ARIZONA DEPARTMENT OF WATER RESOURCES
FLOOD MITIGATION SECTION

State Standard For Hydrologic Modeling Guidelines

Technical Supplement

Under the authority outlined in ARS 48-3605(A) the Director of the Arizona Department of Water Resources establishes the Standard for Hydrologic Modeling Guidelines in Arizona.

This Technical Supplement presents background data for development of the State Standard for Hydrologic Modeling Guidelines.

This requirement is effective August, 2007.

Copies of the State Standard and State Standard Technical Supplement can be obtained by contacting the Department's Water Engineering Section at (602) 771-8652.

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Final Report on Phase I: Literature Search and Assessment of Current Practices

STATE STANDARD WORK GROUP
HYDROLOGIC MODELING GUIDELINES

FINAL REPORT ON PHASE I:
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INTRODUCTION AND PURPOSE

This report has been prepared to document the efforts undertaken during Phase I of the project hereafter referred to as the “State Standard for Hydrologic Modeling Guidelines”.

The objective of this study is to develop technical guidelines for hydrologic modeling in Arizona. This Standard will focus on computer programs used to perform rainfall – runoff modeling for the purposes of engineering design and floodplain management and shall include, but not be limited to, evaluating the design storm event, and modeling guidelines for watersheds impacted by natural or human induced conditions such as rapid snowmelt, fire, logging, drought, grazing, etc. This Standard will outline hydrologic modeling criteria and procedures.

Phase 1 is the literature search review and data collection effort and includes the following;

1. Perform a literature search to identify publications relating to precipitation and runoff within Arizona.
2. Perform data collection activities consisting of a literature search of various databases.
3. Contact federal, state and local agencies engaged in acquiring and maintaining hydrological and meteorological data to assess published standards, guidelines, or manuals that address the topics described above in the study objective description.
4. Contact appropriate private companies and/or vendors to determine if standards, guidelines, or manuals have been developed that meet the requirements of the literature search.
5. Contact local Floodplain Management Agencies within the state to determine the methods used for hydrologic calculations.

LITERATURE SEARCH & DATA COLLECTION

A literature search was performed of a wide variety of information sources. The results of the literature search yielded hundreds of references of which a portion was considered relevant enough to warrant documenting. The selected references are included in Appendix A. Please note that the references have been included in the appendix in the form found during the literature search to facilitate identification of the original source of the reference.

Based on inspection of the titles and (where available) abstracts or brief descriptions, the results of the literature search tended to yield references which appeared to be of varying usefulness in developing hydrologic modeling guidelines for Arizona. The table below provides the titles of some of the more promising references based on title and/or abstract review or previous knowledge of the reference. The table below also includes indicator columns listing five key hydrologic modeling components (HMC). The columns for each reference are marked where it appears that the reference offers guidance on that modeling component.

Reference	**Hydrologic Modeling Component (HMC)**				
	1	2	3	4	5
	Rainfall	Basin Definition	Rainfall Losses	Unit Hydrographs /Basin Response	Hydrologic Routing
Highway Drainage Design Manual – Hydrology, Arizona Department of Transportation, FHWA-AZ93-281, 1993	X	X	X	X	X
Drainage Design Manual for Maricopa County, Volume I, Hydrology, draft revision, 2003	X	X	X	X	X
Drainage Design Manual for Maricopa County, Volume II, Hydraulics, 3rd Edition, draft, revised Sept. 2003					X
Drainage Design Manual for Maricopa County, Arizona, Vol I, Hydrology, Revised 1995	X	X	X	X	X
Drainage Design Manual for Maricopa County, Volume II, Hydraulics, 2nd Edition, revised Jan. 28, 1996					X
Hydrology Manual for Engineering Design and Floodplain Management within Pima County, Arizona, September 1979	X				
Town of Oro Valley Drainage Criteria Manual, October 2002	X	X	X	X	X
Clark County Regional Flood Control District Hydrologic Criteria and Drainage Design Manual, August 1999.	X	X	X	X	X
Urban Storm Drainage Criteria Manual, Volume I, 2004, Denver Co	X	X	X	X	X
HEC-HMS Technical Reference Manual, U.S. Army Corps of Engineers, March 2000	X	X	X	X	X
Pinal County Drainage Manual, Volume II, Design Methodology and Procedures, Final Draft August 2004	X	X	X	X	X
HEC-1 Flood Hydrograph Package – Users Manual, U.S. Army Corps of	X	X	X	X	X

Reference	**Hydrologic Modeling Component (HMC)**				
	1	2	3	4	5
	Rainfall	Basin Definition	Rainfall Losses	Unit Hydrographs /Basin Response	Hydrologic Routing
Engineers, September 1990					
Urban Hydrology for Small Watersheds, TR-55, U.S. Department of Agriculture, Soil Conservation Service, June 1986	X			X	
NRCS, 1997, NEH630 Hydrology National Engineering Handbook, U.S. Department of Agriculture, Washington D.C.	X	X	X	X	X
Cudworth, Jr., A.G., 1989, Flood Hydrology Manual, US Bureau of Reclamation, Denver, CO, 243 p.	X	X	X	X	X
GVSCE, 1987, S-Graph Study, study prepared for FCDMC under contract No. FCD 86-36.				X	
USACE, 1994, EM 1110-2-1417 - Engineering and Design - Flood-Runoff Analysis, CECW-EH, **31 August 1994** http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1417/toc.htm	X	X	X	X	X
USACE, 1990, River Routing with HEC-1 and HEC-2, Training Document No. 30					X
USACE, 1983, Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program, Technical Paper No. 93					X
USACE, 1982, Hydrologic Analysis of Ungaged Watersheds Using HEC-1, Training Document No. 15.	X	X	X	X	X
USACE, 1981, Hydrologic Engineering in Planning, Training Document No. 14.	X	X	X	X	X
USACE, 1979, Introduction and Application of Kinematic Wave Routing Techniques Using HEC-1, Training Document No. 10.					X
USACE, 1998, Runoff from Snow Melt, U.S. Army Corps of Engineers, Washington DC	X				
NOAA Altas 14, 2004, Precipitation-Frequency Atlas of the United States, Volume I: Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Siver Spring	X				
HYDRO-40, 1984, Depth-Area Ratios in the Semi-arid Southwest United States, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Siver Spring, Maryland.	X				
FEMA, 2004, The hydrologic and hydraulic methodology used to estimate post-burn floodplain hazards, FEMA-1498-DR-CA			X		
Lopes, Vicente L., Ffolliott, Peter F., 1993, **Sediment Rating Curves for a Clearcut Ponderosa Pine Watershed in Northern Arizona, Water Resources Bulletin,** Volume 29, Number 3, June 1993, Pages 369-382			X	X	
Bravo, Rolando, Dow, David A., Rogers, Jerry R., 1994, **Parameter**					X

Reference	Hydrologic Modeling Component (HMC)				
	1	2	3	4	5
	Rainfall	Basin Definition	Rainfall Losses	Unit Hydrographs /Basin Response	Hydrologic Routing
Determination for the Muskingum-Cunge Flood Routing Method, Water Resources Bulletin, Volume 30, Number 5, October 1994, Pages 891-899					
Loague, Keith**, 1992, Using Soil Texture to Estimate Saturated Hydraulic Conductivity and the Impact on Rainfall-Runoff Simulations, Water Resources Bulletin**, Volume 28, Number 4, August 1992, Pages 687-693			X		
Grove, Matt, Harbor, Jon M., Engel, Bernard **, 1998, Composite Vs. Distributed Curve Numbers, Water Resources Bulletin,** Volume 34, Number 5, October 1998, Pages 1015-1023			X		
Jan Høybye and Dan Rosbjerg, 1999, Effect of Input and Parameter Uncertainties in Rainfall-Runoff Simulations, J. Hydrologic Engrg., Volume 4, Issue 3, pp. 214-224 (July 1999)	X		X	X	
T. Devi Prasad, Rajiv Gupta, and Satya Prakash, 1999, Determination of Optimal Loss Rate Parameters and Unit Hydrograph, J. Hydrologic Engrg., Volume 4, Issue 1, pp. 83-87 (January 1999)			X	X	
K. D. Sharma and J. S. R. Murthy, 1995, Hydrologic Routing of Flow in Arid Ephemeral Channels, J. Hydr. Engrg., Volume 121, Issue 6, pp. 466-471 (June 1995)					X
Resnick, Sol Donald., Diskin, Mordechai Haim, 1984, Choice, testing, and modification of storm hydrograph models with urban rainfall/runoff data in the semi-arid southwest : research project technical completion report (37307) .				X	
Hill, Gary W., Hales, T. A., Aldridge, B. N., 1987, Flood hydrology near Flagstaff, Arizona / by G.W. Hill, T.A. Hales, and B.N. Aldridge ; prepared in cooperation with the City of Flagstaff, Arizona., USGS **WRI no.87-4210**			X		X
Ward, Timothy J., Bolton, Susan M., 1991, Hydrologic parameters for selected soils in Arizona and New Mexico as determined by rainfall simulation : technical completion report.			X		
Anderson, Eric A., 1973: "National Weather Service River Forecast System -- Snow Accumulation and Ablation Model", NOAA Technical Memorandum NWS HYDRO-17, US Dept. of Commerce, Silver Spring, MD, 217p	X				
Anderson, Eric, A., 1976: "A Point Energy and Mass Balance Model of a Snow Cover", NOAA Technical Report 19, U.S. Dept. of Commerce, Silver Spring, MD, 150p	X				
McLin, S.G., et al, 2001, Prediction floodplain boundary changes following the Cerro Grande wildfire, Hydrological Processes, Vol. 15, pp. 2967-2980.			X	X	
Moody, J.A. and Martin, D.A., 2001, Post-fire, rainfall intensity-peak discharge relations for three mountainous watersheds in the western USA, Hydrological Processes, Vol. 15, pp. 2981-2993					

Reference	**Hydrologic Modeling Component (HMC)**				
	1	2	3	4	5
	Rainfall	Basin Definition	Rainfall Losses	Unit Hydrographs /Basin Response	Hydrologic Routing
Martin, D.A. and Moody, J.A., 2001, Comparison of soil infiltration rates in burned and unburned mountainous watersheds, Hydrological Processes, Vol. 15, pp. 2893-2903.			X		
S. El-Hames, K. S. Richards, 1998, An integrated, physically based model for arid region flash flood prediction capable of simulating dynamic transmission loss, Hydrological Processes, VL: 12, NO: 8, PG: 1219-1232					X
R. García Díaz, 2005, Analysis of Manning coefficient for small-depth flows on vegetated beds, Hydrological Processes, VL: 19, NO: 16, PG: 3221-3233				X	X
Surendra Kumar Mishra, Vijay P. Singh, 2003, Role of dimensionless numbers in wave analysis, Hydrological Processes, VL: 17, NO: 3, PG: 651-669					X
Roger Moussa, 2002, On morphometric properties of basins, scale effects and hydrological response, Hydrological Processes, VL: 17, NO: 1, PG: 33-58				X	X
A. David Knighton, Gerald C. Nanson, 2002, Inbank and overbank velocity conditions in an arid zone anastomosing river, Hydrological Processes, VL: 16, NO: 9, PG: 1771-1791				X	X
Steve W. Lyon, M. Todd Walter, Pierre Gérard-Marchant, Tammo S. Steenhuis, 2004, Using a topographic index to distribute variable source area runoff predicted with the SCS curve-number equation, Hydrological Processes, VL: 18, NO: 15, PG: 2757-2771			X		
G. L. Heritage, B. P. Moon, L. J. Broadhurst, C. S. James, 2004, The frictional resistance characteristics of a bedrock-influenced river channel, Earth Surface Processes and Landforms, VL: 29, NO: 5, PG: 611-627				X	X
Robert N. Armstrong, Lawrence W. Martz, 2003, Topographic parameterization in continental hydrology: a study in scale, Hydrological Processes, VL: 17, NO: 18, PG: 3763-3781		X			
R. Moussa, C. Bocquillon, 1996, Algorithms for solving the diffusive wave flood routing equation, SO: Hydrological Processes, VL: 10, NO: 1, PG: 105-123					X
I. MUZIK, 1996, FLOOD MODELLING WITH GIS-DERIVED DISTRIBUTED UNIT HYDROGRAPHS, Hydrological Processes, VL: 10, NO: 10, PG: 1401-1409				X	
V. P. Singh, 2001, TI: Kinematic wave modeling in water resources: a historical perspective, Hydrological Processes, VL: 15, NO: 4, PG: 671-706				X	X
A Ashfaq, P Webster, 2000, The timing of runoff response in design flood analysis, Hydrological Processes, VL: 14, NO: 7, PG: 1217-1233				X	
T. Moramarco, V. P. Singh, 2000, A practical method for analysis of river waves and for kinematic wave routing in natural channel networks,					X

Reference	Hydrologic Modeling Component (HMC)				
	1	2	3	4	5
	Rainfall	Basin Definition	Rainfall Losses	Unit Hydrographs /Basin Response	Hydrologic Routing
Hydrological Processes, VL: 14, NO: 1, PG: 51-62					
Narendra Kumar Tuteja, Conleth Cunnane, 1999, A quasi physical snowmelt runoff modeling system for small catchments Hydrological Processes, VL: 13, NO: 12-13, PG: 1961-1975		X		X	X
Eylon Shamir, Bisher Imam, Efrat Morin, Hoshin V. Gupta, Soroosh Sorooshian, 2005, The role of hydrograph indices in parameter estimation of rainfall-runoff models, Hydrological Processes, VL: 19, NO: 11, PG: 2187-2207				X	X
Fabrice Rodriguez, Christophe Cudennec, Hervé Andrieu, 2005, Application of morphological approaches to determine unit hydrographs of urban catchments, Hydrological Processes, VL: 19, NO: 5, PG: 1021-1035				X	
Teemu Kokkonen, Harri Koivusalo, Tuomo Karvonen, Barry Croke, Anthony Jakeman, 2004, Exploring streamflow response to effective rainfall across event magnitude scale, Hydrological Processes, VL: 18, NO: 8, PG: 1467-1486	X			X	
C. Cudennec, Y. Fouad, I. Sumarjo Gatot, J. Duchesne, 2004, A geomorphological explanation of the unit hydrograph concept, Hydrological Processes, VL: 18, NO: 4, PG: 603-621				X	

Data sources for historical storms and flooding were investigated by searches of library catalogs of agencies and organizations with storm- and flood-related objectives or responsibilities. These included local flood control districts, federal agencies, and universities.

Appendix B is a bibliographic listing of references of potential use to investigation or evaluation of historic storms and flooding in Arizona. Whenever possible, the URL pointing to the internet resource and/or complete reference is provided. The list is organized by the source where the reference was found, not necessarily by the originator of the reference.

These data will be used to collect historic data needed to validate modeling tests performed as part of the second phase of the Standard development.

AGENCY CONTACTS

A number of federal, state and local agencies were contacted for information related to the study objectives. The table below summarizes the agency contacts.

Agency	**Contact**	**Method**	**Result of contact**
Arizona State University	Dr. Larry Mays	Email	No response
Flood Control District of Maricopa County	Mr. Amir Motamedi Dr. Bing Zhao	Email In-person	Dr. Zhao provided references and direction for obtaining other references.
Salt River Project	Dallas Reigle	Email	Email reply.
U.S. Bureau of Reclamation	Tom Poulson	Email	No response
Central Arizona Project	Brian Henning	Email	No response
City of Flagstaff	Tom Heib	Email	No response
U.S.D.A. Southwest Watershed Research Center (SWWRC)	Dr. David Goodrich	Email In-person	Obtained numerous publications covering a wide range of hydrologic modeling issues and components. Met with staff to discuss project.
Natural Resources Conservation Service	Larry Martinez	Email	No response
U.S.D.A. National Forest Service	Salek Shafiquallah Tom Subirge Grant Loomis	Email	Spoke at length with Salek Shafiquallah who recommended also contacting Grant Loomis for post-fire watershed condition information.

FLOODPLAIN MANAGEMENT SURVEY

As a part of the Phase I effort, floodplain managers in Arizona were surveyed regarding the state of the practice of stormwater. The purpose of this survey was to solicit input from various public and private agencies involved in the preparation or review of hydrologic modeling, which can be incorporated into this evaluation and the effort to develop modeling guidelines.

This effort included sending an initial survey (September 2005) by email to each of the floodplain administrators in Arizona as shown on the floodplain administrator's mailing list maintained by ADWR. The survey was emailed to 97 floodplain administrators around the state. The email list was compiled from ADWR's Floodplain Administrator's list. Email receipts were received from 40 of the 97 sent out. Undeliverable email messages were received from 10 locations. Each of those 10 communities was contacted by telephone for corrected email addresses and resent.

Formal responses to the survey were received from 9 communities/agencies at the time this report was prepared. Those 9 jurisdictions were;

1. Santa Cruz County
2. Coconino County
3. Town of Patagonia
4. Yavapai County
5. City of Sedona
6. Pima County Flood Control
7. City of Tempe
8. Flood Control District of Maricopa County
9. Town of Oro Valley

A follow-up survey was sent in December 2005 to solicit input in regards to design storm data. Responses were received from 14 jurisdictions, including

1. Buckeye
2. Chino Valley
3. Coconino County
4. Gila County
5. Glendale
6. Lake Havasu City
7. Maricopa County
8. Payson
9. Peoria
10. Pima County
11. Scottsdale
12. Surprise
13. Tempe
14. Yavapai County

Appendix C contains:

- A copy of the surveys (in unanswered form)
- A listing of the agencies to which the surveys were sent, and
- A summarization of the findings from the responses received to the surveys.

The highlights of the survey findings are provided in the following paragraphs:

Questions 2 and 3 of the first survey inquired as to whether the jurisdiction had specific regulations regarding hydrologic modeling (Q2) and/or whether the jurisdiction recommended use of a specific manual or reference. Seven of the nine respondents indicated they had either regulations or a recommended manual or reference for hydrologic modeling. Seven different references were cited in the list of recommended or accepted references including; the Arizona Department of Transportation Hydrology Manual (Yavapai County), the Drainage Design Manual for Maricopa County – Volume 1: Hydrology (Maricopa County and Tempe), the Pima County Hydrology Manual (Pima County), the Yavapai County Drainage Criteria Manual (Yavapai County), the Coconino County Drainage Criteria Manual (Coconino County) and the Drainage Criteria Manual for the Town of Oro Valley.
Question 4 of the survey requested input with regard to your jurisdictions experience and/or concerns/problems with the following issues; Design Storm Event, Fire Effects, Logging Effects, Drought Effects, Grazing Effects, Rapid Snowmelt, other. Because of the variety and range of responses to this question, the reader is referred to the summary tables in Appendix C for detailed responses to this question. The responses are summarized in the table below.

Design Storm Event	• Sometimes not adequate for certain features. Culverts should be designed for larger than 100-year events to simulate sedimentation and debris buildup. • With so many of the techniques employing the SCS hydrograph approach, in lieu of the 484 factor, insufficient gaging data in several areas of the state does not allow evaluation of the true hydrograph shape (time to peak, recession, time base) for summer floods as well as winter ones? • For small watersheds we believe the 100-year storm should be the design storm. • Need an open minded evaluation of model parameters including rainfall distribution, NOAA2/NOAA14 data, loss rate (CN, Green AMPT, etc) and unit hydrograph approaches as they influence peak flow estimates.
Fire Effects	• Should be included but need a better understanding of the effects of a given fire and the time it takes to recover (look at Mt. Elden in Flagstaff). • How appropriate are the overland runoff predictors for different phases of revegetation recovery from fire, drought, and over grazing? How sensitive are the 10-yr and 25-yr runoff values to these? Are recoveries from grazing vs. drought effects comparable or should they be treated uniquely? • Have significantly increased runoff due to recent events. • Some extreme fire risk in the area due to proximity of forest lands. • We have modeled the effects of fire. Copies of those reports have been forwarded to Stantec. • Fire effects are generally fairly short duration (4-7 years), however, it would be of value to have an estimate of the increase in 100-year peak and sedimentation association with a major rainfall event immediately

	after a fire.
Logging Effects	• No logging in the area. • Limited issues, but increasing due to bark beetles. • N/A • Not a problem in Tempe. • Not concerned.
Drought Effects	• Long, severe, drought can have the same effect as a fire and should be considered. • Limited issues. • Just coming out of a drought. • Not a problem in Tempe. • Not concerned, except people's perception.
Grazing Effects	• Would be good to include, but you also need to include stop of grazing effects. • Limited. • N/A • Not a problem in Tempe. • Not concerned.
Rapid Snowmelt	• Rainfall on snowpack or wet snow combined with rain has accounted for 9 out of the top 10 floods in Oak Creek near Cornville stream gaging station. See attached flood summary sheet for this gage. • Not included now, but would be good. • Oak Creek rises due to rapid snowmelt/rainstorms in the spring on occasion. • We do not have modeling for this scenario. However, we have watersheds that are impacted by this phenomenon. • Not a problem in Tempe. • Effects winter runoff on major rivers, but regulated by upstream dams.
Other	• Extreme channel slopes (10-15%) and abrupt (drastic) changes in slope (i.e., 1.5% to 3%). • Bark beetles. • Since the Salt River was channeled through Tempe as part of the freeway project our main flooding concern now is the shallow flooding against raised canal banks and railroad beds as indicated on FEMA's FIRMs. Other than those areas, we've been requiring 100-year on-lot retention for most of Tempe since the 1980's, which has reduced our flooding problems to just a few isolated pockets. • Use of rainfall/runoff models and gage analysis alone relies on short-term data, therefore is a moving target. Need better guidelines. • Channel vegetation with no guidelines or plan to manage vegetation at levels/densities similar to when structures built or channel improvements made. • Potential for erosion and lateral migration of channels in non-bank protected areas.

Question 5 of the first survey inquired as to the kinds of problems each agency/jurisdiction has experienced in implementing its hydrologic modeling regulations. Responses to this question focused on lack of consistency or expertise in submitted modeling and on the question of whether to incorporate the new precipitation data developed by NOAA into the communities hydrologic modeling guidelines (see Appendix B also).

Question 6 of the survey inquired as to other contacts or references recommended by the respondent for review as a part of the study effort. Responses to this question included the following;

Santa Cruz County	The design event (100-yr) tends to change with time. Due to development, the Q100 of Nogales Wash downstream of the confluence with Potrero Creek has grown from 17,000 cfs to 24,000 cfs (per COE reports). Perhaps it is time to require the design event to be calculated not on existing conditions, but based on the zoning in the watershed and/or community's comprehensive plan.
Coconino County	Is there a way to take the most frequently used models and do a detailed comparison of strengths and weaknesses in applying them to snowmelt or rainfall with snowmelt, ranges of slopes, ranges in types of forest cover, degree of cinder zones on mountain slopes, ground litter, watershed sizes, and fire, drought and grazing effects? This would help in determining the best models for each set of given conditions.
Town of Patagonia	No response.
Yavapai County Flood Control	An updated website for rainfall data or stream gage data uniformly used.
City of Sedona	No response.
Pima County Regional Flood Control Dist.	ADOT Hydrology Manual.
City of Tempe	No response.
Flood Control District of Maricopa County	Any guidelines that would stabilize hydrologic results (even within 50% is good enough).
Town of Oro Valley	No response.

In summary, the results of the first survey indicated a limited number of specific hydrologic modeling methods/approaches where the jurisdiction indicated a specific approach was required or recommended in that community.

The second survey focused on design storm data. Questions 1 and 2 of inquired as to the design storm duration and rainfall distribution utilized in the jurisdictions. Design storms of the respondents included the 1-, 2-, 6- and 24-hour events. A variety of distributions are utilized, including SCS types I and II, ADOT hypothetical, Queen creek, and historic events. Question 3 asked if a design storm is chosen based upon the greatest volume or greatest discharge. Respondents indicated that the greatest peak discharge is utilized unless volume is critical (such as for flood storage design). Questions 4-7 and 9 of the second survey required yes or no answers and are summarized below:

Question 4 Do you choose different design storms for direct sized watersheds?	6 Yes, 8 No
Question 5 Do you choose different design storms for watersheds based on elevation?	2 Yes, 12 No
Question 6 Do you choose different design storms based upon the shape of the watershed?	3 yes, 11 No
Question 7 Does your 100-year design storm consider rapid snowmelt for those watersheds with higher elevation that could sustain a snow pack during the winter?	1 Yes, 13 No
Question 9 Does your community have good rainfall runoff data from which a design storm could be derived?	3 Yes, 6 No, 3 So-So, 2 Rely on MCFCD data

Question 8 inquired as to the type of seasonal precipitation that creates the most difficult modeling problems. Ten (10) of the respondents indicated monsoon storms, 2 indicated winter storms, 1 jurisdiction (Payson) indicated snow pack and monsoon thunderstorms, and one was not sure. In response to Question 10, the respondents indicated that duration, cost effectiveness, spatial distribution, soils data, perception of requirements, and seasonal variation were all difficult issues to address in choosing a design storm. Detail summary of the second survey is provided in Appendix C.

HYDROLOGIC MODELS

A list of Hydrologic Models, which meet the minimum requirements of the National Flood Insurance Program (NFIP), is provided in Appendix D. This list will be utilized as a starting point for providing a list and description of readily available models in the Standard. The goal will be to recommend a model, or models, which are acceptable to FEMA.

Two major categories of models are expected to be presented: a) distributed models, and b) lumped parameter models. It is expected that an emphasis will be placed on lumped parameter models due to their relative ease of use, data availability, and widespread understanding and use within the engineering community in Arizona.

APPENDIX 1-A

References from Literature Search

Bibliography

Journal Articles

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Agnese, Carmelo, Baiamonte, Giorgio and Corrao, Cecilia, 2001, ”A Simple Model Of Hillslope Response For Overland Flow Generation”, *Hydrological Processes*, Vol. 15 (17): 3225-3238.

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Asquith, William H., Bumgarner, Johnathan R. and Fahlquist, Lynne S., 2003, “A Triangular Model Of Dimensions Runoff Producing Rainfall Hyetographs In Texas”, *American Water Resources Association*, Vol. 39 (4): 911-921.

Barros, Ana P., Kanpton, David and Wang, M.C. and Kuo, C.Y., 1999, “Runoff In Shallow Soils Under Laboratory Conditions”, *Journal of Hydrologic Engineering*, Vol. 4 (1): 28-37.

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Beighley, R. E., Dunne, T. and Melack, J. M., 2005, "Understanding and Modeling Basin Hydrology: Interpreting The Hydrogeological Signature", *Hydrological Processes*, Vol. 19 (7): 1333-1353.

Beldring, Stein, Gottschalk, Lars, Rodhe, Allan and Tallaksen Lena M., 2000, "Kinematic Wave Approximations To Hillslope Hydrological Processes In Tills", *Hydrological Processes*, Vol. 14 (4): 727-745.

Bell, Frederick c, 1969 "Generalized Rainfall- Duration- Frequency Relationships", *Journal Of The Hydraulics Division, American Society Of Civil Engineers*, Vol. 95, No. HY11, 311-327.

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APPENDIX 1-B

Data Sources for Historical Storms and Flooding

DATA SOURCES FOR HISTORICAL STORMS AND FLOODING

Flood Control District of Maricopa County

http://www.fcd.maricopa.gov/Services/ALERT/default.asp
http://www.fcd.maricopa.gov/Services/ALERT/Publications.asp

Call Number: 802.013
Title: Flood-Damage Report on Storm and Flood of 16-17 August 1963, Glendale - Maryvale Area Near Phoenix, Arizona
Author: U. S. Corps of Engineers-COE
Date: 1964

Call Number: 802.028
Title: Flood Damage Report Storm and Flood of September 4-6, 1970, City of Phoenix, Arizona
Author: Attebery, James E.; Phoenix City Engineer
Date: 1971

Call Number: 802.003
Title: The 1970 Labor Day Storm
Author: Thorud, David B.; Folliott, Peter F.; U of A
Date: 1971

Call Number: 802.028
Title: Flood Damage Report Storm and Flood of September 4-6, 1970, City of Phoenix, Arizona
Author: Attebery, James E.; Phoenix City Engineer
Date: 1971

Call Number: 007.168
Title: Flooding, Storm Damage, and Federal Land Photos 1930's-72: Gilbert, Queen Creek, Buckhorn-Mesa Watershed, Powerline Floodway, Harquahala Valley, RWCD, WAFB, Magma Floodwater Retarding Dam - Pinal County
Author: Flood Control District of Maricopa County-FCD
Date: 1972

Call Number: 802.004
Title: A Comprehensive Analysis of a Major Storm and Associated Flooding in Arizona
Author: Thorud, David B.; Folliott, Peter F.; Agricultural Experimental Station at the U of A
Date: 1973

Call Number: 1900.042
Title: Tropical Storm Kathleen, Storm Report September 9-10, 1976 (Including Borrego Valley Thunderstorm September 23, 1976)
Author: County of San Diego Dept. of Sanitation and Flood Control
Date: 1976

Call Number: 802.055
Title: Major Storms and Floods in Arizona 1862-1977 (Complied from the Records of the National Weather Service)
Author: Office of the State Climatologist; National Weather Service
Date: 1978

Call Number: 802.024
Title: February 1979, Flood Damage Report, 28 February - 6 March 1978 on the Storm and Floods in Maricopa County, Arizona
Author: U. S. Corps of Engineers-COE
Date: 1979

Call Number: 1515.001
Title: Storms, Floods, and Debris Flows in Southern California and Arizona 1978 and 1980, Proceedings of a Symposium
Author: National Research Council-NRC
Date: 1980

Call Number: 1515.002
Title: Storms, Floods, and Debris Flows in Southern California and Arizona 1978 and 1980, Overview and Summary of a Symposium
Author: National Research Council-NRC
Date: 1980

Call Number: W030.028
Title: Storm Report
Author: San Diego County Flood Control District
Date: 1980

Call Number: 007.114
Title: Newspaper and Magazine Articles: Storms 1959-1983 Including Salt River and 1891 and 1905 Newspaper Flood Photos of Salt River, Mesa, Allenville, Gila River, Cave Creek, Agua Fria River
Author: Various Newspaper and Magazine Articles
Date: 1983

Call Number: 802.009
Title: Flood Report: Buckhorn Mesa Watershed, Maricopa and Pinal Counties, Storm of July 17 and 18, 1984 (Includes Signal Butte FRS, Spook Hill FRS, Apache Junction FRS, Weeks Wash FRS (Weekes Wash), Bulldog Wash, Pass Mountain, CAP)
Author: McArthur, Robin; Millsaps, Harry; Soil Conservation Service-SCS
Date: 1984

Call Number: 007.128
Title: Newspaper and Magazine Articles, Storms in the Phoenix Metro Area 1965-1988 Including Newspaper Article showing 1943 and 1891 Flooding Photos, Salt River, Gila River, Maryvale Area, Phoenix Area, New River, Apache Junction and Chandler Subsidence Pictures
Author: Various Newspaper and Magazine Articles and Flood Control District of Maricopa County Photos
Date: 1988

Call Number: 899.031
Title: Storm Rainfall Probability Atlas for Arizona, Final Report
Author: Brazel, A. J.; Clark, R. A.; Reich, Brian M. for Arizona Dept. of Transportation-ADOT
Date: 1988

Call Number: 000.009
Title: Historical Flooding/Drainage Problem Events (1890-1990 for Reference of Storm Event Dates and Other Information)
Author: Flood Control District of Maricopa County-FCD
Date: 1990

Call Number: 802.024
Title: February 1979, Flood Damage Report, 28 February - 6 March 1978 on the Storm and Floods in Maricopa County, Arizona
Author: U. S. Corps of Engineers-COE
Date: 1979

Call Number: 802.027
Title: Flood Damage Report Phoenix Metropolitan Area December 1978 Flood
Author: U. S. Corps of Engineers-COE
Date: 1979

Call Number: 802.054
Title: Flood Damage Report Phoenix Metropolitan Area December 1978 Flood
Author: U. S. Corps of Engineers-COE
Date: 1979

Call Number: 802.015
Title: Flood Damage Report January 1980 Southcentral Arizona and Southwestern New Mexico, December 1978 Flood
Author: U. S. Corps of Engineers-COE
Date: 1980

Call Number: 802.029
Title: Phoenix Flood Damage Survey: February 1980
Author: U. S. Corps of Engineers-COE
Date: 1981

Call Number: 802.051
Title: Flood Damage Report, State of Arizona, Floods of 1993
Author: U. S. Army Corps of Engineers-COE
Date: 1994

Call Number: 1700.005
Title: Arizona Climate, The First Hundred Years (1885-1985)
Author: Sellers, William D., Hill, Richard. H., Sanderson-Rae, Margaret
Date: 1985

Call Number: 801.002
Title: Basin Characteristics and Streamflow Statistics in Arizona as of 1989
Author: U. S. Geological Survey-USGS in Cooperation with Arizona Dept. of Water Resources-ADWR and Flood Control District of Maricopa County-FCD
Date: 1991

Call Number: 801.001
Title: Statistical Summaries of Arizona Streamflow Data
Author: U. S. Geological Survey-USGS in Cooperation with Arizona Water Commission-AWC
Date: 1979

Call Number: 801.008
Title: Statistical Summaries of Streamflow Data and Characteristics of Drainage Basins for Selected Streamflow-Gaging Stations in Arizona through Water Year 1996
Author: U. S. Geological Survey-USGS
Date: 1998

NWS

http://www.wrh.noaa.gov/twc/hydro/floodhis.php

This page provides brief text summaries and peak flow data (courtesy of the USGS) for most of the floods and flash floods that have impacted southeast Arizona.

http://hdsc.nws.noaa.gov/hdsc/pfds/sa/az_pfds.html

This page is the NOAA NWS Hydrometeorological Design Studies Center Precipitation Frequency Data Server site. It provides access to precipitation frequency data for all of Arizona based on the NOAA 14 analyses.

http://www.wrcc.dri.edu/pcpnfreq.html

This page is the Western U.S. Precipitation Frequency Maps Source for NOAA Atlas 2 published in 1973. Scanned images of the isohyetal maps from the Atlas 2 can be downloaded here.

http://www.wrcc.dri.edu/CURRENTOBS.html

This page is the Western Regional Climate Center's page with links to Current Observations, Forecasts and Monitoring for weather data in the Western US.

http://www.cbrfc.noaa.gov/

This page is NOAA Colorado Basin River Forecast Center's river forecast and data access site. It provides access to streamflow data and streamflow forecast throughout the Colorado River watershed.

http://www.wrh.noaa.gov/psr/DroughtPage.php?data=ALLDATA

This page is the National Weather Service Phoenix Weather Forecast Office drought monitoring page. It provides access to current and historical monthly precipitation statistics for observation stations throughout Arizona.

http://www.nws.noaa.gov/oh/hdsc/index.html

This is the Home Page for the Hydrometeorological Design Studies Center, part of the National Weather Service's Office of Hydrologic Development, Hydrology Laboratory. This is a specialized web site for those interested in: precipitation frequency (PF) and probable maximum precipitation (PMP).

http://www.nws.noaa.gov/oh/hdsc/max_precip/images/Maxprecpnew.htm#

This page provides a plot of the maximum observed point rainfall values for different durations for the entire globe and the United States.

http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms

This is the search page for the NCDC Storm Event database of various types of storms recorded in your county or use other selection criteria as desired. The database currently contains:

- All Weather Events from 1993 - 1995, as entered into Storm Data. (Except 6/93 - 7/93, which is missing) (NO Latitude/Longitude)
- All Weather Events from 1996 - Current, as entered into Storm Data. (Including Latitude/Longitude)
- Plus additional data from the Storm Prediction Center; Including
    - Tornadoes 1950-1992
    - Thunderstorm Winds 1955-1992
    - Hail 1955-1992

For large scale events such as flooding, winter storms, hurricanes and extreme temperatures, please search by state and/or date instead of by county name.

The Storm Events Database is updated when the data becomes available to NCDC.
The data is updated on a monthly basis and is usually 90-120 days behind the current month

ALERT Systems

http://www.co.yavapai.az.us/YavEnterpriseSoln/FloodControl/IntroPage.aspx

This is the home page for the Yavapai County ALERT System.

http://www.fcd.maricopa.gov/Services/ALERT/default.asp

This is the home page for the Flood Control District of Maricopa County ALERT System.

USACE

Subject

Floods Arizona	13 titles
Floods Arizona 1978-1979 (November-March)	1 title
Floods Arizona Agua Fria River Maps	1 title
Floods Arizona Bridgeport	1 title
Floods Arizona Camp Verde	1 title
Floods Arizona Cave Creek	1 title
Floods Arizona Congresses	1 title
Floods Arizona Flagstaff	1 title
Floods Arizona Gila River Basin November 1965-January 1966	1 title
Floods Arizona Grand Canyon	1 title
Floods Arizona Grand Canyon National Park	1 title
Floods Arizona Hassayampa River	1 title
Floods Arizona Indian Bend Wash	1 title
Floods Arizona Lake Montezuma	1 title
Floods Arizona Maricopa Co	1 title
Floods Arizona Maricopa County	1 title
Floods Arizona New River	1 title
Floods Arizona Phoenix metropolitan area	4 titles
Floods Arizona Prescott	1 title
Floods Arizona Santa Cruz Co	2 titles
Floods Arizona Santa Rosa Wash Valley	1 title

Floods Arizona Skunk Creek	1 title
Floods Arizona Tucson	1 title
Floods Arizona Wickenburg	1 title
Floods Arizona Winslow	2 titles
Floods Arizona Yavapai County	1 title

Author United States. Army. Corps of Engineers. Los Angeles District.

Title **Flood plain information: Sells Wash and tributary, vicinity of Sells Papago Indian Reservation Arizona/prepared for Papago Tribe by Corps of Engineers, U.S. Army Los Angeles District.**

Publisher Los Angeles: U.S. Army Corps of Engineers, 1976.

Title **Report on flood of 22 June 1972 in Phoenix metropolitan area, Arizona/U.S. Army Corps of Engineers, Los Angeles District.**

Publisher [Los Angeles]: The Corps, 1972.

Title **Flood-damage report on storm and flood of 26-30 September 1962: Santa Cruz River and Santa Rosa Wash, southern Arizona/U.S. Army Engineer District, Los Angeles, Corps of Engineers.**

Publisher [Los Angeles: The District, 1963].

Note Cover title.

At head of title: Gila River and tributaries, **Arizona** and New Mexico.

