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
        72          UA     100
                    *

        73          KK     S10   BASIN
        74          KO       3                               21
        75          BA   0.444
        76          LG    0.30    0.21    6.40    0.18      52
        77          UC   0.326   0.275
        78          UA       0     5.0    16.0    30.0    65.0    77.0    84.0    90.0    94.0    97.0
        79          UA     100
                    *
                                                  HEC-1 INPUT                                          PAGE  3

      LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

        80          KK  CLEAN2 COMBINE
        81          KO       5                               21
        82          HC       5
                    *

        83          KK     S11   BASIN
        84          KO       3                               21
        85          BA   1.820
        86          LG    0.17    0.33    4.90    0.30       9
        87          UC   1.002   0.632
        88          UA       0     3.0     5.0     8.0    12.0    20.0    43.0    75.0    90.0    96.0
        89          UA     100
        90          ZZ
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****************************************                                                          ***************************************
*                                      *                                                          *                                     *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                                          *   U.S. ARMY CORPS OF ENGINEERS      *
*             JUN   1998               *                                                          *   HYDROLOGIC ENGINEERING CENTER     *
*          VERSION 4.1                 *                                                          *         609 SECOND STREET           *
*                                      *                                                          *      DAVIS, CALIFORNIA 95616        *
*  RUN DATE   04MAY09  TIME  16:56:01  *                                                          *          (916) 756-1104             *
*                                      *                                                          *                                     *
****************************************                                                          ***************************************



                               Flood Control District of Maricopa County
                               DDM UH EX GIS - DDM Unit Hydrograph Example GIS Method
                               100 YEAR
                               6 Hour  Storm
                               Unit Hydrograph: Clark
                               05/04/2009

   9 IO         OUTPUT CONTROL VARIABLES
                      IPRNT          5  PRINT CONTROL
                      IPLOT          0  PLOT CONTROL
                      QSCAL         0.  HYDROGRAPH PLOT SCALE

     IT         HYDROGRAPH TIME DATA
                       NMIN          5  MINUTES IN COMPUTATION INTERVAL
                      IDATE      1   0  STARTING DATE
                      ITIME       0000  STARTING TIME
                         NQ        300  NUMBER OF HYDROGRAPH ORDINATES
                     NDDATE      2   0  ENDING DATE
                     NDTIME       0055  ENDING TIME
                     ICENT          19  CENTURY MARK

                  COMPUTATION INTERVAL    0.08 HOURS
                       TOTAL TIME BASE   24.92 HOURS

          ENGLISH UNITS
               DRAINAGE AREA          SQUARE MILES
               PRECIPITATION DEPTH    INCHES
               LENGTH, ELEVATION      FEET
               FLOW                   CUBIC FEET PER SECOND
               STORAGE VOLUME         ACRE-FEET
               SURFACE AREA           ACRES
               TEMPERATURE            DEGREES FAHRENHEIT


*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

            **************
            *            *
  10 KK     *        S2  *        BASIN
            *            *
            **************

  11 KO         OUTPUT CONTROL VARIABLES
                      IPRNT          1  PRINT CONTROL
                      IPLOT          0  PLOT CONTROL
                      QSCAL         0.  HYDROGRAPH PLOT SCALE
                      IPNCH          0  PUNCH COMPUTED HYDROGRAPH
                       IOUT         21  SAVE HYDROGRAPH ON THIS UNIT
                      ISAV1          1  FIRST ORDINATE PUNCHED OR SAVED
                      ISAV2        300  LAST ORDINATE PUNCHED OR SAVED
                     TIMINT      0.083  TIME INTERVAL IN HOURS


   8 IN         TIME DATA FOR INPUT TIME SERIES
                      JXMIN         15  TIME INTERVAL IN MINUTES
                     JXDATE      1   0  STARTING DATE
                     JXTIME          0  STARTING TIME

              SUBBASIN RUNOFF DATA

  12 BA         SUBBASIN CHARACTERISTICS
                      TAREA       4.40  SUBBASIN AREA

                PRECIPITATION DATA

  13 PB               STORM       2.98  BASIN TOTAL PRECIPITATION

  14 PI           INCREMENTAL PRECIPITATION PATTERN
                    0.01      0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.01
                    0.01      0.01      0.01      0.00      0.01      0.00      0.00      0.00      0.01      0.00
                    0.01      0.01      0.00      0.01      0.00      0.00      0.00      0.01      0.01      0.01
                    0.01      0.01      0.01      0.01      0.01      0.01      0.02      0.02      0.02      0.03
                    0.03      0.03      0.06      0.06      0.06      0.07      0.07      0.07      0.04      0.04
                    0.04      0.02      0.02      0.02      0.01      0.01      0.01      0.01      0.01      0.01
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                0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
                0.00      0.00

 17 LG          GREEN AND AMPT LOSS RATE
                      STRTL        0.21  STARTING LOSS
                        DTH        0.31  MOISTURE DEFICIT
                       PSIF        4.35  WETTING FRONT SUCTION
                      XKSAT        0.42  HYDRAULIC CONDUCTIVITY
                      RTIMP       41.00  PERCENT IMPERVIOUS AREA

 18 UC          CLARK UNITGRAPH
                         TC        0.79  TIME OF CONCENTRATION
                          R        0.38  STORAGE COEFFICIENT

 19 UA          ACCUMULATED-AREA VS. TIME,  11 ORDINATES
                 0.0       5.0      16.0      30.0      65.0      77.0      84.0      90.0      94.0      97.0
               100.0

                                                 ***

                                      UNIT HYDROGRAPH PARAMETERS
                                CLARK   TC=  0.79 HR,       R=  0.38 HR
                               SNYDER   TP=  0.41 HR,      CP=  0.56

                                           UNIT HYDROGRAPH
                                      29 END-OF-PERIOD ORDINATES
         193.      757.     1653.     3031.     3878.     3725.     3409.     3044.     2672.     2293.
        1881.     1506.     1205.      965.      772.      618.      495.      396.      317.      254.
         203.      163.      130.      104.       83.       67.       53.       43.       34.

*************************************************************************************************************************************

                                   HYDROGRAPH AT STATION       S2

*************************************************************************************************************************************
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DA MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	*	DA MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q
1	0000	1	0.00	0.00	0.00	0.	*	1	1230	151	0.00	0.00	0.00	0.
1	0005	2	0.01	0.01	0.01	1.	*	1	1235	152	0.00	0.00	0.00	0.
1	0010	3	0.01	0.01	0.01	6.	*	1	1240	153	0.00	0.00	0.00	0.
1	0015	4	0.01	0.01	0.01	16.	*	1	1245	154	0.00	0.00	0.00	0.
1	0020	5	0.01	0.00	0.00	34.	*	1	1250	155	0.00	0.00	0.00	0.
1	0025	6	0.01	0.00	0.00	55.	*	1	1255	156	0.00	0.00	0.00	0.
1	0030	7	0.01	0.00	0.00	71.	*	1	1300	157	0.00	0.00	0.00	0.
1	0035	8	0.01	0.01	0.00	81.	*	1	1305	158	0.00	0.00	0.00	0.
1	0040	9	0.01	0.01	0.00	87.	*	1	1310	159	0.00	0.00	0.00	0.
1	0045	10	0.01	0.01	0.00	92.	*	1	1315	160	0.00	0.00	0.00	0.
1	0050	11	0.02	0.01	0.01	100.	*	1	1320	161	0.00	0.00	0.00	0.
1	0055	12	0.02	0.01	0.01	109.	*	1	1325	162	0.00	0.00	0.00	0.
1	0100	13	0.02	0.01	0.01	120.	*	1	1330	163	0.00	0.00	0.00	0.
1	0105	14	0.01	0.01	0.01	134.	*	1	1335	164	0.00	0.00	0.00	0.
1	0110	15	0.01	0.01	0.01	149.	*	1	1340	165	0.00	0.00	0.00	0.
1	0115	16	0.01	0.01	0.01	163.	*	1	1345	166	0.00	0.00	0.00	0.
1	0120	17	0.01	0.01	0.01	173.	*	1	1350	167	0.00	0.00	0.00	0.
1	0125	18	0.01	0.01	0.01	181.	*	1	1355	168	0.00	0.00	0.00	0.
1	0130	19	0.01	0.01	0.01	185.	*	1	1400	169	0.00	0.00	0.00	0.
1	0135	20	0.01	0.01	0.01	188.	*	1	1405	170	0.00	0.00	0.00	0.
1	0140	21	0.01	0.01	0.01	189.	*	1	1410	171	0.00	0.00	0.00	0.
1	0145	22	0.01	0.01	0.01	190.	*	1	1415	172	0.00	0.00	0.00	0.
1	0150	23	0.01	0.01	0.01	192.	*	1	1420	173	0.00	0.00	0.00	0.
1	0155	24	0.01	0.01	0.01	194.	*	1	1425	174	0.00	0.00	0.00	0.
1	0200	25	0.01	0.01	0.01	196.	*	1	1430	175	0.00	0.00	0.00	0.
1	0205	26	0.01	0.01	0.01	198.	*	1	1435	176	0.00	0.00	0.00	0.
1	0210	27	0.01	0.01	0.01	199.	*	1	1440	177	0.00	0.00	0.00	0.
1	0215	28	0.01	0.01	0.01	200.	*	1	1445	178	0.00	0.00	0.00	0.
1	0220	29	0.02	0.01	0.01	201.	*	1	1450	179	0.00	0.00	0.00	0.
1	0225	30	0.02	0.01	0.01	201.	*	1	1455	180	0.00	0.00	0.00	0.
1	0230	31	0.02	0.01	0.01	201.	*	1	1500	181	0.00	0.00	0.00	0.
1	0235	32	0.02	0.01	0.01	203.	*	1	1505	182	0.00	0.00	0.00	0.
1	0240	33	0.02	0.01	0.01	206.	*	1	1510	183	0.00	0.00	0.00	0.
1	0245	34	0.02	0.01	0.01	209.	*	1	1515	184	0.00	0.00	0.00	0.
1	0250	35	0.02	0.01	0.01	213.	*	1	1520	185	0.00	0.00	0.00	0.
1	0255	36	0.02	0.01	0.01	219.	*	1	1525	186	0.00	0.00	0.00	0.
1	0300	37	0.02	0.01	0.01	227.	*	1	1530	187	0.00	0.00	0.00	0.
1	0305	38	0.05	0.03	0.02	240.	*	1	1535	188	0.00	0.00	0.00	0.
1	0310	39	0.05	0.03	0.02	261.	*	1	1540	189	0.00	0.00	0.00	0.
1	0315	40	0.05	0.03	0.02	289.	*	1	1545	190	0.00	0.00	0.00	0.
1	0320	41	0.08	0.05	0.03	331.	*	1	1550	191	0.00	0.00	0.00	0.
1	0325	42	0.08	0.05	0.03	389.	*	1	1555	192	0.00	0.00	0.00	0.
1	0330	43	0.08	0.05	0.03	456.	*	1	1600	193	0.00	0.00	0.00	0.
1	0335	44	0.17	0.06	0.11	553.	*	1	1605	194	0.00	0.00	0.00	0.
1	0340	45	0.17	0.05	0.11	700.	*	1	1610	195	0.00	0.00	0.00	0.
1	0345	46	0.17	0.05	0.11	909.	*	1	1615	196	0.00	0.00	0.00	0.
1	0350	47	0.19	0.05	0.15	1223.	*	1	1620	197	0.00	0.00	0.00	0.
1	0355	48	0.19	0.05	0.15	1616.	*	1	1625	198	0.00	0.00	0.00	0.
1	0400	49	0.19	0.04	0.15	2027.	*	1	1630	199	0.00	0.00	0.00	0.
1	0405	50	0.13	0.04	0.08	2442.	*	1	1635	200	0.00	0.00	0.00	0.
1	0410	51	0.13	0.04	0.08	2813.	*	1	1640	201	0.00	0.00	0.00	0.
1	0415	52	0.13	0.04	0.08	3085.	*	1	1645	202	0.00	0.00	0.00	0.

