Name/Address	*Telephone*	*Fax*
Raymond Acuna, PE City of Phoenix 200 W. Washington, 5th Floor Phoenix, AZ 85004	(602) 262-4960	(602) 262-7322
Gary Benton, PE City of Phoenix Street Transportation Department Design and Construction Management Division 1034 E. Madison Street Phoenix, AZ 85034-2292	(602) 495-2050	(602) 495-3670
Ralph L. Goodall, PE City of Phoenix Street Transportation Department Design and Construction Management Division 1034 E. Madison Street Phoenix, AZ 85034-2292	(602) 495-2050	(602) 495-3670
Robert Gofonia, PE City of Phoenix Street Transportation Department Design and Construction Management Division 1034 E. Madison Street Phoenix, AZ 85034-2292	(602) 495-2050	(602) 495-3670
V. Ottozawa-Chatupron, PE Arizona State Land Department 1616 W. Adams Phoenix, AZ 85007	(602) 542-2683	(602) 542-4668
Joseph W. Warren, PE Drainage Section Leader ADOT Intermodal Transportation Department 205S. 17th Avenue, 283E Phoenix, AZ 83007-3212	(602) 255-7197	(602) 407-3056
Stephen D. Waters FCDMC 2801 W. Durango Phoenix, AZ 85009	(602) 506-1501	(602) 506-4601
Larry Scofield ATRC 1130 N. 22nd Avenue Phoenix, AZ 85009	(602) 407-3131	(602) 256-6367

CITY OF PHOENIX

PHOENIX STORM DRAINAGE DESIGN MANUAL

Meeting No. 4
18 November 1997

REVIEW AND EVALUATION OF THE NOAA SEMI-ARID PRECIPITATION STUDY AND COMPARISON WITH NOAA ATLAS 2 RAINFALL DEPTH-DURATION-FREQUENCY STATISTICS

George V. Sabol, PhD, PE
Stantech Consulting Inc.

SEMI-ARID PRECIPITATION FREQUENCY STUDY

NOAA NATIONAL WEATHER SERVICE
SILVER SPRINGS, MD

Work Products

1. Precipitation Frequency Maps
   Duration: 1-hour and 24-hour
   Frequencies: 2-, 5-, 10-, 25-, 50-, and 100-year
   Orographic effects to be included.

2. Ratios of rainfall for durations less than 1-hour.

3. Depth-duration curves (mass curves) of the temporal distribution of storms for both short-duration (1-hour) and long duration storms.

4. Depth-area curves for both small areas (less than 100 square miles) and large areas.

5. Digital results in a GIS format.

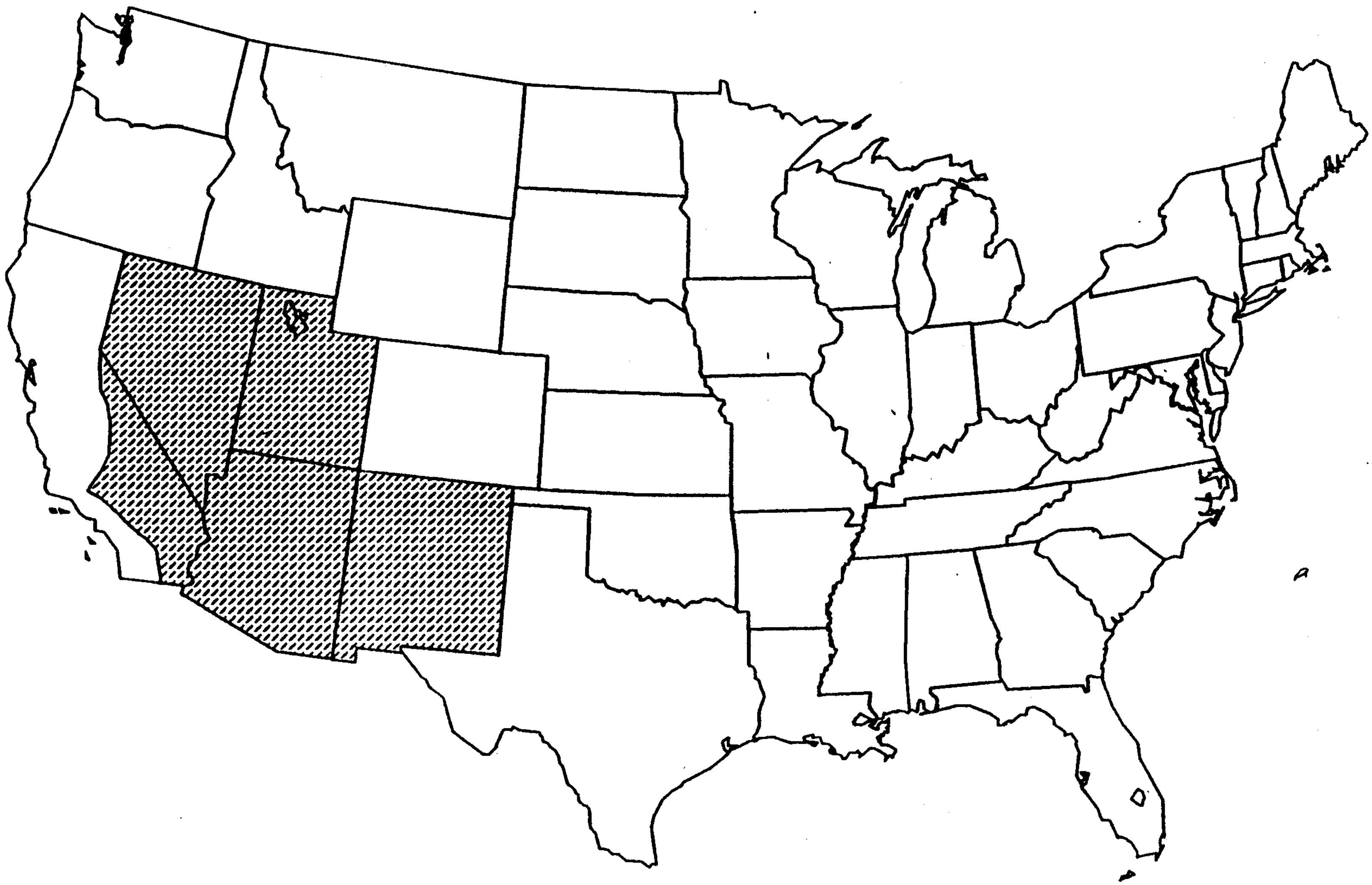
Schedule

3-year duration starting 1 October 1991.

Budget

111 man-month effort
$783,165 cost

Semi-Arid Southwest US Study Area



Enclosure 7a

DATA SETS

NCDC	National Climatic Data Center	NOAA
SNOTEL	SNOwpack TELemetry	USDA/SCS
RAWS	Remote Automated Weather Station	USDA/BLM & FS
ARS	Agricultural Research Service	USDA/ARS
USGS	U.S. Geological Survey	Dept. of Interior
Supplementary	Dept. of Water Resources	California
Supplementary	San Bernardino County, CA	
Supplementary	Riverside County, CA	
ALERT	Automated Local Evaluation in Real Time	
	California Storm Data	J. Goodridge
	New Mexico Climate Data	Ken Kunkel

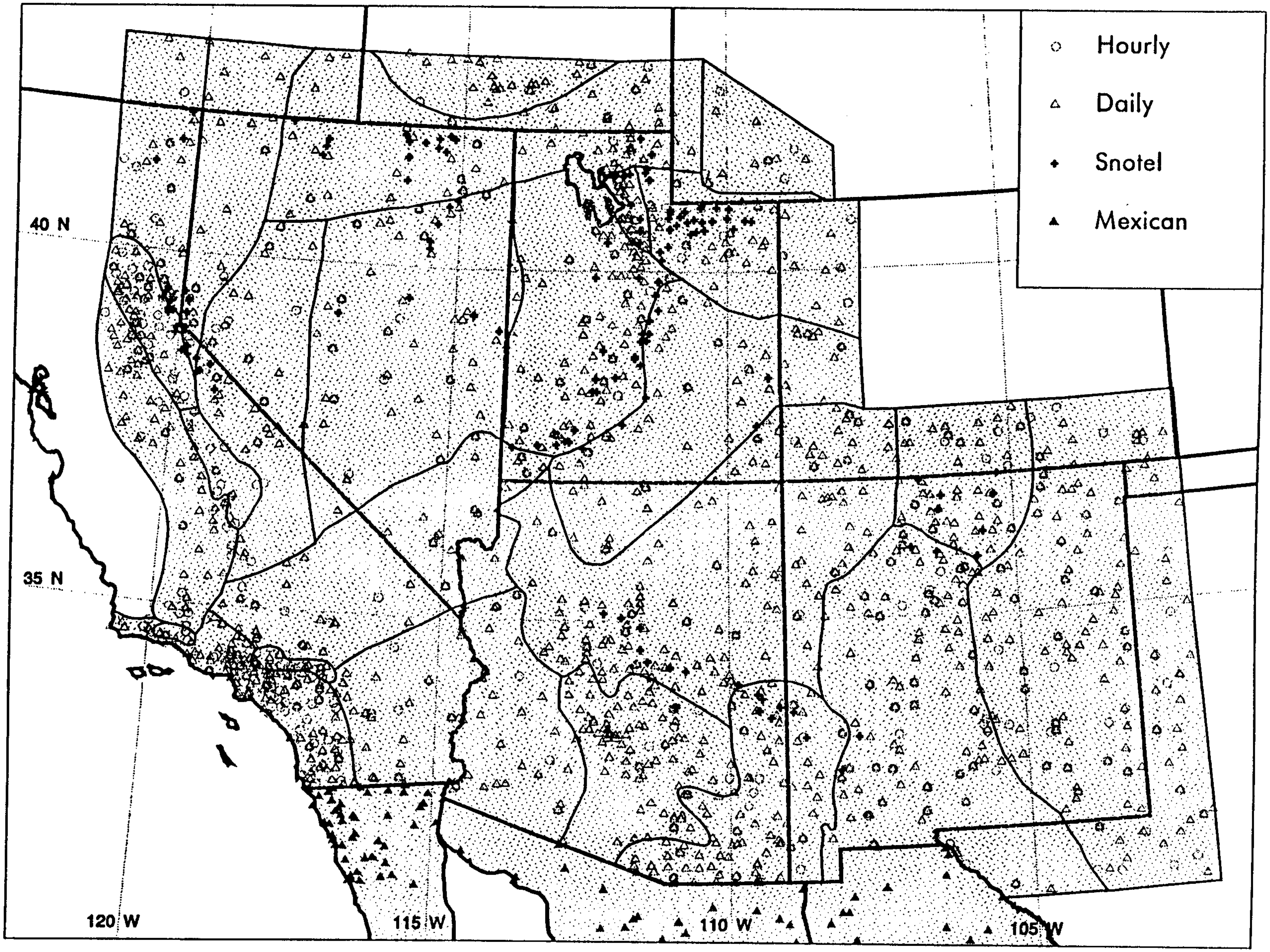


Figure 2. *Semiarid study station locations.*

Table 1.

DAILY STATIONS WITH AT LEAST 19 YEARS OF DATA

Core States	Semiarid	NOAA Atlas 2	Increase
Arizona	267	125	**142**
Nevada	91	34	**57**
New Mexico	212	143	**69**
Utah	171	82	**89**
Total	741	384	**357**

Other Stations	
California	288
Border states	148
SNOTEL	147
Mexico	108
Total Other	691
TOTAL DAILY	1432

HOURLY STATIONS WITH AT LEAST 15 YEARS OF DATA

Core States	Semiarid	NOAA Atlas 2	Increase
Arizona	42	32	**10**
Nevada	41	27	**14**
New Mexico	81	42	**39**
Utah	44	20	**24**
Total	208	121	**87**

Other Stations	
California	182
Border states	59
Total Other	241
TOTAL HOURLY	449

TOTALS	
DAILY	1432
HOURLY	449
TOTAL STATIONS	**1881**

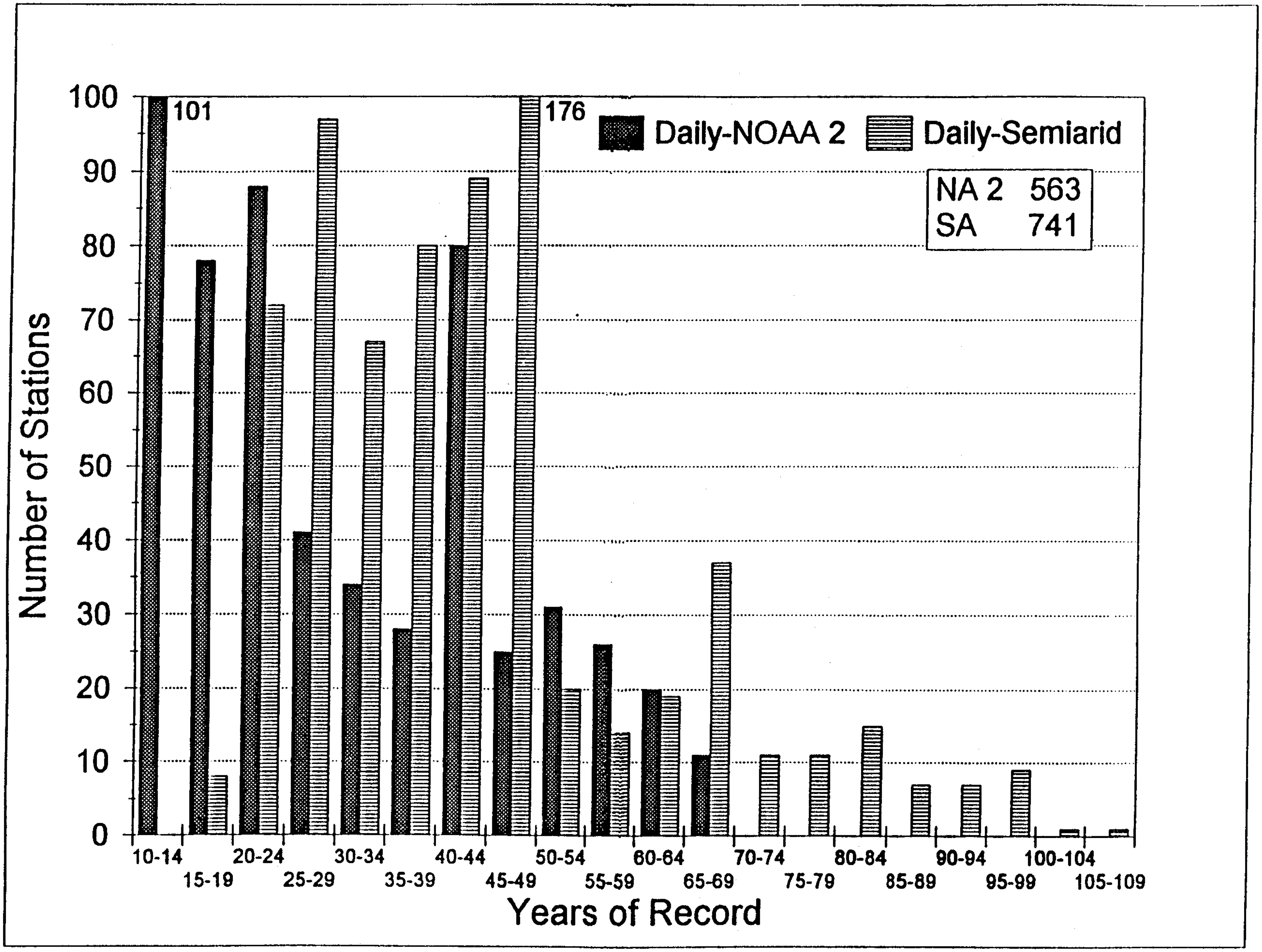


Figure 5a. *Comparison of NOAA Atlas 2 and Semiarid daily stations, by years of record.*

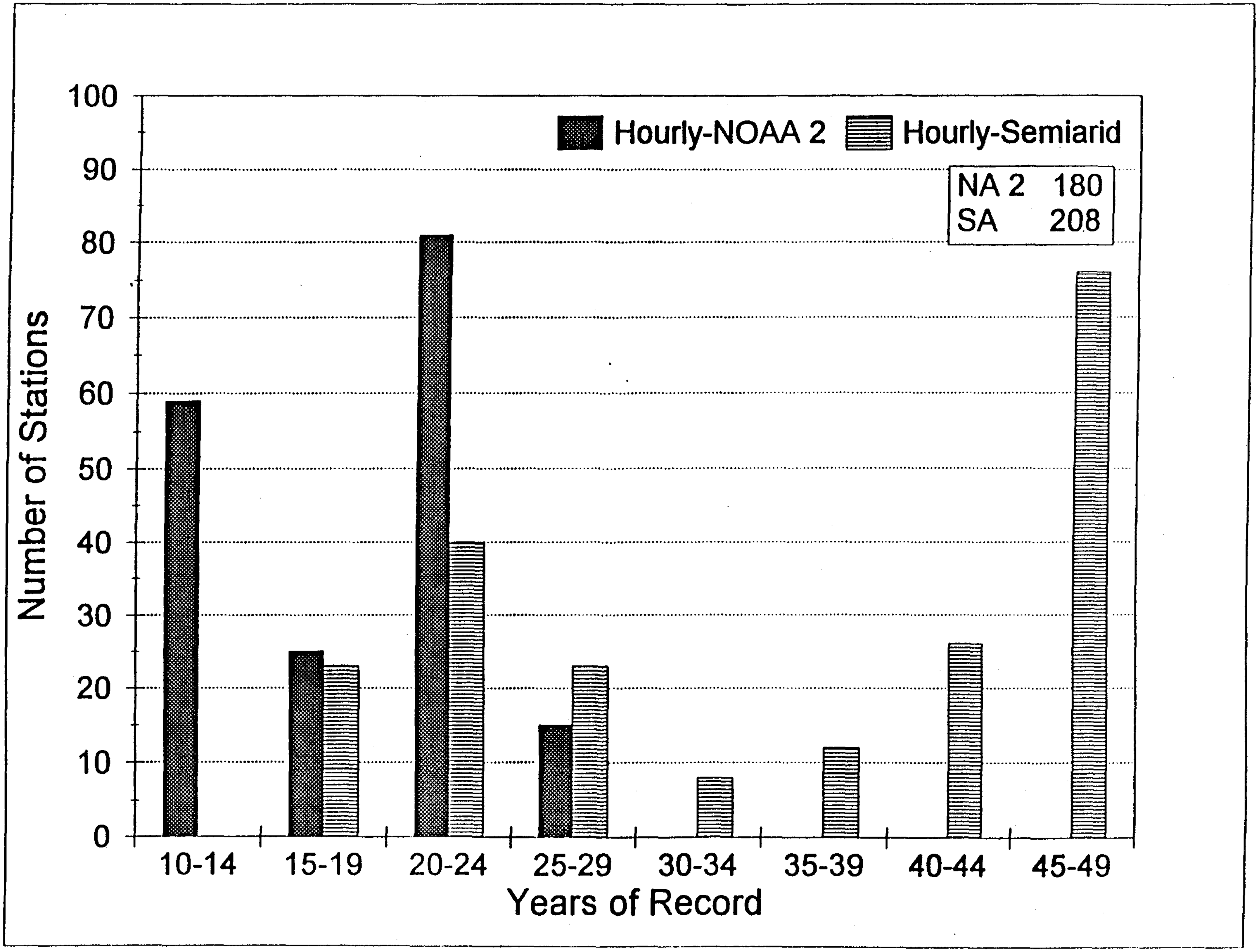


Figure 5b. *Comparison of NOAA Atlas 2 and Semiarid hourly stations, by years of record.*

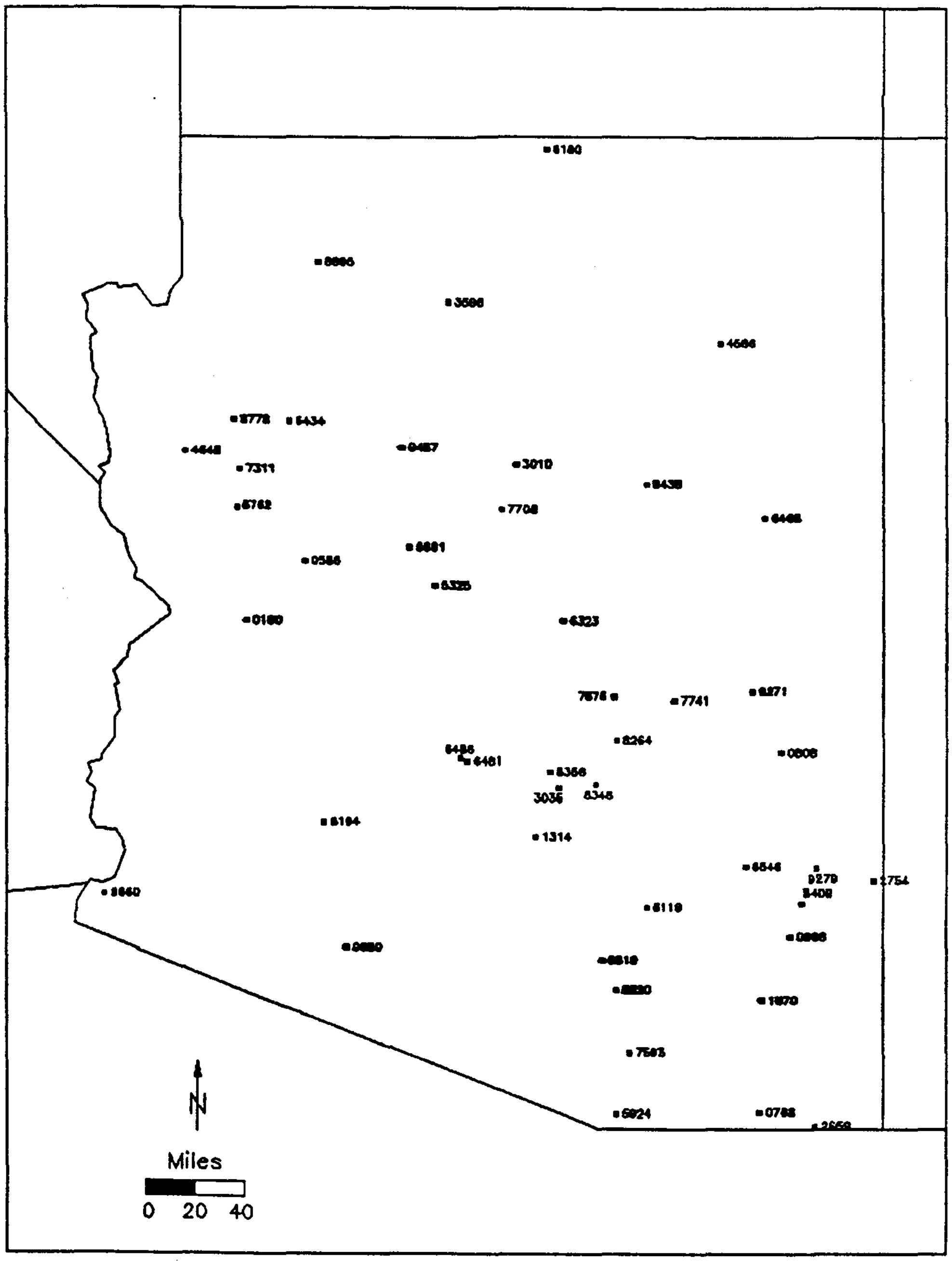


Figure 1a. Arizona hourly stations after quality control, station number.

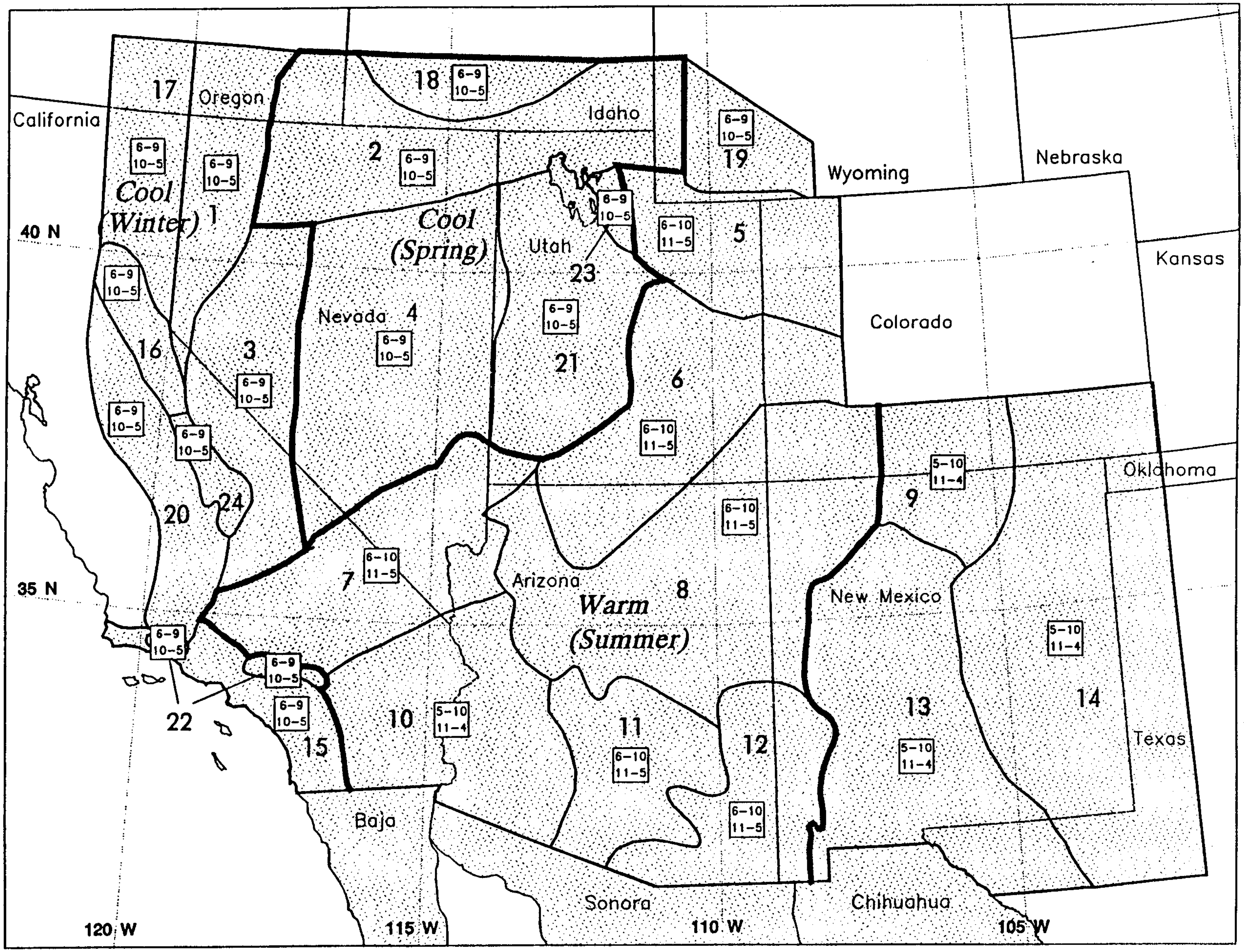
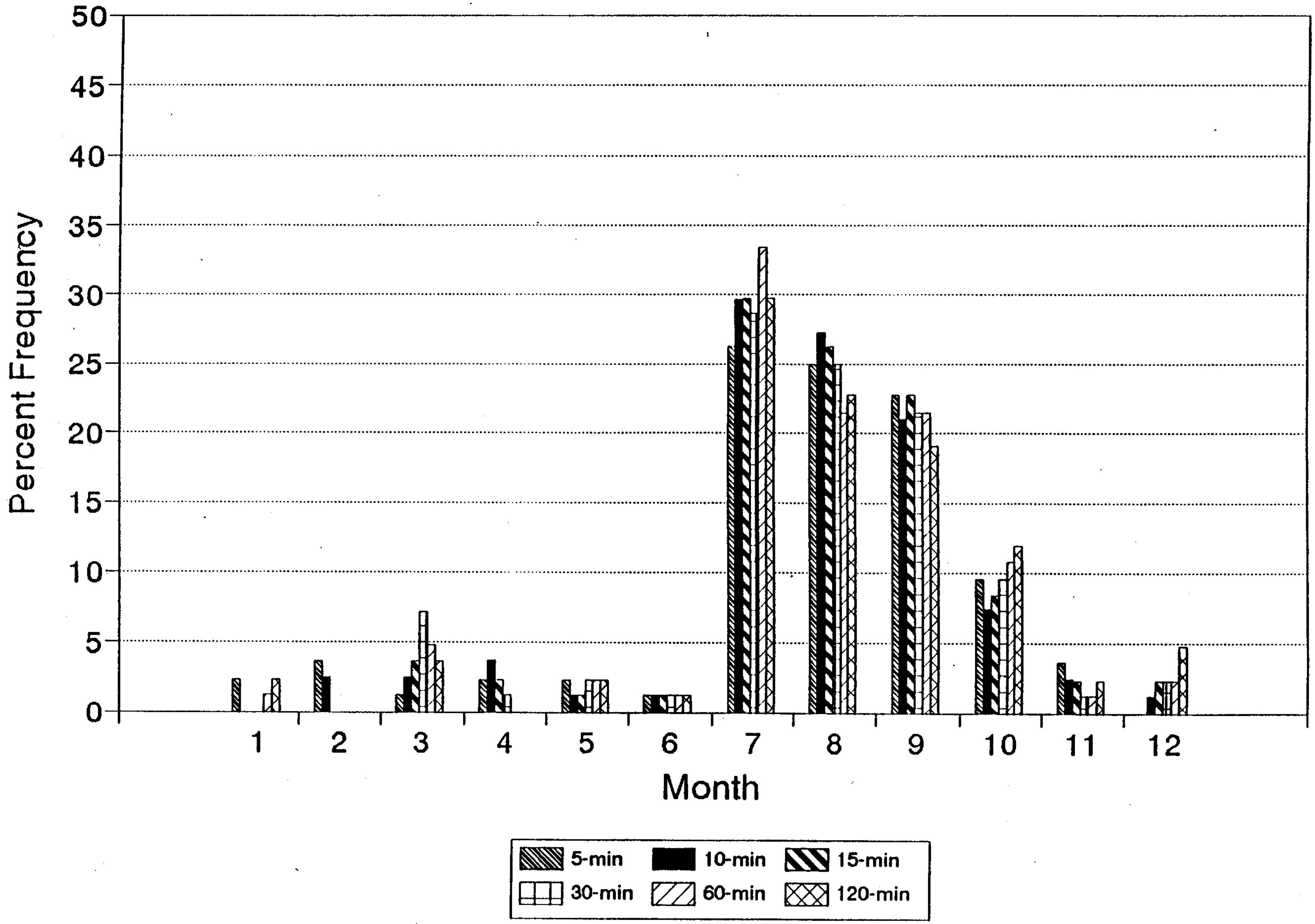


Figure 1. *Semiarid study climatic regions.*

02-6481 Phoenix, AZ 84 YOR
Percent Frequency of N-min max



ATTACHMENT 10c

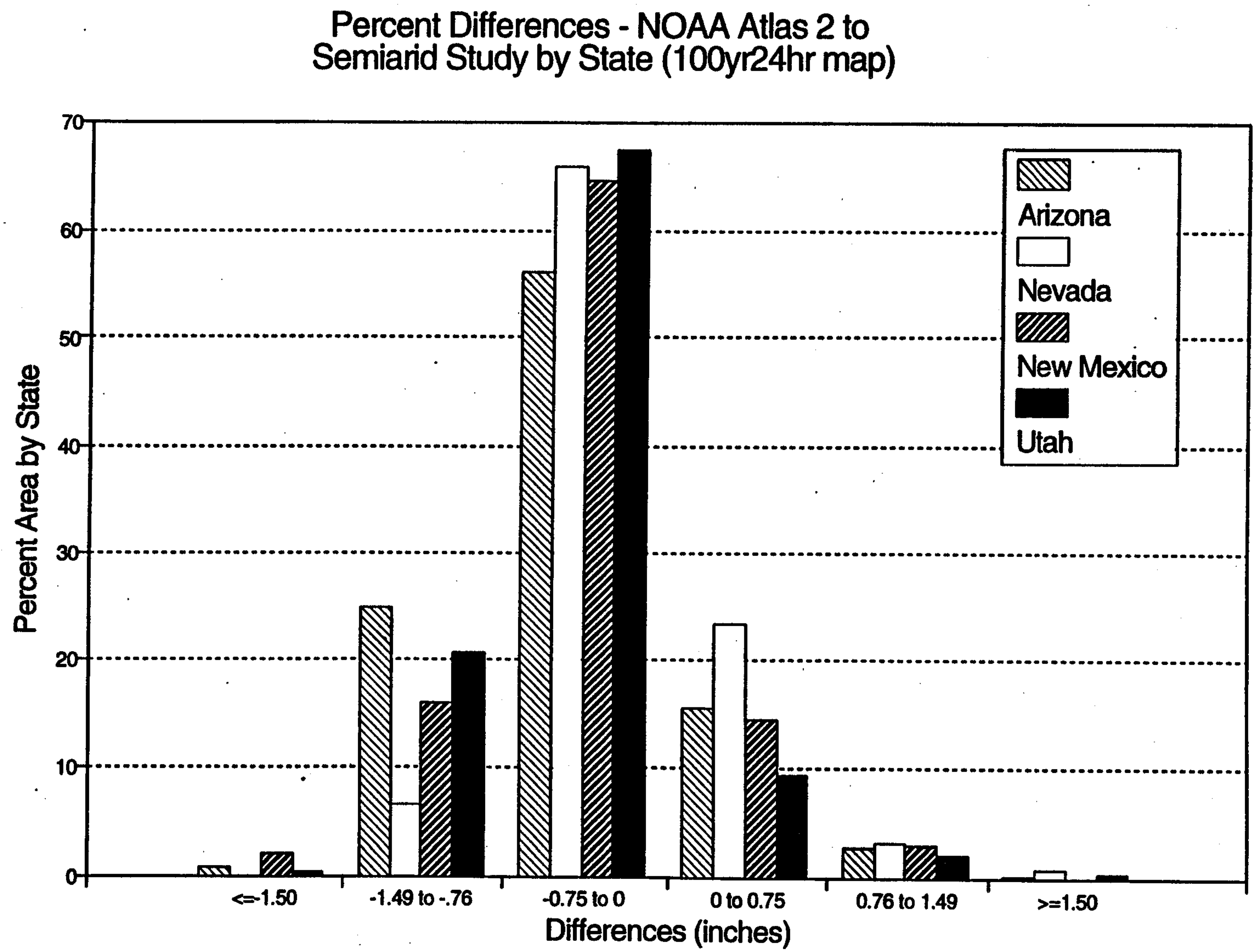


Figure 2. *Percent differences of NOAA Atlas 2 to Semiarid Study, by state.*

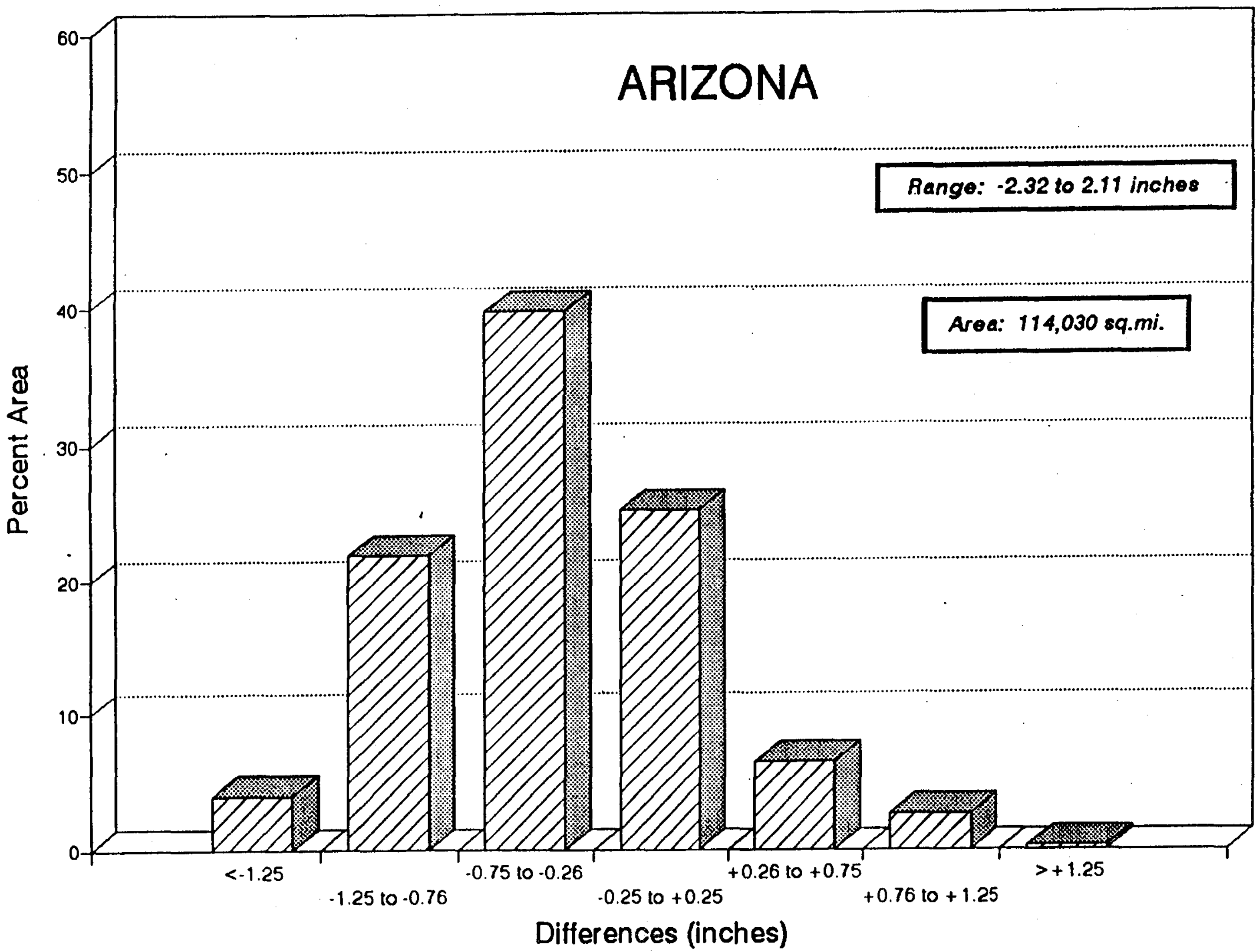


Figure 3a. *Differences of 100-yr, 24-hour values (Semiarid minus NOAA Atlas 2) by percent of area for Arizona.*

Table 3.

Percent area differences from NOAA Atlas 2 to Semiarid Study
by State
100-year 24-hour computer-generated map

DIFFERENCE (inches)	<=-1.50	-1.49 to -0.75	-0.74 to -0.01	0.00 to 0.75	0.76 to 1.49	>=1.50
Arizona	0.7	24.9	56.0	15.5	2.7	0.1
Nevada	0.0	6.6	65.9	23.4	3.2	0.9
New Mexico	2.2	15.9	64.6	14.4	2.9	0.0
Utah	0.3	20.5	67.3	9.2	2.2	0.5

		Range:	
Arizona	81.6% < 0	18.3% > 0	-2.33 to 2.11
Nevada	72.5% < 0	27.5% > 0	-1.46 to 3.29
New Mexico	82.7% < 0	17.3% > 0	-2.69 to 1.49
Utah	88.1% < 0	11.9% > 0	-1.93 to 3.37

The Semiarid (SA) values are lower than NOAA Atlas 2 values over about 80 percent of the area in Arizona, New Mexico and Utah, and over 70 percent of the area in Nevada. Most SA values are between 0 and 0.75 inches less than NOAA Atlas 2. About 20 percent of the area of Arizona and Utah has even lower values, that is from .76 to 1.49 inches lower than NOAA Atlas 2. The SA areas that are higher than NOAA Atlas 2 are generally those in higher elevations where SNOTEL data are now available, such as the Wasatch Range and the Uinta Mountains in Utah and some areas of Nevada. For reference, the SNOTEL station areas are shown in Figure 3. Although in general, SNOTEL values are higher than NOAA Atlas 2 estimates, Arizona provides an exception, where the precipitation observed at SNOTEL stations is not notably higher than NOAA Atlas 2. Another area where SA values are higher is the region 10 part of southwestern Arizona. Region 10 has the highest RGFs, which may have some effect, but other areas within region 10 have values that are lower than NOAA Atlas 2. Another difference between SA and NOAA Atlas 2 is that the 'dry areas are drier and the wet areas wetter' in several areas of the Southwest study area. The changes reflect information from longer datasets, observations in areas where there were none for NOAA Atlas 2, more objective curve-fitting techniques, and regionalized analysis, among others.

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR PHOENIX: LAT. 33N, LONG. 112W
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 8

LATITUDE 33.40N LONGITUDE 112.06W

POINT VALUES

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.33	.43	.50	.60	.68	.76	.94	5-MIN
10-MIN	.49	.65	.77	.92	1.04	1.16	1.44	10-MIN
15-MIN	.59	.82	.97	1.17	1.33	1.49	1.86	15-MIN
30-MIN	.79	1.09	1.30	1.58	1.80	2.02	2.53	30-MIN
1-HR	.96 .90	1.35	1.61	1.97	2.25	2.53 2.0	3.17	1-HR
2-HR	1.04	1.47	1.76	2.15	2.45	2.76	3.46	2-HR
3-HR	1.10	1.55	1.85	2.27	2.59	2.91	3.65	3-HR
6-HR	1.20 1.20	1.70	2.03	2.49	2.85	3.20 3.0	4.01	6-HR
12-HR	1.30	1.85	2.22	2.72	3.11	3.50	4.40	12-HR
24-HR	1.40	2.00	2.40	2.95	3.38	3.80	4.78	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=PHOENIX: LAT. 33N, LONG. 112W
ZONE= 7 SHORT-DURATION ZONE= 8
LATITUDE= 33.40 LONGITUDE= 112.06 ELEVATION= 0
2-YR, 6-HR PCPN= 1.20 100-YR, 6-HR PCPN= 3.20
2-YR, 24-HR PCPN= 1.40 100-YR, 24-HR PCPN= 3.80

* * * * E N D OF R U N * * * *

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR PHOENIX: LAT. 33N, LONG. 112W
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 8

→ OPTION NUMBER 2 --- INPUT OF 12 PRECIP VALUES
LATITUDE 33.40N   LONGITUDE 112.06W   ELEVATION 2000 FEET

POINT VALUES

DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
				RETURN PERIOD				
5-MIN	.32	.43	.50	.60	.68	.75	.93	5-MIN
10-MIN	.48	.65	.76	.91	1.03	1.15	1.43	10-MIN
15-MIN	.59	.81	.96	1.16	1.32	1.48	1.85	15-MIN
30-MIN	.78	1.08	1.29	1.57	1.79	2.01	2.51	30-MIN
1-HR	.95 .90	1.34	1.60	1.95	2.23	2.51 2.0	3.14	1-HR
2-HR	1.03	1.46	1.74	2.14	2.44	2.74	3.44	2-HR
3-HR	1.09	1.54	1.84	2.26	2.58	2.90	3.64	3-HR
6-HR	1.19 1.20	1.69	2.03	2.49	2.85	3.20 3.0	4.02	6-HR
12-HR	1.29	1.85	2.22	2.73	3.13	3.52	4.42	12-HR
24-HR	1.40	2.01	2.42	2.98	3.41	3.84	4.83	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=PHOENIX: LAT. 33N, LONG. 112W
ZONE= 7   SHORT-DURATION ZONE= 8
LATITUDE= 33.40   LONGITUDE= 112.06   ELEVATION= 2000
12-VALUE PRECIPITATION OPTION
PRECIPITATION VALUE:

1.20	1.70	6-hr
2.00	2.50	6-hr
2.85	3.20	6-hr
1.40	2.00	24-hr
2.40	3.00	24-hr
3.45	3.80	24-hr

2-, 5-, 10-, 25-, 50- and 100-yr

* * * * E N D   O F   R U N * * * *

PHOENIX STORM DRAINAGE DESIGN MANUAL
Hydrology - Design Rainfall

SEMI-ARID PRECIPITATION FREQUENCY STUDY
National Weather Service
Silver Springs, Maryland

NOTEBOOK CONTENTS

5. 7 November 1994
    - Meeting Minutes w/enclosures

SECTION 4 - QUARTERLY PROGRESS REPORTS

1. First - February 1992
2. Second - April 1992
3. Third - August 1992
4. Fourth - November 1992
5. Fifth - February 1993
6. Sixth - April 1993
7. Seventh - July 1993
8. Eighth - October 1993
9. Ninth - January 1994
10. Tenth - April 1994
11. Eleventh - August 1994
12. Twelfth - October 1994
13. Thirteenth - January/February 1995
14. Fourteenth - April/May 1995
15. Fifteenth - July 1995
16. Sixteenth - November 1995

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e-mail: stanley.phx@stantech.com
www.stantech.com

Stantech
Consulting

7 November 1997
File: 28900042

NOAA/NWS W/OH2
1325 East-West Highway
Silver Springs, MD 20910

Attention: Lesley T. Julian, PhD

Dear Lesley:

Reference: PHOENIX STORM DRAINAGE DESIGN MANUAL

Since our phone conversation on 22 August 1997, I have been in communication with and obtained information from Larry Scofield (ATRC), V. Ottozawa-Chatupron (ASLD), Joe Warren (ADOT) and Steve Waters (FCDMC). I have obtained the following concerning the Semi-Arid Precipitation Frequency Study (SA Study):

Draft isopluvial maps dated 27 August 1997 for the following:

A. 2-year, 1-hour

2-year, 6-hour

100-year, 1-hour

100-year, 6-hour

NOTE: Those maps were obtained by plotting files from a diskette provided by Larry Scofield.

B. Minutes for five Semi-Annual Meetings:

5 December 1991

10 June 1992

7 December 1992

9 September 1993

7 November 1994

C. Sixteen Quarterly Progress Reports for the Period February 1992 through November 1995

I am in the processing of reviewing that information for our client, the City of Phoenix, in regard to using the results from the SA Study in a new Phoenix Storm Drainage Design Manual. At this time, I have the following questions:

1. Considering the information that I have indicated herein, do I have all of the relevant and "best" available information for reviewing the status and work product for the SA Study?

2. As I understand, the SA Study is also to provide information concerning the spatial and temporal distribution of storms. Such depth-area-duration and depth-area relations are needed for Phoenix (and Arizona) due to the questionable applicability of some existing relations that are currently being used. Is the SA Study still proceeding along those lines? What is presently available, and/or when will those results be available?

3. Orographic factors in the Phoenix meteorologic/hydrologic area probably significantly influence precipitation. The Phoenix area appears to be very complex in this regard with mountain ranges nearly encircling the City. Observation by myself and others seems to indicated preferred storm paths or storm hot-spots. Those may be influenced by orographic factors and possibly by urbanization in the Valley. Do orographic features play a role in the development of the isopluvial maps? To what extent? Is there an accounting for urban influences or storm tracks, etc.? In this regard, are more "detailed" or larger scale maps of the Phoenix meteorologic/hydrologic area available that may provide better detail of the spatial depth-duration-frequency relations (isopluvial maps) for this area?

4. Have comparisons been made, formally or informally, of the difference between the NOAA Atlas 2 isopluvials and those from the SA Study for the Phoenix area? If so, I would be interested in the results.

Over the next few weeks, I will be assessing the presently available SA Study results in regard to depth-duration-frequency for use in Phoenix. I will send you the comparisons that I compile and will ask you to review my work. I do not want to make an error or draw the wrong inference from the information that I have. Your assistance will be greatly appreciated.

The SA Study has great interest to me. Incidentally, I made the initial contact with John Vogel concerning the need for that study back in 1989 or 1990. Please keep me informed of your results. I would like to receive any future reports and to attend review meetings. I understand that you made presentations on this project recently in both San Diego and Laughlin. Regrettably, I could not attend either meeting. If you had publications or presentation handouts, I would appreciate copies. It has been some time since the last review meeting. For my part, I would find such a project meeting useful. Do you have plans for a review meeting sometime in the near future?

Thank you for your assistance. Please keep me informed and I will do likewise.

Sincerely,

STANTECH CONSULTING INC.

George V. Sabol, PhD, PE
Senior Associate

cc: Mr. Robert Gofonia, City of Phoenix
Mr. Ralph Goodall, City of Phoenix
Mr. Gary Benton, City of Phoenix
Mr. Ray Acuna, City of Phoenix
Mr. Larry Scofield, ATRC
Mr. Joe Warren, ADOT
Mr. V. Ottozawa-Chatupron, ASLD
Mr. Steve Waters, FCDMC

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22 Aug 97

phone call w/ Lesley Julian

(301) 713-1669

mail NOAA / NWS W/OH2

1325 East-West Hwy

Silver Spring, MD 20910

E-mail Lesley.Julian@NOAA.DOV

Regarding NOAA Atlas 14 - Semi-Arid study

Draft isohyetal maps

essentially complete for:

2- & 100-year, 1-, 6- & 24-hr duration

something about producing for

1, 2, 3, 6, 12 & 24 hr durations

Accuracy problems in going from hand drawn to electonic form.

Question of production in metric or english.

Draft hard copy to be sent to Larry Scofield next Tuesday.

I will contact Larry & request copies.

amDg

Area-reduction curves

- will be provided
- developing over next couple of months
- more similar to Zier & Myer rather than old NOAA Atlas 2

Temporal distribution

- being developed for 12, 24 & 72 hour
- also seasonal distributions
- for maximum events & also median events

A review draft is to be produced in Mid-Dec 1997 (sounds like a preliminary).

Discussed use of PREFRE.
Will send her a copy.

Lesliey ~~Tarleton~~ Julian (301) 713-1669

review status

receive copies of reports

NOAA Atlas 14 semi-Arid study

Isohyetal maps complete

1, 2, 3, 6, 12, 24 hr

2 & 100-yr 1, 6, 24 hr

Draft

Send to Larry on Tuesday

Area-Reduction curves
developing - next couple months } prelim.

Review Draft mid-Dec

Temp. Dist.

12, 24, 72 dist.

seasonally

max events / median events

Larry Scofield 407-3131

NOAA / NWS ~~#~~
W/OH2

1325 E. West Hwy
Silver Spring MD
20910

E-Mail
Lesley.Julian@
NOAA.GOV

Laughlin AFMA meeting presentation

left draft freq. maps w/ committee

use PREFRE ?   no coef.

area reduction factors
→ will not have for awhile

Leslie Tarleton   (301) 713-1669   MD

oct 91 project start

3 year program   (94)

Progress Reports

John V   in KC - no longer on project

call Larry Scofield

ADOT   Larry Scofield

FCDMC   Steve Waters

Phx   no participation

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Stantech
Consulting

22 August 1997
File: 28900042

NOAA/NWS W/OH2
1325 East-West Highway
Silver Springs, MD 20910

Attention: Ms. Lesley Julian, PhD

Dear Lesley:

Reference: Phoenix Storm Drainage Design Manual

Enclosed is a copy of the PREFRE program and users manual. Please keep me informed in regard to NOAA Atlas 14 and related analysis.

I will ask Larry Scofield to make all work products available to me.

Thank you for your assistance. We look forward to incorporating the study results into the Phoenix manual.

Sincerely,

STANTECH CONSULTING INC.