"November 1963."

http://library.lib.asu.edu/record=b2428337

U.S. Army Corps of Engineers, Los Angeles District, 1982, Gila River Basin, New River and Phoenix City Streams, Arizona, Design Memorandum No. 2, Hydrology, Part 2, 1982.

U.S. Army Corps of Engineers, Los Angeles District, 1974, Gila River Basin, New River and Phoenix City Streams, Arizona, Design Memorandum No. 2, Hydrology, Part 1, October 1974.

U.S. Army Corps of Engineers, 1995, Hydrologic Evaluation of Impacts of New Waddell Dam on Downstream Peak Discharges in the Agua Fria River. July 1995, L.A. District.

U.S. Army Corps of Engineers, 1988, Hydrology for Evaluation of Flood Reduction by New Waddell Dam, Agua Fria River Below New Waddell Dam to the New River Confluence. September 1988, L.A. District.

USBR

From their online catalog (https://ibrlibrary2.usbr.gov/WebOPAC/index.asp)

1. Upper Gila River Fluvial Geomorphology Study: Flood Frequency and Flow Duration Analysis, Arizona/Prepared by John F. England.
   Author: England, John F.
   Call Number: GB 566.U66flo 2001
   Collection Type: Book

2. Gila River and Tributaries: Central Arizona Water Control Study: Hydrology Report.
   Call Number: TC 424 .A6 G553 1982
   Collection Type: Book

3. Flood on the Virgin River, January 1989, In Utah, Arizona, and Nevada/by Darrell D. Carlson and David F. Meyer.
   Author: Carlson, Darrell D.
   Call Number: QE 75.U58w no.94-4159 1995
   Collection Type: Book

4. Flood Plain Information: Colorado River, Palo Verde Dam to Imperial Dam: Colorado River Front Work and Levee System, Arizona-California/Lower Colorado Region, Bureau of Reclamation.
   Call Number: 150-423 1974
   Collection Type: Report

5. Flood plain Information: Colorado River: Davis Dam to Topock/United States Bureau of Reclamation, Region 3.
   Call Number: 116-423 1969
   Collection Type: Report

6. Flood Plain Information: Colorado River: Imperial Dam to San Luis, Including Portion of Lower Gila River Valley/U.S. Bureau of Reclamation, Lower Colorado River Regional Office.
   Call Number: 85-423 1973
   Collection Type: Report
7. Painted Rock dam operation study: information brochure, March 1977.
   Call Number: TC 557 .A6 P35 1977
   Collection Type: Book

8. Precipitation, Streamflow, and Major Floods at Selected Sites in the Gila River Drainage Basin Above Coolidge Dam, Arizona, by D. E. Burkham.
   Author: Burkham, D. E., 1927-
   Call Number: 173-50 1970
   Collection Type: Book

9. Report on Flood Conditions on Colorado River Below Parker Dam - All-American Canal Project
Author: Rohrer, John K.
Call Number: Archives 142027 39A
Collection Type: Report

10. Floods of November 1965 to January 1966 in the Gila River Basin, Arizona and New Mexico, and Adjacent Basins in Arizona
Author: Aldridge, B. N. (Byron Neil)
Call Number: TC 801.U58 no.1850-C 1970
Collection Type: Book

11. Probable Maximum Flood, Salt and Verde River Basins.
Author: Water Resources Associates (Tex.)
Call Number: Archives 146142 83A
Collection Type: Report

12. Sheetfloods, Streamfloods, and the Formation of Pediments
Call Number: 136447 67A
Collection Type: Report

13. Reconstructing Paleohydrology Flood With Slack-Water Deposits: Verde River, Arizona.
Author: Ely, L. L.
Call Number: 138195 85A
Collection Type: Report

14. Hydrology for Painted Rock Reservoir, Gila River, Arizona.
Author: Windermuth, H. D.
Call Number: 139076 54A
Collection Type: Report

15. Floods of February 1980 in Southern California and Central Arizona
Author: Chin, Edwin H.
Call Number: QE 75.U58p No.1494 1991
Collection Type: Book

16. Transmission Loss of Ephemeral Streambeds
Call Number: 203136
Collection Type: Report

17. Stochastic Space-Time Models of Rainfall Runoff
Call Number: 206106 72
Collection Type: Report

18. Major Storms and Floods in Arizona 1862-1977
Call Number: 126300 78
Collection Type: Report

19. Southern Arizona Flood of Sept. 1962
Call Number: 105788
Collection Type: Report

20. Flood Plain Information: Colorado River, Parker Dam to Headgate Rock Dam: Colorado River Front Work and Levee System, Arizona - California
Author: United States. Bureau of Reclamation.
Call Number: Archives 141573 71A
Collection Type: Report
Location Special Coll

USGS

http://waterdata.usgs.gov/az/nwis/sw

This is the page for access to the USGS surface water data for Arizona. The data includes real-time and historical data and statistical summaries.

http://pubs.usgs.gov/wdr/2004/wdr-az-04-1/

This page is provides online access to the Water-Data Report AZ-04-1 (Arizona Water Year 2004). This is an online version of the old paper paper format water data reports for stream gages in Arizona operated in water year 2004.

http://ks.water.usgs.gov/Kansas/pubs/reports/wsp.2499.sumaz0193.html

This page is an online access to USGS Water Supply Paper 2499 – Summary of Floods of 1993.

USGS science for a changing world
Library homepage

Here is the list of books you requested:

1. The Disastrous southern California and central Arizona floods, flash floods, and mudslides of February 1980 : a report to the administrator. Show details
by *United States. National Weather Service.*
U.S. National Weather Service, [1981]
Call #: **P(200) NO22wnds no.81-1**

2. Storms, floods, and debris flow in Southern California and Arizona, 1978 and 1980 : proceedings of a symposium, September 17-18, 1980 / Committee on Natural Disasters, National Research Council [and] Environmental Quality Laboratory, California Institute of Technology. Show details
by *National Research Council (U.S.). Committee on Natural Disasters., California Institute of Technology. Environmental Quality Laboratory.*
National Academy Press ; [1982]
Call #: **552(270) St74**

3. Floods of October 1977 in southern Arizona and March 1978 in central Arizona / by B.N. Aldridge and J.H. Eychaner ; prepared in cooperation with U.S. Bureau of Reclamation ... [et al.]. Show details

by *Aldridge, B. N. (Byron Neil), Eychaner, James H., United States. Bureau of Reclamation.*
U.S. Geological Survey, [1982]
Call #: **(200) R29o no.82-687**

4. Floods of November 1978 to March 1979 in Arizona and west-central New Mexico / by B.N. Aldridge and T.A. Hales ; prepared in cooperation with the U.S. Bureau of Reclamation ... [et al.]. Show details

by *Aldridge, B. N. (Byron Neil), Hales, T. A., United States. Bureau of Reclamation.*
U.S. Geological Survey, [1983]
Call #: **(200) R29o no.83-201**

5. Floods of November 1965 to January 1966 in the Gila River Basin, Arizona and New Mexico, and adjacent basins in Arizona, by B.N. Aldridge. Show details

by *Aldridge, B. N. (Byron Neil)*
U.S. Govt. Print. Off., 1970.
Call #: **(200) G no.1850-C**

6. Methods for estimating the magnitude and frequency of floods in Arizona : final report / by R. H. Roeske. -- Show details

by *Roeske, R. H., Geological Survey (U.S.). Water Resources Division., Arizona. Highway Division., United States. Federal Highway Administration.*
U.S. Geological Survey, Water Resources Division ; available from National Technical Information Service, 1978.
Call #: **(200) R628m**

7. Floods of September 1970 in Arizona, Utah, Colorado, and New Mexico / by R. H. Roeske, M. E. Cooley, and B. N. Aldridge. -- Show details

by *Roeske, R. H., Cooley, Maurice E., 1924-, Aldridge, B. N. (Byron Neil)*
U.S. Govt. Print. Off., 1978.
Call #: **(200) G no.2052**

8. The Tucson, Arizona flood of October 1983 / prepared by Thomas F. Saarinen ... [et al.] for Committee on Natural Disasters, Commission on Engineering and Technical Systems, National Research Council. Show details

by *Saarinen, Thomas F. (Thomas Frederick), National Research Council (U.S.). Committee on Natural Disasters.*
National Academy Press, 1984.
Call #: **552(274) T798**

9. Floods of November 1978 to March 1979 in Arizona and west-central New Mexico / by B.N. Aldridge and T.A. Hales ; prepared in cooperation with the U.S. Bureau of Reclamation ... [et al.]. Show details

by *Aldridge, B. N. (Byron Neil), Hales, T. A., United States. Bureau of Reclamation.*
U.S. G.P.O., 1984.
Call #: **(200) G no.2241**

10. Delineation of flood hazards in the Cave Creek quadrangle, Maricopa County, Arizona / H. W. Hjalmarson. -- Show details
by *Hjalmarson, H. W.*
U.S. Geological Survey, 1978.
Call #: **M(200) I no.843-B**

11. Delineation of flood hazards in the Biscuit Flat quadrangle and New River area, Maricopa County, Arizona / by H. W. Hjalmarson. Show details
by *Hjalmarson, H. W.*
U.S. Geological Survey, 1980.
Call #: **M(200) I no.843-C**

12. Precipitation, streamflow, and major floods at selected sites in the Gila River drainage basin above Coolidge Dam, Arizona, by D. E. Burkham. Show details
by *Burkham, D. E., 1927-*
U.S. Govt. Print. Off., 1970.
Call #: **(200) B no.655-B**

13. Effects of the catastrophic flood of December 1966, north rim area, eastern Grand Canyon, Arizona / by M. E. Cooley, B. N. Aldridge, and R. C. Euler. Show details
by *Cooley, Maurice E., 1924-, Aldridge, B. N. (Byron Neil), Euler, Robert C.*
U.S. Govt. Print. Off., 1977.
Call #: **(200) B no.980**

14. Storms, floods, and debris flows in southern California and Arizona 1978 and 1980 : overview and summary of a symposium, September 17- 18, 1980 / by Norman H. Brooks ; sponsored jointly by Committee on Natural Disasters, Commission on Sociotechnical Systems, National Research Council and the Environmental Quality Laboratory, California Institute of Technology. Show details
by *Brooks, Norman H., National Research Council (U.S.). Committee on Natural Disasters., California Institute of Technology. Environmental Quality Laboratory.*
National Academy Press, 1982.
Call #: **552(270) St74o**

15. Flood of October 1983 in southeastern Arizona-areas of inundation in selected reaches along the Gila River / By Joanne M. Garrett, R.H. Roeske, and Ben N. Bryce ; prepared in cooperation with the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation. Show details
by *Garrett, Joanne M., Roeske, R. H., Bryce, Ben N., United States. Army. Corps of Engineers., United States. Bureau of Reclamation.*
U.S. Geological Survey, 1986.
Call #: **M(274)552 G372g -- (200) WRi no.85-4225-A -- (200) WRi no.85-4225-A**

16. Flooding, Tempe quadrangle, Maricopa County, Arizona / James T. Bales, Cathy S. Wellendorf, Troy L. Péwé, Department of Geology, Arizona State University ; prepared in cooperation with the cities of Tempe, Scottsdale and Phoenix, and the Arizona State Land Department. Show details
by *Bales, James T., Péwé, Troy Lewis, 1918-, Wellendorf, Cathy S., University of Arizona.*

Bureau of Geology and Mineral Technology.
Arizona Bureau of Geology and Mineral Technology, 1986.
Call #: **M(274)552 T244b**

17. Climatic variability and flood frequency of the Santa Cruz River, Pima County, Arizona /by Robert H. Webb and Julio L. Betancourt ; prepared in cooperation with Pima County Department of Transportation and Flood Control District. Show details
by *Webb, Robert H., Betancourt, Julio L., Pima County (Ariz.). Dept. of Transportation and Flood Control District.*
U.S. Geological Survey, 1992.
Call #: **(200) G no.2379**

18. Index and description of flood-prone area maps in the Tucson-Phoenix area, Arizona / compiled by E.S. Davidson. Show details
by *Davidson, Edward Sheldon, 1926-*
U.S. Geological Survey, 1973.
Call #: **M(200) I no.843-A**

19. Flood hazard information : Cave Creek, Arizona Canal to 19th Avenue, Phoenix, Arizona / by Corps of Engineers, U.S. Army, Los Angeles District, California ; prepared for Flood Control District of Maricopa County. Show details
by *United States. Army. Corps of Engineers. Los Angeles District., Flood Control District of Maricopa County.*
The District ; 1971.
Call #: **552(274) U3fca 1971**

20. Flood hazard information: Hassayampa River, vicinity of Wickenburg, Arizona / by Corps of Engineers, U.S. Army, Los Angeles District, California ; prepared for Flood Control District of Maricopa County, Arizona. Show details
by *United States. Army. Corps of Engineers. Los Angeles District.*
The District, 1972.
Call #: **552(274) U3fh 1972**

21. Flood hazard information : Santa Cruz River, State Highway 82 to international boundary, Santa Cruz County, Arizona / by Corps of Engineers, U.S. Army, Los Angeles District, California ; prepared for Santa Cruz County. Show details
by *United States. Army. Corps of Engineers. Los Angeles District.*
The District, 1971.
Call #: **552(274) U3fss 1971**

22. Flood hazard information : Santa Cruz River, vicinity of Sonoita Creek confluence, Santa Cruz County, Arizona / by Corps of Engineers, U.S. Army, Los Angeles District ; prepared for Santa Cruz County. Show details
by *United States. Army. Corps of Engineers. Los Angeles District.*
The District, 1969.
Call #: **552(274) U3fsc 1969**

23. Flood plain information, Tanque Verde Creek and tributaries : vicinity of Tucson, Arizona / prepared for Pima County by Corps of Engineers, U.S. Army, Los Angeles District, California. Show details

by *United States. Army. Corps of Engineers. Los Angeles District.*
The Corps, 1975.
Call #: **552(274) U3ftv 1975**

24. Flood plain information : West Clear Creek, Yavapai County, Arizona / prepared for Yavapai County, Arizona by Corps of Engineers, U.S. Army, Los Angeles District, California. Show details

by *United States. Army. Corps of Engineers. Los Angeles District.*
U.S. Dept. of Defense, Dept. of the Army, Corps of Engineers, Los Angeles District, 1975.
Call #: **552(274) U3fw 1975**

25. Storm-induced geologic hazards : case histories from the 1992-1993 winter in southern California and Arizona / edited by Robert A. Larson and James E. Slosson. Show details

by *Larson, Robert A., 1956-, Slosson, James E., 1923-*
Geological Society of America, 1997.
Call #: **G(200) G29r v.11**

26. Flood-plain information study for Maricopa County, Arizona : volume II : Cave Creek report / U.S. Army Engineer District, Los Angeles, Corps of Engineers. Show details

by *United States. Army. Corps of Engineers. Los Angeles District.*
The District, 1964.
Call #: **552(274) Un32f**

27. Flood of February 1980 along the Agua Fria River, Maricopa County, Arizona / by B.W. Thomsen. Show details

by *Thomsen, B. W., 1926-*
U.S. Geological Survey, [1980]
Call #: **(200) R29o no.80-767**

28. Interim report on survey for flood control, Gila and Salt Rivers, Gillespie Dam to McDowell Dam site, Arizona / by C.T. Newton, District Engineer. Show details

by *United States. Army. Corps of Engineers., Newton, C. T.*
U.S. Army Corps of Engineers, Los Angeles District, 1957.
Call #: **552(274) Un28gg**

29. Compilation of flood data in Arizona, 1862-1953, by Winchell Smith and Wilbur L. Heckler. Prepared in cooperation with the Arizona State Land Department. Show details

by *Smith, Winchell., Heckler, Wilbur., Arizona. State Land Dept., Geological Survey (U.S.).*
Call #: **552(274) Un33c**

30. Gila River flood control : letter from the Secretary of the Interior transmitting, pursuant to law a report on flood control of the Gila River in Graham County, Arizona / [Frank H. Olmstead]. Show details

by *United States. Dept. of the Interior., Olmstead, Frank Henry, 1858-*

U.S. Govt. Print. Off., 1919.
Call #: **552(274) Un3g**

31. Computation and analysis of the instantaneous-discharge record for the Colorado River at Lees Ferry, Arizona : May 8, 1921, through September 30, 2000 / by David J. Topping, John C. Schmidt, and L.E. Vierra, Jr. Show details
by *Topping, David J., Schmidt, John C., 1950-, Vierra, L. E.*
U.S. Geological Survey ; Branch of Information Services [distributor], 2003.
Call #: **(200) B no.1677**

32. Flood of October 1983 and history of flooding along the San Francisco River, Clifton, Arizona / by H.W. Hjalmarson ; prepared in cooperation with the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation. Show details
by *Hjalmarson, H. W., Geological Survey (U.S.), United States. Army. Corps of Engineers., United States. Bureau of Reclamation.*
U.S. Geological Survey ; Books and Open-File Reports Section [distributor], [1990]
Call #: **(200) WRi no.85-4225-B**

33. Climatic variability and flood frequency of the Santa Cruz River, Pima County, Arizona / by Robert H. Webb and Julio L. Betancourt ; prepared in cooperation with the Pima County Department of Transportation and Flood Control District. Show details
by *Webb, Robert H., Betancourt, Julio L., Pima County (Ariz.). Dept. of Transportation and Flood Control District., Geological Survey (U.S.)*
U.S. Geological Survey ; Books and Open-File Reports Section [distributor], [1990]
Call #: **(200) R29o no.90-553**

34. Floods in Arizona, January 1993 / [R.D. Mac Nish, C.F. Smith, and K.E. Goddard]. Show details
by *MacNish, Robert D., Smith, C. F., Goddard, Kimball E., Geological Survey (U.S.)*
U.S. Geological Survey, Dept. of the Interior, 1993.
Call #: **(200) R29o no.93-54**

35. Floods of October 1983 in southeastern Arizona / R.H. Roeske, J.M. Garrett, and J.H. Eychaner ; prepared in cooperation with the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation and Arizona Department of Water Resources. Show details
by *Roeske, R. H., Garrett, Joanne M., Eychaner, James H., Geological Survey (U.S.), United States. Army. Corps of Engineers, United States. Bureau of Reclamation., Arizona. Dept. of Water Resources.*
U.S. Geological Survey; Books and Open-File Reports Section [distributor], [1989]
Call #: **(200) WRi no.85-4225C**

36. Flood on the Virgin River, January 1989, in Utah, Arizona, and Nevada / by Darrell D. Carlson and David F. Meyer. Show details
by *Carlson, Darrell D., Meyer, D. F., Geological Survey (U.S.)*
U.S. Dept. of the Interior, U.S. Geological Survey; Earth Science Information Center, Open-File Reports Section [distributor], 1995.
Call #: **(200) WRi no.94-4159**

37. When the blue-green waters turn red : historical flooding in Havasu Creek, Arizona / by Theodore S. Melis ... [et al.] ; prepared in cooperation with the Bureau of Reclamation. Show details

by *Melis, Theodore S., United States. Bureau of Reclamation., Geological Survey (U.S.)*
U.S. Dept. of the Interior, U.S. Geological Survey; Open-File Reports Section [distributor], 1996.
Call #: **(200) WRi no.96-4059**

38. Floods of August 1963 in Prescott, Arizona / by B.N. Aldridge. Show details

by *Aldridge, B. N. (Byron Neil), Geological Survey (U.S.)*
U.S. Geological Survey, [1963]
Call #: **(200) Al24fap**

Aldridge, B.N., 1972, Investigation of floods from small drainage basins in Arizona, *in* Proceedings of the 21st annual conference on roads and streets: Tucson University of Arizona, Arizona Transportation and Traffic Institute, p. 107-126.

____1978, Unusual hydraulic phenomena of flash floods in Arizona: American Meteorological Society, Hydrometeorological Aspects, p. 117-120.

Carmody, Thomas, 1980, A critical examination of the largest floods in Arizona-a study to advance the methodology of assessing the vulnerability of bridges to floods for the Arizona Department of Transportation: The Engineering Experiment Station, College of Engineering, 52 p.

Eychaner, J.H., 1984, Estimation of magnitude and frequency of floods in Pima County, Arizona, with comparisons of alternative methods: U.S. Geological Survey Water-Resources Investigations Report 84-4142, 69 p.

Hershfield, D.M., 1961, Rainfall frequency atlas of the United States: U.S. Department of Commerce, Weather Bureau Technical Paper 40, 115 p.

House, P.K., and Pearthree, P.R., 1994, A geomorphic and hydraulic evaluation of an extraordinary flood discharge estimate-Bronco Creek, Arizona: Arizona Geological Survey Open-File Report 94-19, 21 p.

Gov doc #	LD 1.3:W 17/31 azdocs
Author	Werho, L. L.
Title	**Compilation of flood data for Maricopa County, Arizona, through September 1965 / by L. L. Werho ; prepared by the Geological Survey, United States Department of the Interior, in cooperation with the Flood Control District of Maricopa County, Bureau of Reclamation, and Corps of Engineers.**
Publisher	Phoenix, Ariz.: **Arizona** State Land Dept., [1967]
Note	"June 1967."
	Chiefly tables.
Bibliog.	Includes bibliographical references.

Gov doc #	LD 1.3:W 17/13 azdocs
Author	Lewis, Douglas Duane, 1903-
Title	**Desert floods: a report on southern Arizona floods of September, 1962/by Douglas D. Lewis.**
Publisher	Tucson, Ariz.: **Arizona** State Land Dept., [1963]
Note	"Prepared by the Geological Survey, United States Department of the Interior, April 1963."--Cover.

Other

http://www.wrcc.dri.edu/summary/climsmaz.html

This page provides access to historical climate data for observation stations across the state of Arizona.

http://www.sahra.arizona.edu/research_data/

This page is the home page for the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) Research Data.

APPENDIX 1-C

Floodplain Manager Survey Documentation, including:

- **Copy of the Agency Survey (in unanswered form)**
- **Summary of Findings from Survey Responses**

AGENCY QUESTIONNAIRE
FOR ARIZONA DEPARTMENT OF WATER RESOURCES STATE STANDARD
REGARDING HYDROLOGIC MODELING GUIDELINES

The Arizona Department of Water Resources (ADWR), through its State Standards Work Group (SSWG) is developing guidelines for hydrologic modeling for the state of Arizona. Stantec and JE Fuller/Hydrology & Geomorphology (JEF) have been contracted to prepare the modeling guidelines. The SSWG is a volunteer group of floodplain management professionals from around the state working in conjunction with ADWR to develop floodplain management standards and training. A list of the existing State Standards are listed under the "Floodplain Management" section of the publications page[1] at the ADWR website[2].

The purpose of this survey is to solicit input from various public and private agencies involved in the preparation or review of hydrologic modeling, which can be incorporated into this evaluation and the effort to develop modeling guidelines. Every effort has been made to keep the survey brief. Please answer the questions on the enclosed survey as fully as possible and return it as follows:

Return by Fax or Email (preferred methods) to: 520-623-3130
john@jefuller.com

Return by mail to: John Wallace
JE Fuller/Hydrology & Geomorphology
1955 W. Grant Rd., Suite 148
Tucson, AZ 85745

If you have any questions or prefer to respond by phone please feel free to call John Wallace (JEF) at 520-623-3112. **Responses must be received by Friday October 7, 2005 to incorporate your input into the study effort**.

1. Please print your name, agency name (e.g., Flood Control Office, Floodplain Office, etc.) and your jurisdiction (e.g., Maricopa County, City of Tempe, etc.) below:

[1] http://www.azwater.gov/dwr/Content/Publications/default.htm
[2] http://www.azwater.gov/dwr/default.htm

Your Name	
Agency Name	
Jurisdiction	

2. Does your jurisdiction have a specific regulation or set of regulations regarding hydrologic modeling requirements? If so, please enclose or attach a copy of the regulation (or portion applicable to hydrologic modeling if contained in a more comprehensive document such as a zoning code, etc.)

   No   Yes   (if yes please enclose regulation or applicable portion)

3. Does you agency require or recommend the use of a particular manual or reference for hydrologic modeling (i.e., a manual or reference other than the regulation discussed in question 2 above)?

   No   Yes   (if yes please enclose title of manual or reference)

4. The study will include evaluation a number of hydrologic modeling technical issues. Please provide your input with regard to your jurisdictions experience and/or concerns/problems with the following issues (please feel free to add additional sheets in your descriptions as needed).

Design Storm Event	
Fire Effects	
Logging Effects	
Drought Effects	
Grazing Effects	
Rapid Snowmelt	
Other (please include input on any specific or unusual conditions encountered in your jurisdiction	

5. What kinds of problems has your agency/jurisdiction experienced in implementing its hydrologic modeling regulations?

6. Please indicate below any other information, contacts, regulations or manuals/references (other than those already described in answer to questions 2 and 3) which you believe would be worth pursuing as a part of this effort (use back of this sheet or attach additional sheet(s) if needed).

AGENCY SURVEY # 2
FOR ARIZONA DEPARTMENT OF WATER RESOURCES STATE STANDARD
REGARDING HYDROLOGIC MODELING GUIDELINES

The Arizona Department of Water Resources (ADWR), through its State Standards Work Group (SSWG) is developing guidelines for hydrologic modeling for the state of Arizona. Stantec and JE Fuller/Hydrology & Geomorphology (JEF) have been contracted to prepare the modeling guidelines. The SSWG is a volunteer group of floodplain management professionals from around the state working in conjunction with ADWR to develop floodplain management standards and training. A list of the existing State Standards are listed under the "Floodplain Management" section of the publications page[3] at the ADWR website[4].

This is a follow-up survey to the one which was sent out in September 2005 to solicit input from various public and private agencies involved in the preparation or review of hydrologic modeling. The additional questions are with regard to design storm data used in your jurisdiction. Please fill out your contact information below and answer the questions on the following page and return as follows:

Return by Fax or Email (preferred methods) to: 520-623-3130
john@jefuller.com

Return by mail to: John Wallace
JE Fuller/Hydrology & Geomorphology
1955 W. Grant Rd., Suite 148
Tucson, AZ 85745

If you have any questions or prefer to respond by phone please feel free to call John Wallace (JEF) at 520-623-3112.

Please print your name, agency name (e.g., Flood Control Office, Floodplain Office, etc.) and your jurisdiction (e.g., Maricopa County, City of Tempe, etc.) below:

[3] http://www.azwater.gov/dwr/Content/Publications/default.htm
[4] http://www.azwater.gov/dwr/default.htm

Your Name	
Agency Name	
Jurisdiction	

<u>Please feel free to add space between questions in this Word document or use additional sheets/pages in your response</u>

1. Within your jurisdiction, what is used for the design storm duration in hydrologic modeling? (Example 1-hour, 3-hour, 6-hour, 24-hour, etc.).

2. What does your jurisdiction use for rainfall distribution? (Example SCS-Type I, SCS-Type II, Historic event, other)

3. When you assess the discharge values for a 100-year storm, do you choose a design storm that will produce the greatest volume or runoff or the greatest peak discharge?

4. Do you choose different design storms for different sized watersheds?

5. Do you choose different design storms for watersheds based on elevation?

6. Do you choose different design storms based upon the shape of the watershed?

7. Does your 100-year design storm consider rapid snowmelt for those watersheds with higher elevation that could sustain a snow pack during the winter?

8. In your opinion, what type of seasonal precipitation events creates the most difficult hydrologic modeling problems?

9. Does your community have good rainfall runoff data from which a design storm could be derived?

In your opinion, what are the most difficult issues to address in choosing a design storm?

SUMMARY OF RESULTS OF FLOODPLAIN ADMINISTRATOR SURVEY RESPONSES; Questions 1 through 3

1. Jurisdiction	2. Does jurisdiction have specific regulations for hydrologic modeling?	3. Does jurisdiction recommend use of a particular manual or reference for hydrologic modeling?
Santa Cruz County	No/State Standards	No
Coconino County	Yes, Coconino County Drainage Criteria Manual	Yes, Coconino County Drainage Criteria Manual
Town of Patagonia	No	No
Yavapai County Flood Control	Yes, Drainage Criteria Manual – Chapter 3	Yes, Drainage Criteria Manual & ADOT Drainage Design Manual - Hydrology
City of Sedona	Yes, Storm Water Master Plan, WMS modeling software	Yes, Yavapai County Drainage Criteria Manual
Pima County Regional Flood Control	Yes, Pima County Method	No. We have accepted ADOT, TSMS, and Maricopa County modeling parameters.
City of Tempe	No	Yes, Drainage Design Manual for Maricopa County
Flood Control District of Maricopa County	Yes, Drainage Design Manual for Maricopa County, Vol. I - Hydrology	
Town of Oro Valley	Yes, Drainage Criteria Manual for Town of Oro Valley	Yes, references cited in Drainage Criteria Manual for Town of Oro Valley

1. Jurisdiction	4. Input with regard to jurisdiction's experience and/or concerns/problems with the following issues:	
Santa Cruz County	Design Storm Event	Sometimes not adequate for certain features. Culverts should be designed for larger than 100-year events to simulate sedimentation and debris buildup.
	Fire Effects	Should be included but need a better understanding of the effects of a given fire and the time it takes to recover (look at Mt. Elden in Flagstaff).
	Logging Effects	No logging in the area.
	Drought Effects	Long, severe, drought can have the same effect as a fire and should be considered.
	Grazing Effects	Would be good to include, but you also need to include stop of grazing effects.
	Rapid Snowmelt	
	Other	Extreme channel slopes (10-15%) and abrupt (drastic) changes in slope (i.e., 1.5% to 3%).
Coconino County	Design Storm Event	With so many of the techniques employing the SCS hydrograph approach, in lieu of the 484 factor, does not enough gaging data exist in several areas of the state to allow evaluation of the true hydrograph shape (time to peak, recession, time base) for summer floods as well as winter ones?
	Fire Effects Logging Effects Drought Effects Grazing Effects	How appropriate are the overland runoff predictors for different phases of revegetation recovery from fire, drought, and over grazing? How sensitive are the 10-yr and 25-yr runoff values to these? Are recoveries from grazing vs. drought effects comparable or should they be treated uniquely?
	Rapid Snowmelt	Rainfall on snowpack or wet snow combined with rain has accounted for 9 out of the top 10 floods in Oak Creek near Cornvill stream gaging station. See attached flood summary sheet for this gage.
	Other	
Town of Patagonia	No comment	
Yavapai County Flood Control	Design Storm Event	2, 10, 25, 100. Reference NOAA Atlas 14.
	Fire Effects	Have significantly increased runoff due to recent events.
	Logging Effects	Limited issues, but increasing due to bark beetles.
	Drought Effects	Limited issues.
	Grazing Effects	Limited.
	Rapid Snowmelt	Not included now, but would be good .
	Other	Bark beetles.
City of Sedona	Design Storm Event	
	Fire Effects	Some extreme fire risk in the area due to proximity of forest lands.
	Logging Effects	N/A
	Drought Effects	Just coming out of a drought.
	Grazing Effects	N/A
	Rapid Snowmelt	Oak Creek riese due to rapid snowmelt/rainstorms in the spring on occasion.
	Other	
Pima County Regional Flood Control	Design Storm Event	For small watersheds we believe the 100-year storm should be the design storm.
	Fire Effects	We have modeled the effects of fire. Copies of those reports have been forwarded to Stantec.
	Logging Effects	
	Drought Effects	

1. Jurisdiction	4. Input with regard to jurisdiction's experience and/or concerns/problems with the following issues:	
	Grazing Effects	
	Rapid Snowmelt	We do not have modeling for this scenario. However, we have watersheds that are impacted by this phenomena.
	Other	Runoff reduction due to distributary flow.
City of Tempe	Design Storm Event	100 year storm for channel design.
	Fire Effects	Not a problem in Tempe.
	Logging Effects	Not a problem in Tempe.
	Drought Effects	Not a problem in Tempe.
	Grazing Effects	Not a problem in Tempe.
	Rapid Snowmelt	Not a problem in Tempe.
	Other	Since the Salt River was channeled through Tempe as part of the freeway project our main flooding concern now is the shallow flooding against raised canal banks and railroad beds as indicated on FEMA's FIRMs. Other than those areas, we've been requiring 100 year on-lot retention for most of Tempe since the 1980's which has reduced our flooding problems to just a few isolated pockets.
Flood Control District of Maricopa County	Design Storm Event	Rainfall/runoff models depend on statistics such as NOAA. Moving target, need a better yard stick than "100-year."
	Fire Effects	Changes statistics, I.e., 100-year flood now 25-year flood. I still think moving to levels such as severe, moderate, low is better.
	Logging Effects	Not concerned.
	Drought Effects	Not concerned, except people's perception.
	Grazing Effects	Not concerned.
	Rapid Snowmelt	Effects winter runoff on major rivers, but regulated by upstream dams.
	Other	Use of rainfall/runoff models and gage analysis alone relies on short term data, therefore is a moving target. Need better guidelines.
Town of Oro Valley	Design Storm Event	Need an open minded evaluation of model parameters including rainfall distribution, NOAA2/NOAA14 data, loss rat4 (CN, Green AMPT, etc) and unit hydrograph approaches as they influence peak flow estimates.
	Fire Effects	Fire effects are generally fairly short duration (4-7 years), however, it would be of value to have an estimate of the increase in 100-year peak and sedimentation association with a major rainfall event immediately after a fire.
	Logging Effects	
	Drought Effects	
	Grazing Effects	
	Rapid Snowmelt	
	Other	• Channel vegetation with no guidelines or plan to manage vegetation at levels/densities similar to when structures built or channel improvements made. • Potential for erosion and lateral migration of channels in non-bank protected areas.

1. Jurisdiction	5. What kinds of problems has jurisdiction experienced implementing its hydrologic modeling regulations?
Santa Cruz County	Finding local engineers who understand what hydrologic modeling is. Pressure from management/BOS not to be too restrictive. Complaints about cost to the builder/buyer.
Coconino County	Peak runoff rates in the Rio de Flag area are lower than expected for watersheds on the peaks. Engineers may use different model s than the county has in-house and even if we had them we would not have any expertise concerning their use. We have insufficient detail in our requirements to guide firms in selecting the appropriate models and levels of documentation for all principal assumptions and approaches used in defining cover, roughness, slopes, soils, etc. For purposes of determining Tc, what are realistic distances for sheet flow and shallow concentrated flow for different slope categories?
Town of Patagonia	No information.
Yavapai County Flood Control	I don’t believe we have had any significant problems. Our main issue is our manual references the ADOT Manual and outdated isotopic maps. We try to direct engineers to NOAA Altas 14 on-line. Engineers tend to ignore attenuation due to local dams, berms, etc., should increase impermeable areas due to growth; use soils maps more.
City of Sedona	The regulation/master plan is new. Little experience of any kind to date.
Pima County Regional Flood Control Dist.	We are looking at switching to NOAA Altas 14 rainfall.
City of Tempe	Hydrologic modeling has never been much of a problem for us because we have always relied on standard county or federal methods for hydrologic modeling.
Flood Control District of Maricopa County	Inconsistencies in modeling. However, this issue has become less important as more and more hydrologists use the same methodology (not necessarily good, it may be consistent, but maybe wrong?). The second problem with using deterministic models is the use of NOAA data, since it is also statistically based and changes in time. To make a long story short, our results change drastically with time and it is hard to regulate when you have a moving target.
Town of Oro Valley	• Comparability between county and local jurisdiction estimates of the 100-year flood. • State/county supported, or partially supported, HEC-RAS modeling classes to improve consistency/comparability in hydrologic modeling approaches.

1. Jurisdiction	6. Other information, contacts, regulations or manuals/references which you believe would be worth pursing as part of this effort.
Santa Cruz County	The design event (100-yr) tends to change with time. Due to development, the Q100 of Nogales Wash downstream of the confluence with Potrero Creek has grown from 17,000 cfs to 24,000 cfs (per COE reports). Perhaps it is time to require the design event to be calculated not on existing conditions, but based no the zoning int eh watershed and/or community's comprehensive plan.
Coconino County	Is there a way to take the most frequently used models and do a detailed comparison of strengths and weaknesses in applying them to snowmelt or rainfall with snowmelt, ranges of slopes, ranges in types of forest cover, degree of cinder zones on mountain slopes, ground litter, watershed sizes, and fire, drought and grazing effects? This would help in determining the best models for each set of given conditions.
Town of Patagonia	No response.
Yavapai County Flood Control	An updated website for rainfall data or stream gage data uniformly used.
City of Sedona	No response.
Pima County Regional Flood Control Dist.	ADOT Hydrology Manual.
City of Tempe	No response.
Flood Control District of Maricopa County	Any guidelines that would stabilize hydrologic results (even within 50% is good enough).
Town of Oro Valley	No response.