1	0420	53	0.07	0.04	0.03	3209.	*	1	1650	203	0.00	0.00	0.00	0.
1	0425	54	0.07	0.04	0.03	3197.	*	1	1655	204	0.00	0.00	0.00	0.
1	0430	55	0.07	0.04	0.03	3104.	*	1	1700	205	0.00	0.00	0.00	0.
1	0435	56	0.04	0.03	0.02	2917.	*	1	1705	206	0.00	0.00	0.00	0.
1	0440	57	0.04	0.03	0.02	2666.	*	1	1710	207	0.00	0.00	0.00	0.
1	0445	58	0.04	0.03	0.02	2403.	*	1	1715	208	0.00	0.00	0.00	0.
1	0450	59	0.03	0.02	0.01	2135.	*	1	1720	209	0.00	0.00	0.00	0.
1	0455	60	0.03	0.02	0.01	1876.	*	1	1725	210	0.00	0.00	0.00	0.
1	0500	61	0.03	0.02	0.01	1644.	*	1	1730	211	0.00	0.00	0.00	0.
1	0505	62	0.01	0.01	0.01	1435.	*	1	1735	212	0.00	0.00	0.00	0.
1	0510	63	0.01	0.01	0.01	1250.	*	1	1740	213	0.00	0.00	0.00	0.
1	0515	64	0.01	0.01	0.01	1088.	*	1	1745	214	0.00	0.00	0.00	0.
1	0520	65	0.01	0.01	0.01	940.	*	1	1750	215	0.00	0.00	0.00	0.
1	0525	66	0.01	0.01	0.01	807.	*	1	1755	216	0.00	0.00	0.00	0.
1	0530	67	0.01	0.01	0.01	695.	*	1	1800	217	0.00	0.00	0.00	0.
1	0535	68	0.01	0.01	0.01	601.	*	1	1805	218	0.00	0.00	0.00	0.
1	0540	69	0.01	0.01	0.01	523.	*	1	1810	219	0.00	0.00	0.00	0.
1	0545	70	0.01	0.01	0.01	458.	*	1	1815	220	0.00	0.00	0.00	0.
1	0550	71	0.01	0.01	0.01	405.	*	1	1820	221	0.00	0.00	0.00	0.
1	0555	72	0.01	0.01	0.01	362.	*	1	1825	222	0.00	0.00	0.00	0.
1	0600	73	0.01	0.01	0.01	325.	*	1	1830	223	0.00	0.00	0.00	0.
1	0605	74	0.00	0.00	0.00	293.	*	1	1835	224	0.00	0.00	0.00	0.
1	0610	75	0.00	0.00	0.00	264.	*	1	1840	225	0.00	0.00	0.00	0.
1	0615	76	0.00	0.00	0.00	234.	*	1	1845	226	0.00	0.00	0.00	0.
1	0620	77	0.00	0.00	0.00	201.	*	1	1850	227	0.00	0.00	0.00	0.
1	0625	78	0.00	0.00	0.00	166.	*	1	1855	228	0.00	0.00	0.00	0.
1	0630	79	0.00	0.00	0.00	137.	*	1	1900	229	0.00	0.00	0.00	0.
1	0635	80	0.00	0.00	0.00	112.	*	1	1905	230	0.00	0.00	0.00	0.
1	0640	81	0.00	0.00	0.00	89.	*	1	1910	231	0.00	0.00	0.00	0.
1	0645	82	0.00	0.00	0.00	72.	*	1	1915	232	0.00	0.00	0.00	0.
1	0650	83	0.00	0.00	0.00	57.	*	1	1920	233	0.00	0.00	0.00	0.
1	0655	84	0.00	0.00	0.00	44.	*	1	1925	234	0.00	0.00	0.00	0.
1	0700	85	0.00	0.00	0.00	35.	*	1	1930	235	0.00	0.00	0.00	0.
1	0705	86	0.00	0.00	0.00	28.	*	1	1935	236	0.00	0.00	0.00	0.
1	0710	87	0.00	0.00	0.00	22.	*	1	1940	237	0.00	0.00	0.00	0.
1	0715	88	0.00	0.00	0.00	17.	*	1	1945	238	0.00	0.00	0.00	0.
1	0720	89	0.00	0.00	0.00	13.	*	1	1950	239	0.00	0.00	0.00	0.
1	0725	90	0.00	0.00	0.00	10.	*	1	1955	240	0.00	0.00	0.00	0.
1	0730	91	0.00	0.00	0.00	8.	*	1	2000	241	0.00	0.00	0.00	0.
1	0735	92	0.00	0.00	0.00	6.	*	1	2005	242	0.00	0.00	0.00	0.
1	0740	93	0.00	0.00	0.00	5.	*	1	2010	243	0.00	0.00	0.00	0.
1	0745	94	0.00	0.00	0.00	4.	*	1	2015	244	0.00	0.00	0.00	0.
1	0750	95	0.00	0.00	0.00	3.	*	1	2020	245	0.00	0.00	0.00	0.
1	0755	96	0.00	0.00	0.00	2.	*	1	2025	246	0.00	0.00	0.00	0.
1	0800	97	0.00	0.00	0.00	2.	*	1	2030	247	0.00	0.00	0.00	0.
1	0805	98	0.00	0.00	0.00	1.	*	1	2035	248	0.00	0.00	0.00	0.
1	0810	99	0.00	0.00	0.00	1.	*	1	2040	249	0.00	0.00	0.00	0.
1	0815	100	0.00	0.00	0.00	0.	*	1	2045	250	0.00	0.00	0.00	0.
1	0820	101	0.00	0.00	0.00	0.	*	1	2050	251	0.00	0.00	0.00	0.
1	0825	102	0.00	0.00	0.00	0.	*	1	2055	252	0.00	0.00	0.00	0.
1	0830	103	0.00	0.00	0.00	0.	*	1	2100	253	0.00	0.00	0.00	0.
1	0835	104	0.00	0.00	0.00	0.	*	1	2105	254	0.00	0.00	0.00	0.
1	0840	105	0.00	0.00	0.00	0.	*	1	2110	255	0.00	0.00	0.00	0.
1	0845	106	0.00	0.00	0.00	0.	*	1	2115	256	0.00	0.00	0.00	0.
1	0850	107	0.00	0.00	0.00	0.	*	1	2120	257	0.00	0.00	0.00	0.
1	0855	108	0.00	0.00	0.00	0.	*	1	2125	258	0.00	0.00	0.00	0.
1	0900	109	0.00	0.00	0.00	0.	*	1	2130	259	0.00	0.00	0.00	0.
1	0905	110	0.00	0.00	0.00	0.	*	1	2135	260	0.00	0.00	0.00	0.
1	0910	111	0.00	0.00	0.00	0.	*	1	2140	261	0.00	0.00	0.00	0.
1	0915	112	0.00	0.00	0.00	0.	*	1	2145	262	0.00	0.00	0.00	0.
1	0920	113	0.00	0.00	0.00	0.	*	1	2150	263	0.00	0.00	0.00	0.
1	0925	114	0.00	0.00	0.00	0.	*	1	2155	264	0.00	0.00	0.00	0.
1	0930	115	0.00	0.00	0.00	0.	*	1	2200	265	0.00	0.00	0.00	0.
1	0935	116	0.00	0.00	0.00	0.	*	1	2205	266	0.00	0.00	0.00	0.
1	0940	117	0.00	0.00	0.00	0.	*	1	2210	267	0.00	0.00	0.00	0.
1	0945	118	0.00	0.00	0.00	0.	*	1	2215	268	0.00	0.00	0.00	0.
1	0950	119	0.00	0.00	0.00	0.	*	1	2220	269	0.00	0.00	0.00	0.