George V. Sabol, PhD, PE
Senior Associate

Enclosure

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Stantech
Consulting

Memo

To: Distribution

From: George Sabol

Date: 8 September 1997

Reference: **PHOENIX STORM DRAINAGE DESIGN MANUAL**
NEW PRECIPITATION ANALYSIS FOR PHOENIX
FILE: 28900040

The source of design rainfall information was, and still is, the NOAA Atlas 2 for Arizona along with a few supplemental publications by other Federal government agencies. However, the need for a revised rainfall analysis of depth-duration-frequency statistics and other rainfall design information for Arizona has been recognized since the mid-1980s. At the time that the Flood Control District of Maricopa County (FCDMC) and the Arizona Department of Transportation (ADOT) were producing its hydrology manuals (from 1986 through about 1992), there was an effort to bring about a reanalysis of rainfall data. That process culminated in an agreement by NOAA to undertake a regional study of rainfall data. Various entities, such as ADOT, FCDMC and other state and county agencies within the region cooperated in financing the NOAA study. That study was initiated in October 1991 and was to have been completed in three years. The document to be produced is NOAA Atlas 14 (semi-arid region precipitation study) and that atlas will cover all or parts of about six states.

I was involved in the initial contacts with NOAA and have had some minor involvement in staying informed about the study since 1991. Over the past few weeks, I have discussed the project with several persons in order to determine the status of that study. The best source of information is the NOAA Project Manager, Dr. Lesley Julian. The status of the study is as follows.

Isohyetal Maps

- Draft isohyetal maps for 2- and 100-year frequency, 1-, 6- and 24-hour duration have been prepared. Those drafts are being sent to Mr. Larry Scofield (Arizona Transportation Research Center) on 27 August 1997.

- I contacted Larry Scofield and requested a copy of those maps and any previous study reports that may be useful to us. He will provide those to me.

- Those maps are apparently in English units and there is a question of whether the final product will be English or metric units. The Phoenix manual is to be in English units, but many of the project sponsors (such as ADOT) will require metric unit products. With the Federal initiative for conversion to metric, I anticipate a metric unit product. Therefore, there may be the need for us to perform a conversion or otherwise repackage those maps. This is presently unknown.

Rainfall Area Reduction Factors

- This is a topic of great interest and need. FCDMC adopted a Corps of Engineers criteria for the 6-hour storm based on historic storms in Arizona, and another criteria for 24-hour storms. ADOT uses the criteria in NOAA Atlas 2 which was originally developed by the National Weather Service (NWS) based on midwest storms.

- NOAA is presently working on this topic, but preliminary results probably will be not available until about mid-December.

Temporal Storm Distributions

- Again, this is a topic of great interest and need. FCDMC developed a 6-hour design storm and adopted an SCS 24-hour storm. ADOT uses a hypothetical 24-hour storm.

- NOAA has developed temporal distributions for 12-, 24- and 72-hour storms. They have also looked at seasonal rainfall patterns for "severe" and "garden variety" storms.

- I will obtain and review what has been produced in this regard.

Lesley was very interested in our plan to produce an electronic version of our manual. In that regard, I sent her a copy of the PREFRE program that is used in conjunction with rainfall statistics from the NOAA Atlas to produce tables of rainfall depth-duration-frequency and intensity-duration-frequency. She will evaluate the use or modification of that program with the new NOAA Atlas.

At this point, my work plan is as follows:

1. Obtain all information that is available from NOAA concerning its new study.

2. Perform a preliminary review of that information.

3. Review the draft report that presumably will be available in mid-December.

4. Within a month of obtaining the draft report, provide an assessment of information that will be available with the new NOAA atlas.

5. Finalize a work plan and schedule for the rainfall section of the manual. This will probably result in some rescheduling of some of the work products because of the delays in obtaining information for the NOAA study.

6. I will report on this topic at our next meeting, which is scheduled for 12 September.

George V. Sabol, PhD, PE
Senior Associate

Attachment

Distribution: Robert Gofonia, City of Phoenix
Gary Benton, City of Phoenix
Ralph Goodall, City of Phoenix
Ken Lewis, KVL Consultants

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Stantech
Consulting

Fax

FAXED

To: Street
Transportation Department

Attention: Bob Gofonia

Reference: **PHOENIX STORM DRAINAGE DESIGN MANUAL FILE: 28900042**

Sender: George Sabol

Fax No. 495-3670

Date: 8 September 1997

3 page(s) total including cover sheet.

Original will **NOT** follow by mail.

E-mail: gsabol@stantech.com

Attached is a memo concerning the ongoing analysis of rainfall data by NOAA as may be relevant to the Phoenix manual.

George V. Sabol, PhD, PE
Senior Associate

Attachment

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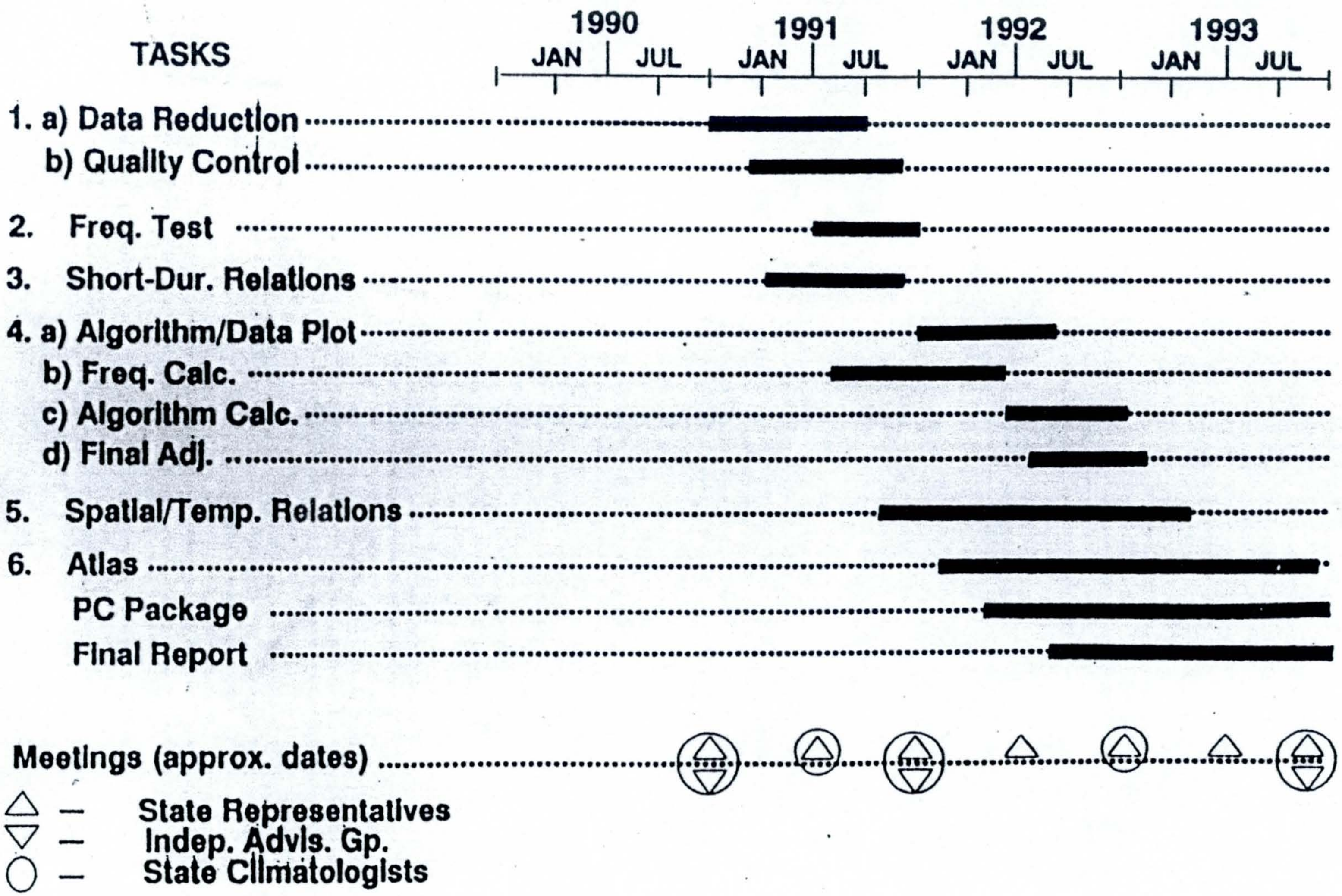
NATIONAL WEATHER SERVICES
SEMI-ARID PRECIPITATION FREQUENCY STUDY

PROJECT TIME TABLE



NATIONAL WEATHER SERVICE
SEMI-ARID PRECIPITATION FREQUENCY STUDY

DETAILED BUDGET

	Tasks	Personnel	Computer Charges	Total	Personnel Months
1	a) Data Reduction	$42,975	$1,500	$44,475	9.47
	b) Quality Control	$43,910	$2,500	$46,410	9.57
2	Frequency Test	$43,650	$500	$44,150	7.48
3	Short-Duration Relations	$50,640	$500	$51,140	10.11
4	a) Algorithm/Data Plot	$40,070	$2,000	$42,070	7.24
	b) Frequency Calculations	$40,525	$1,000	$41,525	7.18
	c) Algorithm Calculation	$46,330	$2,000	$48,330	8.32
	d) Final Adjustments	$48,870	$500	$49,370	8.28
5	Spatial/Temp. Relations	$38,400	$500	$38,900	11.00
6	a) Atlas	$61,055		$61,055	11.03
	b) PC Package	$62,080	$5,500	$67,580	10.82
	c) Final Report	$56,490	$500	$56,990	10.50
	Work Station (IBM RS 6000 or Equivalent			$20,000	
	Laboratory of Climatology, ASU (12 months)			$47,170	
	State Climatologist			$30,000	
	Independent Advisory Group (consulting & travel) 12 trips			$27,000	
	Travel (NWS) 21 trips			$16,000	
	Travel-State Reps. & State Climatologists 35 trips			$25,000	
	Supplies (NWS)			$5,000	
	Data (NWS Obtaining Cost)			$5,000	
	Publication (Report & Atlas)			$16,000	
	TOTAL	$574,995	$17,000	$783,165	111.00

PROJECT TOTAL COST $783,165

SEMI-ARID PRECIPITATION FREQUENCY STUDY

Unsolicited Proposal
for the States of
Arizona, Utah, Nevada and New Mexico

July 1990
(Revised February 1991)

WATER MANAGEMENT INFORMATION DIVISION
OFFICE OF HYDROLOGY
NATIONAL WEATHER SERVICE
SILVER SPRING, MARYLAND

SEMI-ARID PRECIPITATION FREQUENCY STUDY

I. PROBLEM STATEMENT

Current precipitation frequency data as represented in NOAA Atlas 2 (1973) for the 11 western states has been questioned in a number of areas. The National Weather Service (NWS) intends to review available data from all sources (Federal, State, local, and private), consider current statistical practice and techniques, and provide an updated report covering the semi-arid states of Arizona, Nevada, New Mexico, Utah, southeastern California, and western Texas. The product would be available as an atlas and in digitized format for ease in hydrologic applications.

NOAA Atlas 2 was based on available data through the mid- to late 1960's. The period of record for hourly data was relatively short. Only 73 recording raingages for all 11 western states had records of more than 30 years. Regression techniques developed for these studies required extensive manual calculation of data. Relations for durations less than 6 hours were not well founded and durations longer than 24 hours are not available. Depth-area and depth-duration relations were based on studies for other parts of the country. A lack of data did not allow for extensive studies of the relation between terrain and precipitation. These are all topics that will be addressed in the proposed NWS study.

The NWS has a long history of experience and expertise in precipitation-frequency analyses and in this study intends to add to this background by including studies of the fundamental distributions and fitting procedures used in the past as well as those currently available. It is important to consider state of the art techniques in a study that will receive nationwide attention and application. An adjunct to the study will be the involvement of an Independent Advisory Group to review all aspects of the proposed study. The advisory team will be drawn from the private and public sector and include hydrological, statistical, and water resources disciplines.

II. RESEARCH OBJECTIVE

The purpose of this study is to determine annual and seasonal precipitation frequencies from 5 minutes to 10 days for 2 to 100 years. The study results will be published as a NWS report and made available also as a digital file.

The research will review and process all available rainfall data for the homogeneous region of Arizona, Nevada, New Mexico, Utah, southeastern California, and western Texas and utilize accepted statistical methods. It is recognized that the rainfall data as archived by the National Climatic Data Center (NCDC) may not be adequate to accomplish the objectives of this research. Therefore, local, State, and Federal networks that are not compiled by the NCDC, will be added to the NCDC data to define frequency relations, local variations, as well as to provide details with regard to depth-area, depth-duration variations, seasonal and terrain relations.

New statistical techniques for the development of frequency distributions and objective spatial analysis developed over the past 30 years will be evaluated and used for the new frequency relations. The extensive adoption of automated procedures by hydrologists, engineers, and others requires that the results of these efforts be made available in a machine compatible format. Therefore, an additional effort will be directed at producing a digital file that is adaptable to most users.

III. BACKGROUND

The first national precipitation-frequency atlas for durations up to 24 hours for the contiguous United States was prepared by Yarnell in 1935. Subsequently, this work was updated by the National Weather Service beginning in the 1950's. Currently, the NWS has ten reports which provide the standards for precipitation-frequency relations for the 50 states, Puerto Rico, and the Virgin Islands for durations from 5 minutes to 10 days. For some of these reports additional data has been collected for another 30 years.

The NWS recognized the need to review these publications. About two years ago the NWS began a pilot study of the precipitation-frequency relations in Pennsylvania and West Virginia with funding from the Soil Conservation Service. Some preliminary results are now available. The best available extreme-value distribution for precipitation up to the 1970's was the Gumbel extreme-value distribution using a Weibull fitting formula. Recent statistical advances have brought new techniques to test data and frequency distributions, as well as provided better fitting techniques. The preliminary results from Pennsylvania and West Virginia using these techniques indicate that the Generalized Extreme Value (GEV) distribution better describes the frequency distribution for precipitation than does the Gumbel. The Gumbel is a special case of the GEV distribution. Fitting techniques have improved over the years with the Method of Moments being used in the 1970's and the Probability Weighted Moments (PWM) and L-Moment fitting techniques being more recent developments. These new fitting techniques are better able to utilize the shorter periods of record which are often a major problem in meteorology and hydrology. In addition, the techniques are also useful in the quality-control of data. Objective analysis schemes are also being explored to analyze isolines and to develop relations between the topography and precipitation frequency.

IV. WORK PLAN:

The review and revision of precipitation frequency information in the semi-arid southwestern states of Arizona, Nevada, New Mexico, Utah, southeastern California, and western Texas involves the following specific tasks. Some of the tasks need to be worked in sequence because of dependence on results from earlier tasks, some can be considered concurrently. The time table included at the end of the task descriptions (page 13) provides an indication of how the tasks will be managed. A brief discussion of the budget is presented in Section VIII, followed by a breakdown of costs according to the various tasks and other charges.

TASK 1
a) Data Collection b) Quality Control

A. Background

Some 20 years or more of data have accumulated since the completion of NOAA Atlas 2. In addition many stations that were not considered in that publication because of short records, now have as much as 30-40 years of useful records available. Furthermore, unknown quantities of supplemental data exist as a result of networks and stations maintained by Federal, State, county and private agencies, and not archived in NCDC. The attempt will be made to obtain the precipitation data from the northern portions of Sonora, Mexico.

B. Analyses

Both daily and hourly data will be used, and where available 15-minute data will be collected for use in short-duration relations, as well as other data of 1 hour or less collected by the NWS or within special networks. Because of interest in times of special flooding as well as a need for maximum values, the data will be sorted by month.

An attempt will be made to determine the quantity of relevant data available and bring it together in a consistent data base. To this end, use will be made of the knowledge and capabilities of State Climatologists to determine what information exists and how and from whom it may be obtained.

Database will be organized into three groups:

1) NWS precipitation gages (recording and non recording) used in NOAA Atlas 2 and those that could be employed in this analysis,

2) non-NWS precipitation gages and records not used in NOAA Atlas 2 that have data of sufficient length to test the old maps and to use in a new analysis, and

3) precipitation gages (both NWS and non-NWS) with records too short (less than 15 years after 1970) to evaluate return periods, but which could be employed in the analysis of events of interest, and eventually will have archived data for future analyses.

Seasonal distribution of precipitation for all durations will be examined. This requires careful attention to the definition of seasons in the semi-arid region of the Southwest. Quite likely the traditional definition of seasons (summer, winter, fall, spring) may not be applicable. In the Southwest it may be more appropriate to define a monsoonal season, rather than a summer or warm season. The seasonal definition may also be different for various sections within the region.

The seasonal definition probably varies as a function of the duration of the events being investigated. For example short-duration convective storms of 6 hours or less most likely occur most frequently from May through October. However, storms with a duration of 10 days or more most likely occur from October through April. Thus, there may be some overlap of months depending upon the duration of the storms being investigated. Delineation of season must be accomplished early during the data processing period to ensure that the data to be used in the frequency analysis is properly archived in the beginning. These decisions will be made in concert with the NWS, State Climatologists, state participants, and the Independent Advisory Group.

Of considerable importance is the need for quality control of the collected data. Procedures will be applied to the automated routine used in processing the data that will search for unusual extremes and note both missing and accumulated precipitation periods. The degree of quality control that exists in these data is unknown and quite likely varies considerably between various sources. Even the data archived by the NCDC need to be searched for punching or other errors.

The effort to process these data into a useable data base is of major importance to the overall reliability of the final product. It is understandable, therefore that this portion of the study will be given deliberate attention, as well as adequate time allotted, to accomplish this goal.

C. Product

A data base of all-available precipitation data for stations in the semi-arid southwestern states and the immediate surroundings will be created by this task.

TASK 2
Frequency Distribution/Fitting Studies

A. Background

The NWS has provided many studies of precipitation frequency over a period of some 35 years, and almost all these studies have been based on the Gumbel distribution (Fisher-Tippett Type I) fitted by the Gumbel fitting procedure (Weibull Plotting positions). Through the last 20-30 years, much research has described other statistical distributions and fitting techniques, each with an application to a particular type of data or location.

B. Analysis

It is important that in a major review, such as proposed herein, consideration be given to these recent developments, and an attempt made to incorporate any improvements that are real and can be supported. This task will select from the extensive literature those distributions and fitting procedures that appear most applicable. Some of these are the Generalized Extreme Value (GEV), the Pearson III, Generalized Log-Normal, the Gamma, the Generalized Pareto, Generalized Logistic distributions, and the L-moment, method of moments, and other fitting procedures, as examples. Tests and comparisons will be made to evaluate the application of each to the data from the region of study.

Results from a pilot study to update the precipitation-frequency data in the Pennsylvania-West Virginia area have provided much insight into recent statistical techniques and many of the problems that can be expected in a study of the precipitation-frequency relations for a region or a state. Some of the conclusions are: 1) problems in the reduction of data have been recognized and improved software will be developed for future work; and 2) the new statistical techniques provide improved ways of handling outliers in the data; 3) procedures for the quality control of precipitation data have been identified; 4) L-moment statistics, which is an evolution of probability-weighted moments, will be used for future frequency studies; 5) techniques for selecting the frequency distribution which best fits the data for an area have been developed and tested using L-moment statistics and other techniques.

This task will draw on the expertise of the Independent Advisory Group, State Climatologist, and state participants to guide the NWS toward the best solution in this area. Thought needs to be given to the benefits/drawbacks involved in solutions that result in regional variations between selected distributions and fitting procedures. This consideration may require sample tests be made in other regions outside the southwest. In the event different distributions are accepted, a discussion of boundary differences will be needed. Inter-regional consistency is important, but sometimes this can be mitigated by judicious choice of regional boundaries (e.g., consistent with major drainage limits).

C. Product

The outcome of this task will be the selection of a frequency distribution and fitting technique best suited to the precipitation data to be used in this study region.

TASK 3
Short-Duration Relations

A. Background

Short-duration information (durations of less than 1 hour) is valuable in the design for small-area structures, such as, drains, culverts, collections, and other similar hydraulic structures. Presently, NOAA Atlas 2 provides ratios adapted from a national average for durations of less than 1 hour. Other preliminary work by Frederick and Miller (1979) and Arkell and Richards (1986) shows that the ratio of rainfall less than 1 hour is different in the West from that in the East (Frederick et al. 1977), and that these ratios likely vary throughout the West.

B. Analysis

It is necessary to develop relations between 1 hour and shorter durations. Only limited digitized data are available for this analysis. These data sources include: 1) 15 minute and shorter periods available from Fischer-Porter gages as part of the national network maintained by the NWS; 2) special short-duration data from NWS first-order weather stations for intense storms; 3) break-point data from special dense raingage networks maintained by the Agricultural Research Service; and 4) short-duration data captured and archived by a variety of other Federal agencies, and local and state governments.

When analyzing these data we must be careful to maintain the spatial continuity of the meteorology of the data sets. For example, data from east of the Rockies will be useful for those regions east of the Rockies, but would probably not be applicable to areas west of the Rockies. The major reasons for this are the difference in the moisture sources and the types of weather associated with the event. These homogeneous regions must be defined in the early part of the analysis. Special attention will also be paid to urban areas, if sufficient data exists, to determine if there are any differences in the intensity of rainfall in the downstorm direction.

Many of the storms will be due to convective activity. Another natural stratification of the data will be to determine if there are any differences in the temporal distribution of precipitation with height.

C. Product

The final products of these studies will be ratios or maps of ratios that can be applied to the 1-hour duration data to determine the frequency distribution of durations of less than 1 hour.

TASK 4

a) Algorithm/Data Plot (Algorithm Development/Application)

A. Background

For frequency calculations, not all portions of the semi-arid southwest are adequately represented by data. Therefore, it is important to develop algorithms or relations that are based on data-rich areas to be used in data-poor areas.

B. Analysis

Previous studies show that the geographical distribution of gaging stations varies significantly throughout the region. An objective technique is needed that will allow the analyst or the computer, to provide a consistent rule throughout. Investigation of precipitation-terrain relations will be made in data-rich areas to develop algorithms for use in those regions where there are little or no data. A series of topographic and/or meteorological variables are often selected to apply in such studies. These could include distance from moisture sources, seasonality, slope, elevation, height above an arbitrary level, distance from a barrier, etc., as examples. Other data that will be investigated are satellite climatologies providing added definitions about the distribution of precipitation and thunderstorms in data-poor regions.

This task will be coordinated with both the State Climatologists for their knowledge of local variations and anomalies, and the Independent Advisory Group for their experience and recommendations.

C. Product

The most important product in this task is the set of precipitation-terrain relations that apply in data-sparse regions.

b) Frequency Calculations and c) Algorithm Calculations

A. Background

Once the data base has been established in task number 1, and the various relations determined as in tasks number 2 to 4, the data will be processed to obtain various outputs.

B. Analysis

Precipitation frequency values for durations between 5 minutes and 10 days at return periods between 2 and 100 years will be calculated for all stations within and surrounding the semi-arid region. Results will be obtained both monthly and on a maximum annual basis. Consideration will be given in the digital process to establish routines that will allow bi-monthly or weekly products, if needed, to be computed. However these decisions must be made in the beginning, so data-processing costs do not become too expensive.

The results will be examined for inconsistencies, errors, or meteorological unreasonableness. An important part of the study is to provide information that makes sense and can be supported by meteorological experience and theory. Local judgment will be included before these results are confirmed. This is a final form of quality control.

C. Product

The product from this task will be a consistent set of precipitation frequency values and relations.

d) Final Adjustments (Frequency Relation)

A. Background

After all the frequency values are calculated, the spatial analysis of these values will begin. Algorithms will be used to develop relations between the precipitation frequency data and the underlying terrain. Further smoothing will be provided by regionalization of the frequency relations. This ensures that the frequency relations within a region are homogeneous and account for any unusual singular points in the data set and the underlying terrain.

B. Analysis

For selected durations and return periods (e.g., 2-yr 1-hr, 2-yr 24-hr, 2-yr 10-day and comparable 100-yr values), the calculated frequency values will be plotted and an objective spatial analysis program will be used to analyze the results. These analyses will be reviewed for internal consistency, known local effects, meteorological reasonableness, and to develop any supplemental hard copy analyses. The objective spatial analysis program will regionalize the data, providing a smoother final analysis that will account for the underlying terrain.

Seasonal relations can be developed for selected frequency/return periods either by month or by mid-season month, or seasonal average. Tests will be made to provide comparative information that will allow the best relation to be chosen. Comparisons will also be made to other indices, such as runoff.

C. Product

The product from these studies will be a set of frequency maps at least for the annual maximum precipitation for durations probably from 1 hour to 10 days, for various return frequencies up to 100 years. These frequency maps will provide the detail of the effects of terrain. Relations will be given to relate the 1-hour data to smaller durations for general storms, and either a set of maps or relations in table form will be given to relate the annual maximum values to seasons. As part of this task, the method of presentation will be examined to determine if alternate methods of presentation of the frequency relations are possible. Final decisions will be made after consulting with the Independent Advisory Group, the State Climatologists, and the states involved with the project.

TASK 5

Spatial/Temporal Relations (Depth-Duration and Depth-Area Studies)

A. Background

These studies will be divided into two parts. The first part will examine depth-durations or mass curves for durations of 1 hour or less and depth-area curves for area sizes of 100 $miles^2$ or less. Such relations provide information for use over small areas and for short durations, and concentrate on local thunderstorms. The focus of the second part of the study will be on depth-duration curves from 1 hour through 10 days, and the depth-area results will explore areas of 500 $miles^2$ or greater. These results will give details about the longer duration and more generalized storms. This data base will develop information from convective storms, tropical storms and general storms.

B. Analysis

The depth-duration studies for small-area storms will concentrate on convective storms to identify the maximum intensity of rainfall in periods of 1 hour or less. A family of meteorologically consistent mass curves will be prepared. The data base will contain rainfall for periods of less than 1 hour. Arkell and Richards (1986) and Frederick and Miller (1979) have shown that there are different subregions within the area. As a result, special attention must be paid to define the homogenous subregions. If sufficient data exists, urban areas will be examined to determine if there are any differences in the intensity of rainfall downstorm of the city. Another natural stratification of the data will be to determine if there are any differences in the temporal distribution of precipitation with elevation.

Depth-area relation for areas up to 100 $miles^2$ are also important in the design of small area hydraulic structures. The data from the dense raingage networks will be utilized to develop depth-area curves for durations from 5-or-15 minutes, if possible, to 24 hours for areas up to 100 $miles^2$.

In addition to short-duration, small-area relations, it is important that depth-duration and depth-area curves be established for duration from 1 hour to 10 days, and for areas greater than 500 $miles^2$. The data base for this analysis will be derived from the extreme events identified in the data processing procedure. This will include data from the NWS national network, and data from the various dense raingage networks and the individual stations of various Federal, state, local, and private groups.

The depth-duration or temporal analysis of the data will follow the scheme developed by Huff (1967) and Huff and Vogel (1976) which identifies families of mass curves. These families of curves provides a range of meteorologically possible non-dimensional mass curves, showing the median and the extreme possible mass curves that can occur. Durations for this analysis will range from 1 hour up to 10 days. Consequently, a series of non-dimensional mass curves will be assembled that will encompass this wide variation of durations. The analysis will provide extreme point estimates and consider areal-averaged mass curves. For this semi-arid area of the United States there will be differences between convective storms and general storms, the data will be stratified to identify these differences. It will also be necessary to identify any regional variations and differences with elevation.

C. Products

The final products of these small-area, short-duration studies will be relations that can be plotted and smoothed for use in small-area design problems.

Area-depth curves will also be derived for areas greater than 500 miles^2. If possible, a family of curves will be developed to show the extreme area-depths that are possible. These curves will be stratified by duration and area size to maximize the utility for design purposes. A smoothed set of curves will also be generated for generalized results. Regional and elevation variations will be identified, and curves will be generated to distinguish between general storms, tropical storms and convective storms where such stratifications are possible and meteorologically reasonable.

Families of mass curves and area-depth curves will be generated and displayed as a function of the duration and area size. If the data permits, the analysis will also be displayed by storm type and elevation.

TASK 6

Deliverables (a) Atlas (b) PC Package (c) Final Report

This study will produce a final report that will be published in one of the NOAA series with initial distribution according to a mailing list developed by the NWS and the participants. Further distribution will be made through NTIS, and from a reserve supply maintained by the NWS.

The report will contain detailed discussion of the data and procedures used to obtain precipitation frequency values along with background and information about studies made to arrive at these conclusions. Maps of analyzed results will be provided along with graphical relations needed to obtain intermediate values. Seasonal variation, depth-area distribution, and the temporal distribution of rainfall in extreme storms will be discussed, and graphs and figures appropriate to defining these results for the region will be given.

In addition, and unique to this study, a digital file will be created so that the results at any location in the region and the data bases can be obtained. It is intended that the digital file will be a practical solution to most field users needs, particularly those who make continual reference to these data, or wish to incorporate these results into some larger computational routine.

Note: The digital file will be in the GIS form.

References

Arkell, R.A. and F. Richards, 1986. Short Duration Rainfall Relations for the Western United States. Preprints of the Conference on Climate and Water Management - A Critical Era, August 4-7, 1986, Asheville, N.C., by the American Meteorological Society, Boston, MA.

Frederick, R.H., and J.F. Miller, 1979. Short Duration Rainfall Frequency Relations for California. Preprints of the 3rd Conference on Hydrometeorology, August 20-24, 1979. Bogota, Columbia, by the American Meteorological Society, Boston, MA.

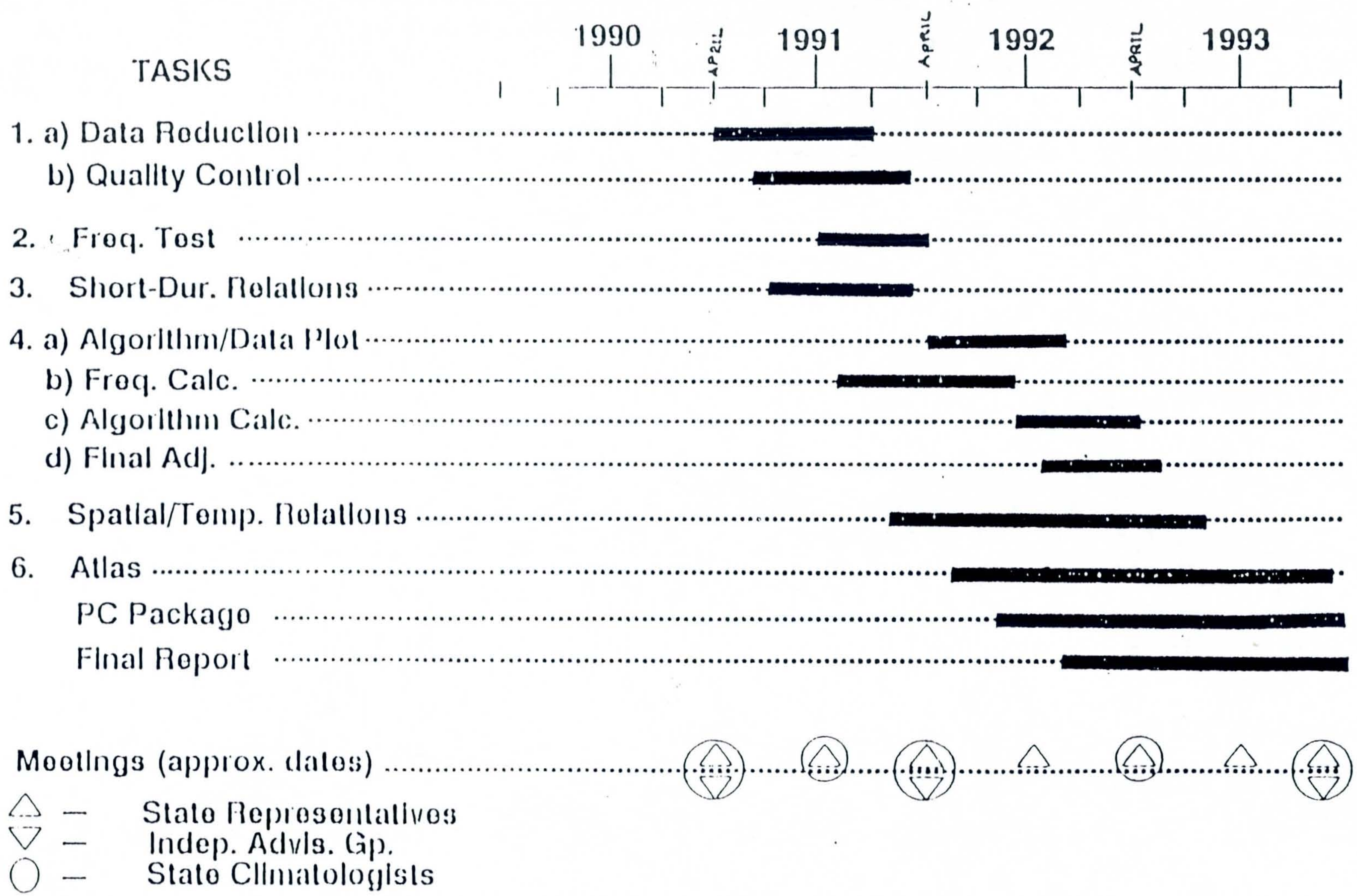
Frederick, R.H., V.A. Myers and E.P. Auciello, 1977. Five-to-60-Minute Precipitation Frequency for the Eastern and Central United States, NOAA Technical Memo. NWS HYDRO-35, National Weather Service, Silver Spring, MD.

Huff, F.A. and J.L. Vogel, 1976. Hydrometeorology of Heavy Rainstorms in Chicago and Northeastern Illinois, Phase I - Historical Studies, Illinois State Water Survey Report of Investigation 82, 63 pp.

Huff, F.A., 1967. Time Distribution of Rainfall in Heavy Storms, Water Resources Research, 3, 1007-1019.

NATIONAL WEATHER SERVICES
SEMI-ARID PRECIPITATION FREQUENCY STUDY

PROJECT TIME TABLE



V. REPORTS AND MEETINGS

A. Reports

During the course of this study, progress reports will be provided by the contractor on a quarterly basis. These reports will include brief summaries of studies under development, comments on conclusions reached, problems encountered and changes that may be necessitated in the initial schedule of work. The progress reports (working summaries of the tasks) will be prepared and submitted to all participants and advisors prior to each meeting.

A draft document of the entire study will be prepared by the contractor for review by the various identified parties, as well as selected outside interests. Comments from this review will be acted upon to form the final report.

B. Meetings

A schedule of meetings has been proposed that calls for general meetings to include all participants and for progress meetings that apply to more limited interests. It is proposed that general meetings be held in the study region, 1) at the onset of the project, 2) after the first year, and 3) during the writing of the draft report. The progress meetings will be held at approximately six-month intervals. These meetings will be held at either a fixed site or on a rotating site basis within the region. At these meetings the contractor will meet with the state representatives and others, as appropriate, to discuss the progress of the study and consider questions or problems important to the individual states.

Similarly, progress review meetings will be held in Washington, D.C. for Federal sponsors.

The meeting schedule has been included in the time table (page 14) and identifies the respective groups expected to attend.

VI. SUPPORT GROUPS

A. Local Hydrologic Representatives

State, county and other offices providing financial support to this study will be represented at all technical meetings called by the contractor (NWS). It is recommended that each such office appoint a technical representative who will have the following responsibilities:

- o Attend all meetings called to discuss or review the precipitation frequency study.

- o Provide their individual state DOT officials with updated status reports on progress of study.

- o Bring to various meetings comments, questions, or information from their individual state DOT offices regarding this study.

- o Be able to technically understand the procedures and processes being applied in the study, as well as the methods used to evaluate different results.

- o Assist in the review of the various products and add local knowledge to these products.

B. State Climatologists

Official NWS-type data will be obtained through information available at the NCDC in Asheville, North Carolina. Since data collection and quality control of the data is an important part of this study; it is anticipated that it will be necessary to include state climatologists from the major states being studies in our meetings. It may also be useful to include representative(s) from the Western Region Climate Center to these meetings as well. The role of these individuals will be to aid in collecting and organizing data from numerous private, local, and state networks for which there are no routine collection and processing centers. Monies have been set aside in the budget to offset some of these efforts. Responsibilities in this area include:

- o Survey, locate, collect, and standardize available long-term precipitation data from sources other than official NWS stations within their state.

- o Provide some degree of quality control or assignment of quality to the individual data sources.

- o Attend meetings called to discuss this study.

- o Provide information and guidance to contractor regarding known local topographical anomalies affecting precipitation.

- o Review draft products and input knowledge of local features in their area.

C. Independent Advisory Group

In order to assure that the study is using the most up-to-date technologies, it is recommended that an independent advisory group be appointed to review all aspects of the technical approach proposed for this study. The independent advisory group should be composed of individuals representing the various major concerns used in the study, e.g., hydrology, statistics, and meteorology/climatology. Three to four experts in these fields will be selected by the contractor to comprise the group with the following responsibilities:

- o Attend all meetings called to discuss the precipitation frequency study. Contractor will interact with advisory group throughout the course of study to determine strategies, preferred approaches, and confirm results.

- o Provide their individual technical expertise with regard to aspects of the study to assure a proper course of action.

- o Participate as a reviewer of draft report at completion of this stage of study.

VII. PROGRAM MANAGEMENT

Mr. John Vogel, Chief of the Hydrometeorological Branch of the Water Management Information Division (WMID), Office of Hydrology, National Weather Service, will be the program manager for this study. Mr. Vogel and Mr. Marshall Hansen, Division Chief of WMID, will be responsible for guiding all technical efforts of the NWS team. This team is responsible for completion of the preliminary and final reports and for calling all meetings. Mr. Vogel is further responsible for enlisting the members of the Independent Advisory Group.

VIII. BUDGET STATEMENT

The total cost of this 3-year project is $558,850. Commitments have already been obtained from the Corps of Engineers, U.S. Department of Agriculture (Soil Conservation Service), FEMA, and the National Weather Service to finance the Federal portion of this work. Additional monetary commitments are being sought and are expected to be forthcoming. In all, it is anticipated that the costs will be shared almost equally between Federal and state funds.

Tasks 1 through 6 have been divided to show the personnel and computer-related charges. These total $376,900. Miscellaneous charges include a special allocation to the Laboratory of Climatology at Arizona State University to develop data bases for many of the special networks of precipitation data in Arizona and in Sonora, Mexico; charges by state climatologists to develop other precipitation data bases within their states; and the consulting fees and travel for the Independent Advisory Group. Other charges include the supplies, data acquisition charges, publication charges, and travel. The travel charges are further divided to show the anticipated travel costs and the total number of trips for the state representatives, state climatologists, and the National Weather Service. Most of the travel will be for attendances at the semi-annual progress meetings. At these meetings the various groups will be providing advice and input to the National Weather Service for the semi-arid region frequency study. It is anticipated that these meetings will last 1 to 2 days. Some of the meetings may be longer; especially at the beginning of the project, when many decisions need to be made, and at the end of the project, when final products and the final report are being prepared and discussed.

This proposal applies primarily to the states of Arizona, Nevada, New Mexico, and Utah. Although Arizona appears prepared to initiate the funding for this study, it is expected the remaining states will provide funds in subsequent years.

NATIONAL WEATHER SERVICE
SEMI-ARID PRECIPITATION FREQUENCY STUDY

DETAILED BUDGET

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5 Spatial/Temp. Relations	$13,700	$500	$14,200	3.92
6 a) Atlas	$31,855		$31,855	5.74
b) PC Package	$38,250	$5,500	$43,750	6.67
c) Final Report	$35,460	$500	$35,960	6.59
	376,900		393,650	
Laboratory of Climatology, ASU (12 months)			$36.000	
State Climatologist			$30.000	
Independent Advisory Group (consulting & travel) 12 trips			$27.900	
Travel (NWS) 21 trips			$16.800	
Travel-State Reps. & State Climatologists 35 trips			$24.500	
Supplies (NWS)			$5.000	
Data (NWS Obtaining Cost)			$5,000	
Publication (Report & Atlas)			$20.000	
			$165,200	
TOTAL	$376,900	$16,750	$542,100	60.10

PROJECT TOTAL COST $558,850

5/8/91

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

April 15, 1992 W/OH11:JLV

Ms. Carol Davis
Hydrology Division
Flood Control District
of Maricopa
2801 West Durango
Phoenix, AZ 85009

Dear Carol,

As I promised, I am forwarding maps and listings of daily and hourly precipitation stations in and within 75 miles of Maricopa County. The listings provide the station name and number assigned by the National Climatic Data Center, as well as the latitude, longitude, elevation and the period of record (POR).

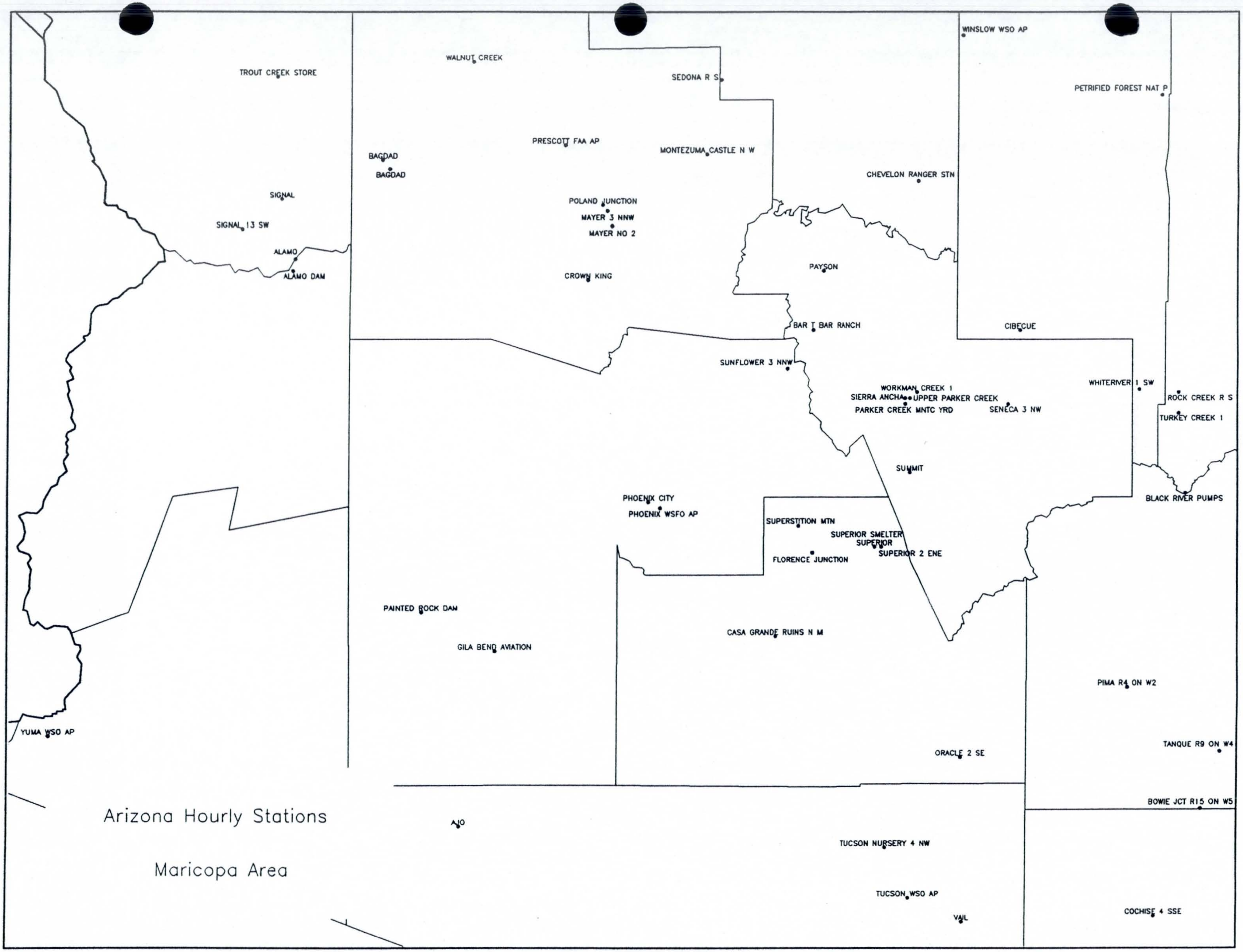
Generally, we require stations with a period of record that covers at least 15 years. However, the period of record can be less for higher elevations or stations that are located in regions which are data sparse. In those circumstances we may not be able to use the data directly, but the data will provide guidance that might not be available in any other way. After a number of storms are identified for processing of area-depth and depth-duration data, we will be obtaining additional data for specific storms and will use all the data we can find.

If you have any questions, please feel free to call me on (301) 713-1669.