	QUESTION 1	QUESTION 2
Jurisdiction	**Within your jurisdiction, what is used for the design storm duration in hydrologic modeling? (Example 1-hour, 3-hour, 6-hour, 24-hour, etc.).**	**What does your jurisdiction use for rainfall distribution? (Example SCS-Type I, SCS-Type II, Historic event, other).**
Buckeye	The 100Year, 2-Hr Retention volume is the entire concern per the Town's current Development Code, Section 7-5-5, C.	The Maricopa County Flood Control District's Manual Vol. I, "Hydrology Design", using the NOAA Atlas isopluvials.
Chino Valley	1 hour	Historic Events
Coconino County	6-hour if the watershed is <= 1 square mile; 24-hour for all larger watersheds	Typically SCS-Type II; we would consider other distributions on a case-by-case basis and only if the situation warrants it and the scientific backup for the alternate distribution is valid
Gila County	We have no definite written standards for hydrologic modeling. Counties like us are why this State Standard is needed. If TR-55 is used, it is of course the 24-hour type II distribution. We will often discuss the approach with the engineer to determine what duration (and other parameters) are reasonable. We normally have been accepting the engineer's judgment on the duration based on the watershed size.	As in number 1, it is on a case-by-case basis. SCS-Type II, ADOT hypothetical distribution, or other reasonable distributions are allowed.
Glendale	2-hour	SCS-Type II
Lake Havasu City	24-hour	SCS-Type I
Maricopa County	6 and 24 hour are the most commonly used rainfall durations, although 2-hour duration is used for retention sizing, and long duration rainfalls (72 hours, etc.) are used to design dams.	6 hour distribution mass curves that were based on an actual storm in Queen Creek, and other mass curves from NOAA Hydro 40.
Payson	24-hour	Historic Event
Peoria	6-hour and 24-hour	SCS Type II
Pima County	For unincorporated Pima County we use the 1-hour storm for small watersheds (less that 10 square miles). For larger watersheds we will allow for the use of design storms that have durations close to the time of concentration. We also allow the use of aerial reduction of the rainfall for larger watershed.	For smaller watersheds our hydrology method is much like the Rational Equation. When we input rainfall we usually use the SCS-Type II or IIa.
Scottsdale	Generally 6 depending on the ultimate use of the lands in question.	Any engineer skilled in hydrology may use any method that produces reasonable results. In general the City follows the Maricopa County Flood Control District guidance for uniformity.
Surprise	MCFCD Standards	MCFCD Standards

	QUESTION 1	QUESTION 2
Jurisdiction	**Within your jurisdiction, what is used for the design storm duration in hydrologic modeling? (Example 1-hour, 3-hour, 6-hour, 24-hour, etc.).**	**What does your jurisdiction use for rainfall distribution? (Example SCS-Type I, SCS-Type II, Historic event, other).**
Tempe	100 year, 1 hour for onsite retention; 10 year storm with intensity determined by time of concentration for street drainage. We have a chart in our design criteria manual from Technical Paper No. 40 that is used to determine the intensity after the time of concentration is known.	We don't other than the response in No. 1 above.
Yavapai County	Currently we reference the 1993 ADOT Drainage Design Manual and the ratio from the manual for the 1 hour 2 year and 100 year event for determining the following: 2-year, 6-hour event; 2 year, 24 hour event; 100-year, 6 hour event; 100, year 24 hour event. In future manuals we would like to Reference NOAA 14: http://hdsc.nws.noaa.gov/hdsc/pfds/sa/az_pfds.html. We will require an analysis of the larger of the 6 hour and 24 hour event for the 2, 10, 25 and 100 year storm event.	We recommend SCS-Type II distribution and generally follow the outlines recommended in the ADOT Manual. As we set up more rain gauges and obtain more data, other methods may be more accurate in the future. Flood frequency and stream gauge data should be utilized where appropriate (larger watercourses).

Jurisdiction	QUESTION 3 When you assess the discharge values for a 100-year storm, do you choose a design storm that will produce the greatest volume or runoff or the greatest peak discharge?	QUESTION 4 Do you choose different design storms for different sized watersheds?
Buckeye	The 2-hour storm is used for required retention without regard for peak. The Town's Development Code, 7-5-5, C., goes on to require that no discharges are allowed that increase the peak or volume. See the Code attachment.	No
Chino Valley	Greatest peak discharge and volume.	Yes
Coconino County	Typically, the emphasis is on the peak discharge. Where detention structures are involved, we also want to be sure the structure and the decant tubes, weirs or orifices are adequately sized such that the structure will drain within 36 hours without exceeding the pre-development peak discharges for the 2, 10 and 100-year storms.	At the present time our drainage design criteria manual does not address this other than the 1 square mile criteria specified in answer to question 1. It would be informative to see what others are doing, especially in light of the localized nature of our convective storms.
Gila County	We look mainly at the greatest peak discharge. We have no regional flood control facilities owned by the Flood Control District, and we do not require detention/retention except in special cases. (Most of our development is along major watercourses, we have only 3% private land, large concentrated developments are rare, and SRP owns all the surface water rights for most of Gila County, so we do not encourage detention/retention. Therefore, volume is not a large concern).	Yes. Of course, that has to be taken into consideration, but we have no set criteria. It is looked at on a case-by-case basis.
Glendale	Greatest Peak Discharge	Not applicable - watersheds are all typically small to medium size
Lake Havasu City	Greatest Peak Discharge	No
Maricopa County	Multiple storm durations are evaluated to assess critical peak as well as volume.	Yes
Payson	Greatest Peak Discharge	No
Peoria	Generally the greatest peak discharge. However, we may use Volume if we have a down stream facility (i.e. regional facility) that we are concerned about, then we may look at the storm that produces the greatest volume.	Generally no, we design for the 100-year, but we evaluate the 2, 10, and 50 in addition.

	QUESTION 3	QUESTION 4
Jurisdiction	**When you assess the discharge values for a 100-year storm, do you choose a design storm that will produce the greatest volume or runoff or the greatest peak discharge?**	**Do you choose different design storms for different sized watersheds?**
Pima County	In general we select storm based on the peak discharge. For the design of large detention basins the runoff volume becomes the design factor.	We allow for the use of different design storm data when the time of concentration go over one hour.
Scottsdale	We look at both. Specifically, what is the use or structure in question.	Yes
Surprise	MCFCD Standards	MCFCD Standards
Tempe	Same as #1.	No
Yavapai County	We general choose the storm that will have the greatest peak as the most conservative.	No. Larger watershed should be more accurately modeled using gauge data and historical events.

	QUESTION 5	QUESTION 6
Jurisdiction	**Do you choose different design storms for watersheds based on elevation?**	**Do you choose different design storms based upon the shape of the watershed?**
Buckeye	No	No
Chino Valley	Yes	Yes
Coconino County	At present our manual does not address this. We have acknowledged elevation affects where FEMA and recent hydrologic models or gaging data show significant differences. Also, in the application of regression approaches as a comparison to modeling results we have incorporated high elevation weighting.	Our manual doesn't address this nor have we required anything different on any studies I have been involved with.
Gila County	The precipitation totals, of course, vary with elevation, but we have insufficient research data to be able to justify variations in the storm distribution based on elevation. Since we have a wide range of elevations in Gila County, if this standard could provide some guidance on this matter it would be helpful.	We do not, unless the engineer recommends it.
Glendale	Not Applicable - relatively little elevation change within the city limits or within contributing watersheds	Not applicable
Lake Havasu City	No	No
Maricopa County	The statistical rainfall totals in NOAA Atlas II, as well as NOAA 14 account for orographic effects, so no other adjustment is made.	Generally no, except for PMP's to assess Dams.
Payson	No	No
Peoria	No	Generally no
Pima County	No, except if the time of concentration goes over one hour.	Our hydrology method takes into account the relations ship for the length of the watercourse to the drainage area. Different design storms are assessed if the time of concentration is greater than one-hour.
Scottsdale	Yes	Yes
Surprise	MCFCD Standards	MCFCD Standards
Tempe	No	No
Yavapai County	No.	No. We may want to look at this in the future. We have several wide basins in gently sloping grassland areas where 100 discharges seem to be exaggerated.

	QUESTION 7	QUESTION 8
Jurisdiction	**Does your 100-year design storm consider rapid snowmelt for those watersheds with higher elevation that could sustain a snow pack during the winter?**	**In your opinion, what type of seasonal precipitation events creates the most difficult hydrologic modeling problems?**
Buckeye	No. There is very little recognition of a basin's upstream watershed basin effects	Cloud burst local intensities that exceed "historical" expectation.
Chino Valley	Only on one major wash, which is Granite Creek.	Monsoon storms that dump a large amount of water in a short period of time.
Coconino County	Our manual does not address this.	Rainfall on snowpack, the localized nature of the more intense cells of precipitation, and assessing the real effects of forest canopy cover and structure within the volcanics on either rainfall or snowmelt runoff.
Gila County	We do not currently have a design storm, but it is recognized that from time to time, there can be sufficient snowpack in selected areas where it can be a significant factor. Snows tend to melt relatively quickly compared to higher mountain areas, and warm rains on snowpack can easily happen.	Monsoon thunderstorms.
Glendale	Not applicable	Summer thunderstorms - intensity can be high
Lake Havasu City	No, because we are lowland desert.	Monsoon rains.
Maricopa County	Not for majority of our watersheds. The larger Watersheds such as Salt and Gila are effected by rain on snow, but that is reflected in the actual runoff and therefore included, by default, in the statistical analysis.	Three distinct rainfall types affect Maricopa County, and each creates their own unique challenges. The Key is choosing the right design rainfall for any specific watershed.
Payson	No	Monsoon storms.
Peoria	Not applicable	Not sure
Pima County	No	Rainfall on snow pack is a problem. We also have problems with Winter storms that create storm duration greater than one day (24-hour storm) creating unusual antecedent moisture and high peak flows.
Scottsdale	NA	Small to medium area monsoonal events, or remnants of hurricanes that stall over the watersheds and are generally a short duration.
Surprise	MCFCD Standards	MCFCD
Tempe	NA	We don't incorporate it into our requirements but the things that cause Tempe the most problems are the micro-bursts in small areas. We don't have a way of measuring the rainfall but we have had some localized flooding from monsoon storms that dump a large amount of water in a small area very quickly.

	QUESTION 7	QUESTION 8
Jurisdiction	**Does your 100-year design storm consider rapid snowmelt for those watersheds with higher elevation that could sustain a snow pack during the winter?**	**In your opinion, what type of seasonal precipitation events creates the most difficult hydrologic modeling problems?**
Yavapai County	Not currently, but is something we need to add in the future.	For larger watersheds, winter storms with snowfall mixed with rainfall create the flooding scenarios for Oak Creek, the Verde River and the larger watercourses. The smaller watersheds are impacted more by quick thunderstorms in the summer with large amounts of runoff.

	QUESTION 9	QUESTION 10
Jurisdiction	**Does your community have good rainfall runoff data from which a design storm could be derived?**	**In your opinion, what are the most difficult issues to address in choosing a design storm?**
Buckeye	The Town has a "94.8% observations" beginning in 1893 and last compiled Apr 14, 2005. Some of the data can be accessed through the Town's website /"About Buckeye"/"Weather".	Public opinion or perception of what may be required by "additional stormwater control" measures.
Chino Valley	Yes	We have had monsoon storms that have dumped up to 4 inches of rain in 20 min. in one area with no major disturbance within the area, but has caused damage to areas downstream from the storm from sheet flow.
Coconino County	In this area of the country I don't think we will ever have enough rainfall and stream gages or know which 30-year period is more representative of the norm. Look at the average standard error of prediction for the regression equations developed for each of the regions in the southwest (Water Supply Paper 2433).	We have two different flood seasons and all the analyses utilize a summer rainstorm approach. What period of precipitation data is more representative of this area? They certainly guessed wrong when they apportioned the Colorado River. If a large forest fire occurs, what will be considered as representative?
Gila County	Probably no better than what NOAA used in NOAA-14.	
Glendale	Don't have any - depend on FCDMC	Risk vs. cost of mitigating the risk, relative to the cost of development.
Lake Havasu City	No	We always begin with the 100-year storm.
Maricopa County	Yes, but I can always hope for more.	Once the design frequency for any project is decided (100 year, 10 year, etc.) the design hydrologist/Engineer will have to examine several durations to decide which is the critical storm for that design. We can come up with rules of thumb (i.e. use 6 hour rainfall for watersheds smaller than 20 square miles), but we have seen many exceptions to this rule also.
Payson	So-so.	1) To design to a storm that is reasonable & realistic and still be cost effective. 2) How to design a detention basin outlet to accommodate large storm events (10yr) while still not increasing the peak flow for a smaller storms (2yr, 5yr, etc.).
Peoria	No, we utilize data from the Flood Control District.	Insuring that the design storm accurately represent the water shed being modeled.

	QUESTION 9	QUESTION 10
Jurisdiction	**Does your community have good rainfall runoff data from which a design storm could be derived?**	**In your opinion, what are the most difficult issues to address in choosing a design storm?**
Pima County	No. Neither the Pima County Regional Flood Control District Flood Warning rain/stream gauge network or the USGS stream gauge network have enough historical rainfall runoff data. After high winter peak flows (1983 & 1993) the 100-year discharge values can get reanalyzed, since it is the design storm of choice. The 100-year discharge is also the basis for the Flood Insurance Rate Map flood zones. Note that the Pima County Hydrology method based on 1-hour rainfall depths is used to predict flood peaks from ungaged watersheds.	Rainfall over moderate to large watersheds is not uniform. Therefore design storms are more difficult to assess unless you are working on a small watershed.
Scottsdale	Theoretical only. Actual data and transposition data may or may not be of the quality to utilize as a standard. Civil site designers have no clue about the geophysical nature of our watersheds let alone rainfall.	Policy by elected officials that are influenced by constituents agendas. Also while not difficult, elected and appointed officials are charged with the responsibility of guarding the public purse from unnecessary expenditures. All too often, (nation wide) the appropriate amount of effort in determining the value of a study is scrapped in favor of a economical decision. It is appropriate to evaluate the risk before performing a study especially a study based on a cookbook approach. As the wise man once said, if your feet are on a cherry red pot belly stove and the head is on a block of ice, on the average you should be comfortable.
Surprise	MCFCD	MCFCD Standards
Tempe	No	We were one of the first if not the first community in the valley to resort to onsite retention. We started out with graduated return storms based on a development's proximity to the Salt River or a storm drain that went to the Salt River. Over the years we bumped it up to the point that all of Tempe is subject to 100 year, 1 hour onsite retention except for the area directly adjacent to the Salt River in which case we require 2 year onsite retention for water quality reasons to eliminate the first flush from reaching a water of the U.W. That is working very well for use and our localized flooding has been reduced to almost nothing so we are comfortable with our current criteria and don't have any difficulties in choosing design storms.
Yavapai County	Our community is too large to have adequate data for the whole County. Due to the need for Flood Warning we are budgeting and installing various rainfall gauges, which we hope to incorporate with the State and obtain better rainfall data in the future.	Obtaining accurate soils data is tough to come by in our community. We have been working with the Forest Service and NRCS to obtain the latest survey data. Our hope is in the future, is the NRCS website will be updated to cover the entire County and all soils data can be transferred to our GIS. The following NRCS website is helpful: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx. Also, some area of our County should include snowfall data as well as rainfall data.

APPENDIX 1- D

Hydrologic Models

Flood Hazard Mapping

Flood Hazard Mapping

Hydrologic Models Meeting the Minimum Requirement of NFIP

(Nationally Accepted Models)
Effective: June 2005

Hydrologic Models: Determination of Flood Hydrographs

TYPE	PROGRAM	DEVELOPED BY	AVAILABLE FROM	COMMENTS	PUBLIC DOMAIN
	HEC-1 4.0.1 and up[2] (May 1991)	U.S. Army Corps of Engineers	Water Resources Support Center[3] Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.	Yes
	HEC-HMS 1.1 and up (March 1998)	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687 http://www.hec.usace.army.mil/	The Hydrologic Modeling System provides a variety of options for simulating precipitation-runoff processes. It has a capability to use gridded rainfall data to simulate runoff. It does not provide snowmelt and snowfall functions; it cannot be used for areas where snowmelt is an important flood hazard source and must be considered in estimation of flood discharges.	Yes
	TR-20 (February 1992)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA 22161	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.	Yes
	TR-20 Win 1.00.002 (Jan. 2005)	U.S. Department of Agriculture, Natural Resources Conservation Service	http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr20.html	The TR-20 computer model has been revised and completely rewritten as a windows based program. It is storm event surface water hydrologic model applied at a watershed scale that can generate, route, and combine hydrographs at points within a watershed.	Yes
	TR-55 (June 1986)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA 22161 http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-tr55.html	Peak discharges and flood hydrographs at a single location.	Yes

Single Event	WinTR-55 1.0.08, (Jan. 2005)	U.S. Department of Agriculture, Natural Resources Conservation Service	http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html	The new WinTR-55 uses the WinTR-20 program as the driving engine for analysis of the hydrology of the small watershed system being studied.	Yes
	SWMM (RUNOFF) 4.30 (May 1994), and 4.31 (January 1997)	U.S. Environmental Protection Agency and Oregon State University	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720 http://www.epa.gov/ceampubl/swater/ Department of Civil, Construction, and Environmental Engineering Oregon State University 202 Apperson Hall Corvallis, OR 97331-2302 http://ccee.oregonstate.edu/swmm/ ftp://ftp.engr.orst.edu/pub/swmm/pc/	Calibration or verification to the actual flood events highly recommended.	Yes
	SWMM 5 Version 5.0.005 (May 2005)	U.S. Environmental Protection Agency	Water Supply and Water Resources Division U.S. Environmental Protection Agency http://www.epa.gov/ednnrmrl/swmm/	SWMM 5 provides an integrated environment for editing study area input data, running hydrologic simulations, and viewing the results in a variety of formats. These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses.	Yes
	MIKE 11 UHM (2002 D, 2004)	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	Simulates flood hydrographs at different locations along streams using unit hydrograph techniques. Three methods are available for calculating infiltration losses and three methods for converting rainfall excess to runoff, including SCS Unit hydrograph method. The web page is at: http://www.dhisoftware.com/mike11/Description/RR_module.htm	No
	DBRM 3.0 (1993)	Bernard L. Golding, P.E. Consulting Water Resources Engineer Orlando, FL	Center for Microcomputers in Transportation (McTrans) University of Florida 512 Weil Hall Gainesville, FL 32611-6585	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.	No
	HYMO	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA 22161	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters.	Yes
	PondPack v.8 (May 2002)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499 http://www.haestad.com	The program is for analyzing watershed networks and aiding in sizing detention or retention ponds. Only the NRCS Unit Hydrograph method and NRCS Tc calculation formulas are acceptable. Other hydrograph generation methods or Tc formulas approved by State agencies in charge of flood control or floodplain management are acceptable for use within the subject State.	No

	XP-SWMM 8.52 and up	XP Software	XP-Software 2000 NE 42nd Ave. #214 Portland, OR 97213-1305 http://www.xpsoftware.com	Model must be calibrated to observed flows, or discharge per unit area must be shown to be reasonable in comparison to nearby gage data, regression equations, or other accepted standards for 1% annual chance events.	No
Continuous Event	DR3M (October 1993)	U.S. Geological Survey	U.S. Geological Survey National Center 12201 Sunrise Valley Drive Reston, VA 22092	Calibration to actual flood events required. The web page is at: http://water.usgs.gov/software/surface_water.html	Yes
	HSPF 10.10 and up (December 1993)	U.S. Environmental Protection Agency, U.S. Geological Survey	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720	Calibration to actual flood events required. The web page is at: http://water.usgs.gov/software/surface_water.html	Yes
	MIKE 11 RR (2002 D, 2004)	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	The Rainfall-Runoff Module (RR, formerly NAM) is a lumped-parameter hydrologic model capable of continuously accounting for water storage in surface and sub-surface zones. Flood hydrographs are estimated at different locations along streams. Calibration to actual flood events is required. The web page is at: http://www.dhisoftware.com/mike11/Description/RR_module.htm	No
	PRMS Version 2.1 (January 1996)	U.S. Geological Survey	U.S. Geological Survey 12201 Sunshine Valley Drive Reston, VA 22092 http://water.usgs.gov/software/surface_water.html U.S. Geological Survey P.O. Box 25046, Mail Stop 412 Denver Federal Center Lakewood, CO 80225-0046 http://wwwbrr.cr.usgs.gov/mms/	PRMS is a modular-designed, deterministic, distributed-parameter modeling system that can be used to estimate flood peaks and volumes for floodplain mapping studies. Calibration to actual flood events required. The program can be implemented within the Modular Modeling System (MMS) that facilitates the user interface with PRMS, input and output of data, graphical display of the data, and an interface with GIS.	Yes
Interior Drainage Analysis	HEC-IFH 1.03 and up	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Provides both continuous simulation and hypothetical event analyses. Coincidence frequency analysis (not included in the model) may be needed for some cases. Supporting documentation is available at: http://www.fema.gov/fhm/dl_ifh.shtm	Yes

[2]The enhancement of these programs in editing and graphical presentation can be obtained from several private companies.

[3]Program is typically distributed by vendors and may not be available through HEC. A list of vendors may be obtained through HEC.

APPENDIX 2

Test Watershed Selection and Modeling Process

Test Watershed Selection and Modeling Process

The scope of work requires that testing of the "selected assumptions" be performed on gaged watersheds in Arizona, specifically watersheds within one of the flood regions identified the State Standards 2-96. Four test watersheds are to be identified for testing. Two of those are to be "relatively simple (less than 10 square miles)" and two are to be "moderately complex (greater than 100 square miles and less than 500 square miles)".

The most current, comprehensive statewide information of gage data is documented in *Statistical Summaries of Streamflow Data and Characteristics of Drainage Basins for Selected Streamflow-Gaging Stations in Arizona Through Water Year 1996, Water-Resources Investigation Report 98-4225* (USGS, 1998). Review of the data contained in that document in regard to the requirements of the scope of work yielded 20 potential test watersheds, 10 for the relatively simple test case and 10 for the moderately complex test case. Criteria for the selection of the twenty potential test watersheds is as follows:

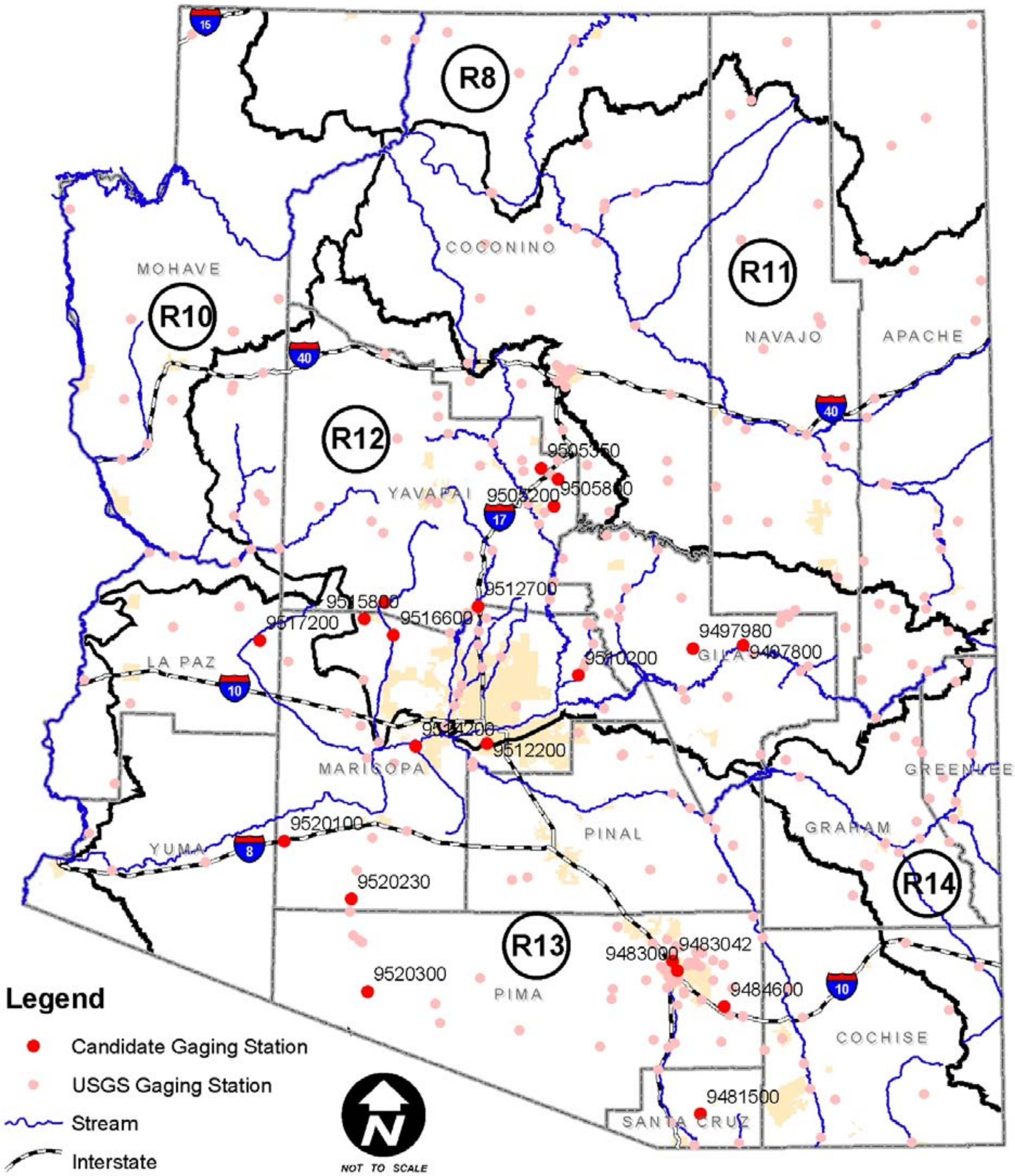
- Minimum period of record of 20 years
- Drainage area less than 500 square miles
- Minimum or no diversions upstream of the station
- No storage and regulation by reservoirs upstream of the station
- Main channel slopes less than 260 feet per mile

A summary of the twenty gaged watersheds is provided in Table 1. Gage locations of the 20 potential test watersheds are shown in Figure 1. Included in that summary is the Log Pearson Type III 100-year peak discharge estimate. The highlighted entries are reported by the USGS to have uncertainty in the 100-year peak discharge estimate. The 100-year peak discharge estimate is based on the period of record as of 1996. Many of the gages listed in Table 1 are still active. It is possible to revise the 100-year peak discharge estimates to include the additional 9 years of record increasing the confidence in the estimate. Two of the potential test watersheds are within urbanized areas and the discharge records have been affected by the urbanization for the entire period of record.

Table 1
Candidate test watersheds

Gage No.	Station Name	Drainage Area sq. miles	Mean Basin Elevation feet	Main Channel Slope ft/mi	Period of Record (as of '96)	100-Year LP 3 Peak Discharge cfs	2005 Available Range of Data: Begin Date	2005 Available Range of Data: End Date	Remarks
Moderately Complex									
09481500	Sonoita Creek Near Patagonia, Ariz.	209	4,800	76.7	44	15,100	Jun-30	Sep-72	
09484600	Pantano Wash Near Vail, Az	457	4,500	46.3	38	32,100	Jan-59	Sep-05	
09497800	Cibecue Creek Near Chrysotile, Ariz.	295	5,700	79.6	37	20,800	May-59	Sep-05	Small div. above station.
09497980	Cherry Creek Near Globe, Ariz.	200	5,600	87.9	30	25,400	May-65	Sep-05	
09505200	Wet Beaver Creek Near Rimrock, Arizona	111	6,410	131	34	15,800	Oct-61	Sep-05	
09505350	Dry Beaver Creek Near Rimrock, Ariz.	142	6,220	137	35	51,400	Oct-60	Sep-05	
09505800	West Clear Creek Near Camp Verde, Ariz.	241	6,680	112	31	32,700	Dec-64	Sep-05	
09510200	Sycamore Creek Near Fort Mcdowell	164	3,820	116	36	46,300	Oct-60	Sep-05	
09514200	Waterman Wash Near Buckeye, Ariz.	420	1,570	21.2	30	8,470	Sep-64	Jul-99	
09515500	Hassayampa R. At Box Damsite Nr Wickenburg Az	417	4,750	71	39	43,000	Jan-38	Sep-82	Small div. above station.
Relatively Simple									
09483000	Tucson Arroyo at Vine Ave, at Tucson	8.2	2,510	37	25	4,890	Aug-56	Jun-81	Urbanized watershed
09483042	Cemetery Wash At Tucson, Ariz.	1.17	2,370	40	24	842	Aug-66	Jul-90	Urbanized watershed
09512200	Salt River Trib. In S. Mnt. Park, Phoenix, Ariz.	1.75	1,730	244	33	2,230	Oct-60	Sep-98	
09512700	Agua Fria River Trib #2 Nr Rock Springs, Ariz	1.07	2,140	173	22	1,570	Aug-63	Jul-99	
09515800	Hartman Wash Near Wickenburg, Ariz.	5.57	2,690	71.6	21	7,100	Aug-64	Jul-99	
09516600	Ox Wash Near Morristown, Ariz.	6.31	2,290	101	22	3,720	1960	Jul-99	
09517200	Centennial Wash Tributary Near Wenden, Ariz.	2.79	2,480	193	22	1,080	Aug-63	Feb-98	
09520100	Military Wash Near Sentinel, Ariz.	8.7	674	56	22	5,220	Aug-63	Mar-98	
09520230	Crater Range Wash Near Ajo, Ariz.	1.49	1,280	69.3	20	2,230	Aug-63	Mar-98	
09520300	Alamo Wash Trib Near Ajo, Ariz.	0.9	2,040	64	30	656	Aug-63	Aug-93	

Figure 1
USGS gage locations



In addition to the 20 watersheds listed in Table 1, 8 watersheds were listed as potential candidates in the March 3, 2006 State Standards Work Group meeting agenda. Of those eight, three (Sabino Canyon, Ventana Canyon and Granite Creek) are USGS gaged watersheds. Those three were not included in Table 1 either due an insufficient period of record or excessive main channel slope per the criteria listed previously.

Initial selection of the 4 test watersheds from the listing in Table 1 is the based on the gages without uncertainty in the 100-year peak discharge estimates. This eliminates all but one of the relatively simple watersheds. One of the relatively simple test cases should be one of the 2 urbanized watersheds. Both of the urbanized watersheds are located in Flood Region 13, specifically in the City of Tucson. The one gage from the relatively simple category without uncertainty in the 100-year peak discharge estimate is gage 09512200 located in Flood Region 12. Since the watershed area at gage 09512200 is small, 1.17 square miles, it is recommended that the larger urbanized basin at gage 09483000 be selected as the other relatively simple test watershed. Recommendations for the moderately complex test cases are the watersheds contributing to gages 09497980 and 09505350. Both test watersheds are located in Flood Region 12. Gage 09497980 is located on Cherry Creek in Gila County. Gage 09505350 is located on Dry Beaver Creek in Yavapai County.

The watershed delineation should be kept as simple as possible. For the two larger watersheds, USGS 7.5 Minute Series topographic mapping should be sufficient for watershed delineation and time of concentration parameter estimation. For the two smaller basins, more detailed topography can be obtained from Pima and Maricopa Counties. It is recommended that the Green and Ampt rainfall loss parameters be estimated using the general soil surveys for the two larger watersheds. For the two smaller watersheds, the detailed soil surveys can be used. It is also recommended that the ADOT Manual be used for the basic procedures to the parameter estimation with modifications as necessary to accommodate refinements to the methodologies proposed for the State Standard.

APPENDIX 3

Hydrologic Modeling Guidelines

Hydrologic Modeling Guidelines

General

Hydrologic modeling guidelines should be accurate, practical and reproducible. The accuracy of the hydrologic modeling guidelines is a measure of how well the methodology and results of the procedure reproduce the physical process being simulated. Although accuracy is highly desired, it is theoretically impossible to achieve in hydrologic modeling. However, relative accuracy of model results can be evaluated quantitatively through testing and verification against recorded data. Also, relative accuracy of methods for estimating individual model elements (i.e. rainfall, rainfall losses, runoff translation, etc.) can be evaluated qualitatively through an understanding of the theory and limitations of the methodologies.

Practicality is a measure of the “best” and most appropriate level of technology to apply considering the:

- Anticipated user
- Current technology being applied
- Availability of data
- Ability to simulate a range of hydrologic conditions
- Consequences of error
- Desired output

The practicality of a guideline is both a quantitative and a qualitative measure developed through an understanding of the goal of the guideline as well as the theory and limitations of the methodology.

Reproducibility is a measure of the degree of interpretation required to implement a guideline. Reproducibility is generally achieved through clear and concise procedures.

Methodology Evaluation

Selection of rainfall-runoff guidelines that can describe the range of hydrologic conditions that exist in the State of Arizona is a significant undertaking. Initial review of the literature collected in Phase I suggests a number of different methodologies appropriate for use in Arizona. However, the literature does not provide conclusive evidence that any single method is superior in regard to the three benchmarks of accuracy, practicality and reproducibility. Since a detailed evaluation of each methodology is beyond the scope of this State Standard, an initial screening is used to identify methodologies that represent the current state of the practice in Arizona for further evaluation.

Based on the results of the Phase I questionnaire, discussions during the kick-off meeting, review of existing hydrologic manuals and personal experience, the current technology being applied in Arizona can be generalized into two categories. The first category is NRCS methodologies. The second category is the methodologies set forth in the ADOT Hydrology Manual. Use of these methodologies in arid and semi-arid lands is supported by an initial review of the literature collected in Phase I. These methods are also the most widely implemented in mathematical models and data needed for estimating the various parameters are readily available. Both sets of methodologies have strengths and weaknesses in regard to the three benchmarks of accuracy, practicality and reproducibility as described in the following sections.

Rainfall

It is generally accepted that for larger watersheds in Arizona, the major flood producing storms generally occur in the winter months due to frontal or convergence activity. A frontal or convergence storm, herein referred to as a general storm, produces large volumes of relatively low intensity rainfall over long durations. General storms are also typically large in areal extent.

For smaller watersheds, the major flood producing storms generally occur in the summer months due to convective activity. A convective storm, herein referred to as a local storm, produces high intensity rainfalls over relatively short durations and small areal extent. Occasionally, these storms can also be imbedded in general summer storms that are typically a result of tropical storms that move into the state from the Pacific Ocean.

For design hydrology, the characteristics of the major flood producing storms are simulated using a synthetic storm. Criteria for synthetic storms can be developed from long-term data or from a historic storm. Components of a synthetic storm are basin average rainfall depth and temporal distribution.

Rainfall Depth-Duration Statistics

Until recently, rainfall depth-duration data for Arizona was obtained from the Precipitation-Frequency Atlas of the Western United States, NOAA Atlas 2. The NOAA Atlas 2 was published in 1973. The rainfall depth-duration data was derived from a period of record of approximately 15 years. In 2004 NOAA published an updated version of the Atlas for Arizona, NOAA Atlas 14. This update extends the period of record used in the derivation of depth-duration data through December of 2000. Depending on the type of data used (e.g. hourly, daily, etc.) the period of record ranges from 37 years to nearly 100 years.

Included in the NOAA Atlas 14 documentation is a figure showing the percent difference between NOAA Atlas 2 and NOAA Atlas 14 for the 100-year, 24-hour precipitation. That figure is provided for reference in Appendix 3-A. For most of the state, the difference in the 100-year, 24-hour precipitation ranges from a 10 percent increase to a 5 percent decrease. The maximum increase is approximately 25 percent and the maximum decrease is approximately 35 percent. To evaluate the differences in the two data sets for other durations, 100-year depth-duration statistics are prepared for one location in each county and plotted graphically. Those graphs are provided in Appendix A. Comparison of the depth-duration statistics from the two atlases illustrates that the comparison of just the 24-hour point precipitation estimates is not necessarily a good indicator of the differences for Arizona. At several sites, the maximum difference in point precipitation estimates occurs between the 1-hour to 12-hour durations. At eight sites, the NOAA Atlas 14 estimates are slightly higher for the short durations (5-minute to 1-hour), then drop below the NOAA Atlas 2 estimates for durations of 1-hour to 12-hours and then approach or even exceed the 24-hour NOAA Atlas 2 estimates. The NOAA Atlas 14 point precipitation estimates are greater than the NOAA Atlas 2 estimates for all durations at only two sites (Bisbee and Globe). At five of the sites (Parker, Phoenix, Clifton, Florence and Yuma), the NOAA Atlas 2 point precipitation estimates are greater than the NOAA Atlas 14 estimates for all durations.

Depth-Area Reduction

Conversion of the point precipitation data to basin average depths (for a given frequency) is accomplished using depth-area reduction factors. Depth-area reduction factors that have been developed for specific regions in Arizona or are currently used for hydrologic modeling in Arizona are listed below along with a brief discussion as well as presented graphically in Figure 1.

- NOAA Atlas 2 – Based on data from the eastern half of the country and a period of record less than 20 years. Reduction factors presented for 24-, 6-, 3- and 1-hour as well as 30-minute durations.
- Agricultural Research Service (ARS): Walnut Gulch – Based on 21 years of data from the experimental watershed located in southern Arizona. Depth-area reduction curves presented are limited to basin areas of approximately 80 square miles. Reduction factors presented for the 2-, 10- and 100-year frequencies of 24-, 6-, 3-, 2- and 1-hour as well as 30-minute durations.
- HYDRO-40 – Based on approximately 20 years of data from precipitation stations in Arizona and New Mexico including data from Walnut Gulch. Divided Arizona into 2 zones. Reduction factors presented for durations of 24-, 12-, 6- and 3-hours.
- Flood Control District of Maricopa County (FCDMC) – For general storms, the 24-hour depth-area factors from HYDRO-40 is specified. For local storms the factors are based on the 1954 storm over Queen Creek, Arizona.
- City of Tucson – For general storms, the depth-area factors from NOAA Atlas 2 are specified. For local storms, factors were developed for drainage areas up to 10 square miles.

As can be seen from Figure 1, the depth-area factors vary in terms of storm frequency and duration. In general, reduction factors decrease as the duration and frequency increase. The slopes of the curves are very steep up to about 50-square miles. The factors developed for the ARS at Walnut Gulch have the greatest reduction while the factors presented in NOAA Atlas 2 have the least reduction. The HYDRO-40 factors for the southeast region for the 3- and 6-hour durations are similar to the ARS factors for the 2-year, 2- and 6-hour factors (note that the HYDRO-40 data includes data from Walnut Gulch and represents the mean frequency of 2.54 years). The Flood Control District of Maricopa County 6-hour factors are more similar to the HYDRO-40 24-hour Central factors than the HYDRO-40 6-hour Central factors.

Temporal Distribution

Many different temporal distributions are being used or can be used to represent the temporal characteristics of local and general storms. Some of those distributions are derived from historic storm data while others are based on regional data. The following are descriptions of the various distributions.

- Hypothetical – A triangular distribution for durations from 5 minutes to 10 days constructed from depth-duration data.
- NRCS Type I and II – Developed from the National Weather Service depth-duration-frequency statistics (NOAA Atlas 2 and TP-40) for durations up to 24 hours and frequencies from 1 to 100 years. The Type I distribution is representative of coastal regions of the western United States and Hawaii. The Type II distribution is representative of areas in which high rates of runoff from small areas are typically generated during summer thunderstorms.
- FCDMC 6-hour – A family of distributions based on the 1954 storm over Queen Creek, Arizona. The distributions vary with storm size.
- City of Tucson 3-hour – A 1-hour distribution based on data from Walnut Gulch that was extended by 2 hours to allow for conversion of 1-hour point rainfall to 3-hour point rainfall.

Mass curves of each of the distributions are provided graphically in Figure 2. The NRCS Type II distribution has a greater maximum intensity than the Type I distribution. The Type II distribution can be characterized as a centrally nested distribution while the Type I distribution is more of a front loaded distribution. The maximum intensity associated with the Type I distribution is less than the maximum intensity of the Type II. The positioning of the maximum intensity for both the Type I and II distributions was based on design considerations, not meteorological factors (NRCS, 1973). The 24-hour hypothetical distribution is similar to the NRCS Type II. The FCDMC 6-hour distributions can be characterized as more back-end loaded distributions that decrease in intensity as the storm area increases. The distribution for the smallest drainage areas is essentially a lagged form of the 6-hour hypothetical distribution.