1	0955	120	0.00	0.00	0.00	0.	*	1	2225	270	0.00	0.00	0.00	0.
1	1000	121	0.00	0.00	0.00	0.	*	1	2230	271	0.00	0.00	0.00	0.
1	1005	122	0.00	0.00	0.00	0.	*	1	2235	272	0.00	0.00	0.00	0.
1	1010	123	0.00	0.00	0.00	0.	*	1	2240	273	0.00	0.00	0.00	0.
1	1015	124	0.00	0.00	0.00	0.	*	1	2245	274	0.00	0.00	0.00	0.
1	1020	125	0.00	0.00	0.00	0.	*	1	2250	275	0.00	0.00	0.00	0.
1	1025	126	0.00	0.00	0.00	0.	*	1	2255	276	0.00	0.00	0.00	0.
1	1030	127	0.00	0.00	0.00	0.	*	1	2300	277	0.00	0.00	0.00	0.
1	1035	128	0.00	0.00	0.00	0.	*	1	2305	278	0.00	0.00	0.00	0.
1	1040	129	0.00	0.00	0.00	0.	*	1	2310	279	0.00	0.00	0.00	0.
1	1045	130	0.00	0.00	0.00	0.	*	1	2315	280	0.00	0.00	0.00	0.
1	1050	131	0.00	0.00	0.00	0.	*	1	2320	281	0.00	0.00	0.00	0.
1	1055	132	0.00	0.00	0.00	0.	*	1	2325	282	0.00	0.00	0.00	0.
1	1100	133	0.00	0.00	0.00	0.	*	1	2330	283	0.00	0.00	0.00	0.
1	1105	134	0.00	0.00	0.00	0.	*	1	2335	284	0.00	0.00	0.00	0.
1	1110	135	0.00	0.00	0.00	0.	*	1	2340	285	0.00	0.00	0.00	0.
1	1115	136	0.00	0.00	0.00	0.	*	1	2345	286	0.00	0.00	0.00	0.
1	1120	137	0.00	0.00	0.00	0.	*	1	2350	287	0.00	0.00	0.00	0.
1	1125	138	0.00	0.00	0.00	0.	*	1	2355	288	0.00	0.00	0.00	0.
1	1130	139	0.00	0.00	0.00	0.	*	2	0000	289	0.00	0.00	0.00	0.
1	1135	140	0.00	0.00	0.00	0.	*	2	0005	290	0.00	0.00	0.00	0.
1	1140	141	0.00	0.00	0.00	0.	*	2	0010	291	0.00	0.00	0.00	0.
1	1145	142	0.00	0.00	0.00	0.	*	2	0015	292	0.00	0.00	0.00	0.

```
      1     1150  143    0.00     0.00     0.00          0.          *          2     0020  293    0.00     0.00     0.00            0.
      1     1155  144    0.00     0.00     0.00          0.          *          2     0025  294    0.00     0.00     0.00            0.
      1     1200  145    0.00     0.00     0.00          0.          *          2     0030  295    0.00     0.00     0.00            0.
      1     1205  146    0.00     0.00     0.00          0.          *          2     0035  296    0.00     0.00     0.00            0.
      1     1210  147    0.00     0.00     0.00          0.          *          2     0040  297    0.00     0.00     0.00            0.
      1     1215  148    0.00     0.00     0.00          0.          *          2     0045  298    0.00     0.00     0.00            0.
      1     1220  149    0.00     0.00     0.00          0.          *          2     0050  299    0.00     0.00     0.00            0.
      1     1225  150    0.00     0.00     0.00          0.          *          2     0055  300    0.00     0.00     0.00            0.
                                                                     *
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```

9.5 CHANNEL ROUTING

9.5.1 Application of Normal-Depth Routing

1. Routing reaches should have relatively constant characteristics along the entire reach (i.e. geometry, slope, roughness, etc). If not, then consider subdividing the reach.

2. Too short of a routing reach may cause numeric instabilities and/or increase the peak discharge. The model output should be checked for unstable warning messages. If unstable warning messages are reported, then check the discharge range of instability in comparison to the peak discharge and plot the hydrograph for inspection.

3. If several short routing reaches occur in succession and attenuation is anticipated, then the channel routing operation can be replaced by a hydrograph lag operation.

4. Channel geometry must have sufficient capacity to convey the peak discharge.

5. The number of computational subreaches (NSTPS), should correspond to the lag time computed by HEC-1 for the routing reach. Example:

   An inflow hydrograph with a time to peak of 4.5 hrs is routed down a 5000 ft natural channel. The estimated NSTPS is 2 and NMIN is set to 5 min. The resulting time to peak of the routing operation is 4.92 hours, a lag of 25 minutes. The actual NSTPS should be (lag/NMIN)=5. This is an interactive process that should be repeated until NSTPS*NMIN approximates the lag.

9.5.2 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, with minimal overbank flow.