Sincerely,

John L. Vogel, Chief
Hydrometeorological Branch

Enclosures


Arizona Hourly Stations
Maricopa Area
TROUT CREEK STORE
WALNUT CREEK
SEDONA R S
WINSLOW WSO AP
PETRIFIED FOREST NAT P
BAGDAD
BAGDAD
PRESCOTT FAA AP
MONTEZUMA CASTLE N W
CHEVELON RANGER STN
SIGNAL
SIGNAL 13 SW
POLAND JUNCTION
MAYER 3 NNW
MAYER NO 2
ALAMO
ALAMO DAM
PAYSON
CROWN KING
BAR T BAR RANCH
CIBECUE
SUNFLOWER 3 NNW
WORKMAN CREEK 1
SIERRA ANCHA
UPPER PARKER CREEK
PARKER CREEK MNTC YRD
SENECA 3 NW
WHITERIVER 1 SW
ROCK CREEK R S
TURKEY CREEK 1
SUMMIT
PHOENIX CITY
PHOENIX WSFO AP
BLACK RIVER PUMPS
SUPERSTITION MTN
SUPERIOR SMELTER
SUPERIOR
SUPERIOR 2 ENE
FLORENCE JUNCTION
PAINTED ROCK DAM
CASA GRANDE RUINS N M
GILA BEND AVIATION
PIMA R4 ON W2
YUMA WSO AP
ORACLE 2 SE
TANQUE R9 ON W4
BOWIE JCT R15 ON W5
AJO
TUCSON NURSERY 4 NW
TUCSON WSO AP
VAIL
COCHISE 4 SSE

Arizona Hourly Stations within ~75 miles of Maricopa County

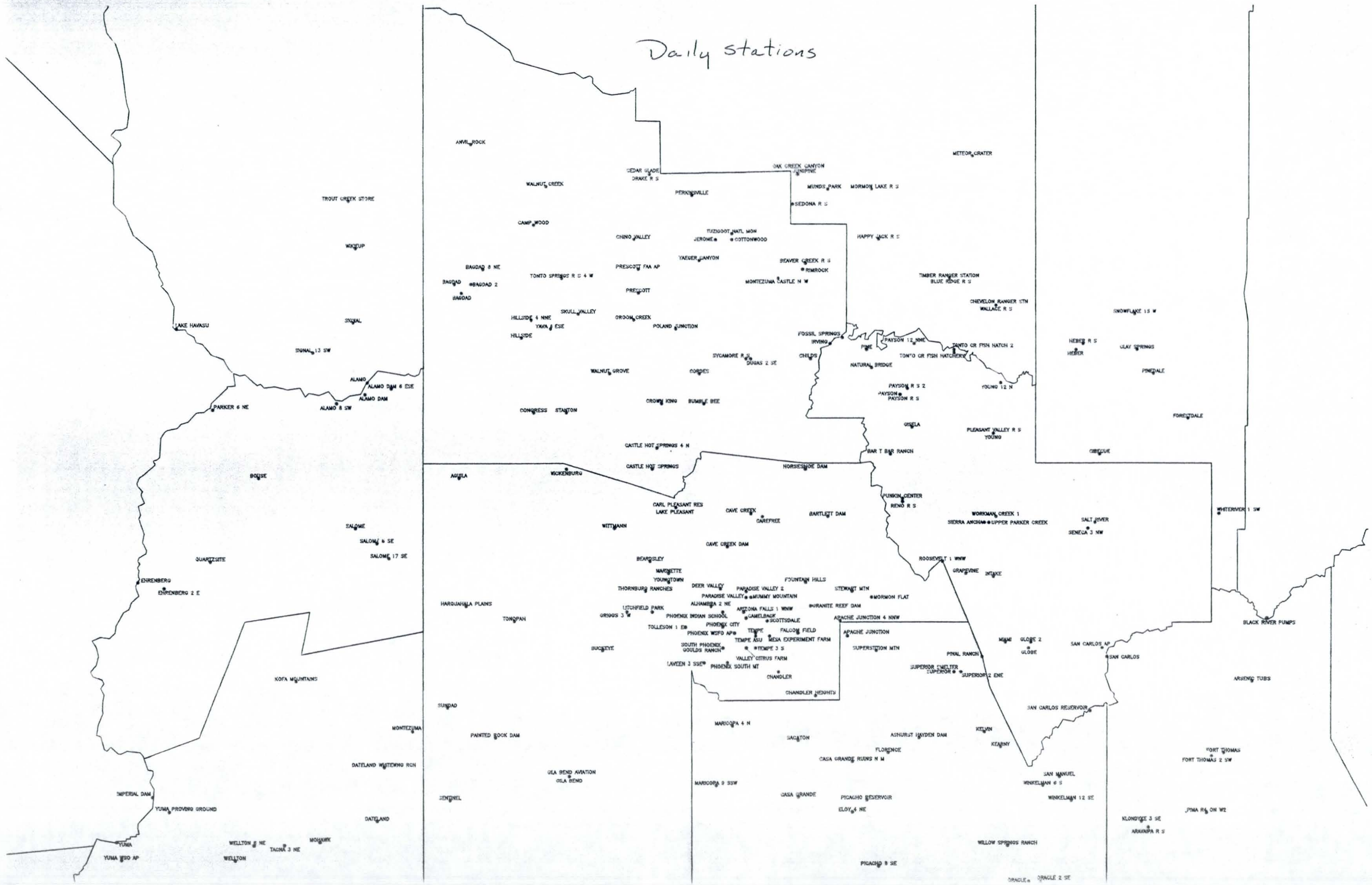
Record#	NAME	STATION	LAT	LON	ELEV	POR
1	AJO	80	32.370000	-112.870000	1800	7/1948-12/1988
2	ALAMO	96	34.270000	-113.570000	1060	7/1948- 3/1965
3	ALAMO DAM	100	34.230000	-113.580000	1290	3/1965-12/1988
4	BAGDAD	582	34.600000	-113.200000	3200	7/1948-11/1949
5	BAGDAD	586	34.570000	-113.170000	3710	12/1949-11/1969
6	BAR T BAR RANCH	625	34.030000	-111.370000	3100	12/1976- 2/1980
7	BLACK RIVER PUMPS	808	33.480000	-109.770000	6040	7/1948-12/1988
8	BOWIE JCT R15 ON W5	966	32.430000	-109.700000	4720	7/1948- 2/1967
9	CASA GRANDE RUINS N M	1314	33.000000	-111.530000	1420	7/1948-12/1988
10	CHEVELON RANGER STN	1574	34.530000	-110.920000	7010	12/1981-12/1988
11	CIBECUE	1749	34.030000	-110.480000	5050	6/1980-12/1988
12	COCHISE 4 SSE	1870	32.070000	-109.900000	4180	7/1948-12/1988
13	CROWN KING	2329	34.200000	-112.330000	5920	6/1980-12/1988
14	FLORENCE JUNCTION	3035	33.280000	-111.370000	1680	1/1968- 9/1982
15	GILA BEND AVIATION	3398	32.950000	-112.720000	720	7/1948- 9/1951
16	MAYER 3 NNW	5325	34.430000	-112.250000	4640	3/1969-11/1986
17	MAYER NO 2	5344	34.380000	-112.230000	340	1/1986-12/1988
18	MONTEZUMA CASTLE N W	5635	34.620000	-111.830000	3180	7/1979-12/1988
19	ORACLE 2 SE	6119	32.600000	-110.730000	4510	2/1950-12/1988
20	PAINTED ROCK DAM	6194	33.080000	-113.030000	550	1/1962-12/1988
21	PARKER CREEK MNTC YRD	6260	33.780000	-110.970000	4990	6/1972-12/1975
22	PAYSON	6323	34.230000	-111.330000	4910	3/1949-12/1988
23	PETRIFIED FOREST NAT P	6468	34.820000	-109.880000	5450	7/1948-12/1988
24	PHOENIX WSFO AP	6481	33.430000	-112.020000	1110	7/1948-12/1988
25	PHOENIX CITY	6486	33.450000	-112.070000	1080	7/1948- 8/1963
26	PIMA R4 ON W2	6546	32.830000	-110.020000	3770	7/1948- 2/1967
27	POLAND JUNCTION	6676	34.450000	-112.270000	4900	7/1948- 3/1969
28	PRESCOTT FAA AP	6801	34.650000	-112.430000	5020	7/1948-11/1969
29	ROCK CREEK R S	7210	33.820000	-109.800000	3630	6/1955- 3/1966
30	SEDONA R S	7708	34.870000	-111.770000	4220	4/1973-12/1988
31	SENECA 3 NW	7741	33.780000	-110.530000	4920	7/1948-11/1965
32	SIERRA ANCHA	7876	33.800000	-110.970000	5100	1/1976-12/1988
33	SIGNAL	7884	34.470000	-113.630000	1520	7/1948- 6/1952
34	SIGNAL 13 SW	7888	34.370000	-113.800000	2510	6/1952- 7/1961
35	SUMMIT	8264	33.550000	-110.950000	3650	10/1951- 5/1977
36	SUNFLOWER 3 NNW	8273	33.900000	-111.480000	3720	7/1980-12/1988
37	SUPERIOR	8348	33.300000	-111.100000	3000	6/1959-10/1978
38	SUPERIOR 2 ENE	8349	33.300000	-111.070000	4160	10/1978-12/1988
39	SUPERIOR SMELTER	8351	33.300000	-111.100000	2790	9/1948- 2/1958
40	SUPERSTITION MTN	8356	33.370000	-111.430000	1960	7/1948- 1/1968
41	TANQUE R9 ON W4	8409	32.620000	-109.620000	3560	7/1948- 2/1967
42	TROUT CREEK STORE	8762	34.880000	-113.650000	2850	7/1948-11/1969
43	TUCSON NURSERY 4 NW	8810	32.300000	-111.050000	2250	7/1948- 2/1965
44	TUCSON WSO AP	8820	32.130000	-110.950000	2580	7/1948-12/1988
45	TURKEY CREEK 1	8875	33.750000	-109.800000	6750	6/1955- 3/1966
46	UPPER PARKER CREEK	8940	33.800000	-110.950000	5500	7/1948- 3/1972
47	VAIL	8995	32.050000	-110.720000	3230	9/1977-12/1988
48	WALNUT CREEK	9158	34.930000	-112.820000	5090	7/1979-12/1988
49	WHITERIVER 1 SW	9271	33.830000	-109.970000	5120	7/1948-12/1988
50	WINSLOW WSO AP	9439	35.020000	-110.730000	4890	7/1948-12/1988
51	WORKMAN CREEK 1	9534	33.820000	-110.920000	6970	7/1948- 2/1986
52	YUMA WSO AP	9660	32.670000	-114.600000	210	9/1948-12/1988

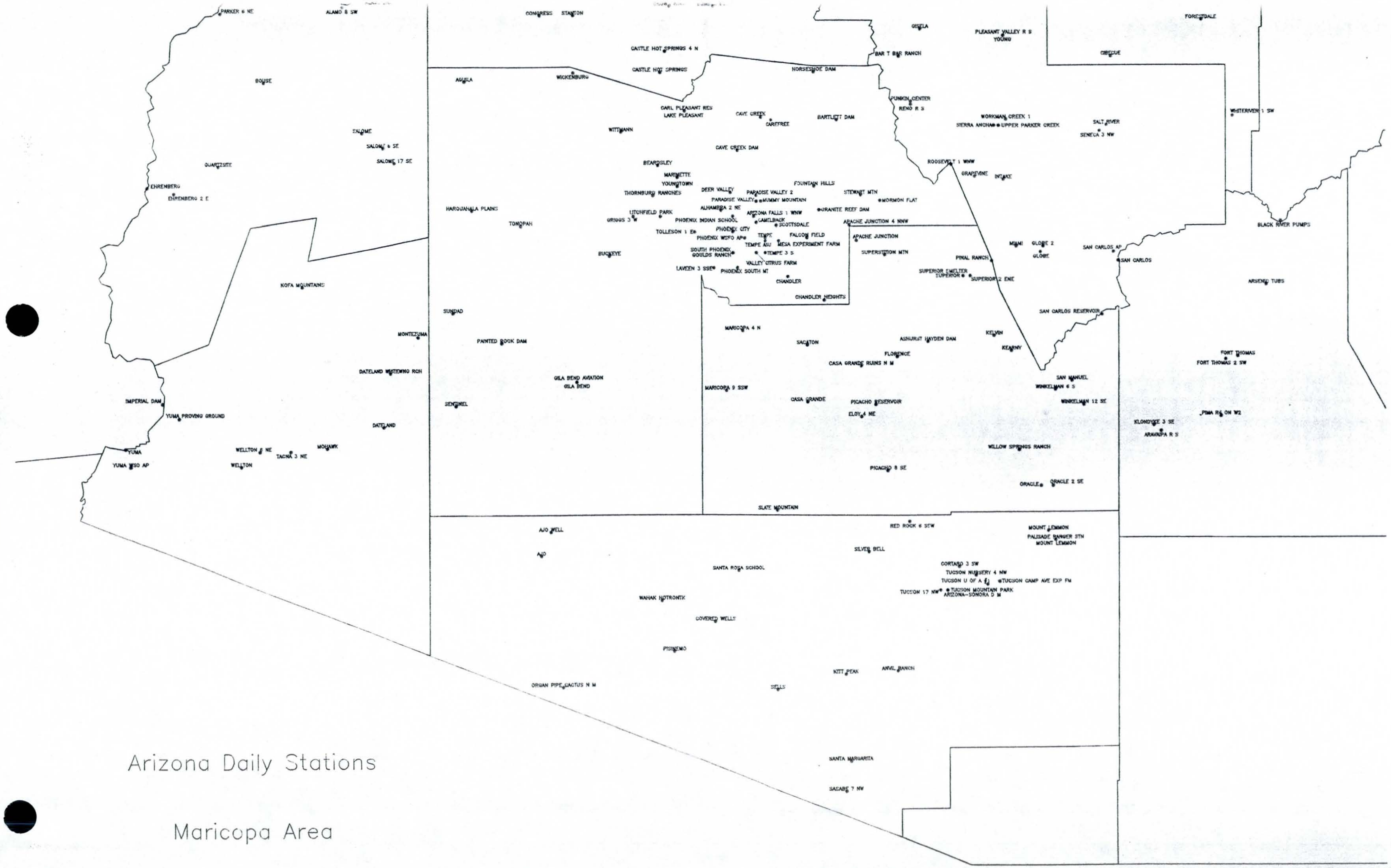
Arizona Daily Stations within 75 miles of Maricopa county

Record#	NAME	STATION	LAT	LON	ELEV	POR
1	AGUILA	60	33.950000	-113.180000	2170	5/1924-12/1986
2	AJO	80	32.370000	-112.870000	1800	5/1914-12/1988
3	AJO WELL	88	32.450000	-112.830000	1430	7/1948- 4/1975
4	ALAMO	96	34.270000	-113.570000	1060	7/1948- 3/1951
5	ALAMO 8 SW	97	34.200000	-113.700000	950	2/1957- 7/1960
6	ALAMO DAM 6 ESE	99	34.250000	-113.470000	1480	2/1962- 9/1974
7	ALAMO DAM	100	34.230000	-113.580000	1290	7/1975-12/1986
8	ALHAMBRA 2 NE	104	33.520000	-112.120000	1140	7/1948- 9/1976
9	ANVIL RANCH	287	31.980000	-111.380000	2750	7/1948-12/1988
10	ANVIL ROCK	291	35.070000	-113.130000	5260	7/1955-11/1956
11	APACHE JUNCTION	306	33.420000	-111.550000	1720	9/1962-12/1979
12	APACHE JUNCTION 4 NNW	307	33.470000	-111.580000	1890	4/1965- 4/1969
13	ARAVAIPA R S	344	32.780000	-110.270000	3670	1/1952- 8/1953
14	ARIZONA FALLS 1 WNW	406	33.500000	-111.980000	1250	7/1963- 2/1968
15	ARIZONA-SONORA D M	415	32.250000	-111.170000	2820	1/1962- 6/1975
16	ARSENIC TUBS	433	33.270000	-109.830000	4700	7/1948-12/1951
17	ASHURST HAYDEN DAM	498	33.080000	-111.250000	1640	1/1956-12/1988
18	BAGDAD	582	34.600000	-113.200000	3200	7/1948-11/1949
19	BAGDAD 2	584	34.600000	-113.130000	4120	9/1978- 6/1986
20	BAGDAD	586	34.570000	-113.170000	3710	5/1925-12/1988
21	BAGDAD 8 NE	590	34.650000	-113.080000	4240	4/1950- 4/1975
22	BAR T BAR RANCH	625	34.030000	-111.370000	3100	1/1952-11/1979
23	BARTLETT DAM	632	33.820000	-111.630000	1650	9/1939-12/1988
24	BEARDSLEY	660	33.670000	-112.380000	1270	1/1950- 3/1978
25	BEAVER CREEK R S	670	34.670000	-111.720000	3820	2/1957-12/1986
26	BLACK RIVER PUMPS	808	33.480000	-109.770000	6040	7/1948-12/1988
27	BLUE RIDGE R S	871	34.620000	-111.120000	6880	7/1967-12/1986
28	BOUSE	949	33.950000	-114.030000	930	1/1952-12/1988
29	BUCKEYE	1026	33.370000	-112.580000	870	3/1893-12/1988
30	BUMBLE BEE	1059	34.200000	-112.150000	2500	12/1952- 9/1979
31	CAMELBACK	1161	33.480000	-111.970000	1250	7/1948- 6/1963
32	CAMP WOOD	1216	34.800000	-112.870000	5710	7/1948-10/1979
33	CAREFREE	1282	33.820000	-111.900000	2530	6/1962-12/1986
34	CARL PLEASANT RES	1295	33.850000	-112.270000	1600	11/1949-12/1958
35	CASA GRANDE	1306	32.880000	-111.750000	1400	6/1898-12/1988
36	CASA GRANDE RUINS N M	1314	33.000000	-111.530000	1420	3/1906-12/1988
37	CASTLE HOT SPRINGS	1353	33.980000	-112.370000	1990	2/1959-12/1988
38	CASTLE HOT SPRINGS 4 N	1356	34.050000	-112.350000	2800	6/1949- 7/1958
39	CAVE CREEK	1361	33.830000	-111.950000	2120	3/1950- 9/1961
40	CAVE CREEK DAM	1365	33.720000	-112.050000	1670	11/1949- 2/1969
41	CEDAR GLADE	1419	34.970000	-112.380000	4650	2/1915- 1/1954
42	CHANDLER	1511	33.300000	-111.830000	1220	7/1948-11/1980
43	CHANDLER HEIGHTS	1514	33.220000	-111.680000	1430	7/1948-12/1988
44	CHEVELON RANGER STN	1574	34.530000	-110.920000	7010	5/1959-12/1988
45	CHILDS	1614	34.350000	-111.700000	2650	9/1915-12/1988
46	CHINO VALLEY	1654	34.750000	-112.450000	4750	7/1948-12/1988
47	CIBECUE	1749	34.030000	-110.480000	5050	6/1927- 1/1979
48	CLAY SPRINGS	1760	34.380000	-110.320000	6320	10/1971- 9/1987
49	CONGRESS	2020	34.170000	-112.870000	3020	2/1970- 5/1980
50	CORDES	2109	34.300000	-112.170000	3770	7/1948-12/1988
51	CORTARO 3 SW	2159	32.330000	-111.120000	2270	7/1948- 9/1976
52	COTTONWOOD	2193	34.750000	-112.030000	3380	4/1949- 6/1977
53	COVERED WELLS	2216	32.150000	-112.150000	2620	2/1956-12/1963
54	CROWN KING	2329	34.200000	-112.330000	5920	12/1914-12/1988
55	DATELAND	2430	32.800000	-113.530000	450	4/1952-10/1968
56	DATELAND WHITEWNG RCH	2434	32.980000	-113.500000	550	6/1972-12/1988
57	DEER VALLEY	2462	33.580000	-112.080000	1260	1/1950- 1/1985
58	DRAKE R S	2705	34.970000	-112.380000	4650	2/1954- 4/1962
59	DUGAS 2 SE	2742	34.350000	-111.950000	4040	2/1960-12/1972
60	EHRENBERG	2787	33.600000	-114.530000	320	7/1948- 1/1977
61	EHRENBERG 2 E	2790	33.580000	-114.420000	470	2/1977-12/1986
62	ELOY 4 NE	2807	32.830000	-111.530000	1550	5/1951-12/1988
63	FALCON FIELD	2927	33.430000	-111.750000	1320	7/1948- 5/1976
64	FLORENCE	3027	33.030000	-111.380000	1510	12/1892-12/1988
65	FORESTDALE	3082	34.150000	-110.100000	6100	7/1948- 5/1971
66	FORT THOMAS	3144	33.030000	-109.950000	2680	12/1958- 5/1966
67	FORT THOMAS 2 SW	3150	33.020000	-110.000000	2800	6/1966-12/1988
68	FOSSIL SPRINGS	3185	34.420000	-111.570000	4270	1/1951-10/1970
69	FOUNTAIN HILLS	3190	33.600000	-111.720000	1580	10/1979-12/1988
70	GILA BEND	3393	32.950000	-112.720000	740	12/1892-12/1988
71	GILA BEND AVIATION	3398	32.950000	-112.720000	720	7/1948-12/1966
72	GISELA	3448	34.120000	-111.280000	2900	4/1895-12/1988
73	GLOBE	3498	33.380000	-110.780000	3550	1/1894- 6/1975
74	GLOBE 2	3500	33.400000	-110.770000	3710	8/1975- 2/1981
75	GLOBE 2	3505	33.400000	-110.770000	3710	3/1981-12/1988
76	GOULDS RANCH	3573	33.380000	-112.070000	1200	1/1915- 8/1960
77	GRANITE REEF DAM	3621	33.520000	-111.700000	1320	1/1893- 9/1979
78	GRAPEVINE	3643	33.630000	-111.050000	2220	7/1948-12/1950

79	GRIGGS 3 W	3702	33.500000	-112.480000	1160	1/1950-12/1988
80	GROOM CREEK	3713	34.480000	-112.450000	6100	7/1948- 4/1976
81	HAPPY JACK R S	3828	34.750000	-111.420000	7480	5/1969-12/1988
82	HARQUAHALA PLAINS	3852	33.520000	-113.150000	1190	4/1952-12/1979
83	HEBER	3958	34.380000	-110.580000	6500	7/1948- 7/1950
84	HEBER R S	3961	34.400000	-110.550000	6590	8/1950-12/1988
85	HILLSIDE	4049	34.420000	-112.920000	3850	7/1948-12/1954
86	HILLSIDE 4 NNE	4053	34.480000	-112.880000	3320	5/1899-12/1988
87	HORSESHOE DAM	4182	33.980000	-111.720000	2020	7/1948-12/1988
88	IMPERIAL DAM	4299	32.880000	-114.470000	170	7/1948- 8/1949
89	INTAKE	4345	33.620000	-110.930000	2220	7/1906- 4/1952
90	IRVING	4391	34.400000	-111.620000	3800	1/1951-12/1988
91	JEROME	4453	34.750000	-112.100000	4950	9/1897-12/1900
92	JUNIPINE	4508	34.970000	-111.750000	5130	7/1948- 6/1982
93	KEARNY	4590	33.050000	-110.900000	1850	6/1984-12/1988
94	KELVIN	4594	33.100000	-110.970000	1850	7/1948-11/1983
95	KITT PEAK	4675	31.970000	-111.600000	6800	9/1960-12/1988
96	KLONDYKE 3 SE	4698	32.800000	-110.300000	3610	9/1953- 4/1978
97	KOFA MOUNTAINS	4702	33.270000	-113.870000	1780	5/1952-12/1988
98	LAKE HAVASU	4759	34.450000	-114.370000	480	9/1967-12/1988
99	LAKE PLEASANT	4770	33.850000	-112.270000	1600	1/1959-12/1977
100	LAVEEN 3 SSE	4829	33.330000	-112.150000	1120	7/1948-12/1988
101	LITCHFIELD PARK	4977	33.500000	-112.370000	1030	8/1917-12/1988
102	MARICOPA 4 N	5270	33.120000	-112.030000	1160	2/1960-12/1988
103	MARICOPA 9 SSW	5274	32.920000	-112.100000	1400	6/1898-12/1956
104	MARINETTE	5282	33.630000	-112.300000	1150	7/1913- 9/1964
105	MESA EXPERIMENT FARM	5467	33.420000	-111.870000	1230	3/1896-12/1988
106	METEOR CRATER	5494	35.030000	-111.020000	5660	3/1962- 1/1967
107	MIAMI	5512	33.400000	-110.880000	3560	2/1914-12/1988
108	MOHAWK	5627	32.730000	-113.770000	540	7/1900- 5/1951
109	MONTEZUMA	5633	33.100000	-113.380000	740	2/1959- 7/1963
110	MONTEZUMA CASTLE N M	5635	34.620000	-111.830000	3180	10/1938-12/1988
111	MORMON FLAT	5700	33.550000	-111.450000	1720	6/1925-12/1988
112	MORMON LAKE R S	5708	34.920000	-111.450000	7180	7/1948- 7/1968
113	MOUNT LEMMON	5732	32.450000	-110.750000	7790	9/1958- 3/1988
114	MOUNT LEMMON	5733	32.420000	-110.720000	7690	3/1950-12/1956
115	MUMMY MOUNTAIN	5765	33.550000	-111.950000	1420	12/1969- 1/1973
116	MUNDS PARK	5780	34.920000	-111.630000	6470	6/1986-12/1988
117	NATURAL BRIDGE	5825	34.320000	-111.450000	4610	1/1893-11/1972
118	OAK CREEK CANYON	6037	34.970000	-111.750000	5080	7/1982-12/1988
119	ORACLE	6116	32.600000	-110.780000	4600	1/1893- 3/1949
120	ORACLE 2 SE	6119	32.600000	-110.730000	4510	2/1950-12/1988
121	ORGAN PIPE CACTUS N M	6132	31.930000	-112.780000	1680	7/1948-12/1988
122	PAINTED ROCK DAM	6194	33.080000	-113.030000	550	12/1960- 1/1962
123	PALISADE RANGER STN	6202	32.420000	-110.720000	7950	1/1965- 9/1981
124	PARADISE VALLEY	6244	33.550000	-111.970000	1420	6/1955- 1/1970
125	PARADISE VALLEY 2	6246	33.570000	-111.970000	1380	3/1973- 9/1976
126	PARKER 6 NE	6250	34.180000	-114.220000	410	10/1893-12/1988
127	PAYSON 12 NNE	6315	34.400000	-111.270000	5500	10/1952- 9/1976
128	PAYSON R S	6320	34.230000	-111.330000	4850	1/1893- 2/1974
129	PAYSON R S 2	6321	34.250000	-111.300000	5000	3/1974-11/1976
130	PAYSON	6323	34.230000	-111.330000	4910	11/1940-12/1988
131	PERKINSVILLE	6424	34.900000	-112.200000	3860	5/1962- 8/1972
132	PHOENIX INDIAN SCHOOL	6476	33.500000	-112.070000	1120	7/1948- 4/1975
133	PHOENIX SOUTH MT	6479	33.330000	-112.050000	2650	1/1975- 3/1983
134	PHOENIX WSFO AP	6481	33.430000	-112.020000	1110	7/1948-12/1988
135	PHOENIX CITY	6486	33.450000	-112.070000	1080	7/1948-12/1988
136	PICACHO RESERVOIR	6506	32.870000	-111.470000	1510	1/1956- 8/1983
137	PICACHO 8 SE	6513	32.650000	-111.420000	1830	12/1987-12/1988
138	PIMA R4 ON W2	6546	32.830000	-110.020000	3770	7/1948- 9/1951
139	PINAL RANCH	6561	33.350000	-110.980000	4520	3/1895- 5/1973
140	PINE	6571	34.380000	-111.470000	5450	7/1973- 9/1974
141	PINEDALE	6581	34.300000	-110.250000	6500	6/1912-12/1968
142	PISINEMO	6630	32.050000	-112.320000	1900	7/1948-10/1955
143	PLEASANT VALLEY R S	6653	34.100000	-110.930000	5050	9/1964-12/1988
144	POLAND JUNCTION	6676	34.450000	-112.270000	4900	7/1948- 9/1951
145	PRESCOTT	6796	34.570000	-112.430000	5210	5/1898-12/1988
146	PRESCOTT FAA AP	6801	34.650000	-112.430000	5020	7/1948-12/1969
147	PUNKIN CENTER	6840	33.880000	-111.320000	2360	7/1973-12/1988
148	QUARTZSITE	6865	33.670000	-114.230000	880	1/1959-12/1988
149	RED ROCK 6 SSW	7058	32.480000	-111.330000	1880	1/1893-10/1973
150	RENO R S	7081	33.870000	-111.320000	2420	11/1915- 4/1973
151	RIMROCK	7131	34.650000	-111.730000	3600	7/1948- 5/1962
152	ROOSEVELT 1 WNW	7281	33.670000	-111.150000	2210	7/1905-12/1988
153	SACATON	7370	33.070000	-111.750000	1290	4/1908-12/1988
154	SALOME	7453	33.780000	-113.620000	1900	5/1957- 1/1973
155	SALOME 6 SE	7460	33.730000	-113.530000	1700	1/1908- 4/1957
156	SALOME 17 SE	7462	33.680000	-113.480000	1600	3/1987-12/1988
157	SALT RIVER	7466	33.800000	-110.500000	3610	4/1949- 2/1966
158	SAN CARLOS	7475	33.350000	-110.450000	2640	7/1948- 4/1977
159	SAN CARLOS AP	7477	33.380000	-110.470000	2890	5/1977- 5/1980
160	SAN CARLOS RESERVOIR	7480	33.170000	-110.520000	2530	7/1948-12/1988
161	SAN MANUEL	7530	32.950000	-110.650000	3560	6/1954-12/1988
162	SANTA MARGARITA	7583	31.680000	-111.580000	3930	6/1917-11/1950
163	SANTA ROSA SCHOOL	7600	32.320000	-112.050000	1840	9/1959- 6/1977
164	SASABE 7 NW	7622	31.580000	-111.600000	3830	12/1950-12/1988
165	SCOTTSDALE	7661	33.470000	-111.880000	1200	3/1968-11/1985
166	SEDONA R S	7708	34.870000	-111.770000	4220	7/1948-12/1988

167	SELLS	7726	31.920000	-111.880000	2410	7/1948- 9/1975
168	SENECA 3 NW	7741	33.780000	-110.530000	4920	7/1948- 9/1951
169	SENTINEL	7751	32.870000	-113.220000	690	1/1899- 3/1960
170	SIERRA ANCHA	7876	33.800000	-110.970000	5100	11/1913- 9/1979
171	SIGNAL	7884	34.470000	-113.630000	1520	7/1948- 6/1951
172	SIGNAL 13 SW	7888	34.370000	-113.800000	2510	6/1952- 6/1961
173	SILVER BELL	7915	32.380000	-111.500000	2740	2/1906- 4/1974
174	SKULL VALLEY	7965	34.500000	-112.680000	4250	9/1972-10/1980
175	SLATE MOUNTAIN	7984	32.520000	-111.880000	1930	8/1974-12/1977
176	SNOWFLAKE 15 W	8018	34.500000	-110.330000	6080	5/1965-12/1988
177	SOUTH PHOENIX	8112	33.380000	-112.070000	1160	1/1961-12/1988
178	STANTON	8184	34.170000	-112.730000	3480	7/1948-12/1969
179	STEWART MTN	8214	33.570000	-111.530000	1420	7/1948-12/1988
180	SUNDAD	8268	33.180000	-113.230000	1010	7/1956- 1/1957
181	SUPERIOR	8348	33.300000	-111.100000	3000	7/1920-12/1988
182	SUPERIOR 2 ENE	8349	33.300000	-111.070000	4160	1/1974-12/1988
183	SUPERIOR SMELTER	8351	33.300000	-111.100000	2790	9/1948- 9/1953
184	SUPERSTITION MTN	8356	33.370000	-111.430000	1960	7/1948- 3/1962
185	SYCAMORE R S	8391	34.350000	-111.970000	4000	7/1919-12/1959
186	TACNA 3 NE	8396	32.720000	-113.920000	320	2/1969-12/1988
187	TEMPE	8489	33.430000	-111.930000	1150	1/1926- 7/1984
188	TEMPE 3 S	8494	33.380000	-111.930000	1180	1/1905- 6/1952
189	TEMPE ASU	8499	33.420000	-111.930000	1170	1/1953-12/1988
190	THORNBURG RANCHES	8566	33.570000	-112.400000	1100	7/1952- 9/1960
191	TIMBER RANGER STATION	8576	34.620000	-111.120000	6810	7/1965- 6/1967
192	TOLLESON 1 E	8598	33.450000	-112.230000	1030	10/1951-12/1988
193	TONOPAH	8641	33.470000	-112.950000	1110	9/1951-12/1988
194	TONTO CR FISH HATCHERY	8649	34.370000	-111.100000	6280	7/1948- 7/1975
195	TONTO CR FISH HATCH 2	8650	34.380000	-111.100000	6390	8/1975-12/1988
196	TONTO SPRINGS R S 4 W	8657	34.620000	-112.750000	4800	7/1948-10/1966
197	TROUT CREEK STORE	8762	34.880000	-113.650000	2850	7/1948- 3/1951
198	TUCSON 17 NW	8795	32.250000	-111.200000	2560	5/1982-12/1988
199	TUCSON CAMP AVE EXP FM	8796	32.280000	-110.950000	2330	2/1949-12/1988
200	TUCSON MOUNTAIN PARK	8805	32.250000	-111.170000	2850	1/1949- 8/1954
201	TUCSON NURSERY 4 NW	8810	32.300000	-111.050000	2250	7/1948- 9/1951
202	TUCSON U OF A #1	8817	32.270000	-111.000000	2300	5/1982-12/1988
203	TUZIGOOT NATL MON	8904	34.770000	-112.030000	3470	7/1977-12/1988
204	UPPER PARKER CREEK	8940	33.800000	-110.950000	5500	7/1948- 9/1951
205	VALLEY CITRUS FARM	9015	33.380000	-111.970000	1180	7/1948-12/1952
206	WAHAK HOTRONTK	9109	32.220000	-112.370000	1900	3/1963- 4/1966
207	WALLACE R S	9150	34.530000	-110.920000	7010	5/1916- 4/1959
208	WALNUT CREEK	9158	34.930000	-112.820000	5090	12/1915-12/1988
209	WALNUT GROVE	9166	34.300000	-112.550000	3760	1/1893-12/1988
210	WELLTON	9211	32.670000	-114.130000	260	3/1922-12/1980
211	WELLTON 6 NE	9215	32.720000	-114.050000	240	2/1950-10/1951
212	WHITERIVER 1 SW	9271	33.830000	-109.970000	5120	2/1900-12/1988
213	WICKENBURG	9287	33.980000	-112.730000	2050	3/1908-12/1988
214	WIKIEUP	9309	34.720000	-113.620000	2010	7/1948-12/1988
215	WILLOW SPRINGS RANCH	9382	32.720000	-110.870000	3690	4/1949-12/1978
216	WINKELMAN 6 S	9420	32.920000	-110.720000	2080	2/1942- 5/1980
217	WINKELMAN 12 SE	9425	32.870000	-110.600000	2590	3/1985-12/1988
218	WITTMANN	9464	33.780000	-112.530000	1700	12/1923-11/1966
219	WORKMAN CREEK 1	9534	33.820000	-110.920000	6970	7/1948- 9/1951
220	YAEGER CANYON	9572	34.680000	-112.170000	6000	12/1917- 8/1948
221	YAVA 6 ESE	9601	34.450000	-112.800000	3780	7/1948- 4/1975
222	YOUNG	9622	34.100000	-110.930000	5050	7/1903- 8/1964
223	YOUNG 12 N	9626	34.270000	-110.900000	6520	4/1952-11/1956
224	YOUNGTOWN	9634	33.600000	-112.300000	1140	10/1964-12/1988
225	YUMA PROVING GROUND	9654	32.830000	-114.400000	320	4/1958-12/1988
226	YUMA WSO AP	9660	32.670000	-114.600000	210	9/1948-12/1988
227	YUMA	9662	32.730000	-114.620000	240	1/1893- 4/1974


Daily stations
ANVIL ROCK
METEOR CRATER
CEDAR GLADE
DRAKE R S
OAK CREEK CANYON
JUNIPINE
WALNUT CREEK
PERKINSVILLE
MUNDS PARK
MORMON LAKE R S
TROUT CREEK STORE
SEDONA R S
CAMP WOOD
TUZIGOOT NATL MON
JEROME
COTTONWOOD
CHINO VALLEY
HAPPY JACK R S
WIKIEUP
YAEGER CANYON
BEAVER CREEK R S
RIMROCK
BAGDAD 8 NE
PRESCOTT FAA AP
BAGDAD
BAGDAD 2
TONTO SPRINGS R S 4 W
MONTEZUMA CASTLE N W
TIMBER RANGER STATION
BLUE RIDGE R S
PRESCOTT
CHEVELON RANGER STN
WALLACE R S
SNOWFLAKE 15 W
SKULL VALLEY
HILLSIDE 4 NNE
GROOM CREEK
YAVA 4 ESE
POLAND JUNCTION
LAKE HAVASU
SIGNAL
HILLSIDE
FOSSIL SPRINGS
IRVING
PAYSON 12 NNE
PINE
TONTO CR FISH HATCH 2
HEBER R S
HEBER
CLAY SPRINGS
SYCAMORE R S
DUGAS 2 SE
CHILDS
TONTO CR FISH HATCHERY
NATURAL BRIDGE
SIGNAL 13 SW
PINEDALE
ALAMO
ALAMO DAM 6 ESE
WALNUT GROVE
CORDES
ALAMO DAM
PAYSON R S 2
PAYSON
PAYSON R S
YOUNG 12 N
PARKER 6 NE
ALAMO 8 SW
CROWN KING
BUMBLE BEE
CONGRESS
STANTON
FORESTDALE
GISELA
PLEASANT VALLEY R S
YOUNG
CASTLE HOT SPRINGS 4 N
BAR T BAR RANCH
CIBECUE
CASTLE HOT SPRINGS
HORSESHOE DAM
BOUSE
AGUILA
WICKENBURG
PUNKIN CENTER
RENO R S
CARL PLEASANT RES
LAKE PLEASANT
CAVE CREEK
CAREFREE
BARTLETT DAM
WORKMAN CREEK 1
SIERRA ANCHA
UPPER PARKER CREEK
SALT RIVER
SENECA 3 NW
WHITERIVER 1 SW
SALOME
WITTMANN
SALOME 6 SE
SALOME 17 SE
CAVE CREEK DAM
QUARTZSITE
BEARDSLEY
ROOSEVELT 1 WNW
GRAPEVINE
INTAKE
MARINETTE
YOUNGTOWN
FOUNTAIN HILLS
EHRENBERG
DEER VALLEY
THORNBURG RANCHES
PARADISE VALLEY 2
STEWART MTN
EHRENBERG 2 E
PARADISE VALLEY
MUMMY MOUNTAIN
MORMON FLAT
ALHAMBRA 2 NE
GRANITE REEF DAM
HARQUAHALA PLAINS
LITCHFIELD PARK
ARIZONA FALLS 1 WNW
PHOENIX INDIAN SCHOOL
CAMELBACK
APACHE JUNCTION 4 NNW
GRIGGS 3 W
TONOPAH
SCOTTSDALE
PHOENIX CITY
TOLLESON 1 EB
TEMPE
FALCON FIELD
BLACK RIVER PUMPS
PHOENIX WSFO AP
APACHE JUNCTION
TEMPE ASU
MESA EXPERIMENT FARM
MIAMI
GLOBE 2
SOUTH PHOENIX
GOULDS RANCH
TEMPE 3 S
SUPERSTITION MTN
GLOBE
SAN CARLOS AP
BUCKEYE
PINAL RANCH
SAN CARLOS
VALLEY CITRUS FARM
KOFA MOUNTAINS
LAVEEN 3 SSE
PHOENIX SOUTH MT
SUPERIOR SMELTER
SUPERIOR
SUPERIOR 2 ENE
ARSENIC TUBS
CHANDLER
CHANDLER HEIGHTS
SUNDAD
SAN CARLOS RESERVOIR
MONTEZUMA
MARICOPA 4 N
PAINTED ROCK DAM
ASHURST HAYDEN DAM
KELVIN
SACATON
KEARNY
FLORENCE
FORT THOMAS
DATELAND WHITEWING RCH
CASA GRANDE RUINS N M
FORT THOMAS 2 SW
GILA BEND AVIATION
GILA BEND
SAN MANUEL
WINKELMAN 6 S
MARICOPA 9 SSW
IMPERIAL DAM
SENTINEL
CASA GRANDE
PICACHO RESERVOIR
WINKELMAN 12 SE
YUMA PROVING GROUND
ELOY 4 NE
PIMA RS ON W2
DATELAND
KLONDYKE 3 SE
ARAVAIPA R S
MOHAWK
WELLTON 8 NE
YUMA
TACNA 3 NE
WILLOW SPRINGS RANCH
YUMA WSO AP
WELLTON
PICACHO 8 SE
ORACLE
ORACLE 2 SE



Arizona Daily Stations

Maricopa Area

ARIZONA DEPARTMENT OF TRANSPORTATION

TRANSPORTATION PLANNING DIVISION

206 South Seventeenth Avenue Phoenix, Arizona 85007-3213

FIFE SYMINGTON
Governor

CHARLES E. COWAN
Director

ARIZONA TRANSPORTATION RESEARCH CENTER

HARRY A. REED
Division Director

November 25, 1992

NOV 30 1992

/ CHD

Carol H. Davis
Hydrologist
Flood Control District Of Maricopa County
2801 West Durango Road
Phoenix, AZ 85009

Subject: Refined Precipitation Frequency Maps Project
Project HPR 018
Request for Precipitation Records/
Quarterly Progress Report

Dear Ms. Davis:

Enclosed is a copy of a letter from the NWS requesting additional data for the subject project. If you or your agency can provide any of the desired information, or know of another source of this information, please provide the information directly to the NWS at the address on the letter.

Enclosed also is a copy of the 4th Quarterly Progress Report.

If you have any questions, please call me. My phone number is (602)831-0662.

Respectfully,

Joseph W. Warren

Joseph W.Warren, P.E.
Senior Research Engineer
Research Section

enclosures
JWW/daj

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

October 22, 1992 W/OH11:LFT

Mr. Joe Warren
Arizona State University
Engineering Research Center
Room 405
Tempe, AZ 85287-6306

Dear Joe,

As you may already be aware, the National Weather Service and several other Federal agencies (Corps of Engineers, Soil Conservation Service, Bureau of Reclamation, FEMA, and the Department of Highways), as well as various state and local government agencies, are working to develop new precipitation frequency atlases. The current precipitation frequency atlases for the western United States are NOAA Atlas 2 (durations through 24 hours) and Technical Paper No. 49 (durations from 2 days to 10 days). These atlases were prepared by the National Weather Service 20 to 30 years ago. As more quality data and new statistical techniques are now available, we have begun this multi-year project with the southwestern United States. Currently, we are revising the precipitation frequency relations, area-depth curves, and depth-duration curves for the semi-arid southwestern states of Arizona, Nevada, New Mexico, Utah, and the southeastern portion of California. Area is shown on enclosed map.

The base data are the precipitation records available from the National Climatic Data Center (NCDC). However, these data are strongly biased by population density and there are only a few precipitation records at high elevations or in sparsely populated regions. Consequently, we are attempting to obtain data records from as many other groups or individuals as possible to supplement the precipitation data available from NCDC. Many Federal, state, and local agencies, as well as private organizations such as power companies, have installed precipitation networks and we want to include as many of these data as feasible to provide the best data set for final analysis.

Specifically, we are looking for precipitation records of any duration (daily, hourly, storm, etc.), and we would prefer to have at least 15 years of record for statistical purposes. Although this is a somewhat marginal record length, it should provide enough information in concert with other stations in the vicinity to provide meaningful information. However, it is also recognized that many of the stations in the data-sparse regions may not have a record length of 15 years long and for these stations we will relax the 15-year record requirement. This is also true if the station has records with durations shorter than 1 hour. For those stations with less than 15 years of data, individual judgments on the application of the data for this project will have to be made. We can supply you with an inventory of the data that are available from NCDC, as well as maps showing the locations of the stations for your area of interest, in order to avoid duplication.

The Project is also examining precipitation within major storms. For this part of the analysis, detailed isohyetal and temporal analyses of major storms will be made. This means that even if some of the precipitation stations do not have sufficient record lengths for the statistical part of the study, precipitation data from major storms will still be very useful in the study of individual storms and contribute valuable insight into their structure.

If you can provide precipitation data useful to this study, your assistance would be greatly appreciated and would help to provide valuable information to the hydrometeorological community. If you have any precipitation data that you believe would be useful to this study or if you have any questions, please feel free to contact me at (301) 713-1669, or you can send correspondence to me at the following address:

NOAA, National Weather Service
1325 East-West Highway
OH11 - SSMC-2 - Station #7166
Silver Spring, MD 20910-3233

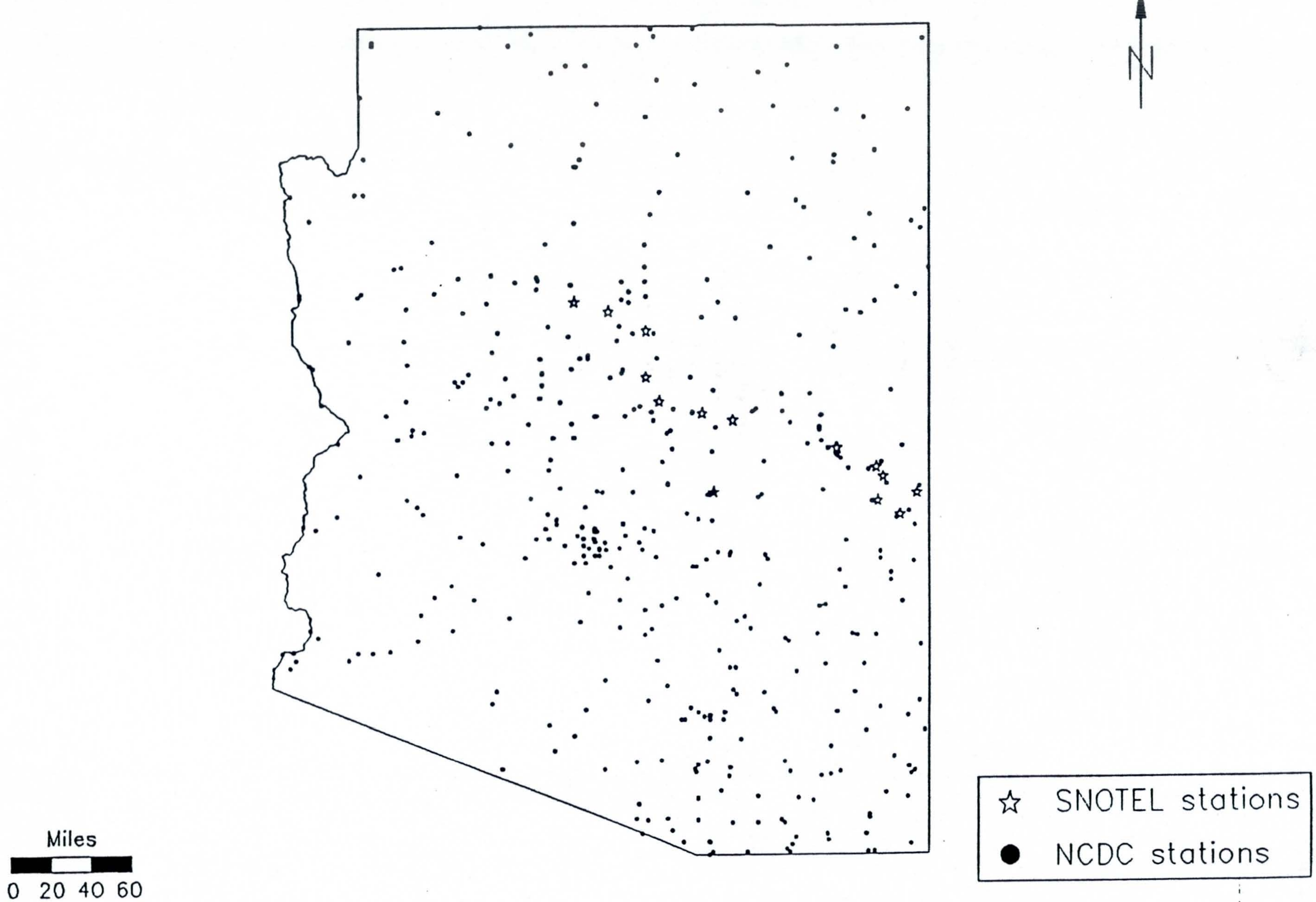
Sincerely,

Lesley F. Tarleton
Meteorologist
Hydrometeorological Branch

Enclosure

Arizona

SNOTEL and NCDC Daily Stations



RC 15658 (#69226) 3/13/90
Mathematics 12 pages

Research Report

Regional Flood Frequency Analysis using L-moments

J. R. M. Hosking and J. R. Wallis

IBM Research Division
T. J. Watson Research Center
Yorktown Heights, NY 10598

IBM Research Division
Almaden • T.J. Watson • Toyko • Zurich

Regional flood frequency analysis using L-moments

J. R. M. Hosking and J. R. Wallis

IBM Research Division
T. J. Watson Research Center
Yorktown Heights, New York 10598

Abstract: An index-flood procedure which uses probability weighted moments (PWMs) [*Greenwood et al.*, 1979] to estimate the parameters of a regional flood frequency distribution has been shown in recent research to perform well. It is easy to use and statistically efficient and gives more accurate flood quantile estimates than the official flood frequency procedures recommended for the U.K. and the U.S. [*Hosking et al.*, 1985; *Wallis and Wood*, 1985; *Potter and Lettenmaier*, 1990].

L-moments are summary statistics for probability distributions. They are derived from PWMs but are more easily interpretable as measures of distributional shape (coefficient of variation, skewness, kurtosis, *etc.*). Their statistical applications are described in *Hosking* [1990].

In this paper we discuss the application of L-moments to flood frequency analysis. Comparison of the spread of at-site sample L-moments with what would be expected of a homogeneous region aids the identification of homogeneous regions. The regional averages of the at-site sample L-moments give an indication of which distributions are plausible flood frequency distributions for the region. The use of L-moments rather than PWMs in the index-flood procedure itself sometimes gives a small improvement in the accuracy of flood quantile estimates. In summary, the use of L-moments makes the PWM-based index-flood procedure easier to use while maintaining its high efficiency.

1. Introduction

Floods are the greatest natural catastrophes that mankind experiences. Year in and year out they cause enormous loss of life and damage to property. Floods on the Huang He (Yellow River) in China are estimated to have caused 6 million deaths in the last 100 years [*Smith*, 1981, p. 441]. Of the 531 Federally declared disaster events in the U.S.A. between 1965 and 1985, 392 were flood-related [*Rubin et al.*, 1986]. The total annual monetary loss due to floods in the U.S.A. averages $3.9 billion [*Platt*, 1979]. Estimation of how often a large flood may be expected at a given site is therefore a matter of great importance. It is needed for the design of dams, bridges and flood-alleviation structures, and for the definition of flood-prone areas for purposes of zoning regulations.

Many factors affect the magnitude of the floods which can be expected at a given site. Some of these factors are known and can be measured or estimated with reasonable accuracy: for example, the catchment area upstream from the site, or the average annual rainfall over the catchment. Some factors are known, but cannot be measured accurately enough for their effect on the pattern of floods to be precisely determined: one such factor is the pattern of soil type within the catchment. Some factors may not be known at all. And the sequence of floods in any given time interval is affected by the unpredictable weather patterns which control both the total amount of water entering the catchment as precipitation and the rate, dependent on how wet the catchment was before a storm, at which this water travels to the catchment outflow.

Because there are numerous sources of uncertainty about the physical processes that control flood magnitude, a statistical approach to the estimation of extreme floods is desirable. Statistical methods acknowledge the existence of uncertainty and enable its effects to be quantified. Let Q be the magnitude of the largest flood which occurs in a year at a given site. We regard Q as a random quantity (a random variable), potentially taking any value between zero and infinity. The fundamental quantity of statistical flood frequency analysis is the *flood frequency distribution*, which specifies how frequently the possible values of Q occur. Denote by $F(x)$ the probability that the actual value of Q is at most x:

$$F(x) = P[\,Q \le x\,]\,. \tag{1}$$

$F(x)$ is the *cumulative distribution function* of the flood frequency distribution. Its inverse function $x(F)$, the *quantile function* of the flood frequency distribution, expresses a flood magnitude in terms of its nonexcession probability

F. The *flood quantile of return period T*, Q_T, is that flood magnitude which has probability $1/T$ of being exceeded in a year, *i.e.*

$$Q_T = x(1 - 1/T) \tag{2}$$

or

$$F(Q_T) = 1 - 1/T. \tag{3}$$

The goal of flood frequency analysis is to obtain a useful estimate of the flood quantile Q_T for a return period of engineering relevance: this period may be the design life of a structure ($T=50$ years, say) or some legally mandated design period (*e.g.* $T=10000$ years in some dam safety applications). More generally, the goal may be to estimate Q_T for a range of return periods, or to estimate the entire quantile function. To be "useful", an estimate should not only be close to the true quantile but should also come with an assessment of how accurate it is likely to be.

2. Regional flood frequency analysis – current ideas

Regional flood frequency analysis has been an established method in hydrology for many years: the index-flood procedure of *Dalrymple* [1960] is an early example. Several methods recommended by national organizations for general use by hydrologists have a strong regional component. Bulletin 17 of the U.S. *Water Resources Council* [1981] fits a log-Pearson type III distribution to annual maximum streamflows at a single site, the skewness of the logarithmically transformed distribution being obtained by combining a data-based estimate with a value read from a map. The method uses regional information insofar as the mapped values are derived from observed skewness statistics at many sites. The U.K. Flood Studies Report [*Natural Environment Research Council*, 1975] divides the British Isles into 11 regions with region boundaries following those of major catchments. Each site in a region is assumed to have the same flood frequency distribution after the at-site data have been divided by the mean annual flood.

Since these methods were published, research has indicated several ways in which regional flood frequency analysis can be improved, and several principles which are useful for constructing a regional flood frequency analysis procedure.

1. Flood frequency analysis should be robust. Flood frequency analysis procedures, like virtually all scientific methods, postulate some kind of model for the process which generates the observed data. The actual flood-generating mechanism is so complicated that it is unreasonable to expect the model to be "true", *i.e.* an exact representation of the physical process: it is at best an approximation. Therefore when fitting the model to the data, any desirable attributes possessed by a model-fitting procedure when the model is true may be irrelevant. Much more important is that the procedure should yield flood quantile estimates whose accuracy is not seriously degraded when the true physical process deviates from the model's assumptions in a hydrologically plausible way. A modeling procedure with this property is said to be *robust*.

2. To assess a flood frequency analysis procedure, use simulation. To establish the properties of a flood frequency analysis procedure, or to compare two or more procedures, we recommend the use of Monte Carlo simulation. Though when specifying a model for flood frequency analysis we may not know the exact mechanism by which floods are generated, we can recognize that some kinds of departure from the model are hydrologically plausible. For example, the flood frequency distribution may have a heavier or a lighter tail than the model assumes, and magnitudes of extreme floods at different sites may be positively correlated. Data can be generated according to whatever pattern of real-world data structure is of concern, and the adequacy of the proposed modeling procedure can be assessed for such data. The advantage of using simulated data for this purpose is that the true flood quantiles are known, so it is easy to judge how well the modeling procedure performs. This is not the case for methods which use only observed flood data, such as split-sample testing or comparing probability plots of observed samples and fitted distributions.

3. Regionalization is valuable. Regionalization is the inclusion in flood frequency analysis of data from sites other than the site at which flood quantile estimates are to be estimated. Because more information is used than in an "at-site" analysis using only a single site's data, there is potential for greater accuracy in the final flood quantile estimates. But the extra information comes at the price of having to specify the relationships between flood frequency distributions at different sites. For example, index-flood procedures assume that flood frequency distributions at different sites are identical apart from a scale factor, *i.e.* that the sites form a "homogeneous" region. *Benson* [1962] suggested that this assumption was not valid for U.S. flood data, because the coefficient of variation (CV) of the flood frequency distribution tends to decrease as catchment area increases. Thus there is reason to doubt whether regionalization is worthwhile. Research has shown these doubts to be unjustified: even though a region may be moderately heterogeneous, regional analysis will still yield much more accurate flood quantile estimates than at-site analysis [*Lettenmaier and Potter*, 1985; *Hosking and Wallis*, 1987; *Lettenmaier et al.*, 1987].

4. Regions need not be geographical. Regional flood frequency analysis is advantageous when the sites forming a region have similar flood frequency distributions. The term "region" suggests a set of contiguous catchments, but geographical closeness is not necessarily an indicator of similarity of flood frequency distribution. Indeed some aspects of the flood frequency distribution can show sharp discontinuities when considered as functions of the location of the site. Consider a site downstream of the confluence of two rivers and sites on the two upstream branches: it is plausible that the CV or skewness of a flood frequency distribution could be very different at the three sites. For this reason maps of regional skewness, as used by Bulletin 17 [*Water Resources Council*, 1981], seem likely to be very unreliable.

It is, however, intuitively reasonable that catchments with similar flood frequency distributions should have similar values of those catchment characteristics that determine the flood frequency distribution. It is therefore reasonable to identify regions by grouping together catchments that are adjacent in some suitably defined space of catchment characteristics. The characteristics used to define this space could be geographical – latitude and longitude, say – but other characteristics more directly and physically related to the occurrence of large floods, such as altitude, average annual rainfall, catchment area or soil type, are intuitively more appropriate. A further advantage of choosing a region that is geographically dispersed rather than compact is that the flood frequency distributions at the different sites are then less likely to be highly correlated, thereby reducing the variability of the eventual flood quantile estimates.