Figure 1
Depth-area reduction curves

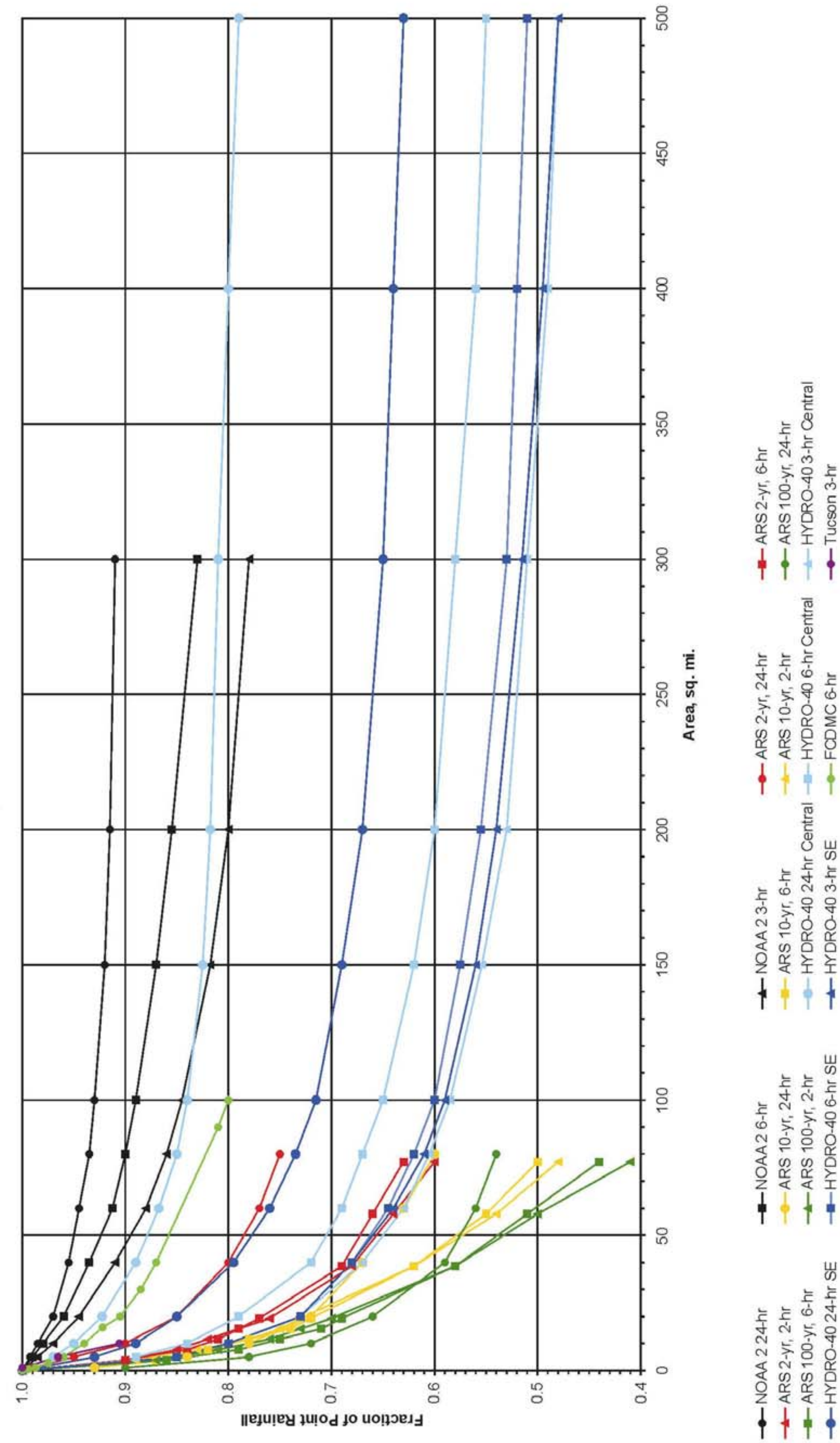
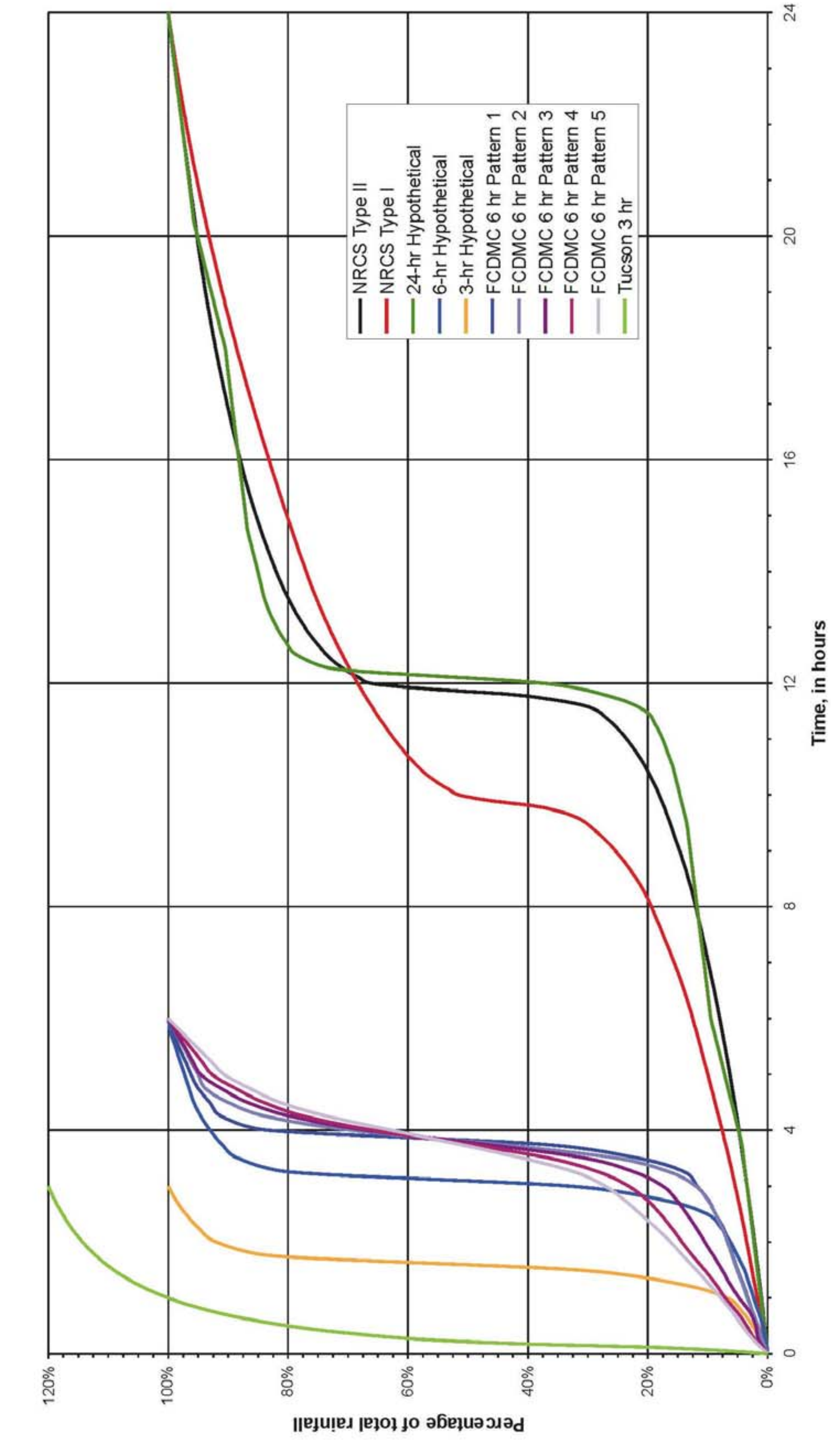


Figure 2
Comparison of rainfall mass curves



Analysis

Federal Emergency Management Agency guidelines for rainfall-runoff modeling of ungaged watershed require the use of a design storm that results in the highest peak discharge and that the critical storm be established through a sensitivity analysis. For the purposes of this State Standard, the depth-area reduction factors and temporal distributions are paired in various combinations to evaluate the "sensitivity" of the input for a hypothetical basin. The combinations are as follows:

- Case A1: NRCS Type I 24-hour rainfall distribution and NOAA Atlas 2 24-hour depth-area reduction factors
- Case A2: NRCS Type I 24-hour rainfall distribution and HYDRO-40 24-hour depth-area reduction factors for southeastern Arizona
- Case A3: NRCS Type I 24-hour rainfall distribution and HYDRO-40 24-hour depth-area reduction factors for central Arizona
- Case B1: NRCS Type II 24-hour rainfall distribution and NOAA Atlas 2 24-hour depth-area reduction factors
- Case B2: NRCS Type II 24-hour rainfall distribution and HYDRO-40 24-hour depth-area reduction factors for southeastern Arizona
- Case B3: NRCS Type II 24-hour rainfall distribution and HYDRO-40 24-hour depth-area reduction factors for central Arizona
- Case C1: Hypothetical 24-hour rainfall distribution and NOAA Atlas 2 24-hour depth-area reduction factors
- Case C2: Hypothetical 24-hour rainfall distribution and HYDRO-40 24-hour depth-area reduction factors for southeastern Arizona
- Case C3: Hypothetical 24-hour rainfall distribution and HYDRO-40 24-hour depth-area reduction factors for central Arizona
- Case D1: FCDMC 6-hour rainfall distributions and depth-area reduction factors
- Case D2: Hypothetical 6-hour rainfall distribution and NOAA Atlas 2 6-hour depth-area reduction factors for southeastern Arizona
- Case D3: Hypothetical 6-hour rainfall distribution and HYDRO-40 6-hour depth-area reduction factors for southeastern Arizona
- Case D4: Hypothetical 6-hour rainfall distribution and HYDRO-40 6-hour depth-area reduction factors for central Arizona
- Case E1: City of Tucson 3-hour rainfall distribution and depth-area reduction factor
- Case E2: City of Tucson 3-hour rainfall distribution and NOAA Atlas 2 3-hour depth-area reduction factors for southeastern Arizona
- Case E3: City of Tucson 3-hour rainfall distribution and HYDRO-40 3-hour depth-area reduction factors for southeastern Arizona
- Case E4: City of Tucson 3-hour rainfall distribution and HYDRO-40 3-hour depth-area reduction factors for central Arizona
- Case F1: Hypothetical 3-hour rainfall distribution and City of Tucson 3-hour depth-area reduction factor
- Case F2: Hypothetical 3-hour rainfall distribution and NOAA Atlas 2 3-hour depth-area reduction factors for southeastern Arizona
- Case F3: Hypothetical 3-hour rainfall distribution and HYDRO-40 3-hour depth-area reduction factors for southeastern Arizona
- Case F4: Hypothetical 3-hour rainfall distribution and HYDRO-40 3-hour depth-area reduction factors for central Arizona

The depth-duration statistics for the 100-year return period are taken from the NOAA Atlas 14. The hypothetical basin is located in Kingman, Arizona. The analysis considers durations of 3-, 6- and 24-hours. The analysis is performed for basin areas ranging from 1 to 100 square miles. Rainfall losses are modeled using the Green and Ampt infiltration equation. Runoff transformation is accomplished using the NRCS dimensionless unit hydrograph. The lag time for each drainage area considered is estimated assuming a basin length to width ratio of 3 to 1 and a velocity of 3 feet per second. Analysis is accomplished using HEC-1 version 4.1. The various combinations of depth-area reduction factors and temporal distributions for each basin area result in 147 models. Input and output files are provided on CD at the back of this document.

HEC-1 model results are summarized in Tables A-1 through A-21 in Appendix A as well as graphically in Figure 3. A few observations from an inspection of the figure and tables are:

- Peak discharges estimated with the COT rainfall distribution (Case E1 – E4) are consistently lower than all other distribution and depth-area factor combinations
- Peak discharges estimated with the hypothetical 6-hour rainfall distribution and HYDRO-40 6-hour depth-area factors (Case D3 and D4) for southeastern Arizona begin to decrease for drainage areas greater than 25 square miles
- The NOAA Atlas 2 depth-area factors result in the greatest peak discharges compared to all other depth-area reduction factors for all drainage areas modeled
- Peak discharges estimated with the hypothetical 3-hour distribution (Case F1 – F4) are only slightly less than the corresponding discharges for the 6-hour hypothetical distribution (Case D1 – D4)
- The 6-hour hypothetical distribution with NOAA Atlas 2 depth-area factors (Case D2) yield similar results compared to the 24-hour hypothetical distribution with the two HYDRO-40 depth-area factors (Case C2 and C3)
- Peak discharges estimated with the NRCS Type I distribution and the NOAA Atlas 2 depth-area factors (Case A1) are less than the 6-hour hypothetical distribution and the NOAA Atlas 2 depth-area factors (Case D2) for all drainage areas modeled
- Peak discharges estimated with the NRCS Type I distribution and the two HYDRO-40 depth-area factors (Case A2 and A3) are less than the 6-hour hypothetical distribution and the two HYDRO-40 depth-area factors (Case D3 and D4) for drainage areas less than 50 square miles
- In general, the duration of rainfall excess decreases with increasing drainage area with the exception of the rainfall distributions used in combination with the NOAA Atlas 2 depth-area reduction factors
- For the modeling scenario devised, lag time exceeds duration of rainfall excess at drainage areas between 10 and 25 square miles for the 24-hour rainfall distribution and depth-area factor combinations, 2 and 10 square miles for the 6-hour combinations and 2 square miles for the 3-hour combinations

In addition to those observations of the results, the peak discharges are compared against indirect methods of peak discharge estimation. The indirect methods of verification presented in the Flood Control District of Maricopa County (FCDMC) Drainage Design Manual (Draft 2003) are used for the comparison. The FCDMC Manual presents three methods for indirect verification.

The first method involves plotting model results on a graph of regional envelope curves of maximum discharge. That graph is reproduced as Figure 4. Model results for each basin area of the 21 different combinations of depth-area factors and temporal distributions are plotted on that figure. All of the combinations plot below the set of envelop curves.

The second method involves the comparison of model results to a plot of 100-year peak discharge estimates (Log Pearson Type 3) for gaged watersheds and a regression curve of the Log Pearson Type 3 (LP3) discharge estimates. That plot is reproduced as Figure 5. Model results for each basin area of the 21 combinations of depth-area factors and temporal distributions are plotted on that figure. In general, the peak discharges estimated with the NRCS Type II, 3-, 6- and 24-hour hypothetical distributions and the FCDMC 6-hour distributions plot above the regression curve but within the 75% tolerance limits. The NRCS Type I and COT distributions plot below the regression curve but within the 75% tolerance limits.

The third method is a comparison of model results to a peak discharge estimate using a regional regression equation. The test watershed is located in Flood Region 10. Peak discharges estimated using the Region 10 regression equation for drainage areas from 1 to 100 square miles are plotted on Figure 6 along with the results from the various model simulations. The peak discharges estimated using the NRCS Type I and COT distributions plot closer to the Region 10 regression equation results for smaller drainage areas. The NRCS Type II and 24-hour hypothetical distributions plot closer to the Region 10 regression equation results for larger drainage areas.

Figure 3
Summary of model results for hypothetical example

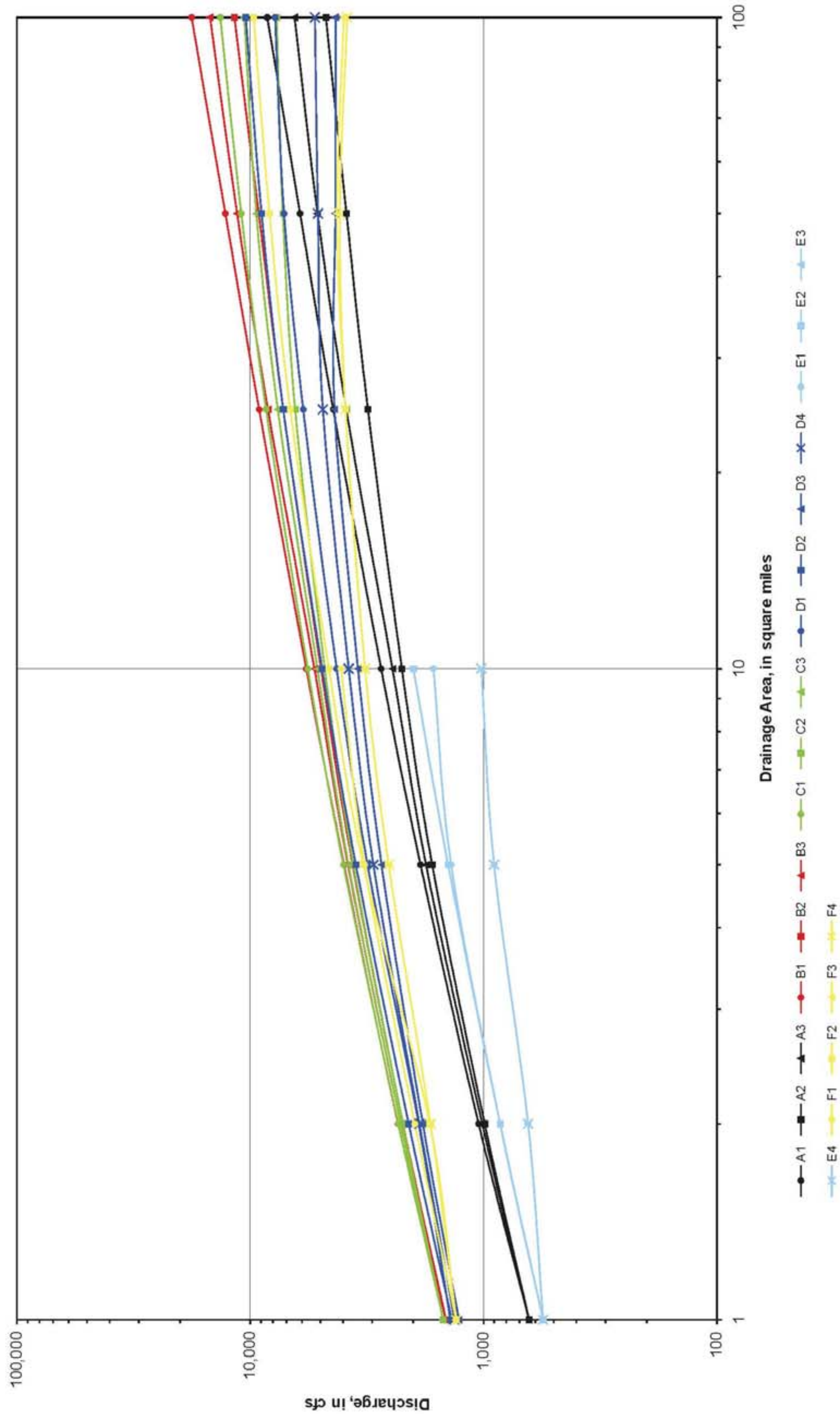


Figure 4
Indirect method of verification - Method 1

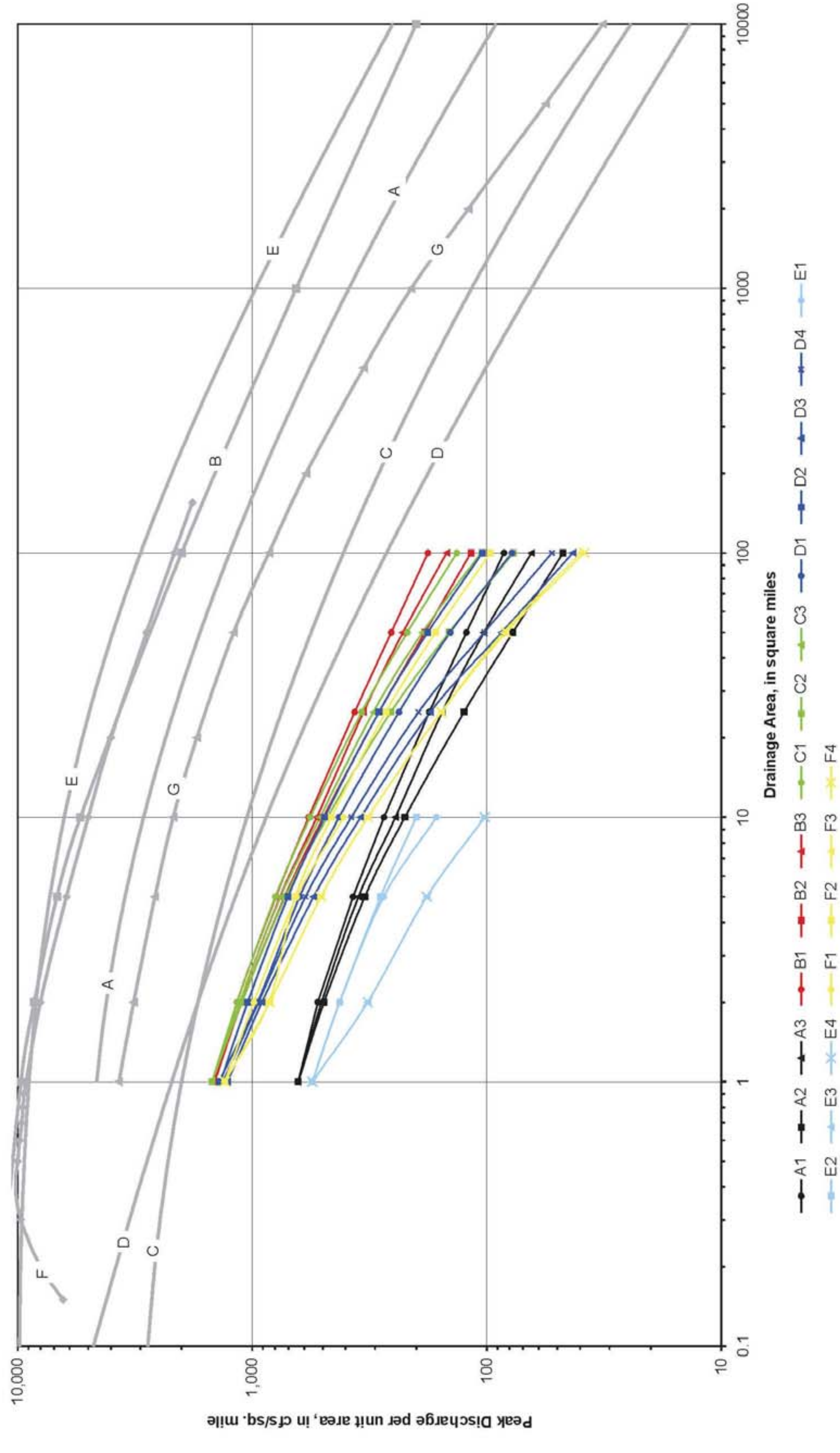


Figure 5
Indirect method of verification - Method 2

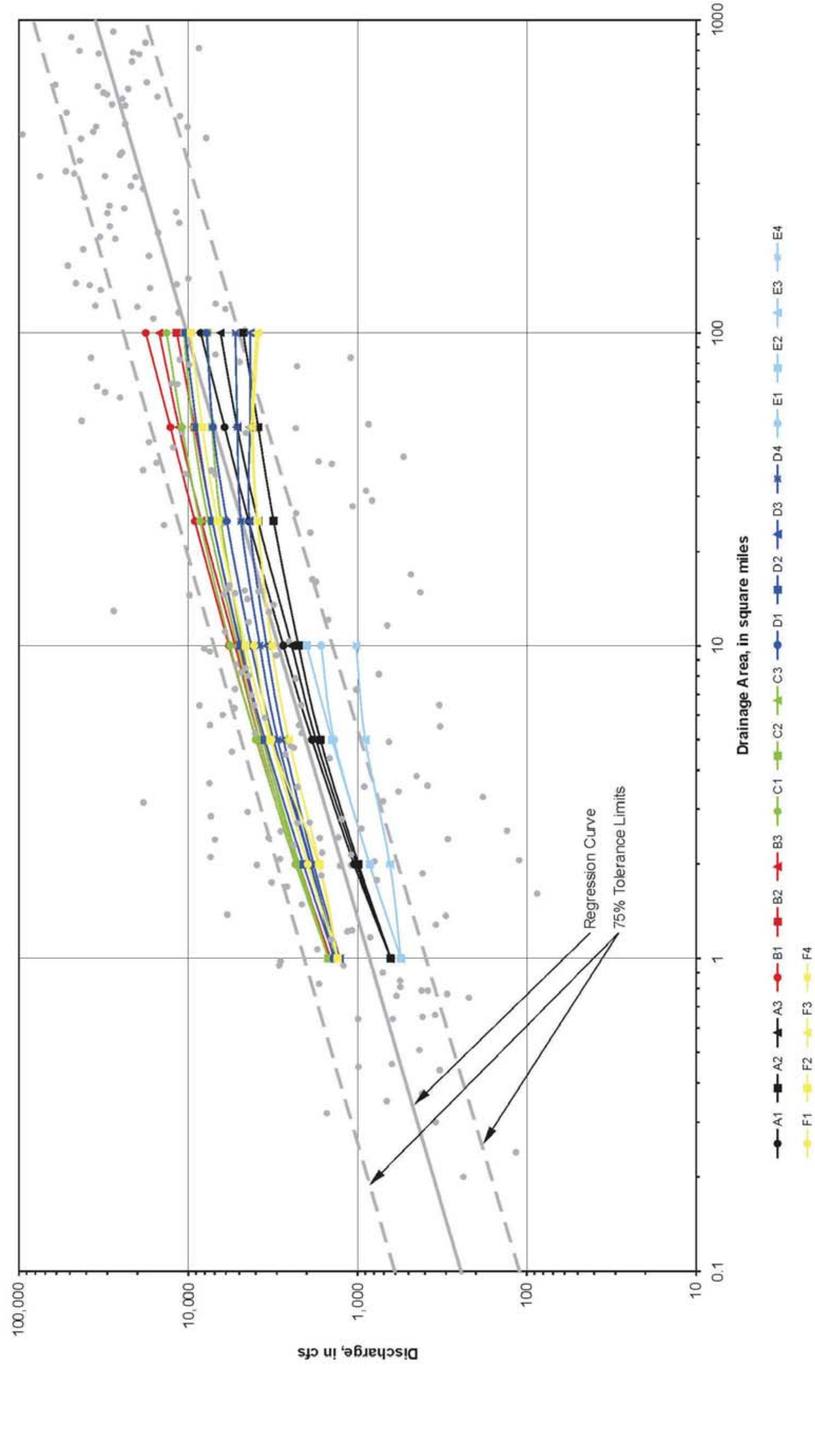
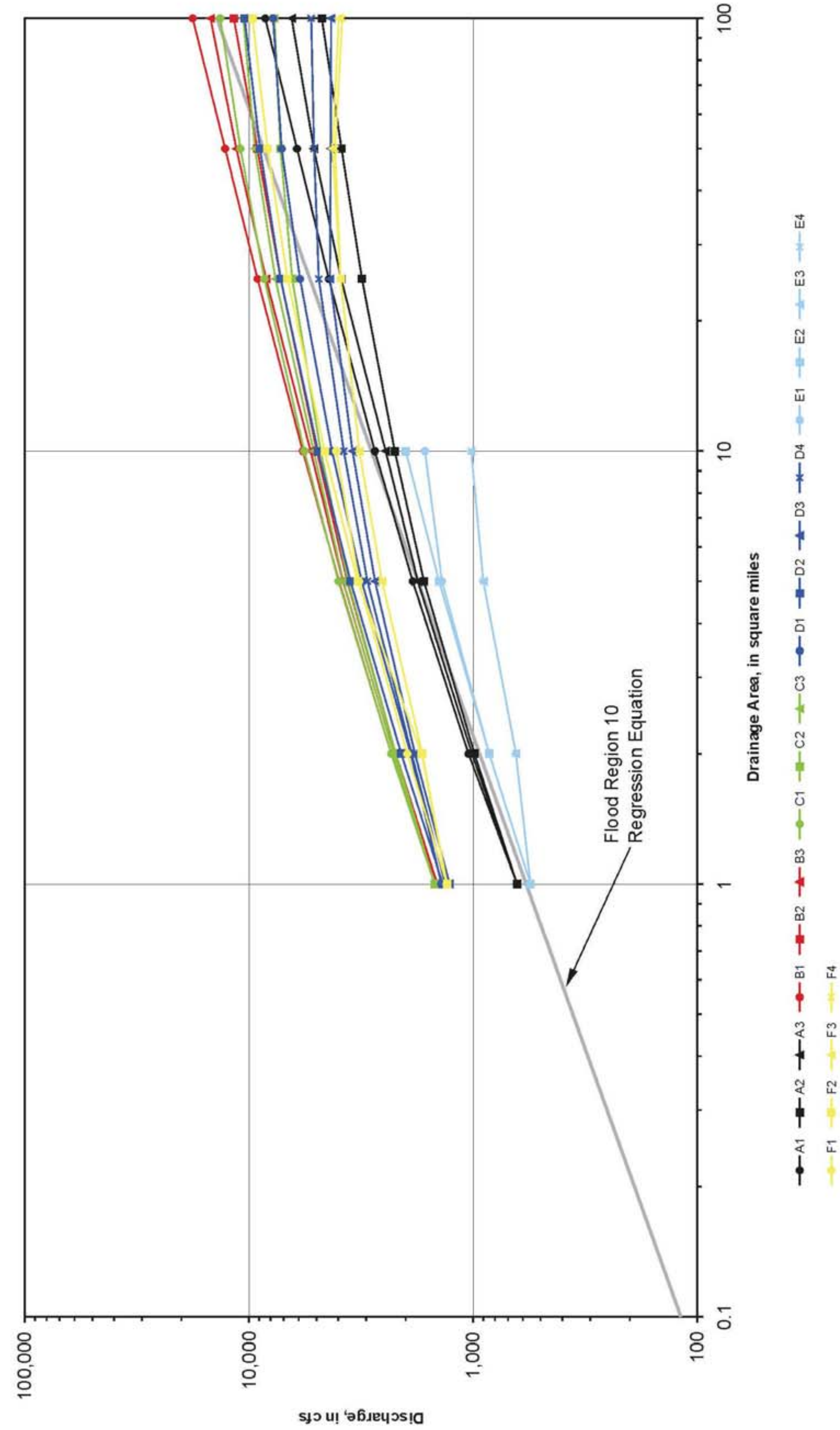


Figure 6
Indirect method of verification - Method 3



Recommendation

While highly desirous, development of rainfall criteria unique to specific regions in Arizona is not practical given the extreme variability and lack of sufficient spatial density and period of record of the rainfall data to characterize the variable conditions. Therefore, it is recommended that a single set of design rainfall criteria be adopted for the entire state.

The recommended source for depth-duration frequency statistics is the NOAA Atlas 14. Use of the NOAA 14 Atlas, despite the reduction in point rainfall in some portions of the state over what has been used in the past, represents the longest period of record and, therefore, the highest degree of confidence in 100-year design rainfall data.

The recommended depth-area reduction factors are the HYDRO-40 relations. Those relations are based on data from Arizona and consider different durations and regional factors. Those factors are representative of a 2.54-year frequency and are therefore conservative for 100-year flood hydrology modeling.

The recommended rainfall distribution is the hypothetical distribution. The hypothetical distribution is easily implemented. Its construction is based on depth-duration data and is therefore specific to the site of interest. The hypothetical distribution can be applied to durations consistent with local storms as well as general storms. However, the specific duration of a local and general storm is unknown. Another characteristic of local storms versus general storms that is unknown is the area at which one storm produces greater runoff magnitudes than the other. Literature suggests that the areal extent of local storms can be as great as 100 square miles. Based on the results of the hypothetical simulations of the various combinations of synthetic rainfall distributions and depth-area reduction factors, the break point is less than 50 square miles and more likely around 10 square miles. Literature also suggests that the duration of a local storm is less than 6-hours. Because the hypothetical distribution can be applied for storm durations between 5 minutes and 10 days, it allows for a convenient solution to the transition difficulty between the local and general storm, which is to use a duration based on time of concentration. The T_c considered would be for the entire watershed. For consistency with the depth-area reduction factors it is recommended that only durations of 3-, 6- and 24-hours be considered and that the first duration larger than the watershed T_c be used. For example, if the T_c is 3.1 hours, then the selected storm duration would be 6-hours. Concerns with this approach are first that the 24-hour duration storm will seldom be employed. Second, it is likely that T_c will exceed the duration of rainfall excess as T_c approaches the selected duration.

Rainfall Loss

Description of the strengths and weaknesses of the NRCS Curve Number (CN) methodology and the ADOT Green-Ampt (G&A) infiltration equation is provided qualitatively based on literature review and personal experience and quantitatively through a simple, hypothetical example.

Strengths of the NRCS CN method are:

- Easily estimated
- Widely accepted/familiarity with application
- Well suited for agricultural and desert rangeland watersheds
- Provides the necessary output for engineering analysis and design

Weaknesses of the NRCS CN method are:

- Hydrologic Soil Group (HSG) assigned to each soil map unit is an interpretation based on the definitions of the 4 groupings considering the entire soil depth. Typically, in arid/semi-arid hydrology only the top 6 to 9 inches is of interest.
- Incorporates vegetative cover, antecedent moisture conditions and impervious area into a single lumped value
- For a given rainfall depth, the volume of runoff is solely dependent upon the selection of CN
- Often subject to a high degree of interpretation
- Results are highly sensitive to CN selection

Strengths of the ADOT G&A method are:

- Data is readily available
- Flexibility to adjust independently for vegetative, antecedent and impervious conditions
- Well suited for a wide range of hydrologic conditions
- Provides the necessary output for engineering analysis and design
- Procedure for estimating parameters reduces sensitivity

Weaknesses of the ADOT G&A method are:

- Higher degree of complexity to estimate parameter values
- Greater opportunity for error

Analysis

Quantitative comparisons are based on a simple, hypothetical example of a small desert rangeland watershed of 2 sq. miles in size located approximately at latitude 33°, longitude 112° (somewhere in Pinal County). Depth-duration-frequency statistics for the site are obtained from the NOAA Atlas 14 web site and are provided in Table A-22 of Appendix A. Those statistics are applied to three different design rainfall distributions and durations:

- Case 1 - SCS Type II (24-hour)
- Case 2 - 24-hour hypothetical distribution
- Case 3 – 6-hour hypothetical distribution

Runoff transformation is approximated using the dimensionless unit hydrograph with a 1-hour lag time. For each case four different rainfall loss estimations are made according to the four Hydrologic Soil Groups (HSG); A, B, C and D. Table 5 of the *Soil Survey for Eastern Maricopa and Northern Pinal Counties Area, Arizona* (SCS, 1974) and Appendix A of Chapter 7 of *Part 630 Hydrology, National Engineering Handbook* (NRCS, 1998) are used to develop a relation between

HSG and soil texture. Table 2-2d from *Urban Hydrology for Small Watersheds* (NRCS, 1986) is used for the selection of CN for a desert scrub environment in poor condition. Values of hydraulic conductivity (XKSAT) assigned to each CN are listed in Table 1. A HSG is an average representation of the soil conditions. In Part 630 Hydrology, Chapter 7, Appendix A, several soil textures are related to each HSG. Therefore, the arithmetic average XKSAT for each range of soil textures is computed as an equivalent value to the selected CN for each HSG. The values for the other variables for the G&A equation are taken from Table 3-2 and Figure 3-3 of the ADOT Hydrology Manual.

Table 1
Curve Number and Green-Ampt hydraulic conductivity values assigned to hydrologic soil groups

Hydrologic Soil Group	Curve Number	XKSAT in/hour
A	63	0.800
B	77	0.200
C	85	0.060
D	88	0.025

The input data was formulated into a set of HEC-1 input files and executed with version 4.1 of the program. Input and output files of the 24 models prepared for this analysis are provided on CD at the back of this document. Results for each rainfall case and each rainfall loss condition are summarized in Table 2. Figures 7 and 8 illustrate the losses calculated at each time step in relation to the rainfall distribution for HSG B of Case 1 and 2. Figures 9 and 10 show the rainfall loss and peak discharge results for each case and HSG.