2. 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.

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

9.5.3 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 stream gage 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:

   a. 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:

$$\frac{1}{2(1-X)} \leq \frac{K \times 60}{NSTPS \times NMIN} \leq \frac{1}{2(X)} \qquad (9.2)$$

   where:

   K = the travel time through the entire reach, in hours,
   X = Muskingum 'X',
   NMIN = the computational time step, (in hours) and
   NSTPS = the integer number of subreaches.

   b. 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, V_m, with the following provisions:

      i. Use an average channel area and wetted perimeter for the reach, assuming bankfull conditions.

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

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

iv. Use the following ratios (Cudworth, 1989) to estimate V_m, the velocity of the floodwave:

Channel Geometry	$\frac{V_m}{V}$
Wide rectangular	1.67
Wide parabolic	1.44
Triangular	1.33

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

c. 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.

9.5.4 Application of Muskingum-Cunge Routing

1. 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.

2. 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, or zero diversion (most often).

9.6 INDIRECT METHODS

9.6.1 Procedures

The following instructions should be followed for verifying peak discharges that are derived by analytic methods (Rational Method or rainfall-runoff modeling).

A. Verification with Unit Peak Discharge Curves:

1. For a given watershed of drainage area (A), in square miles, divide the 100-year primary peak discharge estimate by A.

2. Plot the unit peak discharge on a copy of Figure 8.1. Note the location of the plotted point in relation to the various curves in that figure.

B. Verification with USGS Data for Arizona:

1. Calculate the 100-year peak discharge estimate by Equation (8.1)

2. Select Figure 8.3 or Figure 8.4 according to watershed drainage area size, and plot the 100-year peak discharge estimate on a copy of that figure.

3. Using watershed drainage area as a guide, identify gaged watersheds of the same approximate size from Table 8.1. Tabulate the peak discharge statistics and watershed characteristics for those gaged watersheds by using the USGS report (Garrett and Gellenbeck, 1991). Compare these to the computed peak discharge estimates and watershed characteristics for the watershed of interest.

C. Verification with Regional Regression Equations:

1. Determine the flood region (Figure 8.6).

2. If the basin(s) fall within Region 12 on Figure 8.6, then calculate the mean basin elevation ($ELEV$). This can be done by placing a transparent grid over the largest scale topographic map available. The grid spacing should be selected such that at least 20 elevation points are sampled. The elevation at each grid point is determined and the elevations are then averaged.

3. Check the drainage area using the appropriate scatter diagram to determine if the values are in the “cloud of common values.” Proceed with the analysis regardless of the outcome, but clearly note if the variable values are not within the “cloud of common values.”

4. Calculate the peak discharge estimates using the applicable regression equations for the flood region within which the project site is located.

5. Plot the 100-year peak discharge estimate on a copy of the appropriate Q_{100} data points and 100-year peak discharge relation graph (Figure 8.8 or Figure 8.9).

D. For all three Indirect Methods:

1. Quantitatively and qualitatively analyze the results of the primary and the secondary peak discharge estimates. Address watershed characteristics that may explain differences between the primary and secondary estimates.

2. Prepare a summary of results by all methods and a qualitative evaluation of the results.

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APPENDIX A RAINFALL