5. Flood frequency distributions are not "textbook" distributions. Lognormal, Pearson type III and extreme-value type I (Gumbel) are examples of probability distributions for which a fairly thorough mathematical and statistical theory has been developed, and which resemble in their general shape what experience suggests a typical flood frequency distribution should look like. It is therefore tempting to declare one such "textbook" distribution to be the flood frequency distribution for fitting to flood data, or to choose a distribution from among a small group of textbook distributions. A problem with this approach is that the samples of annual maximum streamflow data which are typically available are not so large that the flood frequency distribution can be unequivocally identified. In particular a heavy-tailed distribution, with Q_T increasing rapidly as T increases, will, if undetected, cause severe underestimation of extreme flood quantiles. Several authors have found evidence that flood frequency distributions can be heavy-tailed [*Houghton*, 1978; *Landwehr et al.*, 1978; *Rossi et al.*, 1984; *Ahmad et al.*, 1988]. It is therefore wise to consider as candidate flood frequency distributions a wide range of moderate- and heavy-tailed distributions, or to use a distribution with enough free parameters that it can mimic a wide range of plausible flood frequency distributions. The Wakeby distribution [*Houghton*, 1978], with 5 parameters, is one such "mimic-everything" distribution.

6. *L*-moments are useful summary statistics for flood data. Although nonparametric methods have been proposed for at-site flood frequency analysis [*e.g. Adamowski*, 1985], most regional flood frequency analysis procedures attempt to fit flood data by a distribution whose form is specified apart from a finite number of undetermined parameters. Sample moment statistics, particularly skewness and kurtosis, are often used to judge the closeness of an observed sample to a postulated distribution. But these statistics are unsatisfactory: they are algebraically bounded, with bounds dependent on sample size [*Kirby*, 1974; *Dalén*, 1987], and in many small or moderate samples it is unusual for sample skewness and kurtosis to take values anywhere near the population values [*Wallis et al.*, 1974].

We recommend an alternative approach based on quantities which we call *L*-moments [*Hosking*, 1986, 1990]. These are analogous to the conventional moments but can be estimated by linear combinations of the elements of an ordered sample, *i.e.* by *L*-statistics. *L*-moments have the theoretical advantages over conventional moments of being able to characterize a wider range of distributions and, when estimated from a sample, of being more robust to the presence of outliers in the data. Experience also shows that, compared with conventional moments, *L*-moments are less subject to bias in estimation.

3. Regional flood frequency analysis – an index-flood procedure

Suppose that annual maximum flood data are available at N sites in a region, with n_i years of record at site i, and let $Q_i(F)$ be the quantile function of the flood frequency distribution at site i. The key assumption of an index-flood procedure is that the region is *homogeneous*, *i.e.* that the flood frequency distributions of the N sites are identical apart from a site-specific scaling factor, the *index flood*. We may then write

$$Q_i(F) = \mu_i \, q(F), \qquad i = 1, \ldots, N. \tag{4}$$

Here μ_i is the index flood. We shall take it to be the mean annual flood (mean annual maximum instantaneous discharge), though any location parameter of the flood frequency distribution may be used instead – for example, *Smith* [1989] uses the 90% quantile $Q_i(0.9)$. The remaining factor in (4), $q(F)$, is the *regional growth curve*, a dimensionless quantile function common to every site.

The mean annual flood is naturally estimated by $\hat{\mu}_i = \overline{Q}_i$, the sample mean of the annual flood data at site i. Other location estimators such as the median or a trimmed mean could be used instead.

The dimensionless rescaled data $q_{ij} = Q_{ij}/\hat{\mu}_i$, $j = 1, \ldots, n_i$, $i = 1, \ldots, N$, are the basis for estimating the regional growth curve $q(F)$. It is usually assumed that the form of $q(F)$ is known apart from p undetermined parameters $\theta_1, \ldots, \theta_p$, so we write $q(F)$ as $q(F; \theta_1, \ldots, \theta_p)$. In our approach the parameters are estimated separately at each site, the site-i estimate of θ_k being denoted by $\hat{\theta}_{ki}$. The at-site estimates are combined to give regional estimates:

$$\hat{\theta}_k^R = \sum_{i=1}^{N} n_i \hat{\theta}_{ki} \Big/ \sum_{i=1}^{N} n_i . \tag{5}$$

This is a weighted average, with the site-i estimate given weight proportional to n_i because for regular statistical models the variance of $\hat{\theta}_{ki}$ is inversely proportional to n_i. Substituting these estimates into $q(F)$ gives the estimated regional growth curve $\hat{q}(F) = q(F; \hat{\theta}_1^R, \ldots, \hat{\theta}_p^R)$. This method of obtaining regional estimates is essentially that of *Wallis* [1980], except that the weighting proportional to n_i is a later addition, suggested by *Wallis* [1982]. Somewhat different methods were used by *Dalrymple* [1960] and *Natural Environment Research Council* [1975].

The flood quantile estimates at site i are obtained by combining the estimates of μ_i and $q(F)$:

$$\hat{Q}_i(F) = \hat{\mu}_i \hat{q}(F). \tag{6}$$

This index-flood procedure makes the following assumptions.

1. Annual floods at any given site are identically distributed.
2. Annual floods at any given site are serially independent.
3. Annual floods at different sites are independent.
4. Flood frequency distributions at different sites are identical apart from a scale factor.
5. The mathematical form of the regional growth curve is correctly specified.

The first two assumptions are plausible. Provided that the data are screened so as to exclude sites whose streamflows are affected by regulation, changes in urbanization, land use or vegetation, or errors in gaging, there is little reason to suspect that flood frequency distributions change over time periods typical of the length of streamflow records. Neither does serial dependence appear to be a significant problem in flood frequency analysis. Some studies have found evidence of serial dependence in annual flood series [*e.g. Carrigan and Huzzen*, 1967] and some have not [*e.g. Wall and Englot*, 1985]. The effect of serial dependence on at-site flood frequency analysis has been investigated by *Landwehr et al.* [1979*a*] and *McMahon and Srikanthan* [1982]. They considered flood frequency distributions of extreme-value type I and log-Pearson type III respectively, and found that serial dependence caused a small amount of bias and a small increase in the standard error of flood quantile estimates. We conclude that a small amount of serial dependence in annual flood series has little effect on the quality of flood quantile estimates.

The last three assumptions are unlikely to be satisfied by real-world flood data. Because a storm can cause floods in many catchments, it may be expected that the magnitudes of annual floods in neighboring catchments are positively correlated. The last two assumptions will never be exactly valid in practice. At best they may be approximately attained, by careful selection of the sites that are to be regarded as forming a region and by careful choice of a flood frequency distribution that is consistent with the data. Therefore an index-flood procedure can be appropriate only if it is robust to hydrologically plausible departures from these three assumptions. Recent research [*Hosking et al.*, 1985; *Lettenmaier and Potter*, 1985; *Wallis and Wood*, 1985; *Hosking and Wallis*, 1987; *Lettenmaier et* *al.*, 1987] has shown that it is possible to construct index-flood procedures that yield suitably robust and accurate flood quantile estimates.

4. *L*-moments

Probability weighted moments of a random variable X with cumulative distribution function F were defined by *Greenwood et al.* [1979] to be the quantities

$$M_{p,r,s} = E[\,X^p\{F(X)\}^r\{1-F(X)\}^s\,]. \tag{7}$$

Particularly useful special cases are the probability weighted moments $\alpha_r = M_{1,0,r}$ and $\beta_r = M_{1,r,0}$. *Hosking* [1986, 1990] defined *L*-moments to be the quantities

$$\lambda_r = E[X\,P^*_{r-1}\{F(X)\}] \tag{8}$$

where $P^*_r(.)$ is the rth shifted Legendre polynomial. *L*-moments and probability weighted moments are related by

$$\lambda_{r+1} = \sum_{k=0}^{r} p^*_{r,k}\,\beta_k \tag{9}$$

where

$$p^*_{r,k} = (-1)^{r-k}\binom{r}{k}\binom{r+k}{k}. \tag{10}$$

L-moment ratios are the quantities

$$\tau_r = \lambda_r/\lambda_2\,. \tag{11}$$

L-moments are more convenient than probability weighted moments, because they are more easily interpretable as measures of distributional shape. In particular λ_1 is the mean of the distribution, a measure of location; λ_2 is a measure of scale; τ_3 and τ_4 are measures of skewness and kurtosis respectively.

The foregoing quantities are defined for a probability distribution, but in practice must often be estimated from a finite sample. Let $x_1 \le x_2 \le \cdots \le x_n$ be the ordered sample. Let

$$\ell_{r+1} = \sum_{k=0}^{r} p^*_{r,k}\,b_k\,, \tag{12}$$

where

$$b_r = n^{-1} \sum_{j=1}^{n} \frac{(j-1)(j-2)\ldots(j-r)}{(n-1)(n-2)\ldots(n-r)} x_j . \qquad (13)$$

Then ℓ_r is an unbiased estimator of λ_r. The estimator $t_r = \ell_r / \ell_2$ of τ_r is consistent but not unbiased. The quantities ℓ_1, ℓ_2, t_3 and t_4 are useful summary statistics of a sample of data. They can be used to identify the distribution from which a sample was drawn *Hosking* [1990, section 3.5]. They can also be used to estimate parameters when fitting a distribution to a sample, by equating the sample and population *L*-moments [*Hosking*, 1990, section 4.1].

5. Steps in regional flood frequency analysis

Given that annual flood data are available at a large number of sites and that flood quantile estimates are required at each site, regional flood frequency analysis using an index-flood procedure will involve the four steps outlined below.

1. **Screening of the data.** As with any statistical analysis, the first stage of flood frequency analysis is a close inspection of the data. Gross errors and inconsistencies should be eliminated and a check made that the data are homogeneous (stationary) over time. External information can be useful here, especially information about methods of data collection and measurement and about any changes in land use that may have affected peak streamflows in any of the catchments.

2. **Identification of homogeneous regions.** The next step in regional flood frequency analysis is the assignment of the sites to regions. A "region", a set of sites whose flood frequency distributions are (after appropriate scaling) approximately the same, is the fundamental unit of regional flood frequency analysis. As noted in section 2, regions need not be geographical, but should instead consist of sites having similar values of those catchment characteristics that determine flood behavior. Suitable catchment characteristics include altitude, average annual rainfall, catchment area, soil type, and the storage capacity of swamps and lakes in the catchment. Of course latitude and longitude are also catchment characteristics and may be used as surrogates for other unmeasured characteristics that vary smoothly with location. The homogeneity of a proposed region should be tested by calculating summary statistics of the at-site flood data and comparing the between-site variability of these statistics with what would be

expected of a homogeneous region. L-moments are suitable statistics for this purpose.

3. Choice of a flood frequency distribution. After a region has been identified, the final stage in the specification of the statistical model is the choice of an appropriate flood frequency distribution, $q(F)$ in (4). This is a common statistical problem, usually solved by computing summary statistics from the data and testing whether their values are consistent with what would be expected if the data were a random sample from some postulated distribution. This approach can be used in flood frequency analysis, but two extra considerations apply. First, the available data are not a single random sample but a set of samples from the different sites; and second, the chosen distribution should not merely fit the data well but should also yield flood quantile estimates that are robust to hydrologically plausible deviations of the true flood frequency distribution from the chosen flood frequency distribution.

4. Estimation of the flood frequency distribution. Estimation of the regional flood frequency distribution can be achieved by estimating the distribution separately at each site and combining the at-site estimates to give a regional average, as described in section 3. An efficient method of doing this is the method of regional L-moments, which combines at-site L-moment statistics via the weighted average (5).

There are two important situations in which the foregoing procedure must be modified or extended.

First, there may be one site of special interest, such as a nuclear power plant or an actual or proposed dam site, with the aim of the analysis being to obtain flood quantile estimates for this site. In this case special care should be taken to make the site typical of the region to which it is assigned. So far as is possible, the site's catchment characteristics should be typical of those of the other sites in its region and should not be at either extreme of the range of values of the catchment characteristics. This is to reduce the bias in flood quantile estimates which can occur at sites that are not typical of the region as a whole.

Second, flood quantile estimates may be required at one or more ungaged sites. On the basis of its catchment characteristics, an ungaged site can be assigned to one of the regions identified for the gaged sites. This gives an estimate of the regional growth curve at the ungaged site. There remains only the problem of estimating the index flood, usually the mean annual flood μ, at ungaged sites.

The most reasonable approach is to regard μ as being a function of catchment characteristics, and to calibrate the relationship between mean annual flood and catchment characteristics by using data from the gaged sites. *Stedinger and Tasker* [1985] describe one appropriate method.

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

January 8, 1992 W/OH1/EMH

MEMORANDUM FOR: Interagency Support Group

FROM: W/OH1 - E. Marshall Hansen

SUBJECT: Minutes of December 5, 1991 Meeting

I have attached a copy of the minutes describing the interagency meeting of December 5, 1991, held in Phoenix, Arizona, to introduce the NWS precipitation frequency study for the Southwestern states. As a matter of record for this project, copies of future meeting minutes, as well as quarterly progress reports, will be provided to members of the "Interagency Support Group," (listing attached) made up of those agency representatives providing funding support, members of the Independent Advisory Group, State Climatologists, and other interested parties.

Attachments

INTERAGENCY SUPPORT GROUP

Name	Agency	Phone
Dr. Frank Tsai	FEMA	(202) 646-2753
Mr. Donald Woodward	DOA, SCS	(202) 205-0543
Mr. Shap Zangeneh	DOD, COE	(202) 272-8508
Dr. Charles Woo	DOT	(703) 285-2444
Mr. Louis Schreiner	DOI, USBR	(303) 236-3791
Mr. Joe Warren	DOT, Arizona	(602) 965-3548
(Includes distribution to DOT, Nevada; DOWR, Arizona; Albuquerque Metro FCA; Cochise Co. FCD; Maricopa Co. FCD; Yavapai Co. FCD; ASU Climatology Laboratory.)		
Mr. Francis Peairs	Riverside, Co. FCD, California	(714) 275-1207
Mr. Ken Guidry	San Bernadino Co. FCD, California	(714) 387-2525
Mr. Fred Sage	DOWR, California	(916) 323-5241
Dr. Ken Kunkel	ISWS, Illinois	(217) 244-1488
Dr. Robert Clark	University of Arizona, Arizona	(602) 621-3842
Dr. James Wallis	IBM, New York	(914) 945-3000
Mr. Arlo Waddoups	DOT, California	FTS 484-2618
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Dr. Tony Brazel	St. Climat., Arizona	(602) 965-6265
Dr. John James	St. Climat., Nevada	(702) 784-6995
Mr. Marshall Hansen	NWS, OH	(301) 713-1543
Mr. John Vogel	NWS, OH	(301) 713-1669
Mr. William Mork	St. Climat., California	(916) 653-8366

#669

Southwest Precipitation Frequency Study
Introductory Meeting - Tempe, Arizona
December 5, 1991

AGENDA

8:30 a.m.	Introductory remarks and introduction of all attendees
8:45 a.m.	Purpose of meeting - review agenda
9:00 a.m.	Review of study background
9:30 a.m.	Proposed study outline
10:15 a.m.	BREAK
10:30 a.m.	Review of recent NWS studies
11:00 a.m.	Review of current progress
11:30 a.m.	LUNCH
12:30 p.m.	Open discussion by attendees
2:00 p.m.	BREAK
2:15 p.m.	Discussion continued
3:00 p.m.	Summarization, revised milestones, next meeting
3:30 p.m.	Close meeting

Attachment F.

PURPOSE OF MEETING

- Introduce participants
- Review agenda
- Explain background
- Review our experience
- Describe proposed study
- Review progress to date
- Understand user needs
- Open discussion

CURRENT VALID REFERENCES

	5 min - 60 min	1 hr - 24 hr	2 day - 10 day
West	Arkell & Richards (1988) Frederick & Miller (1979)	NOAA Atlas 2 (1973)	Tech. Paper 49 (1964)
East	Tech. Memo 35 (1977)	Tech. Paper 40 (1961)	Tech. Paper 49 (1964)

Attachment 2.

STATEMENT OF PROBLEMS

- Present studies 20 - 30 years old
- New stations, longer records
- T.P. 49/NA-2 incompatible
- Short duration not detailed
- Results in different references
- User concerns for adequacy/accuracy of existing reports
- Detail in orographic regions
- New statistical procedures
- Requests for updates
- Political

PROPOSAL

UPDATE PRECIPITATION FREQUENCY FOR ENTIRE UNITED STATES

Include Durations - 5 min. to 10 days

Return Periods - 2 to 100 years

Complete as regional units

Incorporate GIS information

Provide results in both map and digital file

BENEFITS

- Provide updated frequency information
- Improve accuracy through longer record base and supplemental stations
- Make use of local data and expertise in developing frequency relations
- Provide inter-state consistency through region
- Provide extensive experience of NWS
- Create authoritative nature of a Federal product as recognized and accepted standard
- Produce a cost savings by performing multi-state analyses
- Utilize outside expertise with an independent consultant review team
- Provide advice on improving observation networks
- Provide results in digitized format, as well as hard copy maps

Attachment 1

Attachment 5

TASK 1

Data Collection/Quality Control

Daily/hourly records

15-minute data

Data base formation

1. NWS data
2. non-NWS data
3. short record data (< 15 yr)

Seasonal distributions by duration

QC for: outliers
missing data
accumulations
homogeneity
temporal trends

TASK 2

Frequency Distribution/Fitting Studies

Examine most applicable distributions

- GEV
- Pearson III
- GLN
- Gamma
- G Pareto
- G Logistic

Fitting technique

- L-Moment

Pilot study insight

- data reduction programs
- resolve outliers
- aid in quality control
- selection of distribution
- regional analysis

Independent Advisory Group

State Climatologists/Others

Attachment 12.

TASK 3
Short-Duration Relations

California study

Other western states

Develop ratios: N-minute to 1 hour

- NWS data (15 minute)
- Intense storm data
- Breakpoint data
- Other sources

Meteorological homogeneity

Temporal distribution

TASK 4
Algorithm/Data Plots

Geographical distribution of stations

Objective technique for precipitation/terrain relations
- topographic variables
- meteorological variables

Satellite climatologies

Local variations/anomalies

Calculations
- data processing
  - 2 to 100 year return periods
  - 5 minute to 10 day durations
  - monthly/annual results
  - bimonthly/weekly results
- consistency checks/quality control

Algorithm development

Spatial analysis

Attachment 12.

TASK 5

Spatial/Temporal Relations

Depth-duration (mass curves) relations

- 1 hour and less
- 100 mi^2 and less

Depth-duration relations

- 1 hour to 10 days
- 500 mi^2 and more

Subregions

Temporal distributions vs. elevation

Mass-curve families

- storm types
- regional variations

Area-depth relations

- regional variations
- elevation variations
- storm types

TASK 6
Deliverables

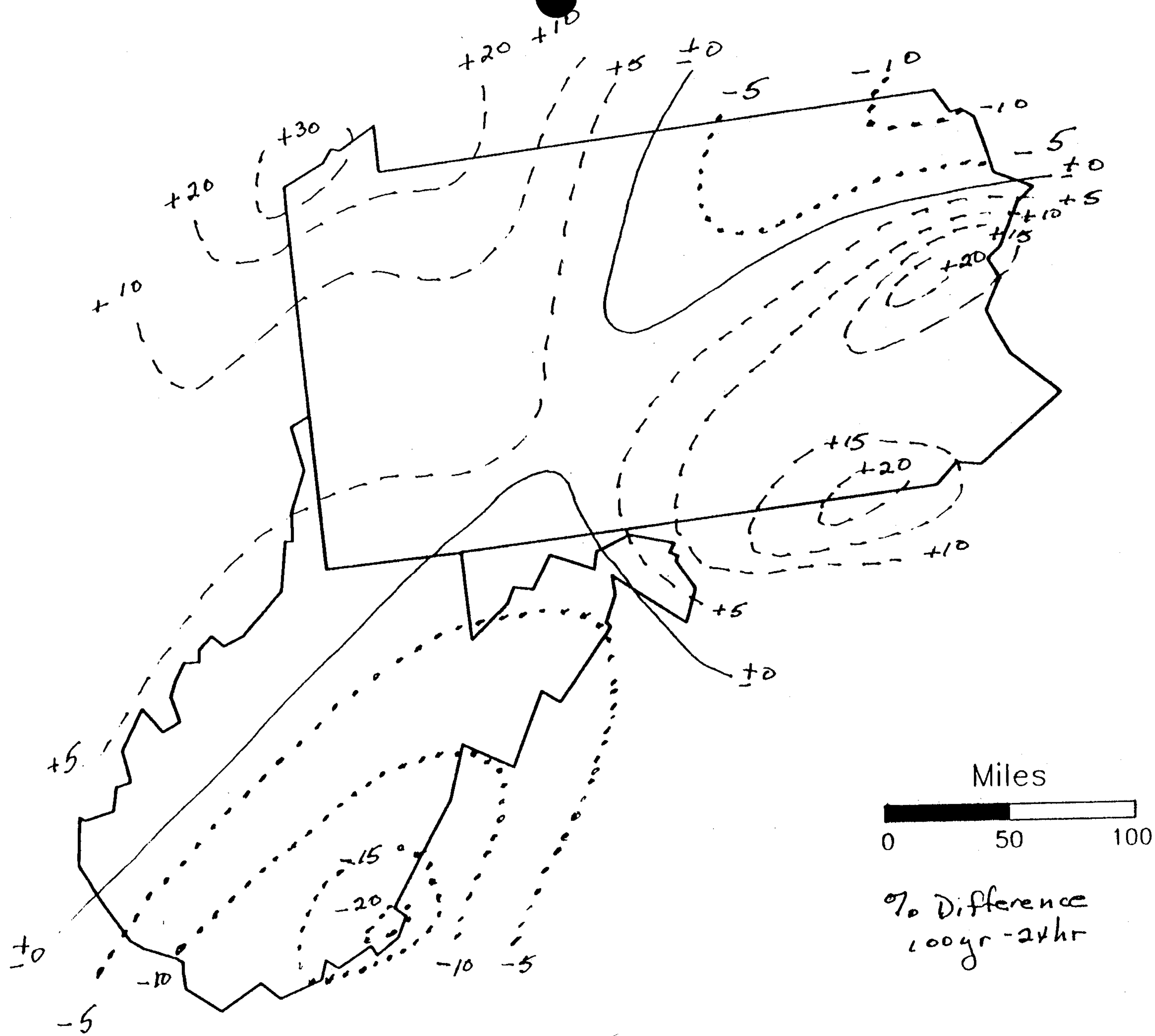
Atlas maps

Digital files

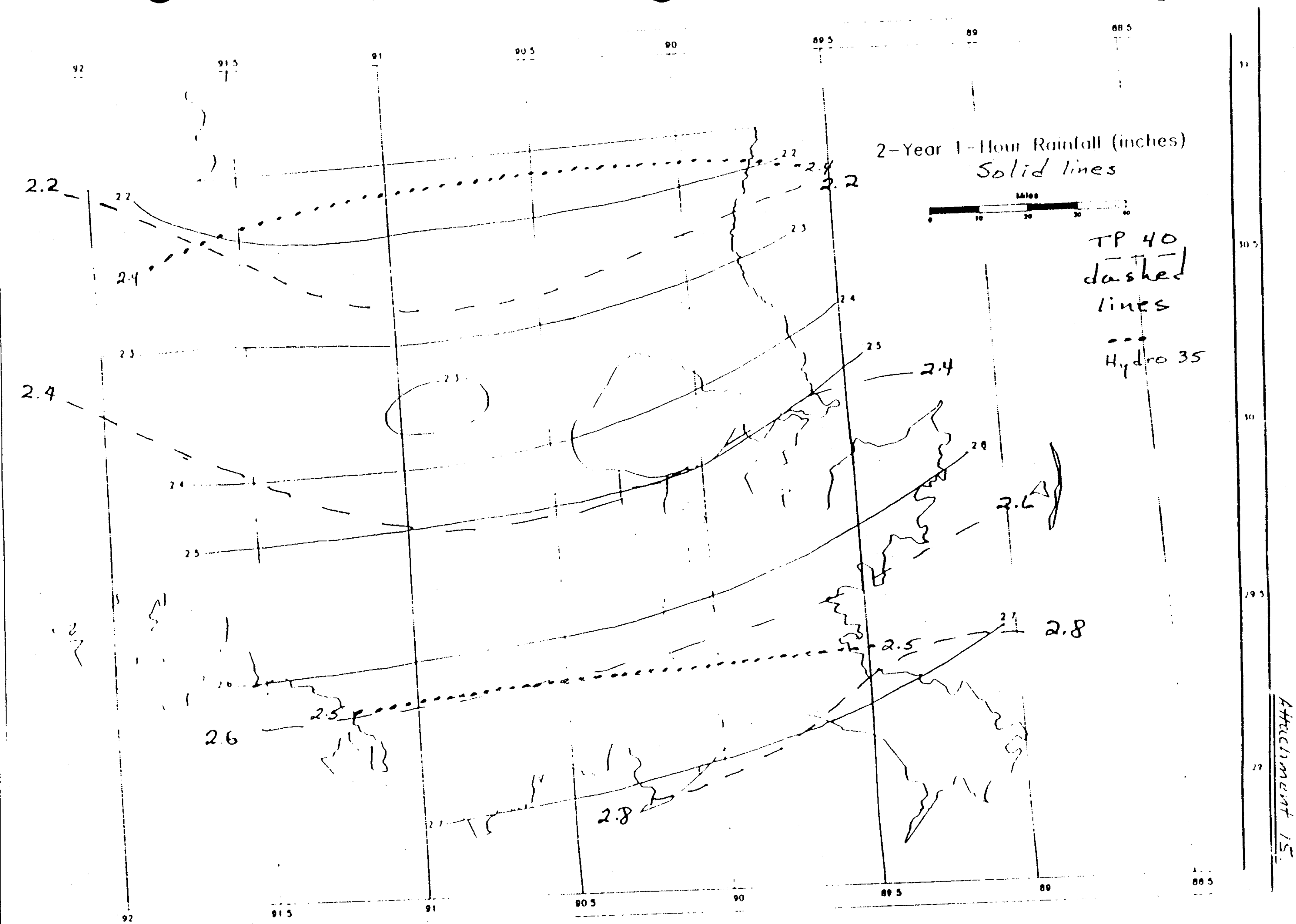
- access by latitude/longitude/season
- GIS support

Final report

- detailed discussion
- background information



Attachment 14


2-Year 1-Hour Rainfall (inches)
Solid lines
Miles
TP 40
dashed lines
Hydro 35
Attachment 15
2.2
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92
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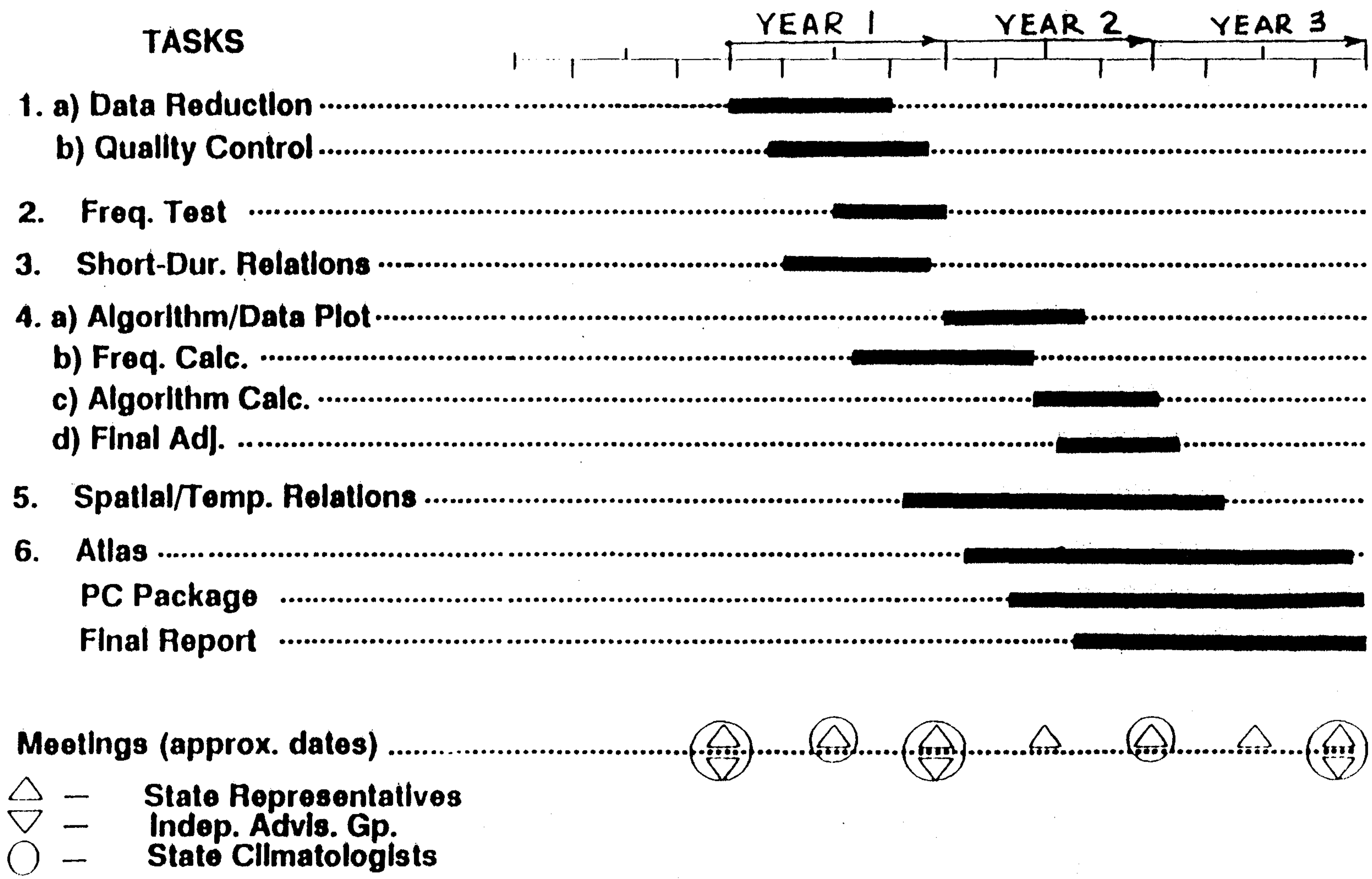
NATIONAL WEATHER SERVICES
SEMI-ARID PRECIPITATION FREQUENCY STUDY

PROJECT TIME TABLE



Paper No. 920241

PREPRINT

Title: A COMPARATIVE EVALUATION OF FOUR REGIONAL FLOOD FREQUENCY ANALYSIS METHODS

Authors: Babak Naghavi, James Cruise, and Senarath Ekanayake

Transportation Research Board
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Washington, D.C.

A COMPARATIVE EVALUATION OF FOUR REGIONAL FLOOD FREQUENCY ANALYSIS METHODS

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ABSTRACT

Four popular regional flood frequency methods were investigated using Louisiana stream flow series. The state was divided into four homogeneous regions and all undistorted, long-term stream gauges were used in the analysis. The generalized extreme value (GEV), two component extreme value (TCEV) and regional log Pearson type 3 (LP3) methods were applied to this data base and compared in terms of descriptive capabilities. Based upon several factors, the GEV method was selected as the overall superior method. The GEV parameters were estimated using the probability weighted moments (PWM). Indexing was accomplished using the first PWM (the mean). A procedure to apply this method to ungauged watersheds using regression equations and a regional non-dimensional flood distribution was developed. It was found that the procedure performed well when applied to data not used in the calibration of the model. The regional GEV procedure was compared with the U.S. Geological Survey (USGS) method and showed significant improvement over the USGS equations in terms of fit to the observed data. This method is easier to apply and more accurate in terms of descriptive and probably predictive ability than other feasible methods for Louisiana data.

INTRODUCTION

Often in hydrologic work, discharges must be estimated for sites at which stream gauge records are unavailable. Several techniques have been developed over the years to accomplish this task. Many of these methods are based upon some type of regional frequency analysis. The Louisiana Department of Transportation and Development employs the USGS regression technique (*1*) to obtain discharge estimates at ungauged sites in the state. These equations contain a fair degree of error and have not been compared to alternate techniques. The USGS equations are based on regression analysis of at-site frequency estimates, which in turn are based upon the LP3 distribution. However, this distribution does not lend itself to regionalization techniques because of the variability of the skew coefficient used in LP3 parameter estimation (*2*). Also, LP3 parameters are not easily related to physical watershed characteristics (*3*). Furthermore, the error reported for the USGS equations (typically 40-50 percent) represents the standard error of the regression estimates and does not include the error inherent in fitting the LP3 to the samples. This error has been shown (*4*) to run anywhere from 10 to 30 percent for Louisiana stations.

Another widely used regional analysis method, recommended by the Interagency Advisory Committee on Water Data (IACWD), is also based on the LP3 distribution but uses a weighted generalized skew coefficient (*5*). The use of a generalized skew coefficient instead of the sample skew coefficient results in a more reliable flood frequency analysis for streams with short records (*5*).

Alternate regional frequency techniques have been proposed by Dalrymple (*6*) and Stedinger (*7*). Greis and Wood (*8*) recommended an indexing method similar to that of Dalrymple (*6*), but with Extreme Value Type 1 (EV1) as the base distribution and parameters estimated by probability weighted moments. This parameter estimation method, first proposed by Greenwood et al. (*9*), has been shown to possess very attractive asymptotic characteristics when used to estimate the parameters of several distributions, especially in cases where the samples exhibit wide variability (*10*). This characteristic makes the method very useful for regional frequency analyses. In support of this, Potter and Lettenmaier (2) tested 10 commonly used frequency methods and found that the GEV index method possessed predictive characteristics superior to the other methods tested.

Another highly regarded method is the TCEV. Rossi, et al. (*11*) applied the TCEV with the maximum likelihood method of parameter estimation to regional data series.

The purpose of this study was to formulate two alternate methods of regional frequency analysis using Louisiana annual peak streamflows; to compare these methods with the LP3 based upon generalized skew coefficients; to select the best method based upon statistical comparison indices of descriptive capabilities and the ease of use (requiring less physical data); and to compare the selected regional method to the USGS regression equations. The two regional methods investigated are the TCEV (*11* and *12*) and the GEV (*13*), indexed by the method of PWM (9) outlined by Greis and Wood (*8*).

REGIONALIZATION

The State of Louisiana was divided into four hydrologically homogeneous regions. The homogeneous regions within the state were determined by soil, geologic, topographic, climatic, and streamflow similarities. The purpose of this analysis was to divide the state into regions such that the hydrologic response of watersheds within each region is comparable. Thus, the regions should have relatively homogeneous soil and topographic characteristics. In addition, the watersheds within each region should be subjected to similar climatic conditions. Information needed to make the determinations was readily available from previously published sources. The Atlas of Louisiana (*14*) and the General Soil Map of Louisiana (*15*) were used in forming the regional groupings. The Geological Map of Louisiana shows that the state is divided into four general regions by the Mississippi alluvium. The regional groupings were further compared based upon climatic and soils information available. A complete description of the methodology used in determining the homogeneous regions is given in Naghavi, et al. (*16*).

Once preliminary regions had been identified, the annual peak streamflows of gauged watersheds within each region were analyzed for similarities. This was accomplished by plotting the log mean (log QM) of the annual flood series (in log space) against the corresponding drainage area (A) for each watershed in the region. A curve through the points was fitted by standard regression techniques. The regression equations for the four regions are as follows:

SE: $\log Q_M = 2.695\ A^{0.072}$ (1)
$R^2 = .86$
$CV = 3.1$

SW: $\log Q_M = 2.561\ A^{0.076}$ (2)
$R^2 = .84$
$CV = 3.22$

NW: $\log Q_M = 2.836\ A^{0.052}$ (3)
$R^2 = .76$
$CV = 2.509$

NE: $\log Q_M = 2.406\ A^{0.063}$ (4)
$R^2 = .97$
$CV = 1.36$

In analyzing these equations, the coefficient of determination (R^2) represents the percentage of the total variance of the dependent variable (log QM) explained by its relationship with the area. The coefficient of variation (CV) represents a dimensionless measure of the error in the regression fit. Thus, the relationship between log mean annual flood values and drainage areas appears to be well confirmed in these cases. Watersheds that fell outside this linear trend (by visual inspection) would not be expected to behave similarly to the other basins within the region. In this way, minor revisions to the regional groupings were determined. These regional boundaries are delineated in Figure 1. The locations of all the stream gauges used in the analysis are also plotted on this figure.

DATA

The data for all stream gauges in the physiographical regions of the state with a minimum of 20 years of systematic record was obtained. A few gauges which fell in the general physiographical regions of Louisiana, but were physically located outside state boundaries, were included in the analysis. Locations of all gauges are shown in Figure 1. The data set consisted of 110 long-term, continuous stream gauge records. These records were then screened for possible anomalies resulting from flow diversions, interbasin transfers at high discharges, or missing records. The records which passed this screening were further analyzed for consistency within the homogeneous regions previously defined. It was ascertained that gauges with drainage areas less than 10 square miles generally did not follow the trend of the rest of the data. Therefore, these records were excluded from the analysis. In the end, 85 gauges passed the screening process and formed the data base for the rest of the analysis. The number of gauges in each region were as follows: 24 in the Southeast region, 32 in the Southwest region, 24 in the Northwest region, and five in the Northeast region. A listing of these gauges along with their drainage areas, periods of record, and skews of the log-transformed data is given in Tables 1 through 4.

FLOOD FREQUENCY ANALYSIS

Regional frequency analyses were performed for each homogeneous region based upon all of the screened annual peaks observed in each region. Flood frequency analyses consist of fitting preselected probability distributions to recorded flood data at individual sites, and then estimating the magnitude (quantile) of flood events corresponding to given exceedance probabilities from the distributions. However, the use of the observed data from only the site under investigation can result in unreliable estimates. This is especially true when the length of record at a single site is relatively short when compared with the recurrence intervals to be estimated from the data. For instance, it may be necessary to estimate the 100-year flood from only 20-30 years of record at an individual site. This is the reason that regional flood frequency analysis has received much attention in the recent engineering literature. Regional frequency analysis consists of using data at other sites, which are considered similar to the site in question, to augment the information at an individual site. This reduces the uncertainty inherent in short, systematic records.

Two Component Extreme Value - The TCEV has been derived as a mixture of two exponential marginal distributions from a Poisson counting process (*10*). Thus, its cumulative distribution function (CDF) can be expressed as the product of two extremal distributions:

$$F(x) = \exp[-\lambda_1 \exp(- x/\theta_1) - \lambda_2 \exp(- x/\theta_2)] \qquad (5)$$

where λ's and θ's are the shape and the scale parameters respectively, and F(x) is the non-exceedance probability of an event of magnitude x. This distribution attempts to account for the possibility that two distinct sub-distributions make up the total annual distribution of flood peaks. In cases where the marginal distributions can be shown to be exponential or the asymptotic distribution is Gumbel, the TCEV has been shown to give accurate results.

In the original formulation (*11*), TCEV parameter estimation was accomplished by maximum likelihood. However, Arnell and Gabriele (*17*) found that maximum likelihood estimates of TCEV regional parameters sometimes failed to converge and resulted in relatively variable quantile estimates. Therefore, in this study the TCEV was fitted to the regional data series by the method of maximum entropy proposed by Fiorentino, et al. (*12*). This method has been shown to be computationally less cumbersome and more reliable than the maximum likelihood procedure originally proposed by Rossi, et al. (*11*).

In the regionalization technique, two dimensionless parameters, $\theta = \theta_2/\theta_1$ and $\lambda = \lambda_2/\lambda_1^{1/\theta}$, are assumed to be constant for the homogeneous region, and the other two parameters, θ_1 and λ_1, are allowed to vary from site to site. The parameters θ_1 and λ_1 represent the basic component and θ_2 and λ_2 represent the outlying component of the compound distribution. The parameters θ and λ represent the regional component of the distribution. Conceptually, θ_1 and λ_1 represent the smaller, more frequently occurring events which would be expected to vary from site to site within the region. θ_1 essentially represents the mean flood for this distribution, while λ_1 represents the number of floods per year over the watershed. The parameters θ and λ represent the regional distribution, which are expected to behave similarly within the homogeneous region. As in the previous case, θ represents the mean flood of this distribution, while λ represents the number of such events occurring per year. The maximum entropy procedure results in four equations to be solved for the four unknowns described above.

Generalized Extreme Value - The index method has been receiving a great deal of attention in recent engineering literature, although its basic premise was outlined by Dalrymple (6) almost 30 years ago. In this procedure, an assumed distribution is fitted to the observed flood series at each site in a hydrologically similar region. The statistics (or parameters) of the distributions at each location are standardized by dividing by the at-site mean in each case. Regional estimates of the parameters are obtained by averaging the parameter estimates for the region. These regional parameters are then used to generate flood quantiles for the site of interest and are subsequently readjusted to account for the differences in scale between watersheds.

The index method has gained popularity since the introduction of the probability weighted moments method of parameter estimation by Greenwood, et al. (*9*). It has recently been used by Greis and Wood (*8*), Landwehr, et al. (*10*), and Stedinger (*7*). The PWM, which is usually applied only to distributions that can be expressed in inverse form such as Gumbel and GEV, offers a method of parameter estimation that may be more robust and less biased than the traditional methods. The GEV can be expressed in inverse form as (*13*):

$$x(F) = \xi + \alpha(1 - (-\log F)^{k})/k \qquad k \neq 0$$
$$= \xi - \alpha \log(-\log F) \qquad k = 0 \qquad (6)$$

where F is the nonexceedance probability corresponding to the quantile x, and ξ, α, and k are the parameters of the distribution. When k = 0, the GEV reduces to the extreme value type I (EV1). The index procedure is applied by calculating the PWM from the observed data at each site in the region. The PWM are standardized at each site by dividing each PWM by the at-site mean. The standardized PWM are then averaged over all of the sites in the region. These regional average PWM are used to obtain the parameters of the regional GEV distribution. Regional indexed quantiles can be generated for any exceedance probability (1-F) from Equation 6. These quantiles are then rescaled for any site of interest by multiplying by the at-site mean. The at-site mean flood can be determined from the plot of log mean Q versus drainage area for any gauged or ungauged site.

Log Pearson Type 3 - The regional procedure recommended in the IACWD guidelines (5) involves the LP3 distribution. The probability density function (pdf) of the LP3 is:

$$f(x) = \frac{1}{|a| \; x \, \Gamma(b)} \left[\frac{\ln(x) - c}{a} \right]^{b-1} \exp\left[- \frac{\ln(x) - c}{a} \right] \tag{7}$$

where x is the raw (untransformed) flood magnitude, and a, b, and c are the scale, shape, and location parameters, respectively. $\Gamma(b)$ is the gamma function of the parameter b where b is always positive. The LP3 density function is very flexible and can take many different forms. Parameters a, b, and c are estimated by the method of logarithmic moments (*4*).

The variability of the skew coefficient of the station record is sensitive to extreme events and sample size, thus making it difficult to obtain accurate skew estimates from small samples. For this reason, the generalized skew values are used in place of at-site skew values, or the at-site skew values are adjusted using the generalized skew when skew estimates are to be obtained from small samples. A generalized skew coefficient for each region was obtained from the arithmetic mean of the station skew values. The generalized skew value was then used to estimate LP3 parameters. Regional quantiles are generated at each site of interest by using the at-site mean and standard deviation of the logarithms of the observed data series, together with the regionalized skew value. In this study, in contrast to Bulletin 17B (*5*), only the generalized skew values were used.

COMPARATIVE ANALYSIS

Each of the three regional frequency methods was fitted to the data by the procedures previously described using the observed annual series at the 85 stream gauges. The purpose of this analysis was to select the most accurate method, based on the comparisons to the observed data, among the three methods. At-site quantiles were generated from the regional distributions for each gauge location in the study. These quantiles were compared to the observed data at each site in terms of standardized root mean square error (SRMSE). The SRMSE between observed and predicted values is given by:

$$SRMSE = [(1/N) \sum_{i=1}^{N} ((x_i - \hat{x}_i)/\bar{x})^2]^{1/2} \quad (9)$$

where

x_i = observed value of standardized variate x

$\hat{x}_i$ = predicted value of variate at the same probability point as xi

N = sample size

$\bar{x}$ = sample mean - used to standardize the root mean square error (RMSE)

$\hat{x}_i$ is calculated as $F^{-1}(p(x_i))$, where $p(x_i)$ is approximated by the Weibull plotting position formula. The RMSE is standardized by dividing by the sample mean to remove the effects of scale and to make the comparison meaningful. This index only measures the descriptive capability of the methods. That is, SRMSE is an index of the ability of each method to interpolate the observed data at each gauged location.

The SRMSE results for the three methods are given in Tables 1 through 4. As can be seen from these results, no one method gave superior fits for all four regions. The TCEV resulted in the lowest SRMSE for the Southwest region, the LP3 method gave superior results in the Southeast region, while the GEV resulted in superior fits to observed data in both the Northwest and Northeast regions. However, the difference between the methods did not appear to be significant in many cases. The TCEV and LP3 methods performed about equally in the Southeast region and both performed significantly better than the GEV for this region. All three methods performed about the same in the Southwest region where the average SRMSE differences between the methods was less than 10 percent. In the Northwest region, the GEV and TCEV performed evenly and resulted in significantly better fits to observed data than did the LP3, while the LP3 and GEV outperformed the TCEV by a considerable margin in the Northeast region. Thus, each method was clearly inferior to its counterparts in one region, was clearly superior in one region each, and performed about equally well elsewhere. It would appear difficult to choose between them on a statistical goodness-of-fit basis.

Based on the extreme ease with which the GEV can be extended to ungauged sites when compared to the other methods, it was selected as the superior method. The only geomorphological relationship needed is between the indexing factor (mean flood, Q_M) and basin characteristics. Since past studies have shown that the mean flood is highly correlated to the drainage area (as shown by Equations 1-4), a simple Q_M versus drainage area relationship is all that is required to apply this method to ungauged sites.

Another important factor in the selection of the GEV is that parameter estimation is done by PWM. It has been shown by Greenwood et al. (*9*) and Hosking et al. (*13*), that PWM are more robust and less biased than conventional methods. Thus, estimates obtained by this method should be better in these respects than those obtained from other methods. This was confirmed in a study by Potter and Lettenmaier (*2*).

REGIONAL COMPARATIVE ANALYSIS

Regional comparative analysis was performed between the USGS equations and the GEV. The combined records of all the gauges within each region comprised the data base for that particular region. The GEV regional procedure was applied by using Equations 1 through 4 to approximate the means at each location in the study. Using the mean values, the at-site quantiles corresponding to recurrent intervals of 2, 5, 10, 25, 50 and 100 years were recalculated from the regional values. These quantiles were then compared to the observed data at each site by the SRMSE. The regional average SRMSE results are given in Table 5. The table shows that the error in the procedure averages about 48 percent for the Southeast, Southwest and Northwest regions, and about 13 percent for the Northeast region. However, the error in the quantile estimates from the distribution itself will be greater for the Northeast region because of the small data base.

Table 5 also shows the average SRMSE values obtained by a comparison of the USGS equations with the observed data at each site in each region. The USGS equations were derived by fitting the LP3 distribution to the data representing 217 gauging stations with more than 10 years of recorded data. Based on the results of this analysis, a regression equation was developed for quantile estimation. The general form of this equation is:

$$\log Q_x = \log a + w \log A + y \log (P - 35) + z \log S \qquad (8)$$

where

Q_x = Peak discharge for a given recurrence interval (x)
a = Regression constant
A = Drainage Area (mi^2)
P = Average annual precipitation (in)
S = Average stream channel slope (ft/mile)
w, y, z = Regression coefficients

This equation was calibrated for quantiles corresponding to recurrence intervals of 2, 5, 10, 25, 50 and 100 years using the LP3 results. Thus, the comparison of this method with the regional GEV can only be based on the analyses of these quantiles.

The results show, in every case, that the GEV procedure showed a significant improvement over the USGS equations in terms of fit to the observed data.

It is assumed that if a method accurately describes the data at gauged sites, it will probably describe the ungauged data within a hydrologic homogeneous region. Of course, a frequency method must not only describe the observed data accurately, but should be capable of extending the data as well. Many times quantiles, which are beyond the systematic record, must be predicted. The SRMSE index does not directly measure this ability. However, studies by Greis and Wood (*8*), Hosking, et al. (*13*), Landwehr, et al. (*10*), and Potter and Lettenmaier (*2*), have examined the predictive capabilities of various regional and at-site frequency techniques. Based on Monte Carlo or Boot Strap sampling methods, the studies concluded that methods based on probability weighted moments possessed asymptotic characteristics in terms of bias and variability of long-term quantile estimates that were superior to other conventional methods.

VERIFICATION OF RESULTS

In order to verify the GEV regional procedure, the procedure was evaluated using short-term data not used in the development and calibration of the distribution. Five gauges were selected in each region, except in the Northeast where only one gauge was available. Because of the lack of adequate data in the Northeast region, verification of results would not be meaningful for this region. The sites from the other three regions were selected in order to gain maximum coverage of each region. The locations of these gauges are shown by the open circles on the regional map in Figure 1.

In performing this analysis, the sites were treated as ungauged areas. The mean floods were estimated from the appropriate drainage area plots and used to scale the respective regional quantiles for each test site. The regional at-site quantiles were then compared to original data for each gauge record by SRMSE. Each gauge used in this phase of the study had between 15 and 20 years of record. Thus, the SRMSE values are based on those number of events in each case.

The SRMSE values shown in Table 6 result from analysis of each site by the GEV regional method, the at-site LP3, and the USGS equations. The LP3 distribution is used for the comparison, considering that the at-site LP3 would give the best possible distributional fit to the observed data. Analysis of the results in the table shows that the average SRMSE value by the GEV regional method for the Southeast region was .278, for the Southwest region was .483, and for the Northwest region was .546. Comparison of these values with those given in Table 5 reveals that the method performed as well or better with the new data as with the data used in its derivation. Furthermore, the GEV method was generally superior by a wide margin to the USGS equations and even compared fairly well with the at-site LP3 in two regions. These results suggest that the method can be used confidently throughout the regions delineated on Figure 1.

LIMITATIONS

The applications of the results of this study are limited by the range of data available. First, the procedure should not be applied outside the physical bounds of the areas where gauge data were available. These areas are delineated on Figure 1 and should be strictly adhered to. This eliminates the coastal zones and the Mississippi alluvium (except the Northeast region) from applicability. Second, the range of drainage basin sizes and the corresponding land uses available in each region also limit the application of this procedure. Note that the drainage basins represent undeveloped conditions. The drainage areas of each basin used in the study are given in Tables 1-4. The method should not be applied to drainage areas smaller than 10 square miles, because preliminary work clearly showed that these areas respond differently to a storm event than do the larger areas. A sufficient number of these small gauges was not available on which to perform a separate study.

CONCLUSIONS

The results of this study indicate that the GEV distribution fitted by the method of probability weighted moments describes the annual flood series of Louisiana streams better than other methods examined in this study. Verification results revealed that the GEV procedure describes data better than the USGS method in the vast majority of cases. Past Monte Carlo studies have shown that this procedure also possesses superior predictive capability in the cases for which flood estimates are required that may be out of the range of the recorded data. Therefore, based upon the results of this analysis as well as previous studies cited in this report, it is concluded that the GEV/PWM procedure results in overall superior flood estimates from both descriptive and predictive points of view and can be used confidently throughout the regions delineated in Figure 1. GEV/PWM is easily extended to the case of ungauged watersheds by using the relationship between the mean of the observed data (indexing factor) and corresponding drainage area of the watershed (Equations 1 - 4) for each region. However, this procedure should not be applied outside the physical bounds of the areas used in its development and verification. Particularly, the method should not be applied to drainage areas smaller than 10 square miles, because preliminary work clearly showed that these areas respond differently to a storm event than do the larger areas.