Table 2
Summary of rainfall loss test results

Test Case	Rainfall Loss		Peak Discharge		Time to Peak	
	NRCS in	ADOT in	NRCS cfs	ADOT cfs	NRCS hrs	ADOT hrs
Case 1 – SCS Type II						
HSG A	2.32	2.82	511	567	12.92	12.92
HSG B	1.79	2.36	778	978	12.92	12.83
HSG C	1.39	1.87	995	1,264	12.92	12.83
HSG D	1.21	1.46	1,092	1,375	12.92	12.83
Case 2 – 24-Hour Hypothetical						
HSG A	2.32	2.54	639	817	13.17	13.00
HSG B	1.79	1.98	966	1,301	13.08	13.08
HSG C	1.39	1.58	1,230	1,608	13.08	13.08
HSG D	1.21	1.34	1,349	1,725	13.08	13.08
Case 3 – 6-Hour Hypothetical						
HSG A	1.92	1.80	488	713	4.17	4.00
HSG B	1.56	1.32	764	1,139	4.17	4.08
HSG C	1.25	0.95	1,003	1,451	4.17	4.08
HSG D	1.11	0.74	1,118	1,588	4.17	4.08

Figure 7
Rainfall loss comparison using the SCS Type II rainfall distribution (Case,1 HSG "B")

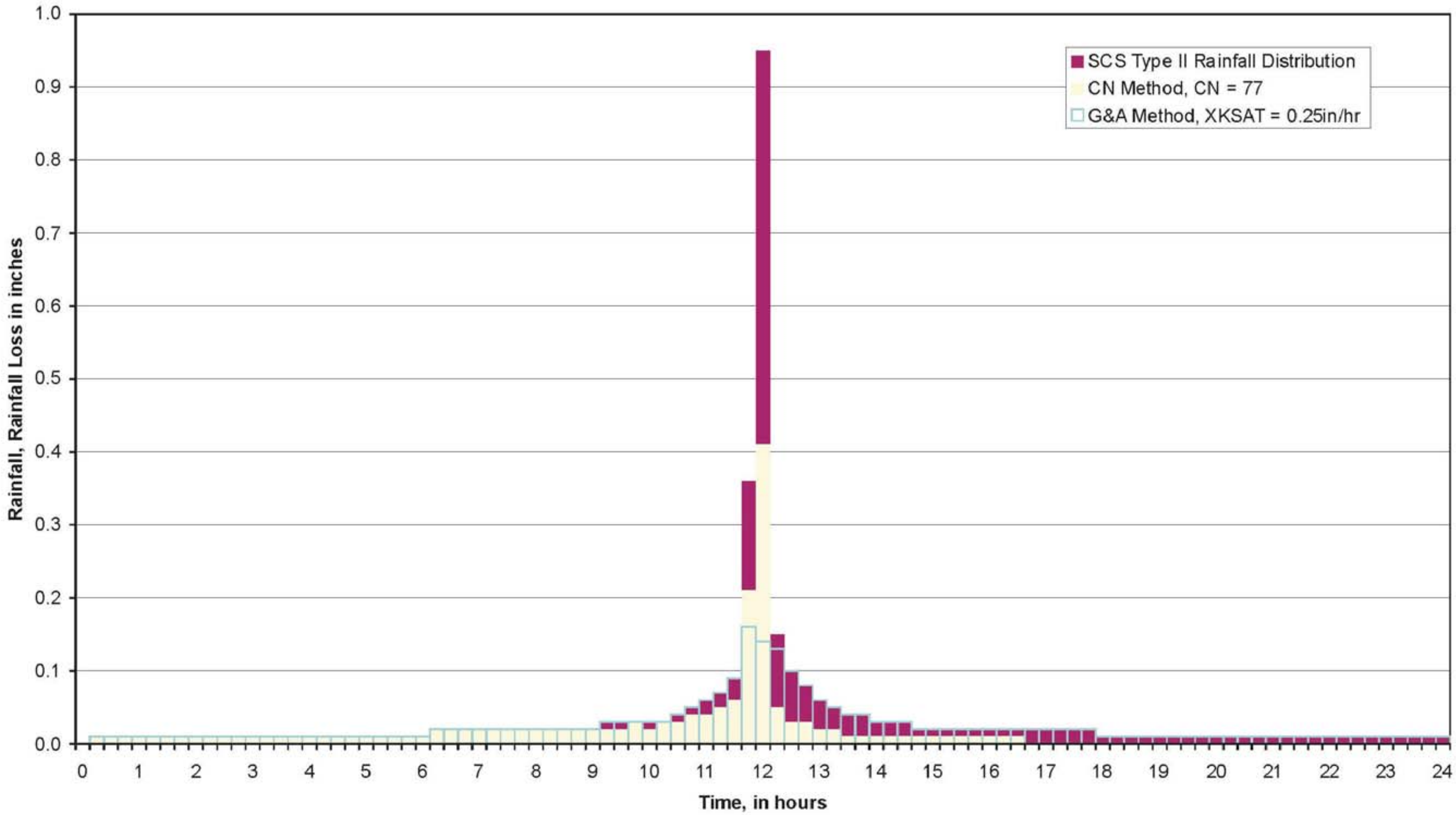


Figure 8

Rainfall loss comparison using the hypothetical rainfall distribution (Case 2, HSG "B")

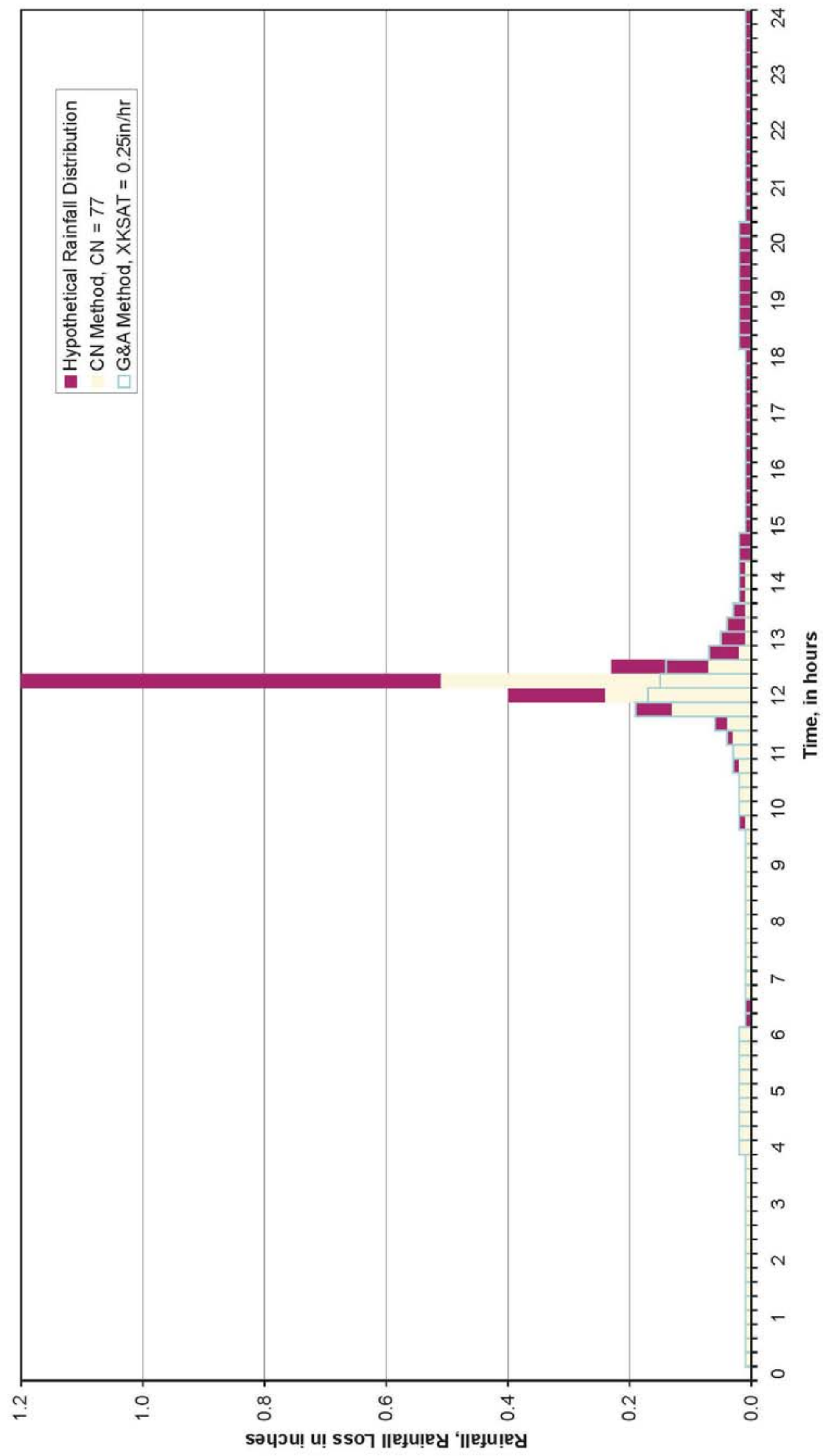


Figure 9
Comparison of rainfall losses

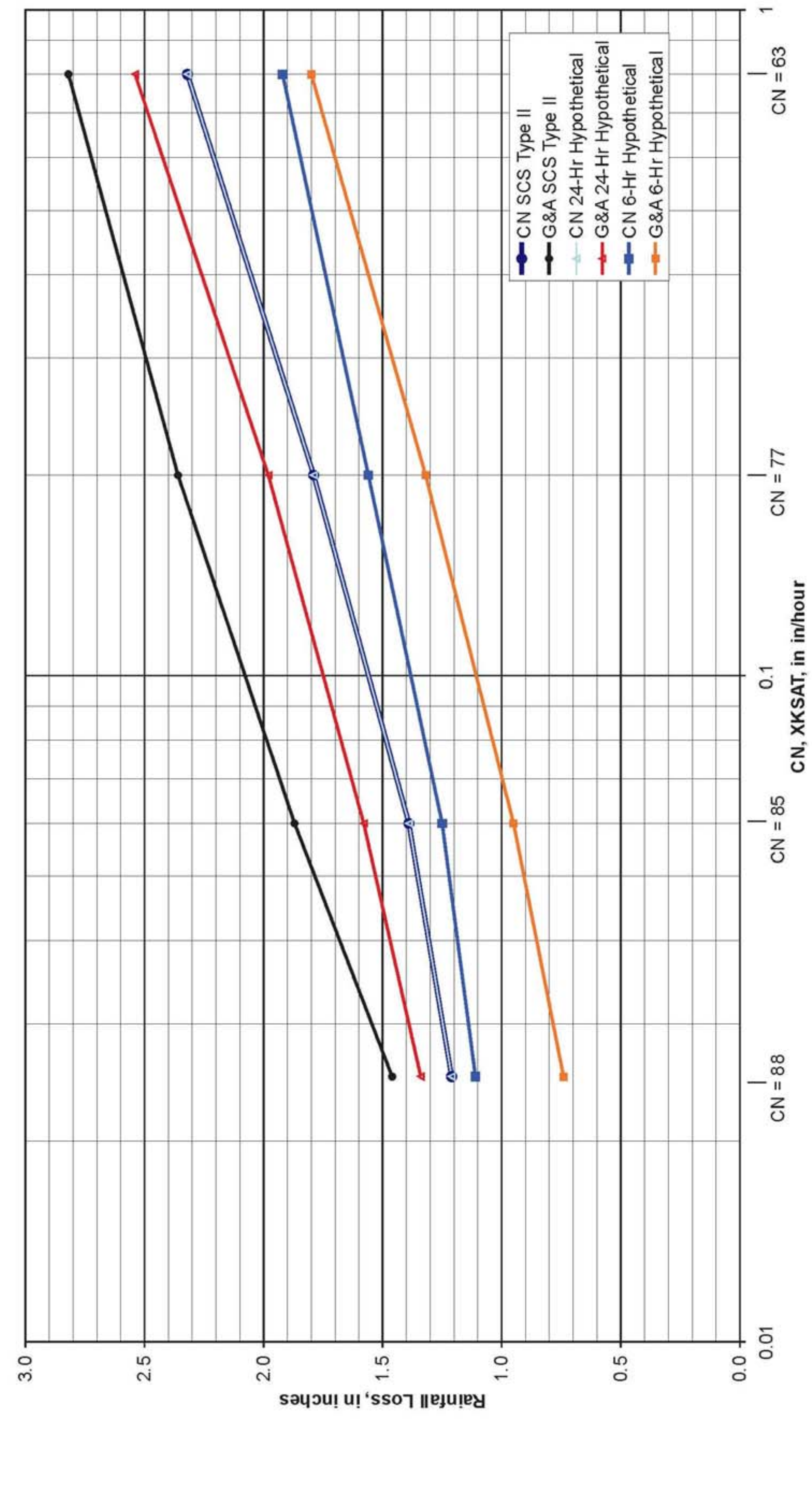
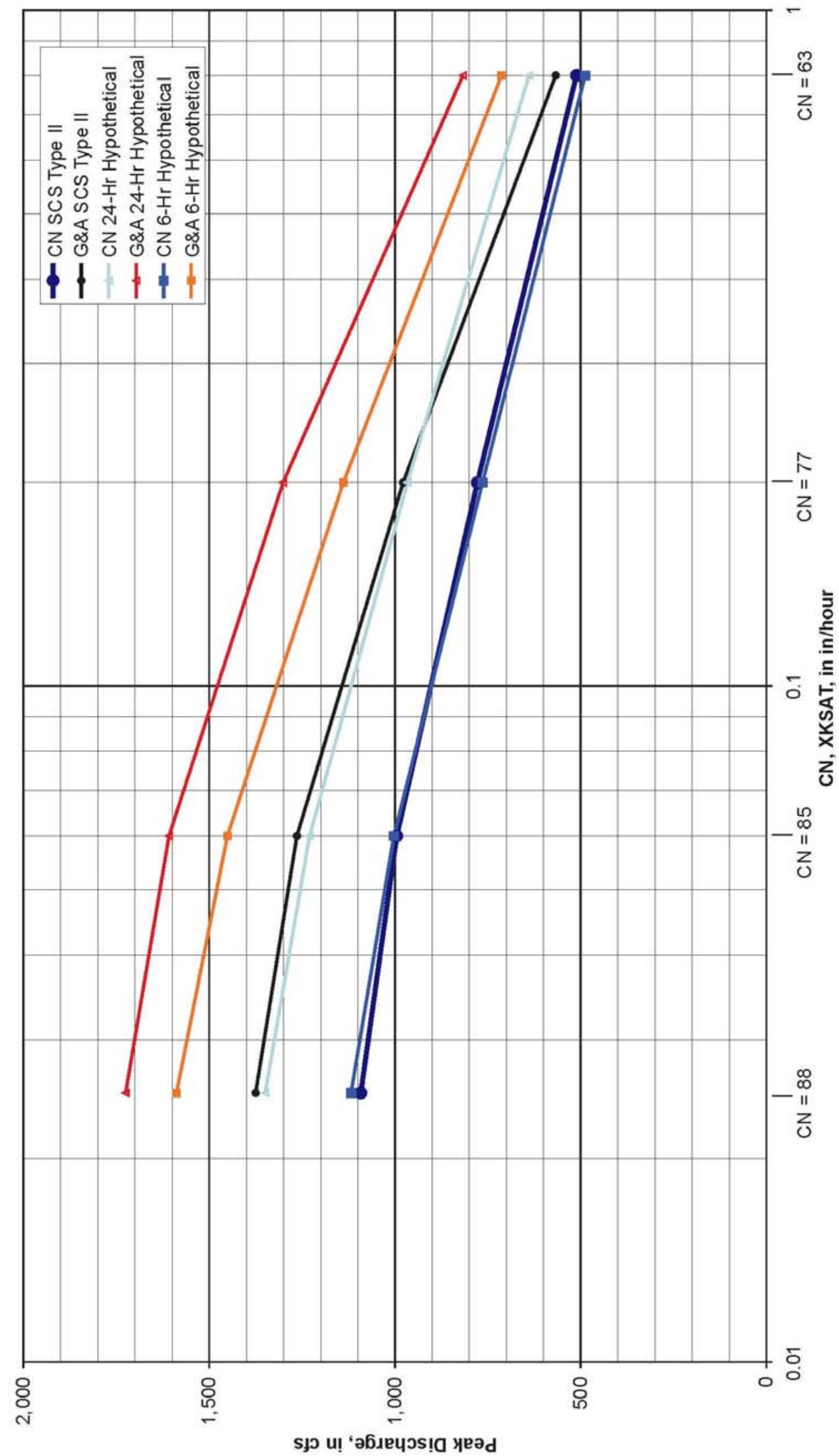


Figure 10
Comparison of peak discharge



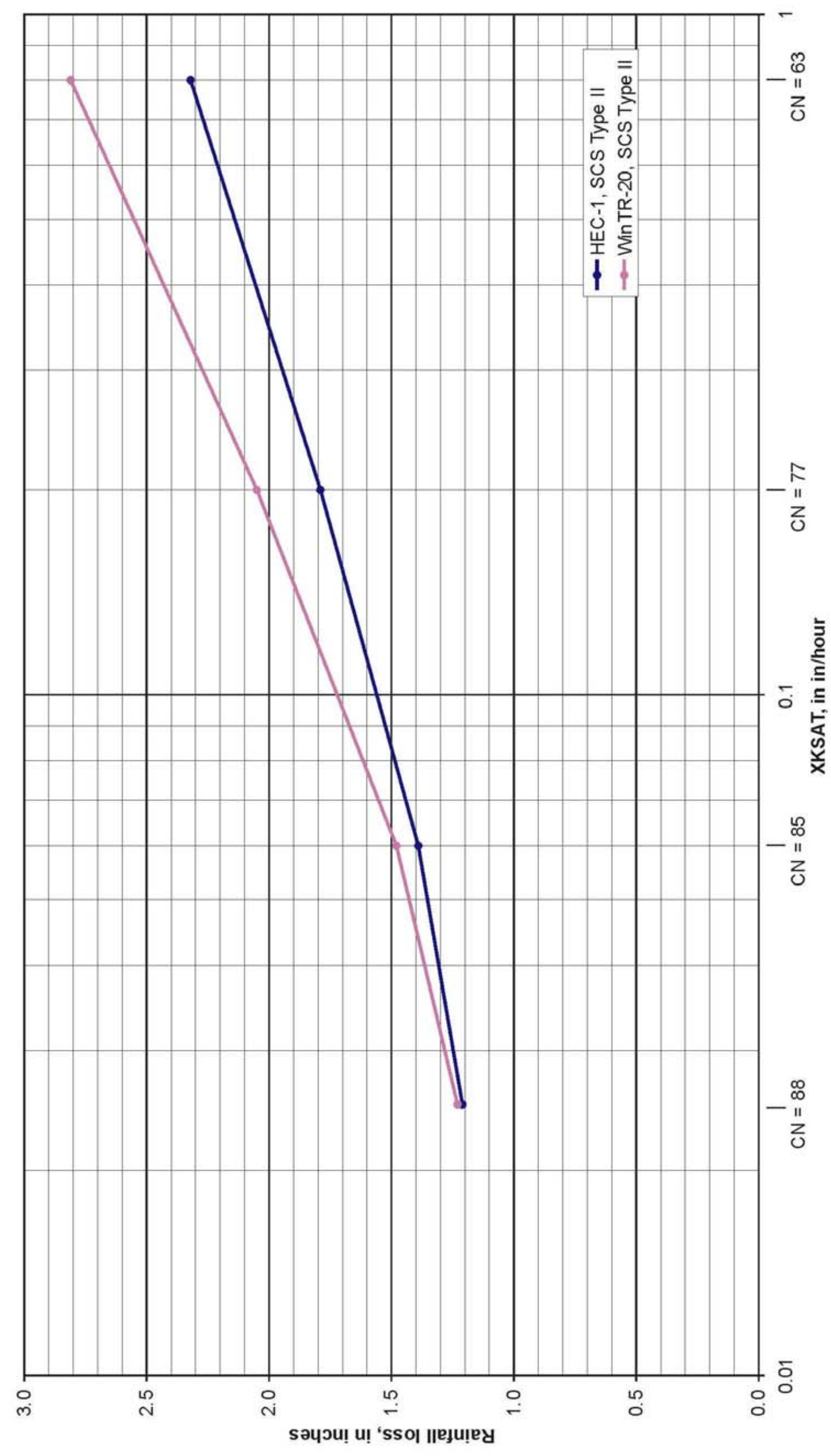
Recommendation

The rainfall loss methodologies that represent the current state of the practice in Arizona are the NRCS CN method and the Green-Ampt infiltration equation. Each method has strengths and weaknesses that influence the balance of the practicality and reproducibility benchmarks. Accuracy is difficult to evaluate due, in part, to the complexity of the physical process and the associated difficulties in formulating a mathematical simulation of the process. However, general statements regarding the relative accuracy of the two methods can be made based on the results. From Table 2 and Figures 7 and 8 it can be seen that for 24-hour storms the CN results in a greater volume of runoff than the Green and Ampt results but with lower peak discharges. The greater runoff volume generated with the CN is due to the allowance (as implemented in HEC-1) of infiltration to go to zero. This generally occurs on the receding limb of the rainfall hyetograph and thus does not impact the magnitude of peak discharge. Peak discharge results for the CN Method are typically lower because the magnitude of rainfall losses is directly proportional to the magnitude of rainfall intensity. As rainfall intensity increases so does the magnitude of the losses. From Figures 9 and 10, it can be seen based on the slope of the lines that the CN is more sensitive to soil conditions than the Green and Ampt equation.

Over the years there has been a healthy debate regarding the accuracy of the CN methodology. Recently, some of the concerns associated with the theoretical basis and procedural issues have been addressed and implemented in a new, Windows version of TR-20. The reformulation of the methodology gives different results than what is estimated using HEC-1 as illustrated in Figure 11 (note that HEC-HMS produces nearly identical results as HEC-1). This is an important consideration in regard to reproducibility. Other concerns with the CN methodology are the limited flexibility to address a range of hydrologic conditions due to the lumping of antecedent moisture, vegetation and impervious conditions into a single parameter and the independence or near independence of rainfall distribution and duration.

While the G&A infiltration equation is more complex to apply, there is much greater flexibility to address a variety of antecedent moisture, vegetative and impervious conditions, particularly conditions such as fire impacted watersheds, urbanization and extensive rock fragments in the soil. This is a key consideration in regard to the goals of this State Standard. Therefore, it is recommended that the Green-Ampt infiltration equation as presented in the ADOT Hydrology Manual be adopted as the methodology for rainfall loss estimation.

Figure 11
Comparison of rainfall losses using the NRCS CN as implemented in WinTR-20 and HEC-1



Runoff Transformation

The NRCS method for transforming rainfall excess to a runoff hydrograph is the dimensionless unit hydrograph. The dimensionless unit hydrograph is a synthetic unit hydrograph derived from a large number of unit hydrographs for watersheds of different sizes and different geographic locations. Generally, the NRCS dimensionless unit hydrograph is applied (e.g. in HEC-1) using a single parameter, Lag, with a fixed shape such that 37.5 percent of the area under the hydrograph occurs from the origin to the peak. Lag is defined as the time from the center of mass of rainfall excess to the peak rate of runoff and is generally estimated as 60 percent of the time of concentration. A common procedure for estimating Time of Concentration (T_c) is presented in TR-55 (NRCS, 1986). That procedure considers T_c as the sum of travel times for three flow conditions; overland flow, shallow concentrated flow and open channel flow.

The ADOT method for transforming rainfall excess to a runoff hydrograph is the Clark unit hydrograph. The Clark unit hydrograph is a synthetic unit hydrograph that accounts for the basin shape and storage of rainfall excess in the basin. Application of the Clark unit hydrograph requires three parameters; T_c, a storage coefficient (R) and a time-area relation. The equations for estimating T_c and R are based on data from numerous watersheds in the Southwest. The time-area relation defines the translation hydrograph. Two of the time-area relations presented in the ADOT Manual are based on data from watersheds in the Southwest. The third is a default relation coded into HEC-1.

Strengths and weaknesses of the NRCS and ADOT runoff transformation methodologies are provided qualitatively based on literature review and personal experience and quantitatively through a simple, hypothetical example.

Strengths of the NRCS methodology are:

- Physically based
- Widely accepted/familiarity with application
- Provides the necessary output for engineering analysis and design
- The parameters of T_c equation can be adjusted to reflect a wide range of hydrologic conditions
- The parameters of T_c equation can be adjusted to reflect conditions associated with a specific return period

Weaknesses of the NRCS methodology are:

- Dimensionless unit hydrograph (in most applications, e.g. HEC-1) is of a fixed shape that tends to over estimate peak discharge for mild to flat sloping watersheds and under estimate steeply sloped watersheds
- The overland flow element of the T_c equation is highly sensitive to length and roughness and under certain circumstances dominates the overall T_c
- The overland flow element of the T_c equation is tied to a 24-hour storm duration
- The selection of roughness for the overland flow element of the T_c equation is very subjective
- Distinction of shallow concentrated flow from overland flow is very subjective

Strengths of the ADOT methodology are:

- Physically based
- Equations for the estimation of the three parameters are based on data from arid/semi-arid watersheds

- The three parameters allows flexibility to account for different watershed conditions such as basin shape, storage and landform/land use
- Provides the necessary output for engineering analysis and design

Weaknesses of the ADOT methodology are:

- Time-area relations are generalized to land use categories but should also vary according to the basin shape
- Site-specific time-are relations are difficult and, in general, not practical to develop
- The storage coefficient is a function of T_c, flow path length and drainage area and cannot be adjusted independently without artificially changing a physical parameter
- The T_c is a constant for all return periods

Analysis

Quantitative investigations of the two methods are based on a simple, hypothetical example of a small desert rangeland watershed of 2 sq. miles in size located approximately at latitude 33°, longitude 112° (somewhere in Pinal County). Depth-duration-frequency statistics for the site were obtained from the NOAA Atlas 14 web site and are provided in Appendix B. Those statistics are applied to the SCS Type II rainfall distribution.

The hypothetical example is designed to test the sensitivity of each method to ranges in watershed conditions represented by the various input parameters for both an undeveloped (Case 1) and urbanized watershed (Case 2). Rainfall losses for both land use conditions are estimated using the Green and Ampt equation. The only difference in the rainfall loss input parameters for the two cases is the inclusion of impervious area for the urbanized watershed of 40 percent.

The input data was formulated into a set of HEC-1 input files and executed with version 4.1 of the program. A total of 40 models were prepared and the input and output files are provided on CD at the back of this document.

For the NRCS method, sensitivity to ranges in input parameters is tested by selecting a base set of parameters that are appropriate for a desert rangeland watershed and then varying individual parameters. For the NRCS method, the basin is assumed to be square in shape. Given that most of the issues associated with the estimation of the NRCS T_c equation deal with the overland flow and the shallow concentrated flow elements, the sensitivity test is focused on those parameters. Calculation worksheets for each condition of each case are provided in Appendix B. Brief descriptions of the conditions tested are as follows:

- Condition A: Minimum overland flow length of 50 feet
- Condition B: Maximum overland flow length of 300 feet (this is a maximum recommended by the NRCS, though there is some dispute that a more realistic maximum should be 100 feet)
- Condition C: Minimum overland roughness coefficient of 0.01 taken from Table 2 of SSA 4-95
- Condition D: Maximum overland roughness coefficient of 0.32 taken from Table 2 of SSA 4-95
- Condition E: Minimum overland slope of 0.005 feet/foot
- Condition F: Maximum overland slope of 0.1 feet/foot
- Condition G: Minimum shallow concentrated flow length of 200 feet
- Condition H: Maximum shallow concentrated flow length of 2,000 feet
- Condition I: Minimum shallow concentrated flow slope of 0.005 feet/foot
- Condition J: Minimum shallow concentrated flow slope of 0.1 feet/foot

Similar to the testing of the NRCS method, sensitivity to ranges in input parameters for the ADOT method is tested by selecting a base set of parameters that are appropriate for a desert rangeland watershed and then varying individual parameters. The base condition is a square basin 2 square miles in size with a slope equivalent to the average slope of the base condition used in the NRCS method testing. The range of input parameters is derived by altering the shape and slope of the basin and then adjusting the parameters accordingly. The basin shapes tested are described briefly below. Calculation worksheets for each condition of each case are provided in Appendix B.

- Condition A: Square basin with a flat slope
- Condition B: Linear basin with the length 5 times the width and a flat slope
- Condition C: Triangular basin with a long L_{ca} (apex at downstream end) and a flat slope
- Condition D: Triangular basin with a short L_{ca} (apex at the upstream end) and a flat slope
- Condition E: Same as Condition A, but with a steep slope
- Condition F: Same as Condition B, but with a steep slope
- Condition G: Same as Condition C, but with a steep slope
- Condition H: Same as Condition D, but with a steep slope

A summary of the input data and results for the hypothetical example for each case of the NRCS method and ADOT method are listed in Tables 3 and 4, respectfully. The HEC-1 models for each case and condition are provided on CD at the back of this document.

Table 3
Summary of NRCS runoff transformation testing

Test Case	T_c hrs	Lag hrs	Peak Discharge cfs	Time to Peak hrs
Natural Conditions				
Case 1A	1.13	0.68	1,301	12.50
Case 1B	1.65	0.99	936	12.83
Case 1C	1.00	0.60	1,444	12.42
Case 1D	1.55	0.93	989	12.75
Case 1E	1.34	0.80	1,134	12.67
Case 1F	1.08	0.65	1,355	12.50
Case 1G	1.15	0.69	1,284	12.50
Case 1H	1.37	0.82	1,109	12.67
Case 1I	1.37	0.82	1,109	12.67
Case 1J	1.18	0.71	1,256	12.58
Urban Conditions				
Case 2A	0.64	0.38	2,328	12.25
Case 2B	0.75	0.45	2,076	12.33
Case 2C	0.64	0.39	2,290	12.25
Case 2D	0.69	0.41	2,216	12.25
Case 2E	0.68	0.41	2,216	12.25
Case 2F	0.63	0.38	2,328	12.25
Case 2G	0.59	0.35	2,422	12.25
Case 2H	0.81	0.49	1,971	12.33

Case 2I	0.78	0.47	2,026	12.33
Case 2J	0.57	0.34	2,460	12.17

Table 4
Summary of ADOT runoff transformation testing

Test Case	T_c hrs	R hrs	Time-area Relation	Peak Discharge cfs	Time to Peak hrs
			Natural Conditions		
Case 1A	1.55	0.74	Desert/Rangeland	977	13.08
Case 1B	1.90	1.27	Desert/Rangeland	652	13.42
Case 1C	1.73	0.88	Desert/Rangeland	848	13.25
Case 1D	1.36	0.61	Desert/Rangeland	1,136	12.92
Case 1E	1.08	0.50	Desert/Rangeland	1,356	12.75
Case 1F	1.32	0.85	Desert/Rangeland	938	12.92
Case 1G	1.20	0.59	Desert/Rangeland	1,203	12.83
Case 1H	0.95	0.41	Desert/Rangeland	1,550	12.67
			Urban Conditions		
Case 2A	0.68	0.30	Urban	2,147	12.25
Case 2B	0.90	0.64	Urban	1,365	12.42
Case 2C	0.75	0.35	Urban	1,938	12.25
Case 2D	0.60	0.24	Urban	2,410	12.17
Case 2E	0.53	0.22	Urban	2,588	12.17
Case 2F	0.64	0.38	Urban	1,958	12.25
Case 2G	0.59	0.27	Urban	2,299	12.17
Case 2H	0.46	0.18	Urban	2,817	12.17

The runoff transformation methodologies that represent the current state of the practice in Arizona are the NRCS dimensionless unit hydrograph and the ADOT Clark unit hydrograph. Each method has strengths and weaknesses that influence the balance of the practicality and reproducibility benchmarks. As stated previously, accuracy is difficult to evaluate. However, statements regarding the reasonableness of the methods can be drawn through inspection of the data in Tables 3 and 4 and the calculation worksheets in Appendix B.

In general, the results of the two methodologies are quite similar. For natural land use conditions, the peak discharges for the ADOT methodology tend to be slightly lower and the time to peaks slightly longer than the NRCS methodology. For developed conditions, the peak for the ADOT methodology tend to be slightly higher and the time to peaks slightly shorter than the NRCS methodology. The NRCS methodology is somewhat more sensitive to ranges in input than the ADOT methodology, particularly in regard to the overland flow element of the T_c procedure. For smaller basin areas, the sensitivity of this element can be significant as in the case for the hypothetical examples. As area increases the sensitivity of the overland flow element will diminish as the total travel time becomes dominated by the open channel flow condition. However, the open channel element also has sensitivity issues due to its basis in the estimation of a bank full condition. Presumably, the use of bank full conditions in the estimation of T_c is representative of the range in flow conditions occurring over that length of time. For many watercourses in Arizona, bank full conditions are not necessarily easily identified. This is somewhat problematic in that, the estimation of open channel travel time is fairly sensitive to channel depth. In the hypothetical example, a channel depth of 3 feet is used. For a roughness coefficient of 0.05, the velocity is 3.3 feet per second. The T_c velocity for the natural conditions example of the ADOT method ranges from 2 – 3 feet per second.

An important tool for evaluating the reasonableness of rainfall-runoff model results for ungaged watersheds is the comparison against indirect methods of peak discharge estimation. The maximum and minimum peak discharge results for the hypothetical examples are compared against the indirect methods of verification presented in the Flood Control District of Maricopa County (FCDMC) Drainage Design Manual (Draft 2003). The FCDMC Manual presents three methods for indirect verification.

The first method involves plotting model results on a graph of regional envelope curves of maximum discharge. That graph is reproduced as Figure 12. The minimum and maximum results for the natural and urbanized cases are shown in green for the NRCS methodology and red for the ADOT methodology. As can be seen from Figure 12, the hypothetical example results for both methodologies plot below the envelope curves of maximum discharge.

The second method involves the comparison of model results to a plot of 100-year peak discharge estimates (Log Pearson Type 3) for gaged watersheds and a regression curve of the Log Pearson Type 3 (LP3) discharge estimates. That plot is reproduced as Figure 13. The maximum and minimum model results for both the natural and urbanized condition are plotted in red for the ADOT methodology and green for the NRCS methodology. As can be seen from Figure 13, the hypothetical example results plot within the scatter of LP3 discharge estimates. The model results for the natural condition generally fall below the LP3 regression curve but within the 75% tolerance limits. The model results for the urbanized condition generally fall above the regression curve but within the 75% tolerance limits.

The third method is a comparison of model results to a peak discharge estimate using a regional regression equation. The test watershed is located in Region 13. The peak discharge estimate based on the Region 13 regression equation for an area of 2 square miles is 1,964 cfs. The Region 13 regression equation, along with the data (LP3 discharge estimates), is also plotted on a graph and that graph is reproduced as Figure 14. As with the other two indirect verification methods, the maximum and minimum model results for both the natural and urbanized condition are plotted in red for the ADOT methodology and green for the NRCS methodology. As can be seen from Figure 14, the hypothetical example results plot within the scatter of LP3 discharge estimates. The model results for the natural condition generally fall below the regression. The model results for the urbanized condition generally fall above the regression.

Recommendation

Given that both methods yield similar results, selection of a method that meets the objectives of this State Standard are more a function of the practicality and reproducibility benchmarks. From a practicality perspective, simulation of a wide range of hydrologic conditions using the NRCS methodology is accomplished through the selection of appropriate T_c input parameters such as the overland flow length and roughness coefficient. However, selection of those parameters is highly subjective and has a direct impact on reproducibility. With the ADOT methodology, simulation of a wide range of hydrologic conditions is accomplished through the selection of appropriate, predefined equations and relations thus improving the opportunity for reproducibility. Therefore, it is recommended that the ADOT method for runoff transformation be adopted for this State Standard.