A.1 NOAA Atlas 14 Point Rainfall Maps

Maps start on following page.

FIGURE A.1
2-YEAR 5-MINUTE RAINFALL ISOPLUVIALS

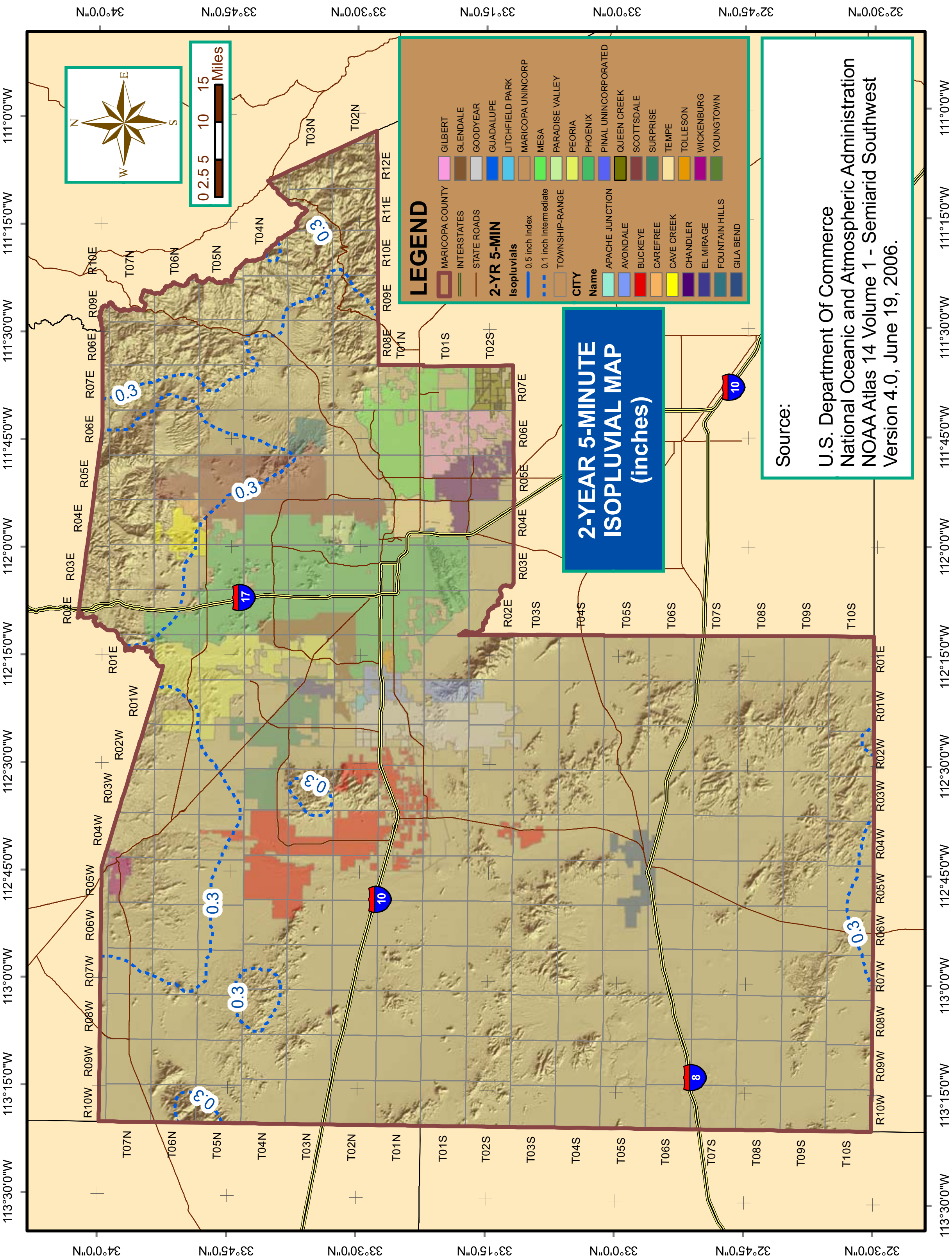


FIGURE A.2
2-YEAR 10-MINUTE RAINFALL ISOPLUVIALS

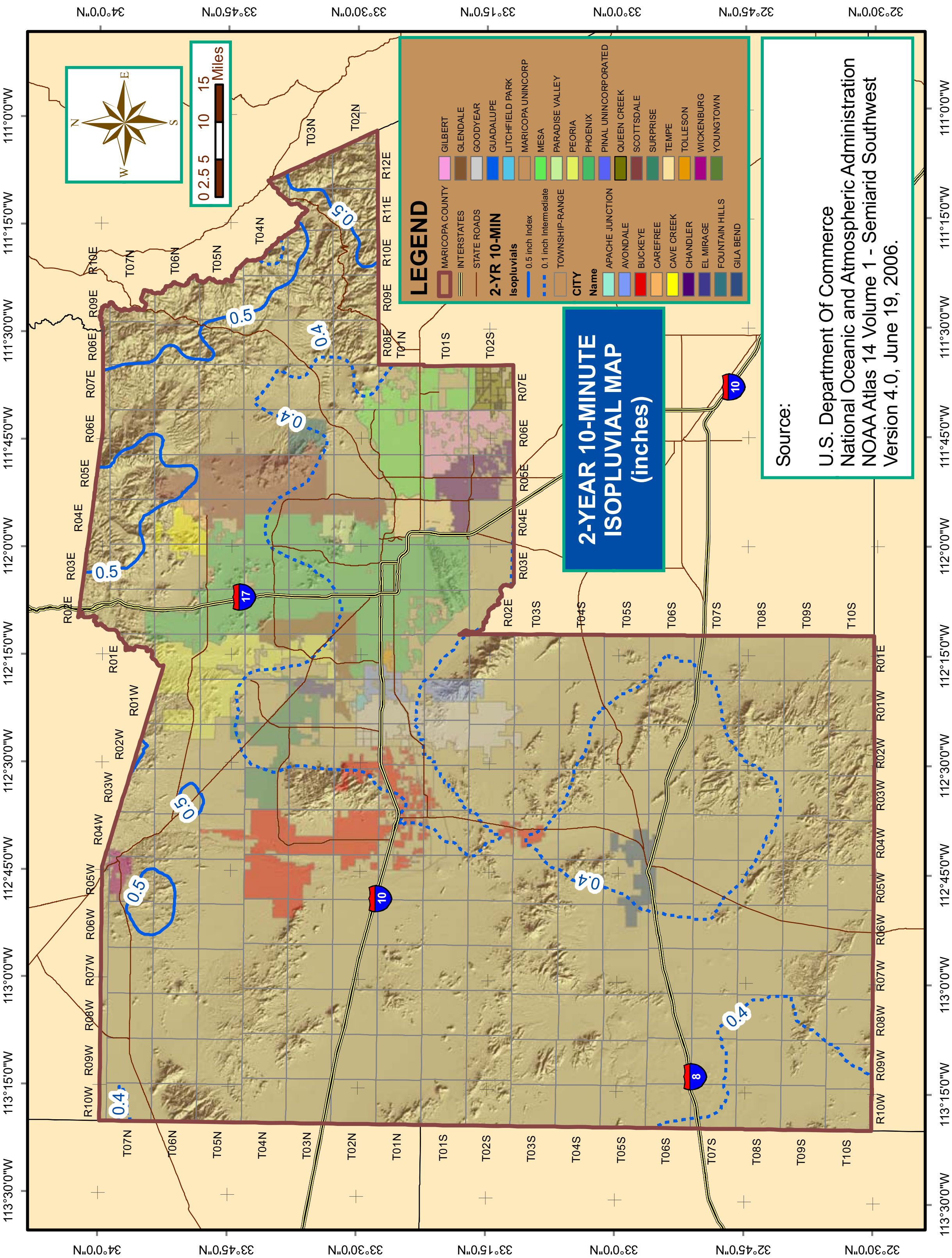


FIGURE A.3
2-YEAR 15-MINUTE RAINFALL ISOPLUVIALS

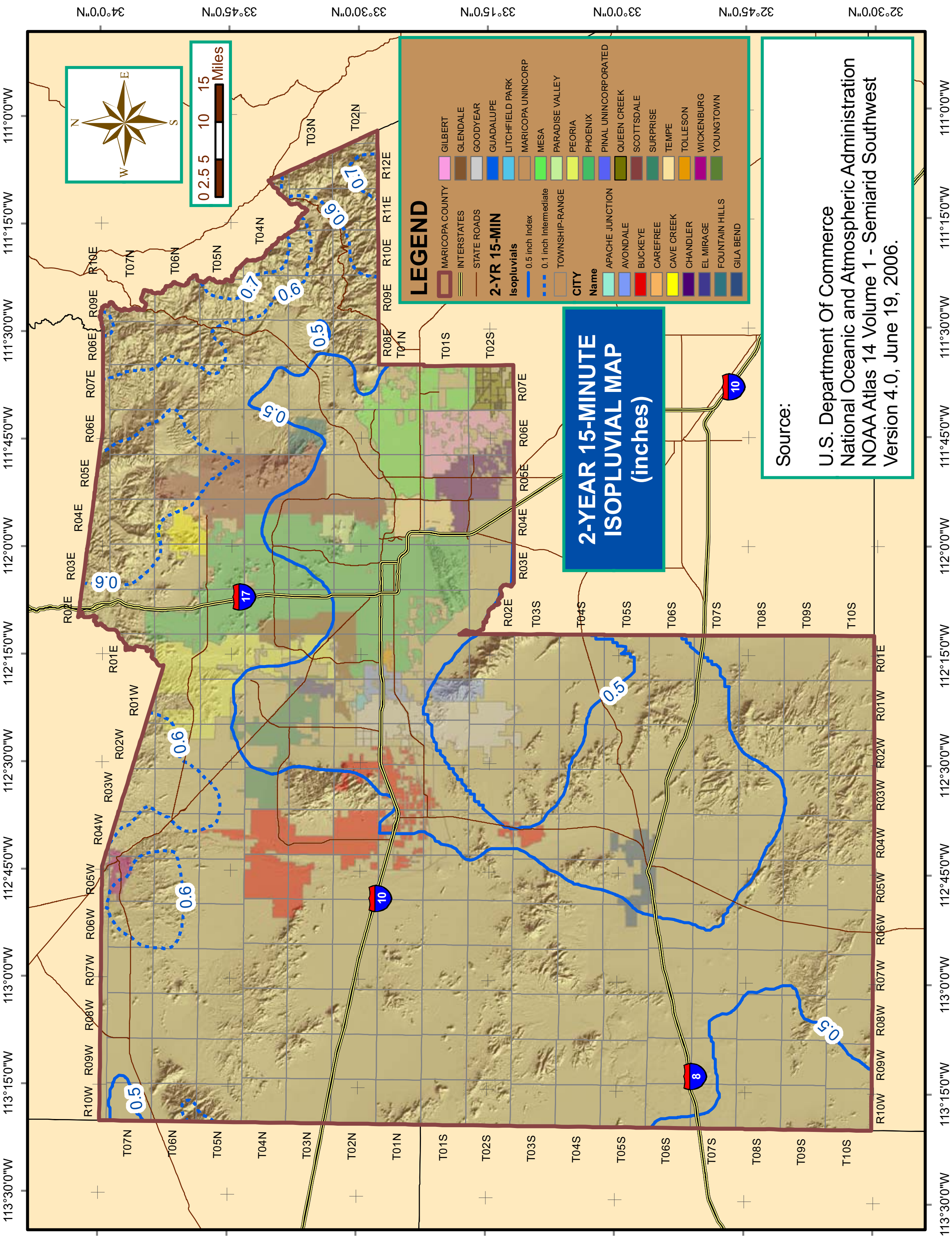


FIGURE A.4
2-YEAR 30-MINUTE RAINFALL ISOPLUVIALS

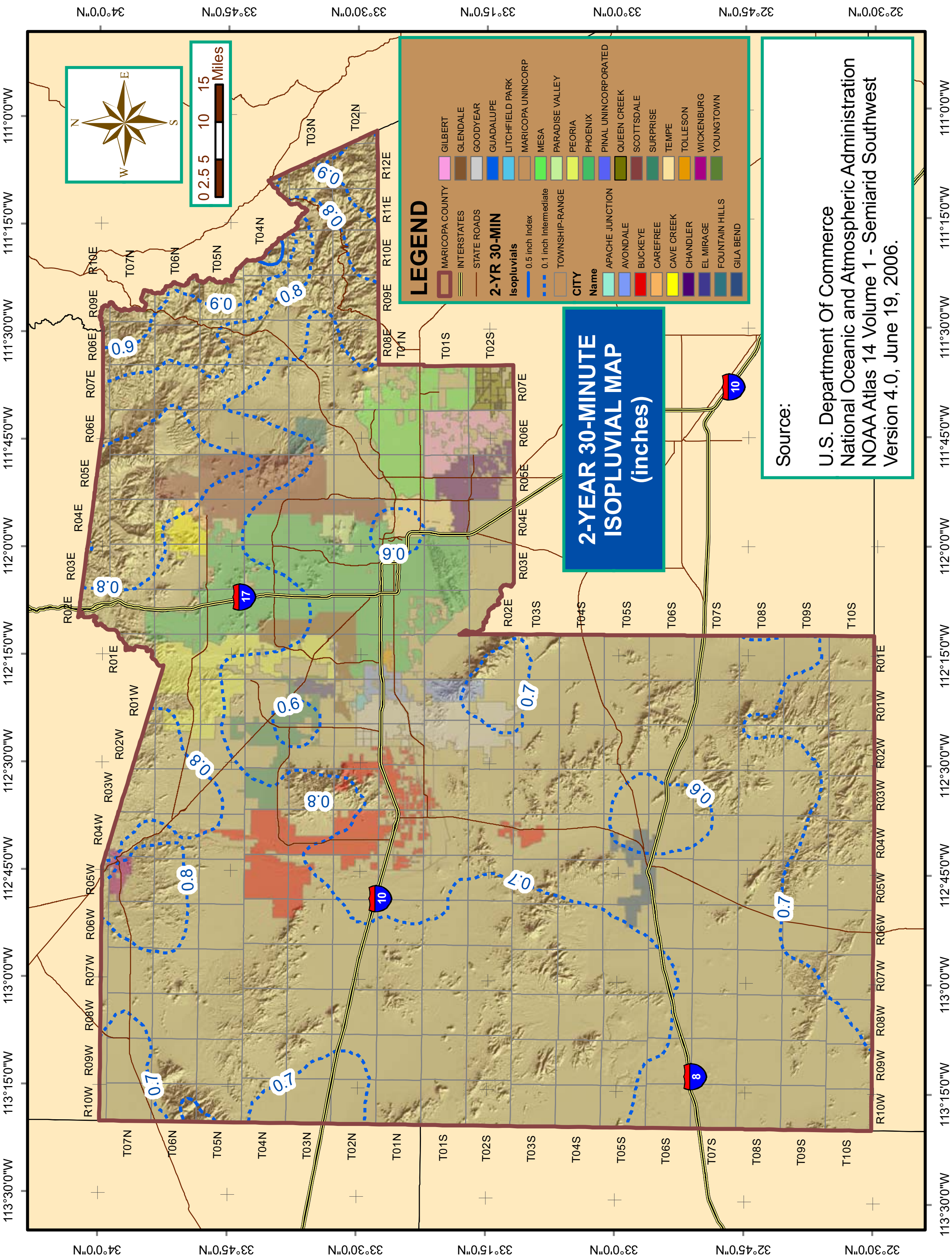


FIGURE A.5
2-YEAR 1-HOUR RAINFALL ISOPLUVIALS

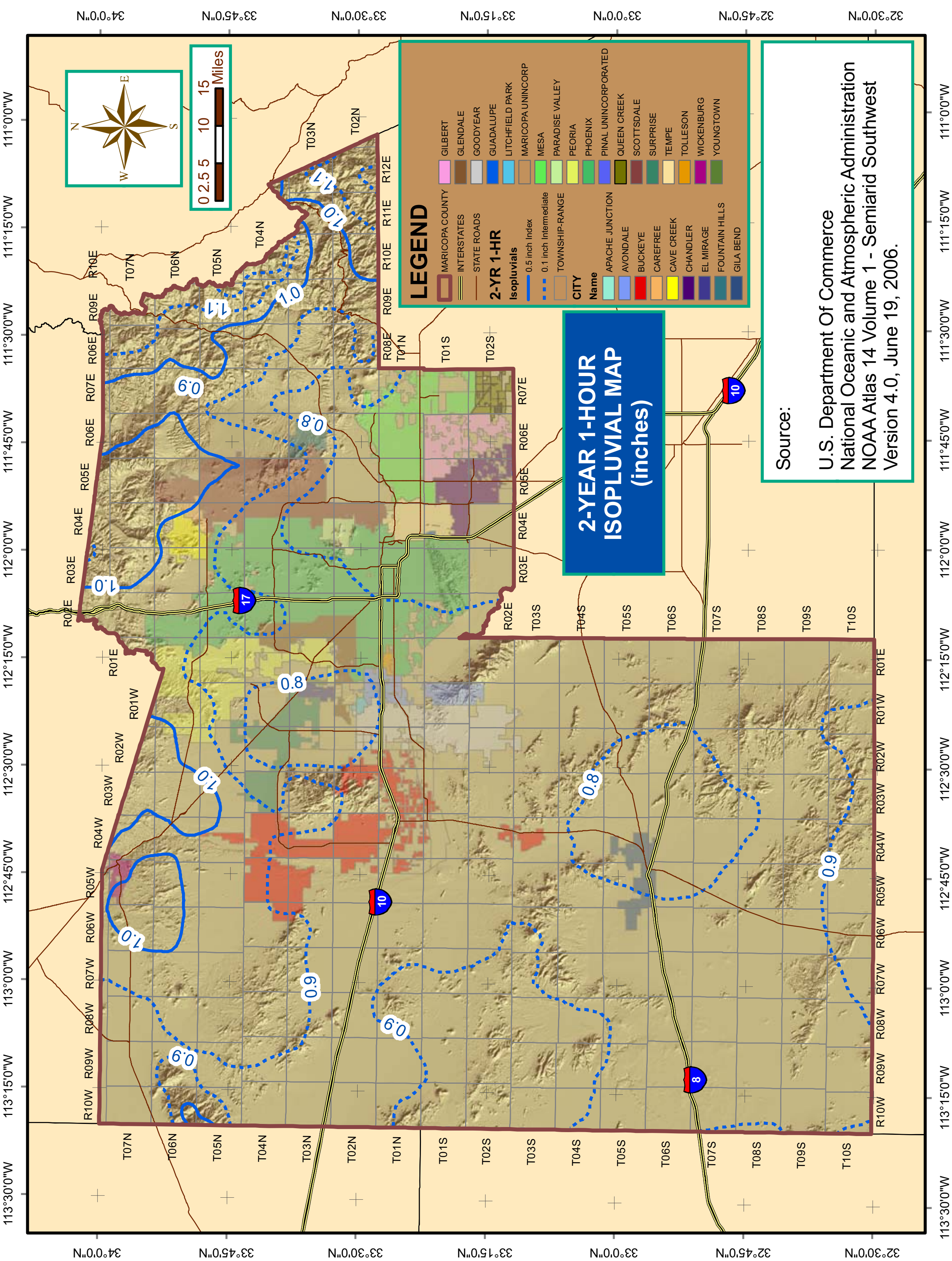


FIGURE A.6
2-YEAR 2-HOUR RAINFALL ISOPLUVIALS

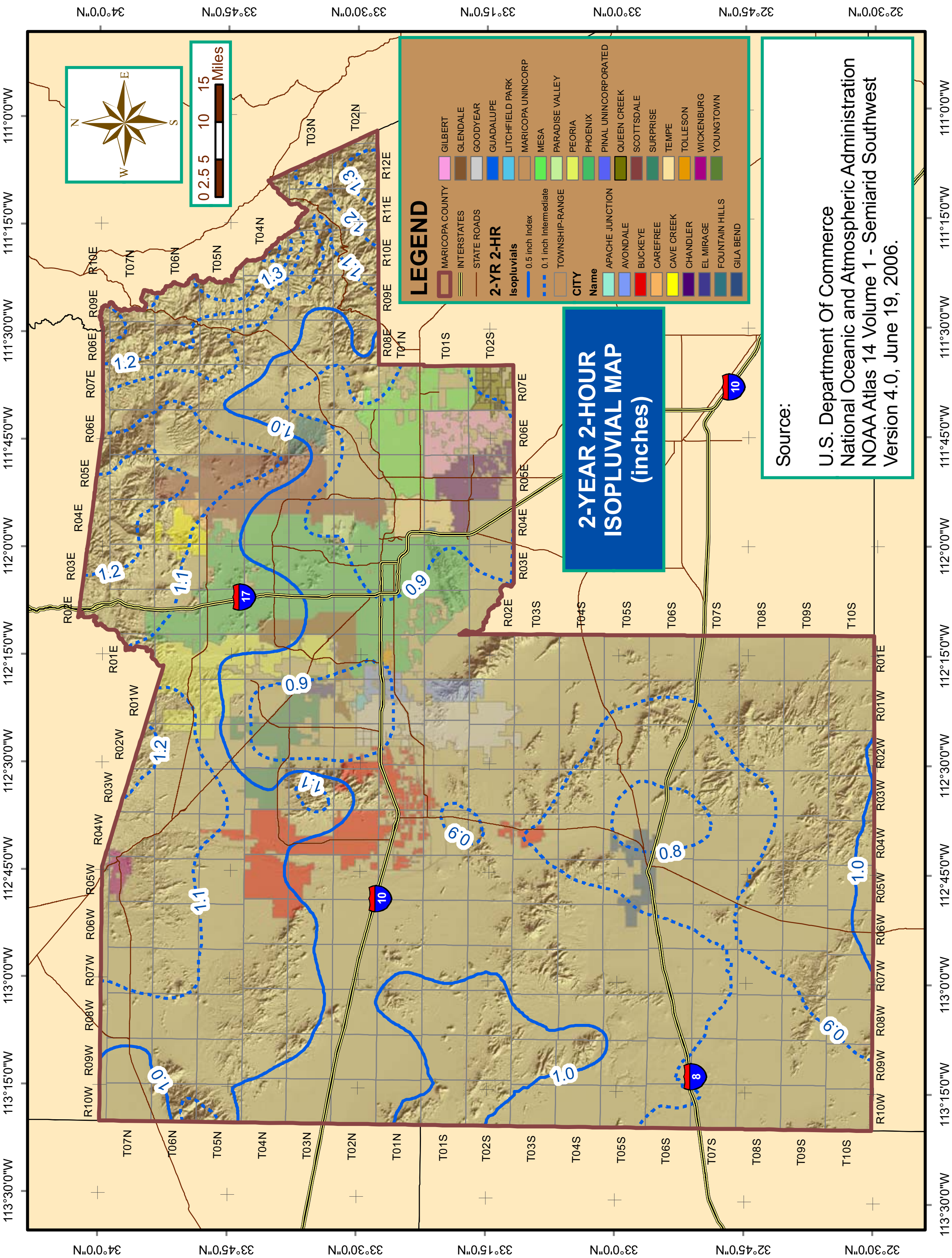


FIGURE A.7
2-YEAR 3-HOUR RAINFALL ISOPLUVIALS

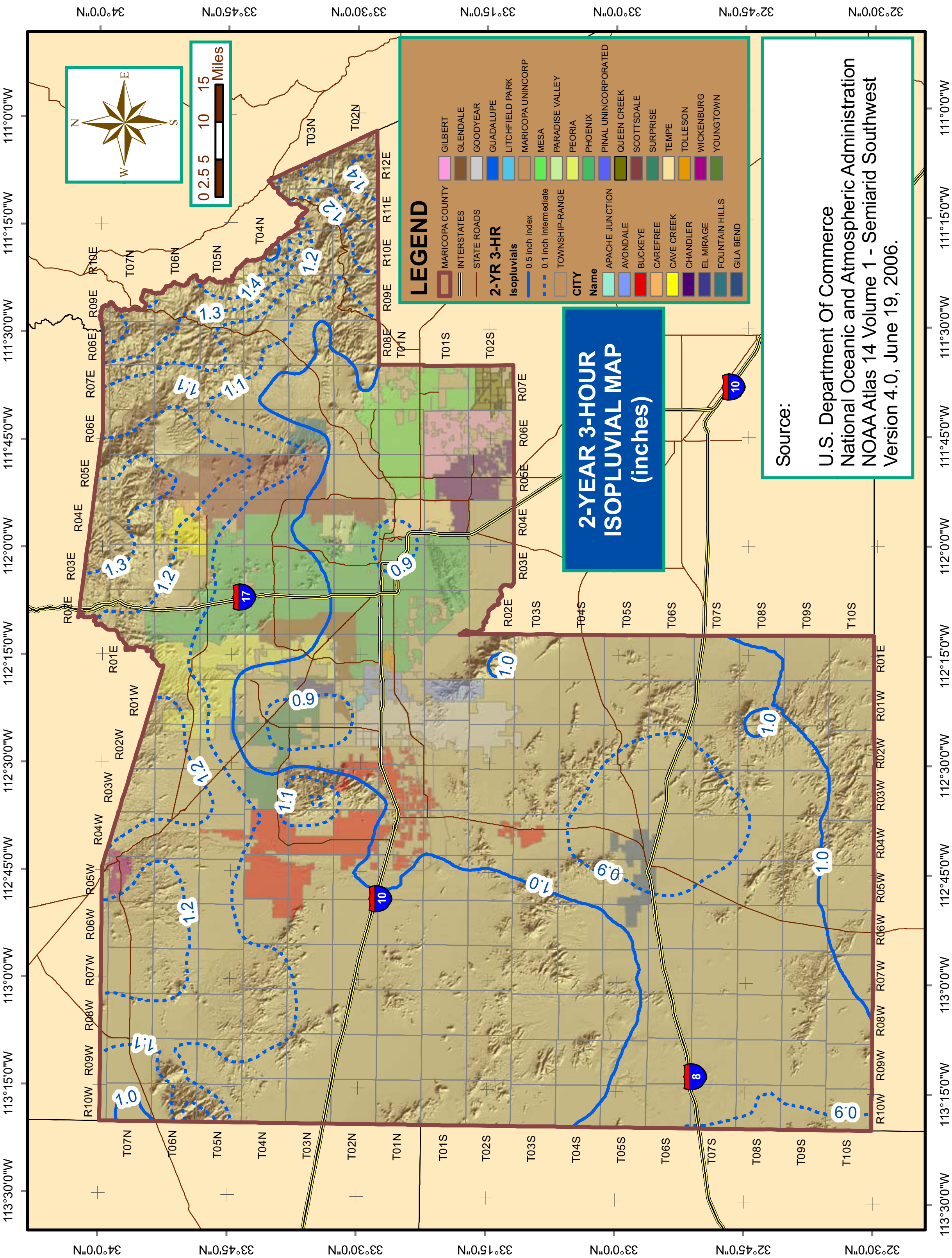


FIGURE A.8
2-YEAR 6-HOUR RAINFALL ISOPLUVIALS

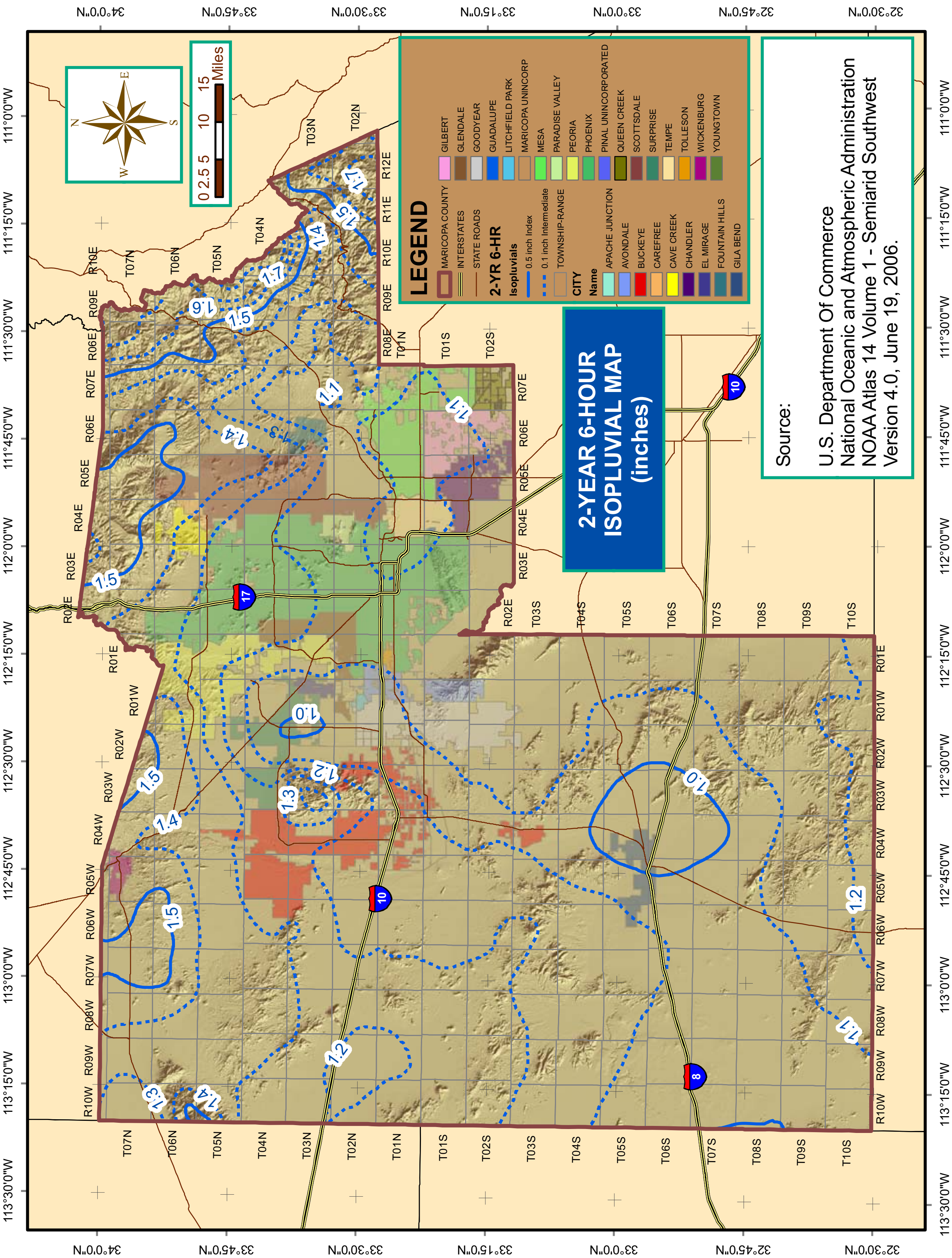


FIGURE A.9
2-YEAR 12-HOUR RAINFALL ISOPLUVIALS

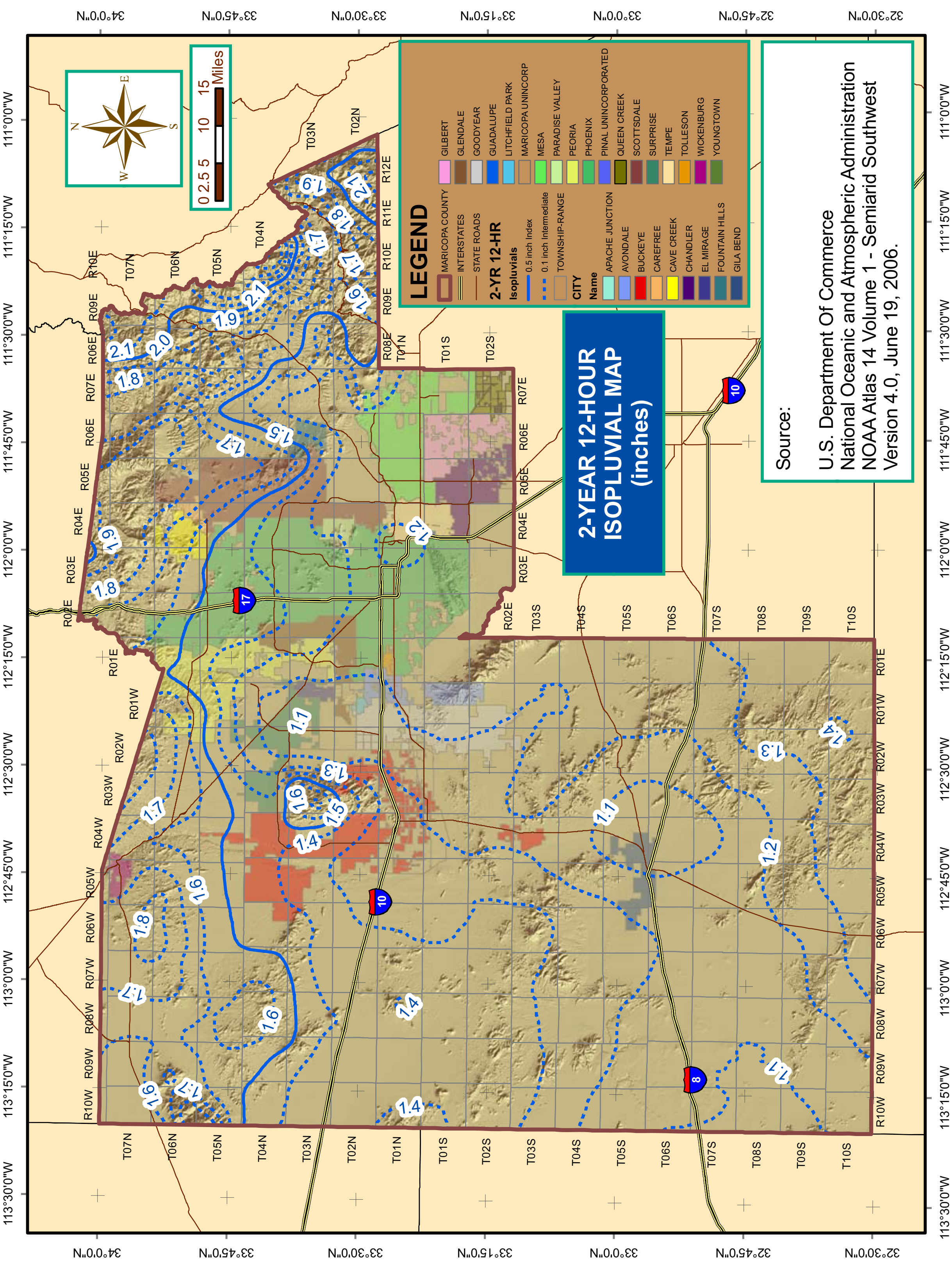


FIGURE A.10
2-YEAR 24-HOUR RAINFALL ISOPLUVIALS

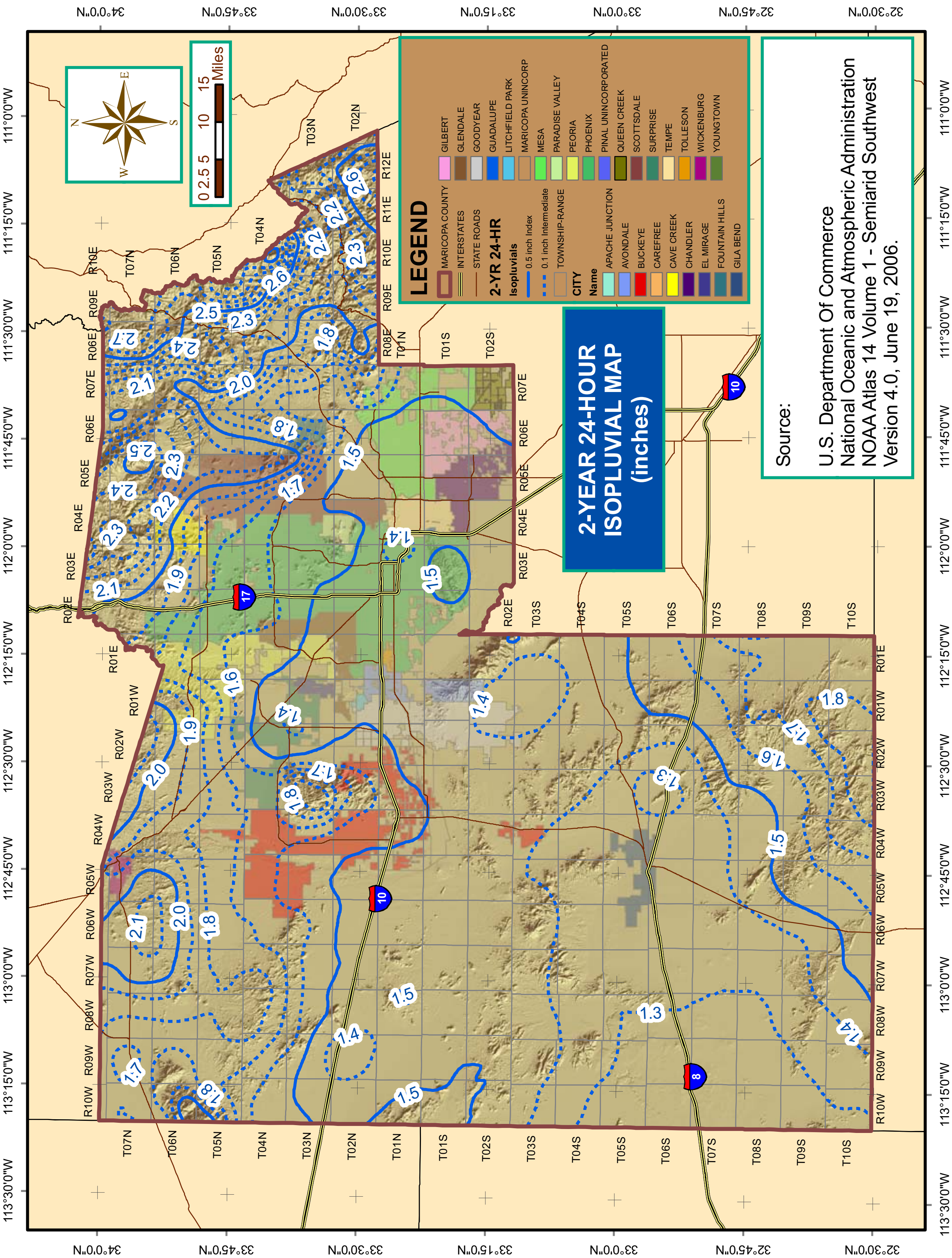


FIGURE A.11
5-YEAR 5-MINUTE RAINFALL ISOPLUVIALS

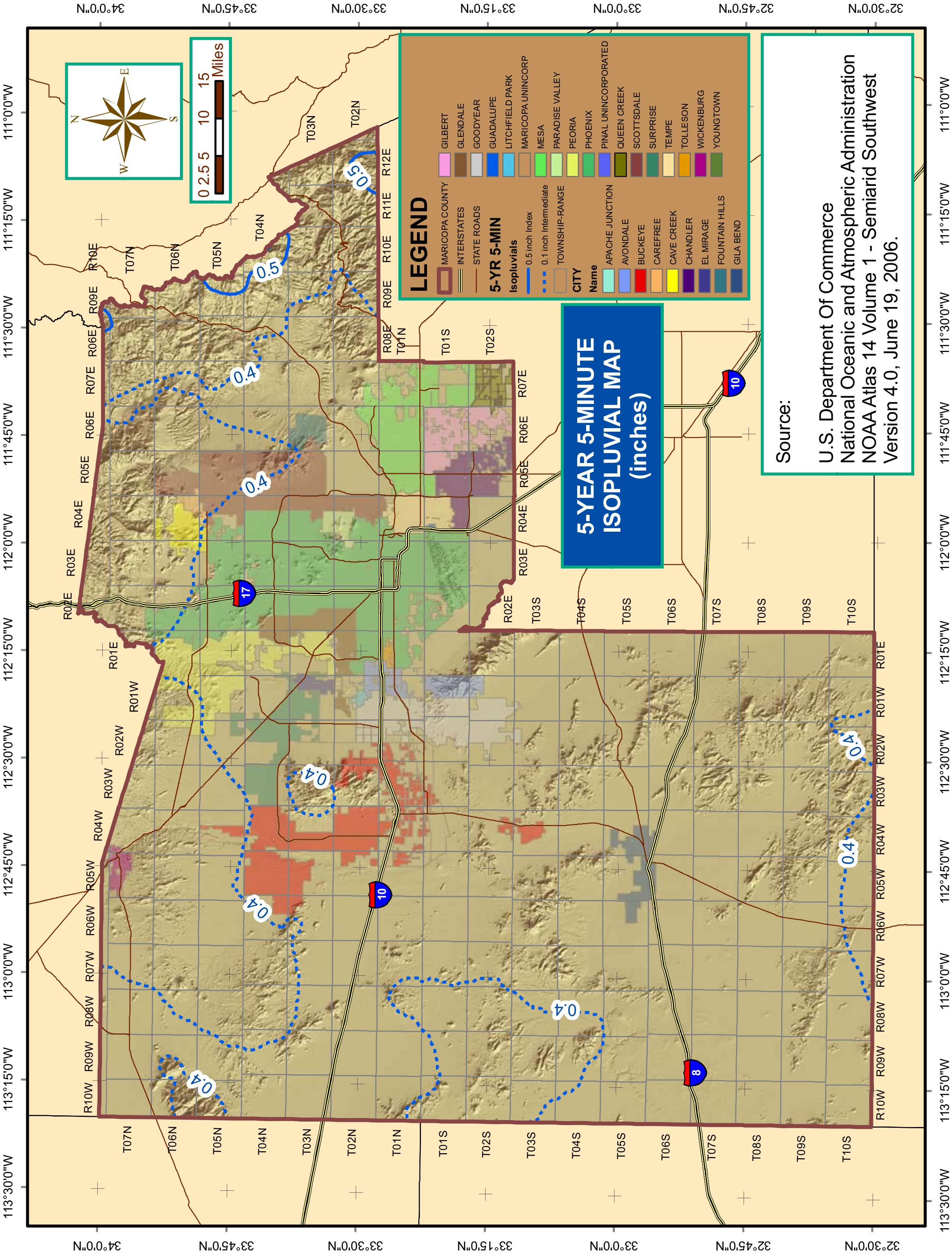


FIGURE A.12
5-YEAR 10-MINUTE RAINFALL ISOPLUVIALS

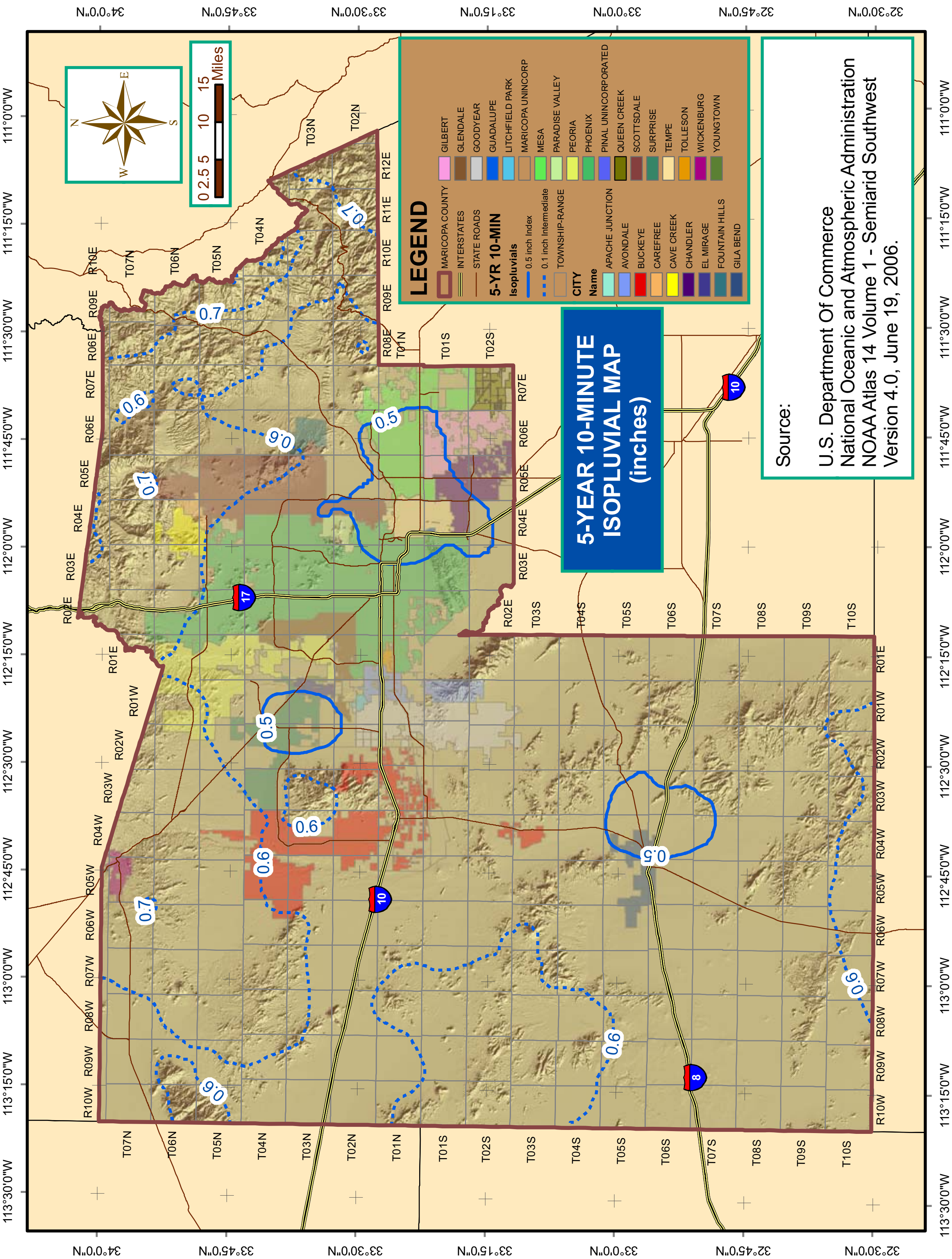


FIGURE A.13
5-YEAR 15-MINUTE RAINFALL ISOPLUVIALS

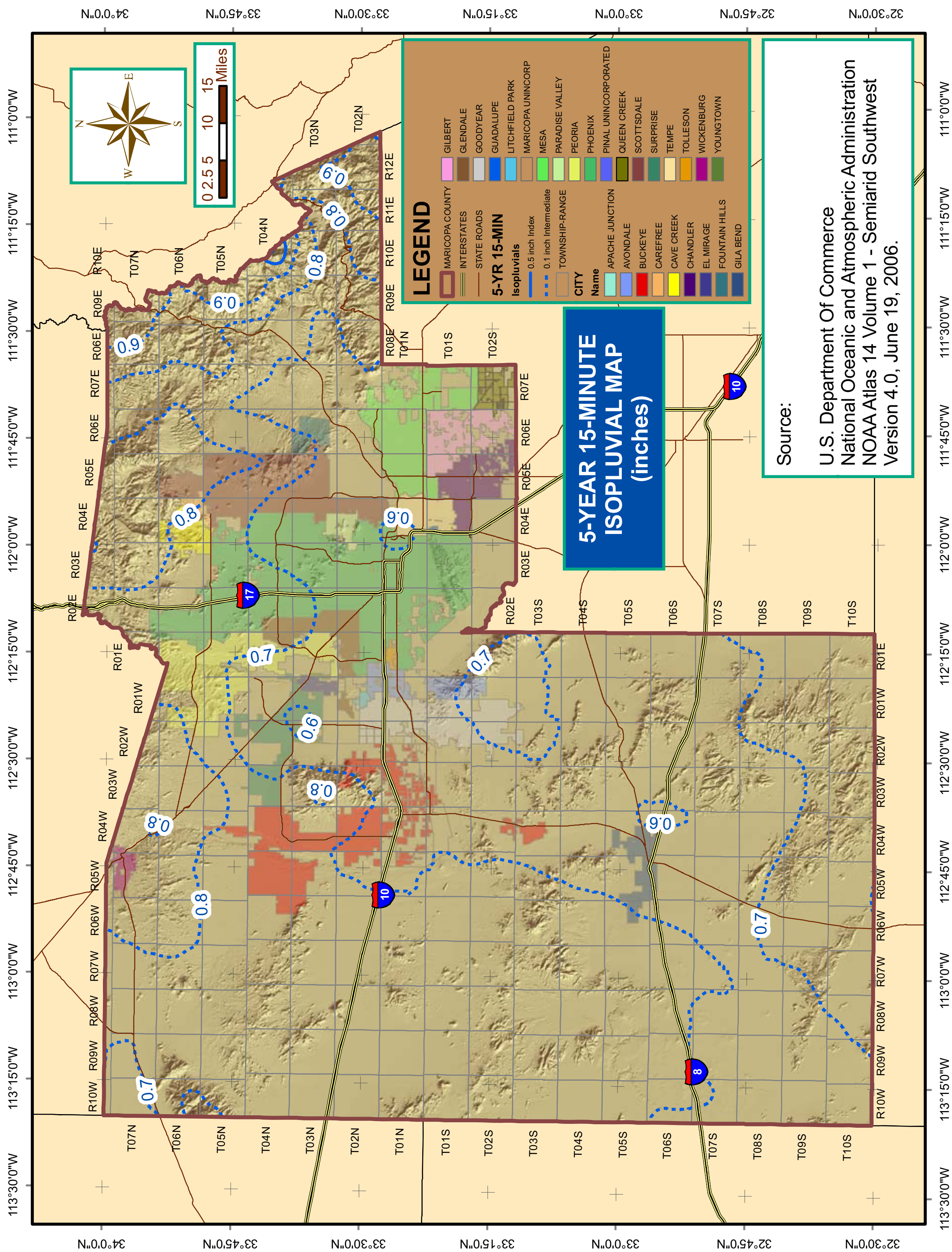


FIGURE A.14
5-YEAR 30-MINUTE RAINFALL ISOPLUVIALS

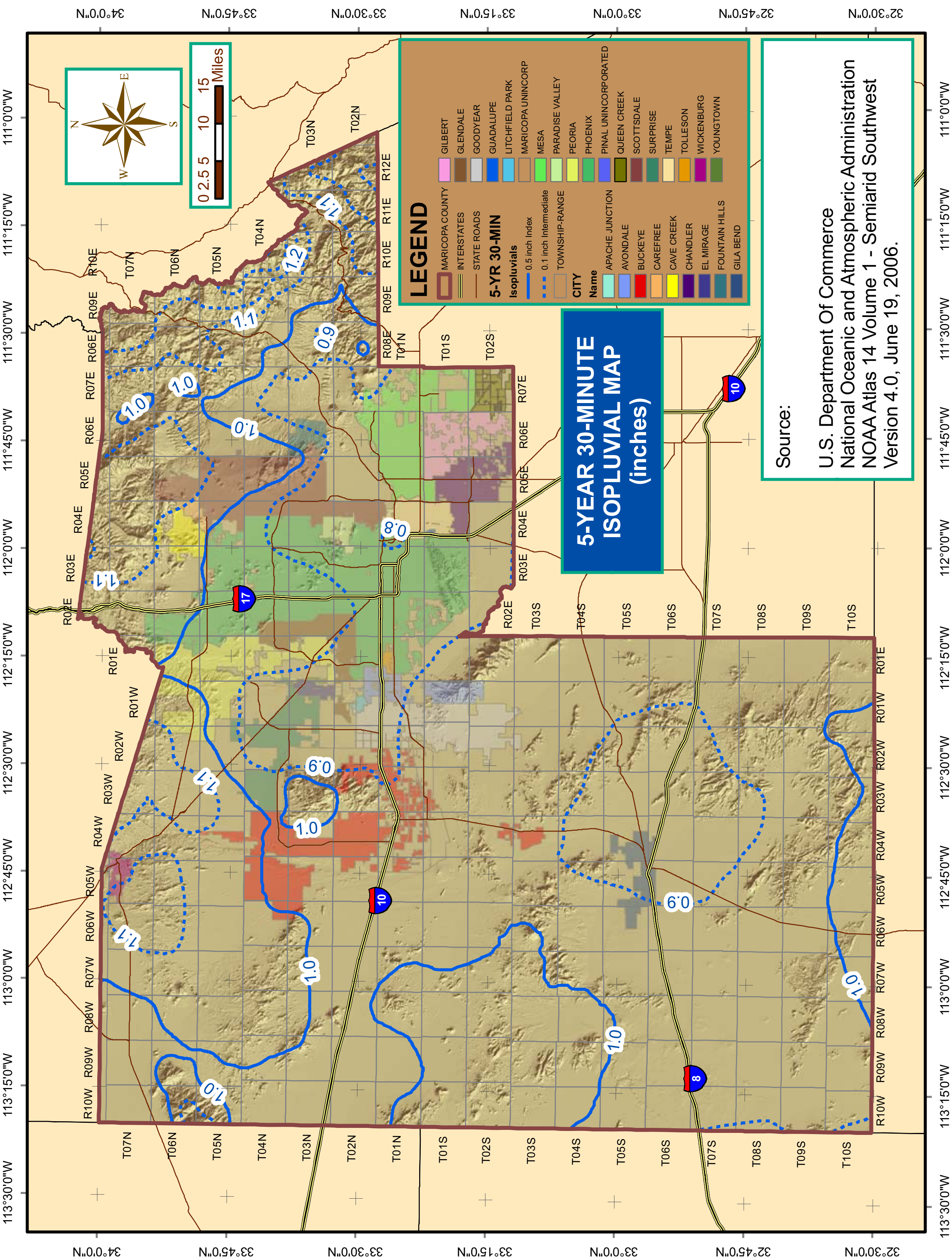


FIGURE A.15
5-YEAR 1-HOUR RAINFALL ISOPLUVIALS

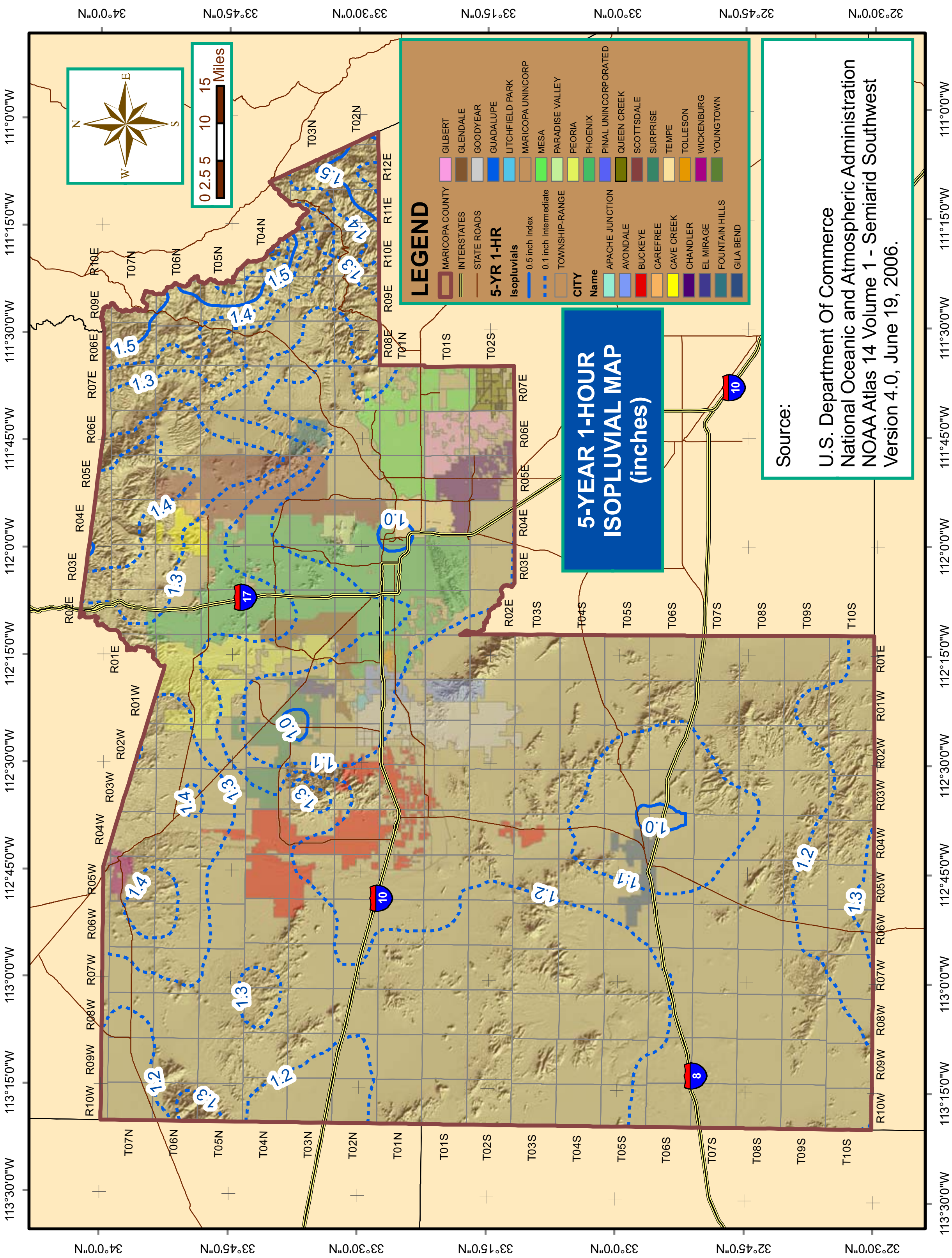


FIGURE A.16
5-YEAR 2-HOUR RAINFALL ISOPLUVIALS

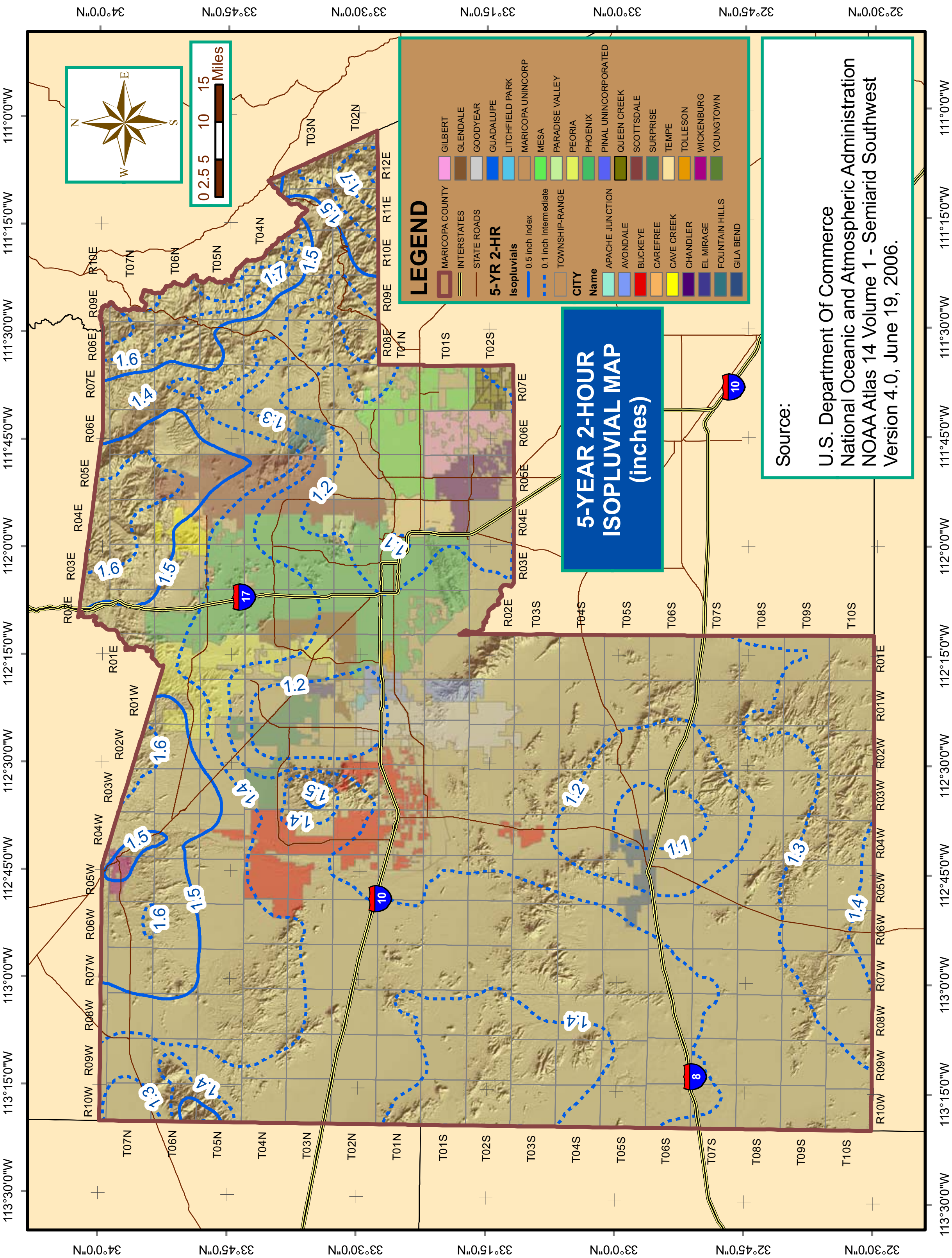


FIGURE A.17
5-YEAR 3-HOUR RAINFALL ISOPLUVIALS

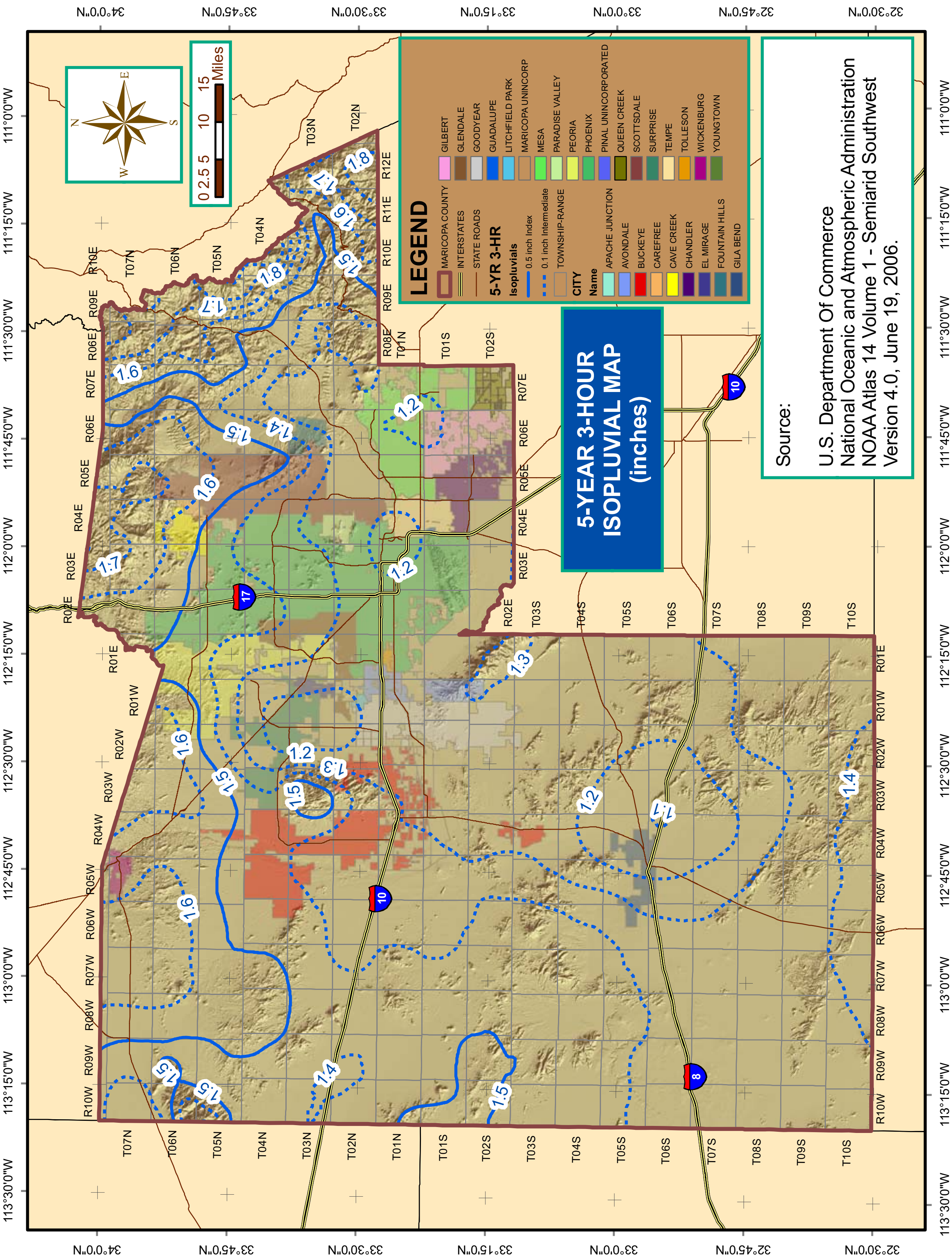


FIGURE A.18
5-YEAR 6-HOUR RAINFALL ISOPLUVIALS

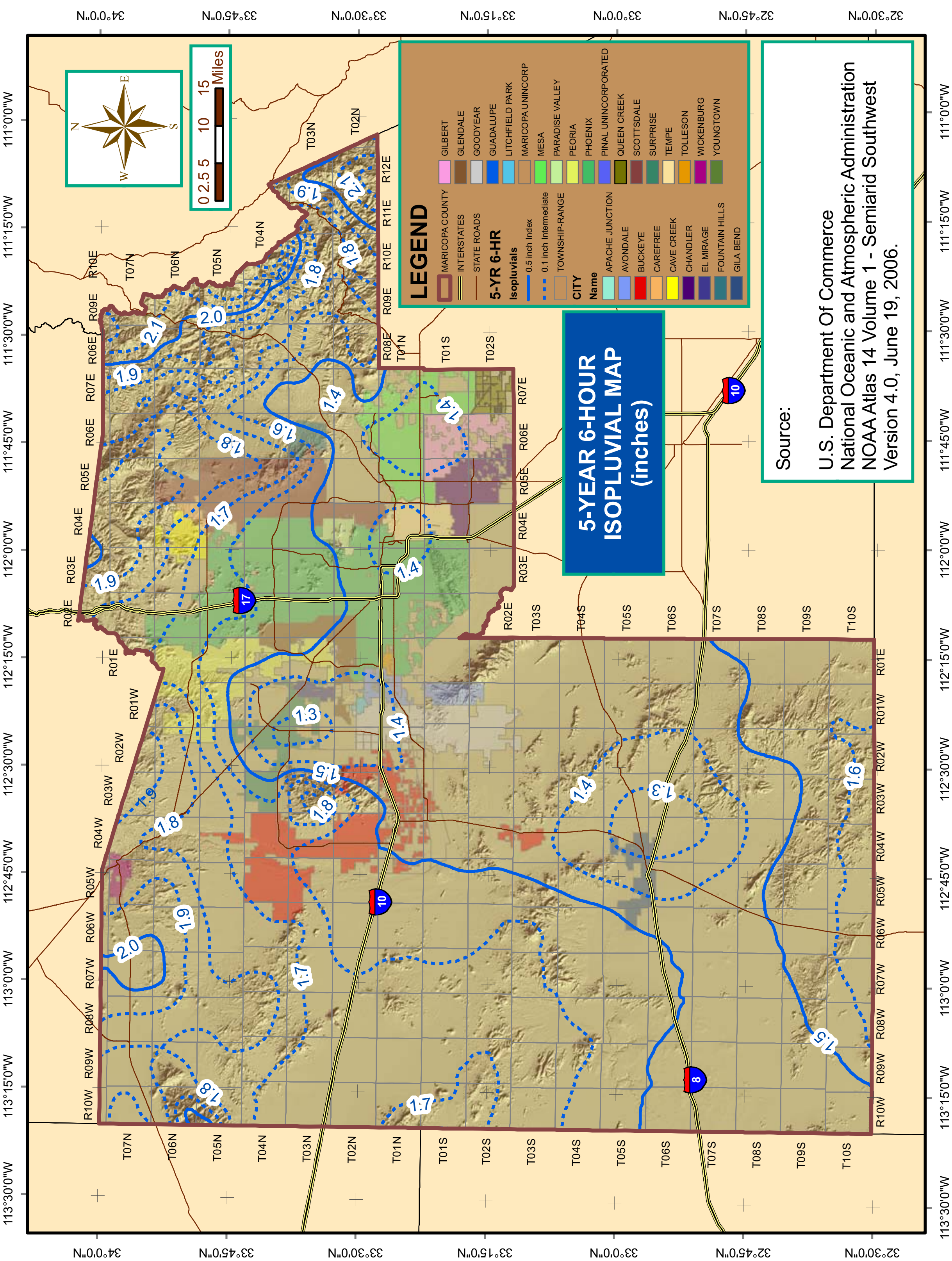


FIGURE A.19
5-YEAR 12-HOUR RAINFALL ISOPLUVIALS

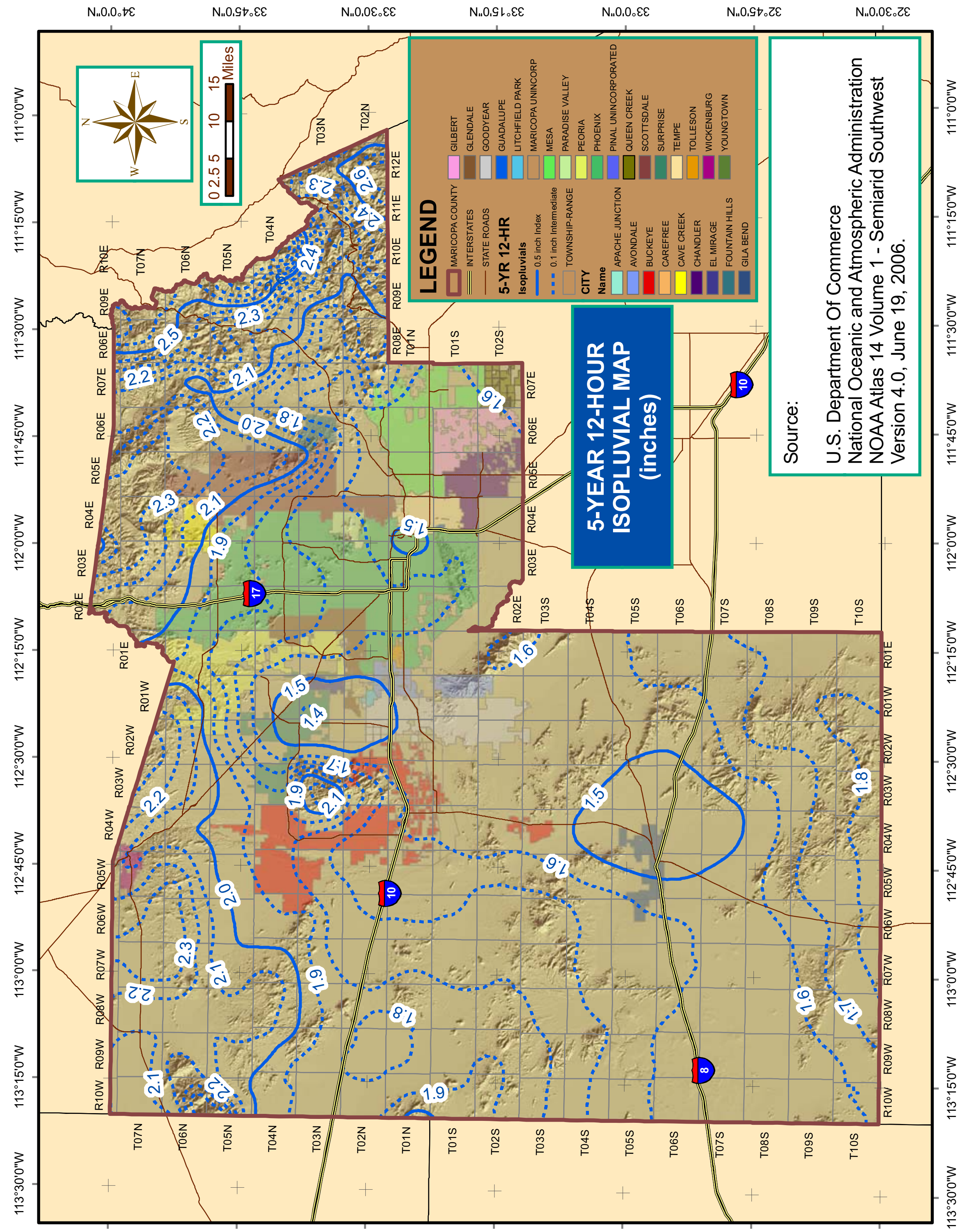


FIGURE A.20
5-YEAR 24-HOUR RAINFALL ISOPLUVIALS

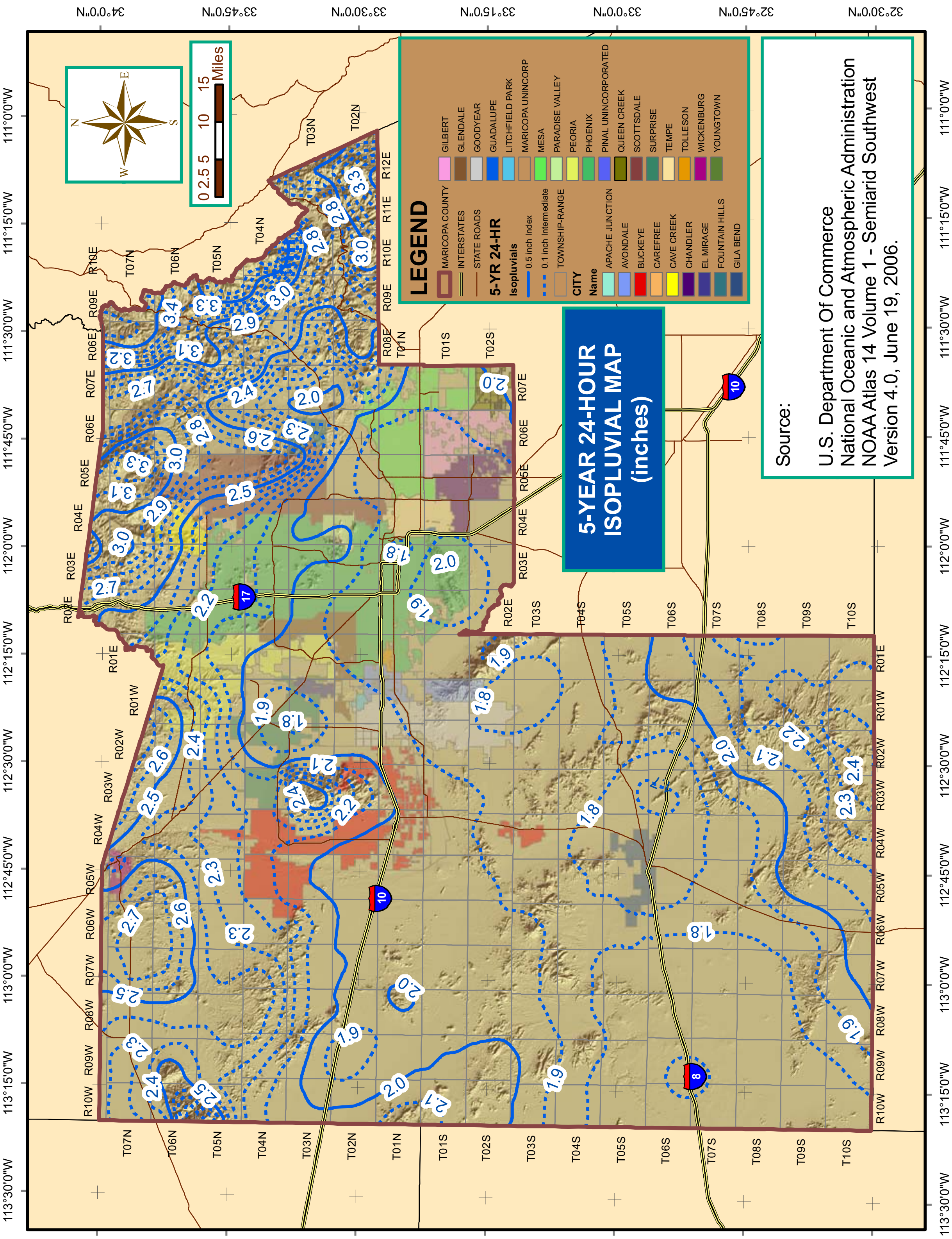


FIGURE A.21
10-YEAR 5-MINUTE RAINFALL ISOPLUVIALS

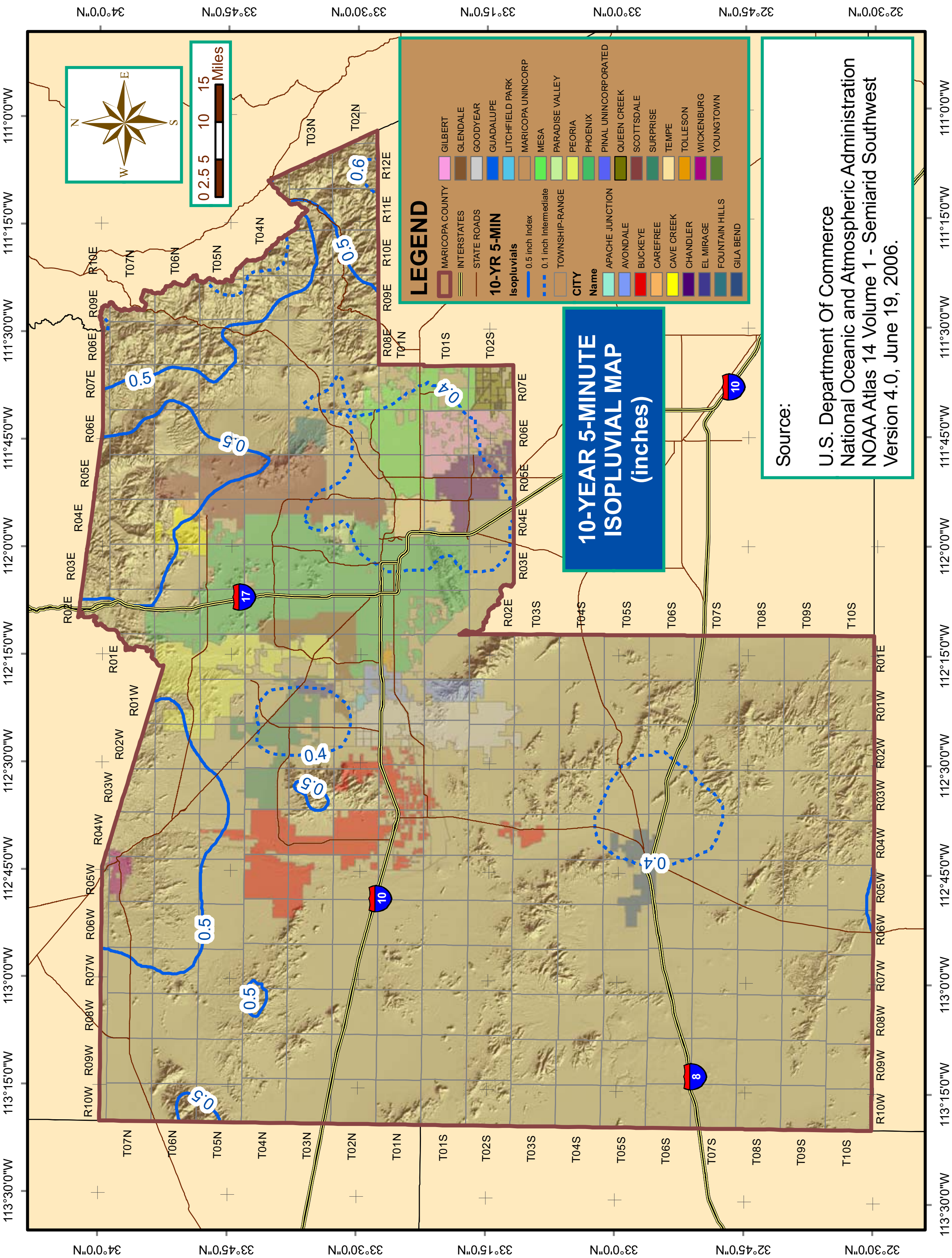


FIGURE A.22
10-YEAR 10-MINUTE RAINFALL ISOPLUVIALS

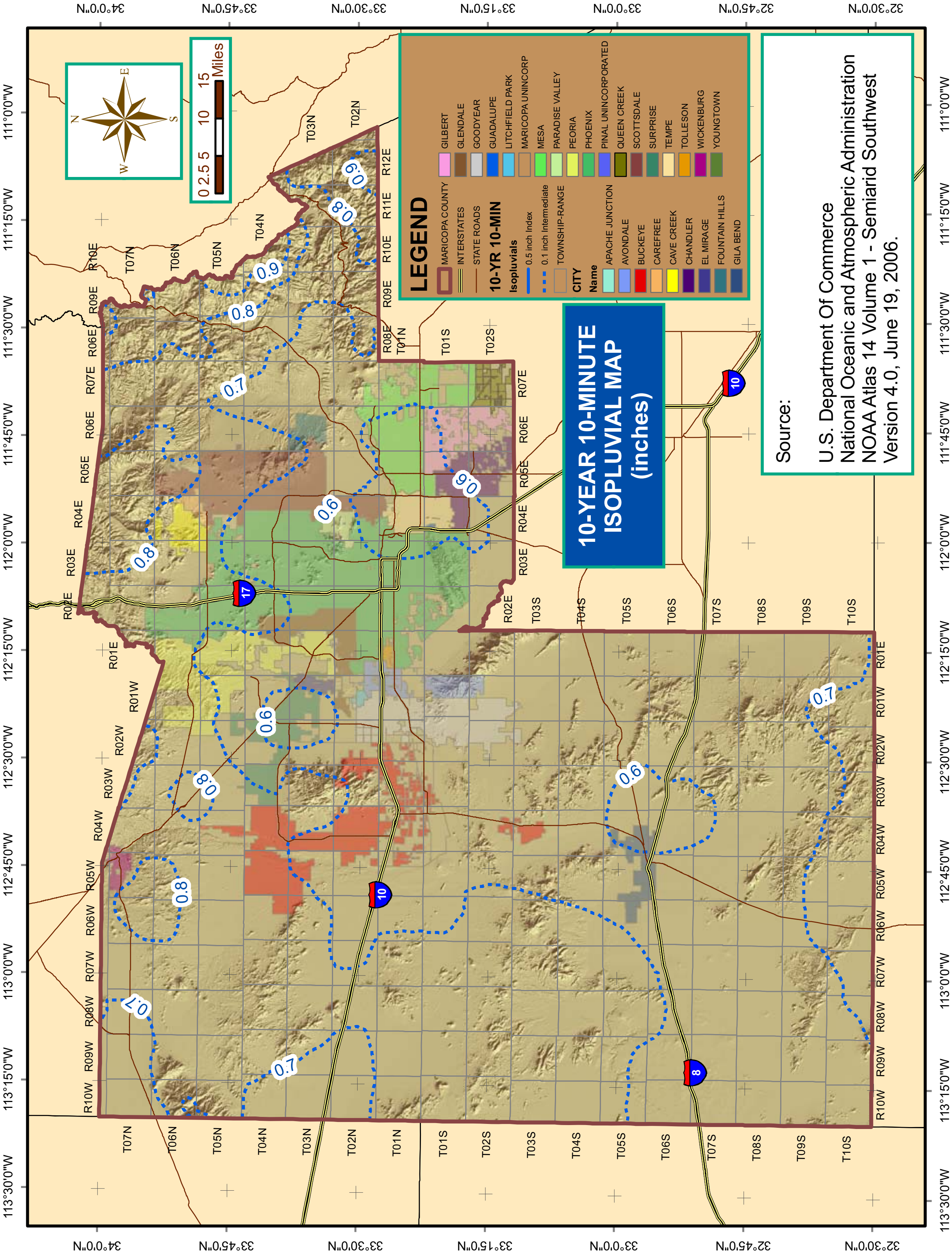


FIGURE A.23
10-YEAR 15-MINUTE RAINFALL ISOPLUVIALS

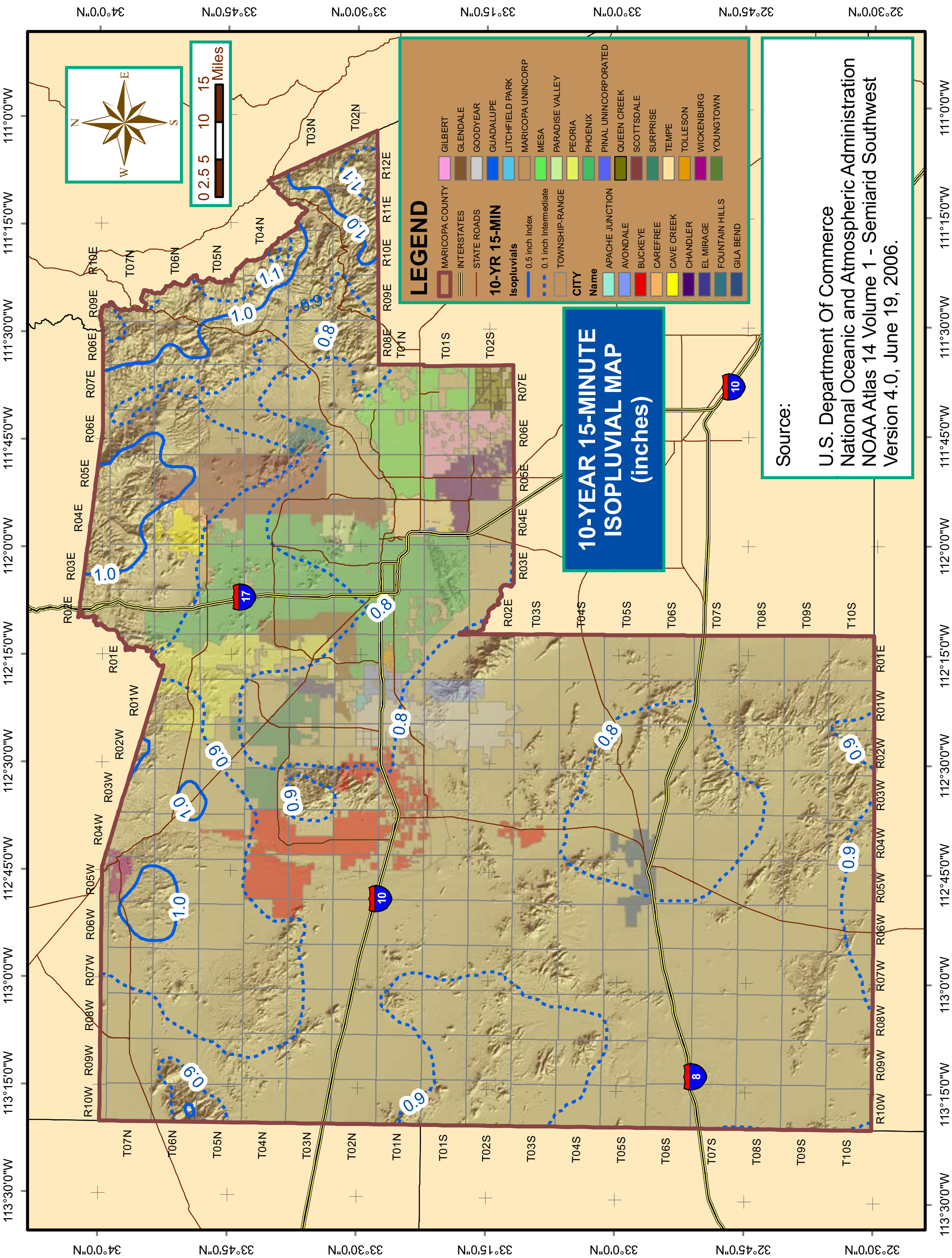


FIGURE A.24
10-YEAR 30-MINUTE RAINFALL ISOPLUVIALS

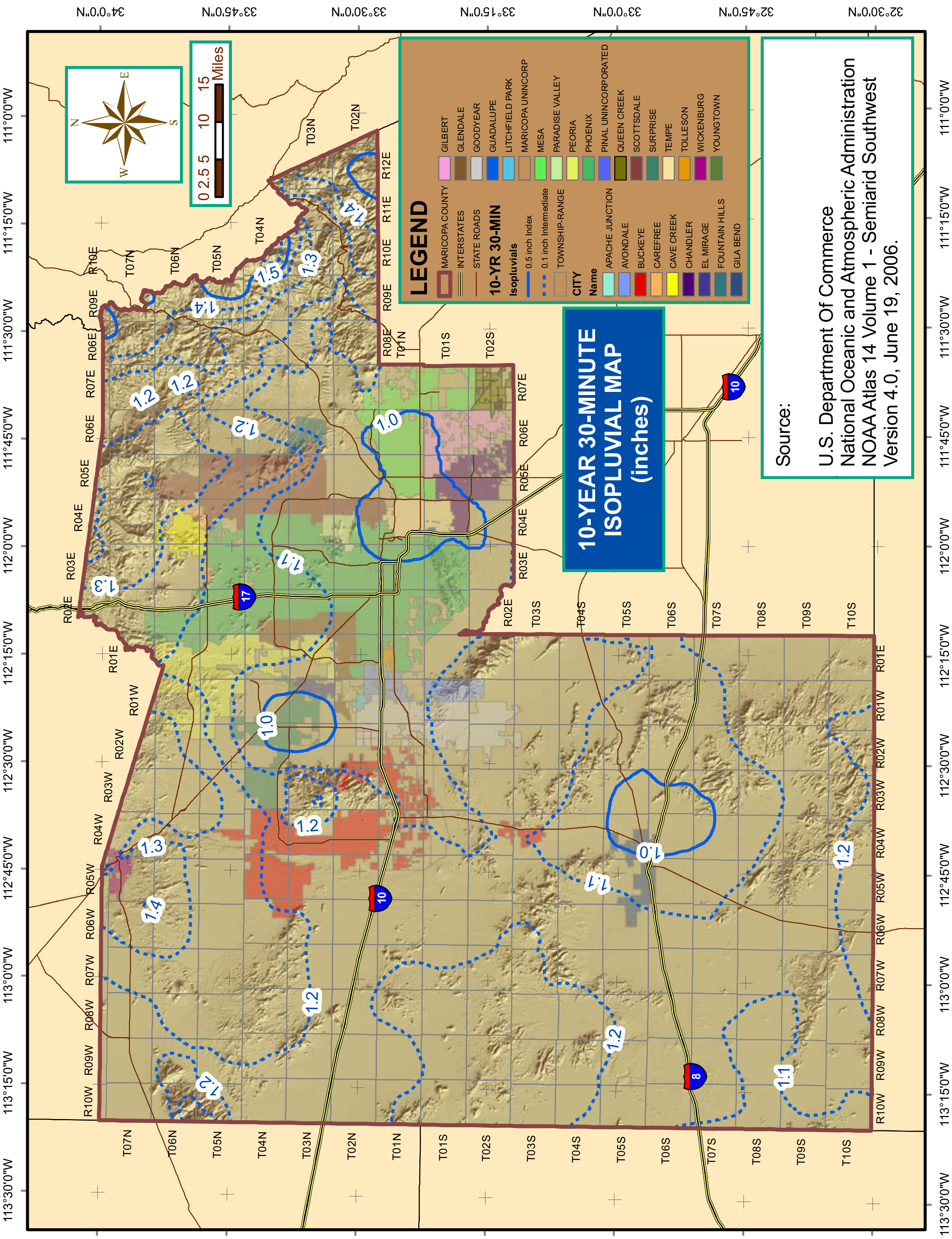


Figure A.25
10-year 1-hour Rainfall Isopluvials

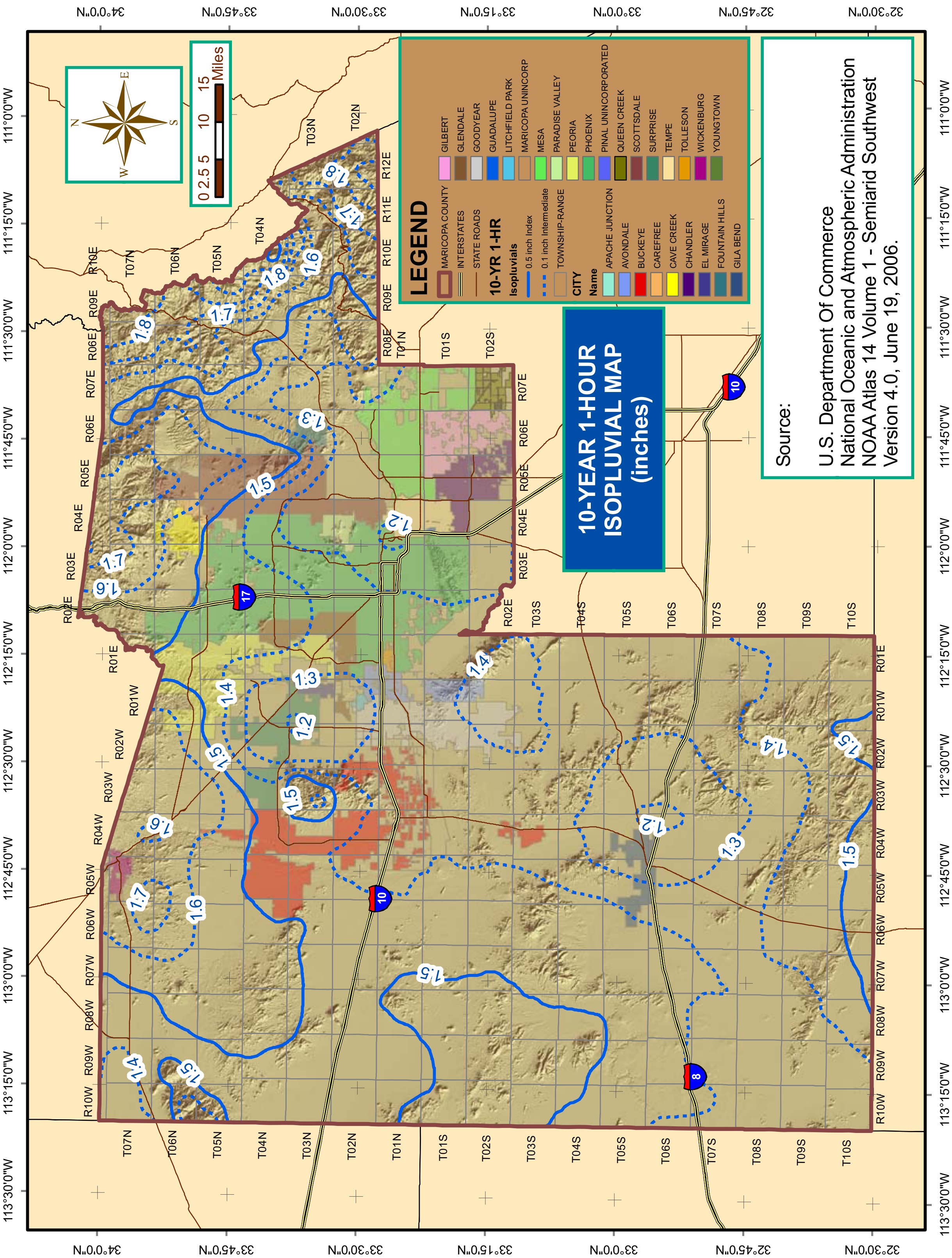


Figure A.26
10-year 2-hour Rainfall Isopluvials

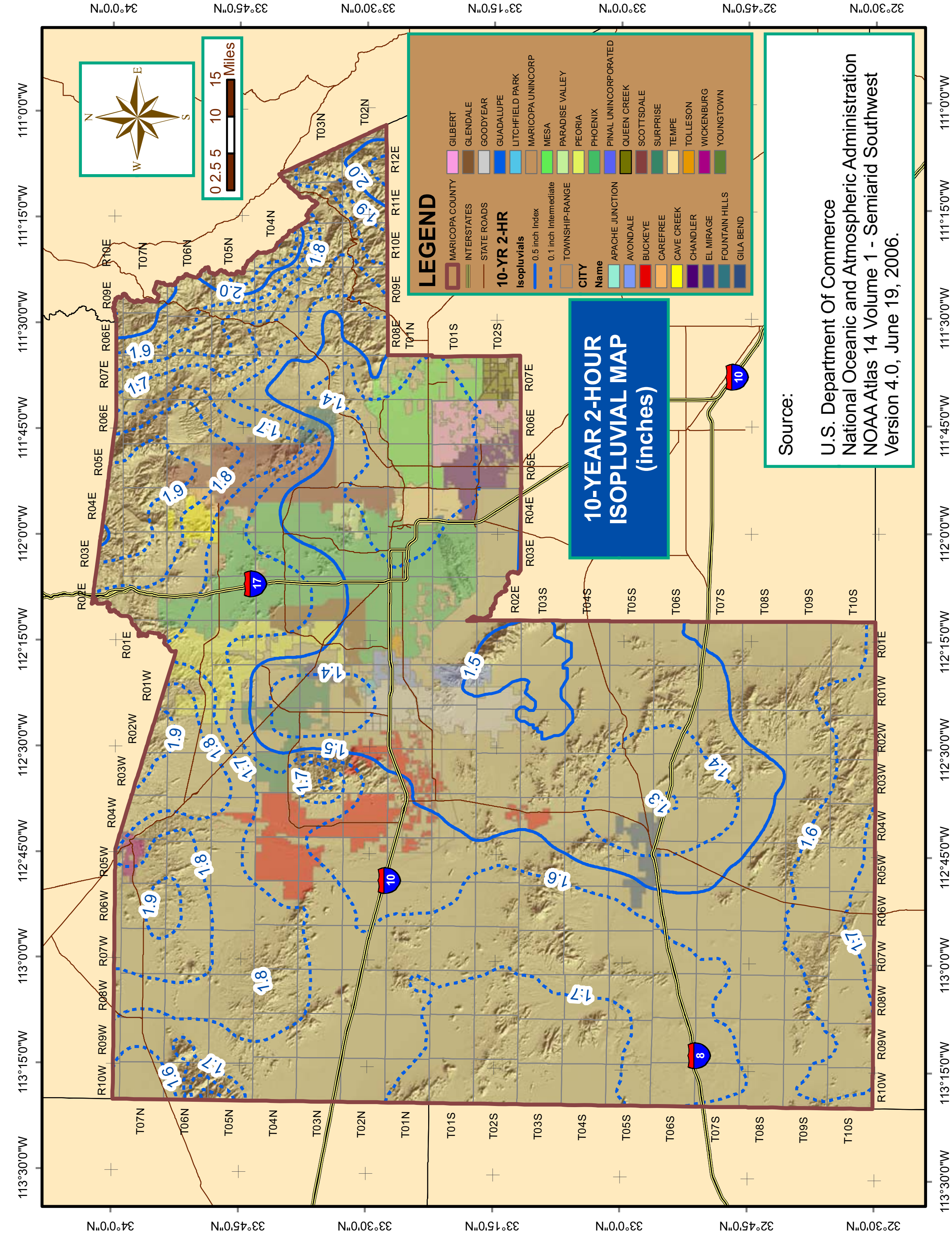


FIGURE A.27
10-YEAR 3-HOUR RAINFALL ISOPLUVIALS

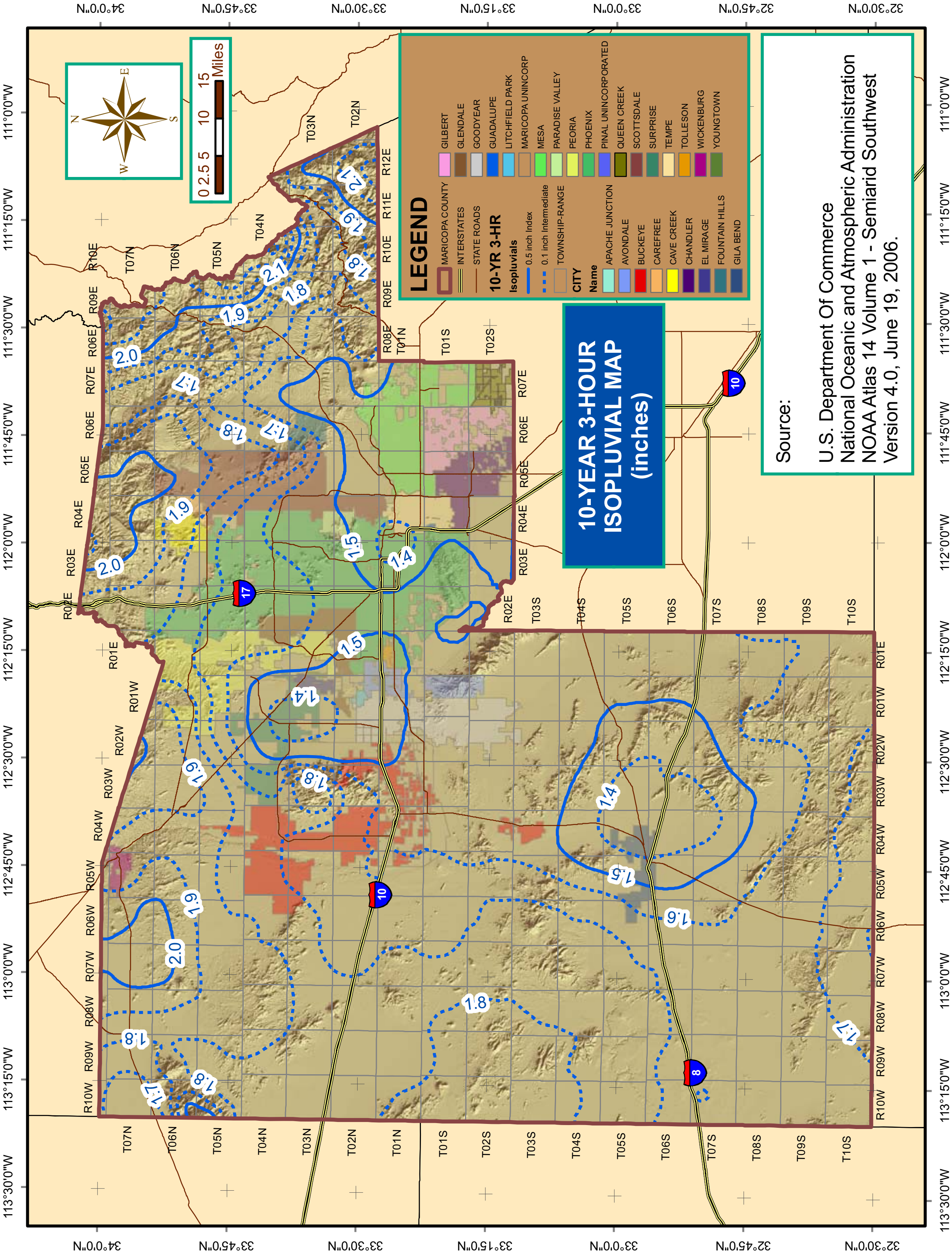


FIGURE A.28
10-YEAR 6-HOUR RAINFALL ISOPLUVIALS

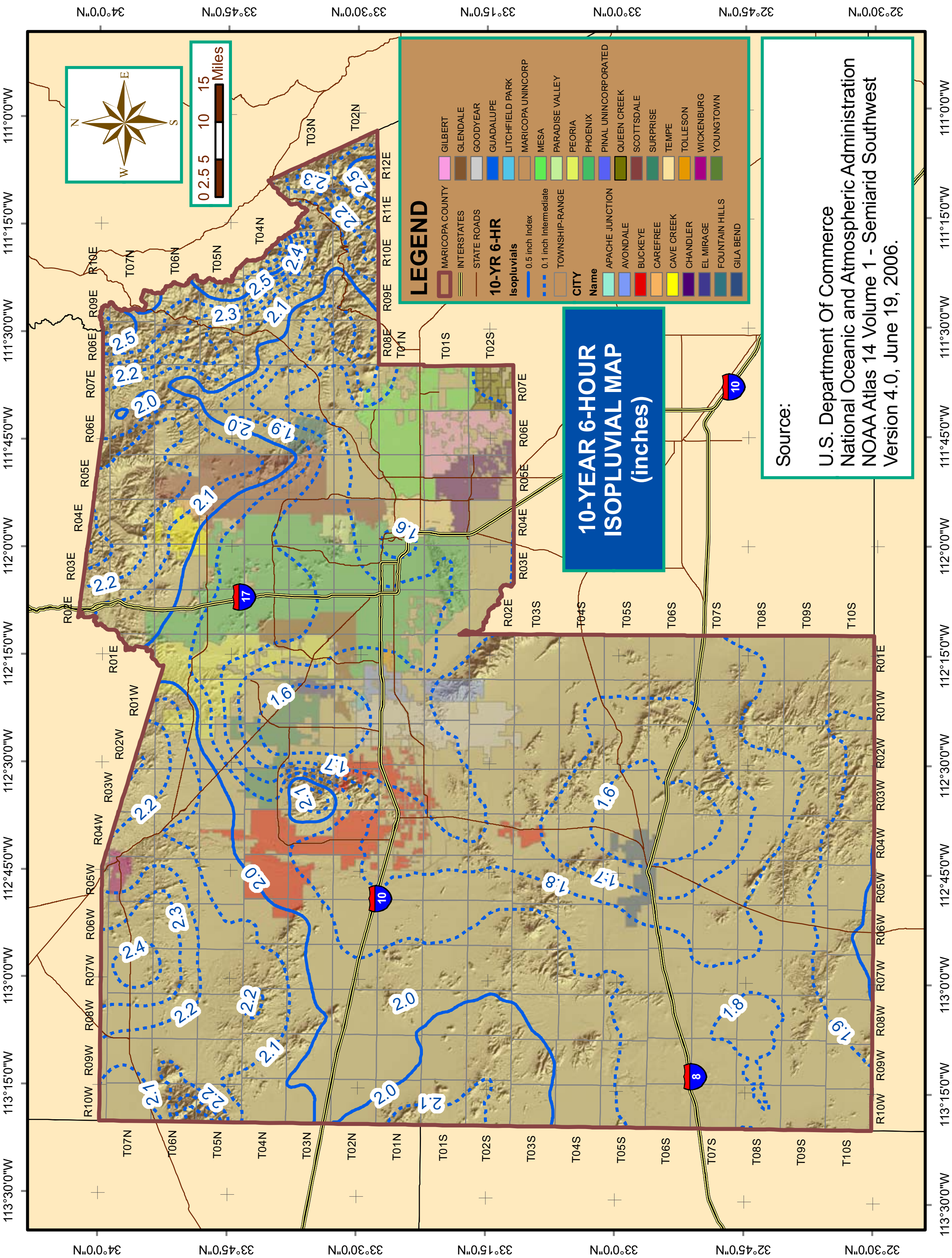


Figure A.29
10-year 12-hour Rainfall Isopluvials

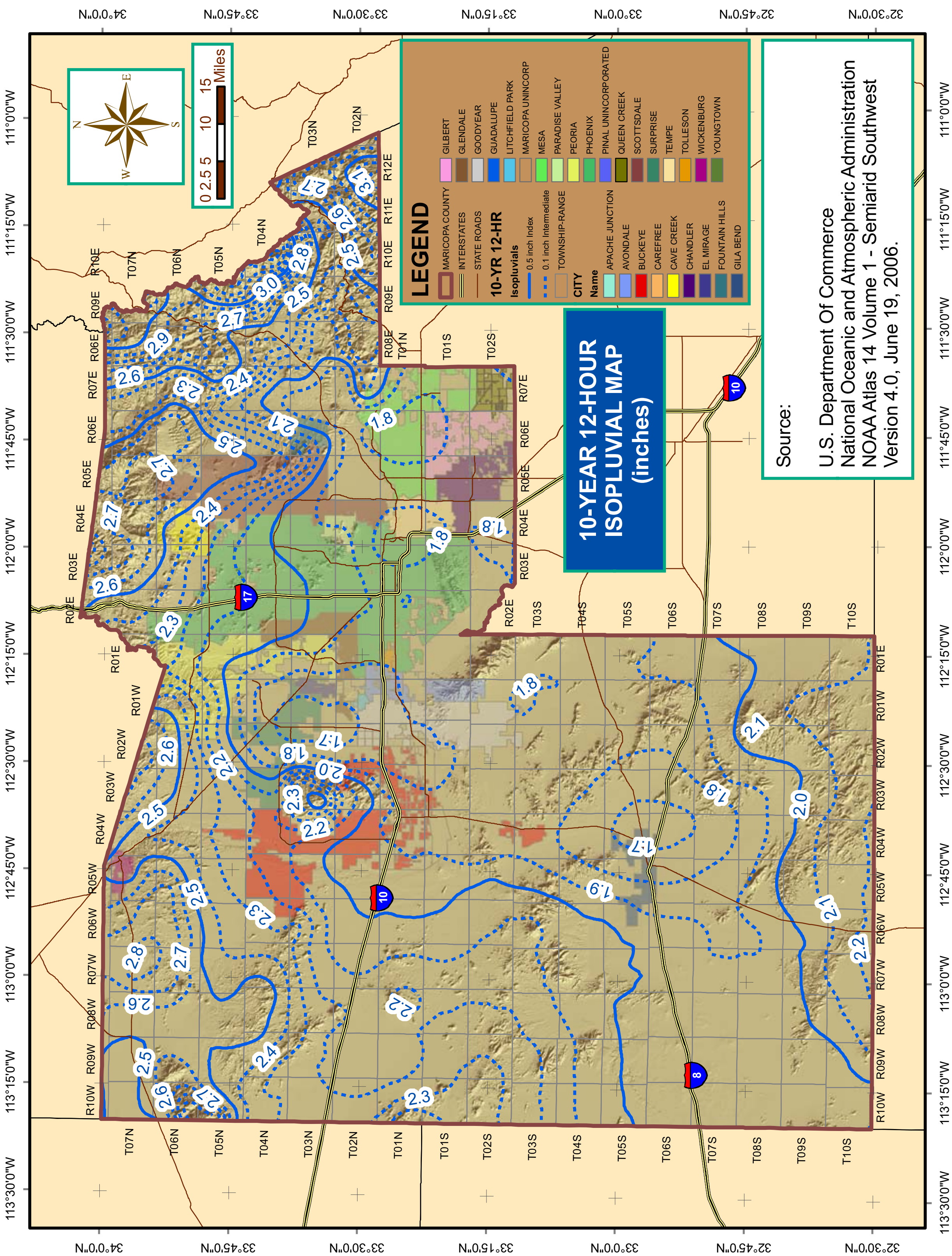


FIGURE A.30
10-YEAR 24-HOUR RAINFALL ISOPLUVIALS

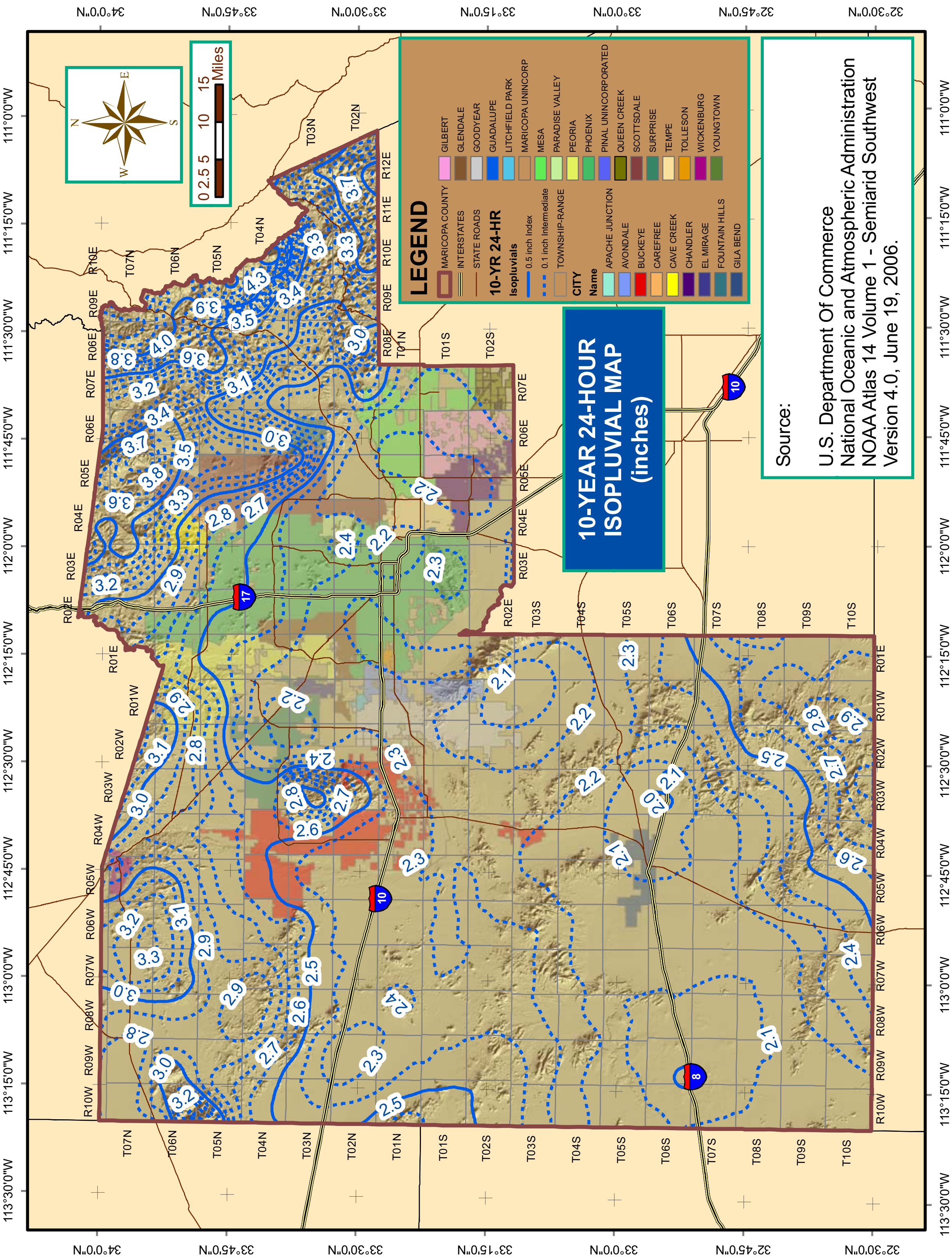


FIGURE A.31
25-YEAR 5-MINUTE RAINFALL ISOPLUVIALS

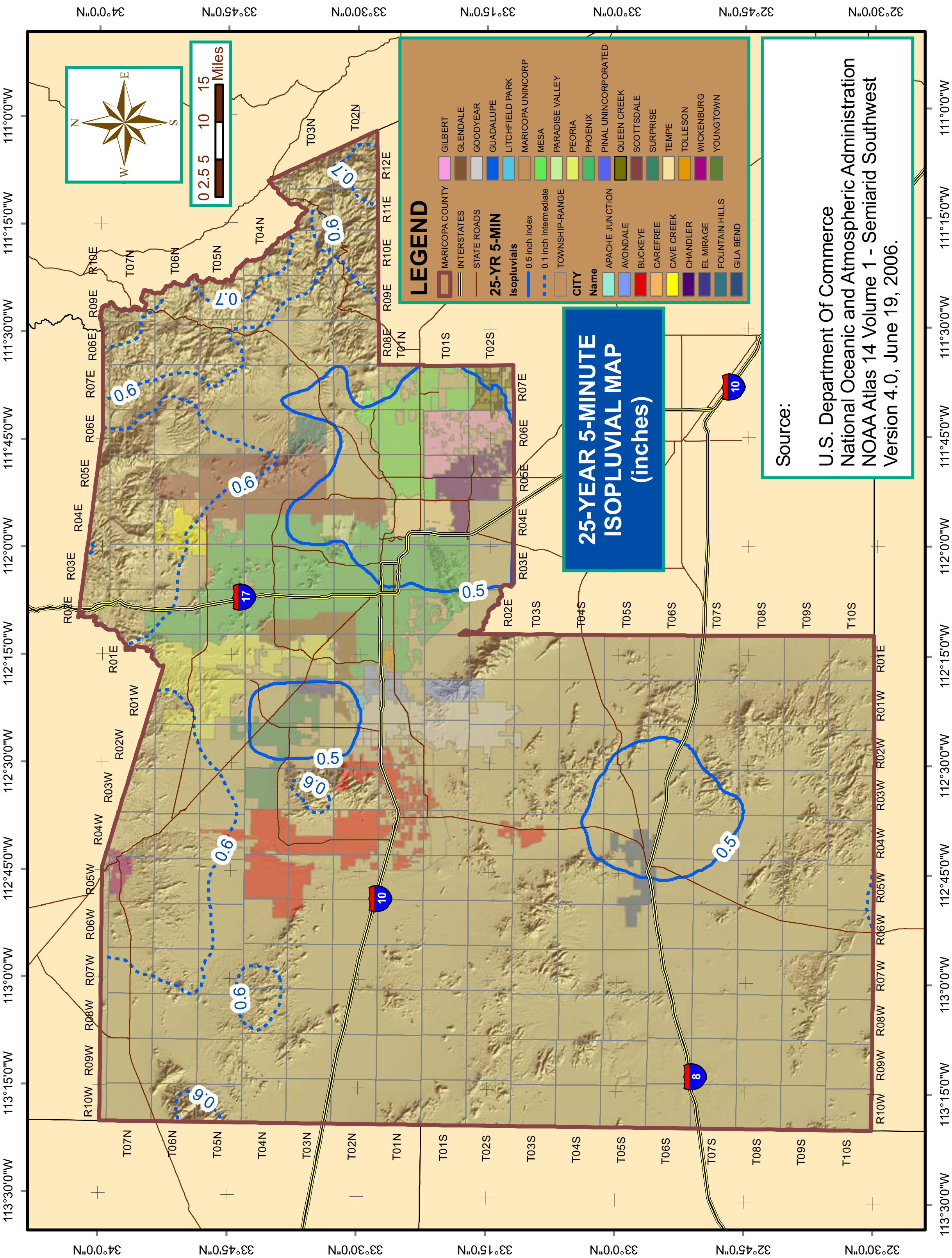


FIGURE A.32
25-YEAR 10-MINUTE RAINFALL ISOPLUVIALS

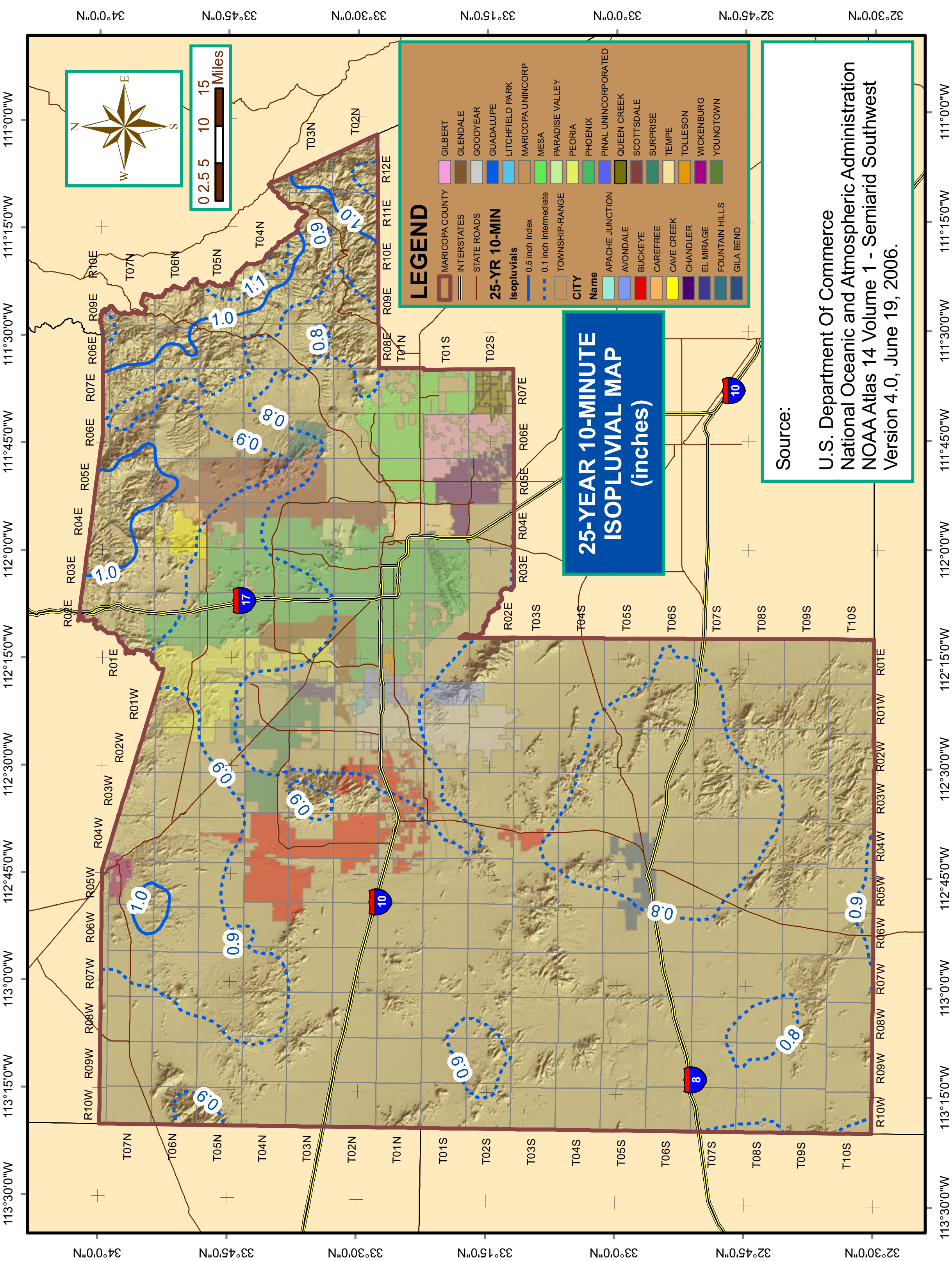


FIGURE A.33
25-YEAR 15-MINUTE RAINFALL ISOPLUVIALS

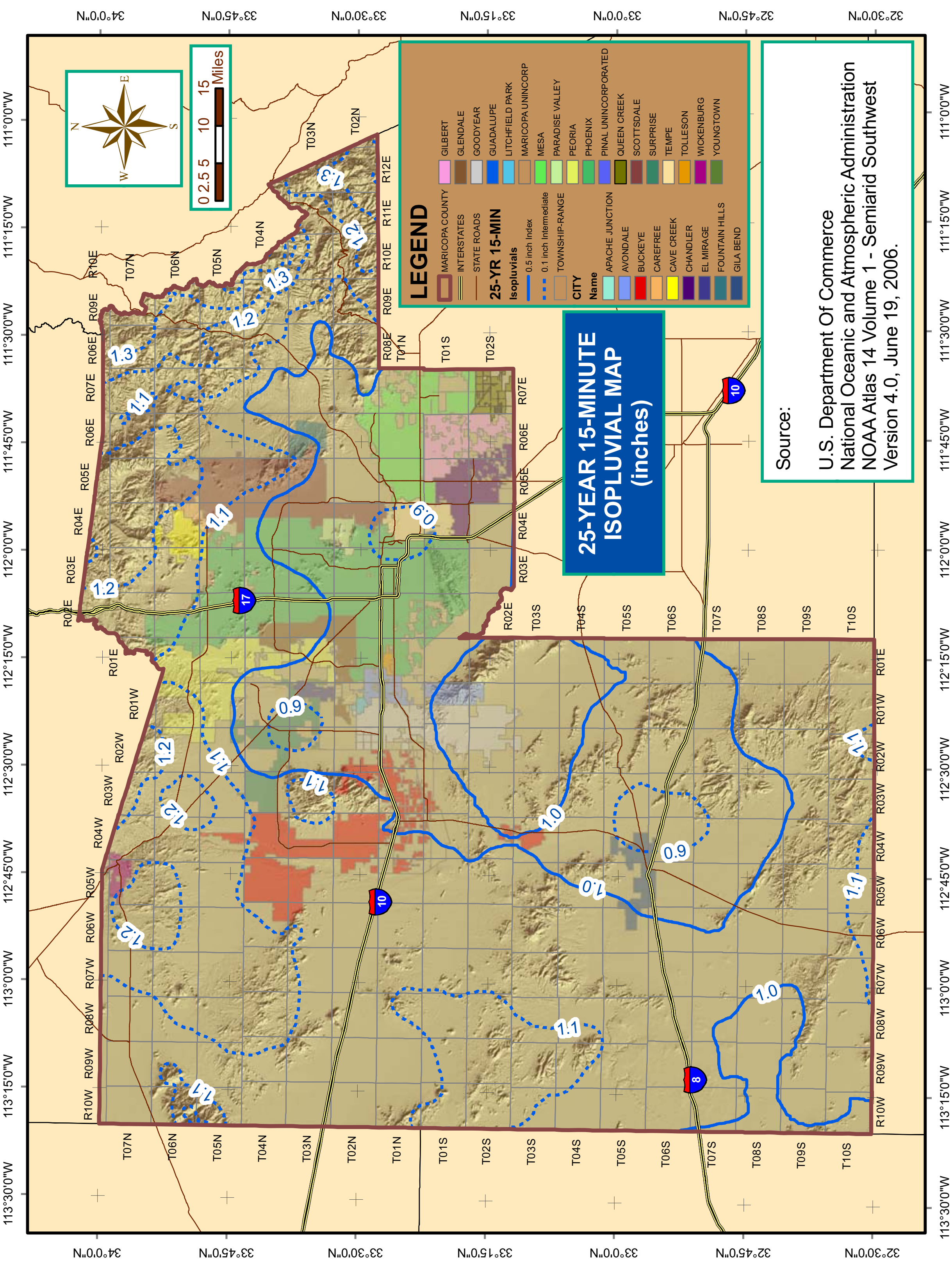


FIGURE A.34
25-YEAR 30-MINUTE RAINFALL ISOPLUVIALS

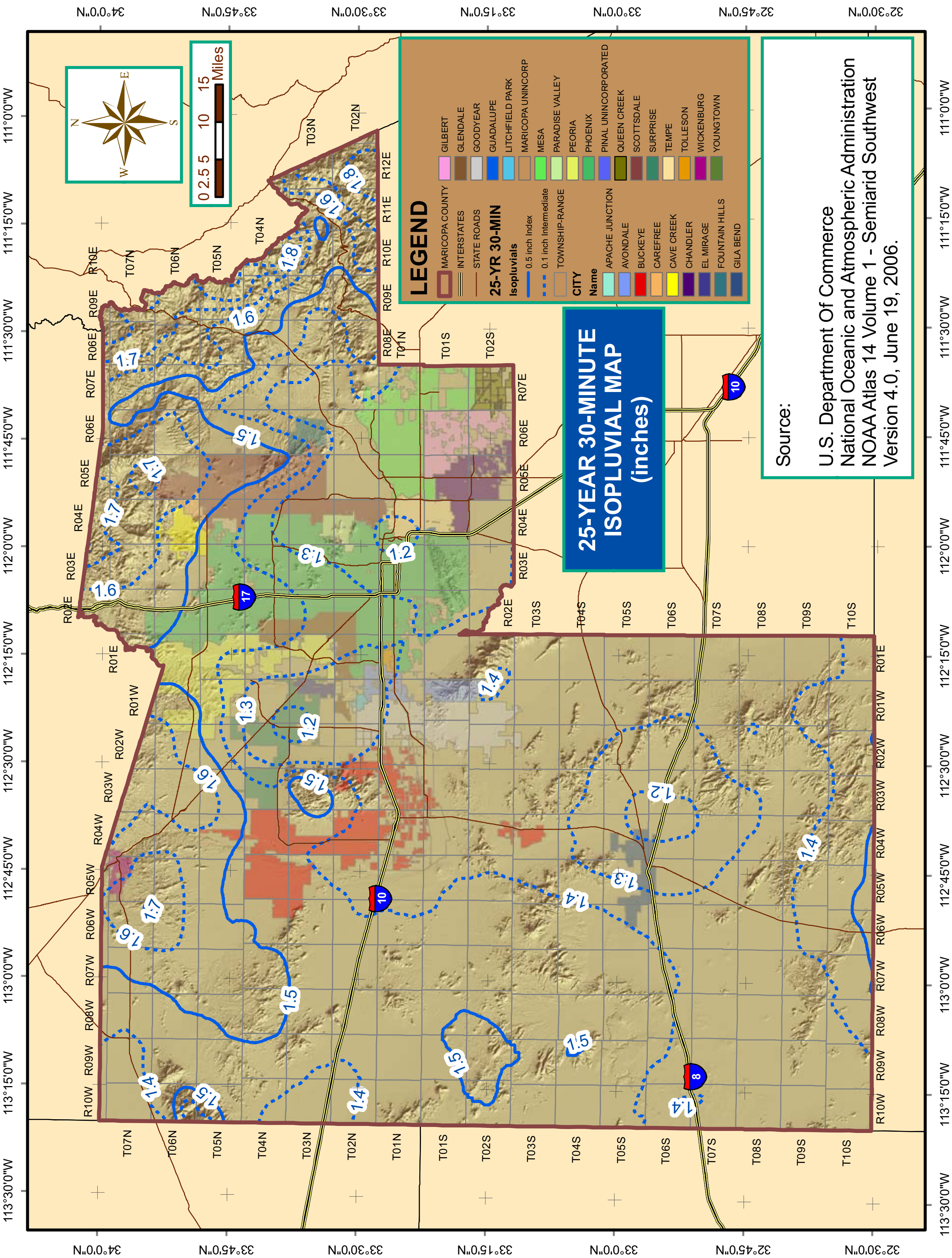


FIGURE A.35
25-YEAR 1-HOUR RAINFALL ISOPLUVIALS

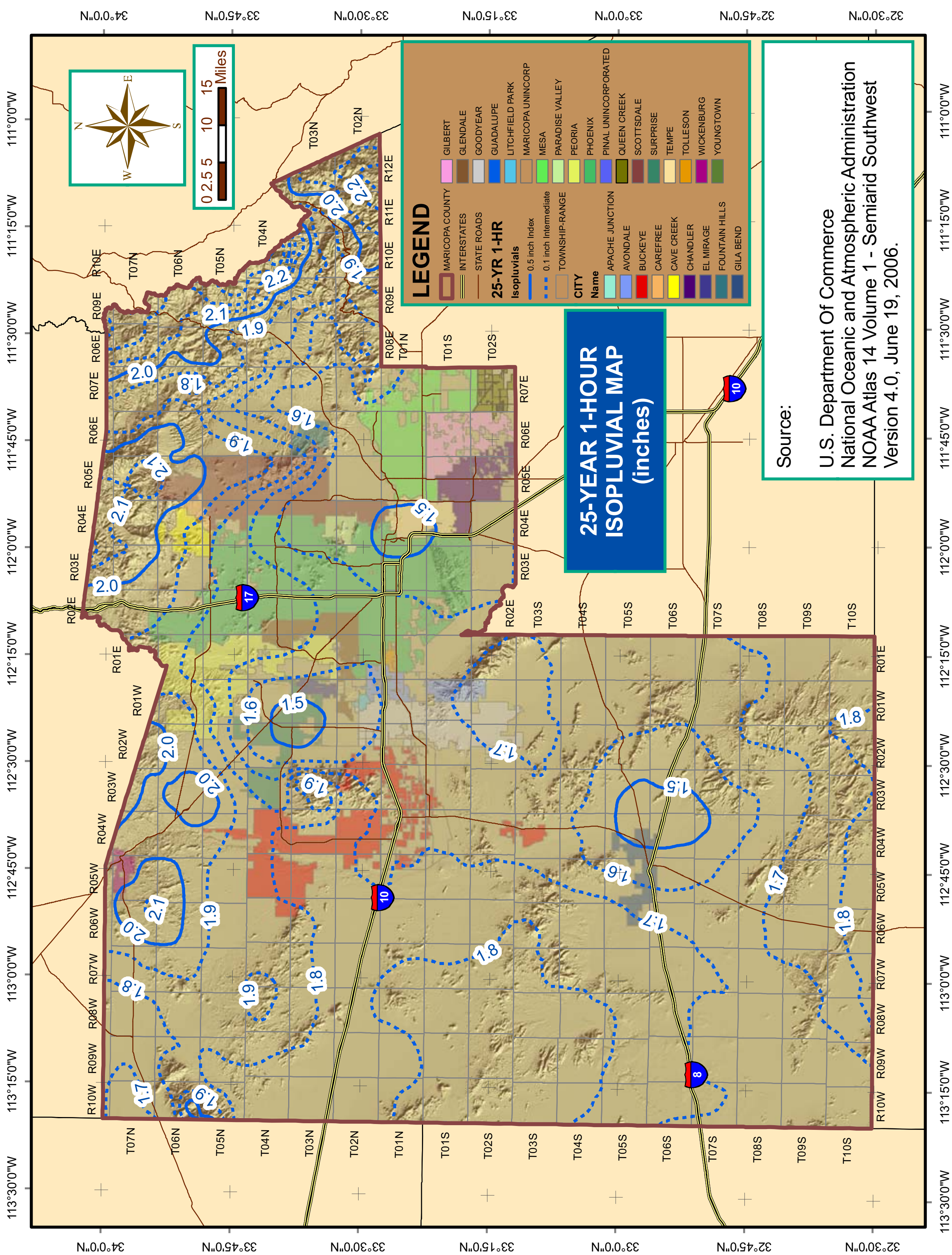


FIGURE A.36
25-YEAR 2-HOUR RAINFALL ISOPLUVIALS

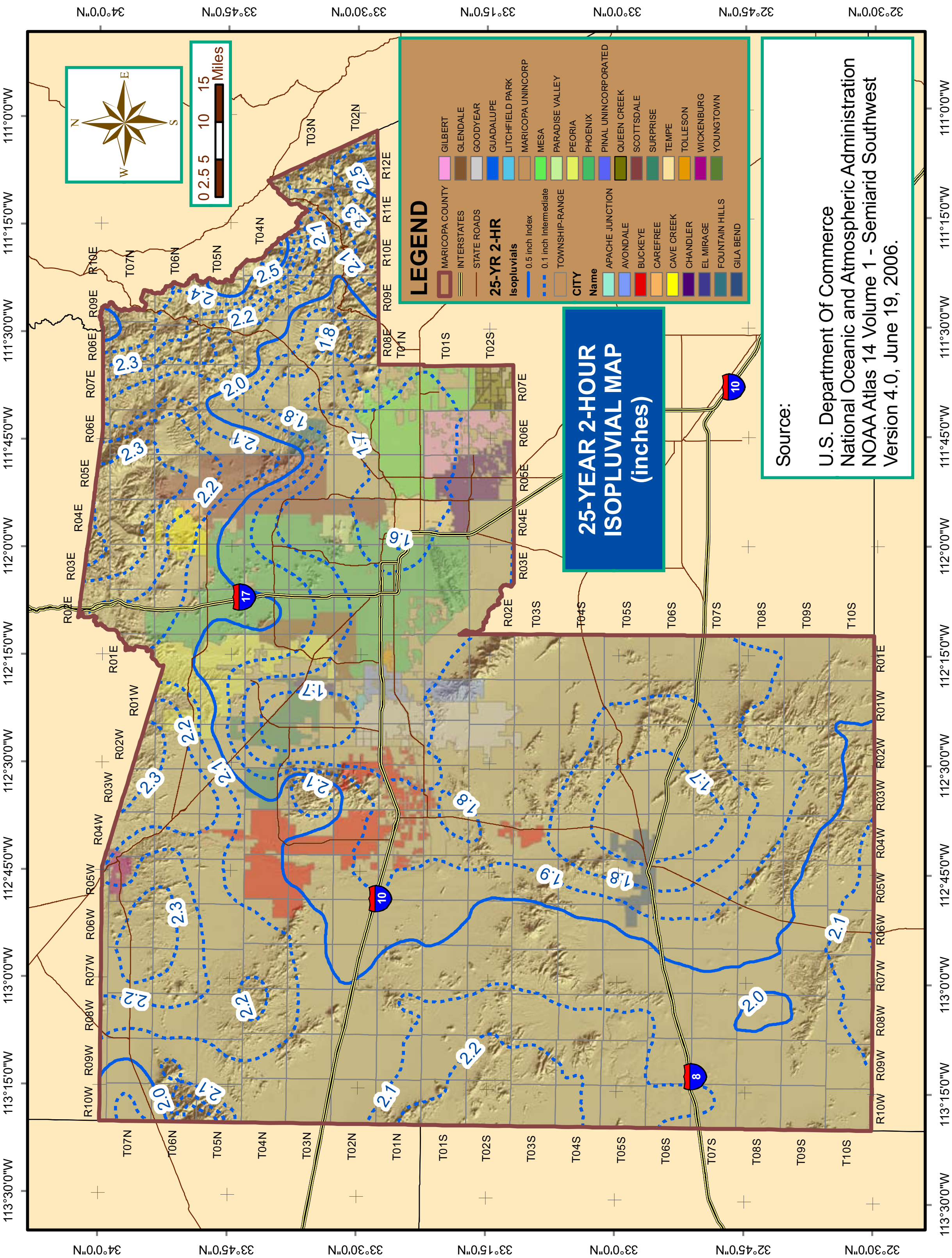


FIGURE A.37
25-YEAR 3-HOUR RAINFALL ISOPLUVIALS

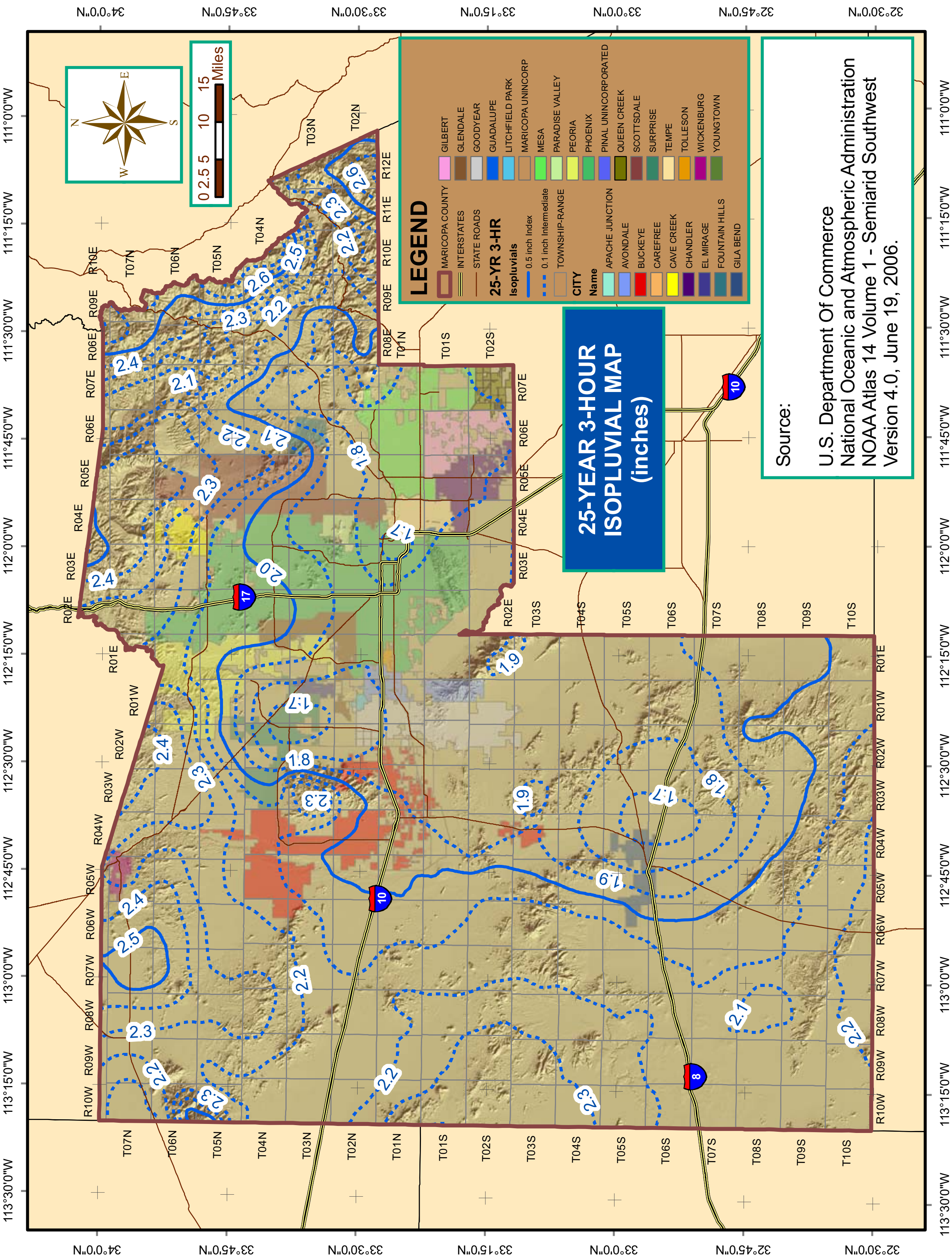


FIGURE A.38
25-YEAR 6-HOUR RAINFALL ISOPLUVIALS

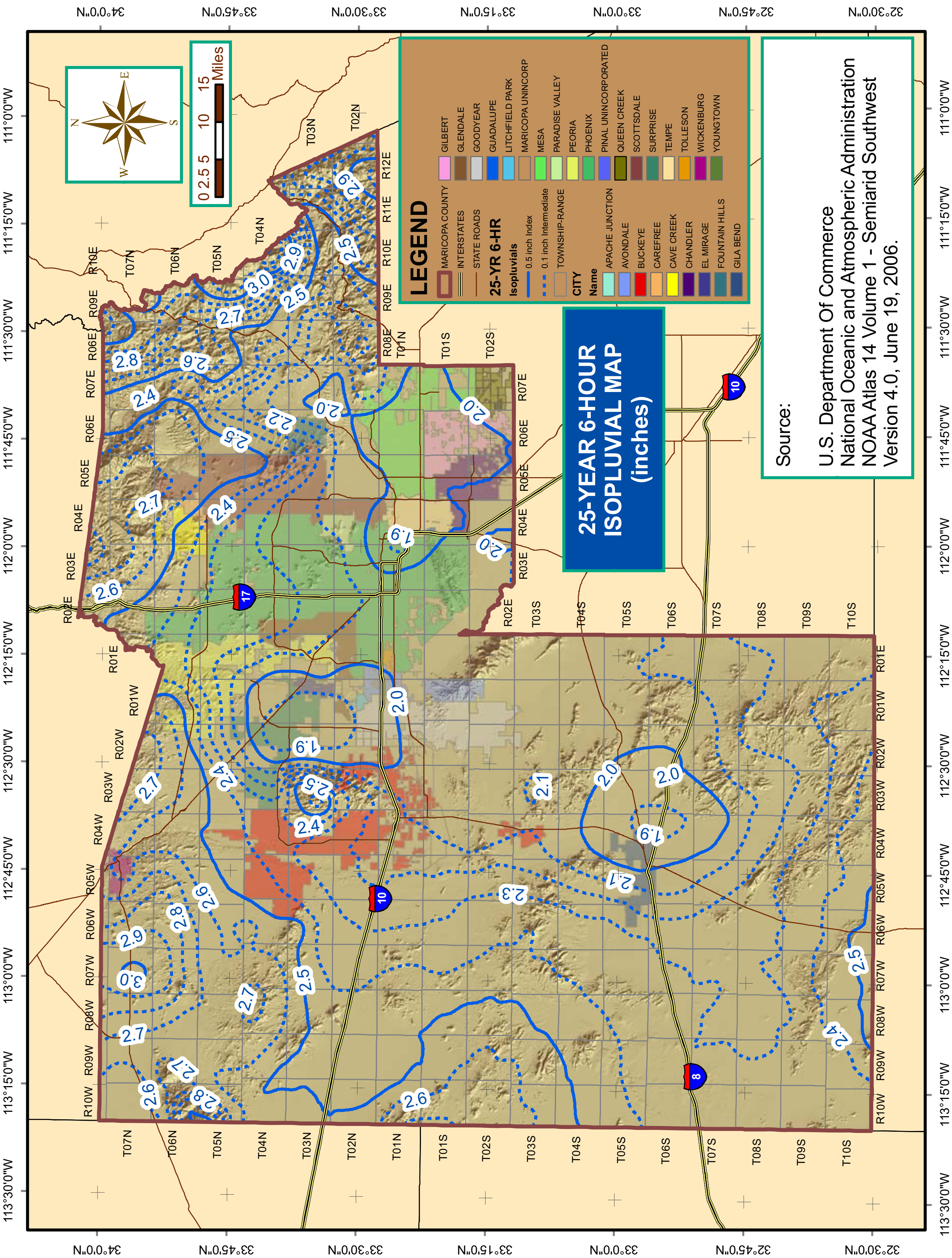


FIGURE A.39
25-YEAR 12-HOUR RAINFALL ISOPLUVIALS

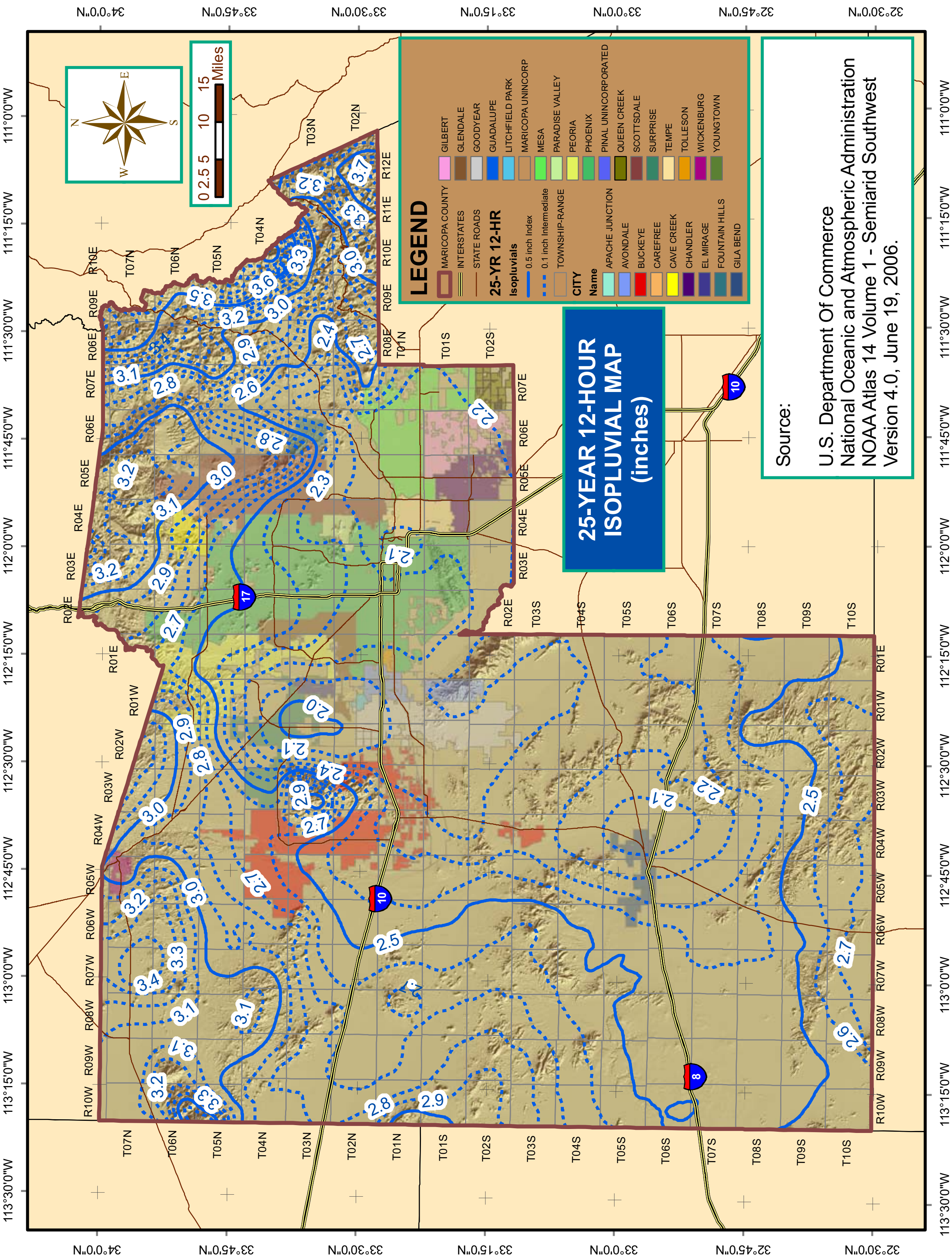


FIGURE A.40
25-YEAR 24-HOUR RAINFALL ISOPLUVIALS

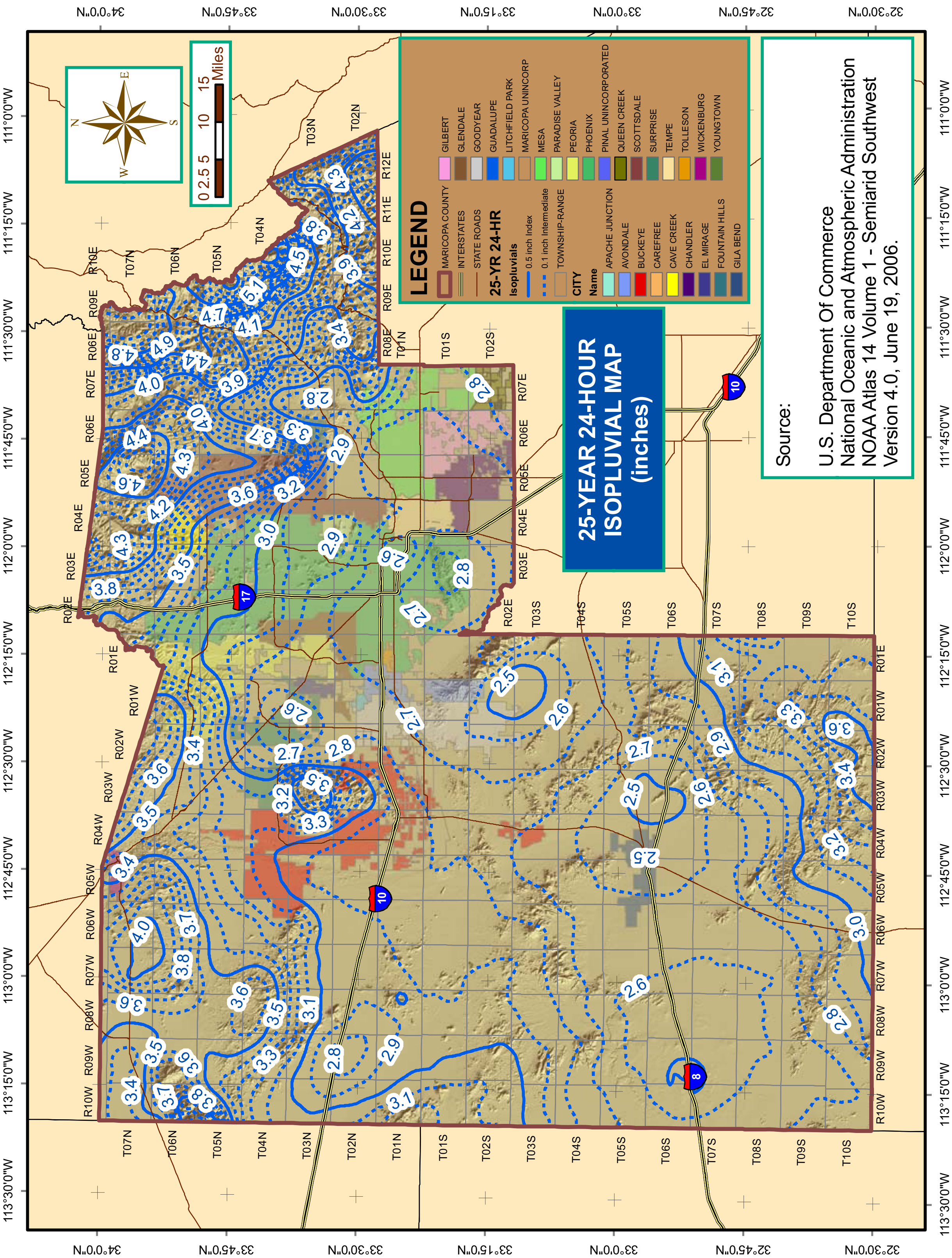


Figure A.41
50-year 5-minute rainfall Isopluvials

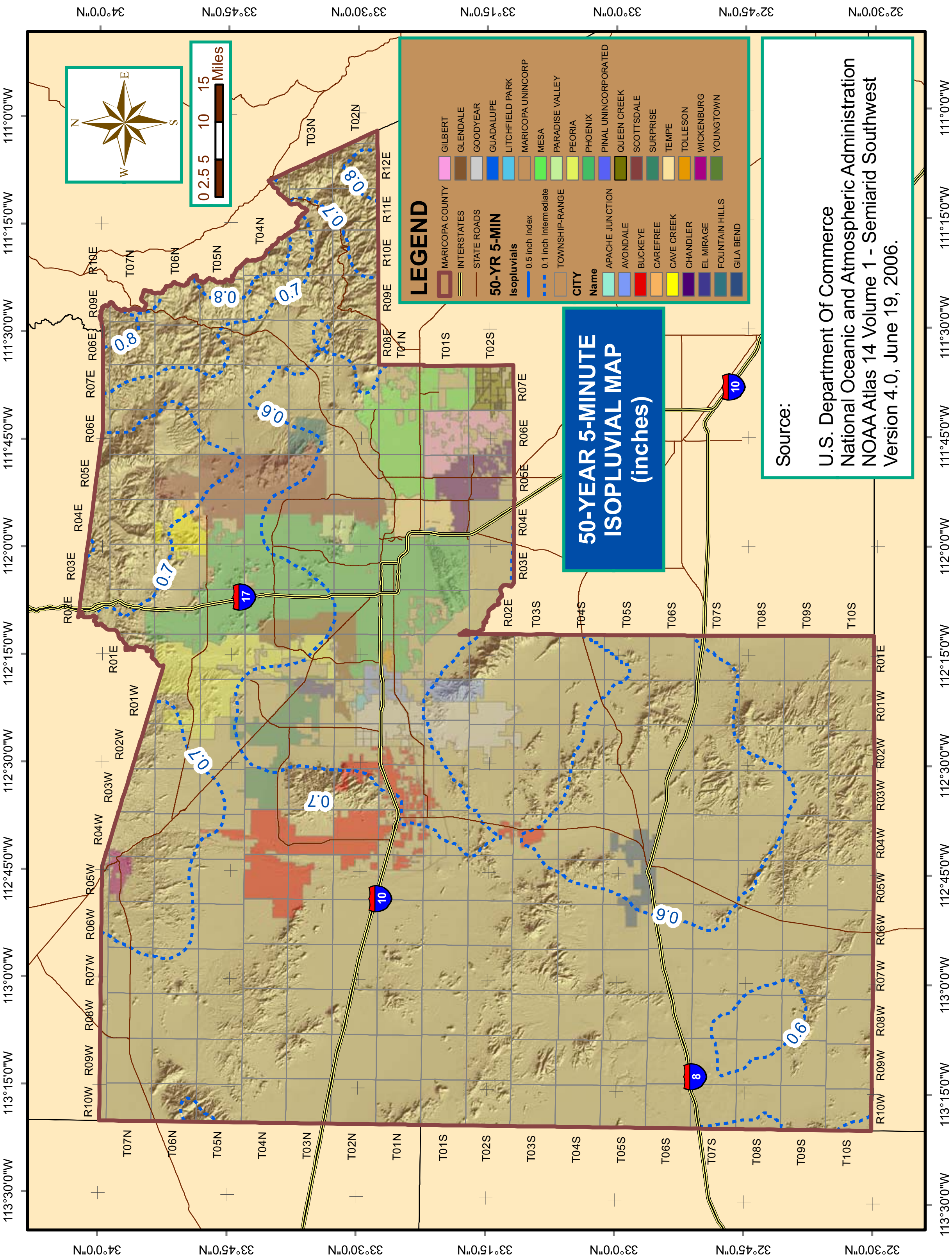


FIGURE A.42
50-YEAR 10-MINUTE RAINFALL ISOPLUVIALS

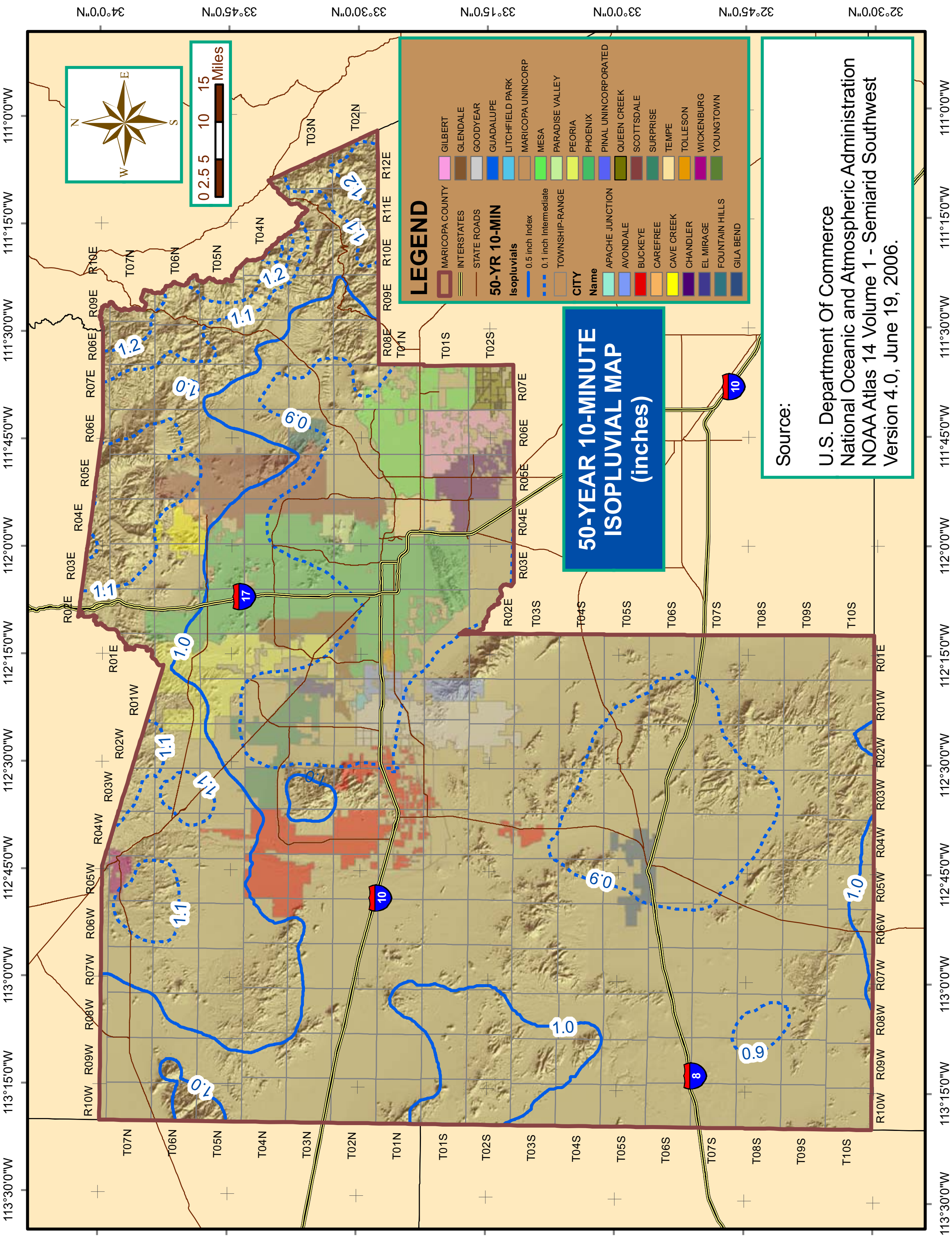


Figure A.43
50-year 15-minute Rainfall Isopluvials