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TABLE 1 - PERTINENT DATA OF WATERSHEDS IN SOUTHEAST LA

STATION No.	AREA IN (sq.mile)	YEARS OF OBS.	SKEW OF LOG TRAN. DATA	SRMSE		
				GEV	TCEV	LP3
02492000	1213	50	-0.08	0.256	0.317	0.327
02492360	175	21	-0.02	0.149	0.107	0.111
02490105	73	22	0.12	0.209	0.222	0.215
02491500	990	66	-0.34	0.171	0.186	0.201
02491700	44	20	-0.69	0.280	0.236	0.188
02491350	42	21	0.70	0.186	0.188	0.179
02490000	12	20	-0.63	0.357	0.319	0.173
07378500	1280	49	-0.12	0.122	0.142	0.130
07375222	46	22	-0.69	0.324	0.227	0.244
07380160	20	33	-0.34	0.298	0.111	0.084
07375170	88	20	0.33	0.144	0.145	0.169
07376000	247	47	-0.20	0.129	0.152	0.108
07376500	80	44	-0.08	0.183	0.097	0.090
07375500	646	49	-0.14	0.157	0.211	0.193
07377300	884	35	0.17	0.159	0.110	0.125
07376600	14	32	-0.89	0.394	0.122	0.081
07375480	91	20	-0.23	0.191	0.200	0.166
07375000	103	44	-0.13	0.266	0.244	0.164
07377000	580	39	-0.44	0.183	0.150	0.198
07375800	90	32	0.24	0.439	0.411	0.379
07375307	52	22	0.20	0.406	0.329	0.262
07378000	284	44	-0.53	0.189	0.069	0.090
07377500	145	45	-0.22	0.215	0.171	0.179
07373500	35	21	-0.32	0.172	0.110	0.104
	REGIONAL AVG.		-0.21	0.232	0.191	0.173

TABLE 2 - PERTINENT DATA OF WATERSHEDS IN SOUTHWEST LA

STATION No.	AREA IN (sq.mile)	YEARS OF OBS.	SKEW OF LOG TRAN. DATA	SRMSE		
				GEV	TCEV	LP3
07386500	19	28	-1.33	0.346	0.100	0.110
07381800	68	33	-0.22	0.169	0.168	0.105
08012000	527	49	0.95	0.188	0.247	0.321
08010000	131	49	-0.96	0.355	0.155	0.087
08011800	44	24	-0.32	0.153	0.110	0.109
08015500	1700	49	0.46	0.215	0.255	0.351
08013500	753	49	-0.17	0.104	0.098	0.165
08014500	510	48	0.16	0.656	0.642	0.720
08014000	171	27	0.29	0.263	0.314	0.323
08014200	94	37	-0.02	0.370	0.387	0.422
08013000	499	44	-0.46	0.139	0.131	0.113
08016800	177	31	0.08	0.186	0.272	0.328
08016400	148	39	0.21	0.161	0.179	0.168
08016600	82	38	0.36	0.278	0.211	0.161
08015000	238	31	0.02	0.262	0.218	0.181
08014800	120	24	-0.30	0.111	0.129	0.121
08014600	26	20	0.13	0.249	0.284	0.270
08013800	10	21	-0.50	0.116	0.150	0.103
08031000	83	34	-0.78	0.221	0.199	0.147
08030000	69	32	-0.17	0.199	0.156	0.145
08028700	13	26	0.68	0.173	0.253	0.332
08029500	128	36	0.84	0.453	0.445	0.514
08028000	365	36	0.38	0.430	0.352	0.301
08025850	10	20	0.80	0.306	0.371	0.437
08025500	148	31	0.72	0.461	0.419	0.457
08023000	97	28	-0.25	0.140	0.136	0.119
07354000	21	30	-0.71	0.353	0.176	0.118
07353990	37	22	-0.02	0.326	0.285	0.219
07351700	20	26	0.36	0.978	0.981	1.050
07351500	66	49	-1.12	0.121	0.095	0.219
07351000	79	43	-1.12	0.192	0.136	0.270
07344450	81	31	0.05	0.354	0.372	0.352
	REGIONAL AVG.		-0.06	0.282	0.263	0.273

TABLE 3 - PERTINENT DATA OF WATERSHEDS IN NORTHWEST LA

STATION No.	AREA IN (sq.mile)	YEARS OF OBS.	SKEW OF LOG TRAN. DATA	SRMSE		
				GEV	TCEV	LP3
07373000	51	46	0.03	0.285	0.295	0.164
07372500	92	31	1.15	0.518	0.566	0.769
07372200	1899	30	-0.31	0.124	0.142	0.208
07370750	48	30	0.53	0.138	0.229	0.318
07372110	24	23	0.72	0.443	0.433	0.517
07372000	654	42	-1.10	0.320	0.254	0.275
07370500	271	30	-1.07	0.194	0.195	0.280
07371500	355	49	-0.44	0.074	0.148	0.123
07366420	113	22	0.16	0.462	0.463	0.533
07365000	355	28	-0.34	0.162	0.185	0.140
07364870	47	22	-1.27	0.173	0.130	0.230
07365500	178	30	0.96	0.547	0.561	0.765
07366000	462	43	0.12	0.385	0.424	0.524
07366200	208	32	-0.13	0.357	0.395	0.431
07364700	141	22	1.28	0.737	0.725	0.875
07362100	385	49	0.04	0.176	0.203	0.327
07365800	180	29	0.39	0.969	0.894	1.044
07352000	154	47	-0.12	0.183	0.240	0.097
07352500	423	43	0.17	0.337	0.289	0.147
07348700	605	30	-0.03	0.173	0.237	0.256
07349500	546	49	-0.36	0.285	0.172	0.122
07348725	33	22	-1.71	0.314	0.213	0.377
07348800	67	24	-0.01	0.094	0.165	0.212
07353500	47	26	-0.17	0.311	0.270	0.180
	REGIONAL AVG.		-0.06	0.323	0.328	0.380

TABLE 4 - PERTINENT DATA OF WATERSHEDS IN NORTHEAST LA

STATION No.	AREA IN (sq.mile)	YEARS OF OBS.	SKEW OF LOG TRAN. DATA	SRMSE		
				GEV	TCEV	LP3
07369500	309	51	-0.58	0.068	0.943	0.038
07370000	782	60	-0.43	0.102	1.270	0.104
07368500	42	28	-0.55	0.048	1.070	0.075
07364500	1645	52	-1.93	0.071	1.103	0.097
07364190	1170	45	-1.92	0.089	1.088	0.101
	REGIONAL AVG.		-1.08	0.076	1.095	0.083

TABLE 5 - MODEL COMPARISON BASED ON SRMSE FOR EACH REGION

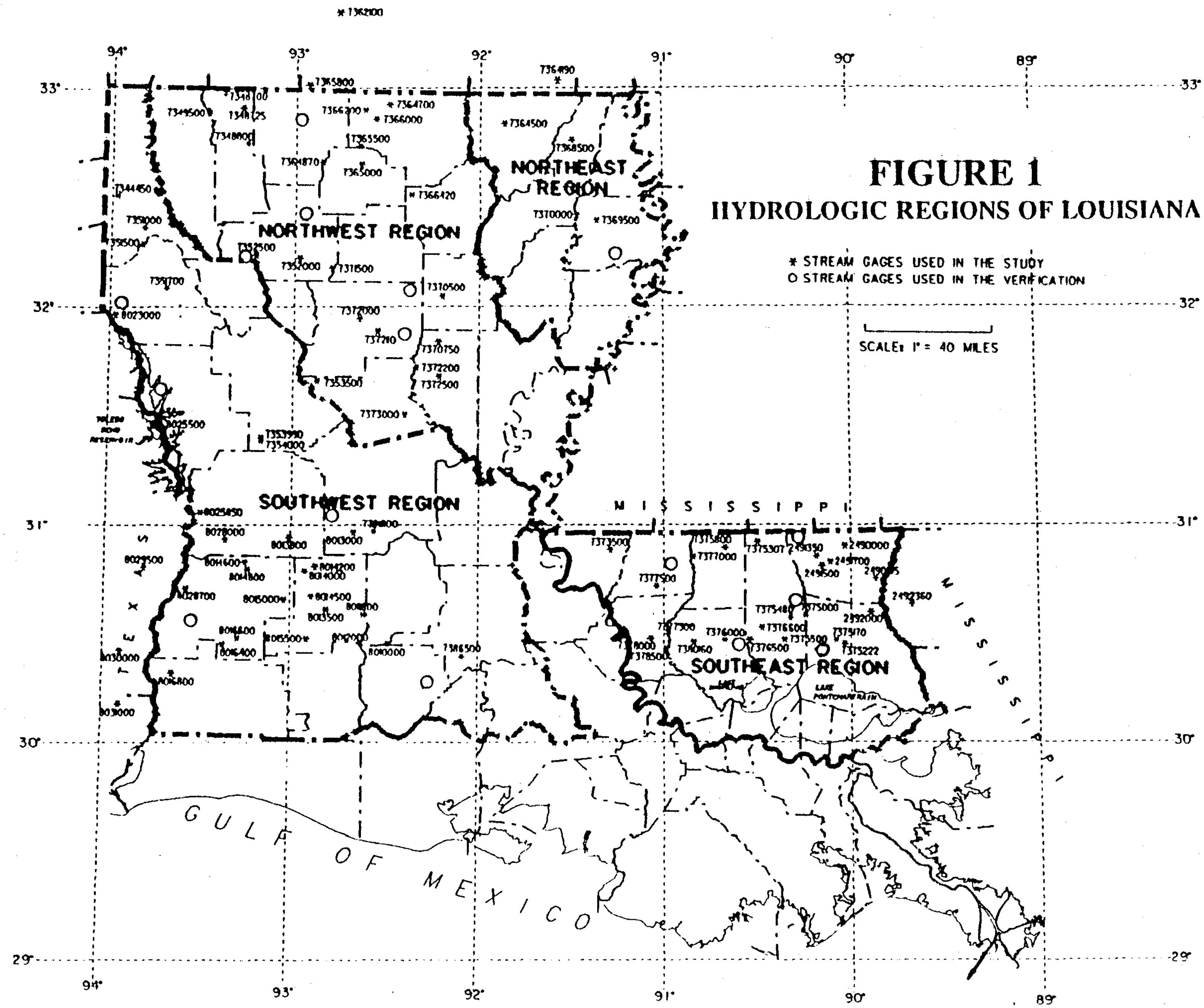
REGION	REGIONAL AVG. SRMSE		% DIFF.
	GEV/PWM	USGS/REG	
SE	0.468	0.536	+ 15
SW	0.491	0.695	+ 42
NW	0.532	0.872	+ 64
NE	0.132	0.563	+ 327

TABLE 6 - VERIFICATION OF REGIONAL GEV MODEL

REGION	STATION NO.	SRMSE		
		REGIONAL GEV/PWM	USGS REGRESSION	AT-SITE LP3
SE	07375050	0.220	0.433	0.201
	07376520	0.230	0.623	0.140
	07375463	0.314	0.315	0.339
	07377190	0.449	0.407	0.248
	02491200	0.176	0.307	0.169
	AVG.	0.278	0.417	0.219
SW	08010500	0.435	--	0.147
	08012900	0.578	0.824	0.277
	08016700	0.661	0.158	0.356
	08022765	0.515	0.389	0.102
	08024000	0.225	0.530	0.267
	AVG.	0.483	0.475	0.230
NW	07370700	0.402	0.520	0.339
	07370600	0.145	0.113	0.161
	07365300	0.888	1.140	0.682
	07352700	0.638	1.291	0.367
	07351980	0.658	1.151	0.155
	AVG.	0.546	0.843	0.341

FIGURE 1: Hydrologic Regions of Louisiana

FIGURE 1
HYDROLOGIC REGIONS OF LOUISIANA



Minutes of Introductory Meeting
Intergovernmental Precipitation Frequency Study
for the Southwest States
December 5, 1991
Arizona Department of Transportation
Phoenix, Arizona

1. INTRODUCTION. The meeting was convened in the Executive Conference Room of the Arizona Department of Transportation Offices, 2612 South 46th Street, Phoenix, Arizona, December 5, 1991. Joe Warren, ADOT Senior Research Engineer, assigned to monitor this study, opened the meeting at 8:30 a.m. by welcoming the attendees and making a few housekeeping announcements.

2. ATTENDEES. See Attachment 1.

3. AGENDA. Marshall Hansen of the National Weather Service (NWS) organized the meeting according to the agenda (Attachment 2). No changes were suggested to change the agenda.

4. PURPOSE OF THE MEETING. Marshall Hansen discussed the basic reason for calling this introductory meeting (Attachment 3). Primarily these were to meet all the parties contributing to this study, review NWS experience in precipitation frequency studies, present some results from recent studies by the NWS and provide everyone an opportunity to ask questions or discuss their interests and needs relative to this project.

5. REVIEW OF STUDY BACKGROUND. Marshall Hansen showed a number of viewgraphs in describing the background and long record of experience (about 50 years) the NWS has had with providing precipitation frequency studies. He listed the evolution of such studies applicable to the southwest and western states showing examples of the coverage and degree of analyzed detail. He also showed a breakdown of the frequency studies currently applicable to the southwest for three duration categories (Attachment 4). Because some of these studies are more than 20 years old and are incompatible with each other, there is an obvious need to update studies for the region, as part of an overall revision planned for the entire United States. A number of problems encountered as a result of current needs were discussed (Attachment 5), that strongly support the present effort to revise and update these data. It was noted that a political consideration exists that if the Federal sector does not provide an update, numerous uncoordinated independent agencies will undertake such studies for their own subregions. If left alone, these independent

studies would cause considerable problems at geographical boundaries, and, where hydrologic concerns crossed such boundaries, results may represent differing analysis bases and techniques.

6. PROPOSED STUDY OUTLINE. Marshall Hansen discussed briefly the outline for the Semi-Arid Southwest Precipitation Frequency

Study (Attachment 6) and noted that primary benefits are provided through the use of new statistical techniques, incorporation of Geographical Information System (GIS) capabilities, and the provision of results both as hard copy maps and in digital formats. These and other benefits are listed in Attachment 7. Marshall noted that the NWS has been criticized for not including an independent peer review as part of the release procedure for past documents. In an effort to improve this image, NWS has appointed an independent advisory group to monitor progress in this study and advise in areas of individual expertise. The members of this group, who were all present at this meeting, are as follows:

Dr. James R. Wallis (Statistical Applications), IBM Research Center, Yorktown Heights, NY

Dr. Robert A. Clark (Hydrology), University of Arizona, Department of Hydrology, Tucson, AZ

Dr. Kenneth Kunkel (Climatology), Illinois State Water Survey, Champagne, IL

Mr. V. Ottozawa-Chatupron (Engineering Applications), Arizona State Land Department, Phoenix, AZ

In addition, there will be an active effort to obtain comments from local users, including the various groups making monetary contributions and from local climatology experts such as state climatologists.

Marshall also pointed out a difference in funding support for this study when compared to previous studies. Past studies have been funded almost exclusively by the Soil Conservation Service, whereas they are unable to bear the entire cost of a new study. Therefore, NWS has resorted to a multi-agency funded program made up of Federal, state and local contributors. Presently, 16 agencies support the southwest study and sufficient funding has been obtained to complete the three-year effort.

Each of the six principle tasks (Attachments 8-13) were reviewed and briefly discussed.

7. REVIEW OF RECENT NWS STUDIES. John Vogel, Chief of the Hydrometeorological Branch of NWS, presented some findings from the Pilot Study initiated three years ago to update precipitation frequency for West Virginia and Pennsylvania. This study has been funded by the Soil Conservation Service and is nearing completion of the draft report. John showed viewgraphs of station distribution, elevation contours and the results of using new statistical techniques. The latter supported selection of the Generalized Extreme Value (GEV) II distribution over others and involved use of L-moment techniques to determine the best fit (see item 9 for brief comments on the L-moment procedure). A comparison (Attachment 14) was shown between the results for 100-year 24 hr from the current study (Pilot Study) and those in Technical Paper No. 40 (Hershfield 1961), the applicable reference study in the eastern United States. Two zones of increased values in the new data are separated by two zones of reduced values relative to Technical Paper No. 40. These variations range between minus 20 and plus thirty percent.

A recent study was made by NWS of the updated precipitation frequency for two parishes in southern Louisiana (Orleans and Jefferson), and John discussed the available data and results obtained for the Corps of Engineers. Comparisons were shown between the new results, Technical Paper No. 40 and Hydrometeorological Report No. 35 (applicable to durations of 1 hour and less). The new results are not significantly different than presented in Technical Paper No. 40, but include a little more detail (Attachment 15). John noted that the new results agree better with Technical Paper No. 40 than with Hydrometeorological Report No. 35 for one hour.

8. REVIEW OF CURRENT PROGRESS. John Vogel described some of the data processing and quality control that is being done for the Southwest Study. A limited effort has been ongoing in this area since April 1991 with most of the official data (available to NWS) for Arizona completed at this time. Processing of data for the other states will be started soon. John noted that the level of effort for this study will be significantly increased now to maintain the time schedule proposed for the study. A question was asked relative to what differences might be expected between results from the Pilot Study and those of the current study. John responded that he expected to see most changes occur at higher elevations. Another question asked if the new techniques are much better than those used in Technical Report No. 40. John said the new techniques give a more accurate result and a better one.

In order to improve the spatial analyses of this study, NWS intends to collect and process as much non-NWS data as available. Two types of data are of interest here, the first is from stations with at least 15 years of record that can be used in the frequency analyses and the second is dense-network data from which depth-area and duration information can be obtained. The Arizona State Climatological Laboratory has submitted a proposal to NWS to collect, format and otherwise process such data for Arizona and some stations in northern Mexico (Sonora). NWS has considered the proposal and intends to implement it early in the study. Similar, but perhaps not as complete sets of non-NWS data will be sought for the other states through contacts with the respective state climatologists. The California Department of Water Resources has offered to make their data available to NWS, as has the various water conservation districts that are participating in this study.

9. COMMENTS ON THE L-MOMENT TECHNIQUE. Jim Wallis presented a short overview on the development of and benefits from use of L-moment techniques in frequency analysis. The procedures have evolved over the last 10 years and are the joint product of studies by Wallis and John Hosking, also of IBM. Jim said a particular advantage is that the statistics are unbiased for small samples and that the data are uniformly distributed about a point and converge to that point (the real value) as the sample size increases. The procedure provides automated tests to check the data for outliers and homogeneity. He notes that errors are not likely to come from the distribution. Jim also noted that usage of this technique is spreading and mentioned some examples of applications in Canada and New Zealand. Copies were made of two IBM research notes on the subject and are attached to these minutes.

10. DISCUSSION. The discussion was opened to those attending to comment on the work being done, the proposed plan of study, or to provide information on individual or agency needs relative to types of results expected, specific formats or other questions. A number of questions were asked that dealt with data and how it was analyzed, quality controlled and its accuracy. Some of the specific comments were:

- Confidence levels need to be determined for results to give engineers an idea of the quality of the analysis.

- Need to output maps or gridded data on a CD ROM because of convenience and replaceability.

- Since some users do not have access to computers, it is still necessary to provide hard copy results.

- Need to improve depth-area analysis over that currently available. It was also asked that temporal distributions be given for various storm types and degrees of urbanization.

- Some applications use duration information longer than 24 hours; e.g., detention basins, and it would be helpful to include discussions of how storms follow one another; frequency, relative magnitudes, etc. John asked that the various users in attendance consider what durations beyond 24 hr would be useful and let him know by January 1991.

- There was a request that results include information on the elevation impact on temporal/spatial information.

- NWS attention was brought to the fact that most field engineers use information based on section, township and range rather than latitude, longitude. Resolution of this issue is immediate for those with access to a GIS capability, but could be facilitated for others by some sort of acetate overlay. Towns, highways and rivers can be handled similarly. In addition, it would be possible to have a central source print the information with different backgrounds for the same nominal fee.

- A question was asked regarding information for "within"-storm events as opposed to "among"-storm events. Within storm implies all durations come from the same storm. The question asked for results to provide information regarding ratios of precipitation within the same storm.

- A question was raised about interest from Nevada (Clark County, specifically) where it was claimed a 1.44 multiplier is applied to NOAA Atlas 2 values. NWS has not made contact with Clark County to date.

11. <u>SUMMATION</u>. Marshall Hansen presented the time lines for the three-year study (Attachment 16). They are the same as presented in the NWS proposal; however, because of delays in completing the intergovernmental agreement for the pooled-funded study with the State of Arizona, it was considered necessary to slide the times for initiating and completing the study. Discussion at this meeting resulting in mutual agreement that the official start of study would be October 3, 1991, when the pooled-fund agreement was signed, and that the completion would be September 1994.

The meeting was concluded at 4:45 p.m., with the date for the next meeting left unspecified, but in the time frame of mid-May to early June 1992.

Attachments

Attachment 1

ATTENDEES

NAME	AGENCY	LOCATION
Joe Warren	ADOT/ATRC	Tempe, AZ
Cliff Anderson	AMAFCA	Albuquerque, NM
Arlo Waddoups	FHWA	San Francisco, CA
Marshall Hansen	NWS/OH	Silver Spring, MD
Ken Guidry	San Ber. Co. FCD	San Bernadino, CA
Lou Schreiner	BUR	Denver, CO
Herbert Verville	ASU/geog.-clim.	Tempe, AZ
Sandra Brazel	ASU/geog.-clim.	Tempe, AZ
Carol Davis	Maricopa FCD	Phoenix, AZ
Robert Clark	UA Dept. of Hydrol.	Tucson, AZ
Jim Wallis	IBM Res., Math. Sci.	Yorktown Hts., NY
Ken Kunkel	ISWS, Off. of Appl. Cl.	Champaign, IL
John Vogel	NWS/OH	Silver Spring, MD
Francis Peairs	Rivers Co. FCD	Riverside, CA
Ray Jordan	ADOT/UHS	Tempe, AZ
George Lopez-Cepero	ADOT/Drainage	Tempe, AZ
Erich Korsten	Cochise Co. FCD	Bisbee, AZ
Elmer Claycomb	Yavapai Co. FCD	Prescott, AZ
V. Ottozawa-Chatupron	Ariz. St. Land Dept.	Phoenix, AZ

#609

AGENDA

SOUTHWEST PRECIPITATION FREQUENCY STUDY
SECOND MEETING--TEMPE, ARIZONA
JUNE 10, 1992

I. Introductory Remarks

II. Data Acquistion

III. Software Development

 A. Hourly Data

 B. Daily Data

IV. Data Quality Control

V. Temporal Trends

VI. Seasonality

VII. Storm Analysis

VIII. Personnel

Enclosure 1 - Agenda.

/odb/nm/snot35 85 prec

Station : 08S01S, FRISCO DIVIDE
------- Unit = inches

day	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
1	0.0	3.3	3.7	9.4	12.6	13.0	15.3	17.8	18.1	19.1	22.3	26.5
2	0.2	3.3	3.7	9.4	12.6	13.0	15.4	17.8	18.1	19.1	22.3	26.5
3	0.8	3.3	3.7	9.4	12.6	13.0	15.4	17.8	18.1	19.1	22.6	26.5
4	1.3	3.3	4.2	9.4	12.6	13.0	15.4	17.8	18.1	19.1	22.6	26.5
5	1.6	3.3	4.7	9.6	12.6	13.2	15.4	18.1	18.1	19.1	22.8	26.5
6	1.7	3.3	4.7	9.6	12.6	13.3	15.4	18.1	18.3	19.1	23.1	26.5
7	1.8	3.3	4.7	9.6	12.6	13.3	15.4	18.1	18.3	19.1	23.1	26.5
8	1.8	3.3	4.7	9.6	12.6	13.3	15.4	18.1	18.5	19.1	23.1	26.5
9	1.8	3.3	4.7	9.9	12.6	13.3	15.4	18.1	18.5	19.1	23.5	26.5
10	1.8	3.3	4.7	9.9	12.6	13.3	15.4	18.1	18.5	19.1	23.6	26.5
11	1.8	3.3	5.2	9.9	12.6	13.3	16.6	18.1	18.5	19.1	23.8	26.5
12	2.1	3.3	5.6	10.3	12.6	13.3	16.6	18.1	18.5	19.1	24.6	26.5
13	2.1	3.3	6.0	10.3	12.6	13.9	16.6	18.1	18.5	19.5	25.5	26.5
14	2.1	3.3	6.4	10.3	12.6	14.0	16.6	18.1	18.5	19.5	25.5	26.5
15	2.1	3.3	6.8	10.3	12.6	14.1	16.6	18.1	18.5	19.5	25.5	26.6
16	2.1	3.3	6.9	10.3	12.6	14.4	16.6	18.1	18.5	19.6	25.5	26.8
17	2.3	3.3	7.0	10.3	12.6	14.7	16.6	18.1	18.5	19.6	25.5	26.9
18	2.3	3.3	7.0	10.3	12.6	14.9	16.6	18.1	18.5	19.6	25.5	26.9
19	2.3	3.3	7.0	10.4	12.6	14.9	16.6	18.1	18.5	19.6	25.5	27.0
20	2.3	3.3	7.2	10.4	12.6	14.9	16.6	18.1	18.5	19.6	25.5	28.2
21	2.3	3.3	7.2	10.4	12.6	15.1	16.6	18.1	18.8	20.0	25.5	28.4
22	2.5	3.3	7.2	10.4	12.7	15.1	16.6	18.1	18.8	20.8	25.5	29.4
23	2.6	3.4	7.3	10.4	12.7	15.1	16.8	18.1	19.0	21.1	25.5	29.4
24	2.9	3.4	7.4	10.7	12.7	15.1	16.8	18.1	19.1	21.1	26.3	28.4
25	3.3	3.6	7.5	10.7	12.9	15.1	17.0	18.1	19.1	21.1	26.3	28.4
26	3.3	3.6	7.6	11.0	13.0	15.1	17.0	18.1	19.1	21.1	26.5	28.4
27	3.3	3.6	7.7	11.0	13.0	15.1	17.1	18.1	19.1	21.3	26.5	28.4
28	3.3	3.7	9.2	11.0	13.0	15.1	17.3	18.1	19.1	21.3	26.5	28.5
29	3.3	3.7	9.4	11.2	---	15.1	17.6	18.1	19.1	21.3	26.5	28.8
30	3.3	3.7	9.4	11.2	---	15.1	17.8	18.1	19.1	21.6	26.5	29.0
31	3.3	---		11.2	---	15.3	---	18.1	---	22.1	26.5	---
mean	2.2	3.4	6.3	10.3	12.7	14.3	16.4	18.1	18.6	20.0	24.9	27.4
max	3.3	3.7	9.4	11.2	13.0	15.3	17.8	18.1	19.1	22.1	26.5	29.8
min	0.0	3.3	3.7	9.4	12.6	13.0	15.3	17.8	18.1	19.1	22.3	26.5

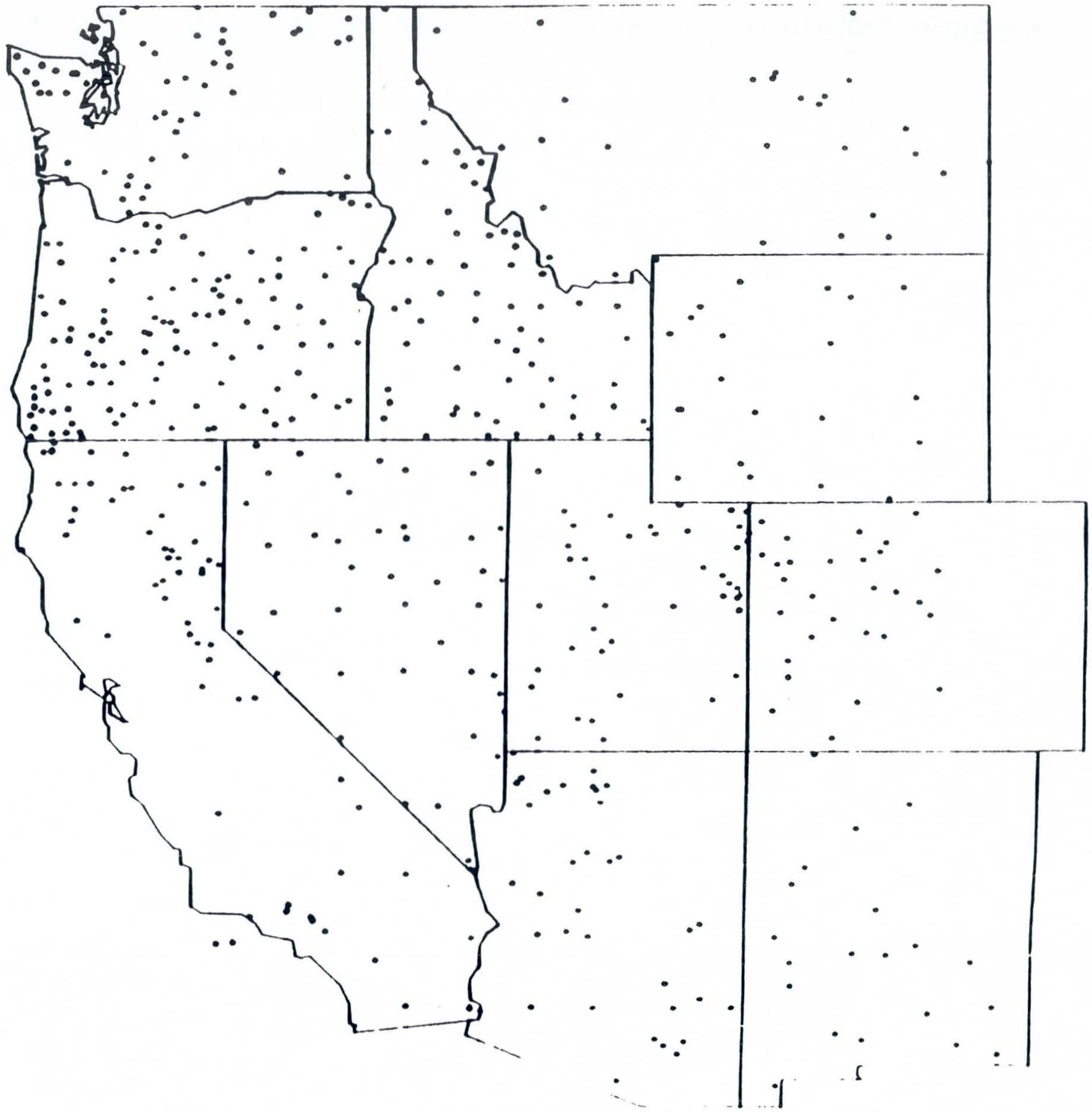
Enclosure 2 - SNOTEL Precipitation Data for Frisco Divide in Water Year 1985 (units: inches).

ACTIVE RAWS SITES IN THE WESTERN U.S.

19 Sep 90

250 Miles

Western Regional Climate Center



Enclosure 3 - RAWS station sites

02-882058	7	1.43	5022	1	0	0	0	5022
02-882058	7	2.39	5022	2	0	0	0	5021
02-882058	7	3.02	5022	3	0	0	0	5021
02-882058	7	3.66	5022	6	0	0	0	5021
02-882058	7	3.87	5022	12	0	0	0	5021
02-882058	7	3.93	5022	24	0	0	0	5020
02-882058	7	3.93	5022	48	0	0	0	5020

Enclosure 4a - Hourly processed precipitation data at Tucson, AZ, for July 1958.

02-88956611	0.12	7481	1	81	16	0	7481
02-88956611	0.15	7481	2	81	16	0	7480
02-88956611	0.15	7456	3	81	16	0	7456*
02-88956611	0.30	7456	6	81	16	0	7456*
02-88956611	0.61	7456	12	81	16	0	7456*
02-88956611	0.86	7481	24	0	0	0	7458*
02-88956611	0.96	7481	48	0	0	0	7456*
02-88956612	0.45	8157	1	0	0	0	8157
02-88956612	0.86	8157	2	0	0	0	8157
02-88956612	1.26	8157	3	0	0	0	8157
02-88956612	1.79	8157	6	0	0	0	8155
02-88956612	2.30	8157	12	0	0	0	8150
02-88956612	3.57	8157	24	0	0	0	8137
02-88956612	4.96	8157	48	0	0	0	8113

Enclosure 4b - Hourly processed precipitation data at Tuweep, AZ, for November and December 1966.

29-0022	1974	210	7	29	145	1	210	7	29	145	1	0	0	0	0	0
29-0022	1974	213	8	1	193	1	213	8	1	113	2	0	0	0	0	0
29-0022	1974	210	7	29	263	1	210	7	29	145	4	0	0	0	0	0
29-0022	1974	210	7	29	396	1	210	7	29	145	7	0	0	0	0	0
29-0022	1974	209	7	28	474	2	210	7	29	145	10	0	0	0	0	0
29-0022	1974	202	7	21	527	9	210	7	29	145	20	0	0	0	0	0
29-0022	1974	207	7	26	583	4	210	7	29	145	30	0	0	0	0	0
29-0022	1974	189	7	8	626	22	210	7	29	145	45	0	0	0	0	0
29-0022	1974	205	7	24	848	6	210	7	29	145	60	0	0	0	0	0
29-0022	1980	118	4	27	240	1	118	4	27	240	1	0	0	0	0	1
29-0022	1980	118	4	27	240	1	118	4	27	240	2	0	0	0	0	1
29-0022	1980	115	4	24	260	4	118	4	27	240	4	0	0	0	0	1
29-0022	1980	115	4	24	260	4	118	4	27	240	7	0	0	0	0	1
29-0022	1980	115	4	24	260	4	118	4	27	240	10	0	0	0	0	1
29-0022	1980	118	4	27	435	1	118	4	27	240	20	-8	0	0	0	1
29-0022	1980	115	4	24	458	4	118	4	27	240	30	-8	0	0	0	1
29-0022	1980	93	4	2	475	26	118	4	27	240	45	-8	0	0	0	1
29-0022	1980	82	3	22	498	37	118	4	27	240	60	-8	0	0	0	1

Enclosure 5 - Daily processed precipitation data showing annual maximum intensities at Abbott 1SE, NM, for 1974 and 1980.

29-0041	1987	211	7	30	161	10-1	0	0	0
29-0041	1987	235	8	23	125	10-2	0	0	0
29-0041	1987	160	6	9	102	10-3	0	0	0
29-0041	1987	303	10	30	96	10-4	0	0	0
29-0041	1987	136	5	16	90	10-5	0	0	0
29-0041	1987	8	1	8	76	10-6	0	0	0
29-0041	1988	211	7	29	379	10-1	0	0	0
29-0041	1988	139	5	18	179	10-2	0	0	0
29-0041	1988	236	8	23	171	10-3	0	0	0
29-0041	1988	255	9	11	90	10-4	0	0	0
29-0041	1988	202	7	20	86	10-5	0	0	0
29-0041	1988	180	6	28	65	10-6	0	0	0

Enclosure 6 - Top six 10-day precipitation intensities at Abiquiu Dam for 1987 and 1988.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

July 28, 1992 W/OH11:JLV

MEMORANDUM FOR: Participants in the Southwest Semi-Arid Precipitation Frequency Study

FROM: W/OH11 - John L. Vogel

SUBJECT: Minutes of the Southwest Semi-Arid Precipitation Frequency Study - Second Meeting

Enclosed is a copy of the minutes for the Second Meeting of the Southwest Semi-Arid Precipitation Frequency Study held on June 10, 1992. These minutes summarizes work through approximately June 1. The Third Quarterly Progress Report should follow in about two weeks.

Enclosure

Minutes--Second Meeting
Semi-Arid Precipitation Frequency Study
Tempe, Arizona
June 10, 1992

Attendance

Joe Warren	ADOT[1]	(602) 965-3548
George Lopez-Depero	ADOT	(602) 255-7481
Ray Jordon	ADOT	(602) 255-7545
Lou Schreiner	USBR[2]	(303) 236-3791
Frank Peairs	RCFCD[3]	(714) 275-1200
John Vogel	NWS[4]	(301) 713-1669

Introductory Remarks

John Vogel opened the meeting about 8:20 am, and thanked Joe Warren for acting as the host. The agenda (enclosure 1) was distributed. It was explained that the major work according to the schedule over the past six months was the development of software for the reduction of the data, hiring of new personnel, and the acquisition of data.

Data Acquisition

Several data acquisitions were made in the six months from December 1991. Hourly and daily precipitation data were obtained in February from the National Climatic Data Center (NCDC) for the years 1989 and 1990. Generally, this means that digitized hourly and daily precipitation data are available from 1948 through 1990. In addition, a reciprocal data agreement between the states and NCDC during the 1950s means that for certain stations in the various states precipitation data were digitized prior to 1948. The number of stations and the number of years vary from state to state. These earlier records are also available from NCDC. In addition to the hourly and daily precipitation data, 15-minute data were obtained from the beginning (about 1971 or 1972) of this data set through 1990. Hourly precipitation stations with 20 years or more of data were highlighted to show the distribution of these data.

Contacts were also made to obtain daily precipitation and snow data from the Soil Conservation Service SNOTEL (SNOwpack TELemetry) network through October 1991. These data were obtained about June 1, 1992, from the Western Regional Technical Center in Portland,

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[1] Arizona Department of Transportation

[2] United States Bureau of Reclamation

[3] Riverside County Flood Control District

[4] National Weather Service

Oregon. An example showing the format of these data are shown in enclosure 2. The data for Frisco Divide in New Mexico were accumulated by water year (1 October through 30 September) in tenths of an inch. The station shows that 0.2 inch of precipitation fell from October 1 to October 2, and an additional 0.6 inch fell between the second and third of October, for an accumulated total of 0.8 inch. Many of the SNOTEL stations are available since 1979, giving 13 years of data. These data are primarily located in the mountainous areas of the West, providing data in regions and elevations which are not normally part of the NCDC data base. For example, in Utah there are 77 SNOTEL stations and 74 of these stations are located above 7,000 feet. These data need to be put into a format compatible with the daily NCDC format.

Contact was made with the Western Region Climate Center (WRCC) in Reno, Nevada, to acquire the hourly precipitation data from the RAWS (Remote Automated Weather System) network. This is one of the few networks that has hourly data available at high altitudes. Examples of these data have been obtained and will be used to supplement hourly data in remote regions of the Southwest. The spatial distribution of these stations is shown in enclosure 3 from Redmond's description of the RAWS network. It is anticipated that these data will be obtained from the WRCC in August.

Software Development

Software is being developed to handle the various nuances of the hourly and daily precipitation data available from NCDC. Examples of how these data are being processed are shown in enclosures 4a and 4b. Enclosure 4a shows processed data for the state of Arizona (02), Tucson WSO Airport (8820) in 1958 (58) and the seventh month (7). The maximum 1-hour duration precipitation was 1.43 inches in Julian hour 5022 (July 29, at the end of the sixth hour). The next three zeros indicate the accumulated amount of precipitation (0), the number of accumulated hours (0), and the number of missing hours (0). The 5022 at the end of the line indicates the beginning Julian hour of the duration. For a 1-hour duration the maximum and beginning hours are identical. The second line indicates that the maximum 2-hour duration was 2.39 inches with the maximum hour of precipitation being in Julian hour 5022, and the beginning Julian hour for this sequence was 5021. Similarly the maximum 3-, 6-, 12, 24, and 48-hour durations are defined. These monthly maximum precipitation intensities will be calculated for each month in a year.

The next example, enclosure 4b, is for Tuweep, Arizona (station number 8895) during November and December of 1966. The maximum 1-hour precipitation was 0.12 inch in Julian hour 7481 (November 8, hour 17). The 81 in the fourth to last column indicates that 0.81 inch of precipitation was accumulated over 16 hours (third to last column), with no missing hours of data. The third line shows that the maximum 3-hour duration was 0.15 inch in Julian hour 7456.

This is the same precipitation intensity shown for the 2-hour precipitation intensity. There was no further precipitation concentrated around Julian hour 7481, and the accumulated data began in Julian hour 7456. If we divide the accumulated amount of 0.81 inch by 16 hours, the average hourly precipitation is 0.0506 inch, so that the 3-hourly accumulation would be 0.15 inch. In the case of a tied precipitation intensity for a month, the decision was made to take the first occurrence. As a result the 3-hourly precipitation intensity was 0.15 in the event beginning at Julian hour 7456, as calculated from the accumulated precipitation amount. The asterisk at the end of the line indicates that the 3-hour intensity is the result of a calculated precipitation amount beginning in Julian hour 7456. The remaining precipitation intensities shown for 6-, 12-, 24-, and 48-hour durations are similarly calculated.

Enclosure 5 provides examples of annual maximum intensities determined from daily precipitation. The 29 indicates the state of New Mexico, 0022 is for Abbott 1 SE, the year is 1974, the Julian day is 210 or 7/29, the maximum precipitation is 1.45 inches, the 1 shows the relative position of the maximum day in the sequence (which for a 1-day duration is identical to the first day or Julian day, 210), and the amount is 1.45 inches. The last five zero are used for various indicators or to define the amount of accumulated precipitation or the accumulated number of days, or missing days in a year. For example, if there had been an accumulated amount that was part of the 10- or 20-day duration intensities then the code, -8, would appear in the fifth last column, (see the second example, year 1980). If part of the duration had some missing data a -9 would appear. The last three columns provide accumulated amount of precipitation (if any), the number of accumulated days (if any), and the number of missing days (if any) for the year. For the year 1974 there were no missing or accumulated days, therefore there was no accumulated precipitation.

The sixth line gives the precipitation intensity for the 20-day duration in 1974. The beginning day of the sequence is Julian day 202 or July 21 with a total of 5.27 inches of precipitation during the 20-day period. The day with the maximum precipitation is Julian day 210 or July 29, and this was day 9 in the sequence, (column 7). The maximum day for each duration in the sequence of days is given in the same manner.

For duration of 7 days and greater, monthly maximums are not being calculated. Rather the top six to ten precipitation intensities for durations of seven days or more are being calculated. Enough of the top intensities for each of the durations greater than 7 day will be calculated so that seasonal relations for these durations can be determined. Enclosure 6 shows the top six durations for Abiquiu Dam (0041) in New Mexico for the years 1987 and 1988. Again the Julian day, date and the precipitation intensity is shown. Interestingly, the highest three 10-day intensities in 1988 are greater than the highest 10-day intensity for 1987.

Temporal Trends

An important assumption in any investigation of precipitation-return frequencies is stationarity of the data set. If there is a shift in the intensities of the return frequencies, then one must adjust for this trend. Several different tests are being investigated for use in this project. One is the Potter test, which is a bivariate test used to detect systematic changes in the mean of the data. Another test being examined is the Kruskal-Wallis test, a nonparametric test for determining if there are any significant differences in the precipitation frequencies between one particular period and another.

Plots of data will also be made to determine if there are any trends in the data that are evident from a simple time plot of the annual or seasonal maximums of data. Additionally, ratios will be made between earlier periods and more recent periods to examine possible spatial relations.

Seasonality

Software development has been started to begin the examination of possible seasonal relations of the precipitation intensities. The initial software only examines the year beginning from January 1. However, this software will be further developed to examine various options beginning with different months.

Storm Analysis

One of the thrusts that will begin during the next quarter is the development of a storm analysis program. The Bureau of Reclamation (Lou Schreiner and Dick Stodt) have developed a program for use on a main-frame computer. It provides a tool that allows for individual storms to be analyzed, providing isohyetal analyses, mass curves, and depth-area-duration (DAD) curves. While the original program was programmed for a main-frame computer, the concepts from the original program will be reprogrammed for the IBM RISC 6000 work station. The results from this software will be used to analyze individual storms for determining DAD curves and mass curves for use along with the precipitation-return frequencies.

Personnel

During the past six months a significant amount of time was spent developing vacancy announcements, interviewing potential new personnel, and hiring new personnel. A major new addition was Lesley Tarleton on June 29. She will come on board to take over many of the day-to-day decisions and work for the Semi-Arid

Precipitation Frequency Project. A computer specialist, Dan Romberger, was hired. He will concentrate over the next six months on the development of the storm analysis program for the IBM RISC 6000 work station. Julie Olson, a recent graduate from the University of Maryland, was hired as a physical scientist to assist in the day-to-day work of this and other projects. Both Julie and Dan joined the Water Management Information Division on June 1.

Agenda for Semi-Annual Meeting of the Semi-Arid Precipitation Frequency Project

December 7, 1992

I. Welcome and Overview

II. Data

  A. Data Reduction

    1. Progress of hourly and daily data processing

    2. Merging/Deletion of stations

  B. Data Acquisition

  C. Data Quality Control

    1. L-Moments

    2. Mass Curves

  D. Data Comparisons Planned

III. Seasonality

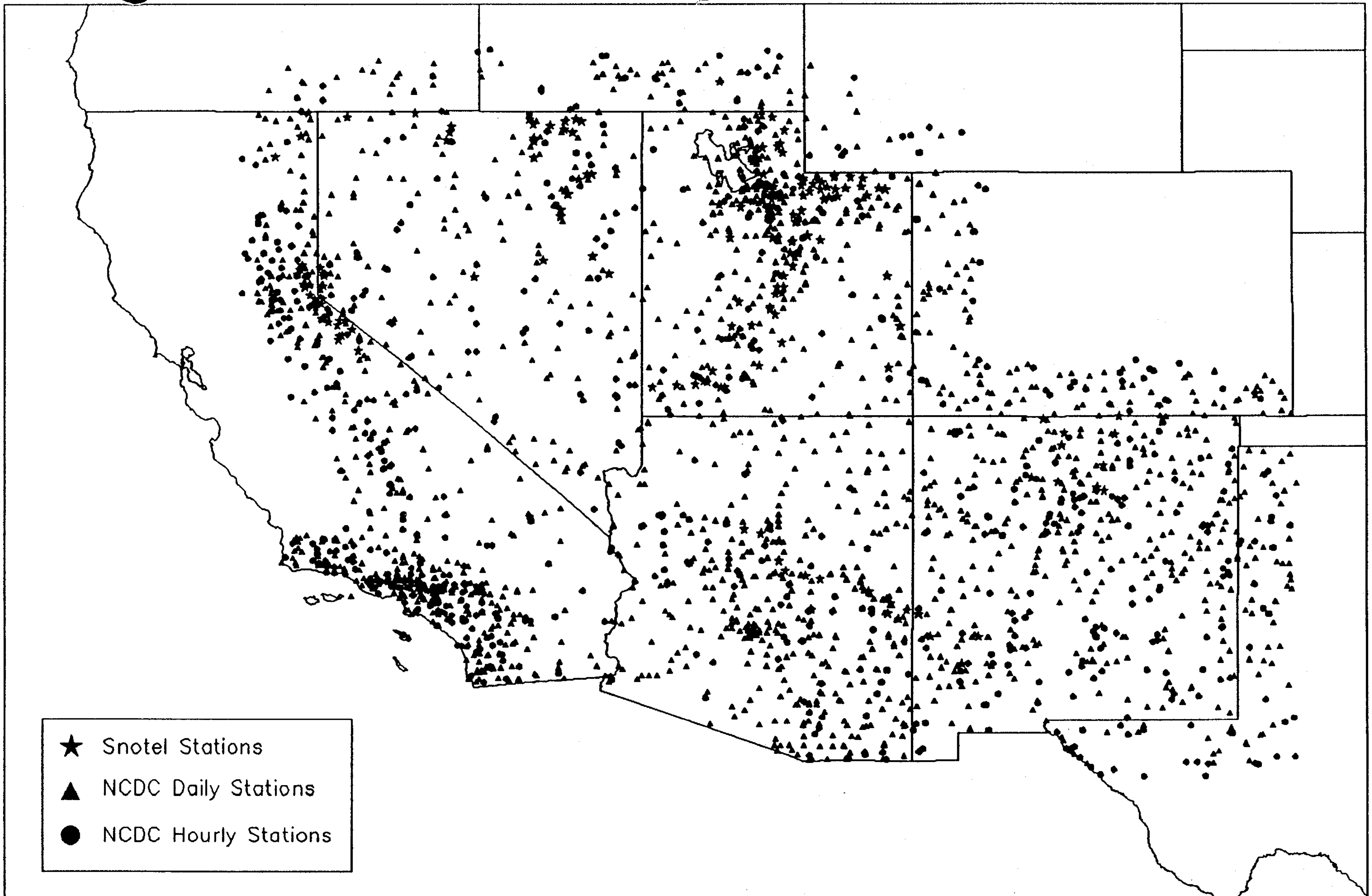
  A. Dry Periods

  B. Probability of Precipitation Amounts

  C. Frequency of Annual Maximum Values

IV. Frequency Calculations

V. Storm Analysis



Stations used in the Southwestern Semiarid Precipitation Frequency Study

DATA REDUCTION

Hourly NCDC 1948-1990

Core States	Initial No. of Stations	After QC
Arizona	81	48
Nevada	73	46
New Mexico	141	54
Utah	91	61
SE California	100	-
Border States 60 miles around Core		
California	160	-
Oregon	19	-
Idaho	37	-
Wyoming	16	-
Colorado	100	-
Texas	86	-

- all formatted by month

- Annual Maximum for durations calculated 1-hr, 2-hr, 3-hr, 6-hr, 12-hr, 24-hr, 48-hr

CRITERIA

To Run L-Moment

- Need at least 5 years

To Combine

- ≤ 5 miles
- ≤ 300 feet difference in elevation

For Frequency Analysis

- "within" cluster of L-skew vs. L-kurtosis plot - i.e., not 'real far out'
- 15 years for frequency analysis

PROCESS

- Use Formatted Statewide Data Set
- Run L-Moment FORTRAN program {MN,CV,SK,K,5th}

    (without < 5-year stations)
- Plot L-skew vs L-kurtosis, check outliers for erroneous data, if outliers:

    correct, if necessary

    combine, if possible

    delete, otherwise
- Check proximity for merging

    < 5 miles

    < 300 feet

  (especially to combine 2 or more short records to make 1 long record)

NEXT STEPS

- Delete < 15 year records to do frequency analysis

- Partial Duration

Semi-Arid Precipiation Frequency

Summary Of Hourly Stations

(as of 12/2/92)

	Arizona	Nevada	New Mexico	Utah
Orginal Number of Stations	81	73	141	91
delete <5 yrs	-3	-4	-25	-17
"loss" to combinations	-11	-6	-24e	-9e
Other Deletions i.e. (L-Moments)	-8	-6e	-8e	-7e
Total	59	57	84	78
Next Step				
delete <15 yrs	-11	-11	-30	-17
TOTAL	48	46	54	61

e = estimated

DATA REDUCTION

<u>Daily</u>

NCDC + TP40
Records mostly 1948-1990
Some as early as 1880

Core States	Initial	≥ 19 yrs
Arizona	438	276
Nevada	211	105
Utah	316	186
New Mexico	*	
California	447	
Border States	462	

<u>SNOTEL</u> (SNOpack TELemetry)

- 163 stations for area
- Software complete

New Mexico Daily Data
Format Problems

Missing Data

	-99 ...	-99	-99	-99	-99	-99 .. ..
	-99 ...	-99	-99	**99**	**99**	
Date:	21 ...	28	29	30	31	

Note: last 2 days of month 99 instead of -99

-99 = missing data

Solution: write program to change 99 at ends of month to -99

DATA REDUCTION

- Storm Analysis Data
    - Software development for GRASS storm format
    - Initial data: California, post - 1948 data
- 15-minute Data
    - Tapes have been read
    - Preparing list of stations
- N-minute Data - packed in zip format
    - 5-, 10-, 15-, 30-, 60-, 90-, 120-, ..., 1440- min

N-Minute Data Base
Arizona

Durations: 5-, 10-, 15-, 30-, 60-, 120-, 1440- minutes

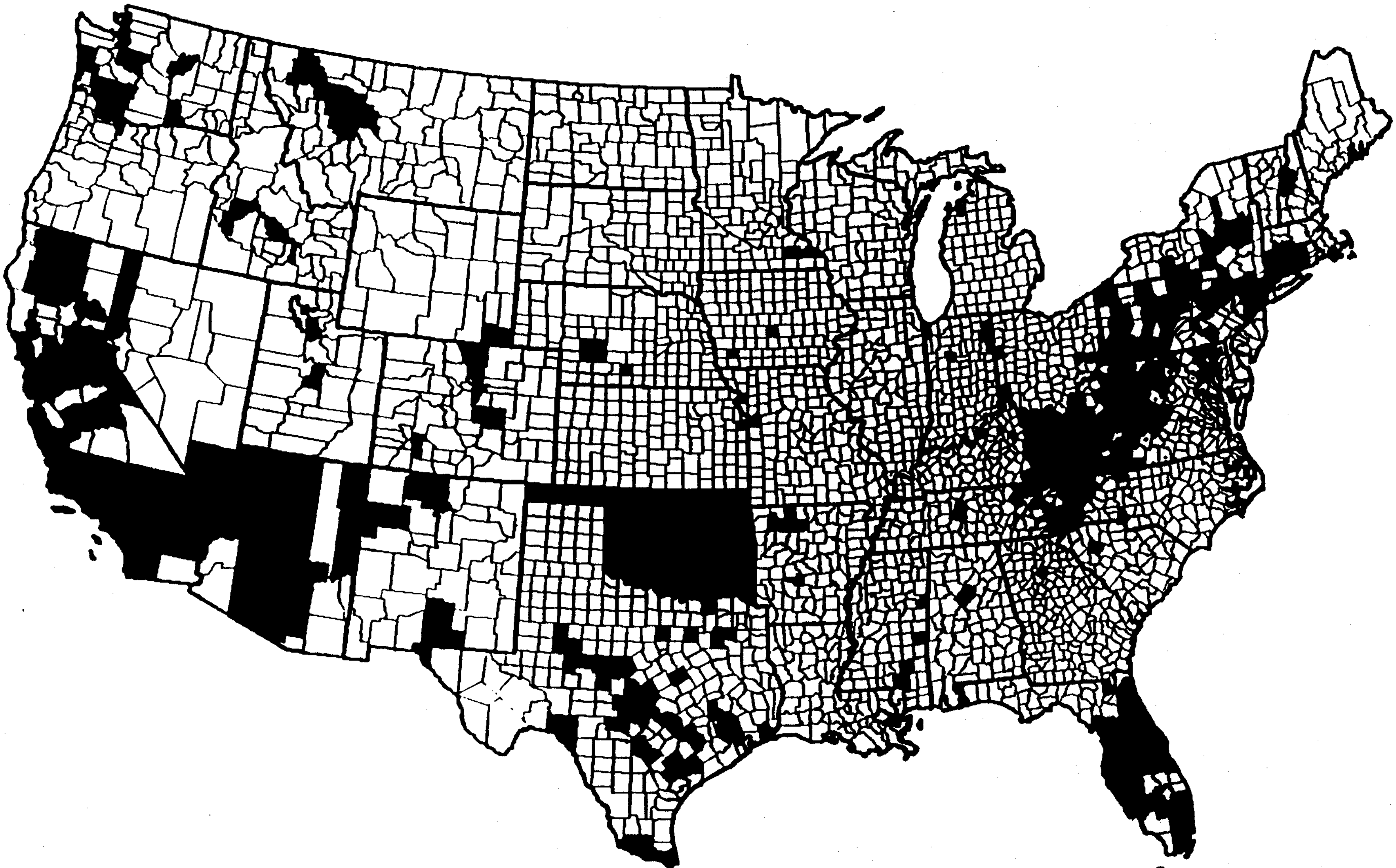
FLAGSTAFF	1951 - 1978	(all)
	1898 - 1978	(1440)
PHOENIX	1906 - 1978	(all)
	1898 - 1978	(1440)
TUCSON	1943 - 1978	(all)
	1924 - 1978	(1440)
WINSLOW	1951 - 1978	(all)
	1881 - 1978	(1440)
YUMA	1881 - 1978	(1440)

Maximum precipitation for each duration for each year

DATA SETS

NCDC	National Climatic Data Center	NOAA
SNOTEL	SNOwpack TELemetry	SCS/USDA
RAWS	Remote Automated Weather Station	BLM & FS/USDA
ARC	Agricultural Research Center includes Walnut Gulch	~~SCS~~ ARS/USDA
USGS	U.S. Geological Survey	Dept. of Interior
	San Bernardino County, CA	
ALERT	Automated Local Evaluation in Real Time	
J. Goodridge	California Storm Data	

Location of Automatic Local Flood Warning Systems in the United States 1992



Plans are currently underway to add automated local warning systems in many other counties.