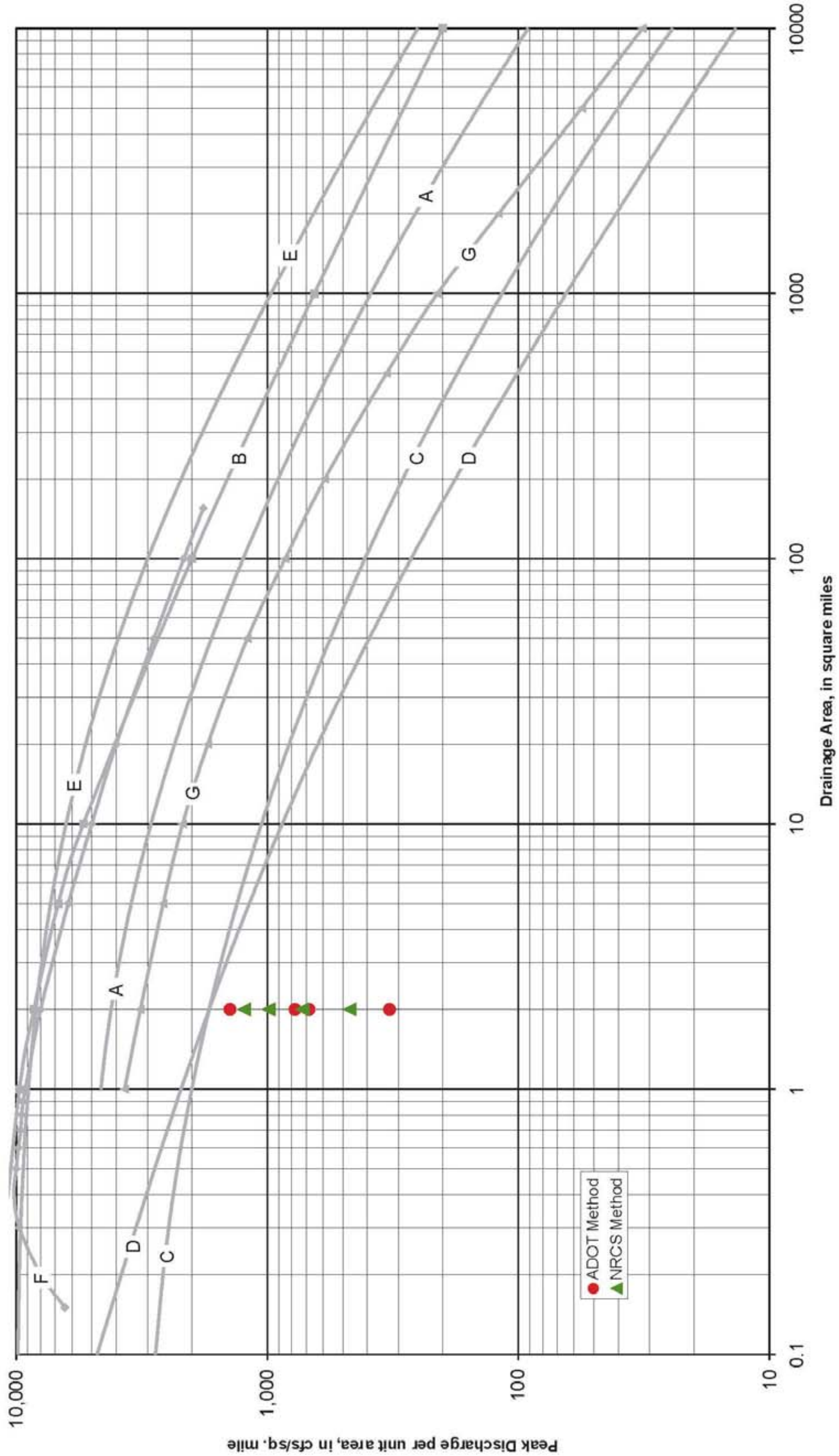


Figure 12
Regional maximum discharge envelope curves

Figure 13
Log Pearson Type 3 peak discharge estimates

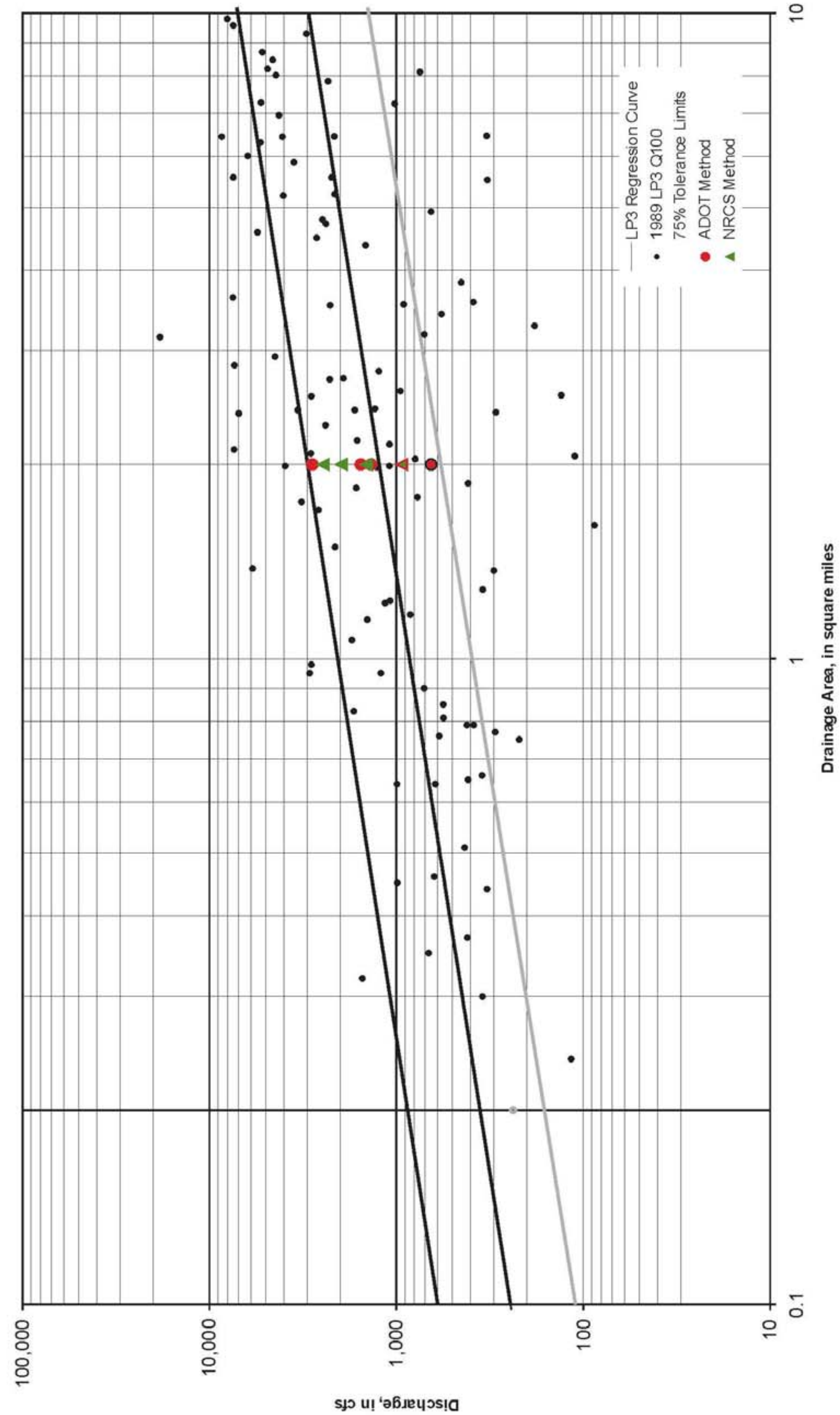
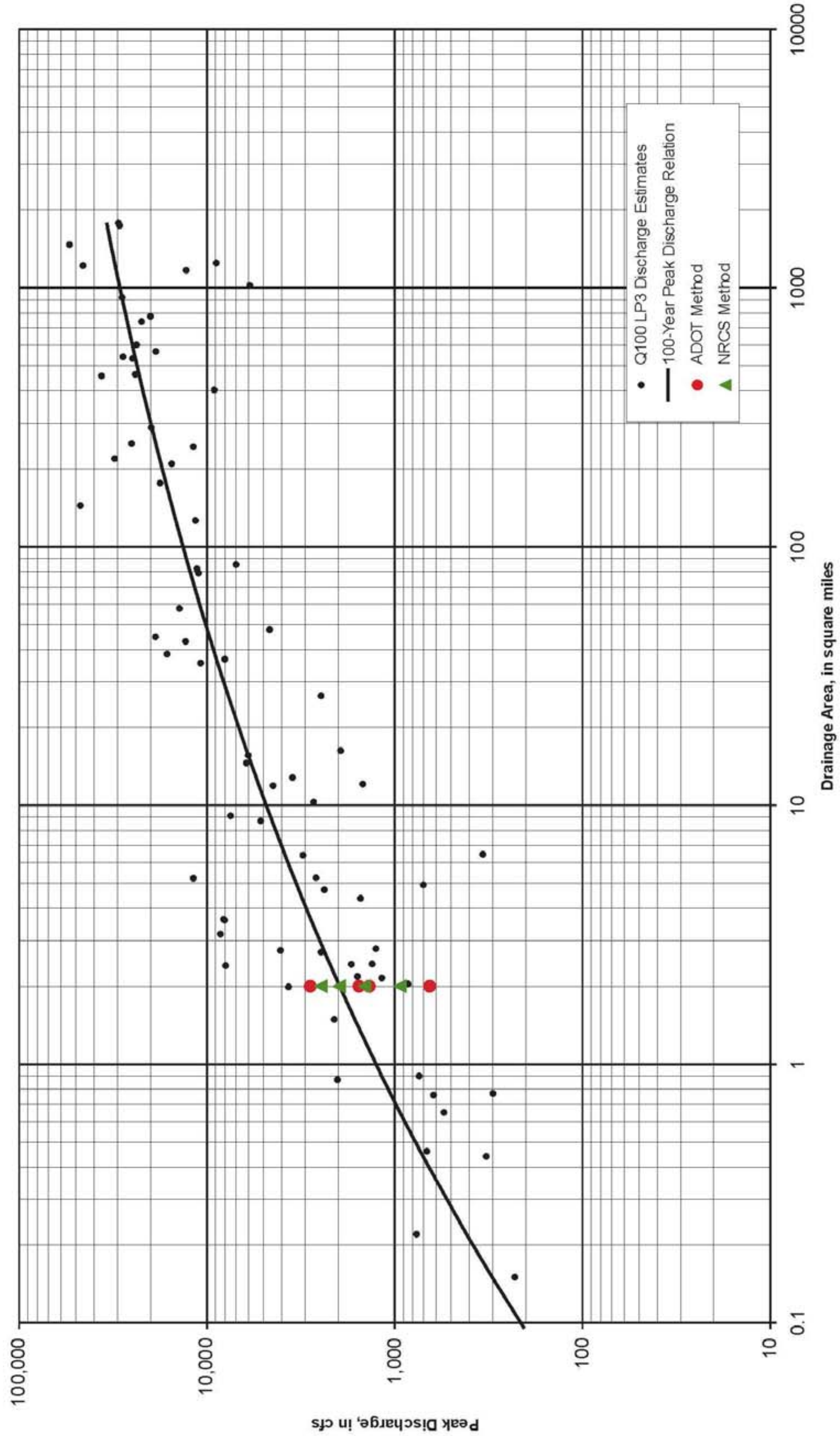


Figure 14
Regional regression equation



Runoff Translation

Runoff translation (channel routing) is a numerical process where flow is moved in time and space from one concentration point to the next. The effects of storage and flow resistance within a river/flow conveyance reach are reflected by changes in the hydrograph shape and timing as the floodwave moves from one concentration point to the next. There are two general categories of numerical methods for simulating this physical process; hydraulic and hydrologic. Hydraulic routing methods are based on some form of the partial differential equations for unsteady flow. Generally, only the Kinematic Wave approximation (the simplest form) is employed in rainfall-runoff models. Hydrologic routing methods are based on the continuity equation and a relation between storage in the channel reach and discharge at the outlet. Hydrologic routing methods are the most commonly employed in rainfall-runoff models. There are numerous hydrologic methods. The most common methods employed in rainfall-runoff models as well as the most commonly used methods in hydrologic modeling in Arizona are:

- Modified Puls – Normal Depth Option
- Muskingum
- Muskingum-Cunge

All of these methods can be and are used for channel routing purposes in rainfall-runoff modeling in Arizona. However, there are some key limitations that should be considered in the selection of a method for this State Standard.

Kinematic Wave

- Most appropriate for “steep” (greater than 10 feet per mile) channels of prismatic shape where little or no attenuation is anticipated
- The ideal application is for urban conditions with “engineered” conveyance elements including non-pressurized conduits
- Not appropriate for backwater areas

Modified Puls – Normal Depth Option

- Normal depth associated with uniform flow does not exist in natural streams, but can be used to estimate water depth and storage if uniform flow conditions can reasonably be assumed
- Attenuation is a function of the number of routing steps used in the solution and is a calibration parameter
- Not appropriate for backwater areas

Muskingum

- Most appropriate for large natural streams with mildly rising hydrographs where significant attenuation is anticipated
- Parameters are difficult to estimate and intended to be calibrated to observed data
- Not appropriate for backwater areas

Muskingum-Cunge

- Most appropriate for mildly rising hydrographs for both natural streams and man-made channels where attenuation is anticipated
- Not appropriate for very mild sloping channels
- Not appropriate for backwater areas

Recommendation

Runoff hydrographs resulting for the design criteria in use and recommended for use in Arizona typically has a very rapidly rising shape. This general characteristic limits the appropriateness of the Muskingum and Muskingum-Cunge channel routing methods. The Kinematic Wave channel routing method can be difficult to apply to natural streams because of the limited options for representing channel geometry and the minimal attenuation that the method accounts for. The Modified Puls – Normal Depth Option can be applied to a variety of channel configurations both natural and man-made, but for many urban conditions the short routing lengths and higher velocities can result in numerical instabilities. Therefore, it is recommended that the Kinematic Wave channel routing method be adopted for urban conditions and the Modified Puls – Normal Depth channel routing option be adopted for natural conditions.

APPENDIX 3-A

RAINFALL DATA

Figure A-1
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
St. Johns, Apache County

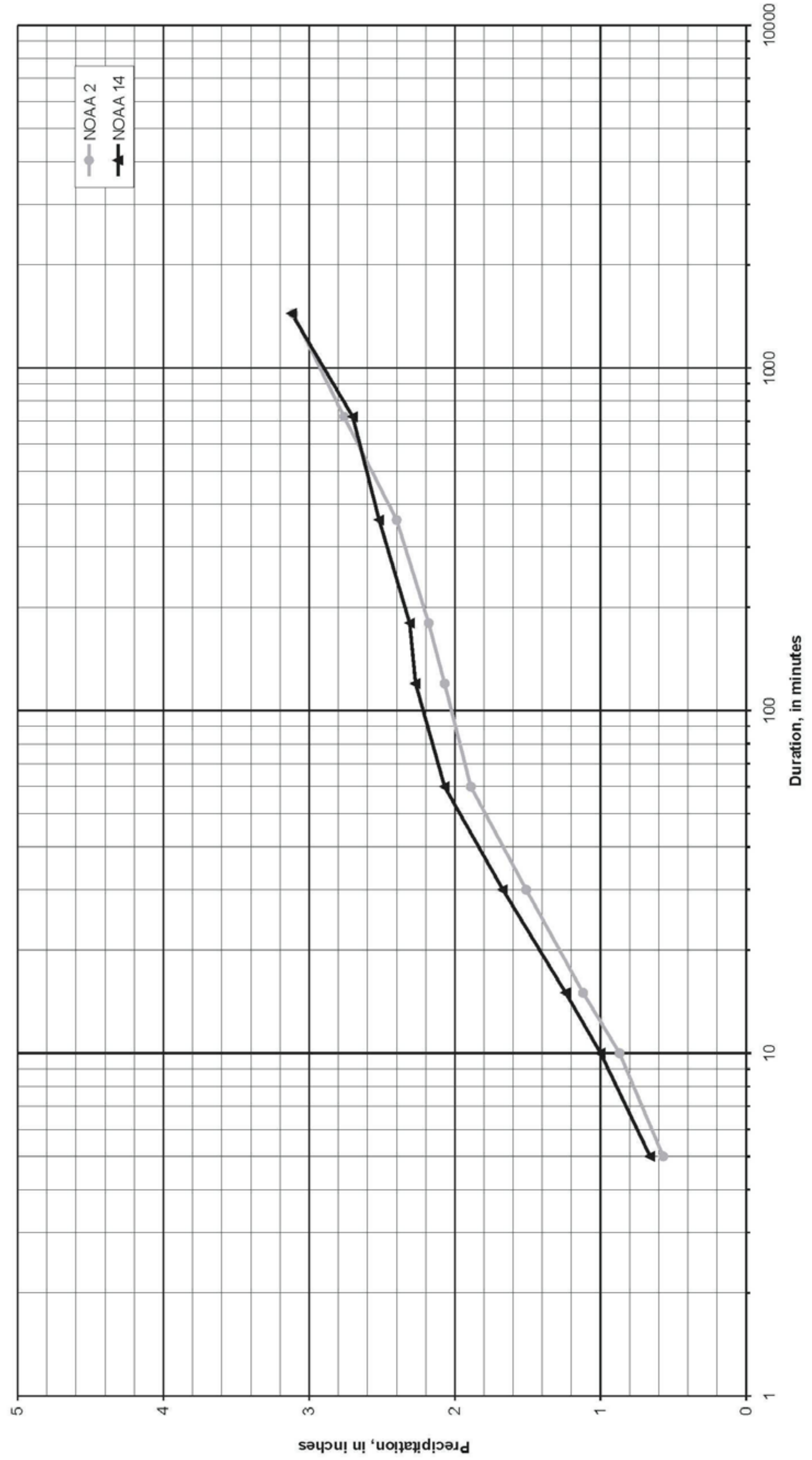


Figure A-2
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Bisbee, Cochise County

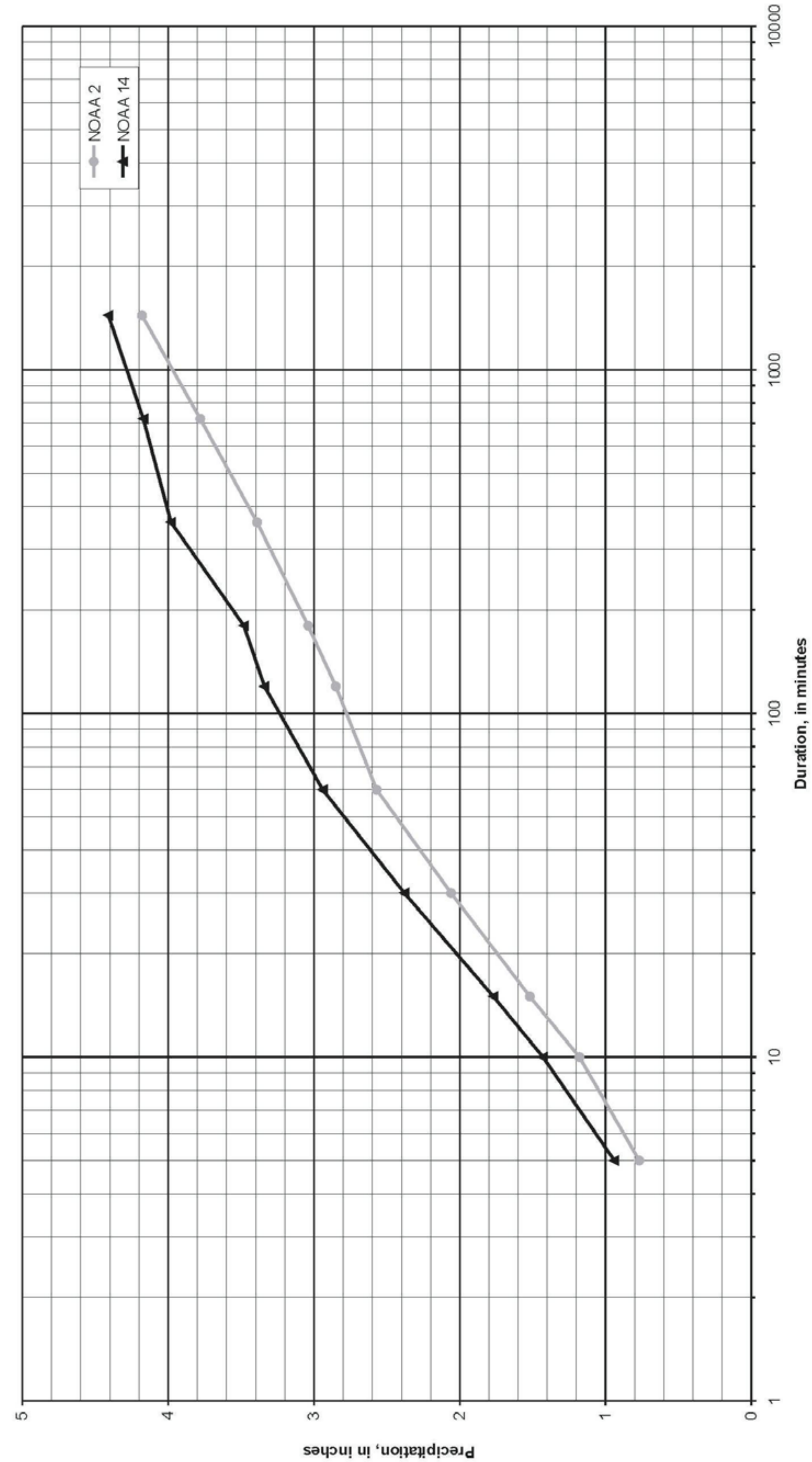


Figure A-3
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Flagstaff, Coconino County

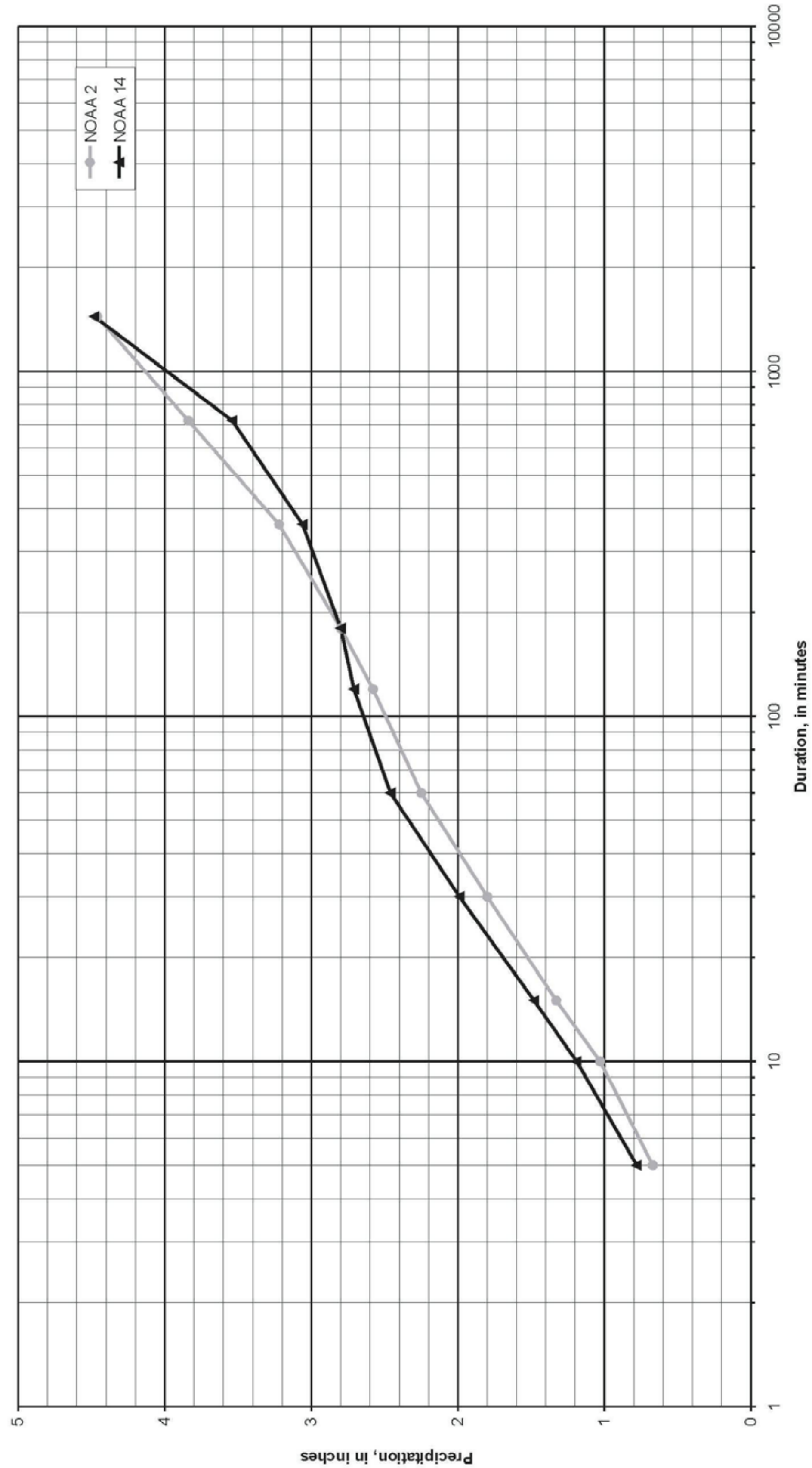


Figure A-4
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Globe, Gila County

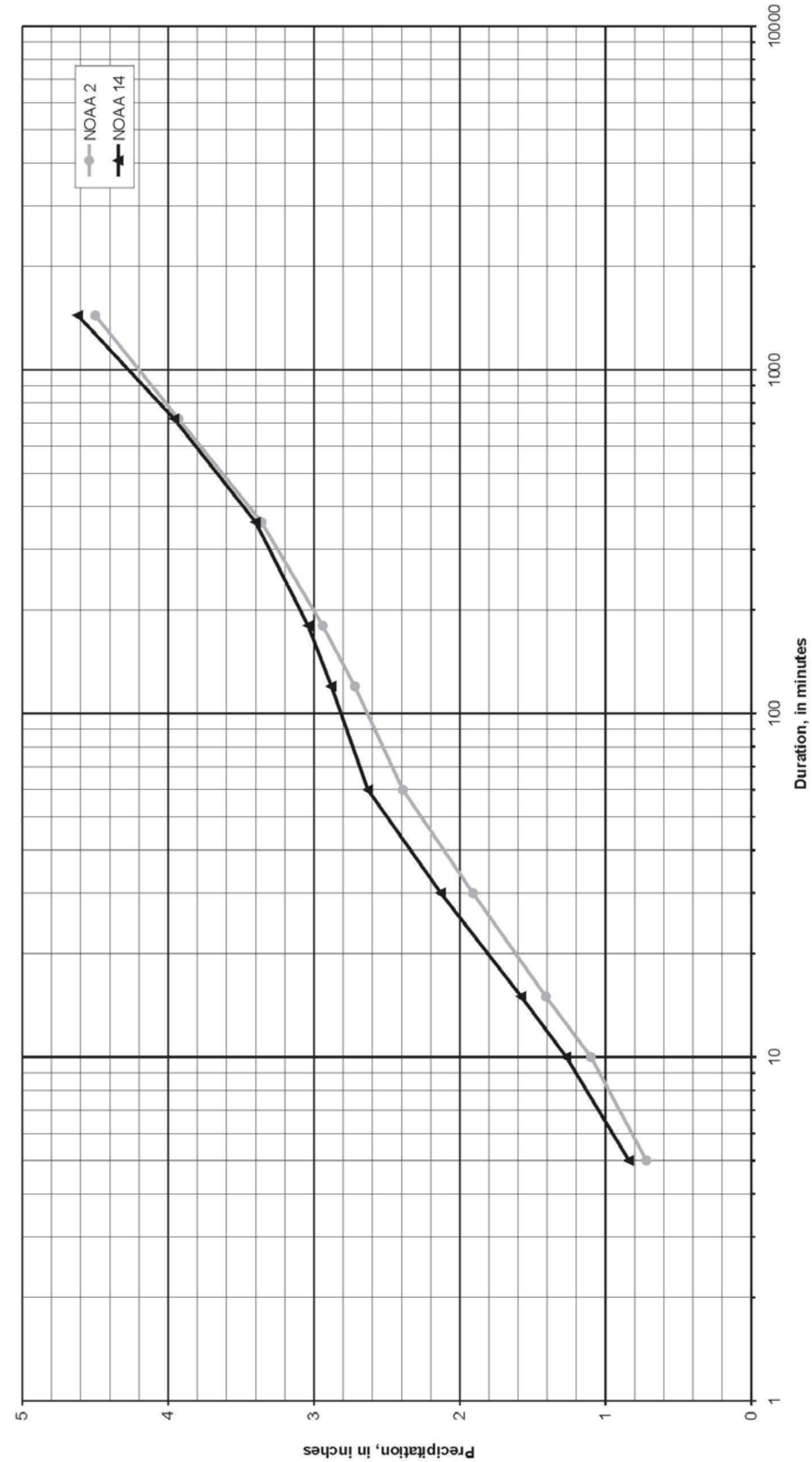


Figure A-5
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Safford, Graham County

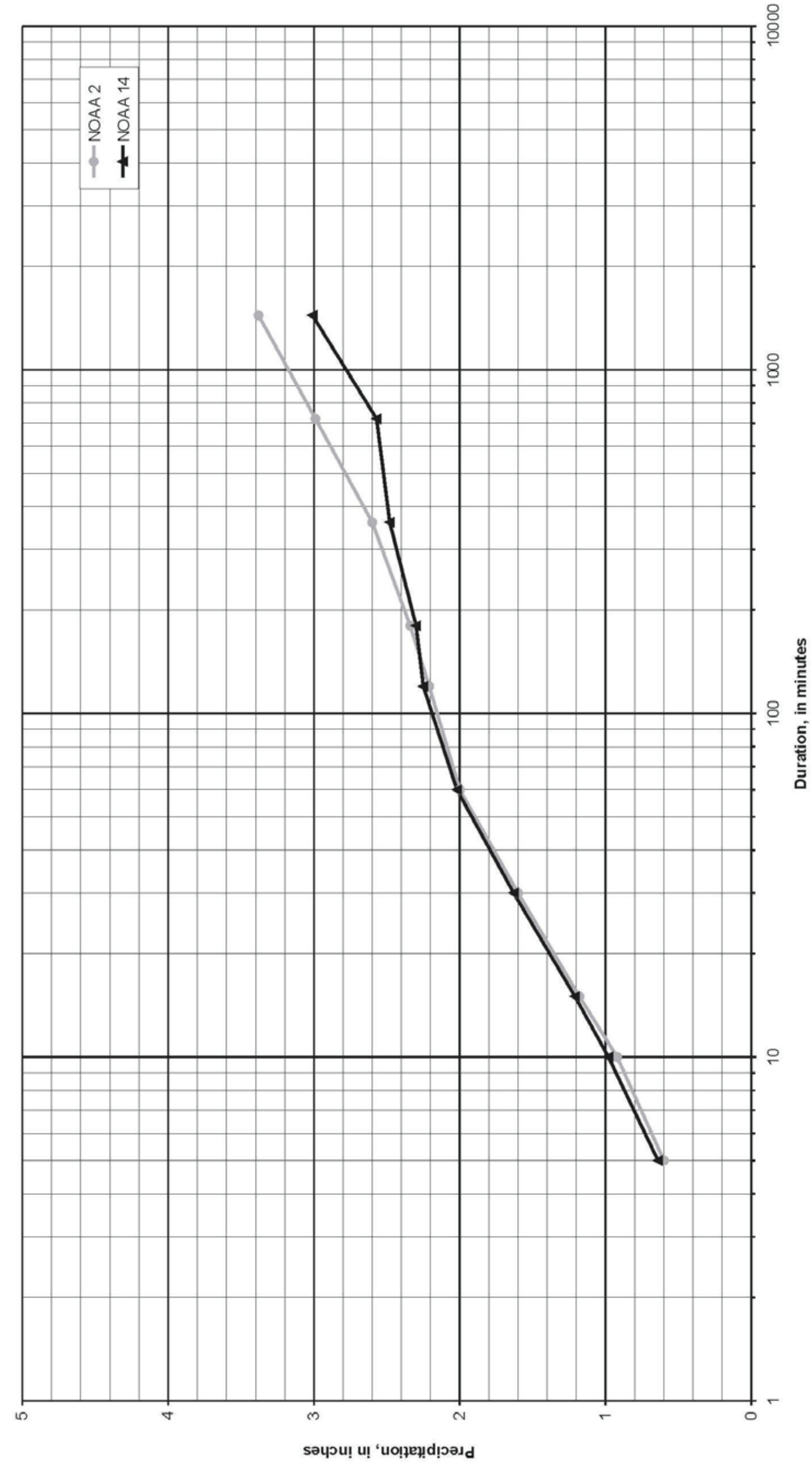


Figure A-6
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Clifton, Greenlee County

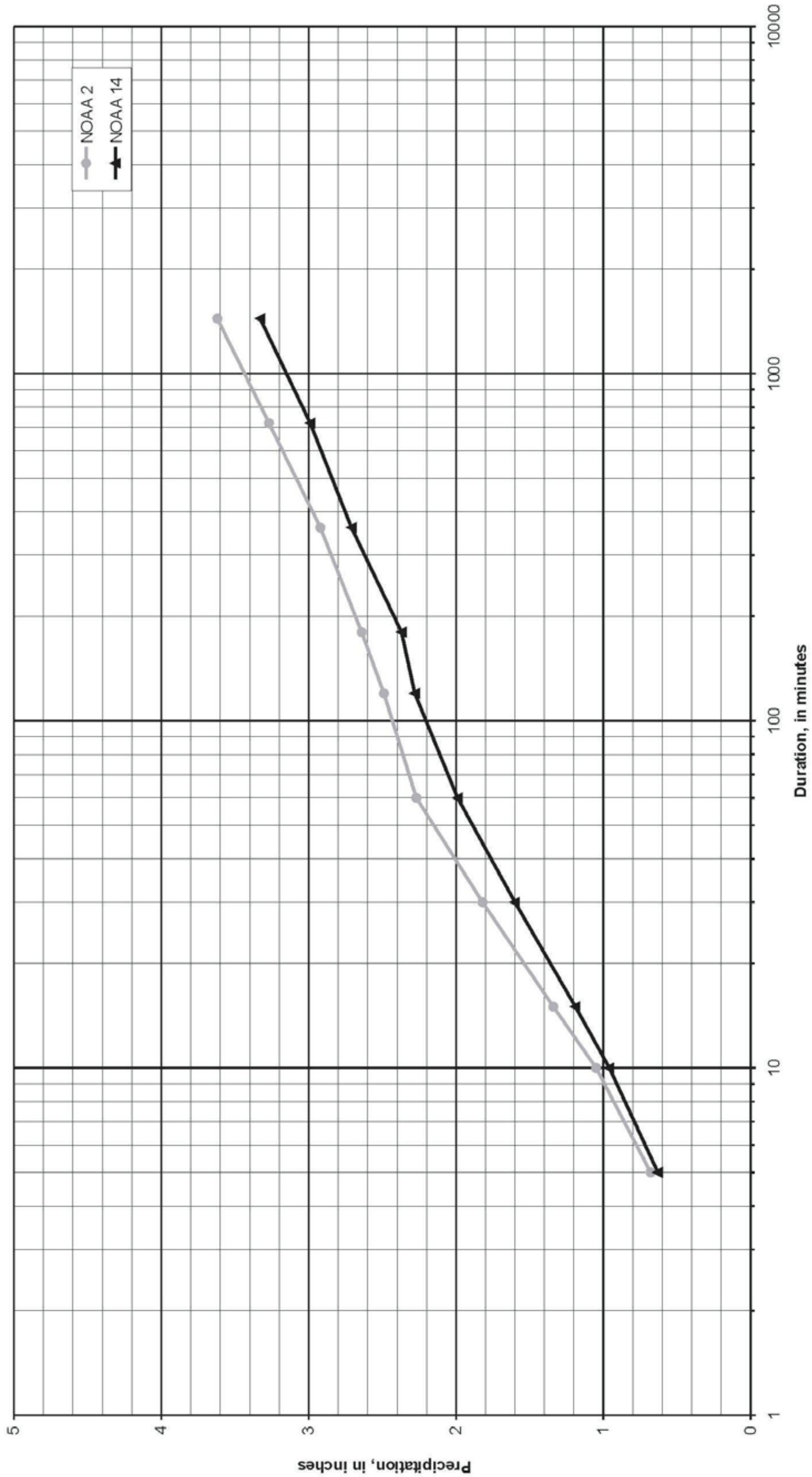


Figure A-7
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Parker, La Paz County

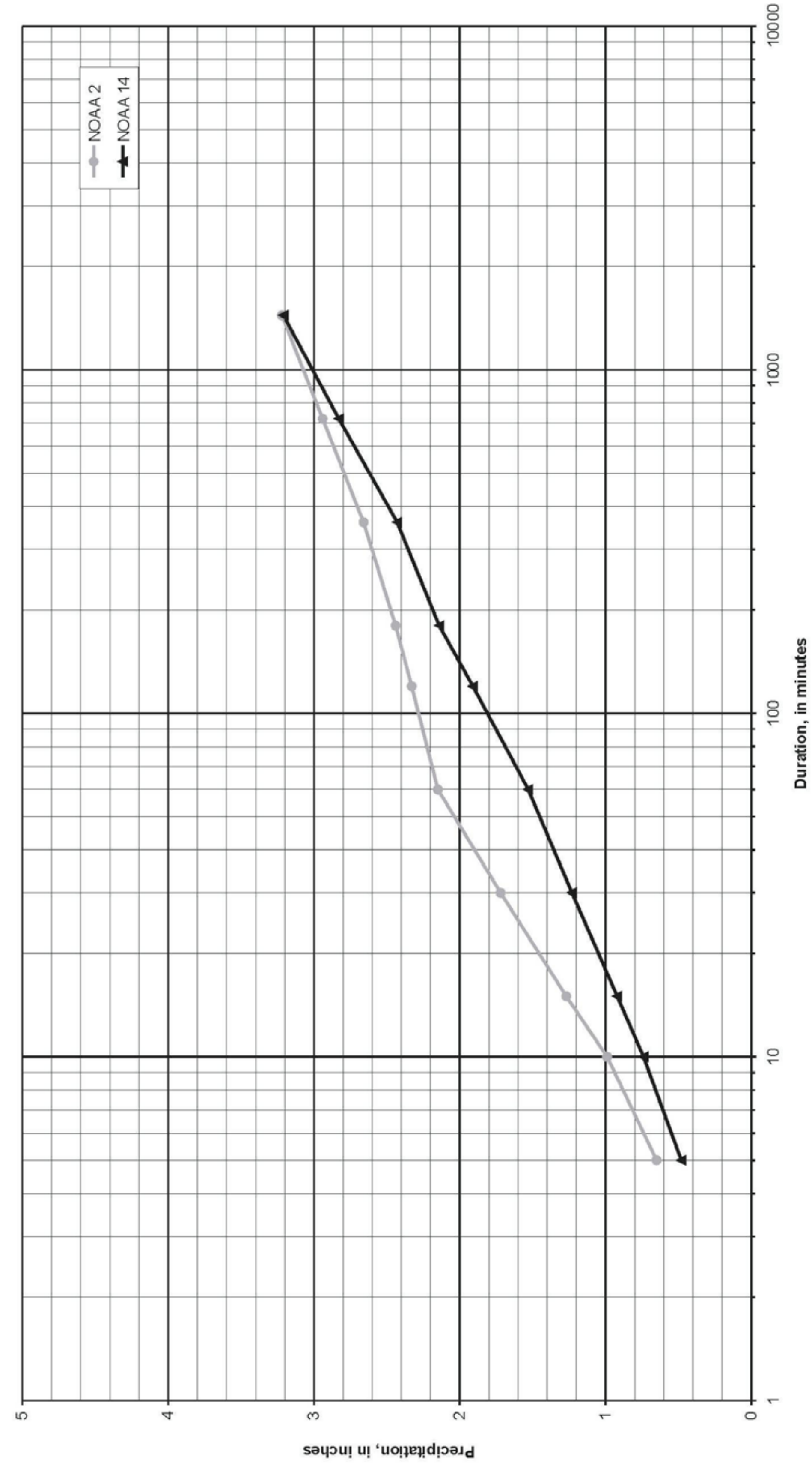


Figure A-8
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Phoenix, Maricopa County

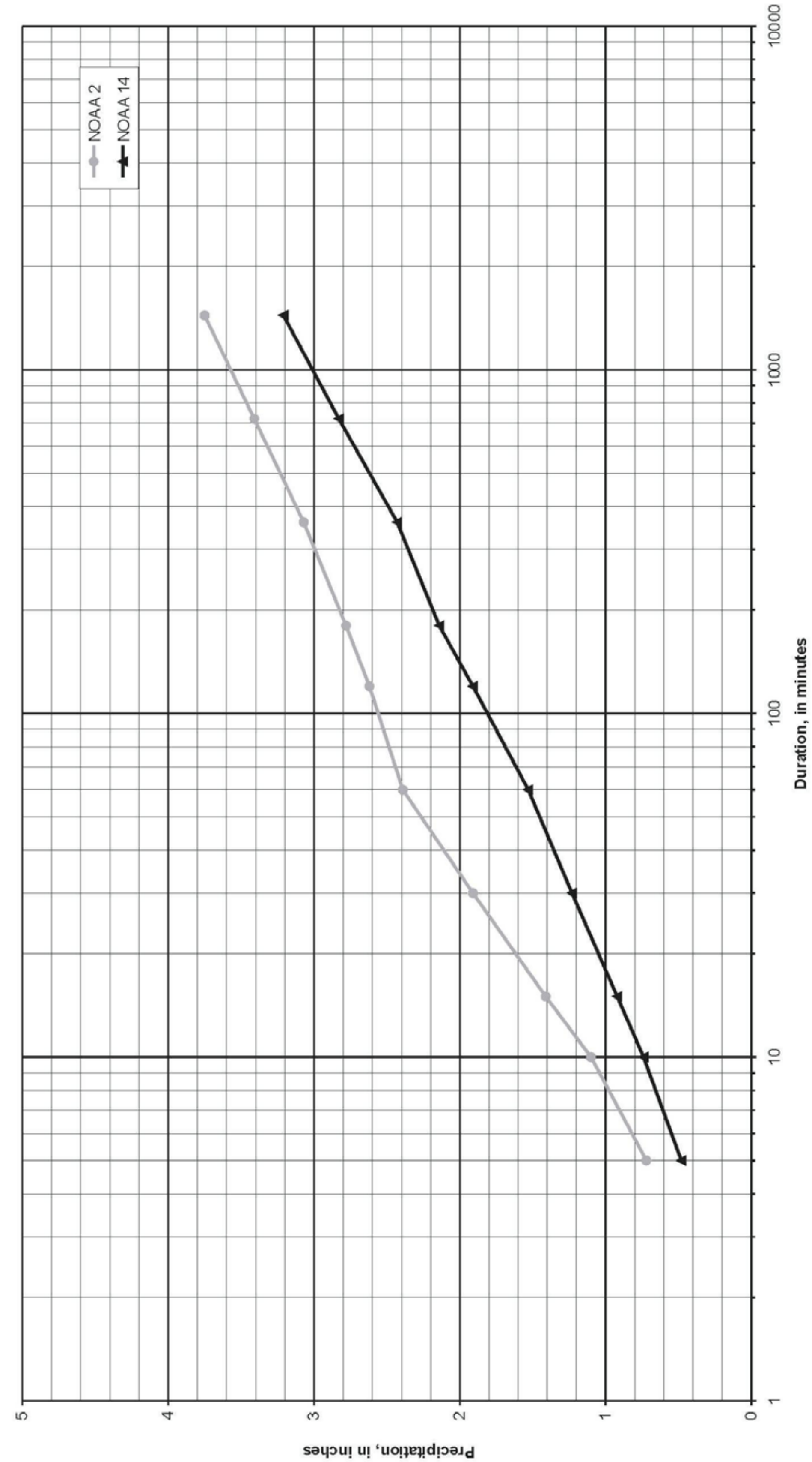


Figure A-9
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Kingman, Mohave County