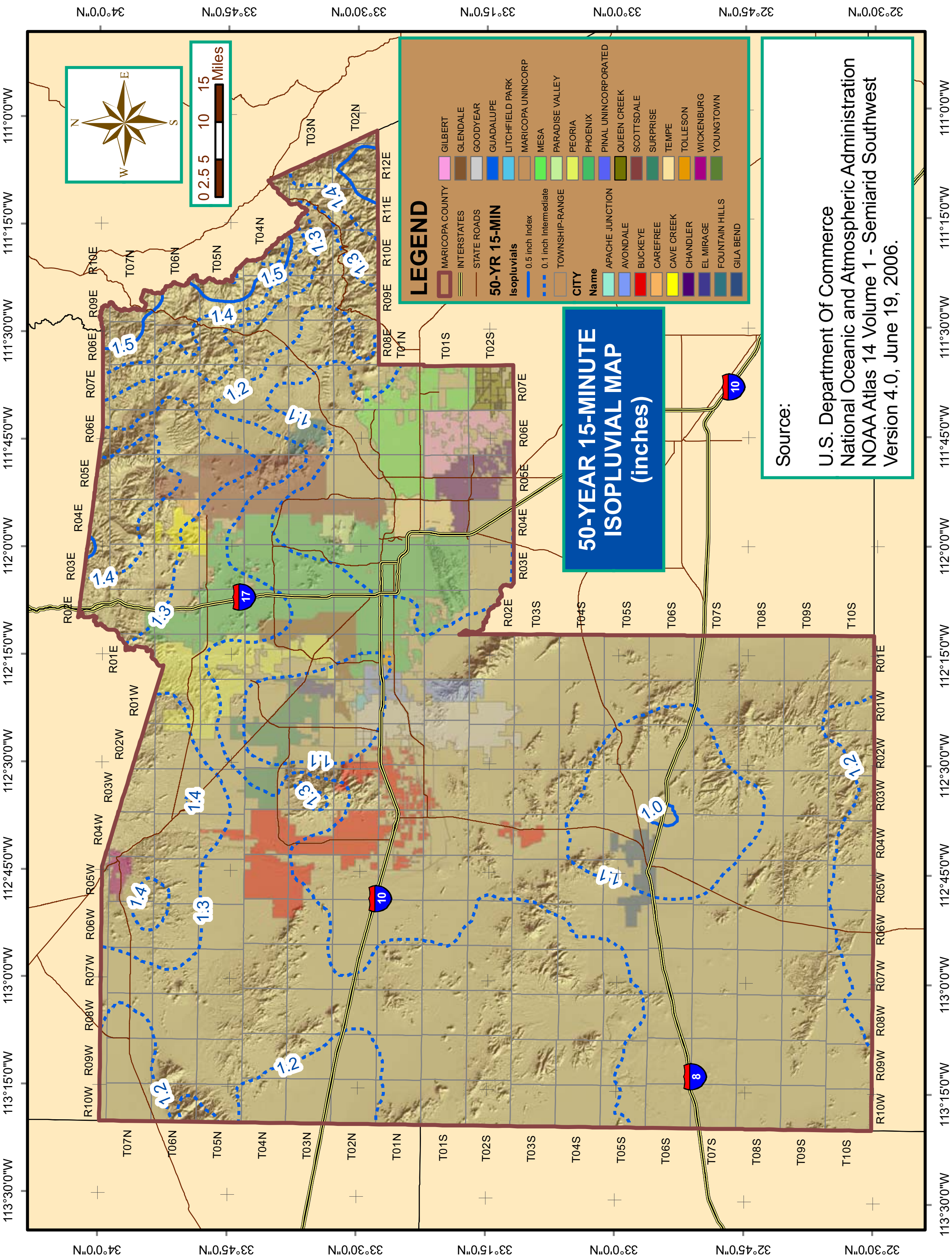


FIGURE A.44
50-YEAR 30-MINUTE RAINFALL ISOPLUVIALS

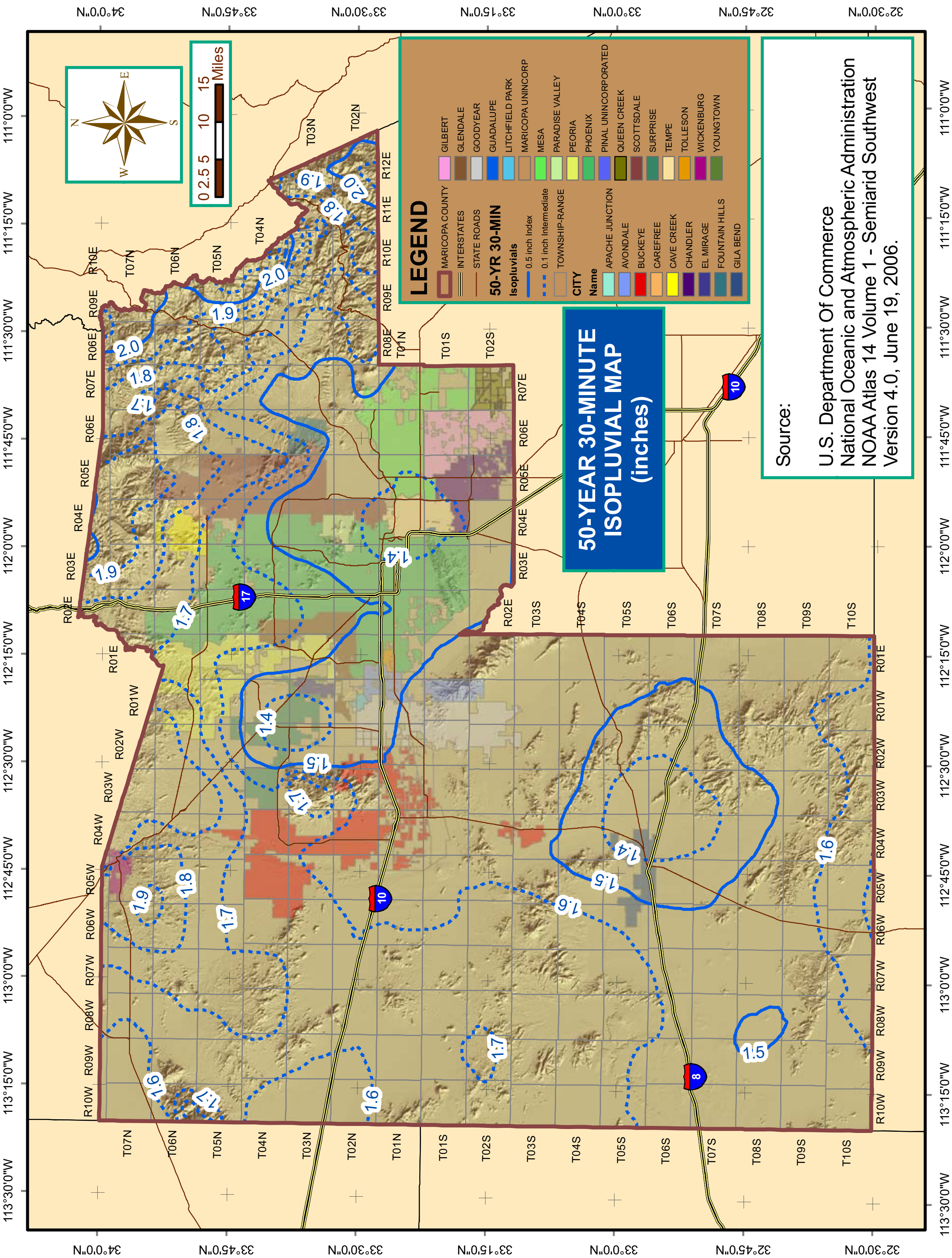


FIGURE A.45
50-YEAR 1-HOUR RAINFALL ISOPLUVIALS

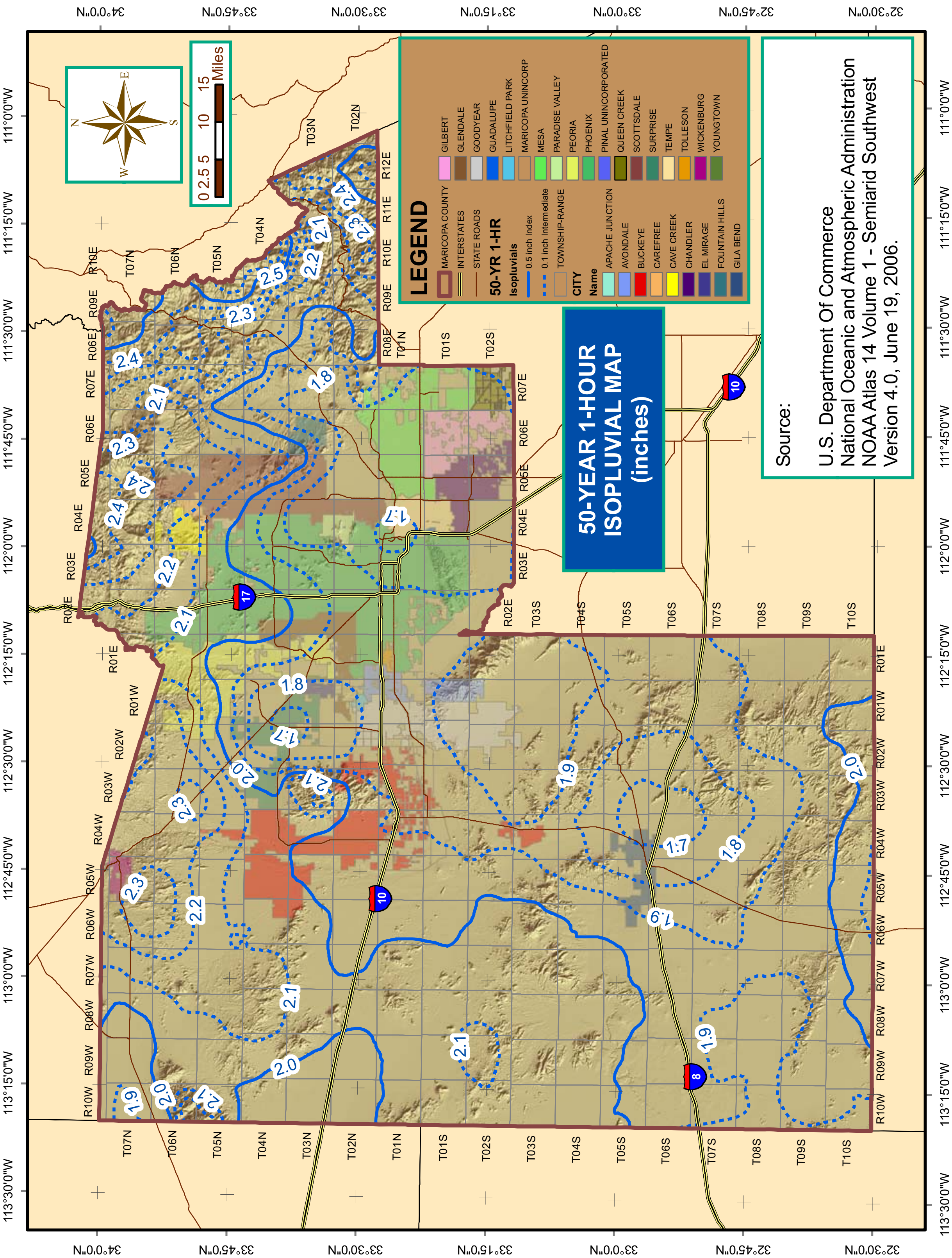


FIGURE A.46
50-YEAR 2-HOUR RAINFALL ISOPLUVIALS

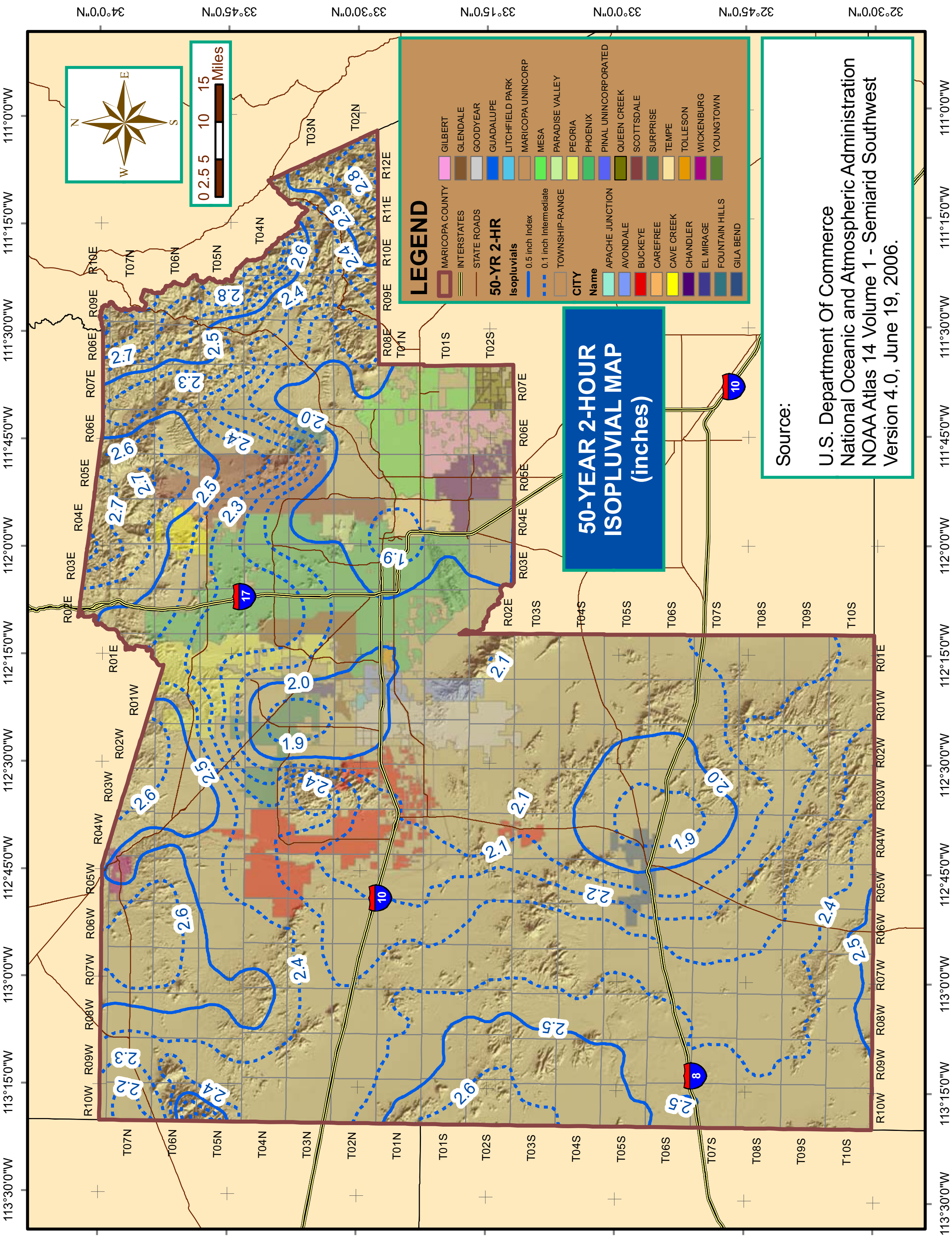


Figure A.47
50-year 3-hour Rainfall Isopluvials

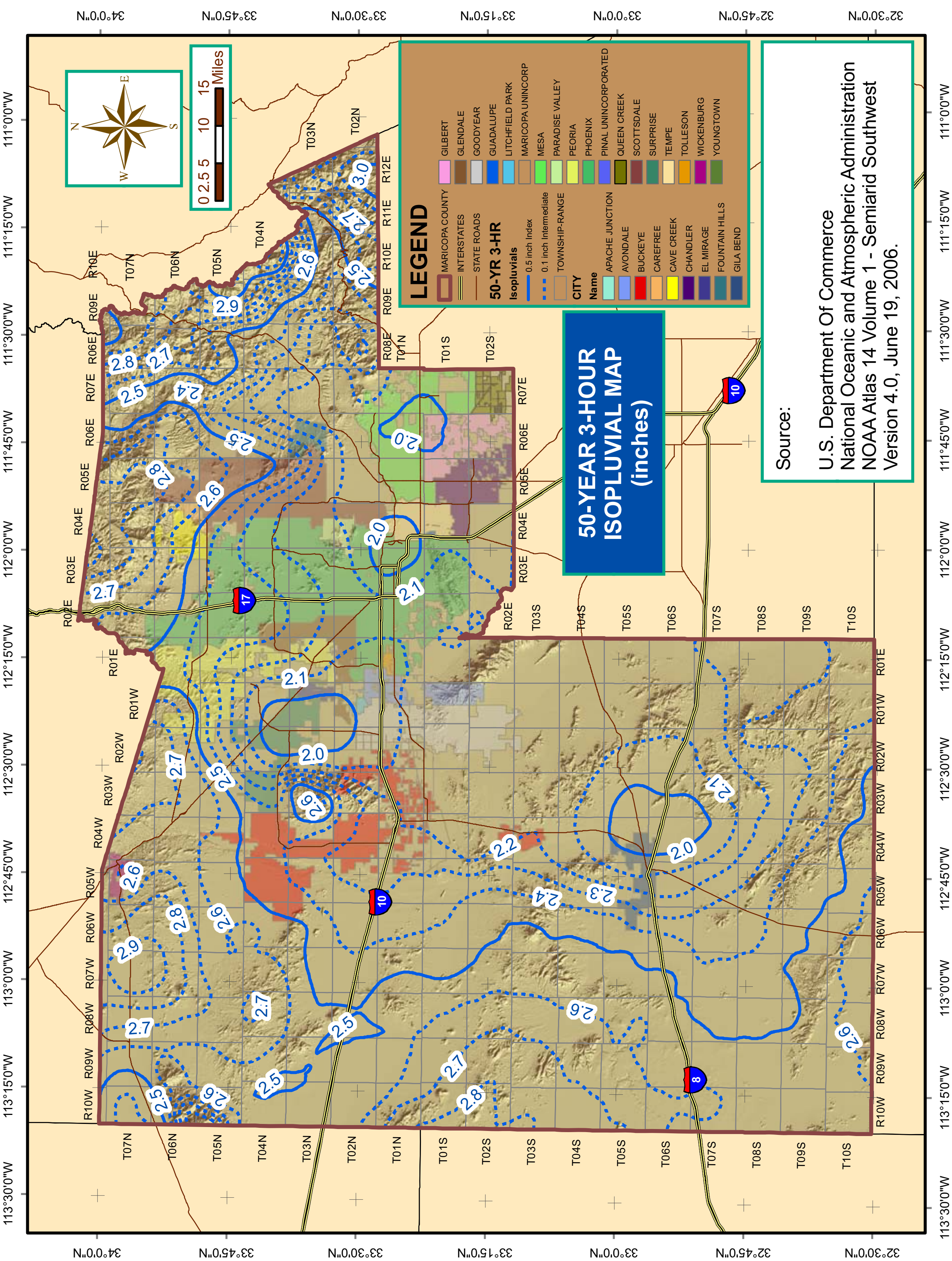


FIGURE A.48
50-YEAR 6-HOUR RAINFALL ISOPLUVIALS

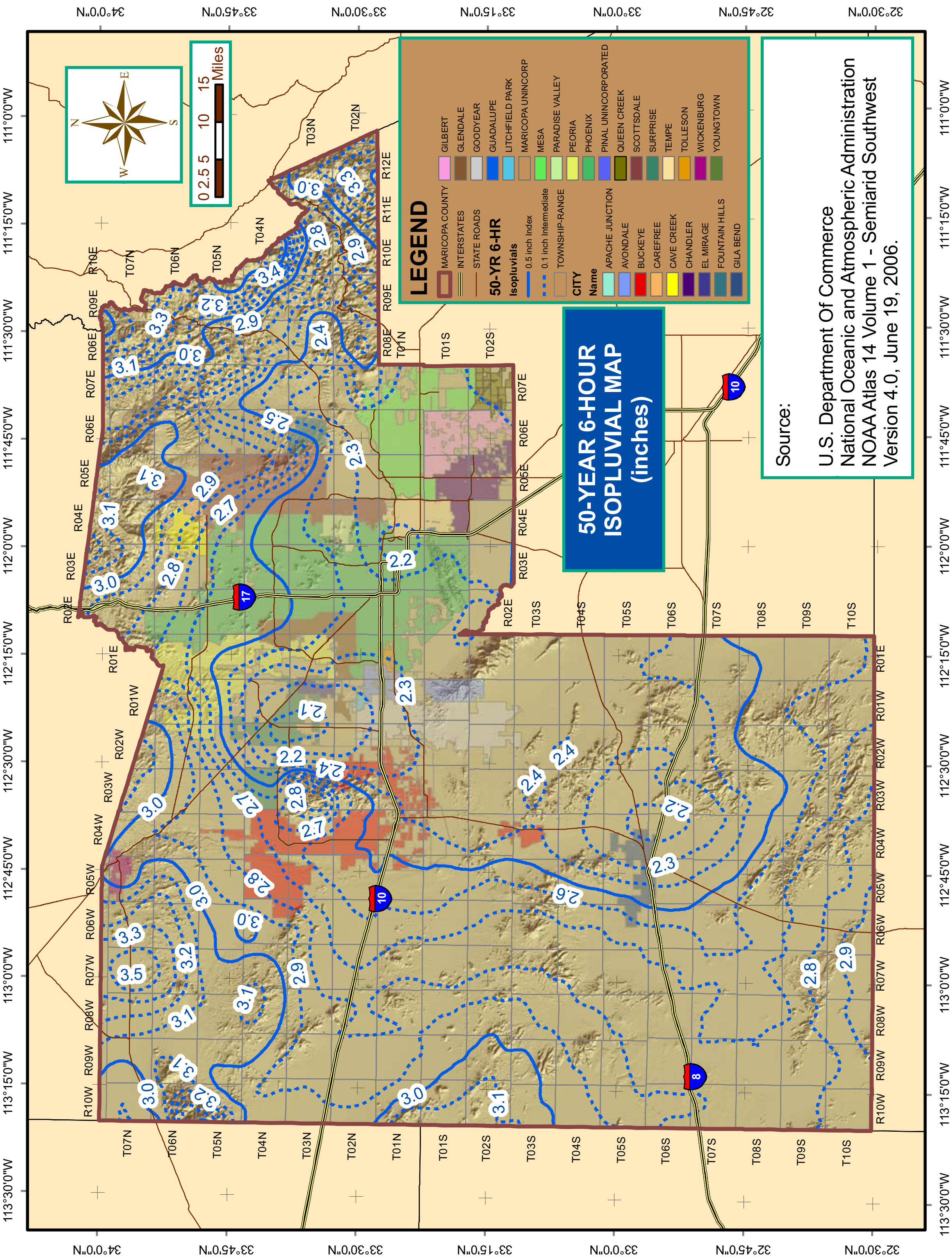


FIGURE A.49
50-YEAR 12-HOUR RAINFALL ISOPLUVIALS

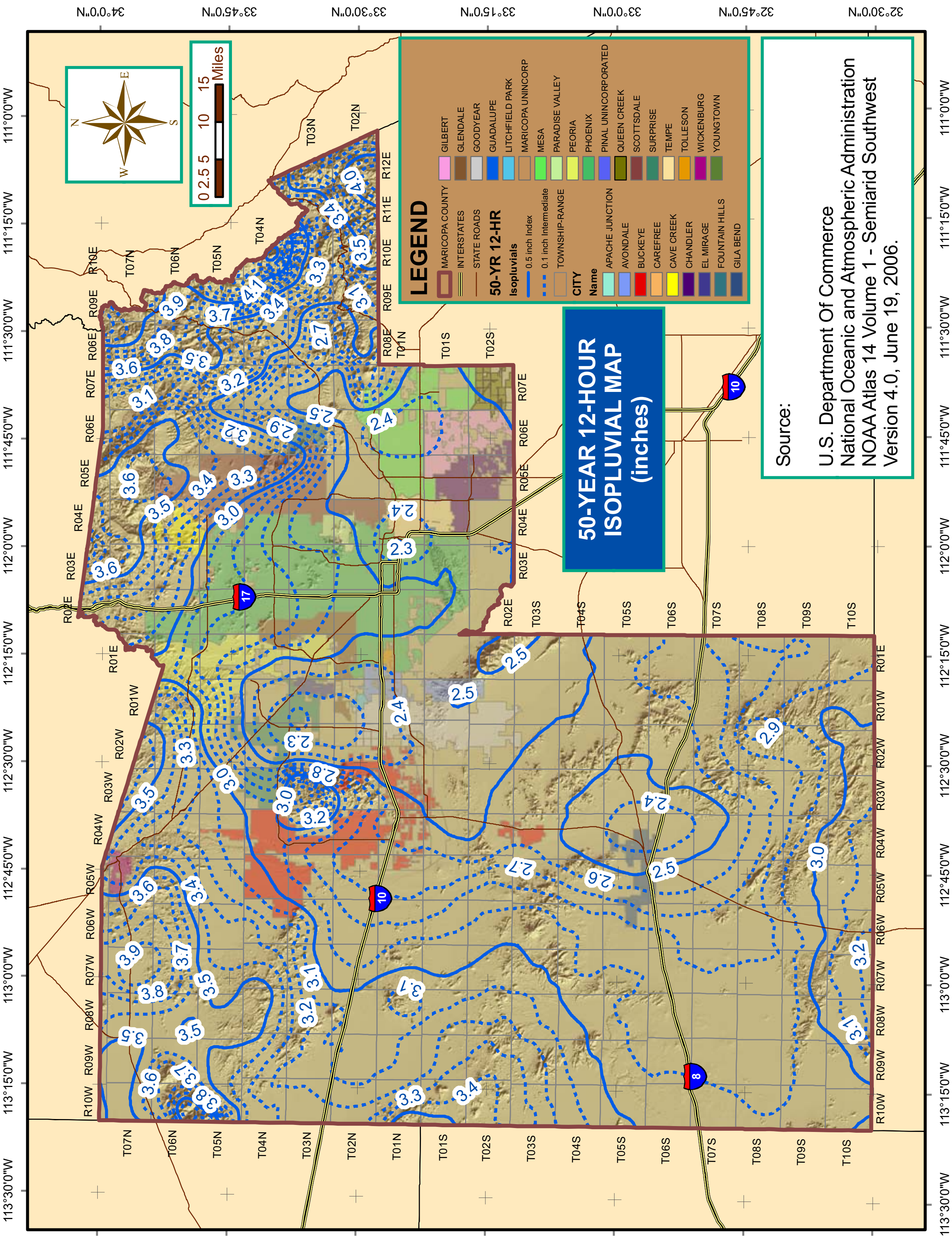


FIGURE A.50
50-YEAR 24-HOUR RAINFALL ISOPLUVIALS

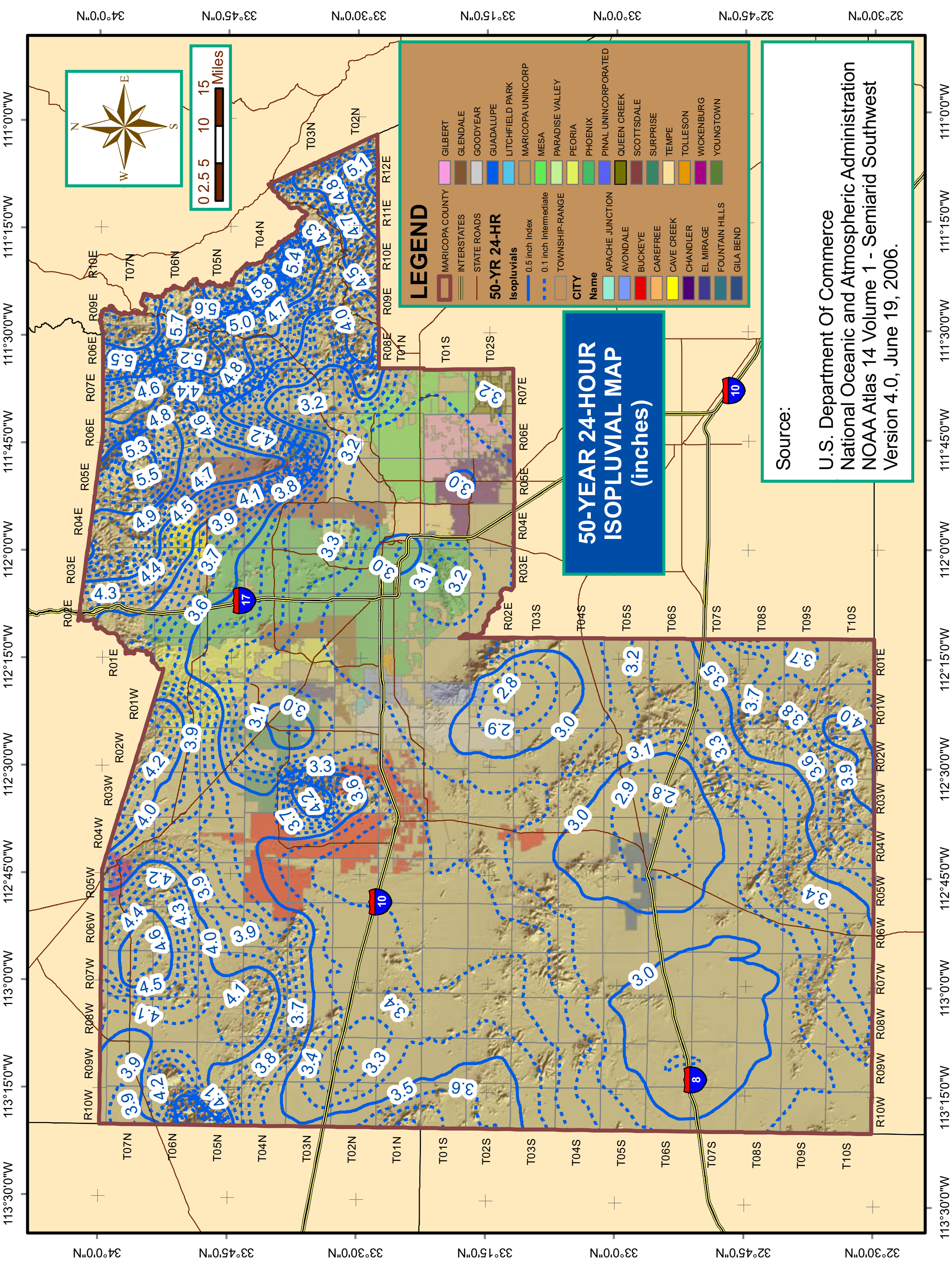


FIGURE A.51
100-YEAR 5-MINUTE RAINFALL ISOPLUVIALS

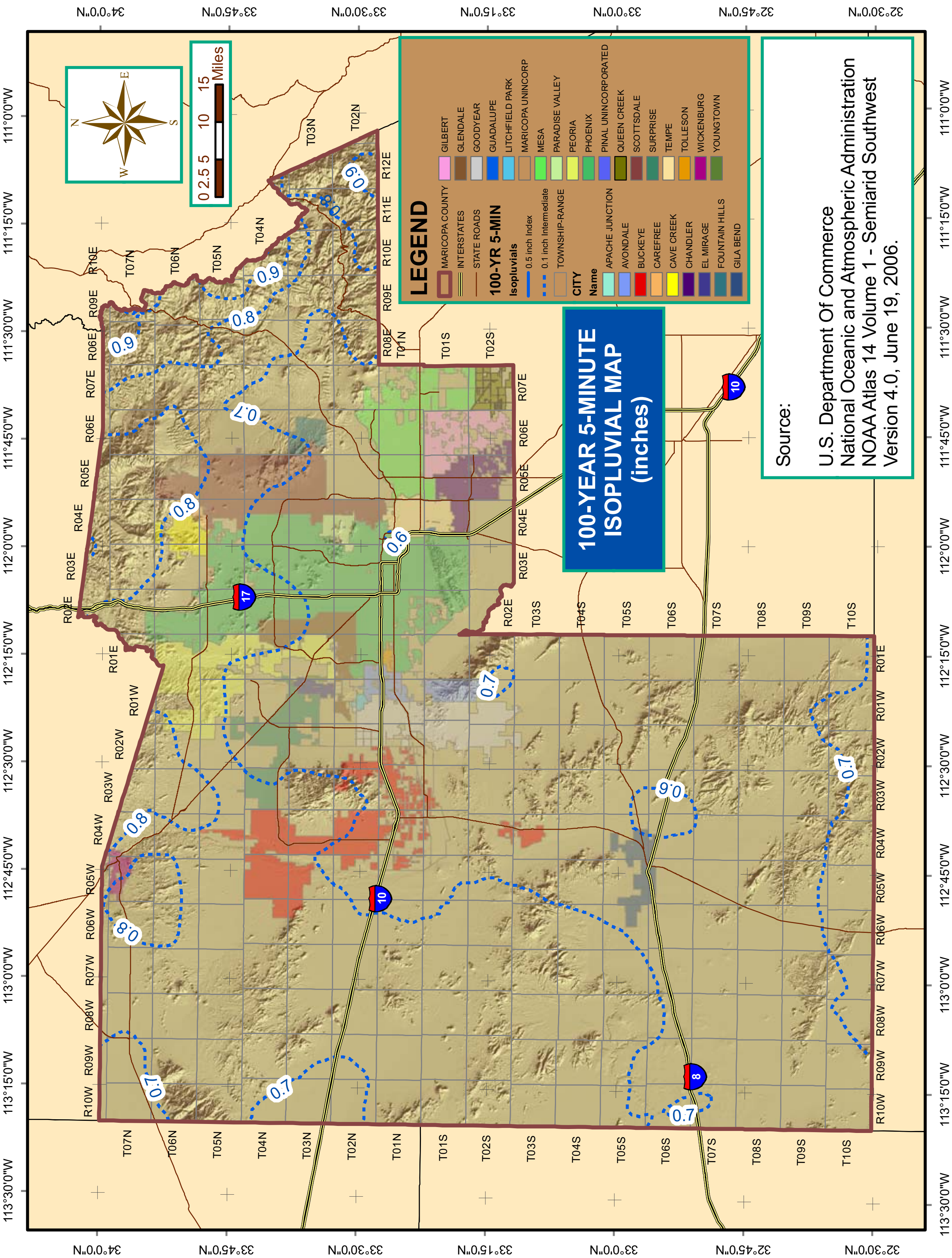


FIGURE A.52
100-YEAR 10-MINUTE RAINFALL ISOPLUVIALS

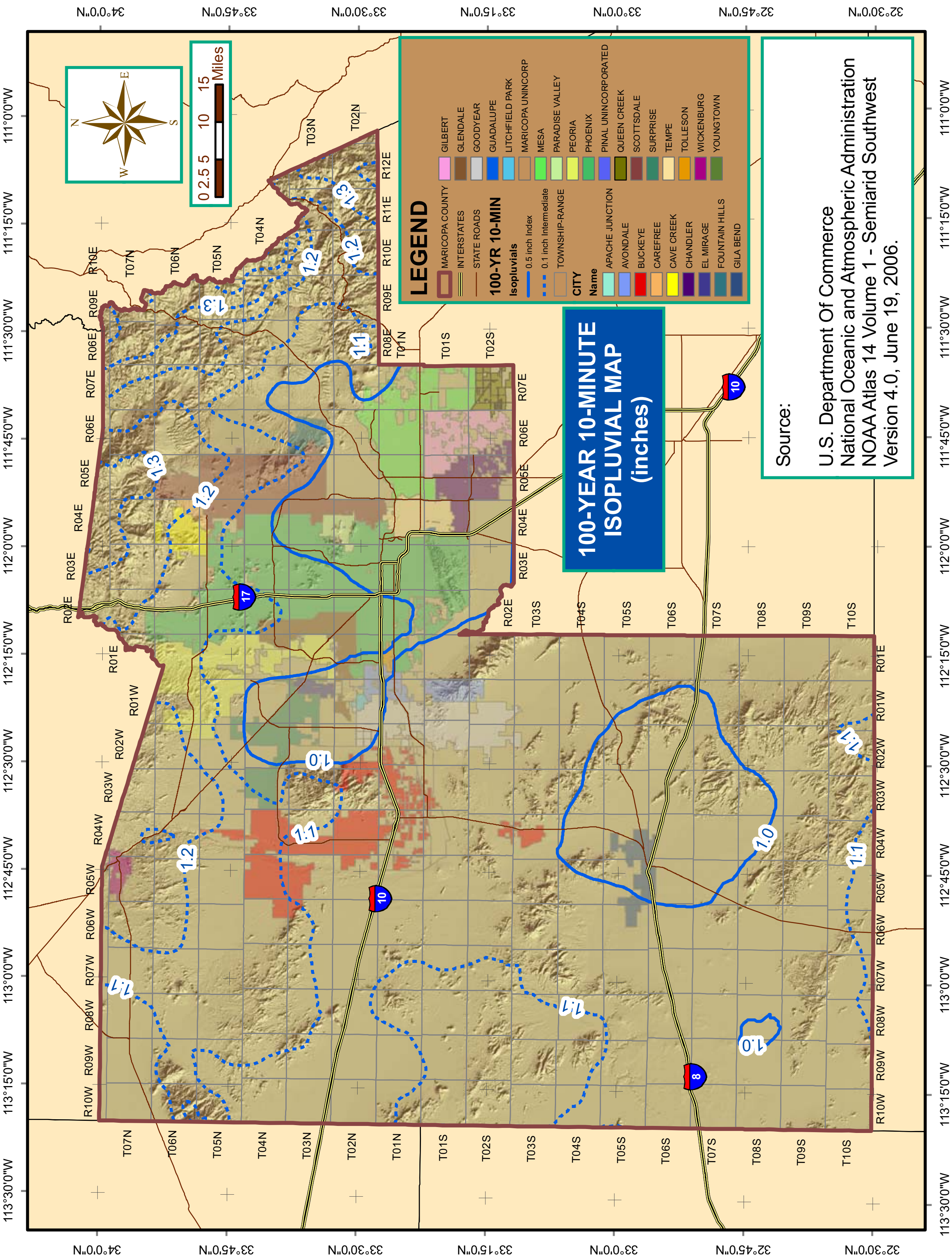


FIGURE A.53
100-YEAR 15-MINUTE RAINFALL ISOPLUVIALS

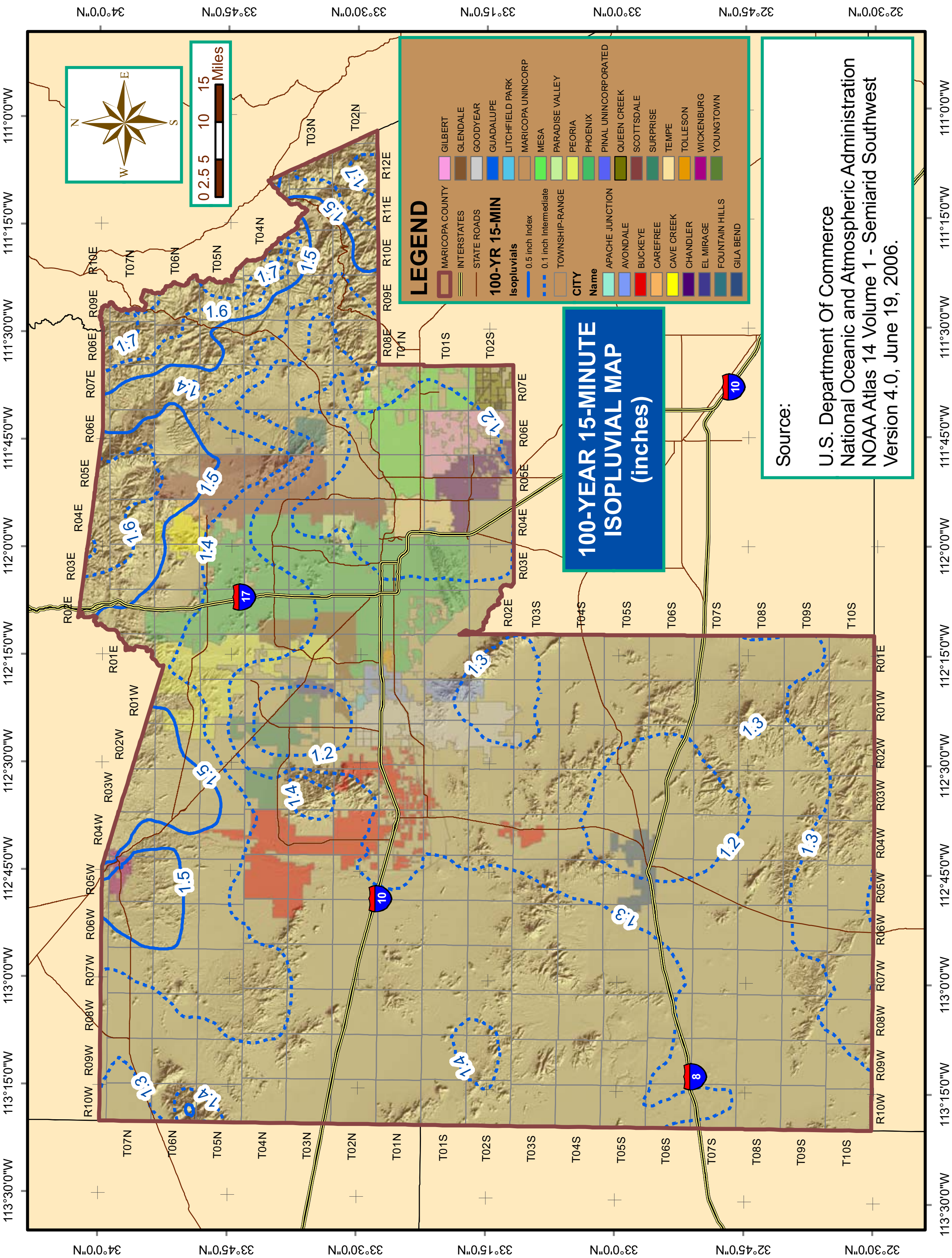


FIGURE A.54
100-YEAR 30-MINUTE RAINFALL ISOPLUVIALS

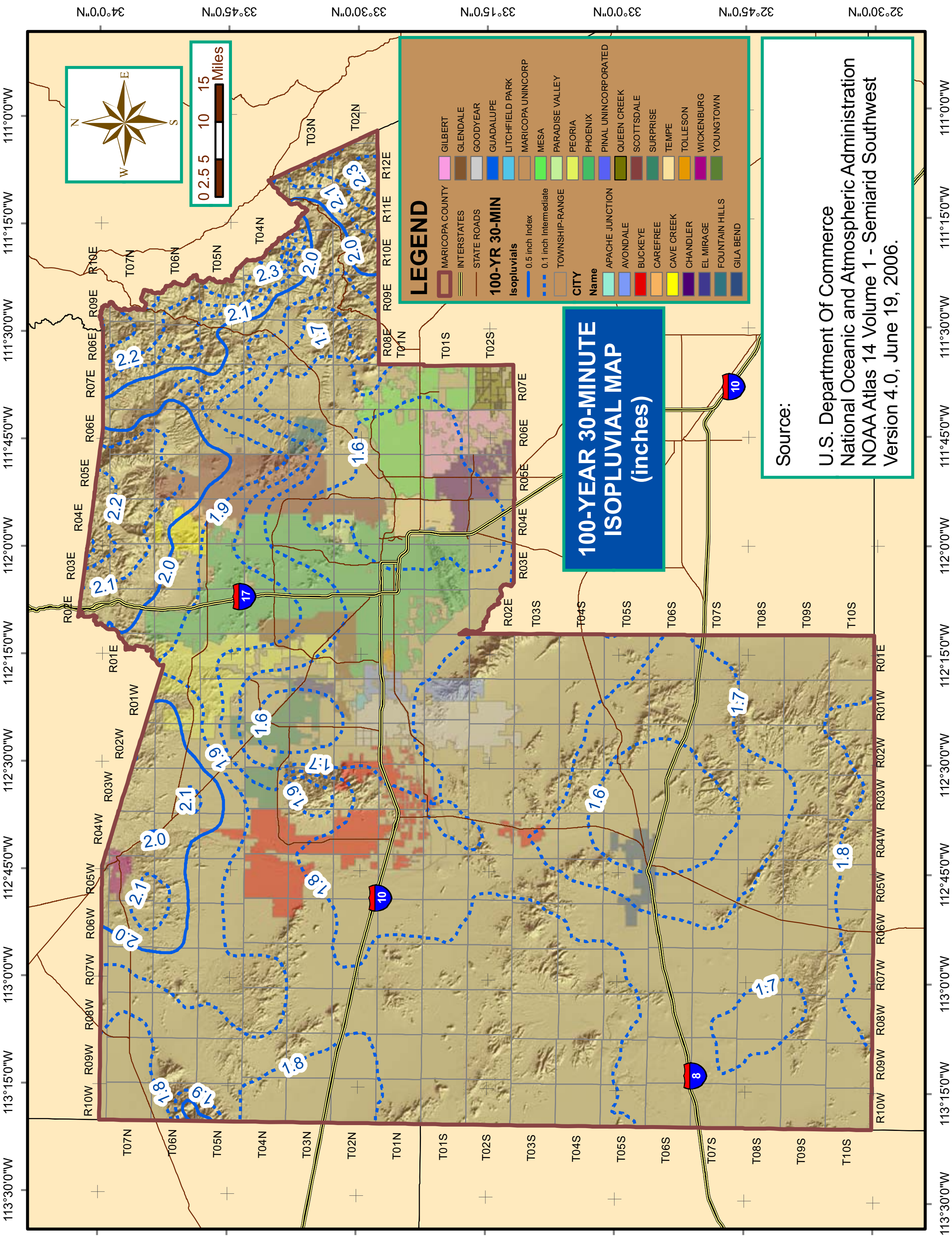


FIGURE A.55
100-YEAR 1-HOUR RAINFALL ISOPLUVIALS

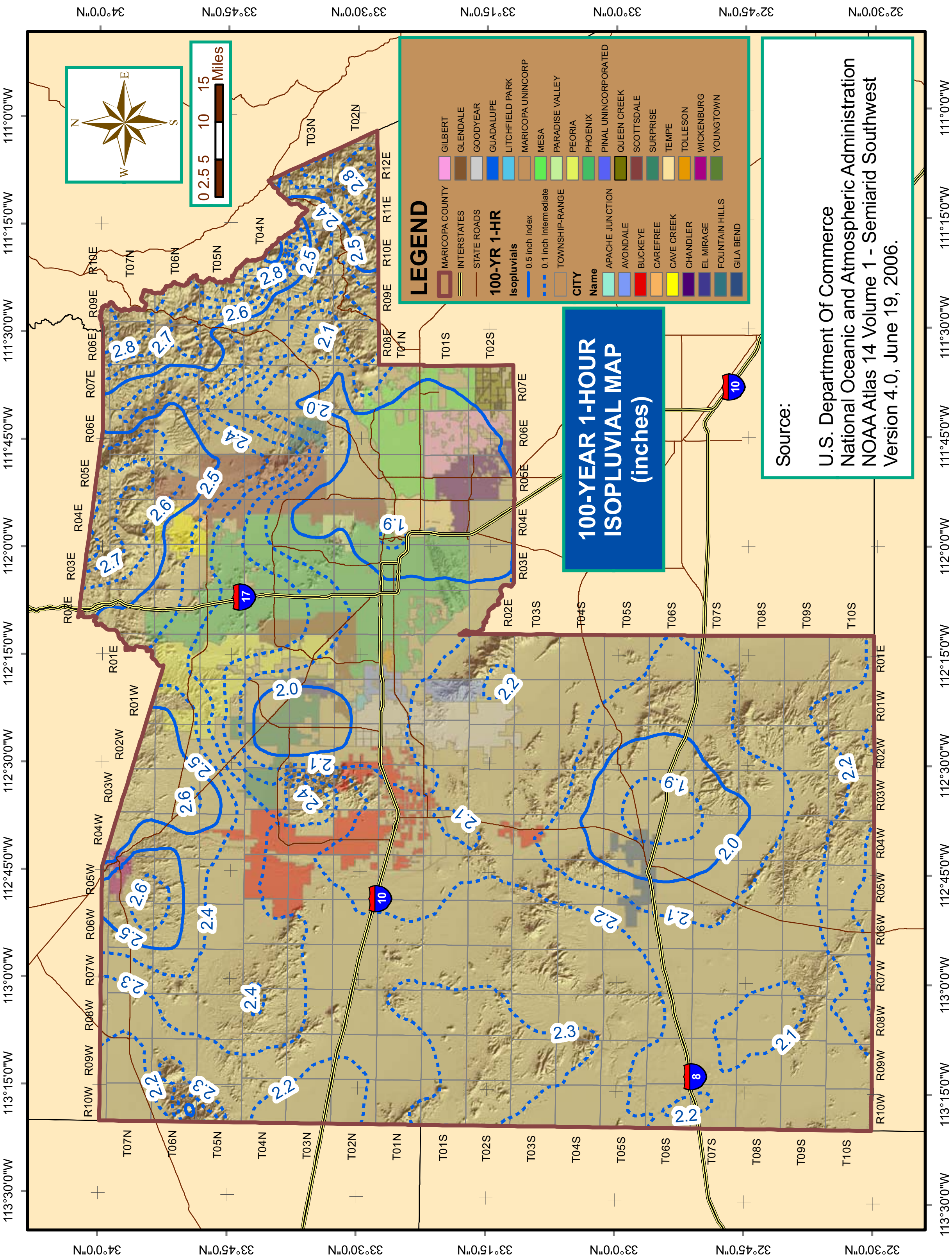


FIGURE A.56
100-YEAR 2-HOUR RAINFALL ISOPLUVIALS

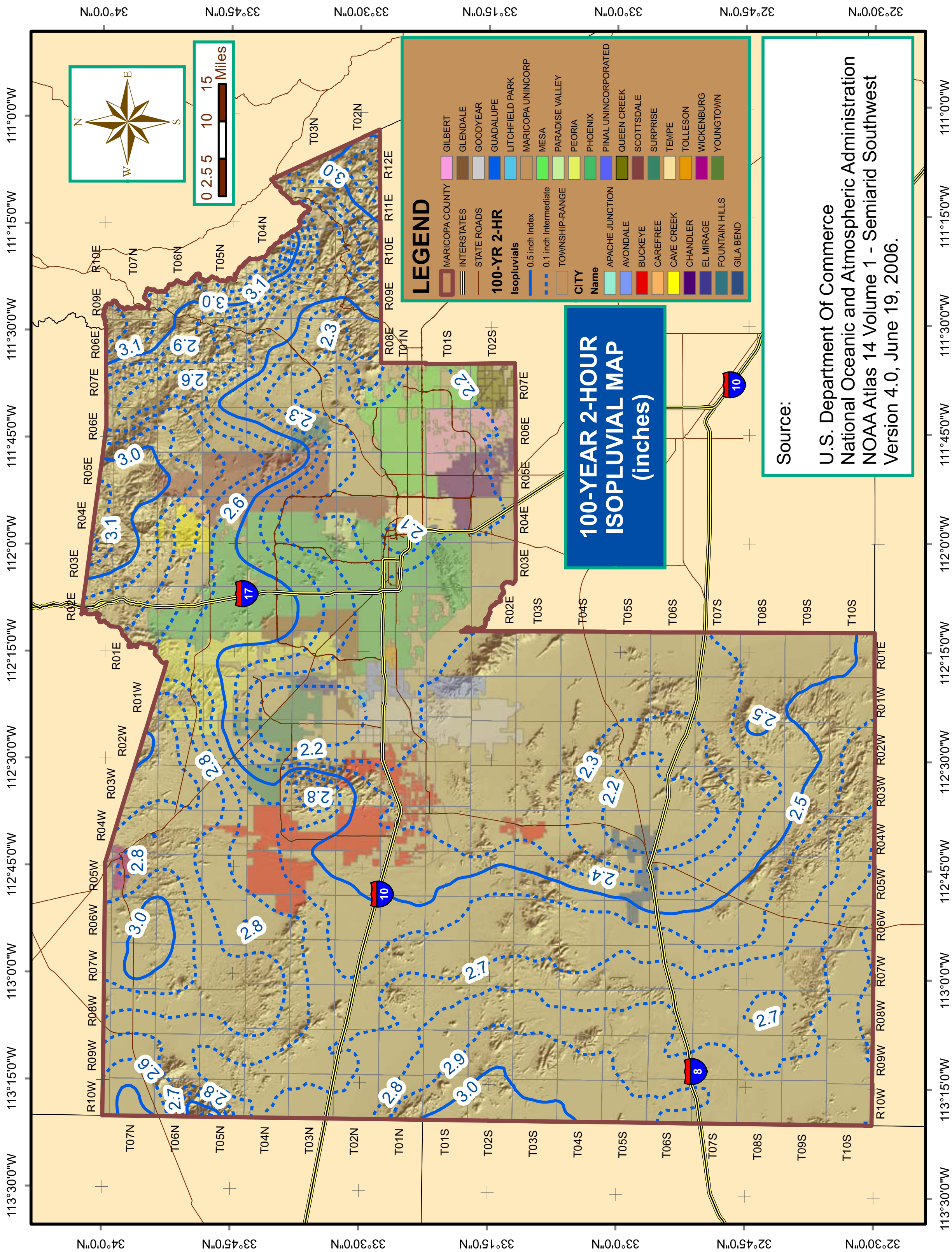


FIGURE A.57
100-YEAR 3-HOUR RAINFALL ISOPLUVIALS

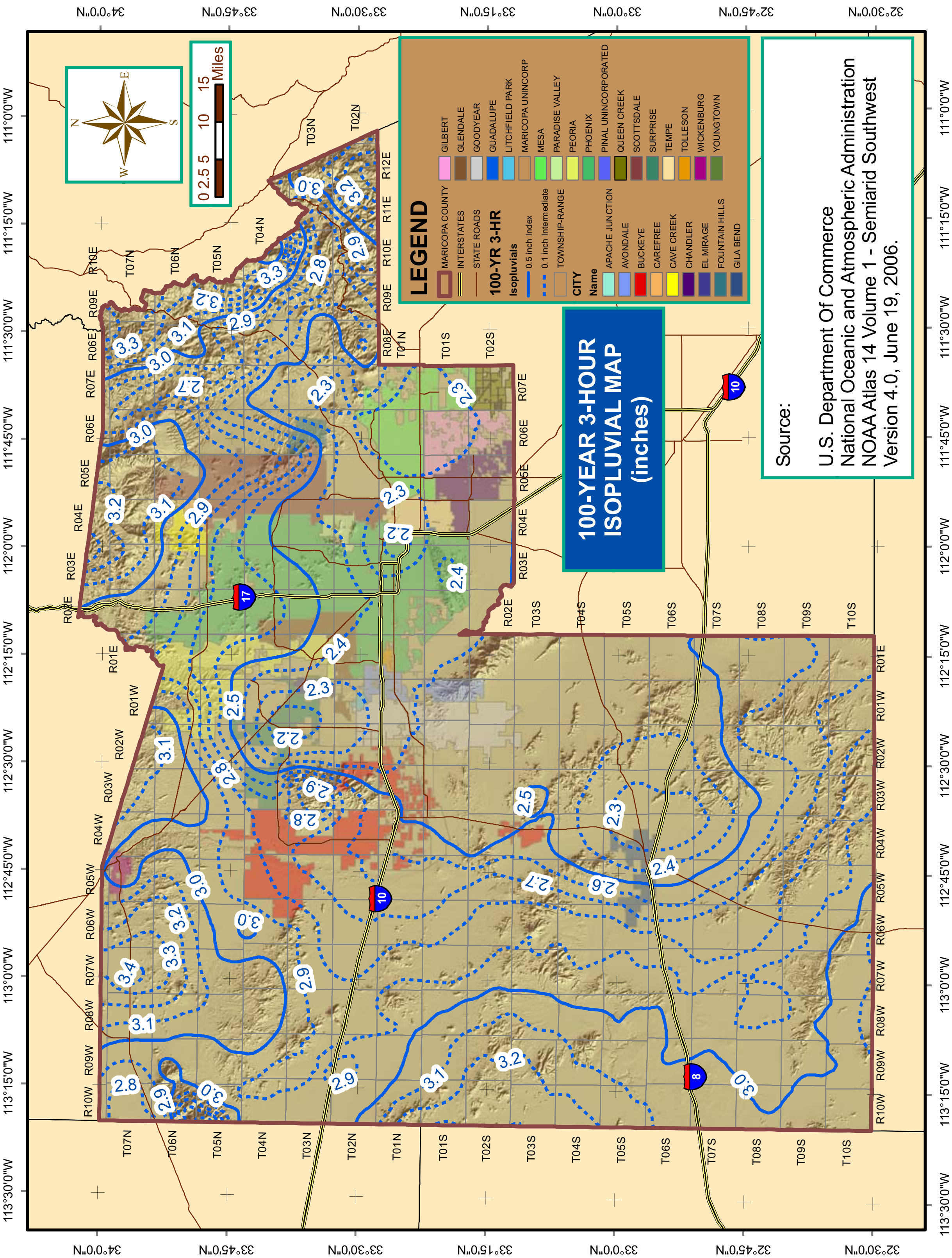


FIGURE A.58
100-YEAR 6-HOUR RAINFALL ISOPLUVIALS

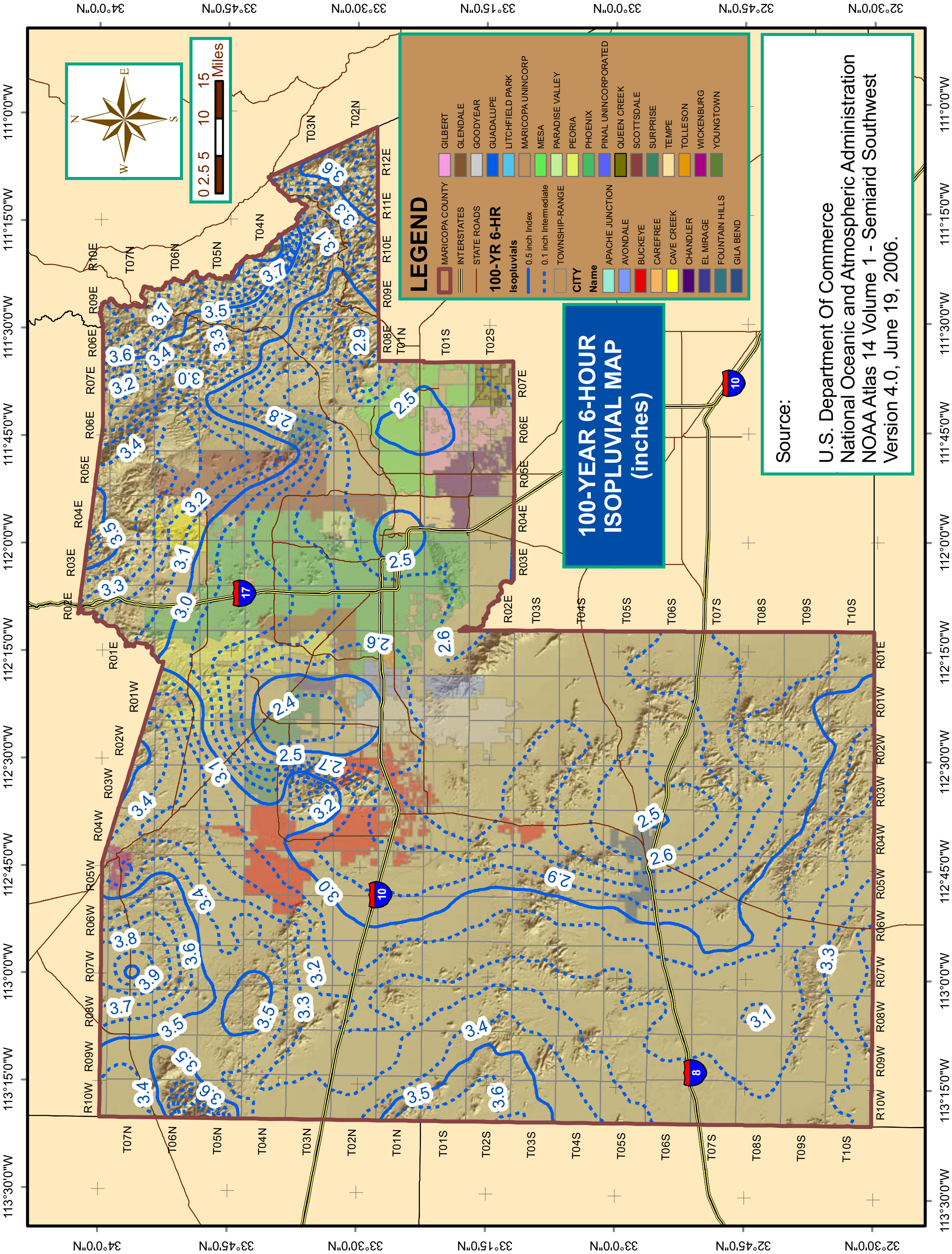


FIGURE A.59
100-YEAR 12-HOUR RAINFALL ISOPLUVIALS

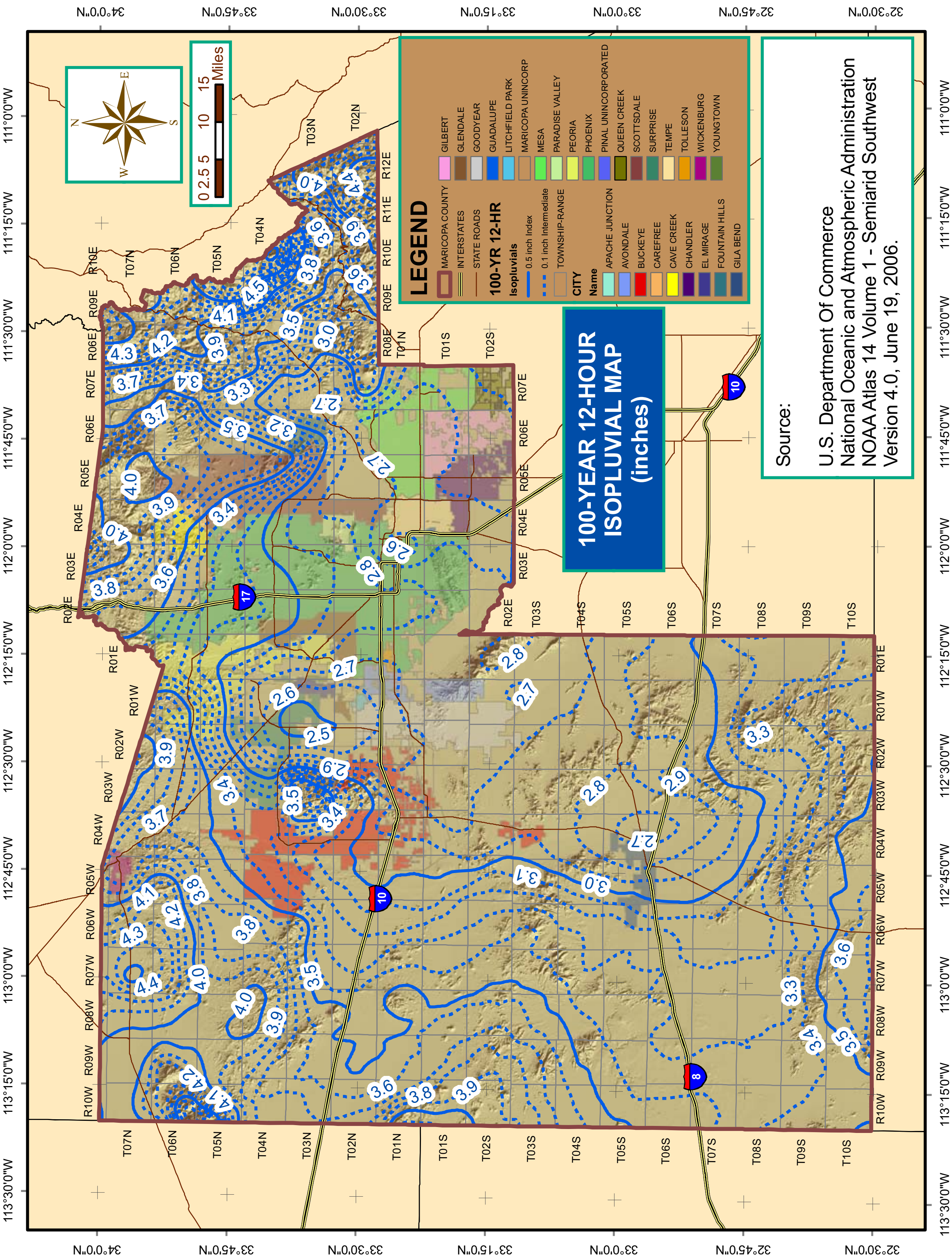
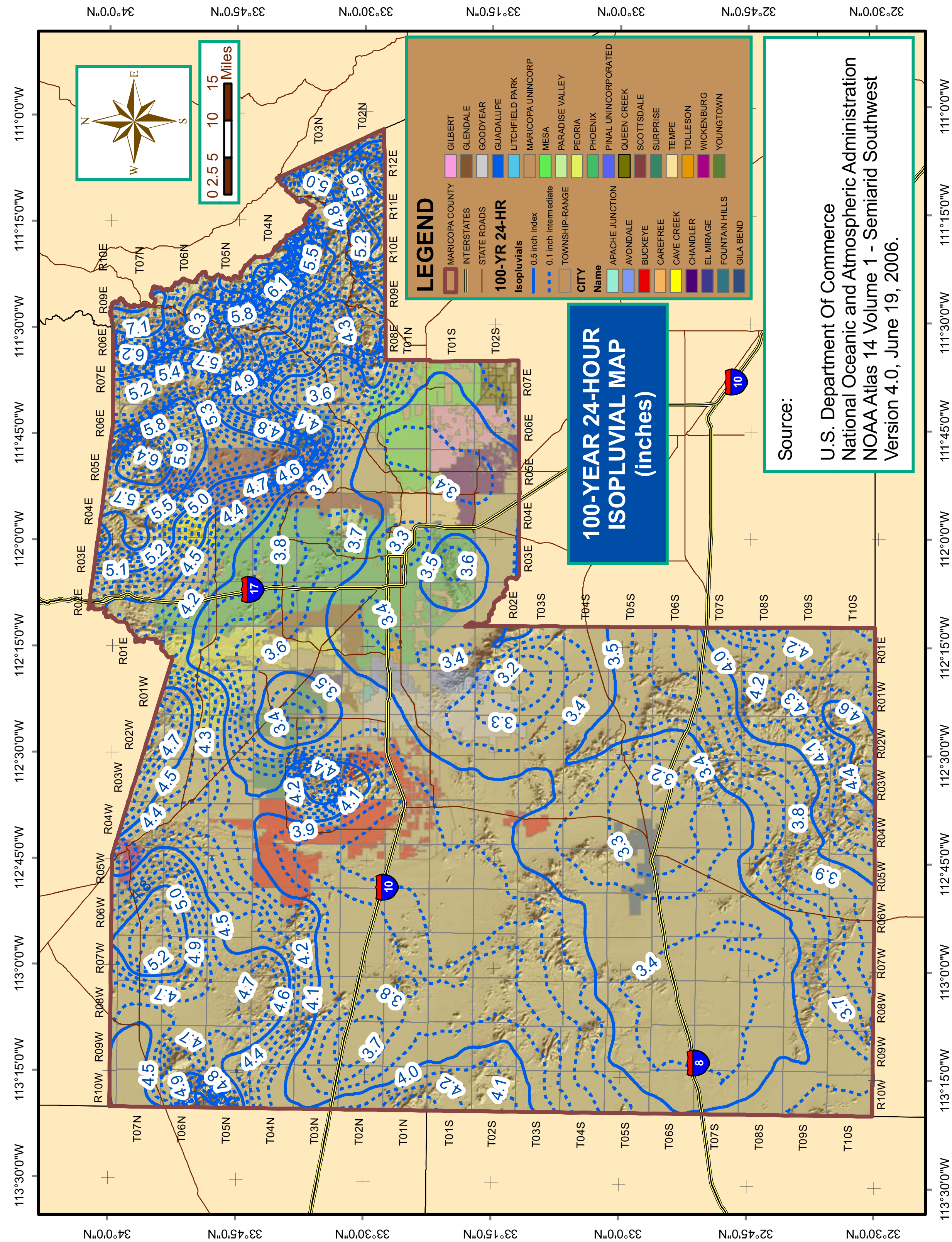


FIGURE A.60
100-YEAR 24-HOUR RAINFALL ISOPLUVIALS



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A.2 NOAA Atlas 2 Point Precipitation Maps

(For historical reference only. Not for use on new projects.)

Maps start on following page.

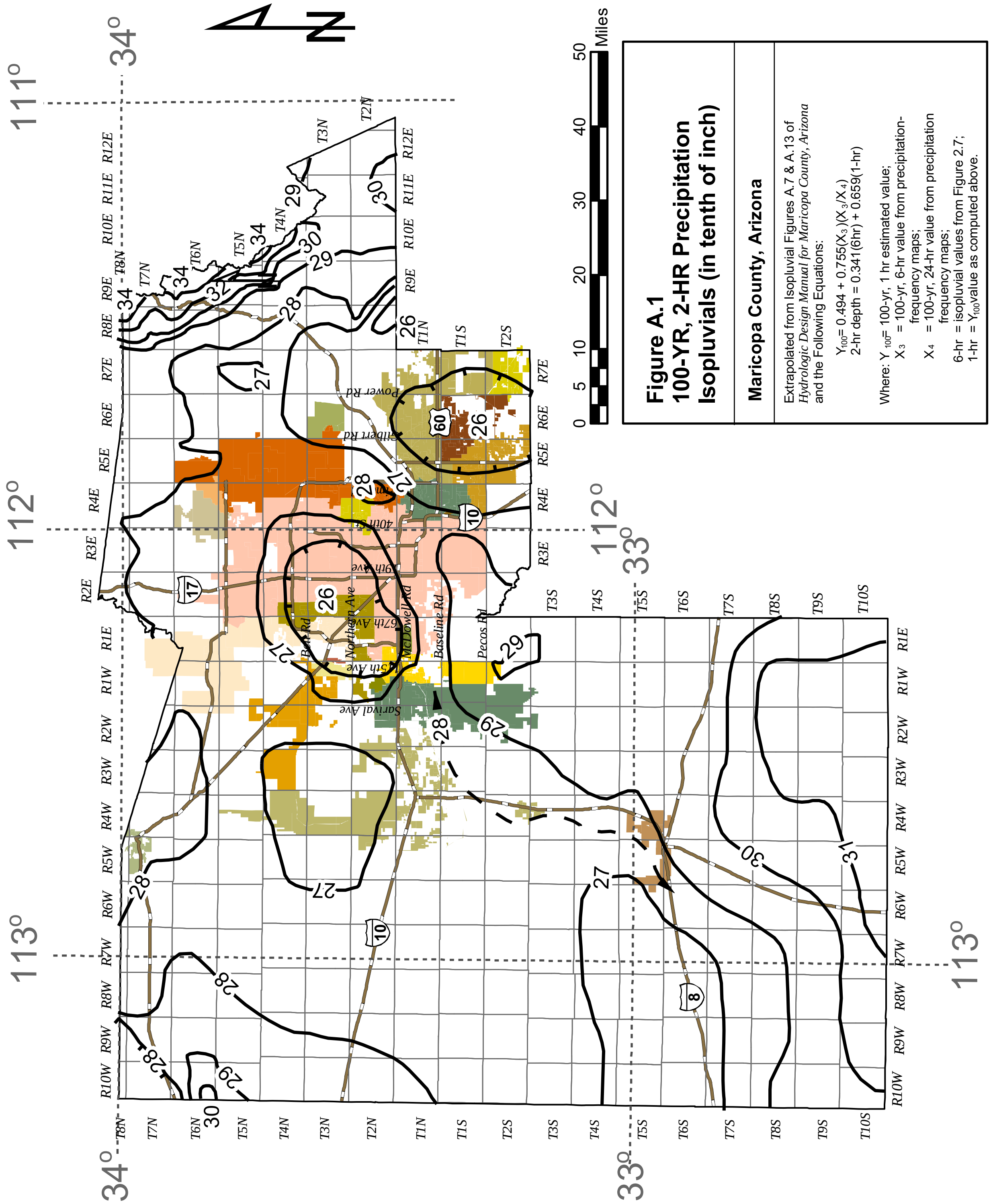

Figure A.1
100-YR, 2-HR Precipitation Isopluvials (in tenth of inch)

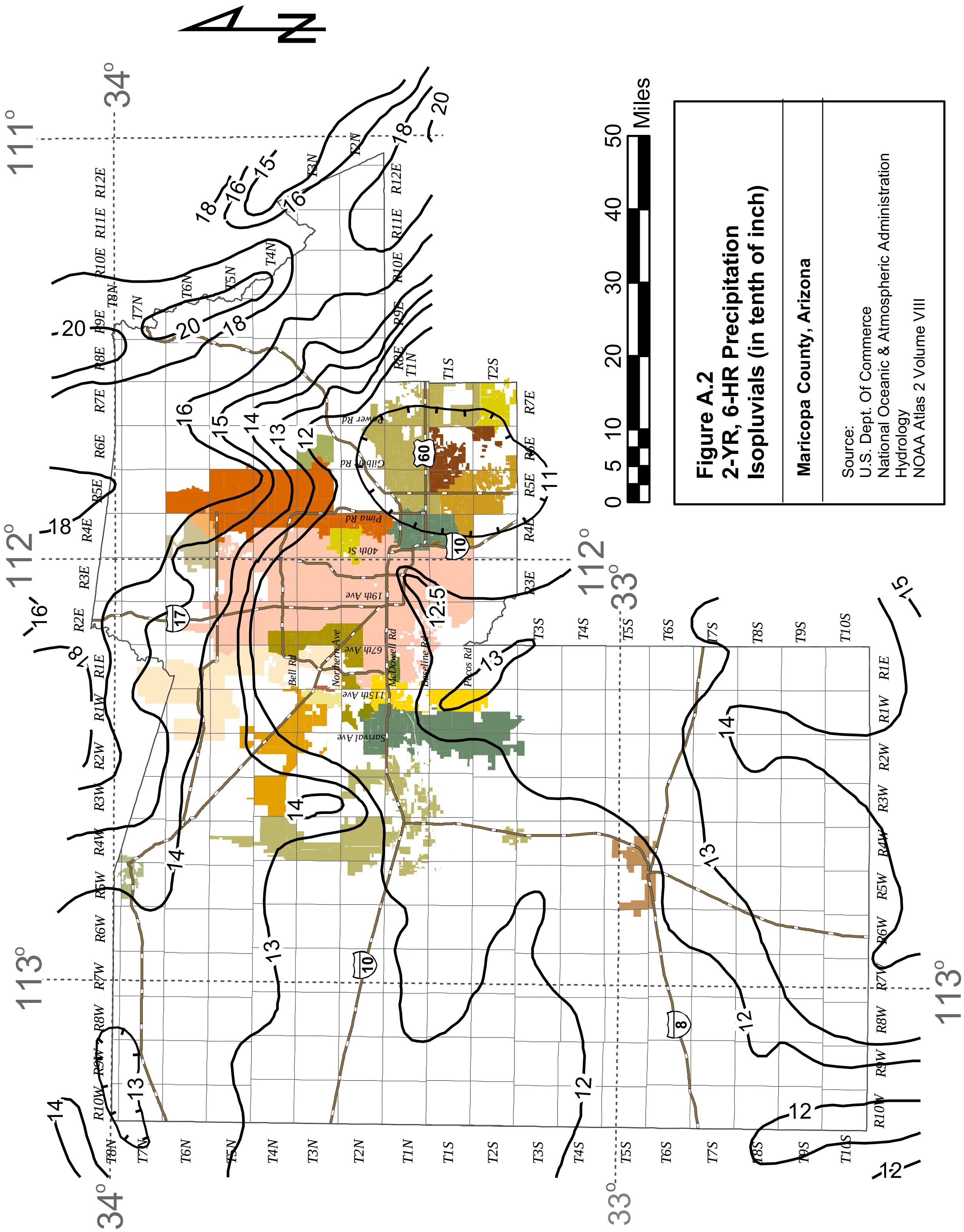

Figure A.2
2-YR, 6-HR Precipitation Isopluvials (in tenth of inch)

Maricopa County, Arizona

Source:
U.S. Dept. Of Commerce
National Oceanic & Atmospheric Administration
Hydrology
NOAA Atlas 2 Volume VIII

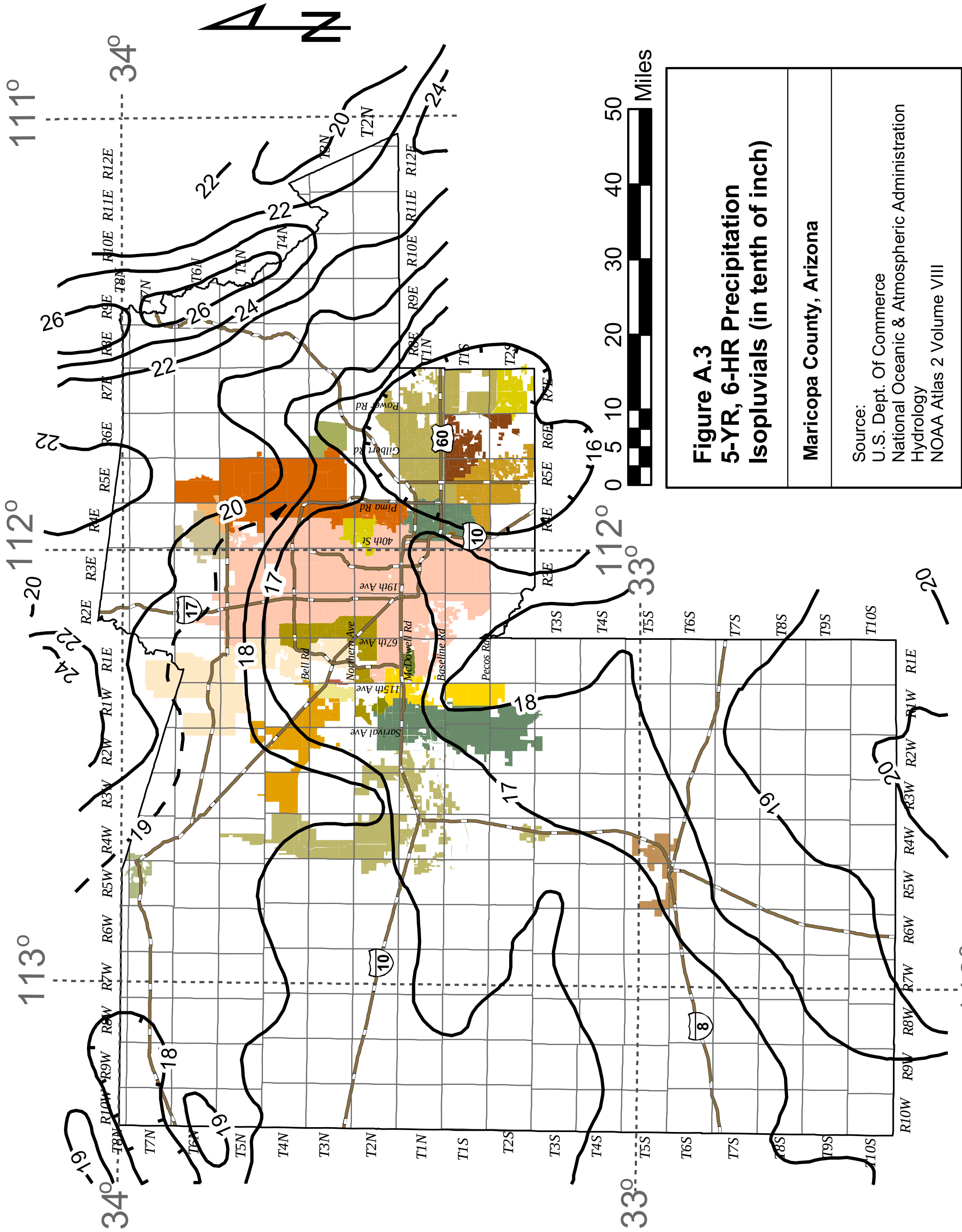

Figure A.3
5-YR, 6-HR Precipitation Isopluvials (in tenth of inch)

Maricopa County, Arizona

Source:
U.S. Dept. Of Commerce
National Oceanic & Atmospheric Administration
Hydrology
NOAA Atlas 2 Volume VIII

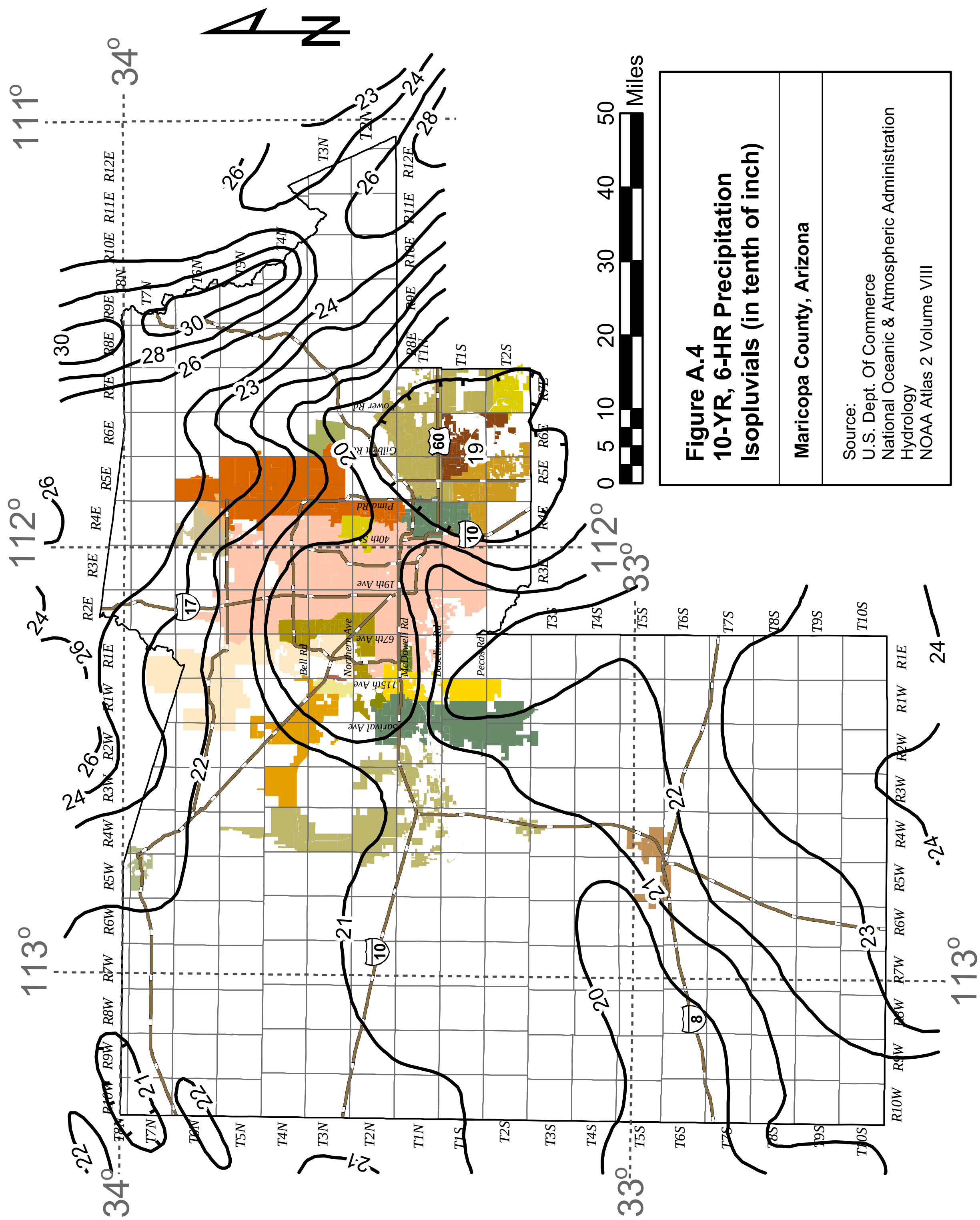

Figure A.4
10-YR, 6-HR Precipitation Isopluvials (in tenth of inch)

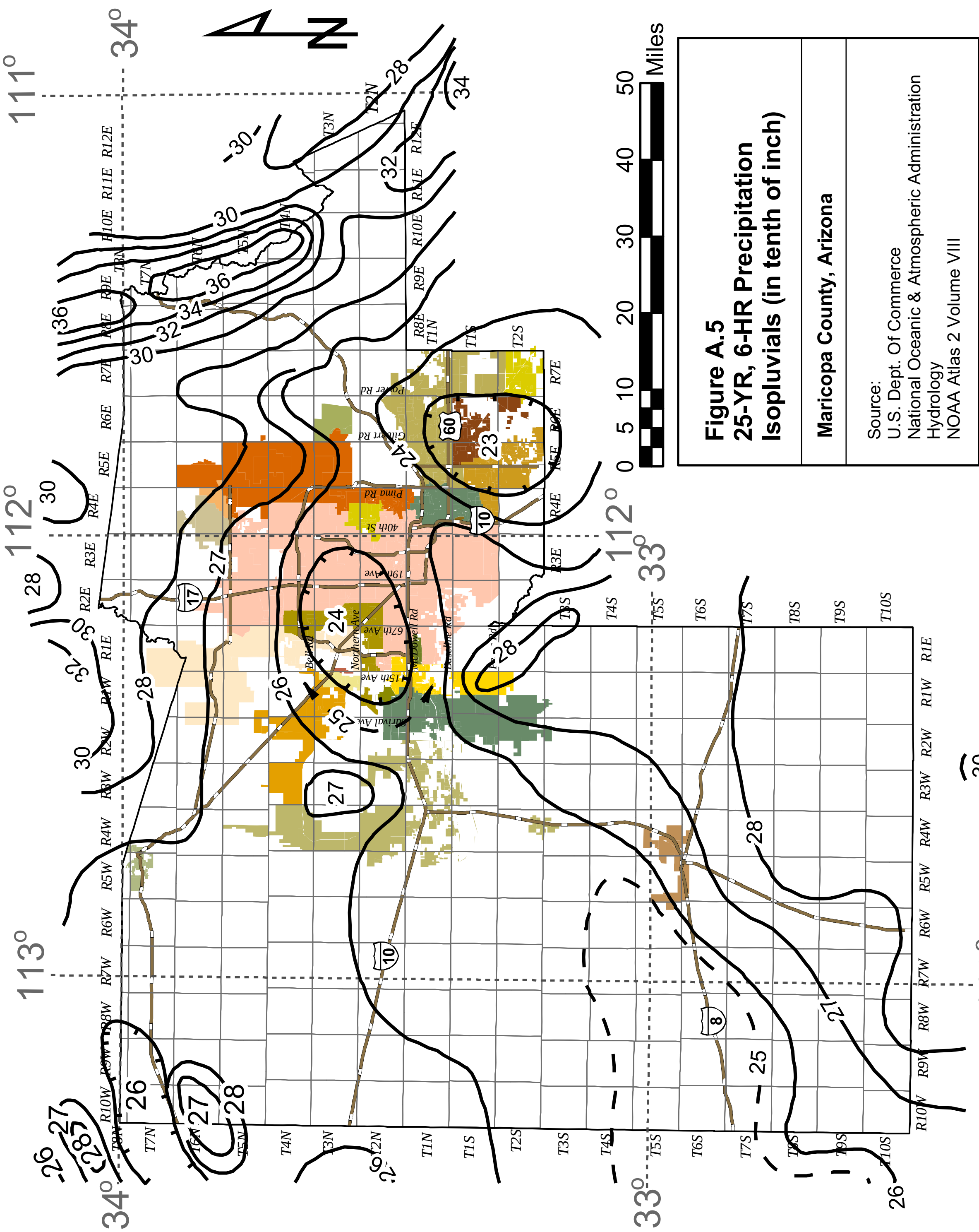

Figure A.5
25-YR, 6-HR Precipitation Isopluvials (in tenth of inch)

Maricopa County, Arizona

Source:
U.S. Dept. Of Commerce
National Oceanic & Atmospheric Administration
Hydrology
NOAA Atlas 2 Volume VIII

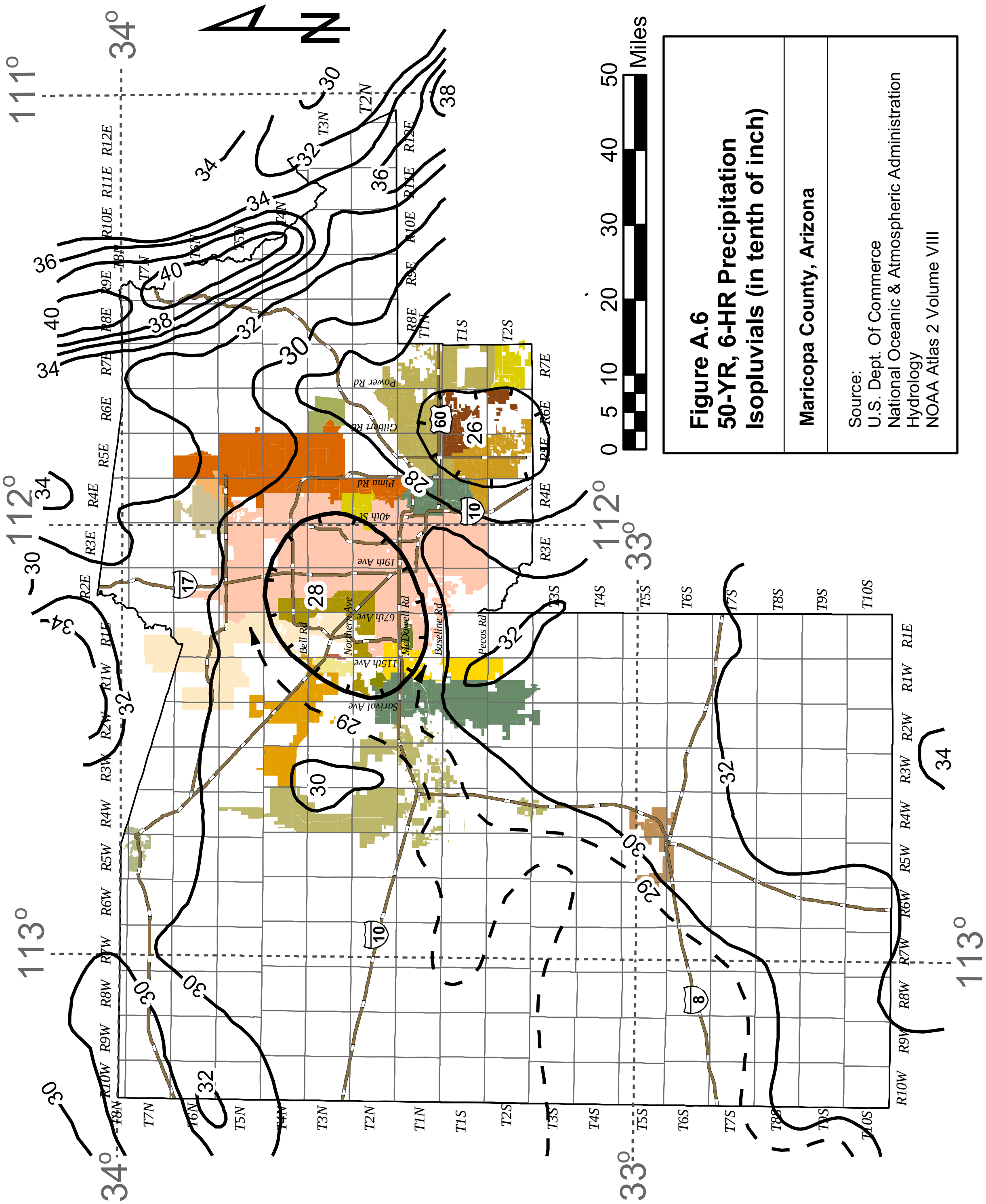

Figure A.6
50-YR, 6-HR Precipitation Isopluvials (in tenth of inch)

Maricopa County, Arizona

Source:
U.S. Dept. Of Commerce
National Oceanic & Atmospheric Administration
Hydrology
NOAA Atlas 2 Volume VIII

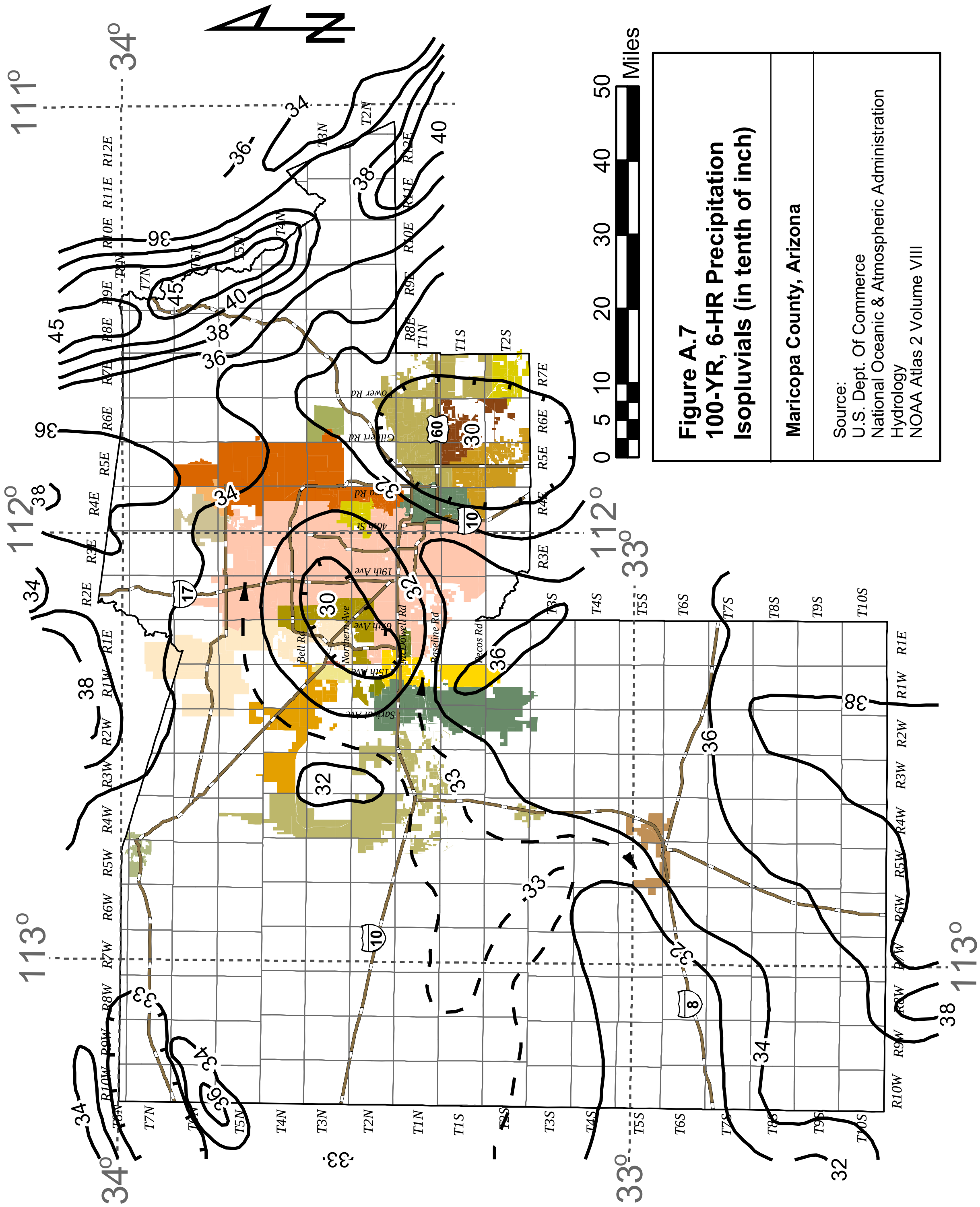
Figure A.7
100-YR, 6-HR Precipitation
Isopluvials (in tenth of inch)
Maricopa County, Arizona
Source:
U.S. Dept. Of Commerce
National Oceanic & Atmospheric Administration
Hydrology
NOAA Atlas 2 Volume VIII
0 5 10 20 30 40 50 Miles
N

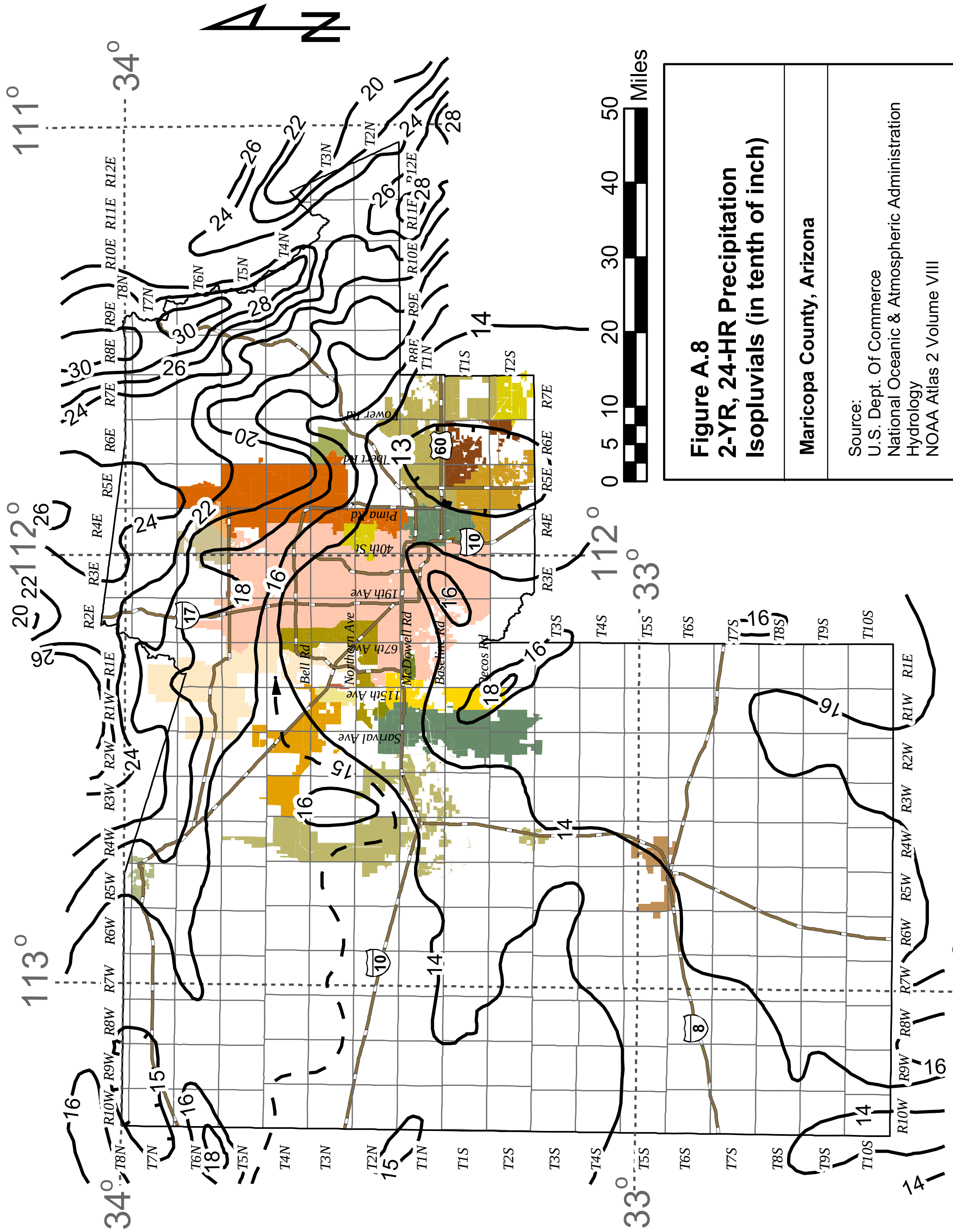

Figure A.8
2-YR, 24-HR Precipitation Isopluvials (in tenth of inch)

Maricopa County, Arizona

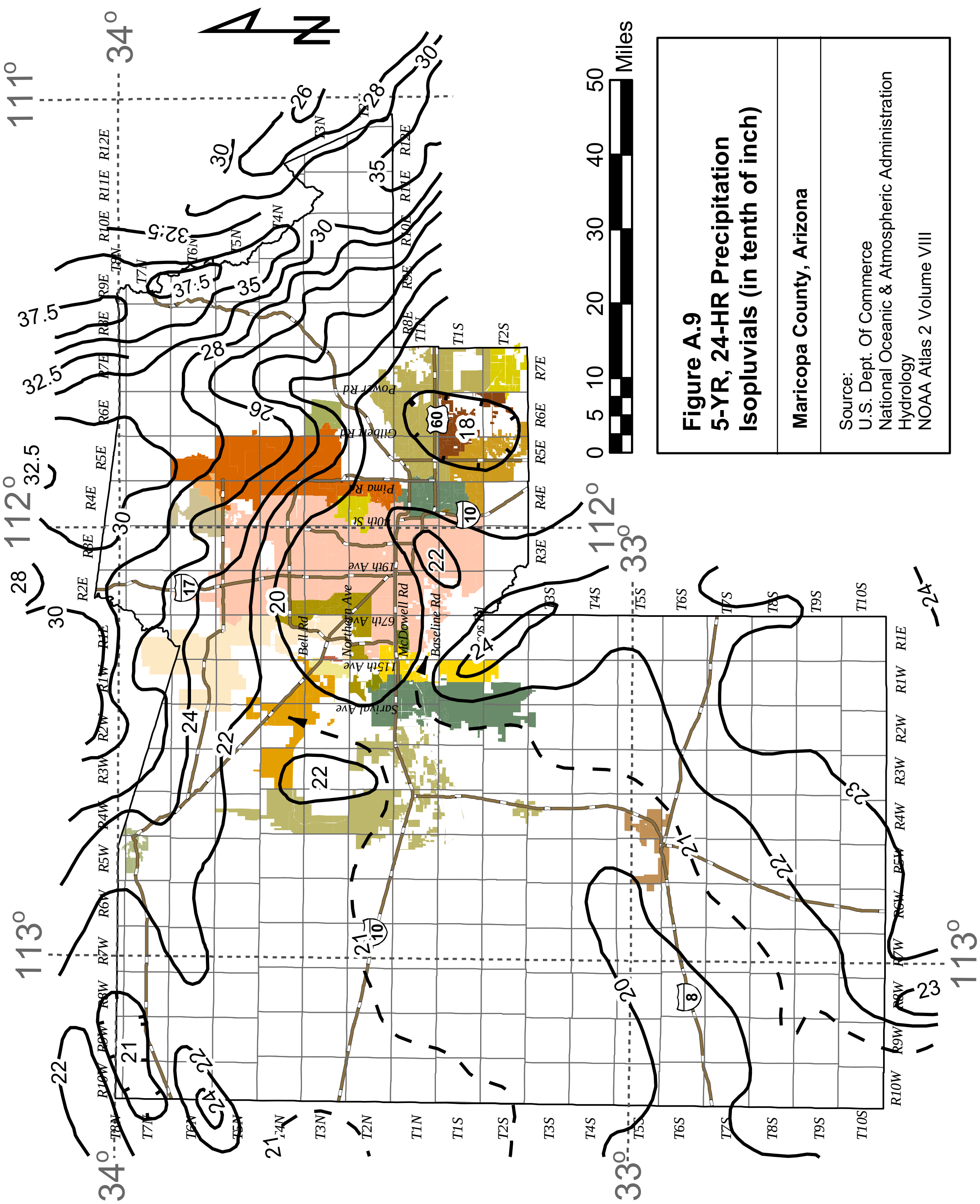

Figure A.9
5-YR, 24-HR Precipitation Isopluvials (in tenth of inch)

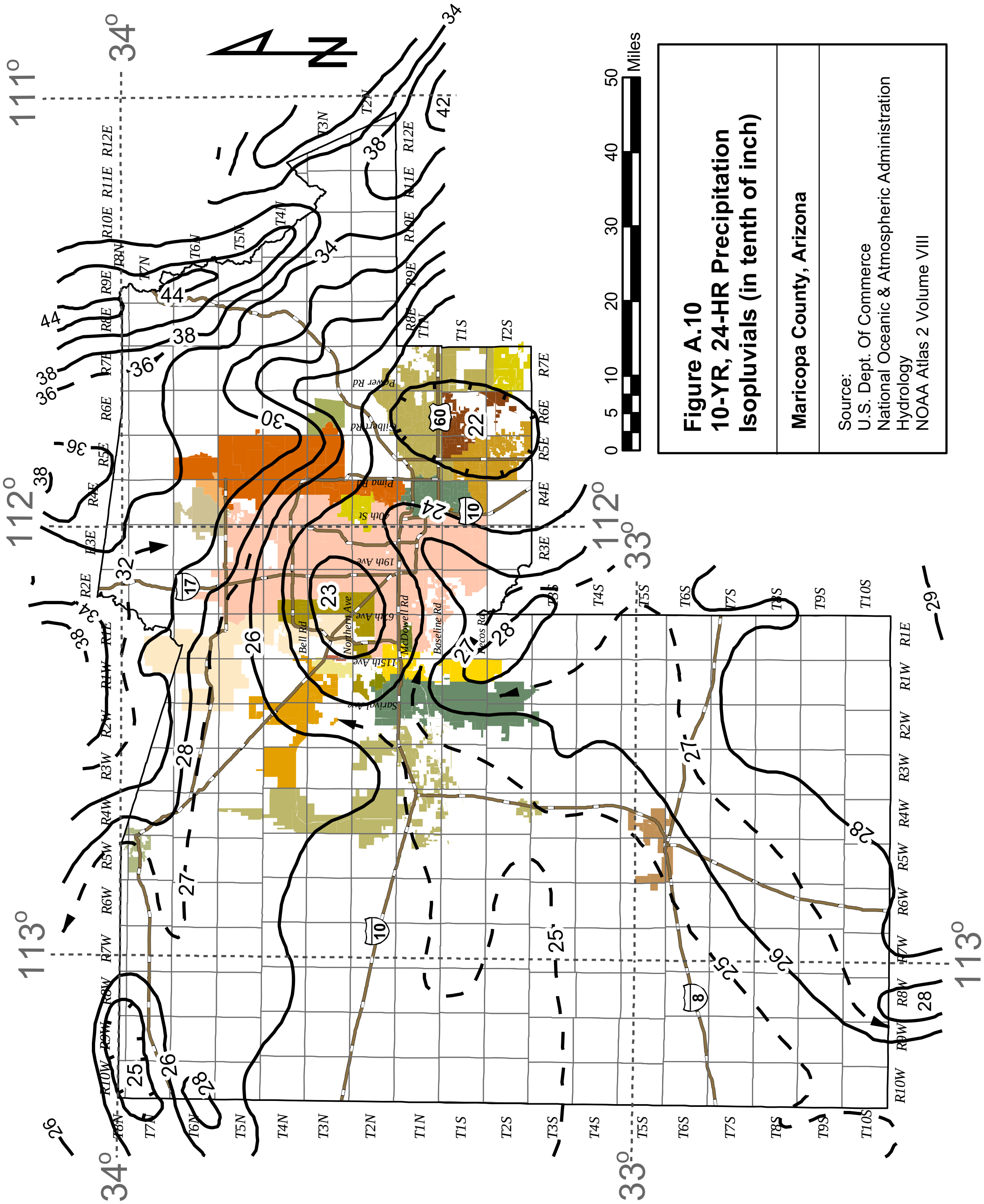

Figure A.10
10-YR, 24-HR Precipitation Isopluvials (in tenth of inch)

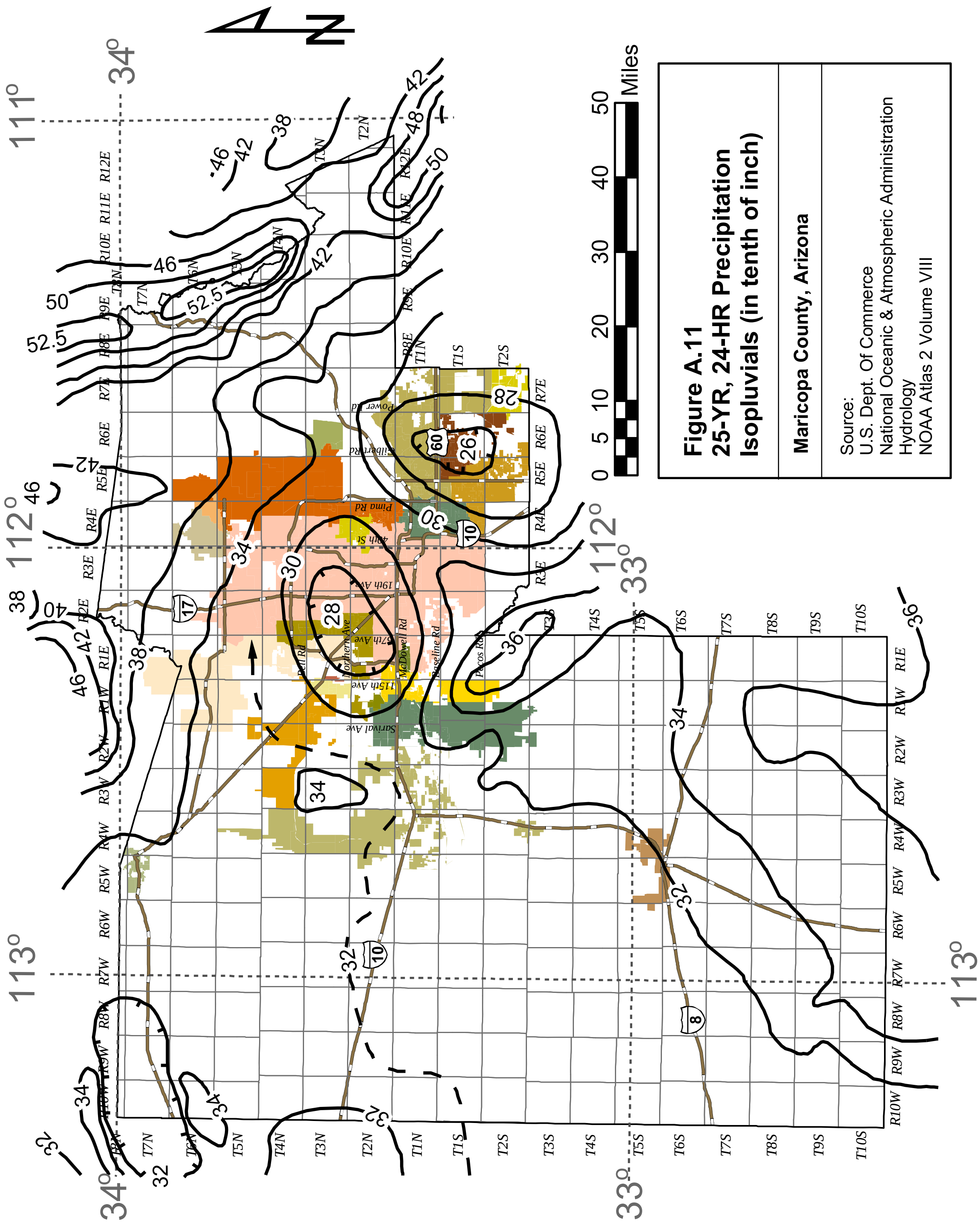

Figure A.11
25-YR, 24-HR Precipitation Isopluvials (in tenth of inch)

Maricopa County, Arizona

Source:
U.S. Dept. Of Commerce
National Oceanic & Atmospheric Administration
Hydrology
NOAA Atlas 2 Volume VIII

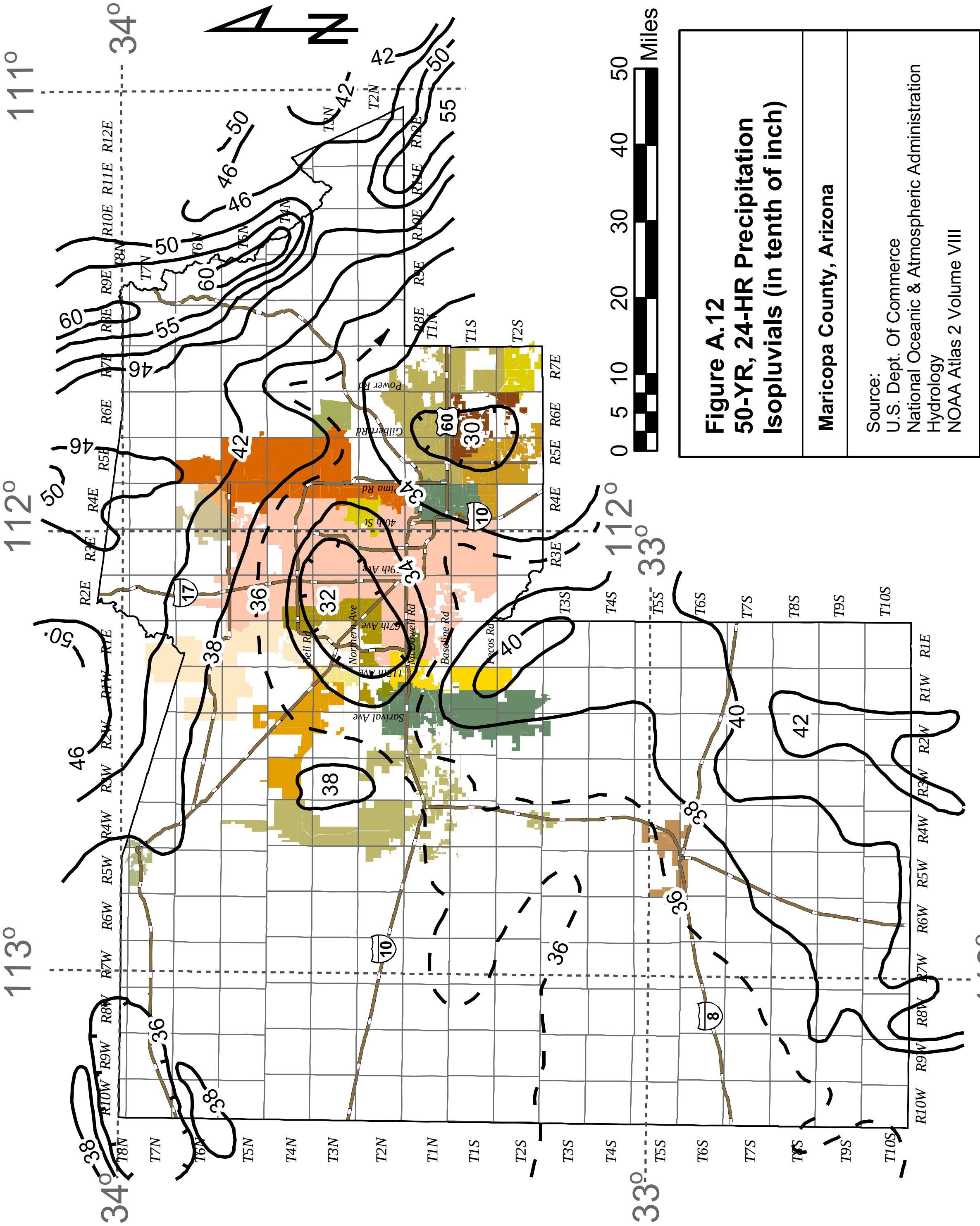

Figure A.12
50-YR, 24-HR Precipitation Isopluvials (in tenth of inch)