Created from FCC permit applications

OBSERVED DATA--PROBABILITY DISTRIBUTION

Oldest 1. METHOD OF MOMENTS

Old 2. METHOD OF MAXIMUM LIKELIHOOD

LET $f(x_i; \theta_1, \theta_2, \ldots)$ BE THE pdf, THEN

$$L = \prod_{i=1}^{n} f(x_i; \theta_1, \theta_2 \ldots) \qquad \textit{Likelihood Function}$$

$$\partial L / \partial \theta_i \qquad \textit{solve for } \theta_i$$

New 3. METHOD OF L-MOMENTS

a) robust, less sensitive to sampling errors and outliers

b) capable of characterizing a wide range of distributions

c) linear combination of order statistics

L-MOMENTS

r.v. X with cdf F(X) & quantile func X(F)

$$X_{1:n} \leq X_{2:n} \leq \cdots \leq X_{n:n}$$

L-MOMENT for r = 1, 2, · · · are:

$$\lambda_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} E X_{r-k:r}$$

$$\text{L-CV} = \lambda_2/\lambda_1$$

$$\text{L-SKEW} = \lambda_3/\lambda_2$$

$$\text{L-KURTOSIS} = \lambda_4/\lambda_3$$

STAGES IN FREQUENCY ANALYSIS

1. DATA SCREENING--DISCORDANCY D_i

Let $\vec{U}_i = \left[t_2^{(i)}, t_3^{(i)}, t_4^{(i)}\right]^T$ *be a vector for site i*

$$\vec{U} = N^{-1} \sum_{i=1}^{N} \vec{U}_i$$ -- *unweighted group mean*

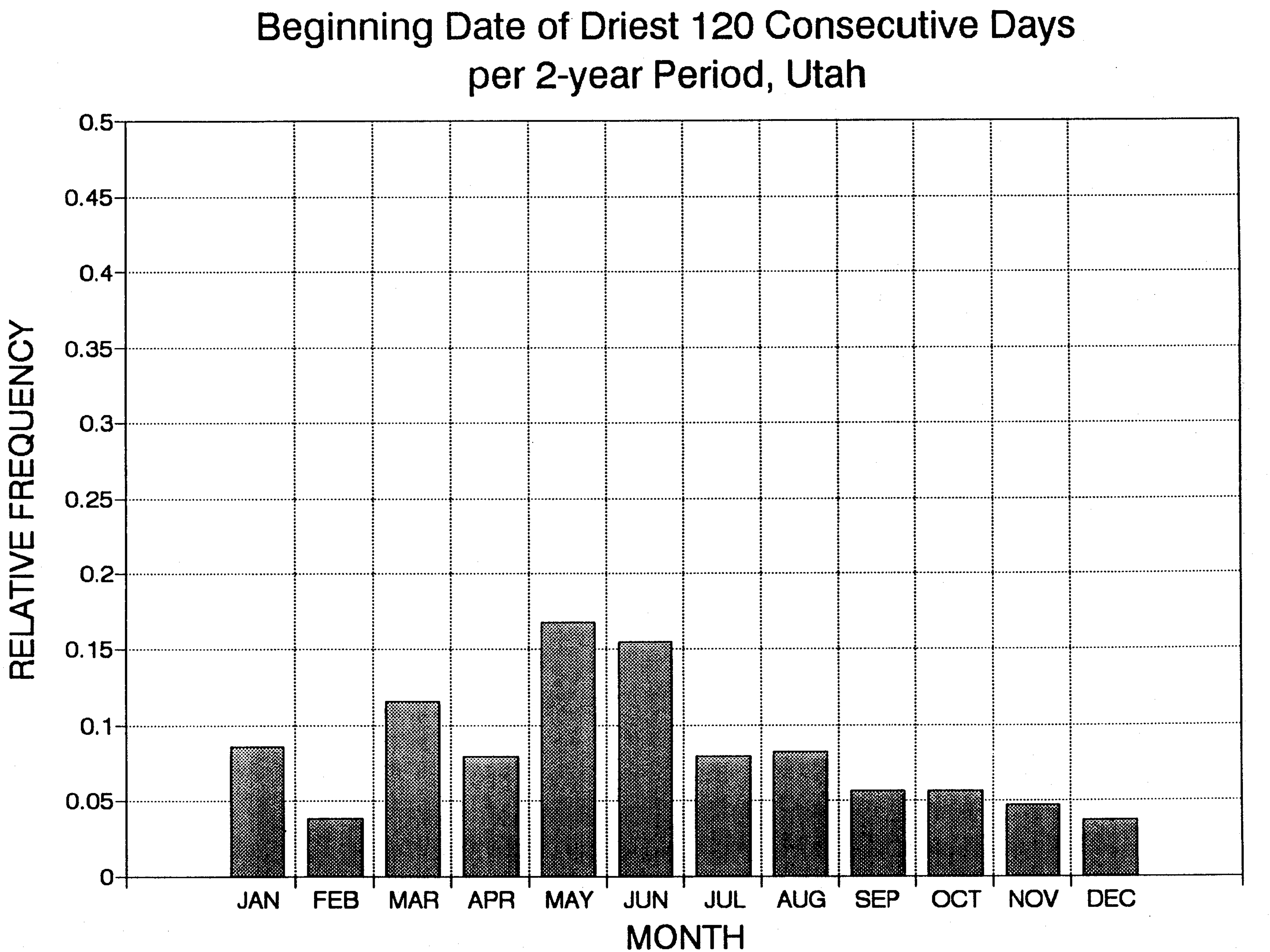
THE DISCORDANCY FOR SITE i IS DEFINED:

$$D_i = \frac{1}{3}(\vec{U}_i - \vec{U})^T \vec{S}^{-1} (\vec{U}_i - \vec{U})$$

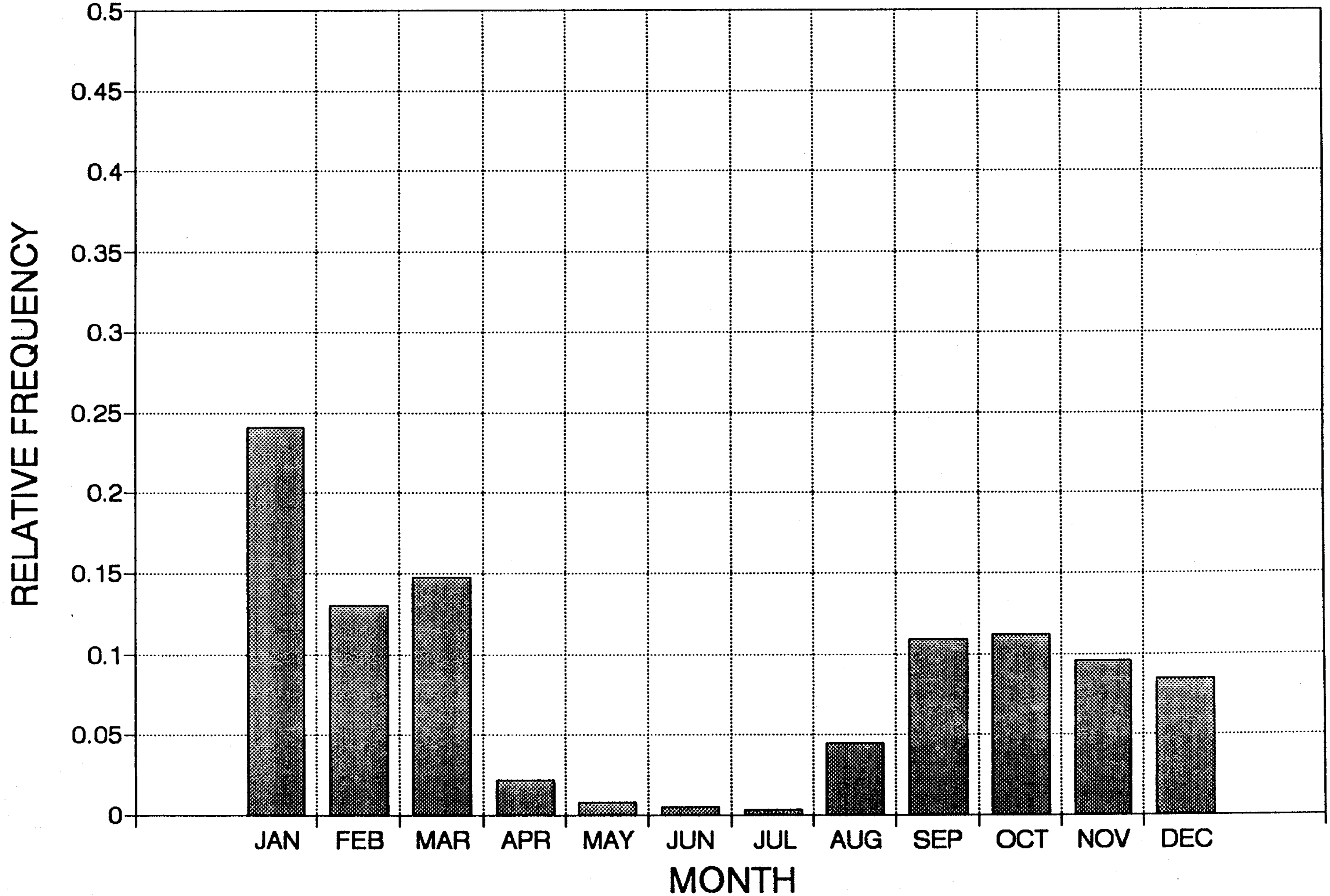
where $$\vec{S} = (N - 1)^{-1} \sum_{i=1}^{N} (\vec{U}_i - \vec{U})(\vec{U}_i - \vec{U})^T$$

ARIZONA 270 SITES

N yrs. data	NAME	L-CV	L-SKEW	L-KURT	D(I) Discordancy
62	0060	.3701	.3096	.1531	1.10 ok
77	0080	.3219	.2578	.2595	0.43 ok
23	0625	.6247	.3033	.0599	6.97**
27	1169	.5143	.3350	.1190	3.54*
20	1248	.3579	.5132	.5364	7.33**
78	2329	.6048	.2209	.1396	4.45**
96	3595	.3050	.3651	.4777	5.51**
22	3926	.6020	.2393	.2772	5.34**
43	4182	.5953	.3706	.2278	4.21**
41	4586	.4228	.5015	.4345	4.59**
31	4675	.5143	.2027	.0470	3.29**
25	8184	.3878	.2024	.3303	3.07*
36	8273	.6879	.3359	.2568	6.84**
21	8329	.2380	.1023	.1926	1.36 ok
31	8649	.4440	.1948	.2993	3.02*
30	9114	.2876	.4463	.4276	4.11**
MEAN		.3204	.2107	.1726	


Beginning Date of Driest 120 Consecutive Days
per 2-year Period, Utah
RELATIVE FREQUENCY
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
JMO 11/24/92

Beginning Date of Driest 120 Consecutive Days per 2-year Period, New Mexico



JMO 11/24/92

WESTERN REGION STATION LOCATIONS

SCALE 1: 10,000,000

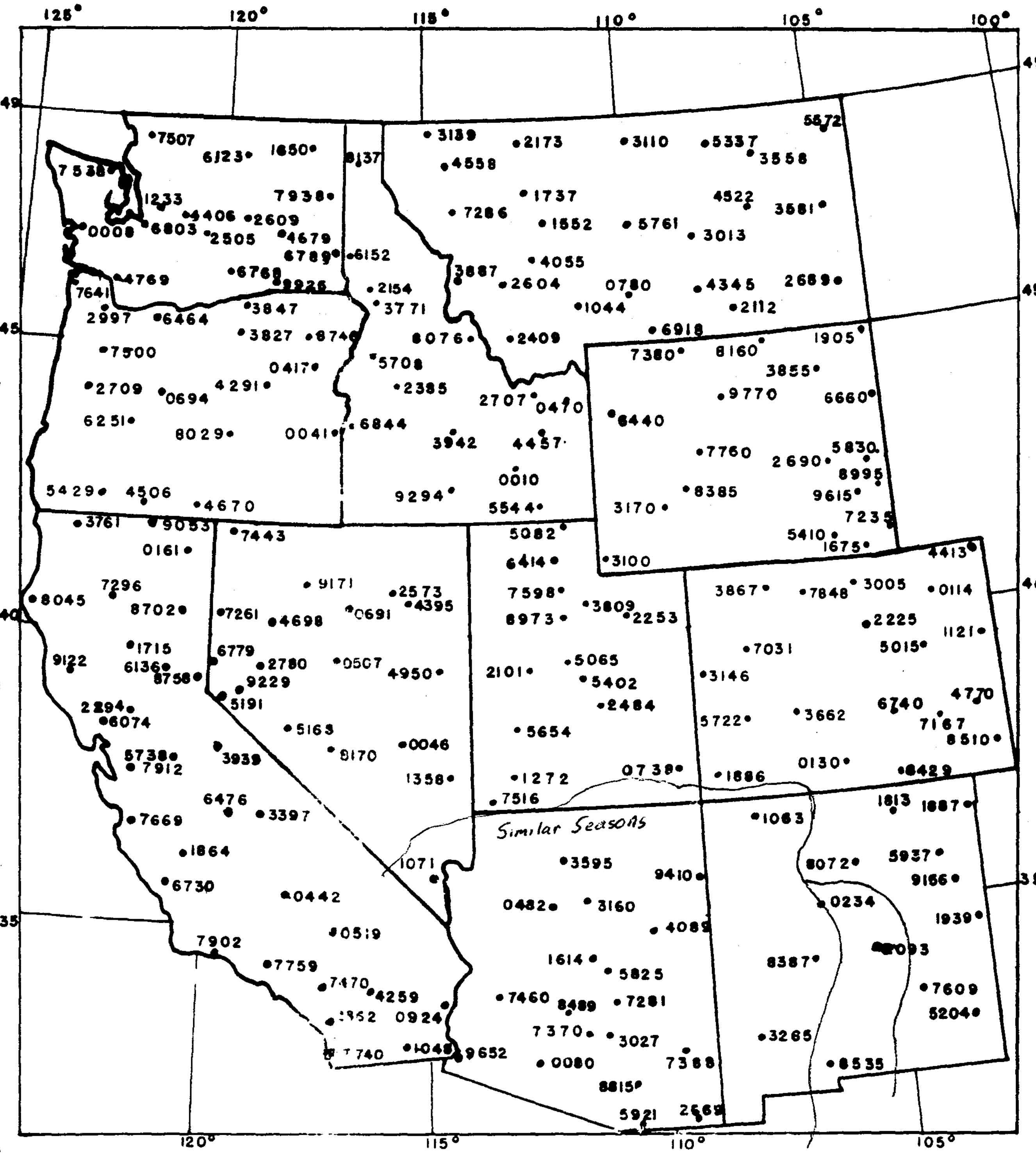


FIGURE 1: STATIONS FOR WHICH PRECIPITATION PROBABILITIES WERE CALCULATED

AJO, ARIZONA 20080

PRECIPITATION MEANS AND PROBABILITIES FOR 1 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION								
			0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.24	53	24	22	18	12	9	5	3	1	
MAR 08	.16	76	26	24	20	15	11	7	4	2	
MAR 15	.25	73	25	23	19	14	10	6	4	2	
MAR 22	.12	60	25	22	17	10	6	3	2	1	
MAR 29	.04	83	19	17	12	6	3	1			
APR 05	.06	80	12	10	7	4	2				
APR 12	0.00	100	7	5	3	2	1				
APR 19	.02	83	10	8	4	1					
APR 26	.05	76	12	10	6	2					
MAY 03	0.00	100	8	6	4	1					
MAY 10	.03	80	8	5	3	1					
MAY 17	.01	93	6	4	1						
MAY 24	0.00	100	4	3	1						
MAY 31	.02	86	6	4	2						
JUN 07	0.00	100	3	2	1						
JUN 14	0.00	100	4	3	2	1					
JUN 21	.05	80	11	9	6	2	1				
JUN 28	.04	76	21	18	12	6	4	1	1		
JUL 05	.19	56	35	32	25	15	10	4	2	1	
JUL 12	.30	40	51	47	38	25	17	8	4	1	
JUL 19	.39	23	64	59	49	34	25	13	7	3	
JUL 26	.56	20	72	68	58	43	32	18	10	4	
AUG 02	.61	20	72	68	60	46	35	20	12	5	
AUG 09	.52	26	68	64	55	41	31	18	10	5	
AUG 16	.44	23	65	61	52	38	28	16	9	4	
AUG 23	.52	30	58	54	45	32	23	13	8	4	
AUG 30	.18	46	45	41	32	21	14	7	4	2	
SEP 06	.18	56	34	31	24	16	11	6	4	2	
SEP 13	.32	60	30	27	22	16	12	7	5	3	
SEP 20	.11	63	29	26	20	13	8	4	2	1	
SEP 27	.13	63	29	26	20	13	8	4	2		
OCT 04	.23	70	27	25	21	14	10	5	3	1	
OCT 11	.08	76	21	19	15	10	6	3	1		
OCT 18	.06	80	19	17	13	8	5	2	1		
OCT 25	.16	70	21	19	14	9	6	3	1		
NOV 01	.04	76	24	21	15	8	5	2	1		
NOV 08	.15	63	30	26	19	10	5	2	1		
NOV 15	.12	46	36	31	22	10	5	1			
NOV 22	.12	63	30	26	18	9	4	1			
NOV 29	.07	76	24	21	16	10	6	2	1		
DEC 06	.19	66	28	25	20	13	8	4	2		
DEC 13	.12	53	36	32	25	15	9	4	2		
DEC 20	.24	50	40	36	29	18	11	4	2		
DEC 27	.18	60	34	31	25	17	11	5	2	1	
JAN 03	.16	63	33	31	25	16	10	4	2	1	
JAN 10	.22	53	38	35	29	18	11	4	1		
JAN 17	.16	60	37	34	27	17	11	4	2		
JAN 24	.21	56	35	32	25	16	10	4	2		
JAN 31	.13	60	37	33	25	15	9	3	1		
FEB 07	.18	46	38	34	25	15	9	3	1		
FEB 14	.19	53	39	34	26	16	10	4	2	1	
FEB 21	.19	46	30	27	21	13	8	3	1		

AJO, ARIZONA 20080

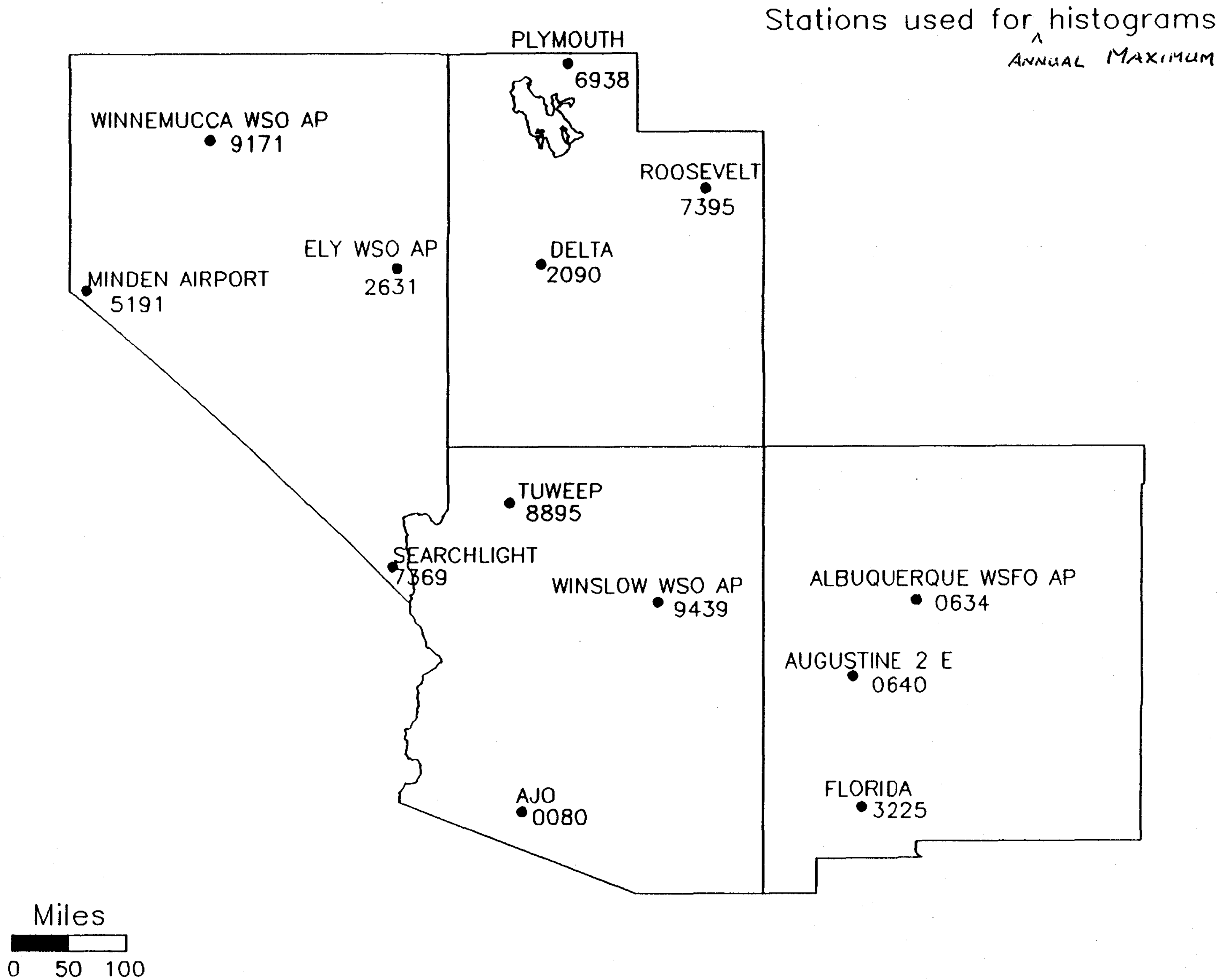
PRECIPITATION MEANS AND PROBABILITIES FOR 2 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION								
			0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.40	46	36	33	28	22	17	11	7	4	1
MAR 15	.36	43	44	41	34	25	18	10	6	3	
MAR 29	.11	66	27	24	17	10	5	2			
APR 12	.03	83	18	15	8	3	1				
APR 26	.07	73	22	19	12	5	2				
MAY 10	.03	73	14	10	5	2					
MAY 24	.03	83	11	8	3						
JUN 07	0.00	100	8	7	4	1					
JUN 21	.09	60	30	26	18	9	5	2	1		
JUL 05	.49	16	71	66	56	40	29	15	8	3	
JUL 19	.95	0	91	87	79	64	52	34	23	12	2
AUG 02	1.13	10	90	88	83	72	61	43	29	16	2
AUG 16	.96	10	81	78	71	59	49	33	23	13	2
AUG 30	.36	33	57	53	44	33	26	16	10	6	1
SEP 13	.43	43	49	45	38	28	21	13	8	5	1
SEP 27	.36	36	49	46	38	26	19	10	5	2	
OCT 11	.14	66	32	30	25	17	12	6	3	1	
OCT 25	.20	56	38	35	28	18	12	5	2	1	
NOV 08	.27	33	53	48	36	22	13	5	2		
NOV 22	.18	53	45	41	32	19	12	5	2		
DEC 06	.32	43	51	48	40	28	19	9	4	2	
DEC 20	.42	30	59	55	46	33	24	12	6	2	
JAN 03	.38	36	57	53	45	32	23	11	6	2	
JAN 17	.37	33	59	55	46	32	22	11	5	2	
JAN 31	.31	30	59	54	44	29	19	9	4	1	
FEB 14	.38	23	57	51	41	27	19	9	5	2	

AJO, ARIZONA 20080

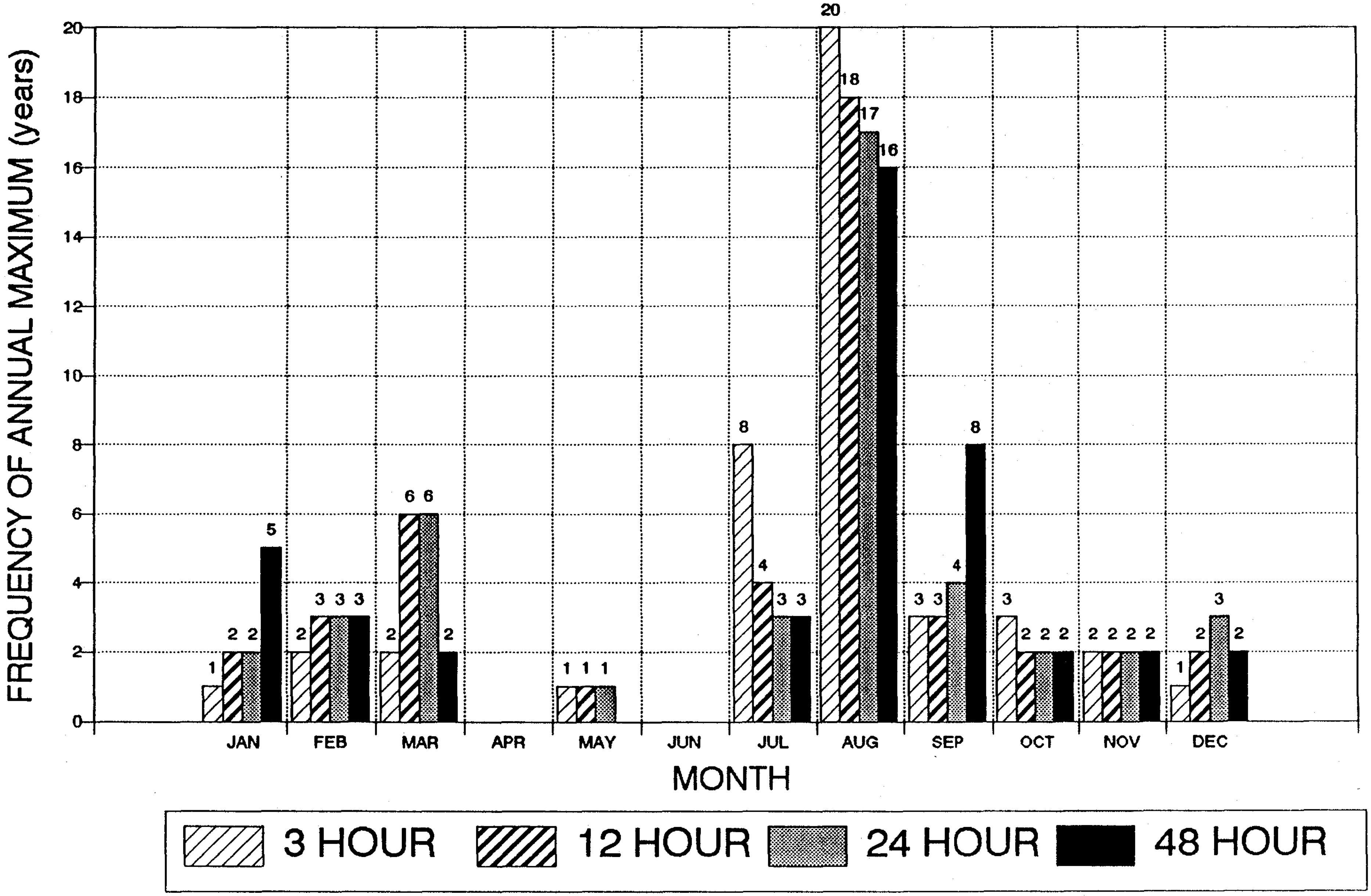
PRECIPITATION MEANS AND PROBABILITIES FOR 3 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION								
			0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.64	40	49	46	40	31	25	17	12	7	1
MAR 22	.22	36	46	41	32	20	13	6	3	1	
APR 12	.07	63	30	25	15	5	2				
MAY 03	.05	70	23	18	11	4	2				
MAY 24	.03	83	15	11	5						
JUN 14	.09	56	34	29	20	11	6	2	1		
JUL 05	.88	6	89	86	77	62	49	32	21	11	2
JUL 26	1.69	0	97	96	93	85	77	60	46	30	6
AUG 16	1.15	6	88	85	79	68	59	43	31	19	4
SEP 06	.61	26	61	57	49	39	31	21	14	9	2
SEP 27	.48	30	60	56	47	34	26	14	8	4	
OCT 18	.26	50	47	43	35	25	17	9	5	2	
NOV 08	.38	30	61	56	45	30	20	9	4	1	
NOV 29	.38	26	64	60	50	36	26	13	7	3	
DEC 20	.58	23	70	67	59	45	35	20	11	5	
JAN 10	.59	23	73	69	61	46	35	19	10	4	
JAN 31	.50	20	73	68	57	41	30	17	10	4	



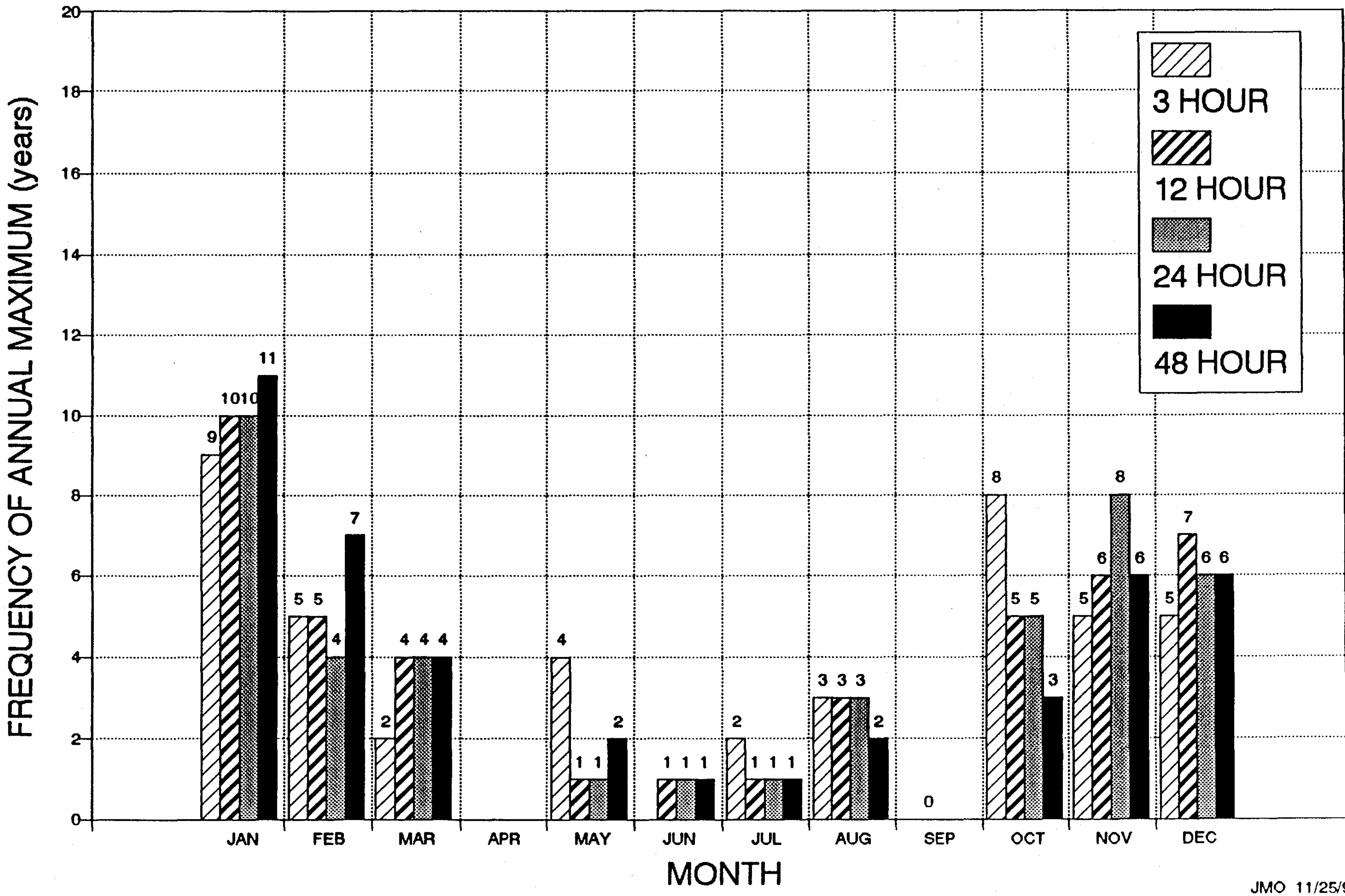
Stations used for annual maximum histograms
PLYMOUTH
6938
WINNEMUCCA WSO AP
9171
ROOSEVELT
7395
ELY WSO AP
2631
DELTA
2090
MINDEN AIRPORT
5191
TUWEEP
8895
SEARCHLIGHT
7369
WINSLOW WSO AP
9439
ALBUQUERQUE WSFO AP
0634
AUGUSTINE 2 E
0640
AJO
0080
FLORIDA
3225
Miles
0 50 100

ANNUAL MAXIMUM HISTOGRAM
AJO, ARIZONA n=43 years



JMO 11/25/92

HISTOGRAM OF ANNUAL MAXIMUM
MINDEN AIRPORT, NEVADA n=43 years



JMO 11/25/92

2. IDENTIFICATION OF HOMOGENEOUS REGION, HETEROGENEITY, H "IS THE OBSERVED BETWEEN-SITE DISPERSION OF THE SAMPLE L-MOMENTS FOR THE GROUP OF SITES UNDER CONSIDERATION LARGER THAN WOULD BE EXPECTED FROM A HOMOGENEOUS REGION?"

[(OBS. DISP) - (MEAN DISP BY SIMULATION)]/SD OF SIM DISP

SIMULATION: 4-PARAMETER KAPPA DISTRIBUTION

$$H = (V - \mu_V)/\sigma_V$$

WHERE V IS THE WEIGHTED SD AT EACH SITE

SAMPLE L-CV OR L-SKEW OR L-KURTOSIS

μ_V, σ_V FROM MONTE CARLO

AZ

HETROGENEITY MEASURES

SIMULATIONS = 500

OBSERVED	SD OF GROUP L-CV	0.0769
SIM. MEAN OF	SD OF GROUP L-CV	0.0351
SIM. SD OF	SD OF GROUP L-CV	0.0015
STANDARIZED TEST VALUE		27.38**

OBSERVED AVG OF	L-CV/L-SKEW DIST	0.0935
SIM MEAN OF AVE	L-CV/L-SKEW DIST	0.0717
SIM SD OF AVE	L-CV/L-SKEW DIST	0.0028
STANDARDIZED TEST VALUE		7.68**

OBSERVED AVG OF	L-SKEW/L-KURT DIST	0.0860
SIM MEAN OF AVG	L-SKEW/L-KURT DIST	0.0860
SIM SD OF AVG	L-SKEW/L-KURT DIST	0.0033
STANDARDIZED TEST VALUE		0.01

show AZ in a single climatic (precip.) region

3. GOODNESS-OF-FIT Z

$$Z^{GEV} = \frac{(\bar{t}_4 - \tau_4^{GEV})}{\sigma_4}$$

where $\bar{t}_4$ is the regional average L-Kurtosis.

τ_4 is the L-kurtosis of the fitted GEV distribution, and

σ_4 is the standard deviation of $\bar{t}_4$

Az

should be zero

GOODNESS-OF-FIT MEASURES

GEN LOGISTIC	L-KURTOSIS = 0.204	Z VALUE = 7.30
* GEV	L-KURTOSIS = 0.167	Z VALUE = -2.06
GEN NORMAL	L-KURTOSIS = 0.157	Z VALUE = -4.62
PEARSON TY III	L-KURTOSIS = 0.138	Z VALUE = -9.75
GEN PARETO	L-KURTOSIS = 0.083	Z VALUE = -23.76

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

February 10, 1993 W/OH11:JLV

MEMORANDUM FOR: Southwest Semi-Arid Precipitation Frequency Study Support Group

FROM: W/OH11 - John L. Vogel

SUBJECT: Minutes from the December 7, 1992 Semi-Annual Meeting

Enclosed is a copy of the minutes from the Third Semi-Annual Meeting for the Southwest Semi-Arid Precipitation Frequency Project. These minutes summarize the progress of the Group from approximately June 1, 1992 through the first part of December 1992. If you have any questions, please feel free to call me or Lesley Tarleton at (301) 713-1669.

Enclosure

Minutes--Third Meeting
Semi-Arid Precipitation Frequency Study
Phoenix, Arizona
December 7, 1992

Attendance

Joe Warren	ADOT[1]	(602) 831-0662
Ray Jordan	ADOT	(602) 255-7197
Tony Brazel	ASU[2]	(602) 965-6265
George Lopez Cepero	ADOT	(602) 255-7481
Cliff Anderson	AMAFCA[3]	(505) 884-2215
Stephen Waters	Maricopa FCD	(602) 506-1501
Jess Romero	Yavapai FCD	(602) 771-3196
Lesley Tarleton	NOAA/NWS	(301) 713-1669
John Vogel	NOAA/NWS	(301) 713-1669

INTRODUCTION

The Third Semi-Annual review meeting for the Southwest Semi-Arid Precipitation Frequency Project was convened at 9 AM at the Arizona Department of Transportation Administration offices in Phoenix. Joe Warren served as the host. The agenda for the meeting is included as Enclosure 1. Lesley Tarleton and John Vogel of the Office of Hydrology, Water Management Information Division (WMID) presented the review. John Vogel led off by summarizing some general progress of the project.

In August, two IBM RISC 6000 computers (models 340 and 220) were obtained by WMID. These computers will be used to assist in mapping the precipitation fields, and to assist in any statistical-physical modeling of the precipitation intensities for this project. As part of this acquisition, GRASS (Geographical Resources Analysis Support System), a GIS system developed by various Federal agencies, was also installed. The Corps of Engineers Research Laboratory (CERL) in Champaign, Illinois, is responsible for coordinating and, in part, developing GRASS. In September 1992, three representatives from CERL presented, in Silver Spring, Maryland, a 3-day training course in GRASS for this and another project, which was attended by most of the technical staff of WMID. Additional training in UNIX for several staff members was taken during October and November. Additional UNIX and C-Language training is anticipated during the first part of 1993.

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[1] Arizona Department of Transportation

[2] Arizona State University, Office of Climate

[3] Albuquerque Metropolitan Arroyo Flood Control District

Currently, the first major software being developed on the RISC 6000 computers is a storm analysis program. This software will be used to develop area-depth, depth-duration, and mass-curve relations for storms in the Semi-Arid regions of the Southwest. This work is progressing and it is anticipated to have a working version early in 1993. This will be the first working version of this software on our system, and will still require considerable staff interaction. Refinements of the software will continue in the future in an effort to develop more objective analysis schemes. Work has begun on reducing data for some storms in the Southwest.

John met with Leonard Lane at the U. S. Department of Agriculture Southwest Watershed Research Center in Tucson, Arizona, on Friday and Saturday, December 4-5. Leonard briefed John on the availability of precipitation data from Walnut Gulch, Arizona, and Alamogordo Creek, New Mexico, Experimental Watersheds. Some precipitation data were obtained previously through the Agricultural Research Service (ARS) in Beltsville, MD. However, Leonard indicated that more data were available for the Walnut Gulch Experimental Watershed. Leonard indicated that his group would supply WMID with daily data for six to nine of the raingages in the dense raingage network. These gages have been shown by statistical analysis to be reasonably independent of each other. Later in the year, when a new data processing system becomes available at the Southwest Watershed Research Center, breakpoint data for the same gages will also be made available. This will give valuable information about short-duration rainfalls.

Since June several new people have joined the staff of the Hydrometeorological Branch. They are Lesley Tarleton as a Project Leader on the Semi-Arid Precipitation Project. She is coordinating many of the day-to-day activities on this project. Dan Romberger is a computer analyst, who is deeply involved in developing the storm analysis software, and assisting in developing techniques for the vector analysis of gridded data. Julie Olson, physical scientist, has been working on the data quality control, and in developing seasonal relations for the Semi-Arid Southwest. Doug Kluck, a meteorologist, is primarily working on another project, but is assisting in the development of storm data for the Semi-Arid Southwest.

DATA

A major portion of the first year of this project was taken up with the development of software for reducing the data and quality-control procedures. Enclosure 2a summarizes the data reduction of the hourly precipitation data from NCDC from 1948 through 1990 for the core and border states in the Semi-Arid Project. The L-moment program requires at least 5 years of data to run the software, but more importantly at least 15 years, preferably 20 years, of record are required to obtain reliable frequency data (Enclosure 2b). Due to missing data, the combination of nearby stations, short record periods, and inconsistencies in the data set, the actual number of stations that have taken data for the past 45 years was reduced by 50% or more for the final analysis.

L-moment statistics have been found to be a powerful technique for quality control of the data (Vogel and Lin, 1992). After determining the maximum annual intensity for various durations, the data are processed using L-moment statistics. As part of this process the mean, L-coefficient of variation, L-skew, L-kurtosis, and the fifth moment are calculated. For example when using L-moment statistics if the L-skew and the L-kurtosis points for a number of stations are plotted in a scatter diagram, a cluster of points is expected. If several points are not near this cluster, this usually means that some data for this station need to be examined carefully (Enclosure 2c). For annual maximum precipitation values, it could mean that one of the years was incorrectly entered, and needs to be corrected; or that there are missing data that have been given a zero value and were not coded as missing. These are but a few examples.

The daily data have been treated in a similar manner, and the number of stations with 19 years or more of data is shown in Enclosure 3. Data for New Mexico were obtained from Ken Kunkel, the former State Climatologist for New Mexico. This is a very valuable data set, since it extends the data base prior to 1948 to the beginning year of the station. However, the format for these data is slightly different from the format used by the National Climatic Data Center (Enclosures 4a and 4b), making it difficult to differentiate between accumulated and missing data. Some different software must be developed to incorporate these differences. New software has been prepared to reduce the daily data from the SNOTEL (SNOw TELemetry) network maintained by the Soil Conservation Service. These data are generally in remote and high-elevation sites in the various states, and will provide information for regions that have not generally been available.

A variety of other data that are being examined (Enclosure 5) are: 1) precipitation data for input into the storm analysis program, initially this will be for the post-1948 era and for Southeast California; 2) the tapes for the 15-minute precipitation data have been read and a list of stations within the core and border area for the Semi-Arid Southwest are being prepared; and 3) N-minute data (rainfall amounts for durations from 5 to 1440 minutes) have been examined and inventoried (Enclosure 6).

Enclosure 7a provides a list of those groups who have supplied or indicated that they will supply precipitation data for the Southwest Semi-Arid project. The RAWS (Remote Automated Weather Station) data are expected to be available by the beginning of the 1993 calendar year. The data from Jim Goodridge were obtained, and still need to be examined and inventoried. A map showing the distribution of daily and hourly stations from the NCDC, and the

SNOTEL data from the SCS is given in Enclosure 7b. Note how the SNOTEL data (starred stations) supplement the data from the NCDC, especially in the high-altitude regions.

L-moment statistics provide a new way of examining data, and our experience shows that it is a very powerful tool. Previously, the analysis of the return frequency of precipitation has used various fitting procedures. For NOAA Atlas 2 (Miller et al, 1973) the method of moments was used, and others more recently have used the method of maximum likelihood, which is more cumbersome. L-moments use probability-weighted moments. This technique 1) supplies a more robust analysis which is less sensitive to sampling errors and outliers, 2) uses linear combinations of order statistics, and 3) is capable of characterizing a wide range of statistical distributions (Enclosure 8a). The basic definition for the L-moments is given in Enclosure 8b. Using the L-coefficient of variation, L-skew, and L-kurtosis, Hosking and Wallis (1991) have developed a measure of discordancy (D_i), which can be used to detect possible non-homogenities within the data set (Enclosure 8c). This measure was tested on 1-day duration precipitation data using the annual maximum series for 276 daily stations in Arizona which had been previously quality controlled. Thirteen stations were found to have D_i values of 3 or greater, indicating that these stations had some unusual data points (Enclosure 8d). Several of these stations had relatively low periods of record (< 25 years); however, many of the stations had long periods of record and these stations are generally considered to be more stable. Discordancy indicates the need to verify the data, but does not indicate that the data are wrong, just different from most of the stations within the data set. Subsequent verification of the data indicated that the values in the annual maximum series of stations were valid.

Another powerful technique that can be used to examine the reliability of precipitation data is the double-mass curve. For our analysis, we compare the accumulated annual maximum rainfall at a station to the average annual rainfall at several nearby stations that are known to be reliable. This technique can be used to determine graphically if there has been any significant change in the exposure of the raingage, and to examine the potential merging of nearby raingages with short records into a longer record period. Three different hourly raingages have been located at the Grand Canyon National Park (3581, 3595, and 3596) from 1949 through 1979. None of these stations has a record length greater than 9 years, and if they could be combined a satisfactory record length could be obtained. The double-mass curve (Enclosure 9) shows that these three stations have experienced only minor changes in slope over the period. These three stations are all within 300 feet and 5 miles of each other. The double-mass curve indicates that the combination of these stations is possible, subject to further checking of the data.

Similarly, double-mass curves were plotted for Alamo and Alamo Dam (stations 0096 and 0100) in Arizona (Enclosure 10). Again these stations met the spatial criteria for possible combination of records to form a longer record period. However, the slopes of these two stations relative to a group of nearby stations showed considerable difference. Alamo had an average slope of 0.94, while Alamo Dam had an average slope of 0.77. It was concluded that these two stations could not be combined into a long record length, they would be analyzed separately, and it would be determined later if either station would provide an accurate hourly analysis of the region.

A variety of other data analyses are planned. These include comparisons of 1) the annual maximum series and the partial duration series for various durations, 2) daily rainfall amounts and 24-hour amounts, and 3) hourly and shorter durations rainfall amounts.

SEASONALITY

An important part of the initial analysis is determining the seasonality of intense precipitation occurrences. In just about any region of the world there are particular months or periods of months which dominate the intensity of the return frequency. During these periods more than half of all the highest intensity rainfalls can be expected. The other periods can have significance for other reasons, and it is important that the precipitation return frequencies for these other seasons also be defined. In addition, the seasonality will delineate the physical first cut of the regionalization of the Semi-Arid Southwest.

Three different sets of data are being examined to define the seasonality for this project. They are 1) the initial month of 120-day dry periods, 2) the probability of precipitation amounts expected during particular weeks of the year, and 3) a monthly frequency count of the annual maximum rainfall intensity for particular durations.