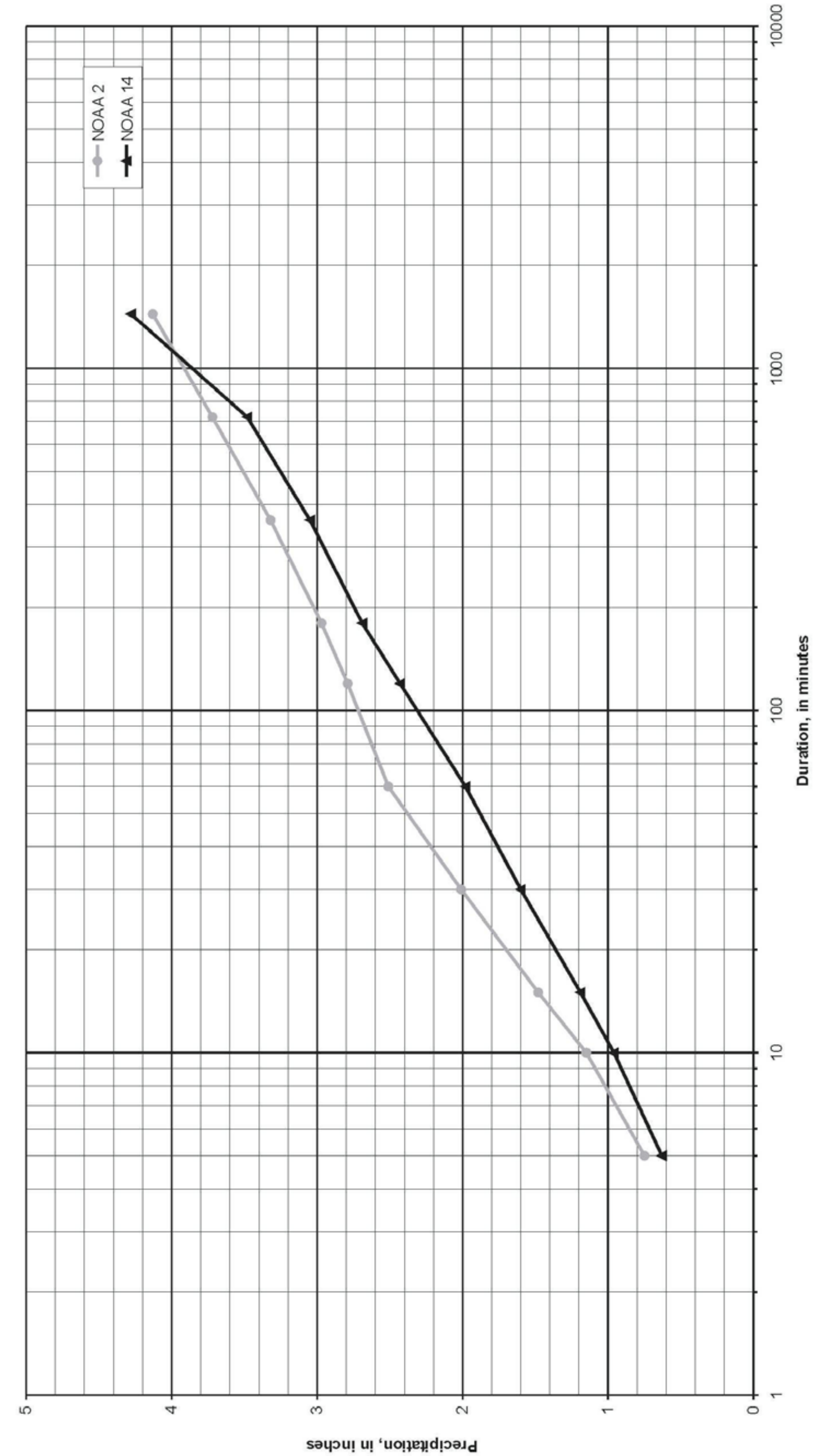


Figure A-10
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Holbrook, Navajo County

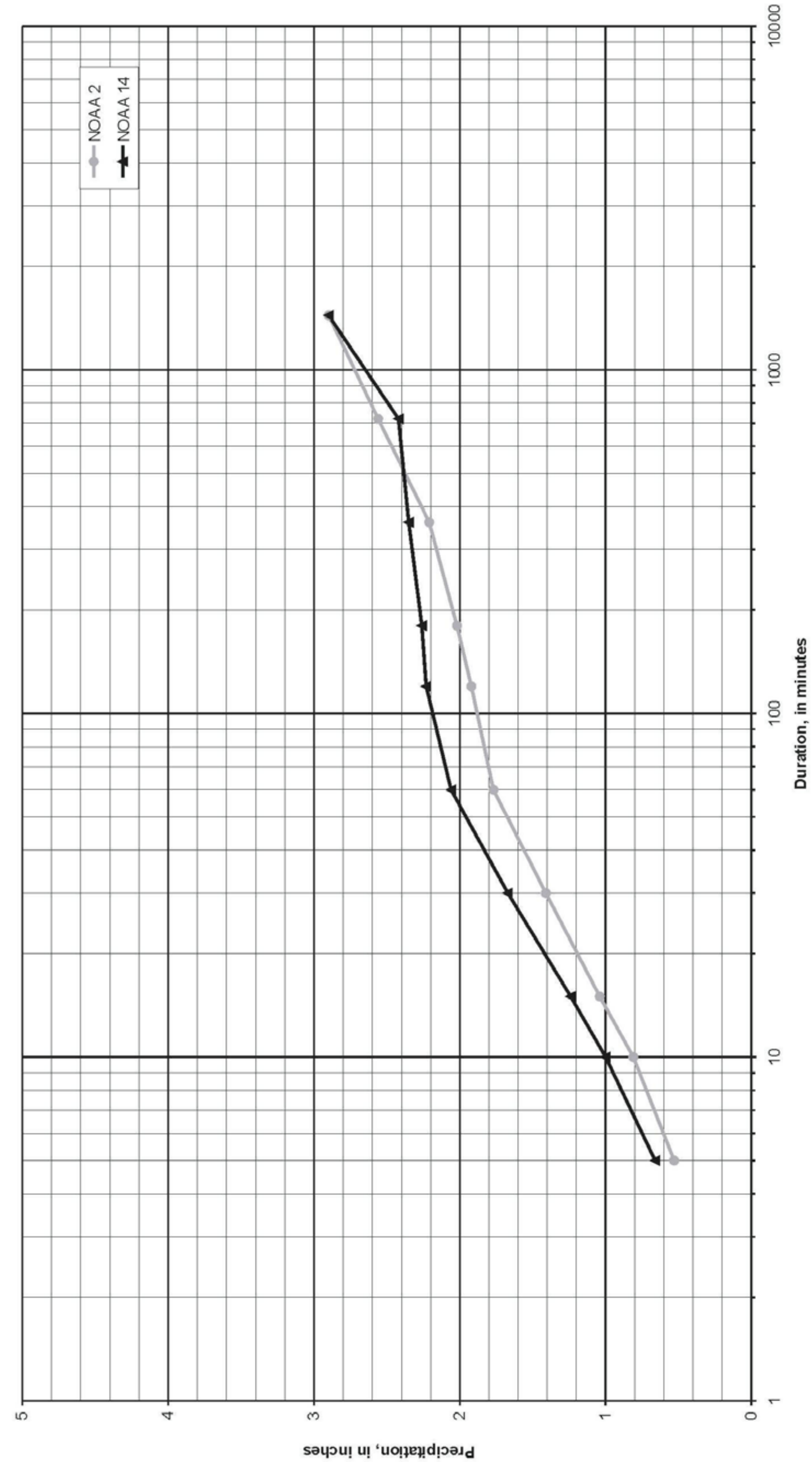


Figure A-11
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Tucson, Pima County

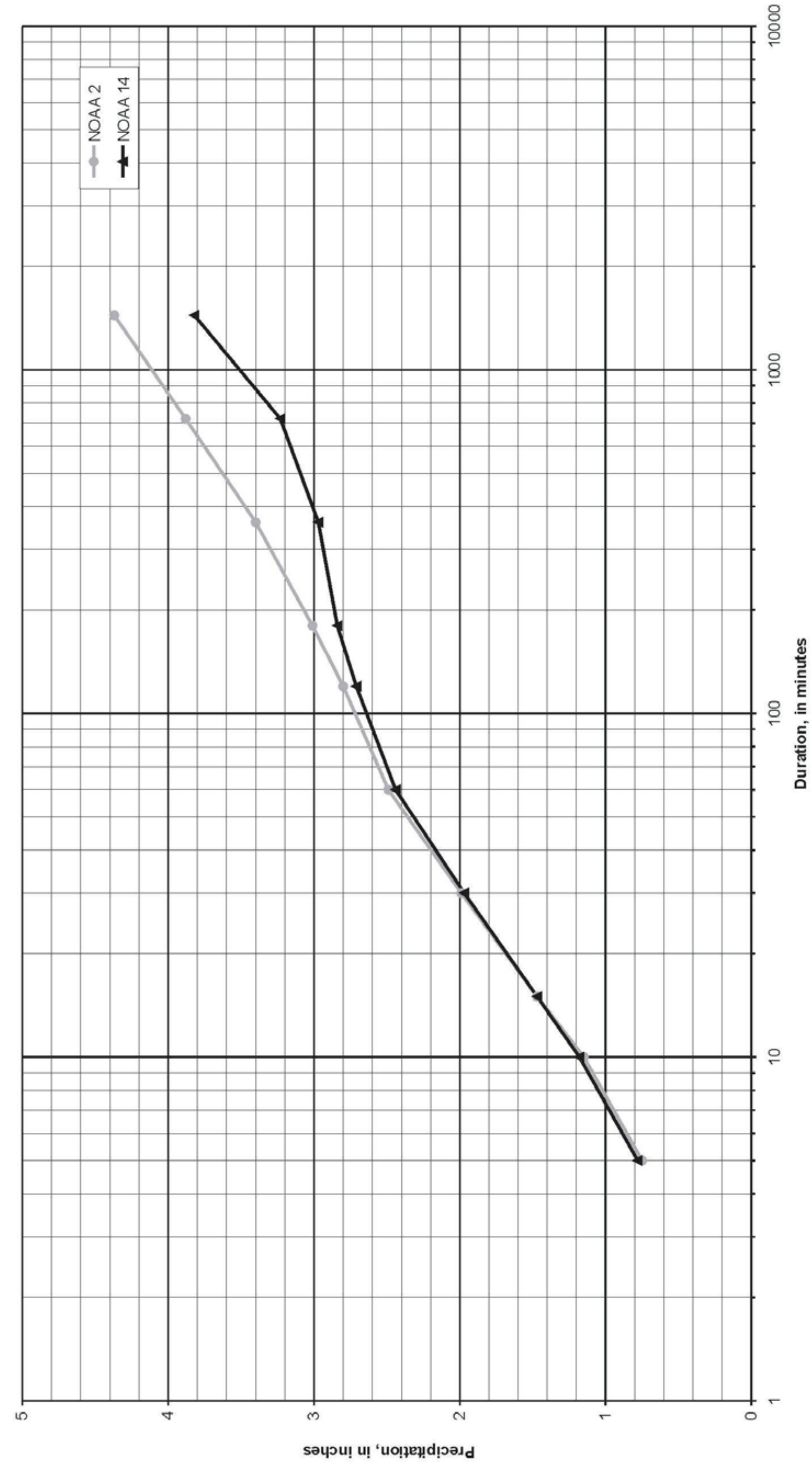


Figure A-12
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Florence, Pinal County

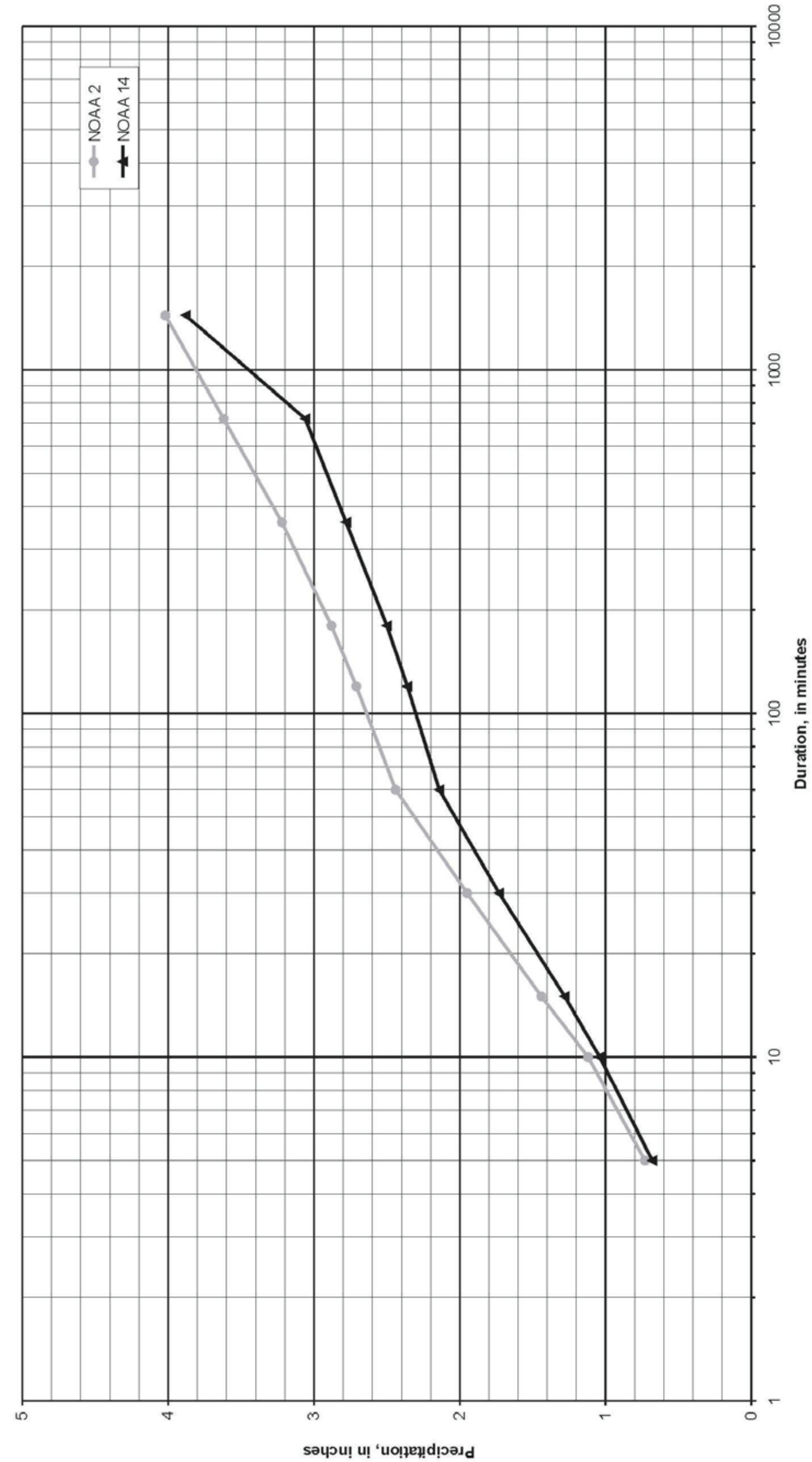


Figure A-13
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Nogales, Santa Cruz County

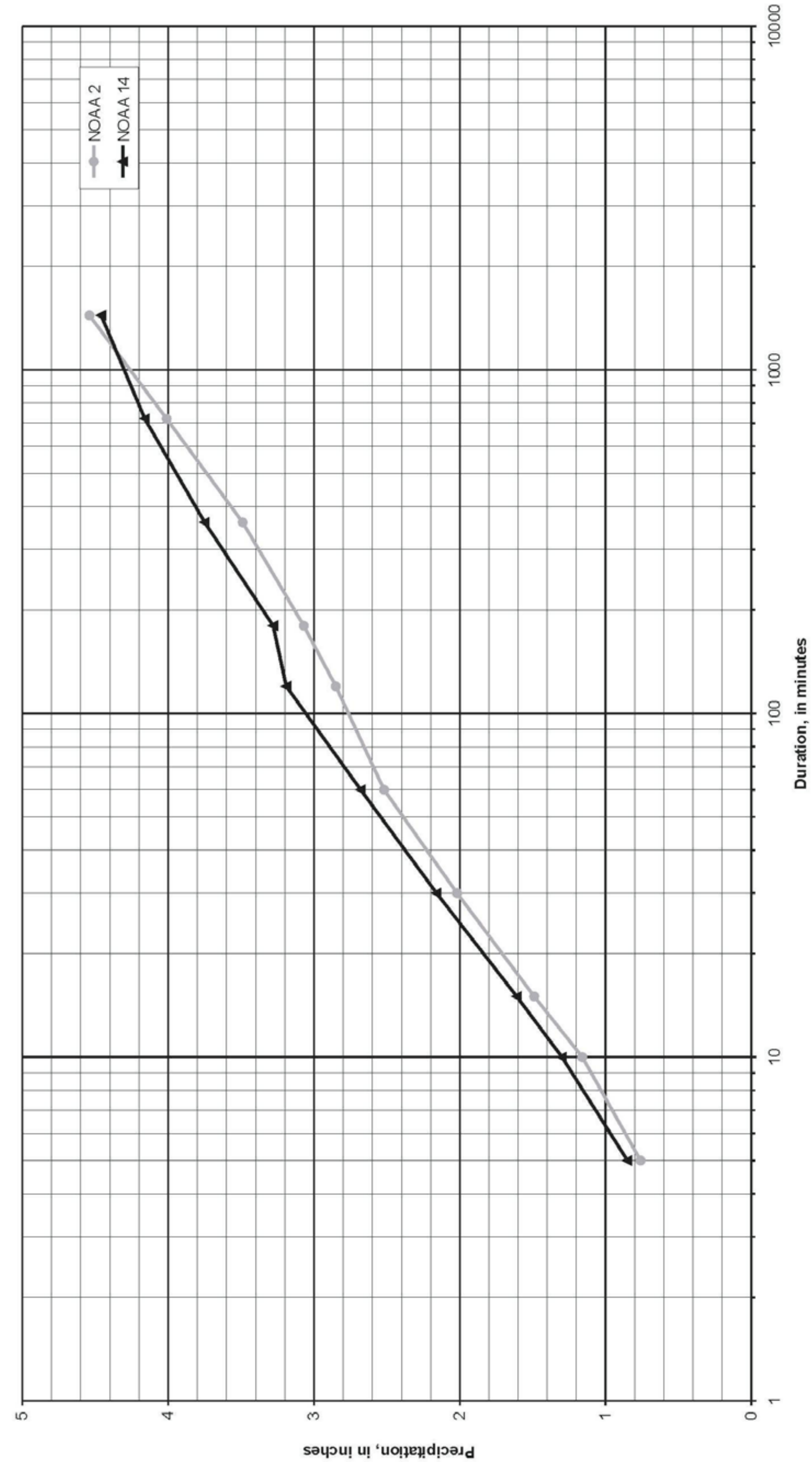


Figure A-14
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Prescott, Yavapai County

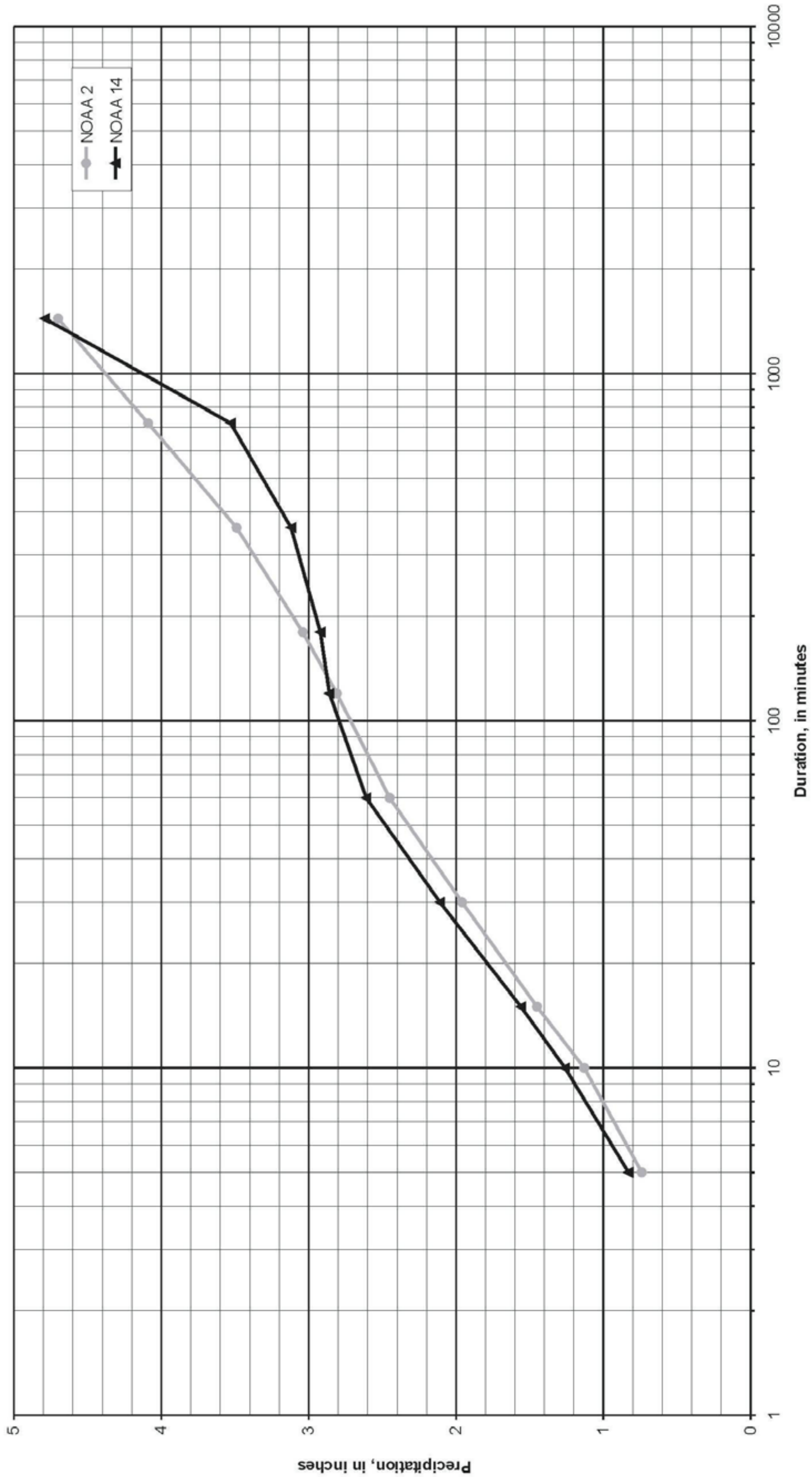


Figure A-15
Comparison of 100-year Depth-duration estimates for Arizona using NOAA 2 and NOAA 14
Yuma, Yuma County

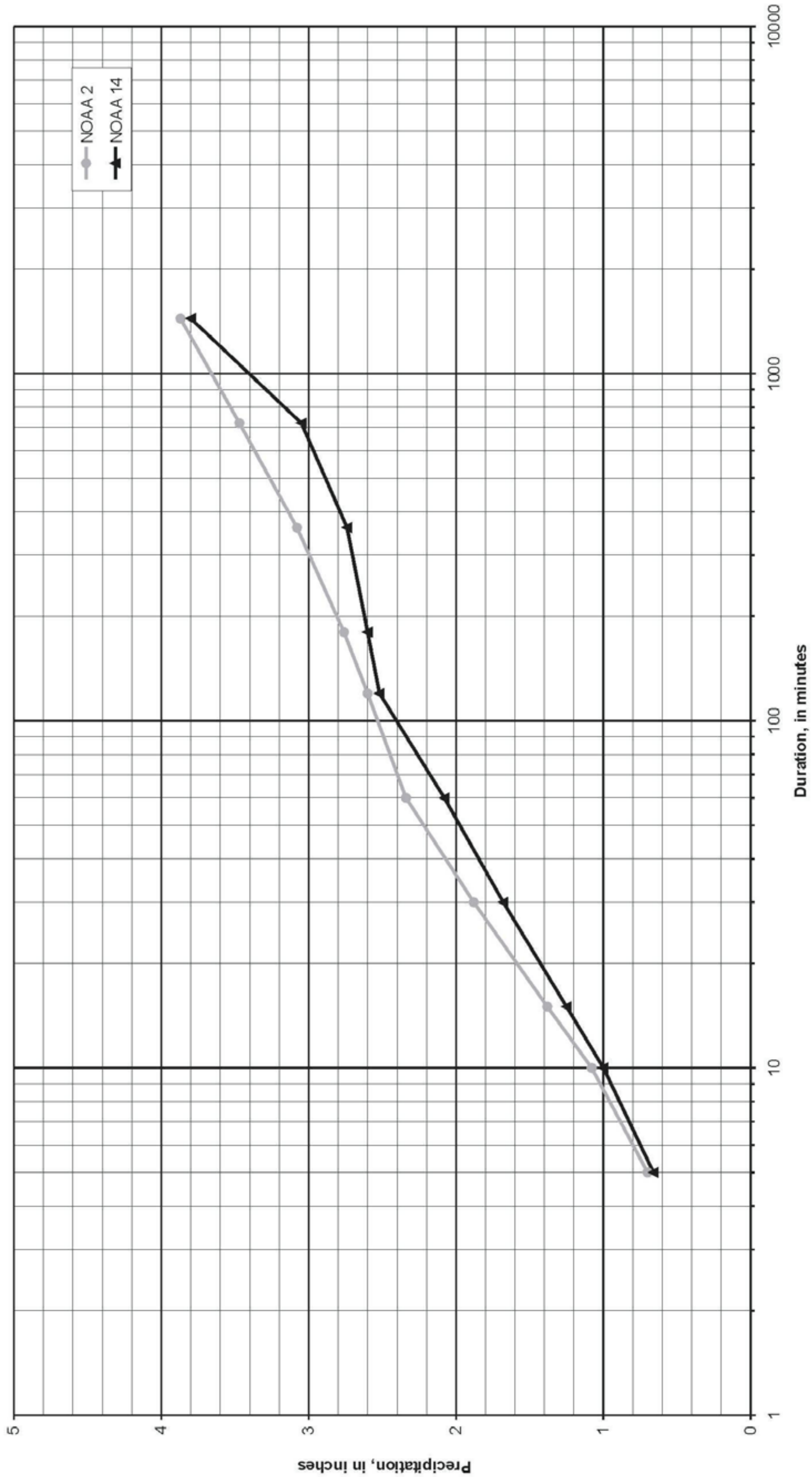


Table A-1
Case A1: NRCS Type I rainfall distribution with
NOAA Atlas 2 24-hour depth-area reduction factors

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	0.71	0.92	637	10.17	1-A1.ih1
2	0.49	0.71	0.92	1,049	10.25	2-A1.ih1
5	0.77	0.69	0.92	1,859	10.58	5-A1.ih1
10	1.10	0.69	0.92	2,744	10.92	10-A1.ih1
25	1.73	0.66	0.92	4,402	11.50	25-A1.ih1
50	2.45	0.64	0.92	6,108	12.25	50-A1.ih1
100	3.46	0.62	0.92	8,452	13.25	100-A1.ih1

Table A-2
Case A2: NRCS Type I rainfall distribution with
HYDRO-40 24-hour depth-area reduction factors for Southeast Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	0.71	0.92	637	10.17	1-A2.ih1
2	0.49	0.66	0.92	988	10.25	2-A2.ih1
5	0.77	0.61	0.92	1,657	10.58	5-A2.ih1
10	1.10	0.55	0.42	2,236	10.83	10-A2.ih1
25	1.73	0.46	0.42	3,129	11.50	25-A2.ih1
50	2.45	0.40	0.42	3,865	12.17	50-A2.ih1
100	3.46	0.34	0.42	4,733	13.25	100-A2.ih1

Table A-3
Case A3: NRCS Type I rainfall distribution with
HYDRO-40 24-hour depth-area reduction factors for Central Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	0.71	0.92	637	10.17	1-A3.ih1
2	0.49	0.68	0.92	1,012	10.25	2-A3.ih1
5	0.77	0.65	0.92	1,762	10.58	5-A3.ih1
10	1.10	0.61	0.92	2,453	10.92	10-A3.ih1
25	1.73	0.58	0.92	3,876	11.50	25-A3.ih1
50	2.45	0.53	0.42	5,139	12.25	50-A3.ih1
100	3.46	0.47	0.42	6,448	13.25	100-A3.ih1

Table A-4
Case B1: NRCS Type II rainfall distribution with
NOAA Atlas 2 24-hour depth-area reduction factors

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.43	0.67	1,446	12.25	1-B1.ih1
2	0.49	1.43	0.67	2,322	12.33	2-B1.ih1
5	0.77	1.41	0.67	3,963	12.58	5-B1.ih1
10	1.10	1.40	0.67	5,747	12.92	10-B1.ih1
25	1.73	1.36	0.67	9,147	13.58	25-B1.ih1
50	2.45	1.32	0.67	12,764	14.25	50-B1.ih1
100	3.46	1.30	0.67	17,814	15.33	100-B1.ih1

Table A-5
Case B2: NRCS Type II rainfall distribution with
HYDRO-40 24-hour depth-area reduction factors for Southeast Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.43	0.67	1,446	12.25	1-B2.ih1
2	0.49	1.36	0.67	2,213	12.33	2-B2.ih1
5	0.77	1.29	0.67	3,638	12.58	5-B2.ih1
10	1.10	1.20	0.67	4,973	12.92	10-B2.ih1
25	1.73	1.07	0.67	7,215	13.58	25-B2.ih1
50	2.45	0.95	0.42	9,178	14.25	50-B2.ih1
100	3.46	0.85	0.42	11,680	15.33	100-B2.ih1

Table A-6
Case B3: NRCS Type II rainfall distribution with
HYDRO-40 24-hour depth-area reduction factors for Central Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.43	0.67	1,446	12.25	1-B3.ih1
2	0.49	1.39	0.67	2,257	12.33	2-B3.ih1
5	0.77	1.35	0.67	3,807	12.58	5-B3.ih1
10	1.10	1.29	0.67	5,303	12.92	10-B3.ih1
25	1.73	1.24	0.67	8,382	13.58	25-B3.ih1
50	2.45	1.18	0.67	11,385	14.25	50-B3.ih1
100	3.46	1.08	0.67	14,839	15.33	100-B3.ih1

Table A-7
Case C1: Hypothetical 24-hour rainfall distribution with
NOAA Atlas 2 24-hour depth-area reduction factors

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name

1	0.35	1.47	1.00	1,485	12.42	1-C2.ih1
2	0.49	1.46	1.00	2,319	12.50	2-C2.ih1
5	0.77	1.43	1.00	3,985	12.83	5-C2.ih1
10	1.10	1.39	1.08	5,660	13.17	10-C2.ih1
25	1.73	1.27	1.08	8,539	13.75	25-C2.ih1
50	2.45	1.14	1.08	10,914	14.50	50-C2.ih1
100	3.46	0.98	1.17	13,429	15.50	100-C2.ih1

Table A-8
Case C2: Hypothetical 24-hour rainfall distribution with
HYDRO-40 24-hour depth-area reduction factors for Southeast Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.47	1.00	1,488	12.42	1-C2.ih1
2	0.49	1.38	0.92	2,216	12.50	2-C2.ih1
5	0.77	1.28	0.92	3,609	12.83	5-C2.ih1
10	1.10	1.16	0.83	4,791	13.17	10-C2.ih1
25	1.73	0.95	0.83	6,410	13.75	25-C2.ih1
50	2.45	0.75	0.75	7,235	14.50	50-C2.ih1
100	3.46	0.56	0.75	7,697	15.50	100-C2.ih1

Table A-9
Case C3: Hypothetical 24-hour rainfall distribution with
HYDRO-40 24-hour depth-area reduction factors for Central Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.47	1.00	1,488	12.42	1-C3.ih1
2	0.49	1.41	1.00	2,261	12.50	2-C3.ih1
5	0.77	1.35	1.00	3,789	12.83	5-C3.ih1
10	1.10	1.25	1.00	5,146	13.17	10-C3.ih1
25	1.73	1.13	1.00	7,617	13.75	25-C3.ih1
50	2.45	0.98	1.00	9,403	14.50	50-C3.ih1
100	3.46	0.77	1.00	10,604	15.50	100-C3.ih1

Table A-10
Case D1: Flood Control District of Maricopa County 6-hour rainfall distribution and depth-area reduction factors

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.44	0.67	1,386	4.25	1-D1.ih1
2	0.49	1.32	1.00	1,897	4.33	2-D1.ih1
5	0.77	1.21	1.00	3,137	4.67	5-D1.ih1
10	1.10	1.09	1.00	4,262	5.00	10-D1.ih1
25	1.73	0.90	1.00	5,922	5.67	25-D1.ih1
50	2.45	0.75	1.00	7,156	6.33	50-D1.ih1
100	3.46	0.57	1.00	7,809	7.33	100-D1.ih1

Table A-11
Case D2: Hypothetical 6-hour rainfall distribution with
NOAA Atlas 2 6-hour depth-area reduction factors

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.27	0.67	1,366	3.42	1-D2.ih1
2	0.49	1.26	0.67	2,092	3.50	2-D2.ih1
5	0.77	1.23	0.67	3,523	3.83	5-D2.ih1
10	1.10	1.18	0.67	4,916	4.17	10-D2.ih1
25	1.73	1.07	0.67	7,214	4.75	25-D2.ih1
50	2.45	0.93	0.75	8,925	5.50	50-D2.ih1
100	3.46	0.76	0.83	10,442	6.50	100-D2.ih1

Table A-12
Case D3: Hypothetical 6-hour rainfall distribution with
HYDRO-40 6-hour depth-area reduction factors for Southeast Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.17	0.67	1,274	3.42	1-D3.ih1
2	0.49	1.08	0.67	1,819	3.50	2-D3.ih1
5	0.77	0.94	0.58	2,736	3.83	5-D3.ih1
10	1.10	0.82	0.50	3,449	4.17	10-D3.ih1
25	1.73	0.64	0.42	4,350	4.75	25-D3.ih1
50	2.45	0.45	0.33	4,318	5.50	50-D3.ih1
100	3.46	0.31	0.17	4,298	6.50	100-D3.ih1

Table A-13
Case D4: Hypothetical 6-hour rainfall distribution with
HYDRO-40 6-hour depth-area reduction factors for Central Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.23	0.67	1,332	3.42	1-D4.ih1
2	0.49	1.12	0.67	1,881	3.50	2-D4.ih1
5	0.77	1.02	0.67	2,962	3.83	5-D4.ih1
10	1.10	0.90	0.58	3,778	4.17	10-D4.ih1
25	1.73	0.72	0.50	4,883	4.75	25-D4.ih1
50	2.45	0.53	0.42	5,124	5.50	50-D4.ih1
100	3.46	0.38	0.42	5,272	6.50	100-D4.ih1

Table A-14
Case E1: City of Tucson 3-hour rainfall distribution and depth-area reduction factors

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	0.52	0.50	555	0.58	1-E1.ih1
2	0.49	0.51	0.50	848	0.75	2-E1.ih1
5	0.77	0.48	0.50	1,377	1.00	5-E1.ih1
10	1.10	0.39	0.42	1,641	1.33	10-E1.ih1

Table A-15
Case E2: City of Tucson 3-hour rainfall distribution and
NOAA Atlas 2 3-hour depth-area reduction factors

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	0.52	0.50	555	0.58	1-E2.ih1
2	0.49	0.51	0.50	848	0.75	2-E2.ih1
5	0.77	0.49	0.50	1,417	1.00	5-E2.ih1
10	1.10	0.48	0.50	1,998	1.33	10-E2.ih1

Table A-16
Case E3: City of Tucson 3-hour rainfall distribution and
HYDRO-40 3-hour depth-area reduction factors for Southeast Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	0.52	0.50	555	0.58	1-E3.ih1
2	0.49	0.38	0.42	644	0.75	2-E3.ih1
5	0.77	0.31	0.33	901	1.00	5-E3.ih1
10	1.10	0.24	0.33	1,021	1.33	10-E3.ih1

Table A-17
Case E4: City of Tucson 3-hour rainfall distribution and
HYDRO-40 3-hour depth-area reduction factors for Central Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	0.52	0.50	555	0.58	1-E4.ih1
2	0.49	0.38	0.42	644	0.75	2-E4.ih1
5	0.77	0.31	0.33	901	1.00	5-E4.ih1
10	1.10	0.24	0.33	1,021	1.33	10-E4.ih1

Table A-18
Case F1: Hypothetical 3-hour rainfall distribution with
City of Tucson depth-area reduction factors