Maricopa County, Arizona

Source:
U.S. Dept. Of Commerce
National Oceanic & Atmospheric Administration
Hydrology
NOAA Atlas 2 Volume VIII

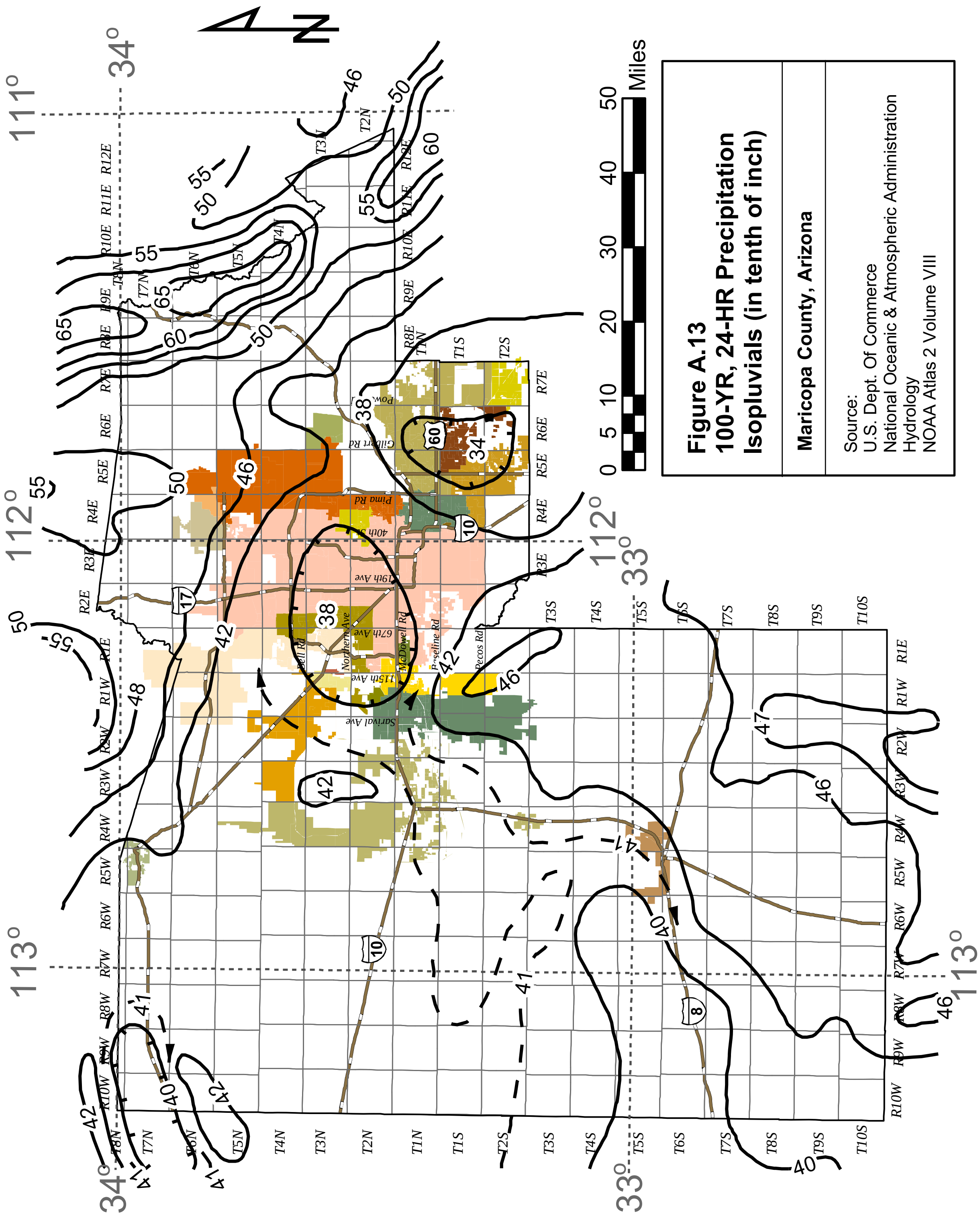

Figure A.13
100-YR, 24-HR Precipitation Isopluvials (in tenth of inch)

A.3 Precipitation Depth-Duration Figure

(For historical reference only. Not for use on new projects.)

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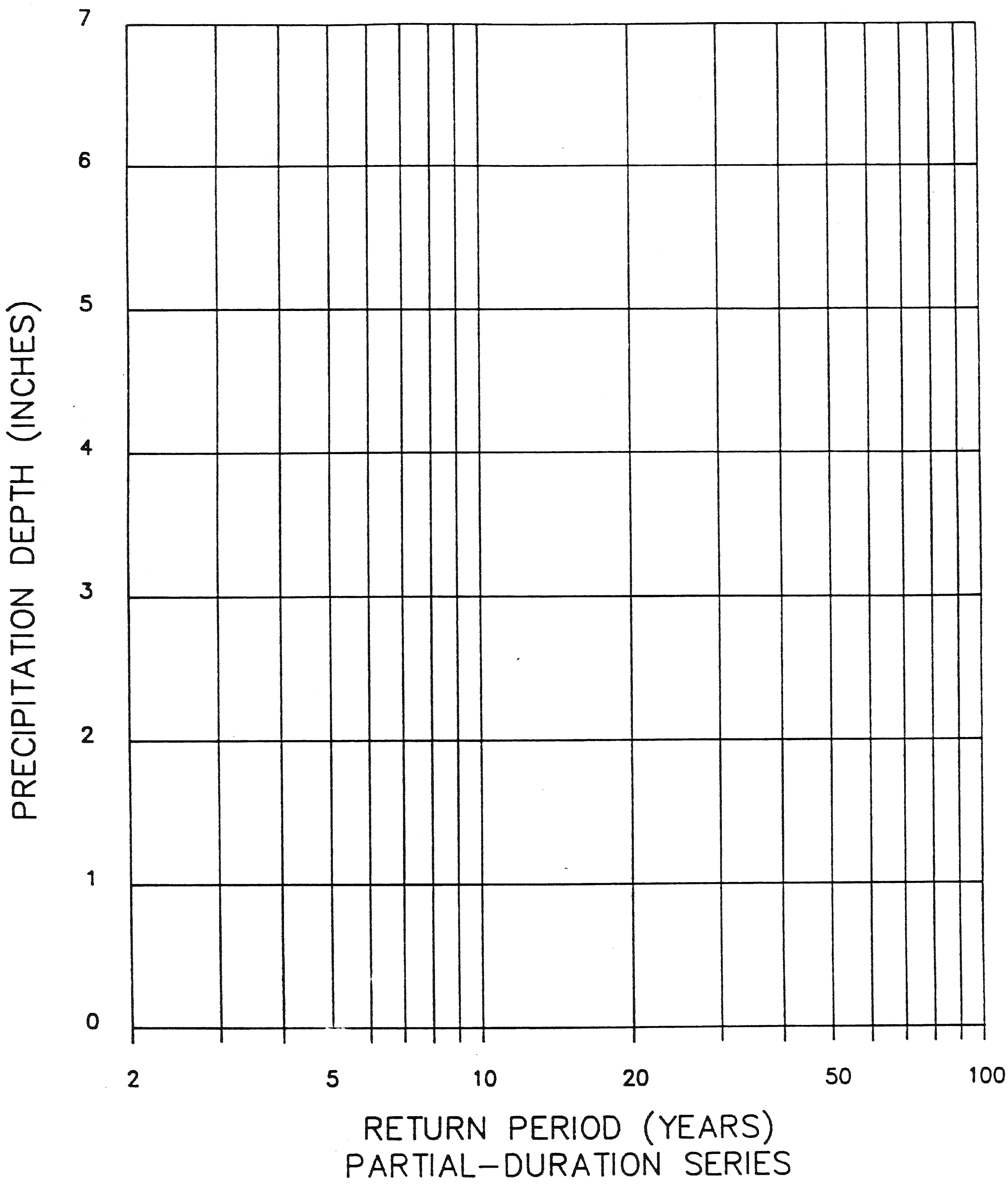

Precipitation Depth versus Return Period for Partial-Duration Series

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A.4 PREFRE Manual

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* 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 <u>primary</u> zones 3, 9, and 11; optional for other primary zones).

e. Site elevation (required for <u>primary</u> 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. <u>Output Data</u>.

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.

2

4. <u>Program Execution</u>.

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. <u>Method of Derivation</u>.

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.

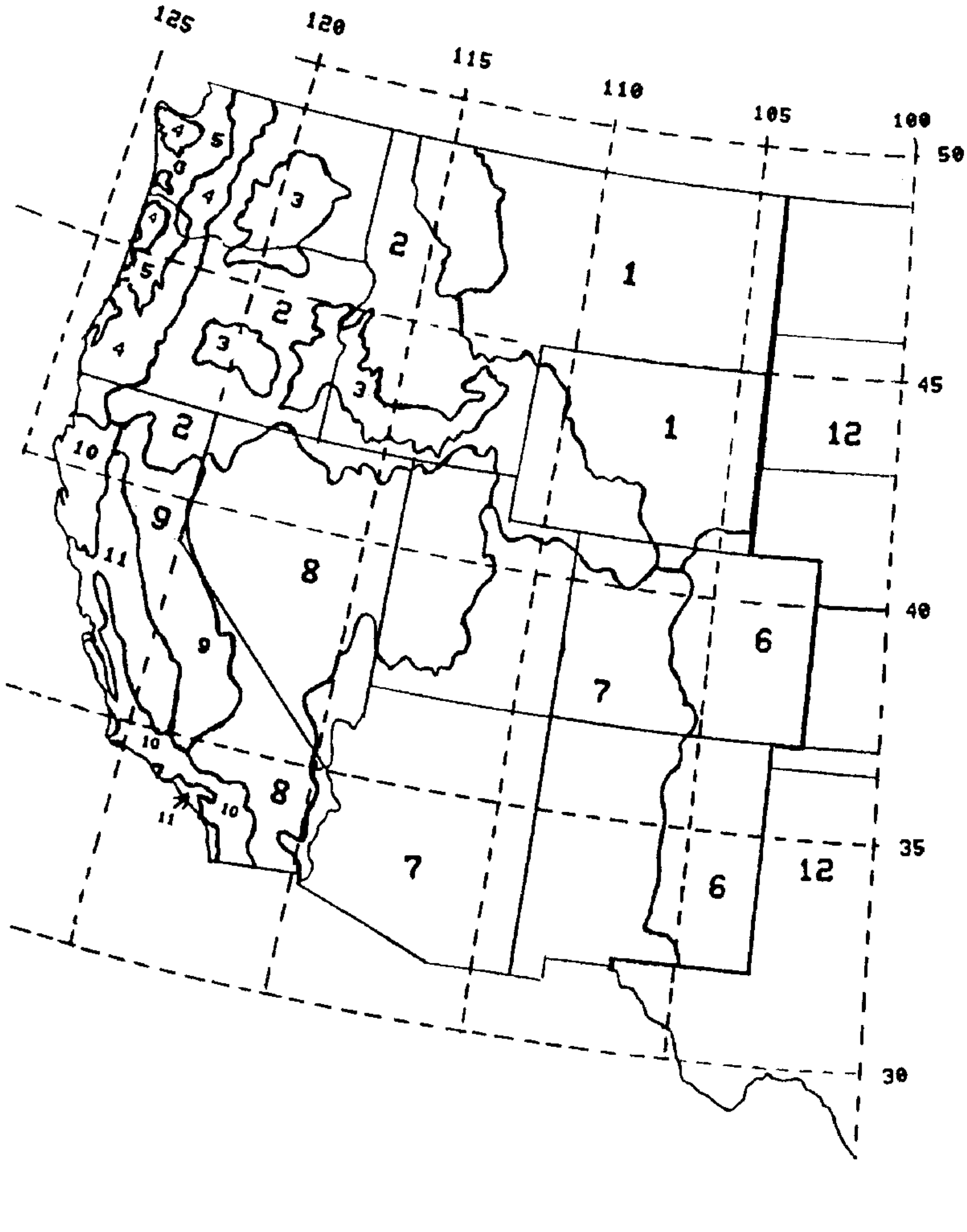
7. References.

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.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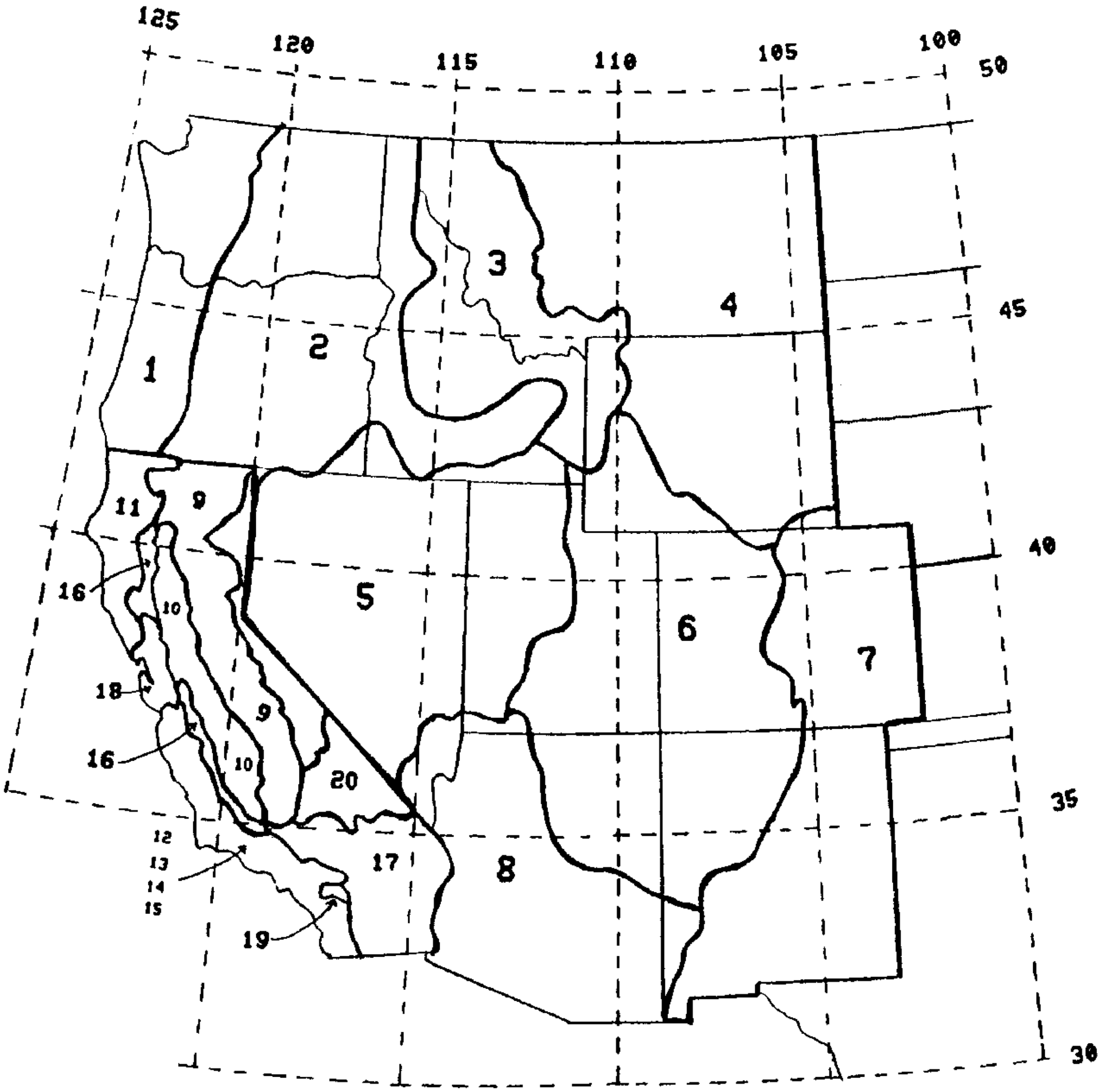
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APPENDIX C1

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 2.05 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

DURATION	RETURN PERIOD 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

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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

DURATION	RETURN PERIOD 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   O F   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

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
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   OF   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.

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APPENDIX B I-D-F GRAPH

B.1 Intensity-Duration-Frequency for Phoenix-Sky Harbor

Table B.1
NOAA ATLAS 14 DEPTH-DURATION-FREQUENCY AT PHOENIX-SKY HARBOR

State	**Arizona**
Station	
Lon (dd)	**-112.05**
Lat (dd)	**33.434**
Elev (feet)	**1122**

Rainfall Depth, inches

Frequency years	Duration									
	5-min	10-min	15-min	30-min	60-min	120-min	3-hr	6-hr	12-hr	24-hr
1	0.18	0.28	0.35	0.47	0.58	0.66	0.70	0.85	0.96	1.11
2	0.24	0.37	0.46	0.61	0.76	0.86	0.89	1.08	1.21	1.41
5	0.33	0.50	0.62	0.84	1.04	1.15	1.18	1.39	1.55	1.83
10	0.40	0.60	0.75	1.01	1.25	1.38	1.41	1.64	1.81	2.16
25	0.49	0.74	0.92	1.24	1.53	1.68	1.73	1.97	2.16	2.62
50	0.56	0.85	1.05	1.42	1.75	1.92	1.98	2.24	2.42	2.98
100	0.63	0.95	1.18	1.59	1.97	2.16	2.25	2.52	2.70	3.35
200	0.70	1.06	1.32	1.78	2.20	2.41	2.52	2.80	2.98	3.74
500	0.80	1.21	1.50	2.02	2.50	2.74	2.91	3.18	3.36	4.28
1000	0.87	1.32	1.64	2.21	2.74	3.00	3.22	3.49	3.65	4.70

Table B.2
NOAA ATLAS 14 INTENSITY-DURATION-FREQUENCY AT PHOENIX-SKY HARBOR

Rainfall Intensity, inches/hour

Duration minutes	Frequency, years					
	2	5	10	25	50	100
5	2.88	3.96	4.80	5.88	6.72	7.56
10	2.22	3.00	3.60	4.44	5.10	5.70
15	1.84	2.48	3.00	3.68	4.20	4.72
30	1.22	1.68	2.02	2.48	2.84	3.18
60	0.76	1.04	1.25	1.53	1.75	1.97
120	0.43	0.58	0.69	0.84	0.96	1.08
180	0.30	0.39	0.47	0.58	0.66	0.75
360	0.18	0.23	0.27	0.33	0.37	0.42
720	0.10	0.13	0.15	0.18	0.20	0.23
1440	0.06	0.08	0.09	0.11	0.12	0.14

Values in Table B.2 are computed using values from Table B.1. For example, the 2-year 5-minute intensity for the 2-year 5-minute duration is computed as follows:

$$i_{2,5} = \frac{D_{2,5}}{5\ min} = \frac{0.24\ inch}{5\ min/60\ min/hour} = 2.88\ inches/hour$$

Figure B.1
NOAA ATLAS 14 D-D-F CURVES AT PHOENIX-SKY HARBOR

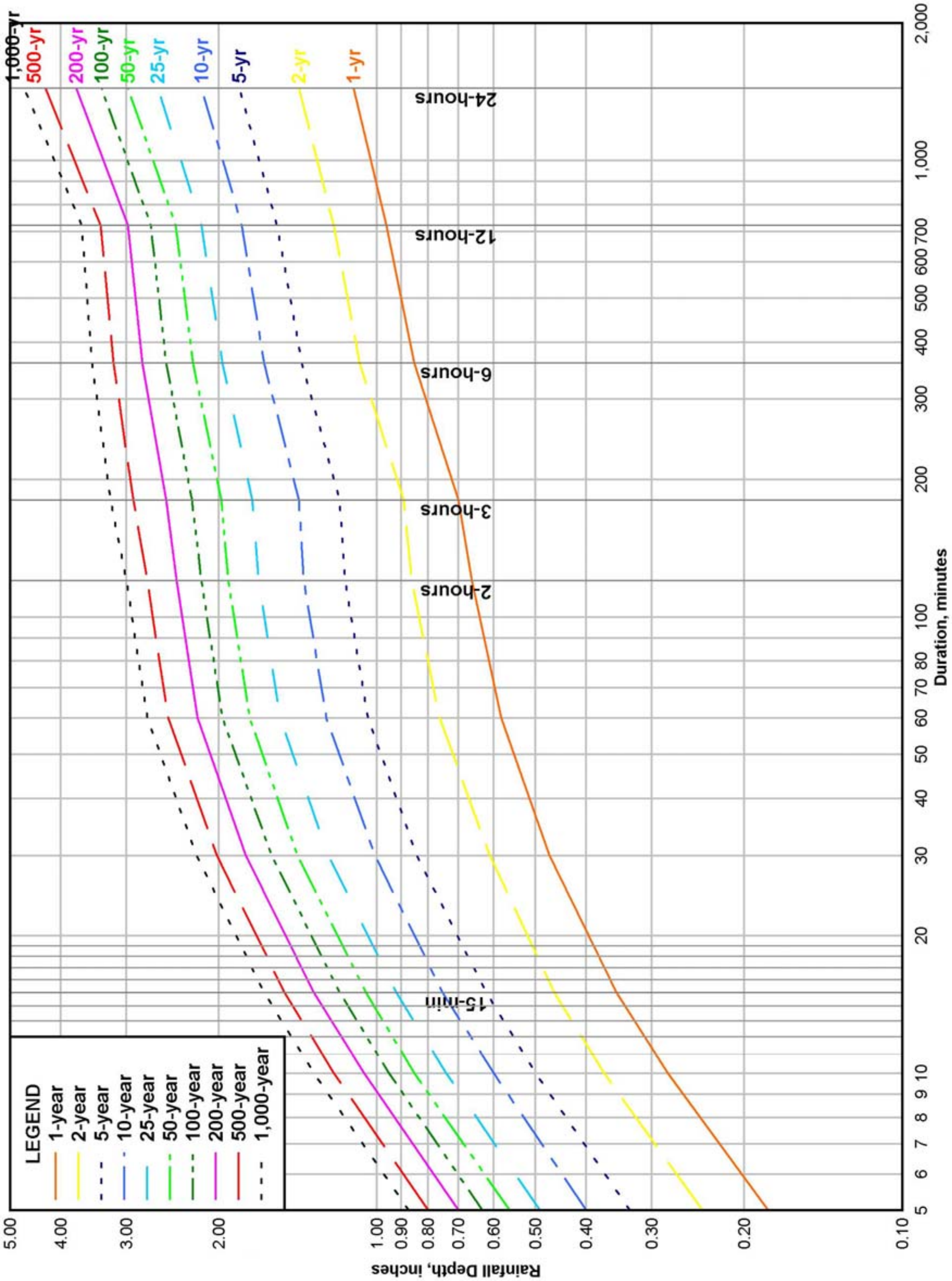
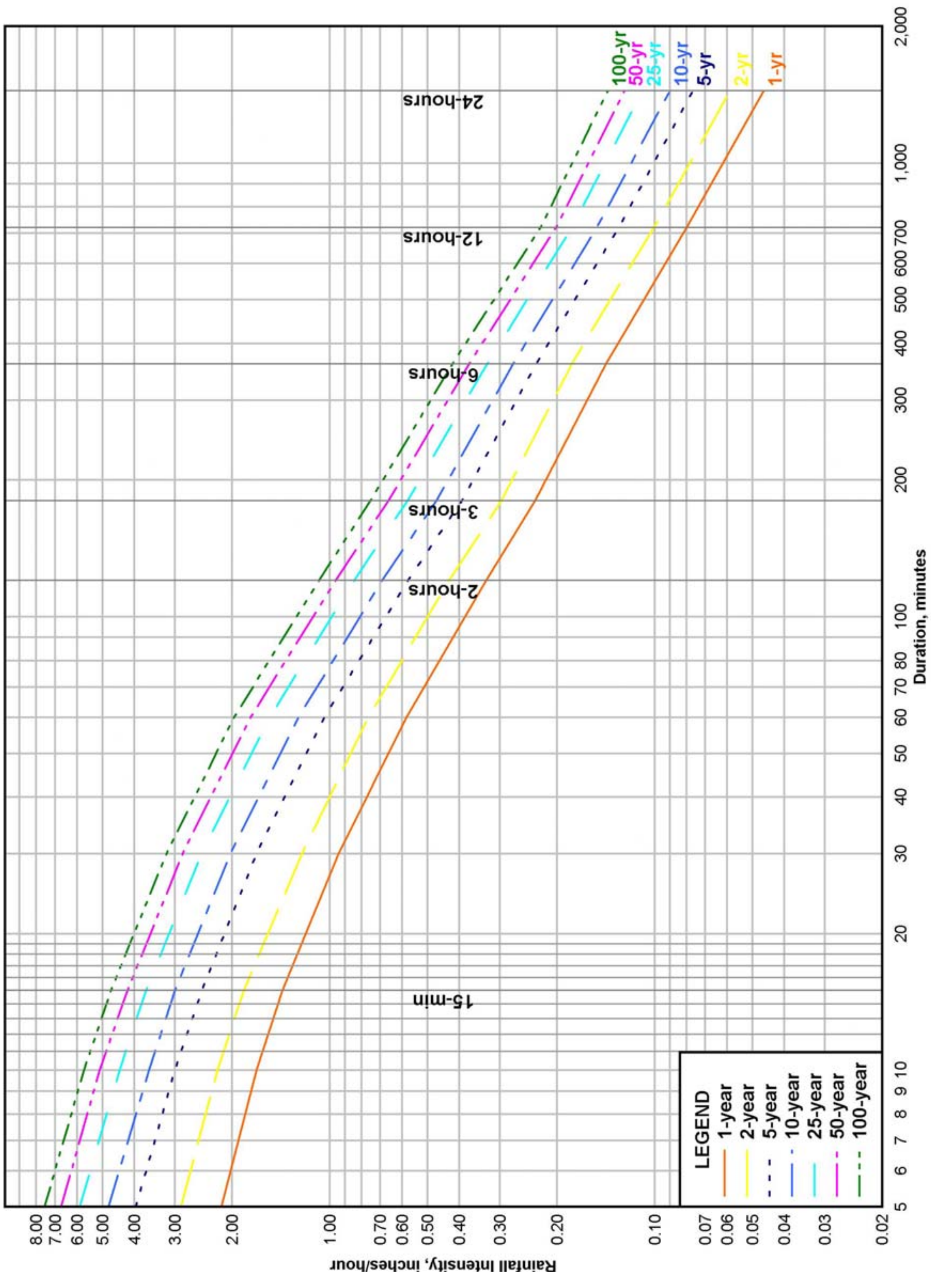


Figure B.2
NOAA ATLAS 14 I-D-F CURVES AT PHOENIX-SKY HARBOR



APPENDIX C LOSS RATE PARAMETER TABLES

C.1 General