Enclosure 11 shows an analysis of the monthly beginning dates of the driest 120 consecutive days for 2-year periods in Arizona, New Mexico, Nevada, and Utah. No attempt at stratifying the data by regions within the state was made at this point, rather for each state all the data for the whole state were lumped together. The highest spike in these data occurs during the month of March for Arizona. It indicates that nearly half of all the 120-day dry periods in Arizona begin during March, and that less than 10% of the dry periods in Arizona begin in other months except for February. This means that over 60% of all the 120-day dry periods begin in March or February. Consequently, the wet period can be expected to maximize during the months from June through August, or during the Monsoon season.

In New Mexico the dry periods generally begin during the months of January through March and September through December. The wet period in New Mexico can be characterized as the period from April through August. Nevada and Utah show that the 120-day dry periods begin mainly from May through September, and that the wet period can be expected from October through February or April.

A second way of exploring seasonality relations is to examine some statistics that provide more detailed information, and at the same time integrate some of the characteristics of the weather systems which characterize different periods of the year. During the 1960s the Western Region Technical Committee of the U. S. Agriculture Department Experiment Stations developed a climatology of the percent probability of selected precipitation amounts within various weeks of the year beginning with March 1, or the climatic year (Gifford et al, 1967). These data were analyzed for the stations shown in Enclosure 12a with an example of this data set shown in Enclosure 12b for Ajo, Arizona. The first column shows the beginning of each one-week period starting with March 1. The next column gives the mean precipitation amount for that week. The third column provides the probability of no rain or only a trace of precipitation within the week, and the next eight columns provides the probability of receiving a precipitation amount equal to or in excess of a given amount. These values vary. If the station averages less than 30 inches of precipitation in a year, the values are 0.06, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.4, and 2.0 inches. If the station averages more than 30 inches of precipitation in a year, the values are 0.06, 0.1, 0.2, 0.4, 0.6, 1.0, 1.4, 2.0 and 4.0 inches.

For each station in the Semi-Arid Southwest region an isopercental analysis was done, as shown in Enclosure 12b. The isopercental analysis for one-week periods clearly shows a maximum beginning about June 21 and ending about September 20 at Ajo, Arizona. This maximum also corresponds to some of the highest weekly average precipitation amounts and some of the lowest probabilities of zero or trace rainfall amounts during a week. In this instance the Monsoon Season is at its peak, and is characterized by convective rainshowers. A second maximum begins about November 1 and continues through the middle or last part of March. The mean rainfall amounts during these weeks are less than those experienced during the warmer months, and represent a secondary maximum of mean rainfall. The third period, middle or late March through mid June, is characterized by very low rainfall amounts and high probabilities of zero or trace rainfall amounts.

A similar analysis was done for all the stations in the Semi-Arid region shown in Enclosure 12a. For our analysis no attempt is being made to divide the seasons into less than a one-month period. The preliminary analysis of these data, Enclosure 12c, indicates that Arizona and New Mexico west of the Continental Divide can be characterized by three seasons: 1) July through October (primarily the Monsoon Season, 2) November through February (a period characterized by large-scale general storms), and 3) March through June (a relatively dry period). New Mexico east of the Continental Divide can be depicted by two seasons. The eastern most region can be divided into a warm season (April through October) and a cold season (November through March). A second region is south-central New Mexico, where the seasons appear to be defined by June through October (warm season) and November through May (cold season). For Nevada and Utah the seasonality is not clearly defined from the preliminary analysis. The northern parts of Nevada and Utah appear to be divided into two seasons: a dry period beginning in June or July through September, and a wet period from October through May or June. The central and southern regions of Nevada and New Mexico are portrayed by transitional periods between northern Nevada and New Mexico and Arizona-New Mexico.

The third data set is a frequency count of the months in which the annual maximum intensity occurred for durations of 3, 12, 24, and 48 hours. Thirteen stations have been chosen for the initial analysis (Enclosure 13a). The frequency counts by months for Ajo, Arizona, is shown in Enclosure 13b. July through September dominate the maximum annual occurrence for all durations through 48 hours, with a dry period from April through June. This analysis is in agreement with the results found from the other two data sets, which indicate a wet period from July through October, a secondary maximum from November through February or March, and a dry period from April through June. The analysis for the other stations show similar results for the various reasons, including some sort of a transitional period over central and southern portions of Nevada and Utah. There are minor differences in the results from this preliminary analysis of the three data sets, but these three data sets should be sufficient to define the seasonality of the Semi-Arid Southwest.

FREQUENCY CALCULATIONS

An important part of determining the intensity of the frequency relations for the various durations using L-moments is to determine if the data in the physical regions that are being defined are homogeneous or non-homogeneous (heterogeneous). Hosking and Wallis (1991) have developed a test that examines heterogeneity, H. This measure of H "compares the between-site variations in sample L-moments for the group of sites with what would be expected for a homogeneous region." (See Enclosure 14a.) This technique essentially uses the graphical property of anticipating a close cluster of points around some central value for a plot of the L-coefficient of variation and the L-skew. If the points are closely clustered around a central point then the region might be considered to be homogeneous; but if the points are scattered then the region is considered to be heterogenous.

As a numerical measure of heterogeneity Hosking and Wallis determine the average distance from a site's plotted point to the group average point that would be expected of a "homogeneous region." The expected value of the homogeneous region is obtained by simulating the expected values of a homogeneous region using a 4-parameter kappa distribution. The 4-parameter kappa distribution was chosen, so that a particular distribution for the data is not forced. After the simulation a comparison between the observed and simulated dispersion is made, using the appropriate statistics, as follows:

$$\frac{\text{(observed dispersion) - (mean of simulation)}}{\text{(standard deviation of simulation)}}$$

This can be done for the L-coefficient of variation, the combination of L-coefficient of variation and L-skew, or the combination of L-skew and L-kurtosis. The farther one gets from only using the L-coefficient of variation, the more tolerance on what is considered to be homogeneous.

As a crude first investigation an analysis was performed using the 276 daily stations in Arizona (Enclosure 14b). For this data set the threshold was 3.0; i.e., if the measure of heterogeneity (H) is greater than 3.0, then the data are not homogeneous, but if H is less than 3.0 than the data are homogeneous. This analysis showed that if only the L-coefficient of variation is used the Arizona daily data are not homogeneous; if the L-coefficient and the L-skew are used the daily data are not homogeneous; but if the L-skew and the L-kurtosis are used then H equals 0.01 and the data are homogeneous. This means that in a gross sense the daily data from Arizona are homogeneous, but one should expect other physical divisions if one expects to have a truly homogeneous data set.

Another important part of any frequency investigation is the determination of the optimum frequency distribution for the data set. Hosking and Wallis (1991) developed a goodness-of-fit measure, Z, (Enclosure 14c) which can be used to determine the optimum frequency distribution for a given data set. Again the 276 daily stations for 1-day durations and an annual-maximum series were chosen for a test run of this measure. The closer the absolute value of Z is to zero, the better the frequency distribution. The results from this test run are shown in Enclosure 14d. They indicate that the GEV or the Generalized Extreme Value distribution, with a Z value of -2.06, is the optimum distribution for a duration of one-day for Arizona. This is the same result that was found for precipitation data over West Virginia and Pennsylvania. The next best frequency distribution is the generalized normal distribution with a Z value of -4.62. The generalized logistic is third with an absolute value of Z equal to 7.30. Results for some other frequency distributions are also shown on Enclosure 14d.

Various people have worked on these projects. The data processing, quality control of data, and data for future storm analyses have been done in part by Ed Chin, Doug Kluck, Julie Olson, Lesley Tarleton, John Vogel, and Mike Yekta. Seasonality has been tackled by Ed Chin, Julie Olson, Lesley Tarleton, and John Vogel. The frequency calculations has been accomplished by Ed Chin, Julie Olson, and John Vogel.

The progress for the storm analysis software were summarized in the introduction, and were not further discussed. The meeting was adjourned at about 1220 PM.

Reference

Gifford, R. O., G. L. Ashcroft, and M. D. Magnuson, 1967: Probability of Selected Precipitation Amounts in the Western Regions of the United States. **Western Regional Research Publication T-8**, Agricultural Experiment Station, University of Nevada, Reno, NV.

Hosking, J. R. M., and J. R. Wallis, 1991: Some Statistics Useful in Regional Frequency Analysis. **IBM Report No. RC 17096 (#75863)**, IBM Research Center, Yorktown Heights, NY 10598.

Miller, J. F., R. H. Frederick, and R. J. Tracey, 1973: Precipitation-Frequency Atlas of the United States. **NOAA Atlas 2**, NOAA, National Weather Service, Silver Spring, MD.

Vogel, J. L., and B. Lin, 1992: Precipitation Return Frequencies and L-Moment Statistics. **Preprints of the 12th Conference on Probability and Statistics of Atmospheric Science**, American Meteorological Society, Boston, MA.

Enclosure 1

Agenda for Semi-Annual Meeting of the Semi-Arid Precipitation Frequency Project

December 7, 1992

I. Welcome and Overview

II. Data

A. Data Reduction

1. Progress of hourly and daily data processing

2. Merging/Deletion of stations

B. Data Acquisition

C. Data Quality Control

1. L-Moments

2. Mass Curves

D. Data Comparisons Planned

III. Seasonality

A. Dry Periods

B. Probability of Precipitation Amounts

C. Frequency of Annual Maximum Values

IV. Frequency Calculations

V. Storm Analysis

Enclosure 2c

Semi-Arid Precipitation Frequency

Summary Of Hourly Stations
(as of 12/2/92)

	Arizona	Nevada	New Mexico	Utah
Orginal Number of Stations	81	73	141	91
delete <5 yrs	-3	-4	-25	-17
"loss" to combinations	-11	-6	-24e	-9e
Other Deletions i.e. (L-Moments)	-8	-6e	-8e	-7e
Total	59	57	84	78
Next Step				
delete <15 yrs	-11	-11	-30	-17
TOTAL	48	46	54	61

e = estimated

Enclosure 2b

CRITERIA

To Run L-Moment

- Need at least 5 years

To Combine

- $\leq$ 5 miles
- $\leq$ 300 feet difference in elevation

For Frequency Analysis

- "within" cluster of L-skew vs. L-kurtosis plot - i.e., not 'real far out'
- 15 years for frequency analysis

PROCESS

- Use Formatted Statewide Data Set
- Run L-Moment FORTRAN program {MN,CV,SK,K,5th}

  (without < 5-year stations)
- Plot L-skew vs L-kurtosis, check outliers for erroneous data, if outliers:

  correct, if necessary

  combine, if possible

  delete, otherwise
- Check proximity for merging

  < 5 miles

  < 300 feet

  (especially to combine 2 or more short records to make 1 long record)

Enclosure 3

DATA REDUCTION

Daily

NCDC + TP40

Records mostly 1948-1990

Some as early as 1880

Core States	Initial	≥ 19 yrs
Arizona	438	276
Nevada	211	105
Utah	316	186
New Mexico	*	
California	447	
Border States	462	

SNOTEL (SNOpack TELemetry)

- 163 stations for area
- Software complete

Enclosure 4a

New Mexico Daily Data
Format Problems

Missing Data

	-99 ...	-99	-99	-99	-99	-99 .. ..
	-99 ...	-99	-99	**99**	**99**	
Date:	21 ...	28	29	30	31	

Note: last 2 days of month 99 instead of -99

-99 = missing data

Solution: write program to change 99 at ends of month to -99

New Mexico Daily Data Format Problems

Accumulated Data

...0 0 0 -99 **110** 0 0 .. .

Note: Accumulated data is not coded -88 in this data set, it is coded -99, same as missing.

-88 = Accumulated data

Solution: Distribute data over days with -99 prior to observation.

Example:	-99	110	(1.10)	
	55	55	(.55	.55)

Enclosure 5

DATA REDUCTION

- Storm Analysis Data
  - Software development for GRASS storm format
  - Initial data: California, post - 1948 data
- 15-minute Data
  - Tapes have been read
  - Preparing list of stations
- N-minute Data - packed in zip format
  - 5-, 10-, 15-, 30-, 60-, 90-, 120-, ..., 1440- min

Enclosure 6

N-Minute Data Base
Arizona

Durations: 5-, 10-, 15-, 30-, 60-, 120-, 1440- minutes

FLAGSTAFF	1951 - 1978	(all)
	1898 - 1978	(1440)
PHOENIX	1906 - 1978	(all)
	1898 - 1978	(1440)
TUCSON	1943 - 1978	(all)
	1924 - 1978	(1440)
WINSLOW	1951 - 1978	(all)
	1881 - 1978	(1440)
YUMA	1881 - 1978	(1440)

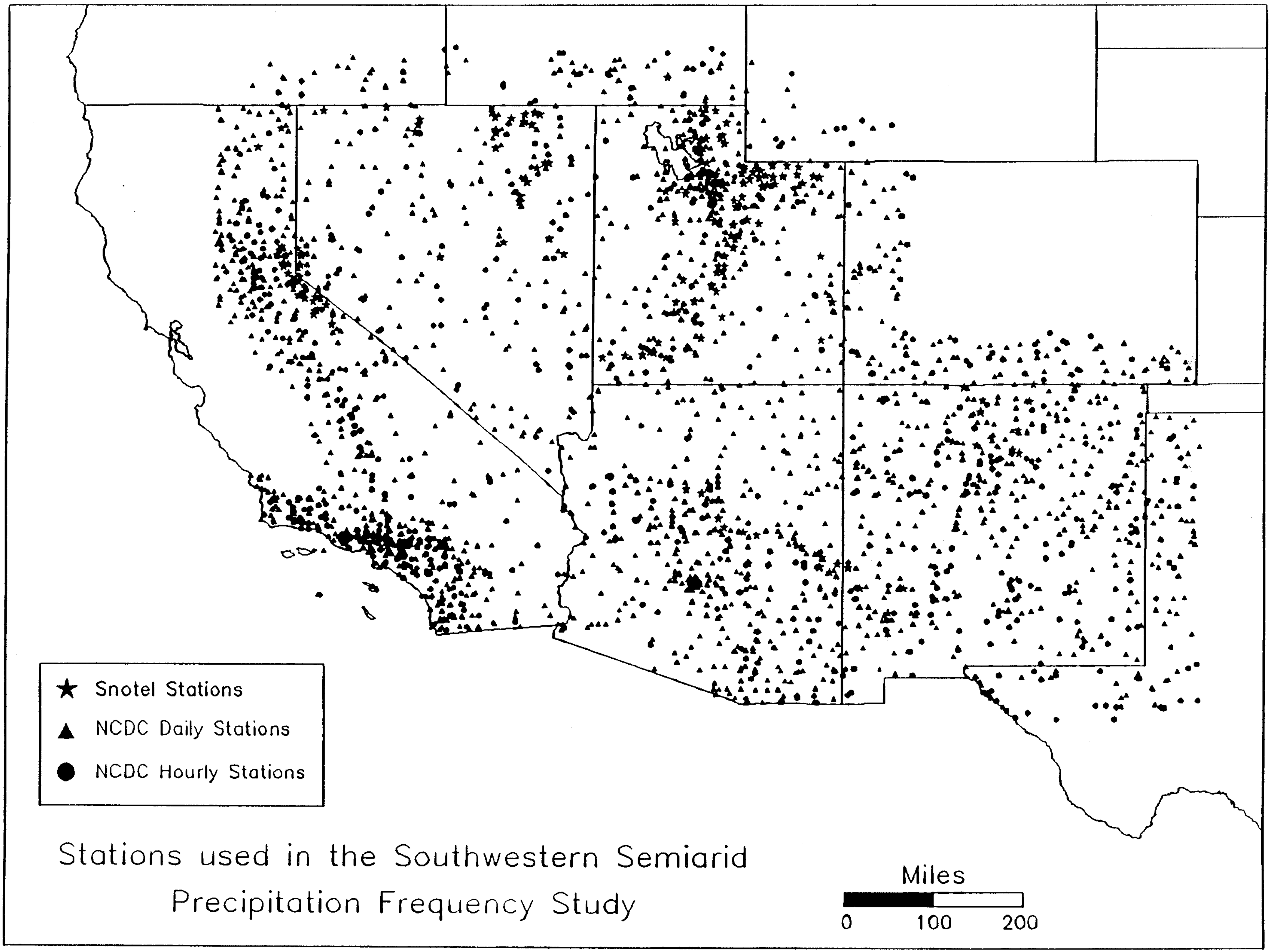
Maximum precipitation for each duration for each year

Enclosure 7a

DATA SETS

NCDC	National Climatic Data Center	NOAA
SNOTEL	SNOwpack TELemetry	USDA/SCS
RAWS	Remote Automated Weather Station	USDA/BLM & FS
ARS	Agricultural Research Service	USDA/ARS
USGS	U.S. Geological Survey	Dept. of Interior
Supplementary	Dept. of Water Resources	California
Supplementary	San Bernardino County, CA	
Supplementary	Riverside County, CA	
ALERT	Automated Local Evaluation in Real Time	
	California Storm Data	J. Goodridge
	New Mexico Climate Data	Ken Kunkel

Enclosure [illegible]



Snotel Stations
NCDC Daily Stations
NCDC Hourly Stations
Stations used in the Southwestern Semiarid Precipitation Frequency Study
Miles
0
100
200

Enclosure 8a

OBSERVED DATA--PROBABILITY DISTRIBUTI(

1. METHOD OF MOMENTS

2. METHOD OF MAXIMUM LIKELIHOOD

LET $f(x_i;\ \theta_1,\theta_2,\ldots)$ BE THE pdf, THEN

$$L = \prod_{i=1}^{n} f(x_i;\theta_1,\theta_2\ldots) \qquad \textit{Likelihood Function}$$

$$\partial L/\partial \theta_i \qquad \textit{solve for } \theta_i$$

3. METHOD OF L-MOMENTS

a) robust, less sensitive to sampling errc and outliers

b) capable of characterizing a wide ran of distributions

c) linear combination of order statistics

L-MOMENTS

r.v. X with cdf F(X) & quantile func X(F)

$$X_{1:n} \leq X_{2:n} \leq \cdots \leq X_{n:n}$$

L-MOMENT for r = 1, 2, · · · are:

$$\lambda_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} E\, X_{r-k:r}$$

$$\text{L-CV} = \lambda_2/\lambda_1$$

$$\text{L-SKEW} = \lambda_3/\lambda_2$$

$$\text{L-KURTOSIS} = \lambda_4/\lambda_3$$

Enclosure 8c

STAGES IN FREQUENCY ANALYSIS

1. DATA SCREENING--DISCORDANCY D_i

Let $\dot{U}_i = \left[t_2^{(i)}, t_3^{(i)}, t_4^{(i)}\right]^T$ *be a vector for site i*

$$\dot{U} = N^{-1}\sum_{i=1}^{N} \dot{U}_i$$ *-- unweighted group mean*

THE DISCORDANCY FOR SITE i IS DEFINED:

$$D_i = \frac{1}{3}(\dot{U}_i - \bar{U})^T \dot{S}^{-1} (\dot{U}_i - \bar{U})$$

where $$\dot{S} = (N - 1)^{-1} \sum_{i=1}^{N} (\dot{U}_i - \bar{U})(\dot{U}_i - \bar{U})^T$$

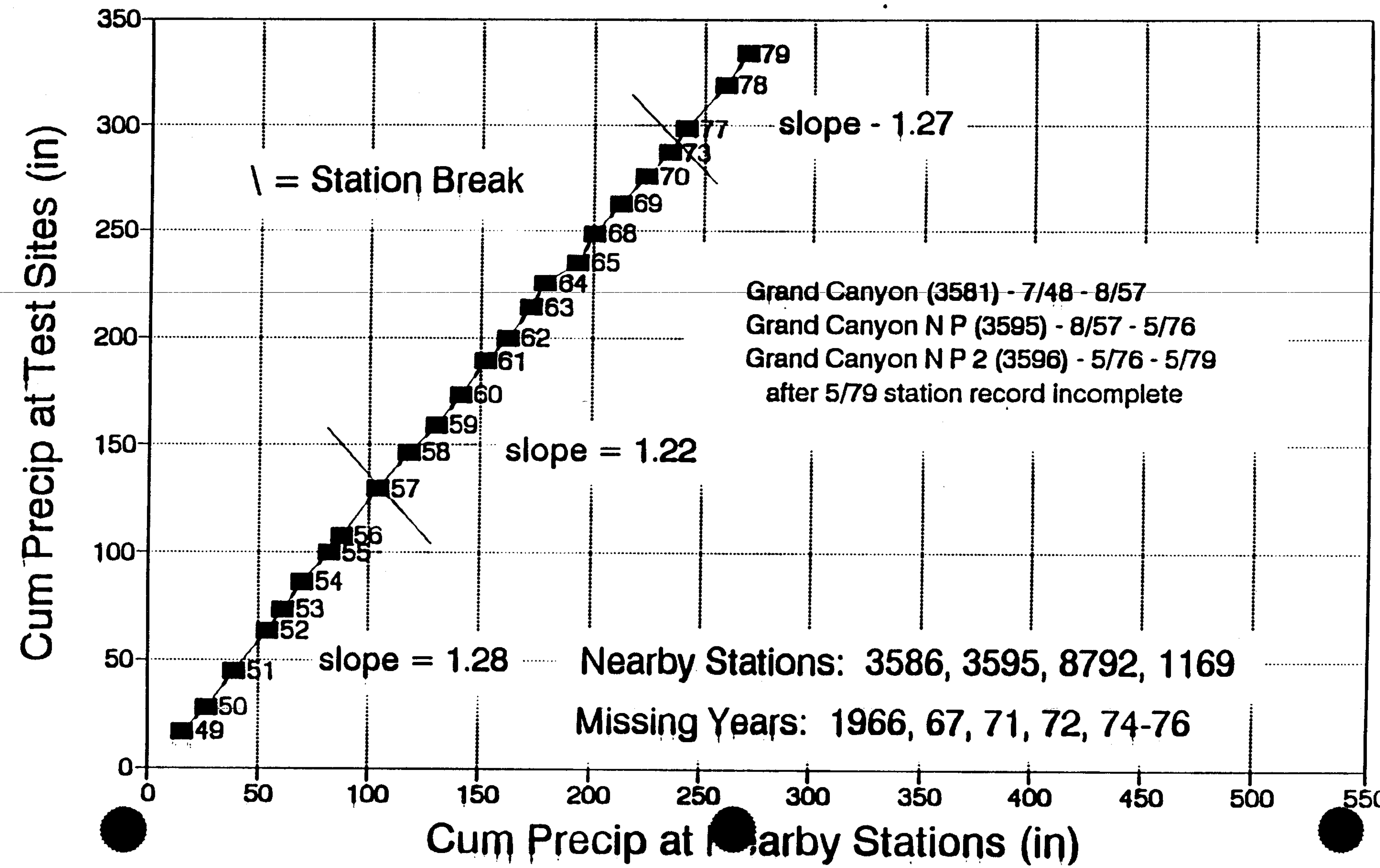
Enclosure 81

ARIZONA 270 SITES

N	NAME	L-CV	L-SKEW	L-KURT	D(I)
62	0060	.3701	.3096	.1531	1.10
77	0080	.3219	.2578	.2595	0.43
23	0625	.6247	.3033	.0599	6.97**
27	1169	.5143	.3350	.1190	3.54*
20	1248	.3579	.5132	.5364	7.33**
78	2329	.6048	.2209	.1396	4.45**
96	3595	.3050	.3651	.4777	5.51**
22	3926	.6020	.2393	.2772	5.34**
43	4182	.5953	.3706	.2278	4.21**
41	4586	.4228	.5015	.4345	4.59**
31	4675	.5143	.2027	.0470	3.29**
25	8184	.3878	.2024	.3303	3.07*
36	8273	.6879	.3359	.2568	6.84**
21	8329	.2380	.1023	.1926	1.36
31	8649	.4440	.1948	.2993	3.02*
30	9114	.2876	.4463	.4276	4.11**
MEAN		.3204	.2107	.1726	

Enclosure 9

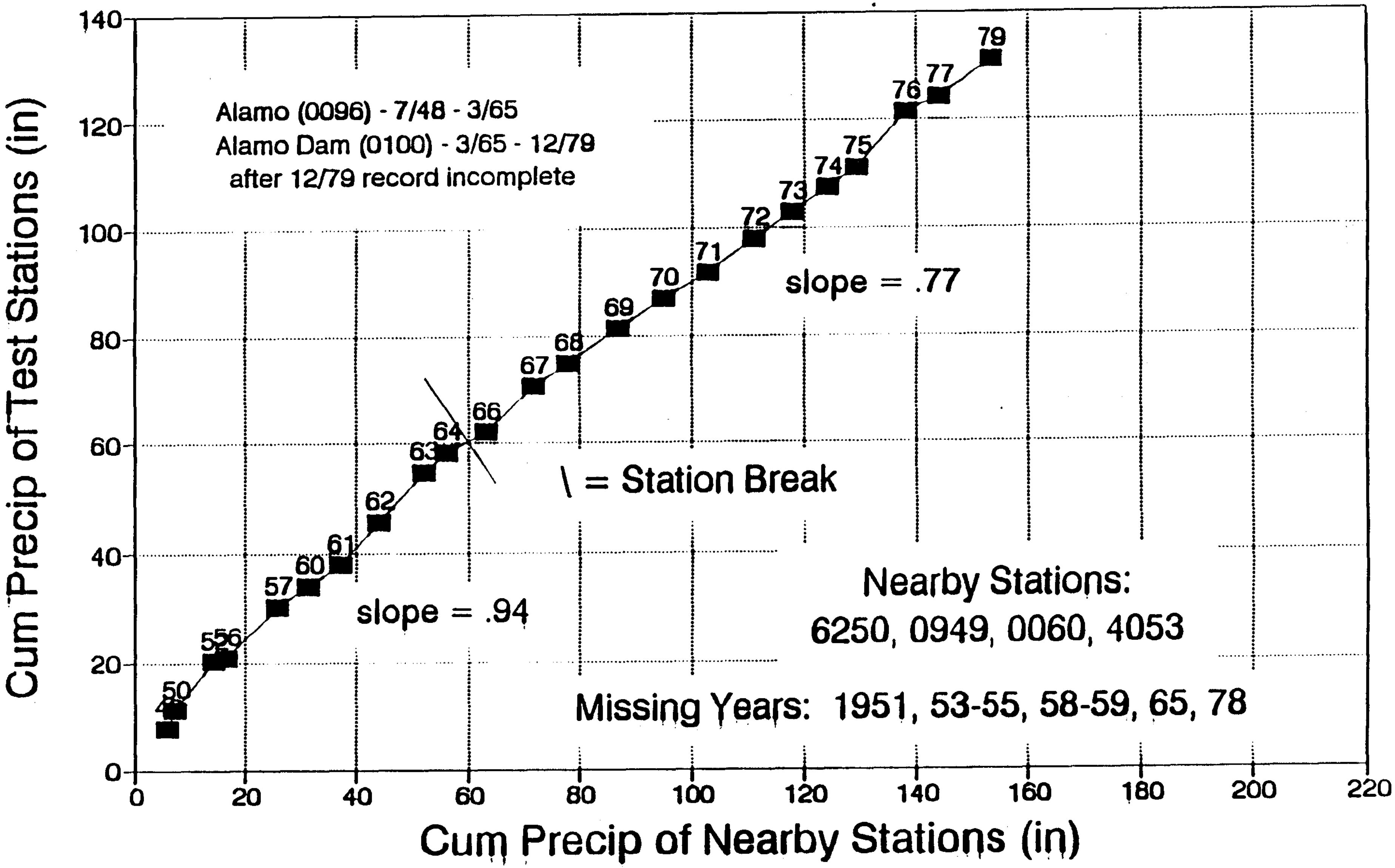
DOUBLE MASS CURVE (1949-1979)
Stations 3581, 3595, 3596



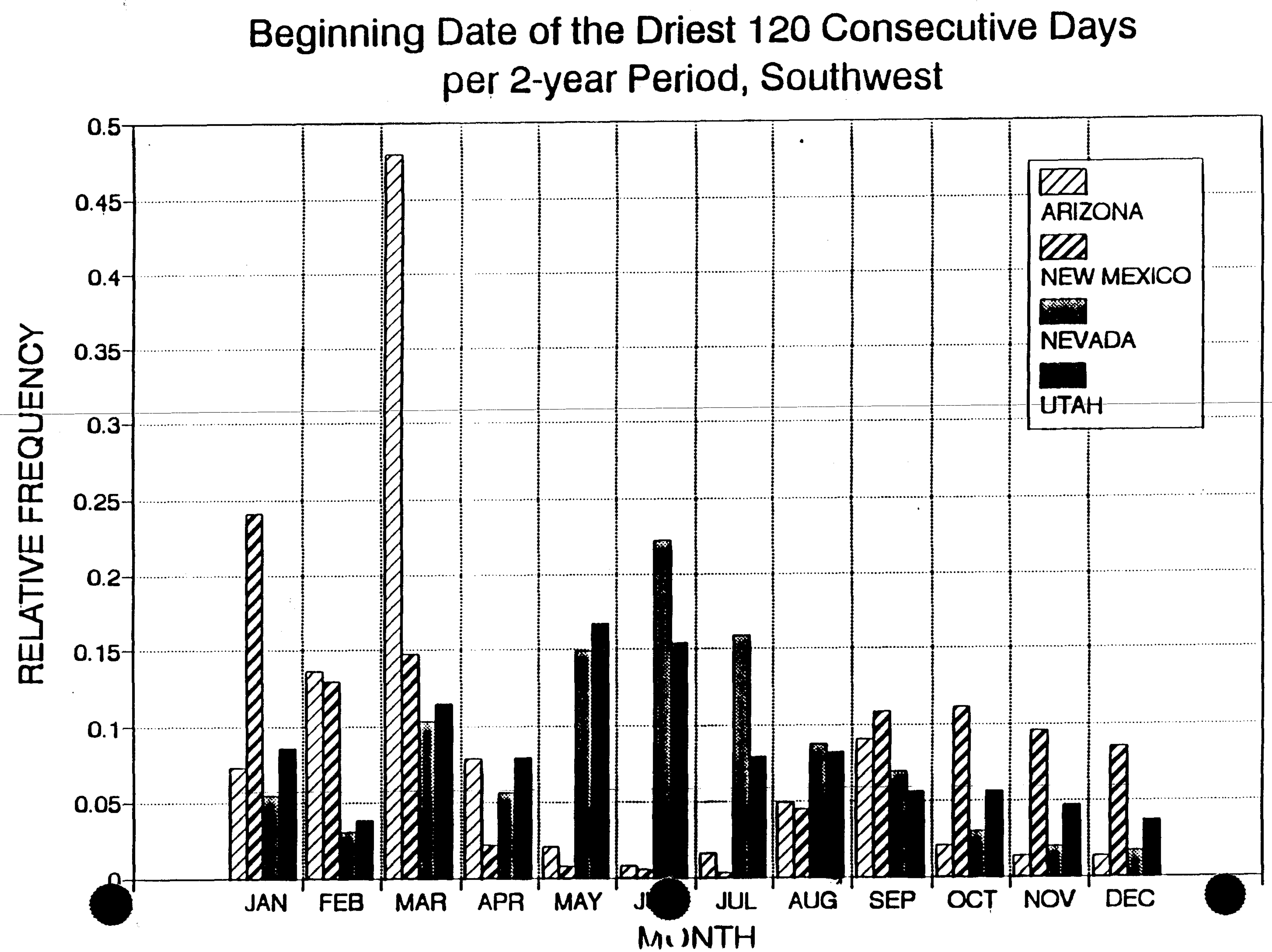
Enclosure 10

DOUBLE MASS CURVE (1949-1979)

Stations 0096 & 0100



Enclosure 11



Enclosure 12a

WESTERN REGION STATION LOCATIONS

SCALE 1: 10,000,000

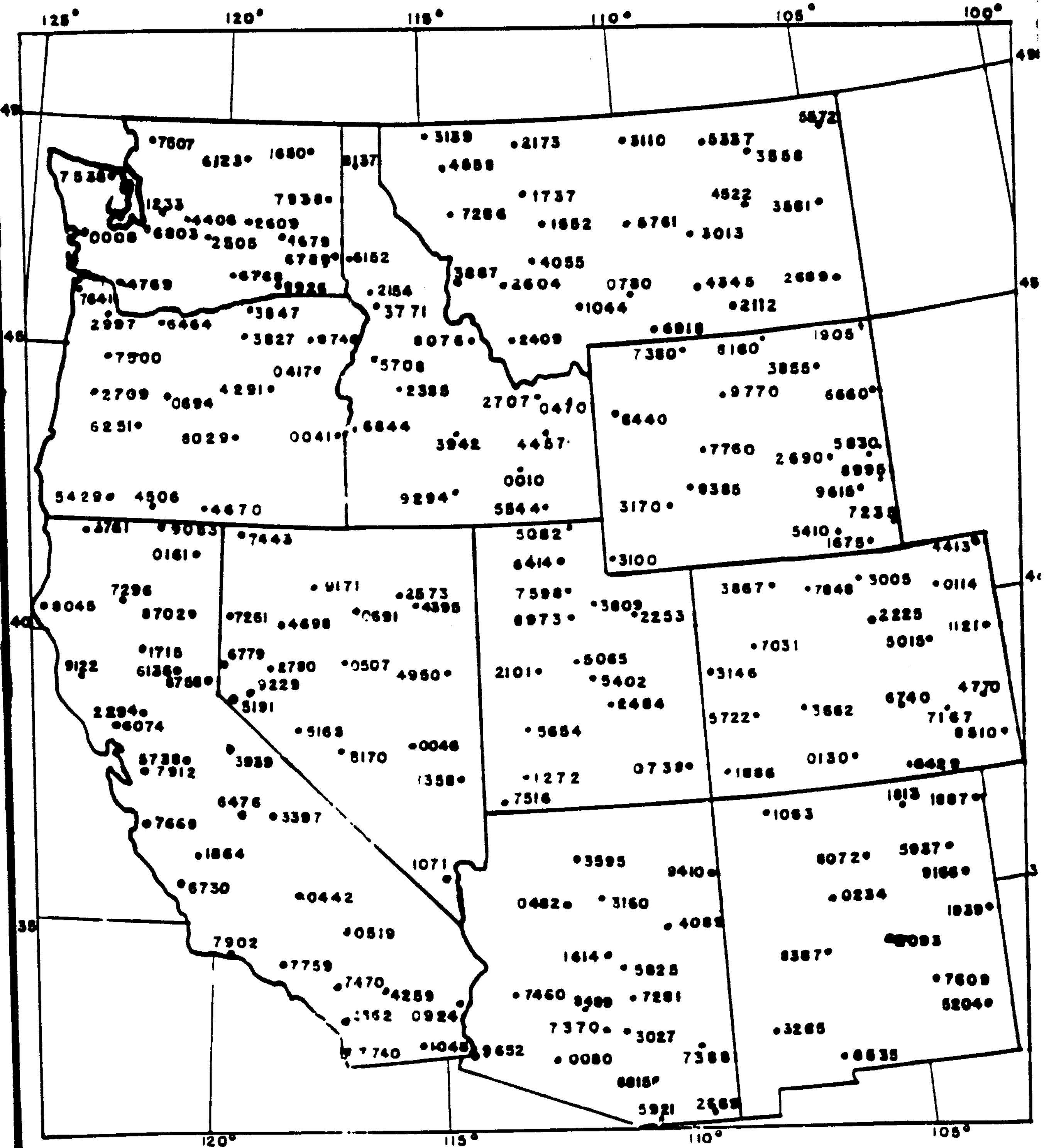


FIGURE 1: STATIONS FOR WHICH PRECIPITATION PROBABILITIES WERE CALCULATED

Enclosure 12b

AJO, ARIZONA 20080

PRECIPITATION MEANS AND PROBABILITIES FOR 1 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.24	53	24	22	18	12	9	5	3	1	
MAR 08	.16	76	26	24	20	15	11	7	4	2	
MAR 15	.25	73	25	23	19	14	10	6	4	2	
MAR 22	.12	60	25	22	17	10	6	3	2	1	
MAR 29	.04	83	19	17	12	6	3	1			
APR 05	.06	80	12	10	7	4	2				
APR 12	0.00	100	7	5	3	2	1				
APR 19	.02	83	10	8	4	1					
APR 26	.05	76	12	10	6	2					
MAY 03	0.00	100	8	6	4	1					
MAY 10	.03	80	8	5	3	1					
MAY 17	.01	93	6	4	1						
MAY 24	0.00	100	4	3	1						
MAY 31	.02	86	6	4	2						
JUN 07	0.00	100	3	2	1						
JUN 14	0.00	100	4	3	2	1					
JUN 21	.05	80	11	9	6	2	1				
JUN 28	.04	76	21	18	12	6	4	1	1		
JUL 05	.19	56	33	32	25	15	10	4	2	1	
JUL 12	.30	40	51	47	38	25	17	8	4	1	
JUL 19	.39	23	64	59	49	34	25	13	7	3	
JUL 26	.56	20	72	68	58	43	32	18	10	4	
AUG 02	.61	20	72	68	60	46	35	20	12	5	
AUG 09	.52	26	68	64	55	41	31	18	10	5	
AUG 16	.44	23	65	61	52	38	28	16	9	4	
AUG 23	.52	30	58	54	45	32	23	13	8	4	
AUG 30	.18	46	45	41	32	21	14	7	4	2	
SEP 06	.18	56	34	31	24	16	11	6	4	2	
SEP 13	.32	60	30	27	22	16	12	7	5	3	
SEP 20	.11	63	29	26	20	13	8	4	2	1	
SEP 27	.13	63	29	26	20	13	8	4	2		
OCT 04	.23	70	27	25	21	14	10	5	3	1	
OCT 11	.08	76	21	19	15	10	6	3	1		
OCT 18	.06	80	19	17	13	8	5	2	1		
OCT 25	.16	70	21	19	14	9	6	3	1		
NOV 01	.04	76	24	21	15	8	5	2	1		
NOV 08	.15	63	30	26	19	10	5	2	1		
NOV 15	.12	46	36	31	22	10	5	1			
NOV 22	.12	63	30	26	18	9	4	1			
NOV 29	.07	76	24	21	16	10	6	2	1		
DEC 06	.19	66	28	25	20	13	8	4	2		
DEC 13	.12	53	36	32	25	15	9	4	2		
DEC 20	.24	50	40	36	29	18	11	4	2		
DEC 27	.18	60	34	31	25	17	11	5	2	1	
JAN 03	.16	63	33	31	25	16	10	4	2	1	
JAN 10	.22	53	38	35	29	18	11	4	1		
JAN 17	.16	60	37	34	27	17	11	4	2		
JAN 24	.21	56	35	32	25	16	10	4	2		
JAN 31	.13	60	37	33	25	15	9	3	1		
FEB 07	.18	46	38	34	25	15	9	3	1		
FEB 14	.19	53	39	34	26	16	10	4	2	1	
FEB 21	.19	46	30	27	21	13	8	3	1		

AJO, ARIZONA 20080

PRECIPITATION MEANS AND PROBABILITIES FOR 2 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.40	46	36	33	28	22	17	11	7	4	1
MAR 15	.36	43	44	41	34	25	18	10	6	3	
MAR 29	.11	66	27	24	17	10	5	2			
APR 12	.03	83	18	15	8	3	1				
APR 26	.07	73	22	19	12	5	2				
MAY 10	.03	73	14	10	5	2					
MAY 24	.03	83	11	8	3						
JUN 07	0.00	100	8	7	4	1					
JUN 21	.09	60	30	26	18	9	5	2	1		
JUL 05	.49	16	71	66	56	40	29	15	8	3	
JUL 19	.95	0	91	87	79	64	52	34	23	12	2
AUG 02	1.13	10	90	88	83	72	61	43	29	16	2
AUG 16	.96	10	81	78	71	59	49	33	23	13	2
AUG 30	.36	33	57	53	44	33	26	16	10	6	1
SEP 13	.43	43	49	45	38	28	21	13	8	5	1
SEP 27	.36	36	49	46	38	26	19	10	5	2	
OCT 11	.14	66	32	30	25	17	12	6	3	1	
OCT 25	.20	56	38	35	28	18	12	5	2	1	
NOV 08	.27	33	53	48	36	22	13	5	2		
NOV 22	.18	53	45	41	32	19	12	5	2		
DEC 06	.32	43	51	48	40	28	19	9	4	2	
DEC 20	.42	30	59	55	46	33	24	12	6	2	
JAN 03	.38	36	57	53	45	32	23	11	6	2	
JAN 17	.37	33	59	55	46	32	22	11	5	2	
JAN 31	.31	30	59	54	44	29	19	9	4	1	
FEB 14	.38	23	57	51	41	27	19	9	5	2	

AJO, ARIZONA 20080

PRECIPITATION MEANS AND PROBABILITIES FOR 3 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.64	40	49	46	40	31	25	17	12	7	1
MAR 22	.22	36	46	41	32	20	13	6	3	1	
APR 12	.07	63	30	25	15	5	2				
MAY 03	.05	70	23	18	11	4	2				
MAY 24	.03	83	15	11	5						
JUN 14	.09	56	34	29	20	11	6	2	1		
JUL 05	.88	6	89	86	77	62	49	32	21	11	2
JUL 26	1.69	0	97	96	93	85	77	60	46	30	6
AUG 16	1.15	6	88	85	79	68	59	43	31	19	4
SEP 06	.61	26	61	57	49	39	31	21	14	9	2
SEP 27	.48	30	60	56	47	34	26	14	8	4	
OCT 18	.26	50	47	43	35	25	17	9	5	2	
NOV 08	.38	30	61	56	45	30	20	9	4	1	
NOV 29	.38	26	64	60	50	36	26	13	7	3	
DEC 20	.58	23	70	67	59	45	35	20	11	5	
JAN 10	.59	23	73	69	61	46	35	19	10	4	
JAN 31	.50	20	73	68	57	41	30	17	10	4	

Enclosure 12c

WESTERN REGION STATION LOCATIONS

SCALE 1: 10,000,000

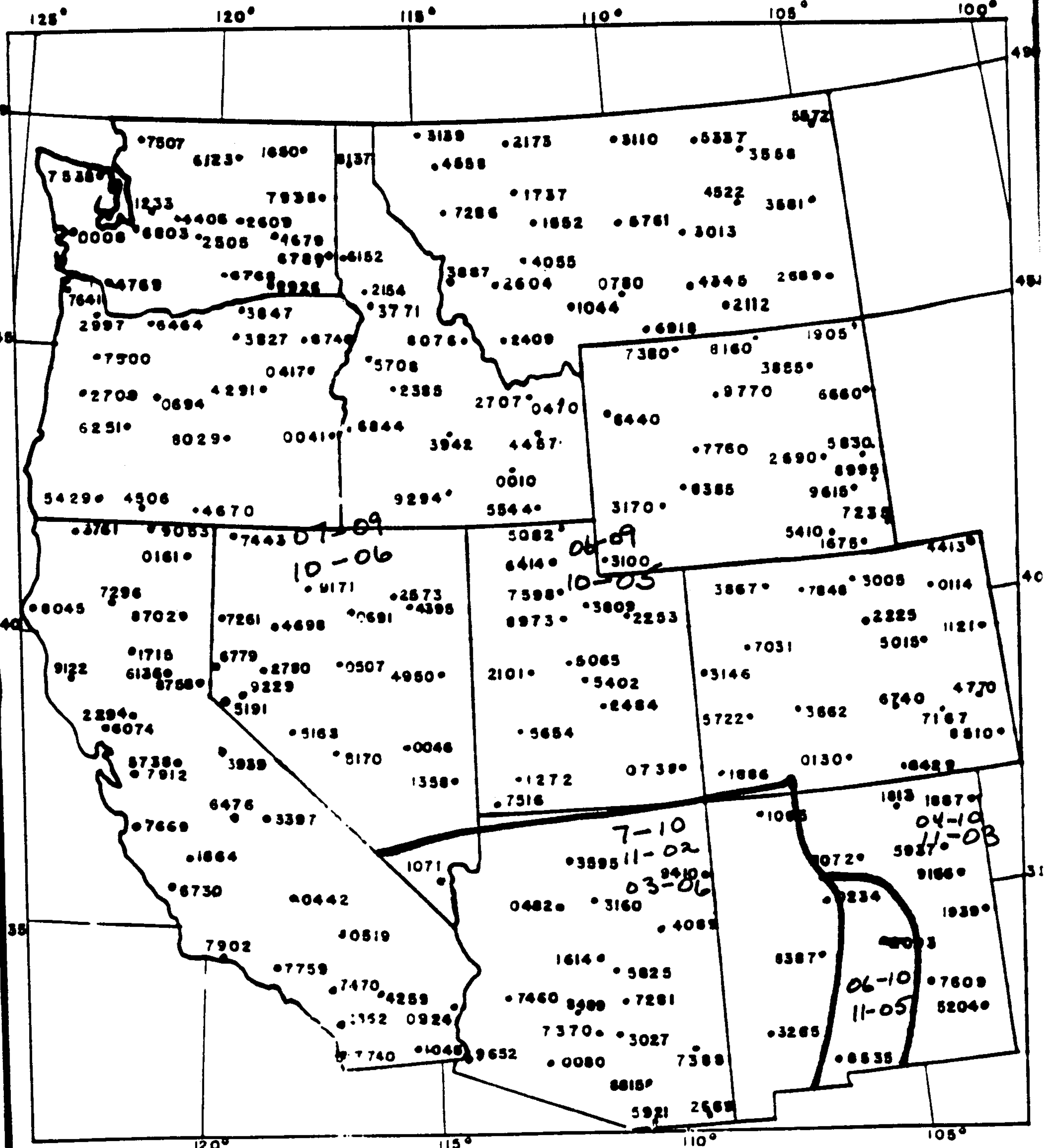
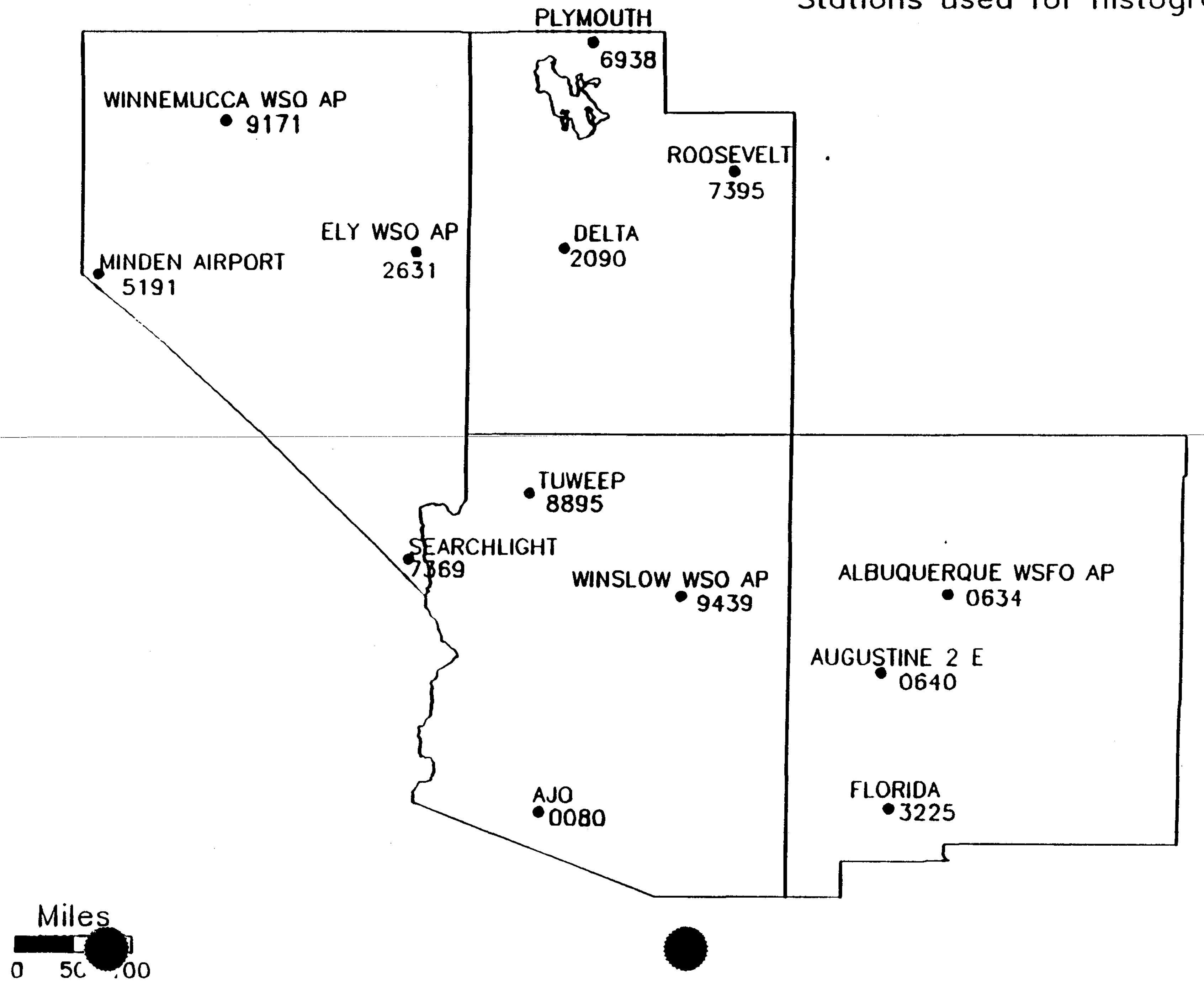


FIGURE I: STATIONS FOR WHICH PRECIPITATION PROBABILITIES WERE CALCULATED

Enclosure 13a

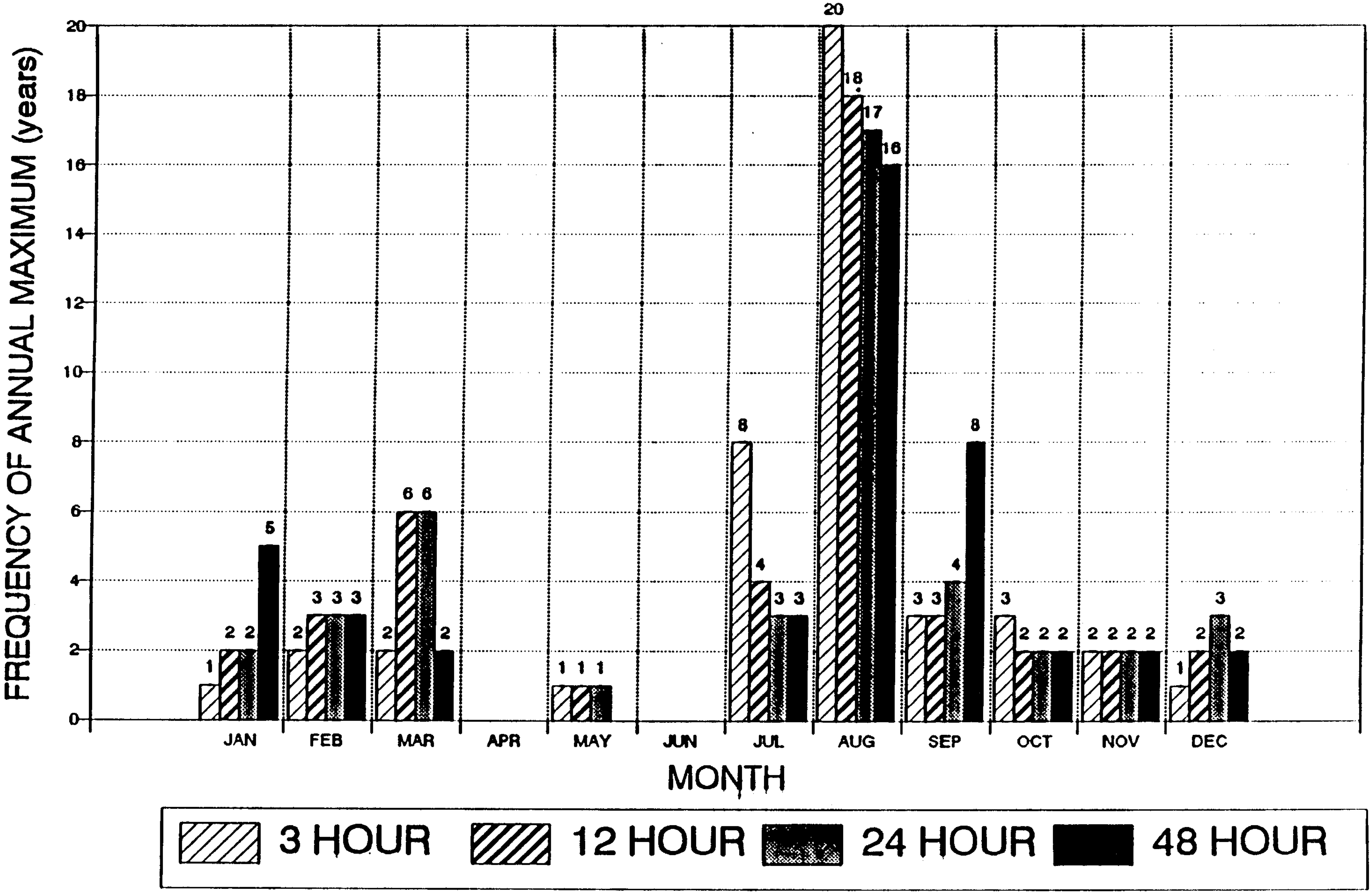
Stations used for histograms



Enclosure 13b

ANNUAL MAXIMUM HISTOGRAM

AJO, ARIZONA n=43 years



JMO 11/25/92

Enclosure 14a

2. IDENTIFICATION OF HOMOGENEOUS REGION
HETEROGENEITY, H "IS THE OBSERVE BETWEEN-SITE DISPERSION OF THE SAMPL L-MOMENTS FOR THE GROUP OF SITE UNDER CONSIDERATION LARGER THAN WOUL BE EXPECTED FROM A HOMOGENEOU REGION?"