Drainage Area sq. miles	**Lag Time hours**	**Rainfall Excess inches**	**Duration of Rainfall Excess hours**	**Peak Discharge cfs**	**Time to Peak hours**	**HEC-1 File Name**
1	0.35	1.19	0.67	1,310	1.92	1-F1.ih1
2	0.49	1.17	0.67	1,967	2.08	2-F1.ih1
5	0.77	1.12	0.67	3,232	2.33	5-F1.ih1
10	1.10	0.98	0.58	4,079	2.67	10-F1.ih1

Table A-19
Case F2: Hypothetical 3-hour rainfall distribution with
NOAA Atlas 2 3-hour depth-area reduction factors

Drainage Area sq. miles	**Lag Time hours**	**Rainfall Excess inches**	**Duration of Rainfall Excess hours**	**Peak Discharge cfs**	**Time to Peak hours**	**HEC-1 File Name**
1	0.35	1.19	0.67	1,310	1.92	1-F2.ih1
2	0.49	1.17	0.67	1,967	2.08	2-F2.ih1
5	0.77	1.13	0.67	3,274	2.33	5-F2.ih1
10	1.10	1.10	0.67	4,598	2.67	10-F2.ih1
25	1.73	1.00	0.67	6,729	3.33	25-F2.ih1
50	2.45	0.86	0.58	8,257	4.00	50-F2.ih1
100	3.46	0.70	0.58	9,656	5.00	100-F2.ih1

Table A-20
Case F3: Hypothetical 3-hour rainfall distribution with
HYDRO-40 3-hour depth-area reduction factors for Southeast Arizona

Drainage Area sq. miles	**Lag Time hours**	**Rainfall Excess inches**	**Duration of Rainfall Excess hours**	**Peak Discharge cfs**	**Time to Peak hours**	**HEC-1 File Name**
1	0.35	1.19	0.67	1,310	1.92	1-F3.ih1
2	0.49	0.98	0.50	1,685	2.08	2-F3.ih1
5	0.77	0.87	0.42	2,549	2.33	5-F3.ih1
10	1.10	0.77	0.42	3,218	2.67	10-F3.ih1
25	1.73	0.57	0.42	3,905	3.25	25-F3.ih1
50	2.45	0.44	0.25	4,243	4.00	50-F3.ih1
100	3.46	0.29	0.17	3,968	5.00	100-F3.ih1

Table A-21
Case F4: Hypothetical 3-hour rainfall distribution with
HYDRO-40 3-hour depth-area reduction factors for Central Arizona

Drainage Area sq. miles	Lag Time hours	Rainfall Excess inches	Duration of Rainfall Excess hours	Peak Discharge cfs	Time to Peak hours	HEC-1 File Name
1	0.35	1.19	0.67	1,310	1.92	1-F4.ih1
2	0.49	0.98	0.50	1,685	2.08	2-F4.ih1
5	0.77	0.87	0.42	2,549	2.33	5-F4.ih1
10	1.10	0.77	0.42	3,218	2.67	10-F4.ih1
25	1.73	0.57	0.42	3,905	3.25	25-F4.ih1
50	2.45	0.43	0.25	4,130	4.00	50-F4.ih1
100	3.46	0.28	0.17	3,834	5.00	100-F4.ih1

Table A-22
Hypothetical example depth-duration-frequency statistics
Location:
Lon (dd), -112
Lat (dd), 33
Elev (feet), 1302

Return Period years	Rainfall Depth, in inches									
	5-min	10-min	15-min	30-min	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr
2	0.24	0.37	0.46	0.62	0.77	0.86	0.92	1.07	1.18	1.44
5	0.33	0.51	0.63	0.85	1.05	1.17	1.22	1.39	1.51	1.87
10	0.40	0.61	0.76	1.02	1.26	1.40	1.45	1.64	1.78	2.21
25	0.50	0.76	0.94	1.26	1.56	1.72	1.80	1.99	2.15	2.68
50	0.57	0.87	1.08	1.45	1.79	1.98	2.07	2.28	2.44	3.05
100	0.65	0.98	1.22	1.64	2.04	2.25	2.38	2.59	2.75	3.44
200	0.73	1.11	1.37	1.85	2.29	2.53	2.69	2.91	3.07	3.85
500	0.84	1.27	1.58	2.12	2.63	2.92	3.15	3.37	3.52	4.41
1000	0.92	1.41	1.74	2.35	2.90	3.23	3.53	3.74	3.88	4.85

APPENDIX 3-B

TIME OF CONCENTRATION WORKSHEETS

Table B-1

State Standards - Hydrologic Modeling Guidelines

NRCS time of concentration and dimensionless unit hydrography sensitivity evaluation

Date: 17 Jan. 06
By: mcg

	Case 1A: Minimum overland flow length	**Case 1B: Maximum overland flow length**	**Case 1C: Minimum overland flow roughness coefficient**	**Case 1D: Maximum overland flow roughness coefficient**
Overland Flow				
Length =	50 feet	300 feet	100 feet	100 feet
$P_{2,24}$ =	1.44 inches	1.44 inches	1.44 inches	1.44 inches
n =	0.13	0.13	0.01	0.32
Slope =	0.01 ft/ft	0.01 ft/ft	0.01 ft/ft	0.01 ft/ft
T_t =	**0.16 hours**	**0.69 hours**	**0.04 hours**	**0.59 hours**
Shallow Concentrated Flow				
Land Cover =	Unpaved	Unpaved	Unpaved	Unpaved
Length =	1,000 feet	1,000 feet	1,000 feet	1,000 feet
Slope =	0.02 ft/ft	0.02 ft/ft	0.02 ft/ft	0.02 ft/ft
Velocity =	2.3 fps	2.3 fps	2.3 fps	2.3 fps
T_t =	**0.12 hours**	**0.12 hours**	**0.12 hours**	**0.12 hours**
Open Channel Flow				
Shape =	Trap	Trap	Trap	Trap
Length =	10,000 feet	10,000 feet	10,000 feet	10,000 feet
Bottom Width =	10 feet	10 feet	10 feet	10 feet
Depth =	3 feet	3 feet	3 feet	3 feet
Side Slopes =	3 :1	3 :1	3 :1	3 :1
n =	0.05	0.05	0.05	0.05
Slope =	0.005 ft/ft	0.005 ft/ft	0.005 ft/ft	0.005 ft/ft
Velocity =	3.31 fps	3.31 fps	3.31 fps	3.31 fps
T_t =	**0.84 hours**	**0.84 hours**	**0.84 hours**	**0.84 hours**
T_c =	**1.13 hours**	**1.65 hours**	**1.00 hours**	**1.55 hours**

Table B-1

State Standards - Hydrologic Modeling Guidelines

NRCS time of concentration and dimensionless unit hydrography sensitivity evaluation

Date: 17 Jan. 06
By: mcg

Parameter	Case 1E: Minimum overland flow "land" slope	Case 1F: Maximum overland flow "land" slope	Case 1G: Minimum shallow concentrated flow length	Case 1H: Maximum shallow concentrated flow length
Overland Flow				
Length =	100 feet	100 feet	100 feet	100 feet
$P_{2,24}$ =	1.44 inches	1.44 inches	1.44 inches	1.44 inches
n =	0.13	0.13	0.13	0.13
Slope =	0.005 ft/ft	0.1 ft/ft	0.01 ft/ft	0.01 ft/ft
T_t =	**0.38 hours**	**0.11 hours**	**0.29 hours**	**0.29 hours**
Shallow Concentrated Flow				
Land Cover =	Unpaved	Unpaved	Unpaved	Unpaved
Length =	1,000 feet	1,000 feet	200 feet	2,000 feet
Slope =	0.02 ft/ft	0.02 ft/ft	0.02 ft/ft	0.02 ft/ft
Velocity =	2.3 fps	2.3 fps	2.3 fps	2.3 fps
T_t =	**0.12 hours**	**0.12 hours**	**0.02 hours**	**0.24 hours**
Open Channel Flow				
Shape =	Trap	Trap	Trap	Trap
Length =	10,000 feet	10,000 feet	10,000 feet	10,000 feet
Bottom Width =	10 feet	10 feet	10 feet	10 feet
Depth =	3 feet	3 feet	3 feet	3 feet
Side Slopes =	3 :1	3 :1	3 :1	3 :1
n =	0.05	0.05	0.05	0.05
Slope =	0.005 ft/ft	0.005 ft/ft	0.005 ft/ft	0.005 ft/ft
Velocity =	3.31 fps	3.31 fps	3.31 fps	3.31 fps
T_t =	**0.84 hours**	**0.84 hours**	**0.84 hours**	**0.84 hours**
T_c =	**1.34 hours**	**1.08 hours**	**1.15 hours**	**1.37 hours**

Table B-1

State Standards - Hydrologic Modeling Guidelines

NRCS time of concentration and dimensionless unit hydrography sensitivity evaluation

Date: 17 Jan. 06
By: mcg

	Case 1I: Minimum shallow concentrated flow "land" slope	Case IJ: Maximum shallow concentrated flow "land" slope	Case 2A: Minimum overland flow length	Case 2B: Maximum overland flow length
Overland Flow				
Length =	100 feet	100 feet	50 feet	300 feet
$P_{2,24}$ =	1.44 inches	1.44 inches	1.44 inches	1.44 inches
n =	0.13	0.13	0.02	0.02
Slope =	0.01 ft/ft	0.01 ft/ft	0.01 ft/ft	0.01 ft/ft
T_t =	**0.29 hours**	**0.29 hours**	**0.04 hours**	**0.15 hours**
Shallow Concentrated Flow				
Land Cover =	Unpaved	Unpaved	Paved	Paved
Length =	1,000 feet	1,000 feet	1,000 feet	1,000 feet
Slope =	0.005 ft/ft	0.1 ft/ft	0.02 ft/ft	0.02 ft/ft
Velocity =	1.1 fps	5.1 fps	2.9 fps	2.9 fps
T_t =	**0.24 hours**	**0.05 hours**	**0.10 hours**	**0.10 hours**
Open Channel Flow				
Shape =	Trap	Trap	Trap	Trap
Length =	10,000 feet	10,000 feet	10,000 feet	10,000 feet
Bottom Width =	10 feet	10 feet	10 feet	10 feet
Depth =	3 feet	3 feet	3 feet	3 feet
Side Slopes =	3 :1	3 :1	3 :1	3 :1
n =	0.05	0.05	0.03	0.03
Slope =	0.005 ft/ft	0.005 ft/ft	0.005 ft/ft	0.005 ft/ft
Velocity =	3.31 fps	3.31 fps	5.51 fps	5.51 fps
T_t =	**0.84 hours**	**0.84 hours**	**0.50 hours**	**0.50 hours**
T_c =	**1.37 hours**	**1.18 hours**	**0.64 hours**	**0.75 hours**

Table B-1

State Standards - Hydrologic Modeling Guidelines

NRCS time of concentration and dimensionless unit hydrography sensitivity evaluation

Date: 17 Jan. 06
By: mcg

Case 2C: Minimum overland flow roughness coefficient		
Overland Flow		
Length =	100	feet
$P_{2,24}$ =	1.44	inches
n =	0.012	
Slope =	0.01	ft/ft
T_t =	**0.04**	**hours**
Shallow Concentrated Flow		
Land Cover =	Paved	
Length =	1,000	feet
Slope =	0.02	ft/ft
Velocity =	2.9	fps
T_t =	**0.10**	**hours**
Open Channel Flow		
Shape =	Trap	
Length =	10,000	feet
Bottom Width =	10	feet
Depth =	3	feet
Side Slopes =	3	:1
n =	0.03	
Slope =	0.005	ft/ft
Velocity =	5.51	fps
T_t =	**0.50**	**hours**
T_c =	**0.64**	**hours**

Case 2D: Maximum overland flow roughness coefficient		
Overland Flow		
Length =	100	feet
$P_{2,24}$ =	1.44	inches
n =	0.03	
Slope =	0.01	ft/ft
T_t =	**0.09**	**hours**
Shallow Concentrated Flow		
Land Cover =	Paved	
Length =	1,000	feet
Slope =	0.02	ft/ft
Velocity =	2.9	fps
T_t =	**0.10**	**hours**
Open Channel Flow		
Shape =	Trap	
Length =	10,000	feet
Bottom Width =	10	feet
Depth =	3	feet
Side Slopes =	3	:1
n =	0.03	
Slope =	0.005	ft/ft
Velocity =	5.51	fps
T_t =	**0.50**	**hours**
T_c =	**0.69**	**hours**

Case 2E: Minimum overland flow "land" slope		
Overland Flow		
Length =	100	feet
$P_{2,24}$ =	1.44	inches
n =	0.02	
Slope =	0.005	ft/ft
T_t =	**0.08**	**hours**
Shallow Concentrated Flow		
Land Cover =	Paved	
Length =	1,000	feet
Slope =	0.02	ft/ft
Velocity =	2.9	fps
T_t =	**0.10**	**hours**
Open Channel Flow		
Shape =	Trap	
Length =	10,000	feet
Bottom Width =	10	feet
Depth =	3	feet
Side Slopes =	3	:1
n =	0.03	
Slope =	0.005	ft/ft
Velocity =	5.51	fps
T_t =	**0.50**	**hours**
T_c =	**0.68**	**hours**

Case 2F: Maximum overland flow "land" slope		
Overland Flow		
Length =	100	feet
$P_{2,24}$ =	1.44	inches
n =	0.02	
Slope =	0.1	ft/ft
T_t =	**0.03**	**hours**
Shallow Concentrated Flow		
Land Cover =	Paved	
Length =	1,000	feet
Slope =	0.02	ft/ft
Velocity =	2.9	fps
T_t =	**0.10**	**hours**
Open Channel Flow		
Shape =	Trap	
Length =	10,000	feet
Bottom Width =	10	feet
Depth =	3	feet
Side Slopes =	3	:1
n =	0.03	
Slope =	0.005	ft/ft
Velocity =	5.51	fps
T_t =	**0.50**	**hours**
T_c =	**0.63**	**hours**

Table B-1

State Standards - Hydrologic Modeling Guidelines

NRCS time of concentration and dimensionless unit hydrography sensitivity evaluation

Date: 17 Jan. 06
By: mcg

	Case 2G: Minimum shallow concentrated flow length		**Case 2H: Maximum shallow concentrated flow length**		**Case 2I: Minimum overland flow "land" slope**		**Case 2J: Maximum overland flow "land" slope**	
Overland Flow								
Length =	100	feet	100	feet	100	feet	100	feet
$P_{2,24}$ =	1.44	inches	1.44	inches	1.44	inches	1.44	inches
n =	0.02		0.02		0.02		0.02	
Slope =	0.01	ft/ft	0.01	ft/ft	0.005	ft/ft	0.1	ft/ft
T_t =	**0.06**	**hours**	**0.06**	**hours**	**0.08**	**hours**	**0.03**	**hours**
Shallow Concentrated Flow								
Land Cover =	Paved		Unpaved		Paved		Paved	
Length =	200	feet	2,000	feet	1,000	feet	1,000	feet
Slope =	0.02	ft/ft	0.02	ft/ft	0.005	ft/ft	0.1	ft/ft
Velocity =	2.9	fps	2.3	fps	1.4	fps	6.4	fps
T_t =	**0.02**	**hours**	**0.24**	**hours**	**0.19**	**hours**	**0.04**	**hours**
Open Channel Flow								
Shape =	Trap		Trap		Trap		Trap	
Length =	10,000	feet	10,000	feet	10,000	feet	10,000	feet
Bottom Width =	10	feet	10	feet	10	feet	10	feet
Depth =	3	feet	3	feet	3	feet	3	feet
Side Slopes =	3	:1	3	:1	3	:1	3	:1
n =	0.03		0.03		0.03		0.03	
Slope =	0.005	ft/ft	0.005	ft/ft	0.005	ft/ft	0.005	ft/ft
Velocity =	5.51	fps	5.51	fps	5.51	fps	5.51	fps
T_t =	**0.50**	**hours**	**0.50**	**hours**	**0.50**	**hours**	**0.50**	**hours**
T_c =	**0.59**	**hours**	**0.81**	**hours**	**0.78**	**hours**	**0.57**	**hours**

Table B-2

State Standards - Hydrologic Modeling Guidelines

ADOT time of concentration and Clark unit hydrography sensitivity evaluation

Date: 17 Jan. 06
By: mcg

Case	Length =	Lca	Slope =	T_c =	R =	Time-area =
Case 1A: Square basin, flat slope	11,200 feet	5,600 feet	0.0065 ft/ft	**1.55 hours**	**0.74 hours**	**Natural**
Case 1B: Linear basin, flat slope	16,700 feet	8,350 feet	0.0065 ft/ft	**1.90 hours**	**1.27 hours**	**Natural**
Case 1C: Triangular basin with long Lca, flat slope	12,000 feet	8,000 feet	0.0065 ft/ft	**1.73 hours**	**0.88 hours**	**Natural**
Case 1D: Triangular basin with short Lca, flat slope	10,560 feet	3,520 feet	0.0065 ft/ft	**1.36 hours**	**0.61 hours**	**Natural**
Case 1E: Square basin, steep slope	11,200 feet	5,600 feet	0.04 ft/ft	**1.08 hours**	**0.50 hours**	**Natural**
Case 1F: Linear basin, steep slope	16,700 feet	8,350 feet	0.04 ft/ft	**1.32 hours**	**0.85 hours**	**Natural**
Case 1G: Triangular basin with long Lca, steep slope	12,000 feet	8,000 feet	0.04 ft/ft	**1.20 hours**	**0.59 hours**	**Natural**
Case 1H: Triangular basin with short Lca, steep slope	10,560 feet	3,520 feet	0.04 ft/ft	**0.95 hours**	**0.41 hours**	**Natural**
Case 2A: Square basin, flat slope	11,200 feet	5,600 feet	0.0065 ft/ft	**0.68 hours**	**0.30 hours**	**Urban**
Case 2B: Linear basin, flat slope	19,700 feet	9,850 feet	0.0065 ft/ft	**0.90 hours**	**0.64 hours**	**Urban**
Case 2C: Triangular basin with long Lca, flat slope	12,000 feet	8,000 feet	0.0065 ft/ft	**0.75 hours**	**0.35 hours**	**Urban**
Case 2D: Triangular basin with short Lca, flat slope	10,560 feet	3,520 feet	0.0065 ft/ft	**0.60 hours**	**0.24 hours**	**Urban**

Table B-2

State Standards - Hydrologic Modeling Guidelines

ADOT time of concentration and Clark unit hydrography sensitivity evaluation

Date: 17 Jan. 06
By: mcg

Case 2E: Square basin, steep slope		
Length =	11,200	feet
Lca	5,600	feet
Slope =	0.04	ft/ft
T_c =	**0.53**	**hours**
R =	**0.22**	**hours**
Time-area =	**Urban**	

Case 2F: Linear basin, steep slope		
Length =	16,700	feet
Lca	8,350	feet
Slope =	0.04	ft/ft
T_c =	**0.64**	**hours**
R =	**0.38**	**hours**
Time-area =	**Urban**	

Case 2G: Triangular basin with long Lca, steep slope		
Length =	12,000	feet
Lca	8,000	feet
Slope =	0.04	ft/ft
T_c =	**0.59**	**hours**
R =	**0.27**	**hours**
Time-area =	**Urban**	

Case 2H: Triangular basin with short Lca, steep slope		
Length =	10,560	feet
Lca	3,520	feet
Slope =	0.04	ft/ft
T_c =	**0.46**	**hours**
R =	**0.18**	**hours**
Time-area =	**Urban**	

APPENDIX 4

Rain-on-Snow

Rain-on-Snow

Background

Runoff from snowmelt is, most often, a relatively slow process that, according to the Federal Emergency Management Agency (FEMA) is equivalent to a light to moderate rainfall. Yet, certain areas of the country (Northeast and North Central portions along with some areas of the Western U.S.) are particularly susceptible to snowmelt flooding. In Arizona runoff snowmelt alone is not generally a major source of flooding. However, it has been observed that rainfall in addition to snowmelt has contributed to some large runoff events. Areas in Arizona that may be particularly susceptible to rain-on-snow runoff events are the mid elevation zones (around 7,000 feet) such as the Mogollon Rim and the mountain islands of the southern/southeaster portions of the state (Gottfried *el al*., 2002).

Runoff from snowmelt is a very complex process that occurs when the snow becomes isothermal at 32 °F and its liquid water holding capacity has been reached (USACE, 1998). The snowpack in this condition is often referred to as ripe. This condition is important because very little energy is required to initiate melting (Harr, 1981). Sources of energy that initiate the snowmelt process are:

- Shortwave radiation
- Long-wave radiation
- Convection from the air (sensible energy)
- Vapor condensation (latent energy)
- Conduction from the ground
- Energy contained in rainfall

The degree to which each form of energy drives the process is a function of numerous environmental, topographic and meteorological factors such as:

- Canopy cover
- Cloud cover
- Aspect and slope of terrain
- Latitude of site
- Season
- Time of day
- Reflectivity of the snow (albedo)
- Wind direction and speed
- Temperature

For rain free conditions, shortwave radiation is the most significant source of energy input. For rain-on-snow conditions turbulent exchange (sensible and latent energy) is the most significant form of energy input. The principle factors affecting sensible energy are the temperature gradient and the corresponding wind speed (USACE, 1998; Marks et. al., 1998).

Methodologies

There are several methods, equations and tools available for estimating runoff from snowmelt. Two of the most common are the Degree-Day and Energy-Budget Methods. Both of those are coded in HEC-1 and can be coupled with rainfall-runoff.

The Degree-Day Method is a relatively simple model of the snowmelt processes that is often referred to as the Temperature Index Method. The Degree-Day

Method relies on temperature as an index to the energy budget. It is implemented in HEC-1 with the following data inputs.

- Elevation zone data
  - Drainage area
  - Snow-water equivalent
  - Normal annual precipitation
- Melt coefficient data
  - Temperature lapse rate
  - Snowmelt coefficient
  - Index temperature at which snow will melt
- Temperature time series data

The Energy-Budget Method considers the major sources on energy input and is a more sophisticated and accurate model of the snowmelt processes. It is implemented in HEC-1 with the three input data sets listed for the Degree-Day Method plus the following.

- Shortwave radiation time series data
- Dew point time series data
- Wind speed time series

Use of one method over another is ideally a function of the intended application and required output. Table 1 summarizes generally accepted approaches for modeling several typical applications for rainfall/snowmelt runoff conditions. Other factors that must also be considered in the method selection are data availability and degree to which snow is a factor (USACE, 1998). While the Energy-Budget Method provides a more accurate representation of the snowmelt processes, Table 1 indicates that either method is generally acceptable for most rain-on-snow applications. Use of the Energy-Budget Method is also restricted in practice due to data availability limitations. Therefore, for this State Standard, the recommended method for estimating snowmelt is the Degree-Day Method.

Table 1
Snowmelt method considerations

Application	Example	Melt Calculation		
		Snow Conditioning	**Degree-Day**	**Energy-Budget**
Single event: rain-on-snow	Hypothetical floods in coastal mountains	Assume Ripe	Possibly	Possibly
Single event: snow (plus rain)	Hypothetical floods in interior basins	Assume Ripe	Yes	Yes
Single event forecasting: rain-on-snow	Short-term flood forecasting	Optional	Yes	No
Single event forecasting: snow (plus rain)	Short-term flood forecasting	Optional	Yes	No
Continuous simulation	Long-term flood and drought forecasting	Required	Yes	Possibly
Detailed simulation on small watersheds	Research and Development	Required	No	Yes

Source: adapted from Table 10-1 EM 1110-2-1406 Runoff from Snowmelt (USACE, 1998)

Guidelines

Modeling of rain-on-snow events requires the characterization of both rainfall-runoff and snowmelt-runoff conditions. Characterization of the rainfall-runoff conditions for a rain-on-snow event is essentially the same as discussed in previous sections with a few minor modifications/considerations. Information and guidelines for modeling snowmelt conditions and rainfall-runoff conditions are provided in the following sections.

Snowmelt-Runoff

The Degree-Day Method as implemented in HEC-1 is described by the following equation.

$$M_s = C_m\left(T_a - T_b\right)$$

where

M_s = *snowmelt, in inches/period*
C_m = *melt rate coefficient, in inches/(degree/period)*
T_a = *air temperature lapsed to the midpoint of the elevation zone, in °F*
T_b = *base temperature at which snow melts, in °F*

Information and guidance for the selection/determination of each variable are provided in the following sections.

Snowmelt Coefficient

The key variable in the snowmelt equation is the melt rate coefficient, C_m. The magnitude of C_m is a function of albedo, canopy cover, cloud cover, rainfall and wind. For rain-free conditions, C_m typically ranges from 0.04 to 0.08 inches/°F (USACE, 1998). For rain-on-snow conditions, values of C_m can range from 0.06 to 0.20 inches/°F (USACE, 1994). In general, the magnitude of C_m tends to increase with increases in wind velocity (Marks et. al., 1998) and to a lesser extent with increases in rainfall and humidity.

The magnitude of C_m is also relative to the basis of the temperature index and can vary with time. This is typically only a consideration for long-duration simulations where temperature index data is on the order of days and the basis of input is the maximum or minimum daily temperature.

Base Temperature

The base temperature is the temperature at which snow melts and precipitation falls as either rain or snow. For most applications and locations, the base temperature is at or near 32 °F (USACE, 1998 and others). At temperatures greater than 2 °F plus the base temperature, precipitation is treated as rain.

Similar to the snowmelt coefficient, the base temperature is relative to the temperature index. For example, if the temperature index is based on the maximum daily temperatures, the base temperature is higher, possibly as high as 40 °F (USACE, 1998). This, again, is generally only a concern for long-duration simulations.

Air Temperature

Air temperature (temperature index) is a highly variable parameter that cannot readily be generalized. This is complicated by the fact that the areas within the State that are susceptible to snowmelt, limited data is available. Sources of temperature data are listed in Table 2. The source(s) that provides the most appropriate data depends on the specific application. For long-duration simulations, daily data (mean, maximum and minimum) temperature may be sufficient. For short-duration simulation/hypothetical simulations, hourly data is preferred. If hourly data is unavailable, a synthetic data set can be generalized using local mean, maximum and minimum data temporally distributed according to a representative patter (e.g. trapezoidal) or mimicking the distribution from an adjacent/meteorologically similar location.

Table 2
Temperature data sources

Source	Internet Address	Data Type
Western Regional Climate Center	http://www.wrcc.dri.edu/summary/Climsmaz.html	Daily
NRCS SNOTEL	http://www.wcc.nrcs.usda.gov/snow/	Daily
National Weather Service	http://www7.ncdc.noaa.gov/IPS/getcoopstates.html	Daily
Arizona Meteorological Network	http://ag.arizona.edu/azmet/azdata.htm	Hourly

Each of these data sources maintains temperature (and other climate data) extending back several years (often 30 or more). This data should be inspected to identify representative conditions, particularly in regard to know rain-on-snow events. Generally this can be limited to the months of January, February and March.

If more than one temperature station is located within the watershed/region, then the data should be inspected in regard to the establishment of a site-specific temperature lapse rate. Temperature lapse rate is the rate at which temperature changes with elevation. Lapse rate varies with time of day and season (Harlow et. al., 2004). Typical values for lapse rate range from –3 to –5 °F per 1,000 feet of elevation gain. In a study specific to southeastern Arizona, lapse rates for January, February and March are estimated for mean, maximum and minimum air temperatures. Those values are listed in Table 3.

Table 3
Temperature lapse rate for southeastern Arizona

Temperature	Lapse Rate °F/1,000 ft
Mean	-1.65 to -3.84
Maximum	-2.19 to -4.11
Minimum	-0.55 to -2.19

Source: Derivation of temperature lapse rates in semi-arid south-eastern Arizona (Harlow et. al., 2004))

Snow Water Equivalent

Snow water equivalent, SWE, is the depth of water that results from melting a given depth of snow and it is a function of both the depth and density of the snow (NRCS, 1997). In other words, SWE is the volume of water stored in the snow pack that is available for runoff. Estimates of SWE are determined by the NRCS at each of the SNOTEL stations. SNOTEL data can be viewed and downloaded from the link listed in Table 2.

In lieu of site-specific SWE data, estimates of SWE can be made using snow depth and density. Snow depth data is collected at numerous sites throughout Arizona and published on the Arizona Meteorological Network website (address listed in Table 2). One limiting factor with this approach is that snow density varies with depth in the snow pack and time. In the mountainous areas of California, the typical snow density is 12 percent. However, late in the snow season (after May) snow density is typically above 50 percent (California Department of Water Resources).

Snowmelt Losses

As snow melts, the volume of water released is subject to the same loss conditions as rainfall on the watershed. In HEC-1, when the snowmelt routines are invoked only the HEC Exponential Loss Rate or Initial and Uniform Loss Rate Methods can be used (for both rainfall and snowmelt). Of these, the Initial and Uniform Loss Rate Method is recommended for this State Standard for the rainfall component.

The Initial and Uniform Loss Rate Method can be a convenient substitute for the Green and Ampt infiltration equation for rain-on-snow conditions if an assumption is made that the watershed is saturated. Under saturated conditions, DTHETA of the Green and Ampt infiltration equation is zero and the magnitude of the losses during the decay of the infiltration capacity from normal antecedent conditions to a stead state condition becomes less significant. Thus, for saturated conditions the Green and Ampt infiltration equation essentially behaves as the Initial and Uniform Loss Rate. In the Initial and Uniform Loss Rate Method, the uniform loss rate is the same as XKSAT of the Green and Ampt infiltration equation. The initial loss is the same as the surface retention of the Green and Ampt infiltration equation with the addition of infiltration prior to the steady state condition. The additional losses can easily be “calibrated” against the results of the model with the Green and Ampt infiltration equation parameters.

For the snowmelt component, losses (if appropriate) can only be modeled using the HEC Exponential Snowmelt Loss Rate Method. For this method, there are not initial losses only a loss rate. The loss rate can either be uniform or decay based on some rate of change. For most purposes, assuming a uniform loss rate is sufficient.

Rainfall-Runoff

The rainfall-runoff model parameters for a rain-on-snow event are essentially the same as discussed previously. The only differences are the precipitation losses as discussed previously and temporal issues associated with the movement of water through snow. The movement of water through snow is more complex than the infiltration of water into soil due to the continuously changing conditions of the snow pack during the rainfall/snowmelt event (USACE, 1998). In addition, the routing processes are complicated by the influence of environmental factors such as canopy cover. For example, in the shallow snow packs of British Columbia the difference in time to peak runoff between forest and open sites can be several hours (Kattelmann, 1987). Another factor influencing the time delay is the watershed slope. For steep, mountainous watersheds, the time delay may be minimal (USACE, 1998). Because of the complexity of the process adjustments to unit hydrograph parameters for movement of water through snow are not recommended unless approved by the appropriate jurisdictional agency.

Procedures

Starting with the basic input for a rainfall-runoff model for the watershed add/change the following:

1. Change the Green and Ampt infiltration equation rainfall loss parameters to the Initial and Uniform Loss infiltration parameters. Uniform loss is the same as XKSAT in the Green and Ampt infiltration equation. Initial loss should be calibrated to yield similar results as the base model with the Green and Ampt infiltration equation.
2. Elevation zone data – elevation zone data characterizes the effects that topographic relief play in the physical characteristics of snowmelt and the point at which precipitation is either snowfall or rainfall. In HEC-1 up to 10 elevation zones can be used to characterize the topographic relief of the drainage area. Elevation zones must be in equal intervals (e.g. 1,000-foot intervals) and correspond to the temperature lapse rate. The drainage area is incremental area associated with each elevation zone.
    a. Determine the drainage area associated with each elevation zone, in square miles
    b. Determine the SWE associated with each elevation zone, in inches,
    c. Input the annual precipitation associated with each elevation zone, in inches
3. Melt coefficient data
    a. Select the temperature lapse rate associated with the elevation zone interval, in degrees Fahrenheit. For southeastern Arizona, select a value from Table 3. For other areas, estimate from available data or use a value between –3 and –5 °F/1000 feet.
    b. Select a melt rate coefficient associated with the appropriate basis of the temperature index. For non-forested areas with windy conditions select a value toward the upper end of the range of 0.06 to 0.2 inches/°F.
    c. Select a base temperature. Typical values for base temperature are 32 to 34 °F.
4. Temperature index data – input temperature series data for the entire simulation period. The starting time is assumed to be the same starting time as the rainfall.

Example

Compute the runoff magnitudes from a 100-year rainfall event on snow event at Fool Hollow Dam. Assume that the March 2006 snow conditions were typical for this location.

Fool Hollow Dam is located just north and west of the Town of Show Low. The watershed characteristics are:

- Drainage area: 111 square miles
- Flow path length: 26 miles

- Flow path length to watershed centroid: 11 miles
- Flow path slope: 80.5 feet/mile
- Minimum elevation: 6,256 feet
- Maximum elevation: 9,160 feet

Climate data – collect climate data (snow and temperature) for March 2006

- Payson – closest site with detailed (hourly) temperature data
    - Station elevation: 4,849 feet
    - Average hourly temperature listed in Table 4
- Heber SNOTEL station – closest site with detailed snow data
    - Station elevation: 7,640 feet
    - Maximum SWE: 4.1 inches
    - Average snow density: 25%
- Show Low Airport – located immediately adjacent to the watershed and provides daily temperature and average snow depth
    - Station elevation: 6,400 feet
    - Average daily mean temperature: 42.6 °F
    - Average snow depth: 0 inches
- Pinetop – located within the watershed and provides daily temperature and average snow depth
    - Station elevation: 6,960 feet
    - Average daily mean temperature: 40.1 °F
    - Average snow depth: 1 inch
- McNary – located immediately adjacent to the watershed and provides daily temperature and average snow depth
    - Station elevation: 7,320 feet
    - Average daily mean temperature: 37.2 °F
    - Average snow depth: 2 inch
- Hawley Lake – located near the watershed and provides daily temperature and average snow depth that are representative of the higher elevations of the watershed.
    - Station elevation: 8,180 feet
    - Average daily mean temperature: 29.8 °F
    - Average snow depth: 27 inches

Table 4
Average hourly temperature at Payson, AZ

Hour	Temp (°F)	Hour	Temp (°F)	Hour	Temp (°F)
1	35.5	9	43.2	17	52.2
2	34.6	10	47.9	18	51.1
3	33.8	11	49.7	19	48.5
4	33.5	12	50.7	20	44.3
5	32.8	13	51.3	21	42.0
6	32.1	14	52.0	22	39.8
7	31.5	15	52.5	23	37.8
8	34.6	16	52.7	24	36.6

Rainfall statistics – 100-year rainfall statistics for the watershed based on NOAA Atlas 14 using the Pinetop Fish Hatchery station as representative of the entire watershed are listed in Table 5.

Table 5
Depth-duration rainfall statistics for

Duration	Depth in
5-min	0.91
15-min	1.72
60-min	2.87
2-hr	3.24
3-hr	3.33
6-hr	3.71
12-hr	4.32
24-hr	4.71

Precipitation losses – losses estimated from the general soil survey for the State. The typical soil texture for all soils in the watershed is clay loam. The corresponding Green and Ampt infiltration equation parameters are

- I_a: 0.25 inches
- DTHETA: 0 (assume saturated conditions)
- PSIF: 8.2 inches
- XKSAT: 0.04 inches/hour

The equivalent Initial and Uniform Loss Rate Method parameters are

- STRTL: 0.25 inches (initial loss)
- CNSTL: 0.04 inches/hour (constant loss rate)

The HEC Exponential Snowmelt Loss Rate Method parameters are

- STRKS: 0.04 inches/hour (initial loss rate)
- RTIOK: 1 (rate of change of loss rate, value of 1 simulates a constant loss)

The unit hydrograph parameters are

- $T_c = 2.4(111^{0.1})(26^{0.25})(11^{0.25})(80.5^{-0.2}) = 6.6$ hours
- $R = 0.37(6.6^{1.11})(26^{0.8})(111^{-0.57}) = 2.8$ hours
- Time-area relation: HEC-1 default

Elevation zone data – divide the watershed in zones of 1,000-foot intervals. Elevation zone area and snow water equivalent are listed in Table 6.

Table 6
Elevation zone data

Zone	Range	SWE inches	Area sq. miles
1	6,250 – 7,250	0.25[a]	66
2	7,250 – 8,250	4.00[b]	40
3	8,250 – 9,250	9.00[c]	5

Notes:

a. Average snow depth for Show Low Airport, Pinetop and McNary range from 0 – 2 inches. Assumed snow density from Heber SNOTEL site is 25 percent. SWE = (25%)(1-inch) = 0.25 inches.
b. Snow depth for McNary is 2 inches (lower end of elevation range). Snow depth for Hawley Lake is 27 inches (upper end of elevation range). Midpoint of elevation range similar to Heber SNOTEL site, therefore use data from the Heber SNOTEL site.
c. Hawley Lake snow depth = 27 inches. SWE = (25%)(27) = 9 inches.

Temperature lapse rate – inspection of average daily mean temperature data compared to the general accepted range of temperature lapse rate indicates that a lapse rate of –5 °F/1,000 feet is appropriate. The air temperature from the Payson station is adjusted to the midpoint of elevation zone 1.

Snowmelt coefficient – wind conditions during the month of March (based on the Payson climate station) were mild, use a value of 0.08 inches/°F.

Results – the model was run for rainfall only as well as for the rain-on-snow condition. Results are summarized in Table 7. This particular model demonstrates a unique feature of rain-on-snow modeling in that the form of the precipitation is a function of temperature. For this model there are periods in the simulation that the temperature is below the threshold that precipitation falls as rain. The snowfall is not translated to runoff until the air temperature is above the base temperature. By the time the snowfall is melted, the timing in relation to the rainfall and magnitudes are such that much of the snowmelt is loss to the soil.

To test the sensitivity of the key snowmelt parameters, melt coefficient and air temperature, the example was run with a the maximum recommended melt coefficient of 0.2 inches/°F and then with a high air temperature (10 °F higher for each hour of the simulation). Those results are listed in Table 7. The sensitivity results indicate that the melt coefficient input is not as sensitive as the air temperature input.

Table 7
Example rain-on-snow model results

Case	Rainfall Excess inches	Peak Discharge cfs	Time to Peak hours
Rain only	3.06	28,675	17.25
Rain-on-snow	3.03	28,470	17.25
Max. melt coefficient	3.36	30,722	17.50
High air temperature	3.50	31,594	17.25

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