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.

Aguila-Carefree Area, AZ, Parts of Maricopa and Pinal Counties

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: OHACO CLAY LOAM
SUN CITY SANDY CLAY LOAM
CAVE LOAM
MOHAVE CLAY LOAM
ARIZO LOAMY SAND
} 3% each

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

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

Maricopa County, AZ, Central Part

MAP UNIT CO : CHERIONI - ROCK OUTCROP COMPLEX

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

MINOR SOILS: GACHADO VERY GRAVELLY CLAY LOAM
PINAL LOAM
GUNSIGHT LOAM
RILLITO LOAM
} 30%

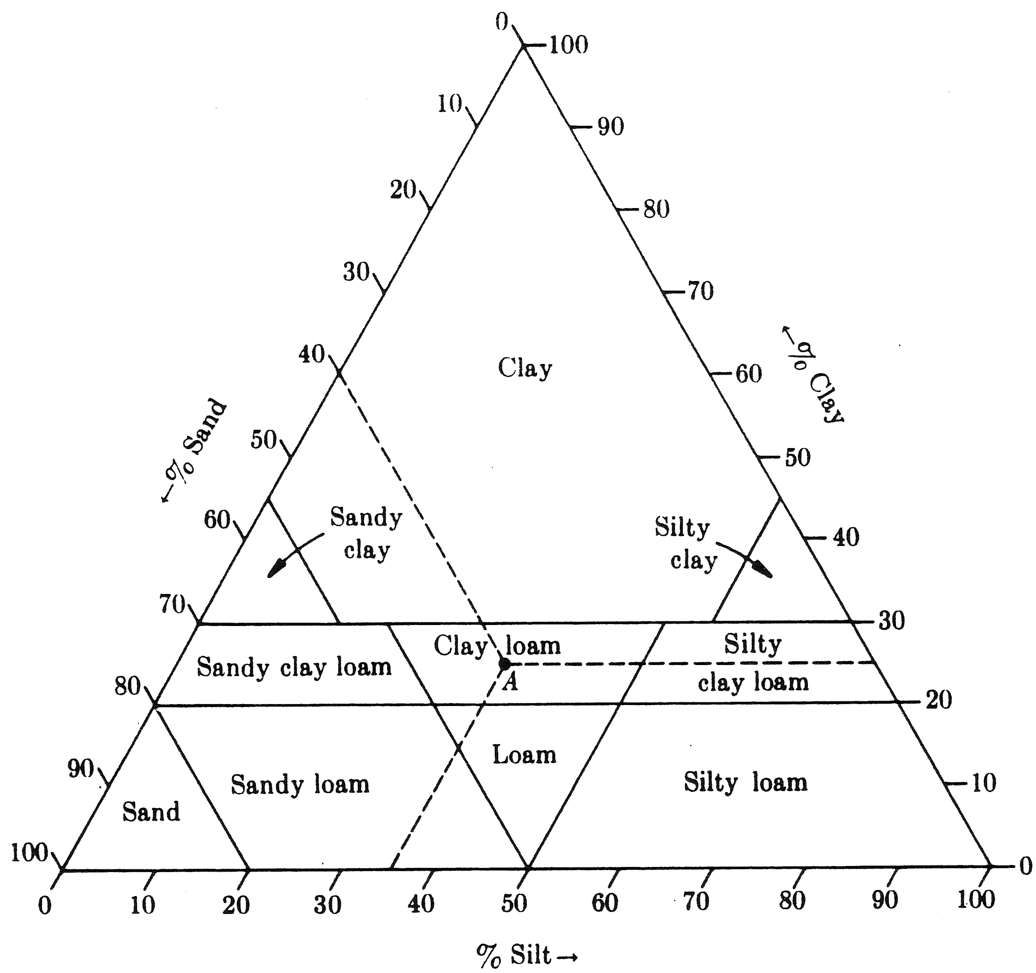
SINCE THIS MAP UNIT CONTAINS ROCK OUTCROP, THE SOIL PERCENTAGES MUST BE NORMALIZED:
CHERIONI → 50/100-20 = 62.5%
MINOR SOILS → 30/80 = 37.5% /4 = 9.4% each

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.

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

SOIL TEXTURE CLASSIFICATION

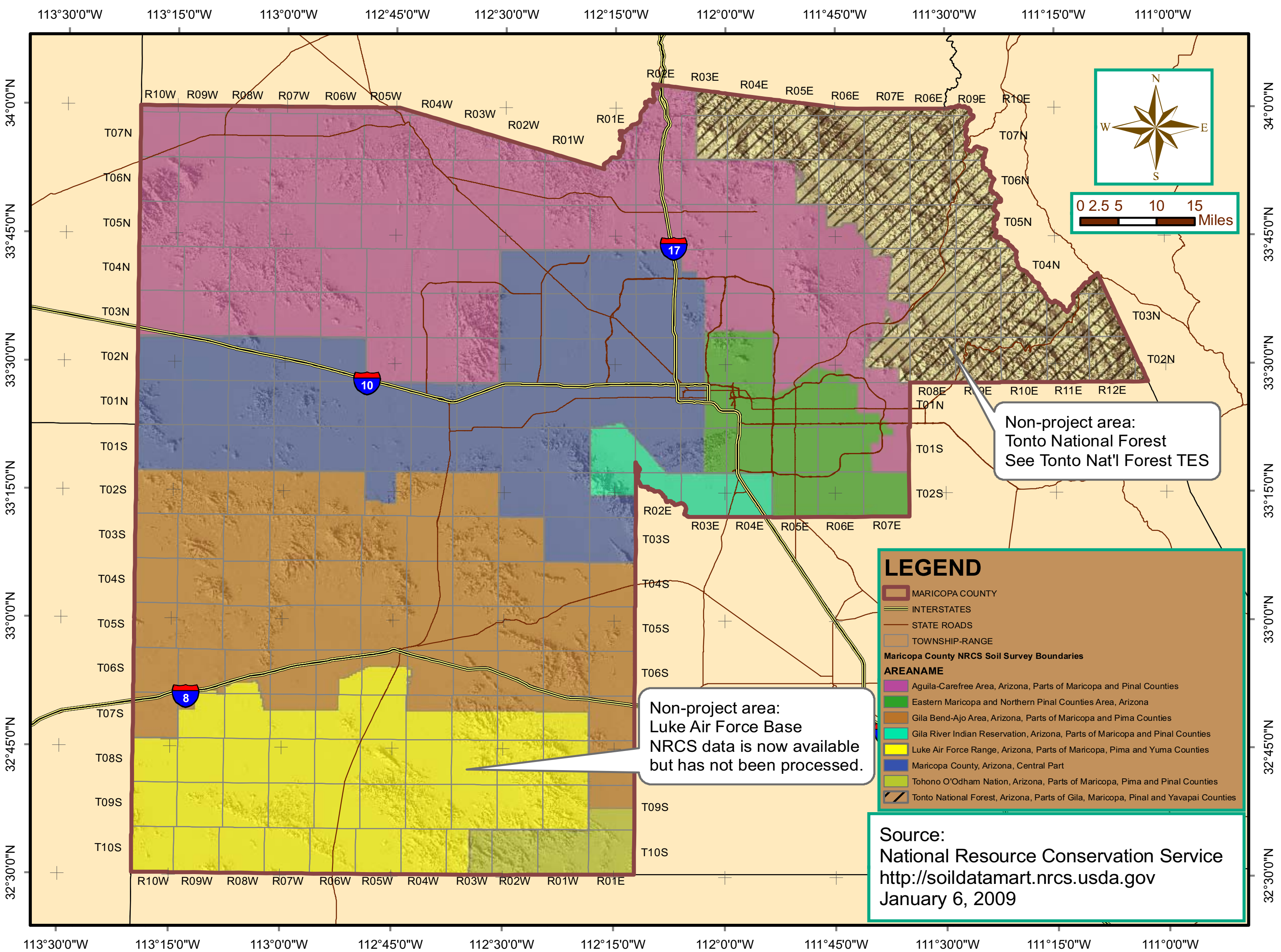
TRIANGLE



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.

FIGURE C.1
NRCS SOIL SURVEYS FOR THE MARICOPA COUNTY AREA



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C.2 Aguila-Carefree Soil Survey

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	XKS/ 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	XKS 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	

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
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	XKS inc.. 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	XKS/ Inc. 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	

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C.3 Maricopa Central Soil Survey

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	XKS/ 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	
	Antho	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	XKSA 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	

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
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	

C.4 Eastern Maricopa/Northern Pinal Soil Survey

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 UNIT HYDROGRAPH

D.1 K_n Values

Data starts on page D-3.

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		CONTRIBUTING AREA	L	L_{ca}	S	LAG	ESTIMATED $K\bar{n}$
		SQ. MI.	MILES	MILES	FT./MI.	HOURS	
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	168.0	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	0.8	.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	20.8	.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	88.0	45	18.8	.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	13.8	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

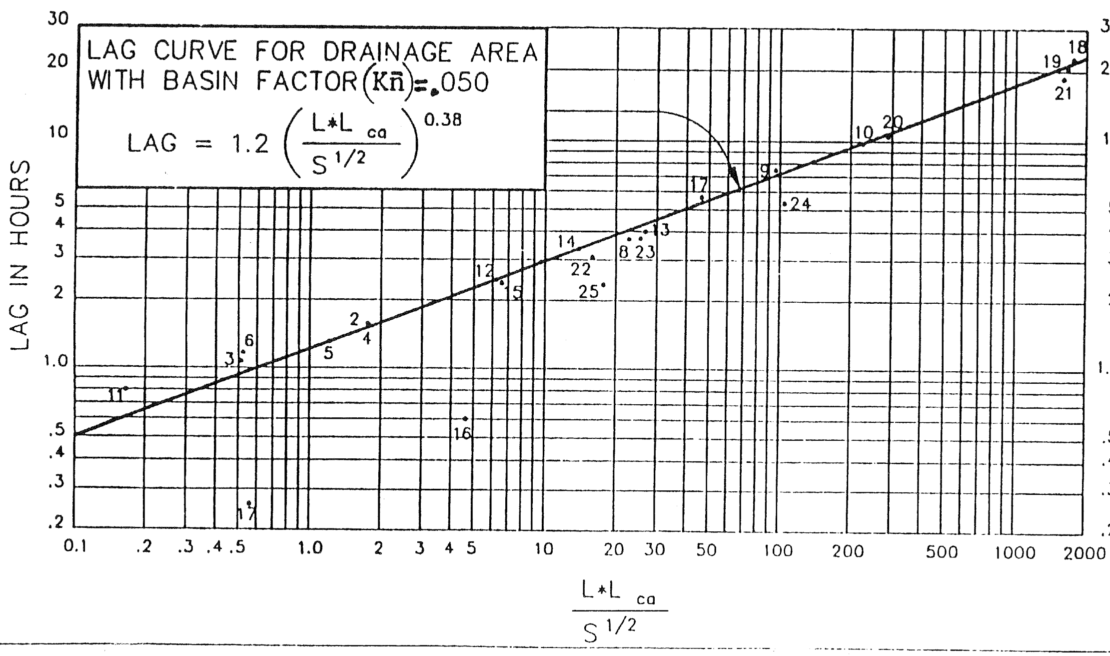
GUIDE FOR ESTIMATING BASIN FACTOR $K\bar{n}$

$K\bar{n}$ = 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 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.				Watershed	Location	A	L	Lca	S	L*Lca	Lag	kn
B	C	D	F			(sq. miles)	(miles)	(miles)	(ft/ml)	S^.5	(hrs)	
		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	0.640	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	29.4616	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	5.380	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	18.000	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	29.4616	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	3.600	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 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	88.90	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	0.1096	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	38.000	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

Not representative of Maricopa County mountain and foothil watersheds.

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 Desert/Rangeland Watersheds
(Kn values sorted in ascending order)

Reference and I.D. No.			Watershed	Location	A	L	Lca	S	L*Lca / S^.5	Lag	kn
C	D	F			(sq. miles)	(miles)	(miles)	(ft/mi)		(hrs)	
	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.