[(OBS. DISP) - (MEAN DISP B SIMULATION)]/SD OF SIM DISP

SIMULATION: 4-PARAMETER KAPP. DISTRIBUTION

$$H = (V - \mu_V)/\sigma_V$$

WHERE V IS THE WEIGHTED SD AT EACH SITE

SAMPLE L-CV OR L-SKEW OR L-KURTOSIS

μ_V, σ_V FROM MONTE CARLO

Enclosure 14k

*** HETROGENEITY MEASURES ***

SIMULATIONS = 500

OBSERVED	SD OF GROUP L-CV	0.0769
SIM. MEAN OF	SD OF GROUP L-CV	0.0351
SIM. SD OF	SD OF GROUP L-CV	0.0015
STANDARIZED TEST VALUE		27.38**

OBSERVED AVG OF	L-CV/L-SKEW DIST	0.0935
SIM MEAN OF AVE	L-CV/L-SKEW DIST	0.0717
SIM SD OF AVE	L-CV/L-SKEW DIST	0.0028
STANDARDIZED TEST VALUE		7.68**

OBSERVED AVG OF	L-SKEW/L-KURT DIST	0.0860
SIM MEAN OF AVG	L-SKEW/L-KURT DIST	0.0860
SIM SD OF AVG	L-SKEW/L-KURT DIST	0.0033
STANDARDIZED TEST VALUE		0.01

Enclosure 14e

3. GOODNESS-OF-FIT Z

$$Z^{GEV} = \frac{(\bar{t}_4 - \tau_4^{GEV})}{\sigma_4}$$

where $\bar{t}_4$ is the regional average L-Kurtosis.

τ_4 is the L-kurtosis of the fitted GEV distribution, and

σ_4 is the standard deviation of $\bar{t}_4$

Enclosure 14.

GOODNESS-OF-FIT MEASURES

GEN LOGISTIC	L-KURTOSIS = 0.204	Z VALUE = 7.3
GEV	L-KURTOSIS = 0.167	Z VALUE = -2.0
GEN NORMAL	L-KURTOSIS = 0.157	Z VALUE = -4.6
PEARSON TY III	L-KURTOSIS = 0.138	Z VALUE = -9.7
GEN PARETO	L-KURTOSIS = 0.083	Z VALUE = -23.7

ARIZONA DEPARTMENT OF TRANSPORTATION

TRANSPORTATION PLANNING DIVISION

206 South Seventeenth Avenue Phoenix, Arizona 85007-3213

FIFE SYMINGTON
Governor

LARRY S. BONINE
Director

HARRY A. REED
Division Director

ARIZONA TRANSPORTATION RESEARCH CENTER

August ~~16~~ 23, 1993

FLOOD CONTROL DISTRICT
RECEIVED
AUG 26 1993

Joe Rumann
Maricopa County Flood Control District
3335 West Durango Road
Phoenix, Arizona 85009

Re: Revised Storm Rainfall Probability Atlas for Arizona

Dear Mr. Rumann:

A meeting of the above referenced subject will be held at the Arizona Department of Transportation Human Resouce Development Center, 1130 North 22nd Avenue, Phoenix, Arizona, (602)255-7613 on September 9, 1993 from 8:30 a.m. - 12:30 p.m. A map of the area is attached.

SDW Could you attend? Joe

If you have any questions please contact our office (602)831-2620.

Respectfully,

Larry Scofield

Larry A. Scofield
Manager-Transportation Research
ATRC

Agenda for Semiannual Meeting
of the Semiarid Precipitation Frequency Project

9 September 1993

I. Welcome and Overview

II. Data

- A. Datasets
- B. Annual maximum versus partial duration series
- C. Comparisons of daily and 24-hour data

III. Analysis

- A. Seasonality
- B. Regionality - criteria, statistical tests, etc.
- C. Regional frequency analysis
- D. Precipitation-elevation relationships

IV. Storm Analysis

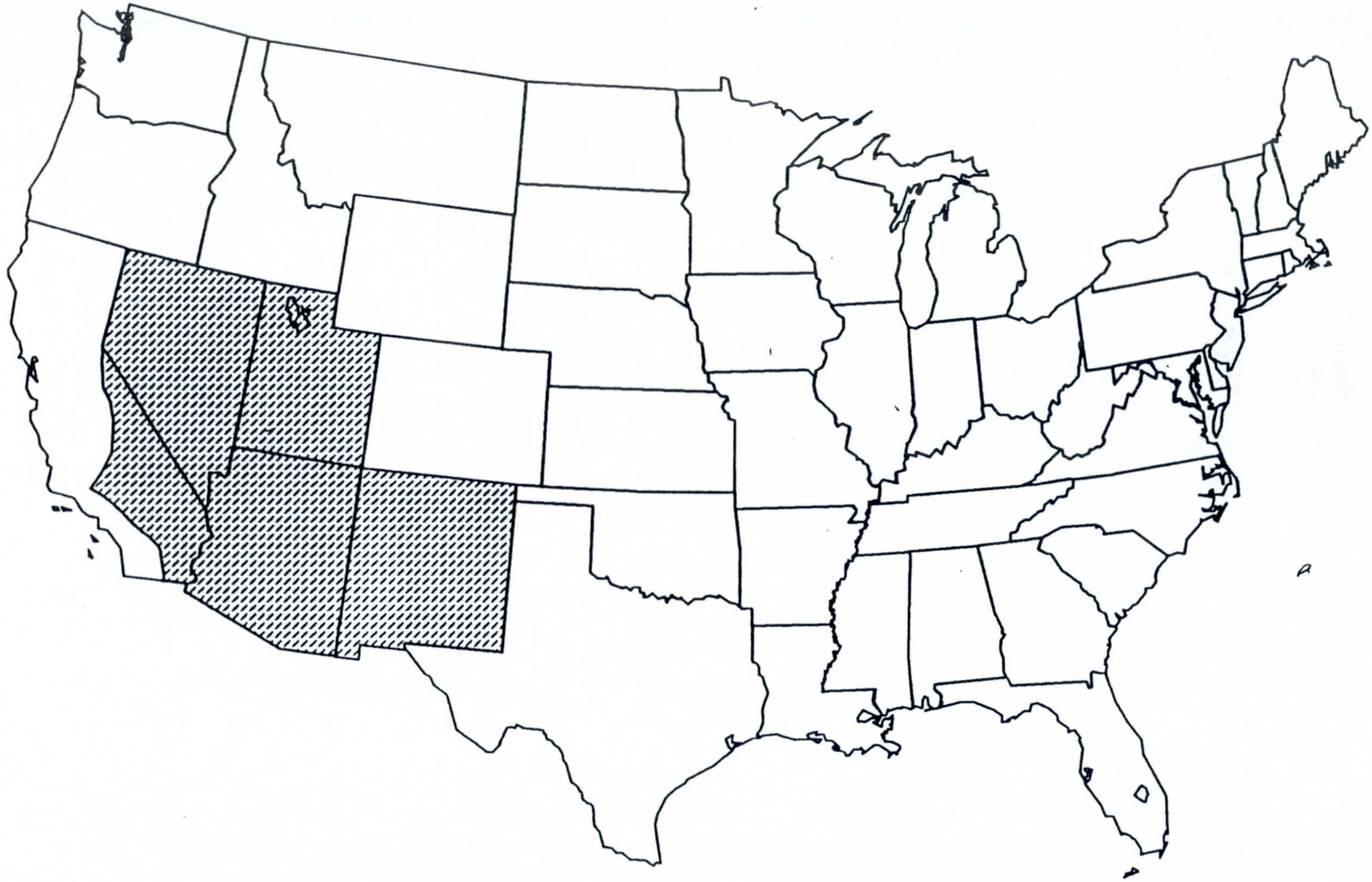
V. Discussion and Comment

3 - maps → Annual
Primary Season (Summer)
Secondary Season (Winter)

2 Formats → Paper
Digital (GIS)

Left to do: More work w/ Ann Max vs PDS ratios
Orographic relationships
Depth-Area Reduction

Semi-Arid Southwest US Study Area



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

October 13, 1993

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Project Study Group

FROM: W/OH11 - Julie Olson Julie Olson

SUBJECT: Minutes from the Semiannual Meeting - Semiarid Precipitation Frequency Project

Enclosed is a copy of the minutes from the forth semiannual meeting of the Semiarid Precipitation Frequency Project, which was held on September 9, 1993 in Phoenix, Arizona. These minutes were written by Lesley Tarleton, who presided at the meeting.

If you have any questions or comments, please feel free to call her at (301) 713-1669.

Minutes--Fourth Meeting
Semiarid Precipitation Frequency Project
Phoenix, Arizona
9 September 1993

Attendance

George Lopez-Cepero	ADOT[1]	(602) 225-7481
Joe Warren	Pinal County FCD	(602) 868-6501
David Creighton	ADWR[2]	(602) 542-1541
Patrick J. Ellison	Cella Barr Assc.	(602) 242-2999
Lou Schreiner	USBR[3]	(303) 236-3791
Cliff Anderson	AMAFCA[4]	(505) 884-2215
Steve Waters	Maricopa County FCD	(602) 506-1501
Lesley Tarleton	NOAA/NWS	(301) 713-1669

INTRODUCTION

The Fourth Semiannual review meeting for the Semiarid Precipitation Frequency Project was convened at 8:30 AM September 9, 1993 at the Arizona Department of Transportation (ADOT) Human Resource Development Center. George Lopez hosted the meeting for ADOT. The agenda is included as Attachment 1. Lesley Tarleton of the National Weather Service, Office of Hydrology presented the review. She pointed out that the quality control for the daily and hourly data is complete, with the caveat that one must consider some quality control until the last line is drawn. Attachment 2 is a map of the southwestern region with daily, hourly, and SNOTEL (SNOwpack TELemetry) stations shown. Essential to the analysis is the division of the project area into subregions based on seasonality, orography, synoptic climatology, and other factors. Fourteen subregions have been defined and final frequency analysis is underway. The report included discussion of partial duration (PD) versus annual maximum (AMX) series, daily to hourly conversion factors, and the large numbers of 'front end' or short-duration extreme events that exert a major influence on the longer durations as well. The main emphasis in the report was on the seasonality and regionalization. A comparison of preliminary frequency results from the current study with NOAA Atlas 2 was also shown. Discussion included a number of questions from Lou Schreiner and others regarding the implications of new findings on final results and on the schedule for completion.

---

1 Arizona Department of Transportation

2 Arizona Department of Water Resources

3 U.S. Bureau of Reclamation

4 Albuquerque Metropolitan Flood Control District

DATA

Partial Duration Versus Annual Maximum Series

An annual maximum series consists of the highest precipitation amount for each duration in each year. A partial duration series consists of the **n** highest amounts, where **n** is the number of years of record, regardless of year of occurrence. Thus, partial duration series are more representative of the occurrence of extreme events. The maps in NOAA Atlas 2 were analyzed from annual maximum series, and then converted to partial duration by multiplying the annual maximum return frequency results by the empirical factor 1.13 for 2-year return periods, 1.05 for 5-year return periods, and 1.01 for 10-year return periods. However, as we now have the computing power to quickly calculate partial duration series, it is preferable to analyze partial duration data directly. Some of the differences between the two series are: the partial duration series has fewer low values, a smaller range, the same high values, and a higher median. These differences are illustrated in various ways in Attachments 3a-3f.

o Attachment 3a shows box-and-whisker plots for two stations in Arizona, Buckeye-1026 (97 years) and Clifton-1849 (98 years). The 'box' contains the middle 50 percent, while the 'whiskers' show the range of the data. The line inside the box is the median line. As expected, the partial duration series has a much smaller range for both stations, and, in fact, the lowest partial duration values are <u>greater</u> than the lowest quartile of the annual maximum series.
o The same information is illustrated in another way in Attachment 3b, with an x-y plot of the partial duration and annual maximum series at Clifton. <u>No</u> partial duration value is less than 1.1, and <u>more than 20</u> annual maximum values are less than 1.1.

o In another analysis the L-statistics were calculated for 277 Arizona stations, and plotted with the L-coefficient of variation (L-CV) against the L-skewness (L-SK) for AMX (Attachment 3c) and PD (Attachment 3d). Comparing the two, one sees that the AMX has higher variability (higher L-CV) and less skewness (L-SK) than the PD. Furthermore, The PD shows no negative skewness (L-SK). Plots of L-skewness and L-kurtosis (not shown) also confirmed differences between AMX and PD.

Differences between annual maximum series and partial duration series are important for at least two reasons: 1) for the determination of the best-fit distribution, and 2) for possible differences in the frequency analysis results. For example, implications for frequency analysis are shown in the log-log plots of precipitation and return frequencies for Buckeye (1026), Arizona, for AMX and PD (Attachments 3e and 3f, respectively). The AMX (Attachment 3e) gives much lower estimates, ranging from

0.31 to 1.20 inches for the 1- to 2-year return frequencies. The estimates from the PD series (Attachment 3f) range from 1.00 to 1.29 inches for the same return periods. The differences also have implications for determining the optimum probability distribution for return frequency analysis. The distribution to be used for the final analysis is being determined using L-moment statistical tests for goodness-of-fit (Hosking and Wallis 1991), and a real-data-check against return frequency results (Lin and Vogel,1993). Furthermore, the distribution must be one that satisfactorily fits all subregions throughout the study area.

Conversion of Daily Data to 24-hour Data

In the final quality-controlled dataset, there are 1307 daily stations and 452 hourly stations, or about 3 times as many daily as hourly observations (Table 1). Therefore, for shorter durations (e.g., 1-, 2-, 3-, 12-hour, etc.), we need to know the relationship of the daily data to 24-hour data in order to extend the daily data to hourly analysis. Technical Paper 40 and NOAA Atlas 2 used an empirical factor to convert daily data to 24 hours:

24-hour precipitation = 1.13 X observation day precipitation

Although this factor was used on all return frequencies, NOAA Atlas 2 gives no information about other possible empirical conversion for return frequencies greater than two years. As in Technical Paper No. 40, the assumption was made that the relation between the 2-year, 24-hour and the 2-year daily return frequencies would also be valid for all return frequencies. Intuitively, one would anticipate that for the highest daily values in a series the empirical value would decrease as the values approach the maximum value, because the higher daily maximum values probably more closely approach a true 24-hour value. Furthermore, as the factor was computed many years ago and applied to the entire country, it was decided to evaluate its use on southwestern precipitation data. Initial results using annual maximum data from 20 stations in Arizona, Nevada, New Mexico, and Utah are shown in Attachments 4a-4c. The values of 1.15, 2-year (4a) and 1.12, 10-year (4b) are comparable to the 1.13 used in earlier works. However, the 100-year return frequency value (4c) of 1.06 needs further investigation. In order to explore this relationship, we are comparing and evaluating return frequencies from annual maximum and partial duration series for the entire dataset in each subregion. This will be completed shortly.

Table 1.

	Daily	Hourly
Arizona	277	42
Nevada	102	41
New Mexico	271	81
Utah	185	44
California[1]	324	185
Border States	148	59
Totals	1307	452

[1]Note: California includes SE California and the part of California bordering the core area, including many stations in the Los Angeles area.

Discordancy Test Examples

In regard to quality assurance, one of the most effective techniques is a discordancy test (Hosking and Wallis 1991). The discordancy test was described in the Fifth Quarterly Progress Report for the Semiarid Project (Oct-Dec 1992) and a summary of L-moment definitions, including Discordancy is repeated here in Attachment 5. The discordancy test is also used to help assess the homogeneity of a region and is discussed later in this report in the section on Seasonality and Regionality.

Several examples will illustrate its functionality in flagging data series that contain erroneous data. In the list in Table 2 of Arizona annual maximum data, each record had a high discordancy score. The data were examined for extreme outliers - which were found - and, going back to original data sources (e.g., microfiche, climate summaries, etc.), the correct annual maximums were found. The station numbers, errors, and corrections are given in Table 2.

Table 2.

Station #	**Error**	**Comment**	**Correct Annual Maximum Value**
29-8015	70.02	should be .02	1.80
29-3128	11.10	should be trace	1.04
29-5490	40.15	should be 0.15	2.29
29-3511	13.00	should be missing	0.83
29-1063	8.00	should be 0.00	0.38
29-1403	11.10	should be trace	1.43

SEASONALITY AND REGIONALITY

Regions

In order to choose appropriate regions for analysis with L-moment statistics, several criteria need to be considered. Among these are: the season (or seasons) of highest precipitation, the precipitation type (e.g., general storm, convection, monsoon, decayed tropical storms or decayed hurricanes, or a combination), the climate, the topography (especially as it interacts with the weather systems), and the homogeneity of these factors in a single area.

Seasons

An analysis of the seasonality of each station was based on several sources: 1) Gifford et al.(1967), a report on the weekly probabilities of various precipitation amounts (.01,...,1.00,2.00 inches) for over 200 stations in the Western United States; 2) the National Weather Service (NWS) regions from the Climate Data Summaries (NOAA, 1989); and 3) histograms of the frequencies of the maximum precipitation for various durations by month, among others. The analysis using Gifford et al.(1967) was described in the Semiarid Project Fifth Quarterly Report (10/1/92-12/31/92). The example used in that report is repeated in Attachment 6, which illustrates the high precipitation in July and August in Ajo, Arizona. The second source noted is the NWS climate regions. As an illustration, the NWS Arizona climate regions are shown in Attachment 7. The third method, using monthly histograms from over 30 stations (Attachment 8), is described below. However, a discussion of the 'naming' of the seasons precedes the details of the seasonal analysis.

A discussion of the problems of naming seasons seems appropriate. In meteorological terms we commonly define precipitation as 'summer precipitation' or 'winter precipitation" meaning of course, the type of rain or snow most commonly associated with that season. It is important to note that the various types of precipitation may occur nearly any time of year, but are usually more common in a particular season. In summer, showery precipitation, short-term and intense, is prevalent. The thunderstorm exemplifies the most common summer convective precipitation. In general, winter precipitation is of the general storm type, widespread in area, and with durations of one to several days. However, the use of the words winter and summer may not suggest southwestern precipitation types. For example, the word winter may conjure up blizzards and deep snow, which may and do occur in the northern part of the southwest; but the emphasis needed here is that of the precipitation climate or precipitation regime appropriate to various areas of the southwest. Therefore, the terms, warm and cool, are used to designate the two precipitation seasons into which we have divided the subregions (Attachment 9).

Over thirty stations over the entire study area were used to develop seasonal histograms. The map in Attachment 10 shows the initial 14 regions defined within the bounds of the four core states and southeastern California. The dates of the two seasons for each region are outlined within each area on the map. In Attachment 10 the regions are also grouped with regard to the season in which the greatest number of annual maximum values occur, or the maximum season. After determining the maximum season, the next consideration was to separate a secondary maximum into the 'other' season. Therefore, months of few or no extremes are scarcely considered and can be included in either of the two seasons. However, dry months can be used to separate cool and warm regimes. Although each region has been divided into only two seasons, <u>warm</u> and <u>cool</u>; the bounds of <u>warm</u> and <u>cool</u> are different in different regions. They vary from warm = May-October (5-10) and cool = November-April (11-4), to warm = August-September (7-9) and cool = October-June (10-6). Also, the length of a season may vary from a minimum of three months to its complement, a maximum of nine months. Note also, that there are two cool seasons, 'winter' and 'spring'. To clarify, spring precipitation in the southwest is most commonly of a general storm type, similar to winter weather precipitation. Therefore, in regions 2 and 4, with spring maximums, the cool seasons run from October to May or June and include the spring months. On the other hand, convective summertime (warm) type precipitation may run into the fall. In this situation, we have included the fall months with summer. Thus far, a primary maximum has not been found in the fall. To illustrate the seasonal precipitation distribution, Attachments 11a-11d show representative histograms for the seasons.

Cool (winter).
The histogram for Minden AP, Nevada (Attachment 11a) in region 1 shows the prevalence of extreme precipitation in the cool season (October-February), with relatively little activity in the other months of the year.

Cool (spring).
A spring maximum in region 2 is illustrated with the Owyhee, Nevada histogram (Attachment 11b) with a warm season (July-September) and a cool one (October-June). The transition from winter to spring precipitation maximums is gradual and 'moves' eastward from northern California across Nevada, with an increase toward spring the farther east one goes.

Warm (summer).
Two different warm maximum regimes are illustrated with Tuweep, Arizona in region 8 (Attachment 11c), and Albuquerque, New Mexico in region 13 (Attachment 11d). Although both stations have most of their extremes in July and August, Tuweep has some extremes throughout the year, including winter. On the other hand, Albuquerque's precipitation extends later into the fall and has almost no extremes in the winter (November-March). Note October, particularly: Albuquerque has an October frequency nearly equal to the highest months of July and August; Tuweep has almost no October occurrences.

October.
In general, October has proved to be extremely difficult to categorize in several regions of the southwest. It is not only transitional between summer and winter; it is possible, even likely, to have several varieties of precipitation - warm convection, monsoon, decaying tropical storm, general storm, or a combination of these at a single station. On the other hand, October may be routinely a dry month, as at Tuweep (Attachment 11c).

Other Regional Factors

After determining two seasons for each station, the stations were grouped on the basis of seasons and physiography, using a digital shaded-relief map of the United States (Thelin and Pike, 1991). Consideration was given to barriers, synoptic climatology, homogeneity, precipitation climatology, among other parameters. Spatial differences in variability have also been taken into account. For example, maps of L-Coefficient of variation (L-CV) across the study area (Attachment 12) were included in the analysis. It must be emphasized that these are 'first trial' regions, to be confirmed by the L-moment analysis, or to be brought into question, and final regions to be determined through an iterative analytic process.

STATISTICAL TESTS AND ANALYSIS

Hosking and Wallis (1991) have developed three tests using L-moments for assessment of the homogeneity and appropriate probability distribution for regional frequency analyses: 1) Discordancy (described above in the Data section), 2) Heterogeneity, and 3) Goodness-of-Fit. Mathematical definitions for these three tests were given in Attachment 5.

Discordancy.
Initially, the discordancy measure was used for data checking and quality control. In evaluating regions, it used to determine if a site has been assigned to the appropriate region. It is based on the L-moments (L-CV, L-skewness, and L-kurtosis), which represent a point in 3-dimensional space, for each site. Then, the discordancy is a function of the distance from the 'cloud' of points for the sites in the region being tested. The 'cloud' is in fact the unweighted mean of the three moments for the sites within the region being tested. Sites with a discordancy value of 3 or greater are considered discordant, and should be examined to see if they possibly belong in another region or have a data problem. The threshold value of 3 is not a rigorous test, but a reasonable level to be expected within a homogeneous region. Attachments 13 and 14 show results from discordancy, heterogeneity, and goodness-of-fit tests for region 8. The annual maximum series (AMX) is shown in Attachment 13, and the partial duration (PD) series, in Attachment 14. A discordant station (D(I) >= 3) would be flagged with an asterisk. Thus, none of the 22 sites in region 8 is discordant. (The example shown at the meeting had a software error and mistakenly showed a discordant station).

Heterogeneity. Actually, the heterogeneity test (see Attachment 5) consists of three parts, one based on L-CV, the second based on L-CV and L-skew, and the third based on L-skew and L-kurtosis. Like the discordancy test, there is also a threshold value; Hosking and Wallis (1991) recommend a threshold of 1 (absolute value). For both the AMX and PD, all three measures indicate that this region is homogeneous.

Goodness-of-fit. This test measures the "distance" of L-moment statistical parameters of a dataset from various theoretical probability distributions. The threshold for goodness-of-fit tests is 1.64 (absolute value), and 'best-fit' values (those less than the threshold) are starred. For AMX (Attachment 13) the GENERALIZED LOGISTIC and GENERALIZED EXTREME VALUE (GEV) are both 'best-fit' distributions. For PD (Attachment 14), the GENERALIZED LOG NORMAL and GENERALIZED PARETO are acceptable distributions. The final choice of distribution will depend on these tests and a real-data-check, Lin and Vogel (1993).

SHORT DURATIONS

In reviewing the return frequency results for the various durations (e.g., 1-, 2-, 3-, 6-, 12-, and 24-hour), it was noted that the higher return frequency values may be the same or very similar regardless of duration. For example, the 2-, 3-, and 6-hr values for Soldier Summit (7959), Utah, (Attachment 15a) 'converge' to about 1.90 inches at the 100-year return frequency. They are also close at the 50-year return frequency. In the data plot for Soldier Summit (Attachment 15b), the highest values for all durations, except 1-hour, are the same. This indicates that the data sample contains many more short-duration events and that they affect the frequency analysis results at the longer durations. This provides a reasonable picture of the prevalence of convective extreme events in the study area. However, it means that less frequent, but important, longer duration storms are being masked (and/or not sampled) by the influence of extreme 1-, 2-, and 3-hour events. Another example is the return frequency plot for Blanding (0738), Utah, (Attachment 16a), which does not converge as much as Soldier Summit, except at 2- and 3-hour durations. The data plot for Blanding (Attachment 16b) shows that the highest 11 values for 2-hour and 3-hour durations are essentially equal. As under-represented, longer duration events occur primarily in winter, seasonal analysis should help determine their return frequency. The seasonal analysis is being done.

The influence of short duration events is shown in the sample of 15-minute data for Oracle 2 SE (6119), Arizona, in Attachment 17. Reading the first line: 02=Arizona, 6119=station number, 8=August, 0.80=15-minute annual maximum in inches, and 5149=Julian hour of occurrence. The column with 1, 2, 3, 4,.., 96 indicates the duration: 1=15-minute, 2=30-minute, and so on up to 96=24-hour. The final 4-digit number is the beginning Julian hour of the event. It is evident that the same event is noted for all durations.

STORM ANALYSIS

Depth-Area Duration

Area-depth and depth-duration curves are an integral part of storm analysis. Data from major storms in the semiarid Southwest will be used to develop these curves. The various software components are being developed using PCs and the GRASS GIS system on a workstation environment. The process begins with data extraction from a digital database and pairing the daily stations with an hourly station to establish a mass curve for the storm duration. The mass curve software is complete, and a sample set of curves is shown in Attachment 18 for a southern California storm on January 20 through 24, 1943. The hourly station for this set of stations is Glenville, and the two daily stations that are timed are Glenville (near) and Kernville. The data are verified to determine whether the assigned daily and hourly stations are compatible. If there is a problem a new hourly station is sought for the daily station or a composite of several hourly stations is used to define an hourly station that best fits the daily values. A spreadsheet is being used as the base software for this work.

After the mass curves are defined, ratios between the observed values and the NOAA Atlas 2 (Miller et al, 1973) 100-year return values are calculated. These percents are plotted and an isopercental analysis is made with these data. The isopercental map is then transformed into an isohyetal analysis. From this analysis, depth-area-duration curves are developed. The depth-area-duration curve software has been developed and is being used. Some further refinements still need to be done, but the system is producing good results.

Depth-area-duration curves for major storms in the Semiarid Southwest will be developed, and these will be provided to the users. Users will then be able to define the volume of precipitation within major storms. These curves will replace the curves that are currently provided in NOAA Atlas 2. It is anticipated that the curves will extend well beyond 400 square-miles, which is all that is available in NOAA Atlas 2.

Elevation Data

Rugged terrain covers much of the Semiarid Southwest. Such terrain often augments precipitation on the windward side, and causes lower moisture conditions on the leeward side. Thus, the intensities of the return frequencies in such regions can be directly affected by elevations, aspects, and slopes. It is important that terrain and its many effect be incorporated into any study of this region. Digital terrain elevation data have been obtained from the Defense Mapping Agency on a CDRom in binary format. These data are being extracted in meters with a resolution of 3 arc/sec or roughly a data point every 90 meters, and are being stored in units of 1 degree by 1 degree. Software has been developed to convert from binary to ASCII format, which places the data in a 1201 x 1201 matrix of points. The data are then imported into the GRASS GIS system for further use.

Future work will experiment with the spacing necessary for resolving the elevation data for use in the mapping of precipitation intensities. Also, these data will be used to develop relations so that precipitation intensities for different return periods can be estimated in regions with little or no precipitation data. Elevation, slope, and aspect will be important inputs into these analyses and the GRASS GIS system will be used to examine possible relations among precipitation, aspect, slope, and elevation. Other parameters, such as the distance from moisture sources will also be considered.

SNOTEL (SNOwpack TELemetry) data are also being used to assess precipitation/elevation relationships. Ratios are being determined to extend data analysis into data-sparse mountainous areas. The SNOTEL sites are operated by the Soil Conservation Service (SCS) in the mountains of western United States. There are about 200 sites with elevations ranging from about 6000 feet to over 11,000 feet in the study area. Each site has 14 years of daily observations measured to 0.01 inches using tipping bucket gages.

RETURN FREQUENCY COMPARISONS

Some preliminary return frequency results for region 8 are shown in Attachments 19a and 19b. The 2-year, 24-hour return frequencies using a GEV distribution for both AMX and PD are mapped in Attachment 19a. The 100-year AMX and PD are mapped in Attachment 19b. Partial duration series will be used for the final analysis; however, comparisons with annual maximum results provide additional quality control.

DISCUSSION AND COMMENT

Discussion and some questions and answers are summarized here.

Lou Schreiner raised the questions of whether our results will be different from NOAA Atlas 2, and if so, how? and why? There are differences - modest in magnitude and real. They are due to increased record lengths, more stations, improved statistical techniques (L-moment statistics) that are especially applicable to extreme-value analysis, computer capability, and other factors. The relatively homogeneous regions used in the L-moment provides a spatial component to the frequency analysis, that was impossible with earlier techniques. The computing power also makes it possible to analyze the more representative partial duration series directly. Changes will be thoroughly documented and justifiable.

Additional regional studies are anticipated. A contract with New Jersey is nearly complete and work will start shortly. A contract with Puerto Rico is pending. The Semiarid project has included considerable upfront development, which means that further studies can be done with less startup time.

Although problems and questions have been raised in our study, e.g., partial duration versus annual maximum series, the conversion of daily data to 24-hour data, software development glitches, etc., we are at the 'edge' of production mode, especially for the frequency analysis. Precipitation - elevation relationships are being evaluated with SNOTEL data. Storm analysis and preparation of depth-area-duration curves has been computerized to a significant extent and the process is working well. Therefore, we expect to have a draft frequency analysis report on the Semiarid Project by early summer 1993. The final report will include frequency maps, area-depth curves for representative storms and short-duration (less than 1 hour, down to 5-minute durations) information. Several attendees expressed interest in the very short duration events, and this will be analyzed with the dense raingage networks and n-minute data.

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Attachment 1

Agenda for Semiannual Meeting
of the Semiarid Precipitation Frequency Project
Phoenix, Arizona

9 September 1993

I. Welcome and Overview

II. Data

  A. Datasets

  B. Annual maximum versus partial duration series

  C. Comparisons of daily and 24-hour data

III. Analysis

  A. Seasonality

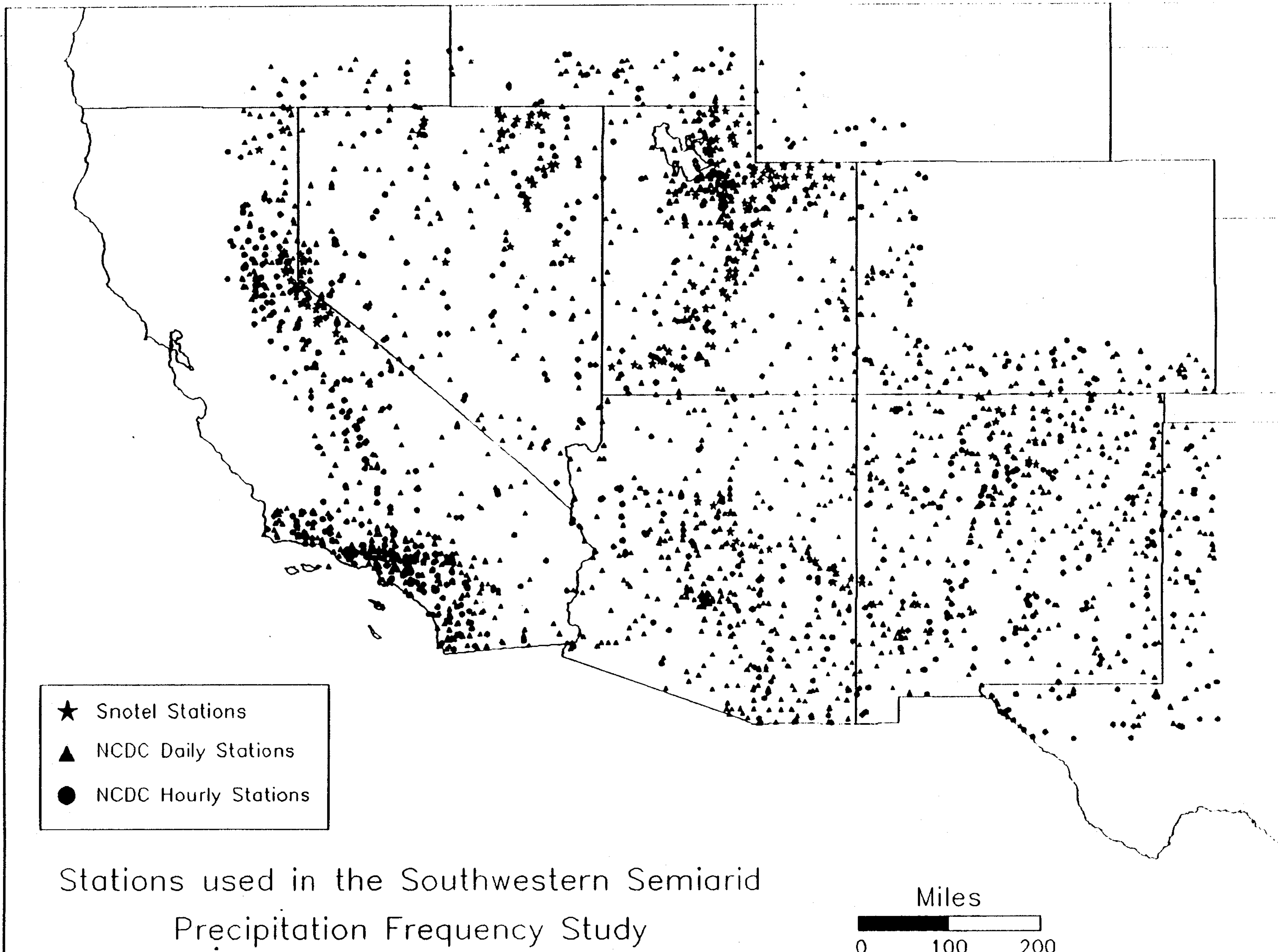
  B. Regionality - criteria, statistical tests, etc.

  C. Regional frequency analysis

  D. Precipitation-elevation relationships

IV. Storm Analysis

V. Discussion and Comment

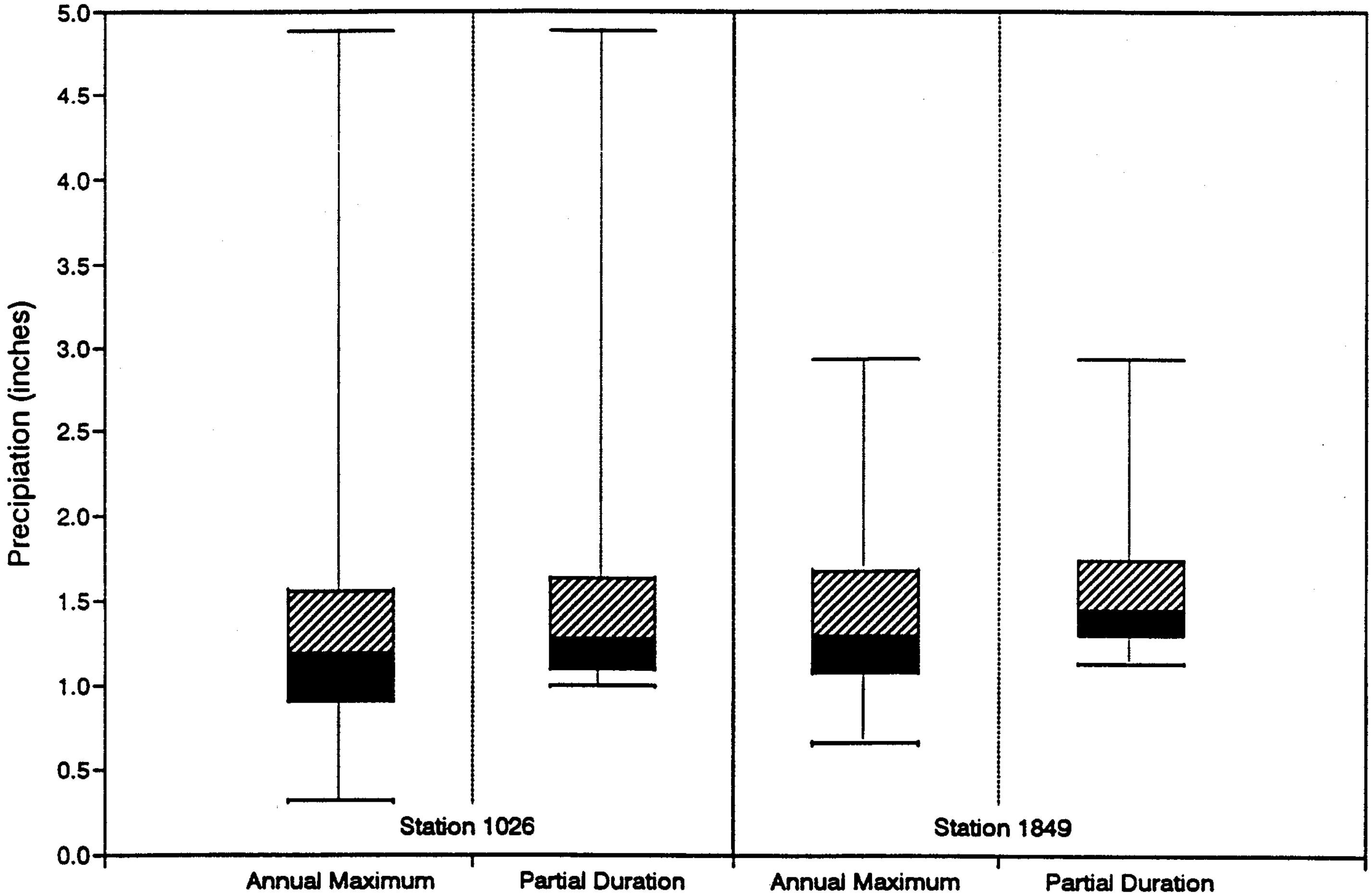


Stations used in the Southwestern Semiarid Precipitation Frequency Study

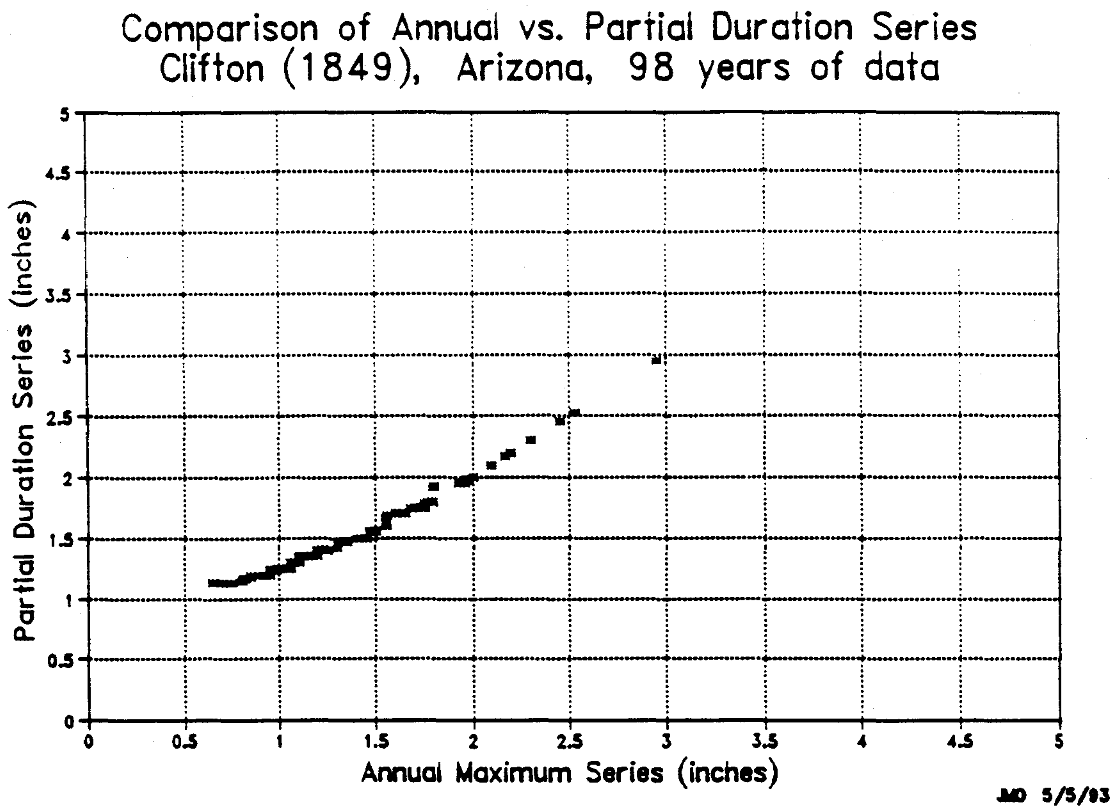
Attachment 2

Attachment 3a

Box Plots of Annual Maximum and Partial Duration Series, Arizona



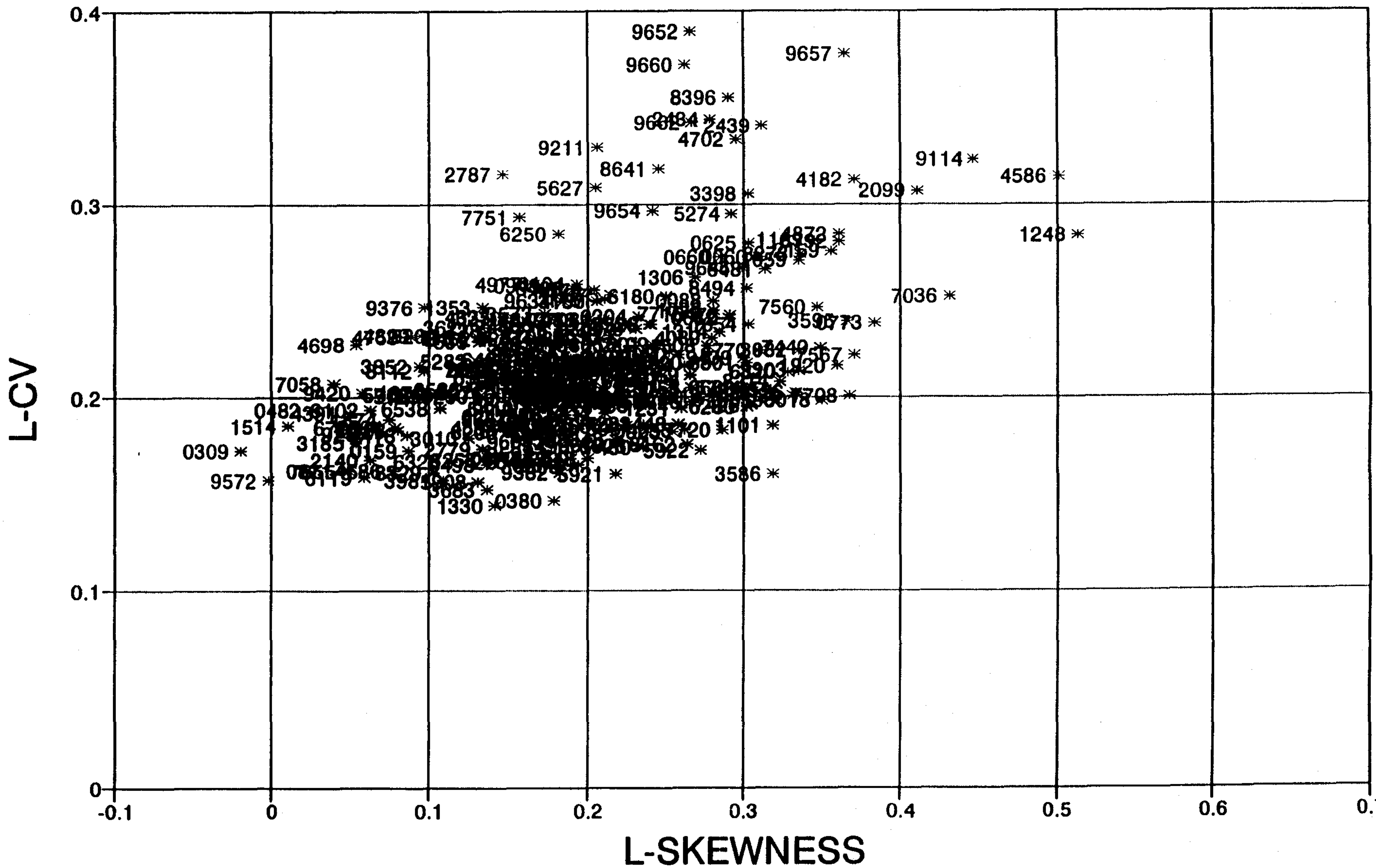
Attachment 3b



Comparison of Annual Maximum and Partial Duration Series Data for Clifton, Arizona.

L-Skewness vs. L-CV

Annual Maximum, 1-Day, Arizona - 277 stations

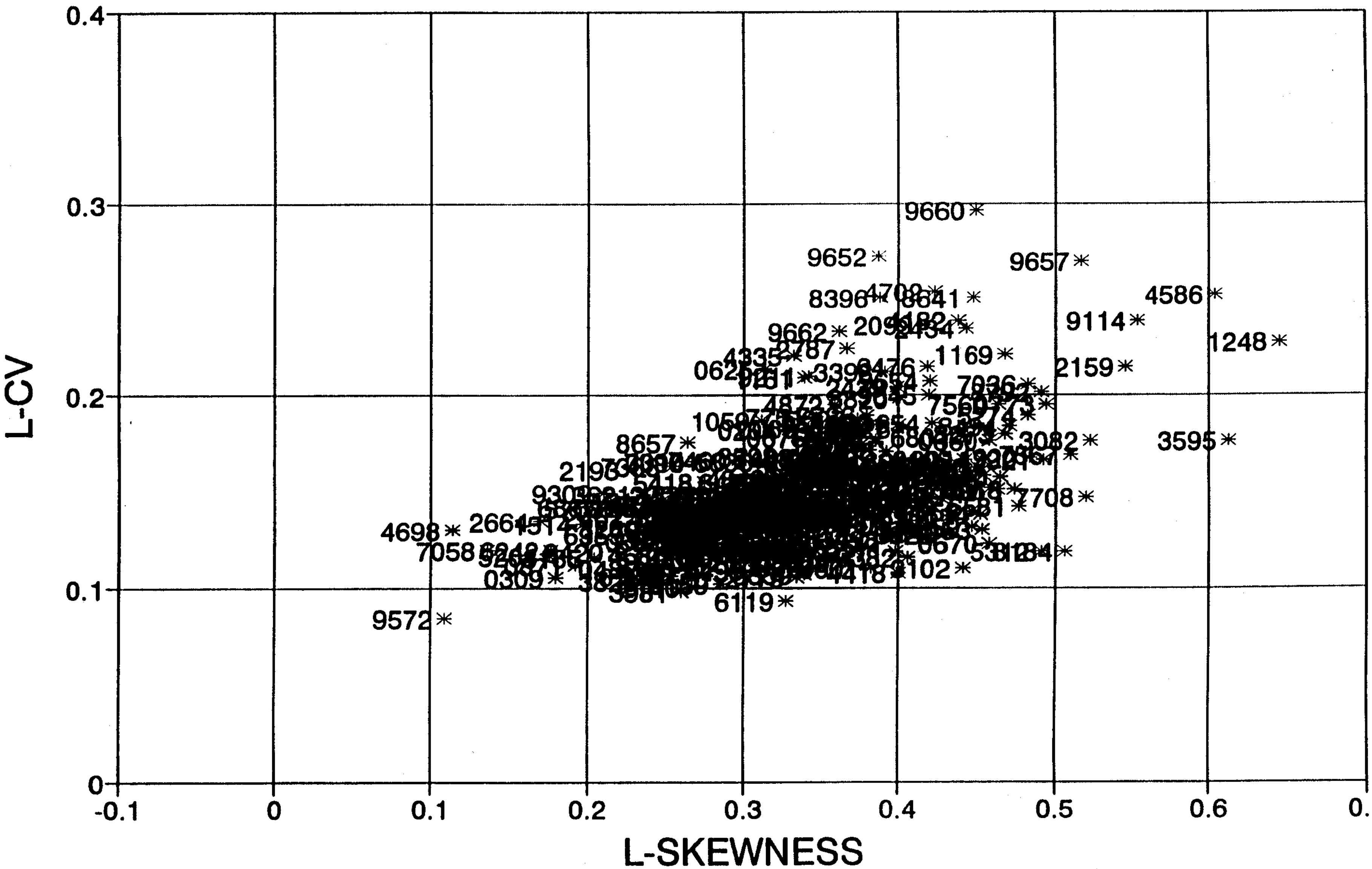


Attachment 3c

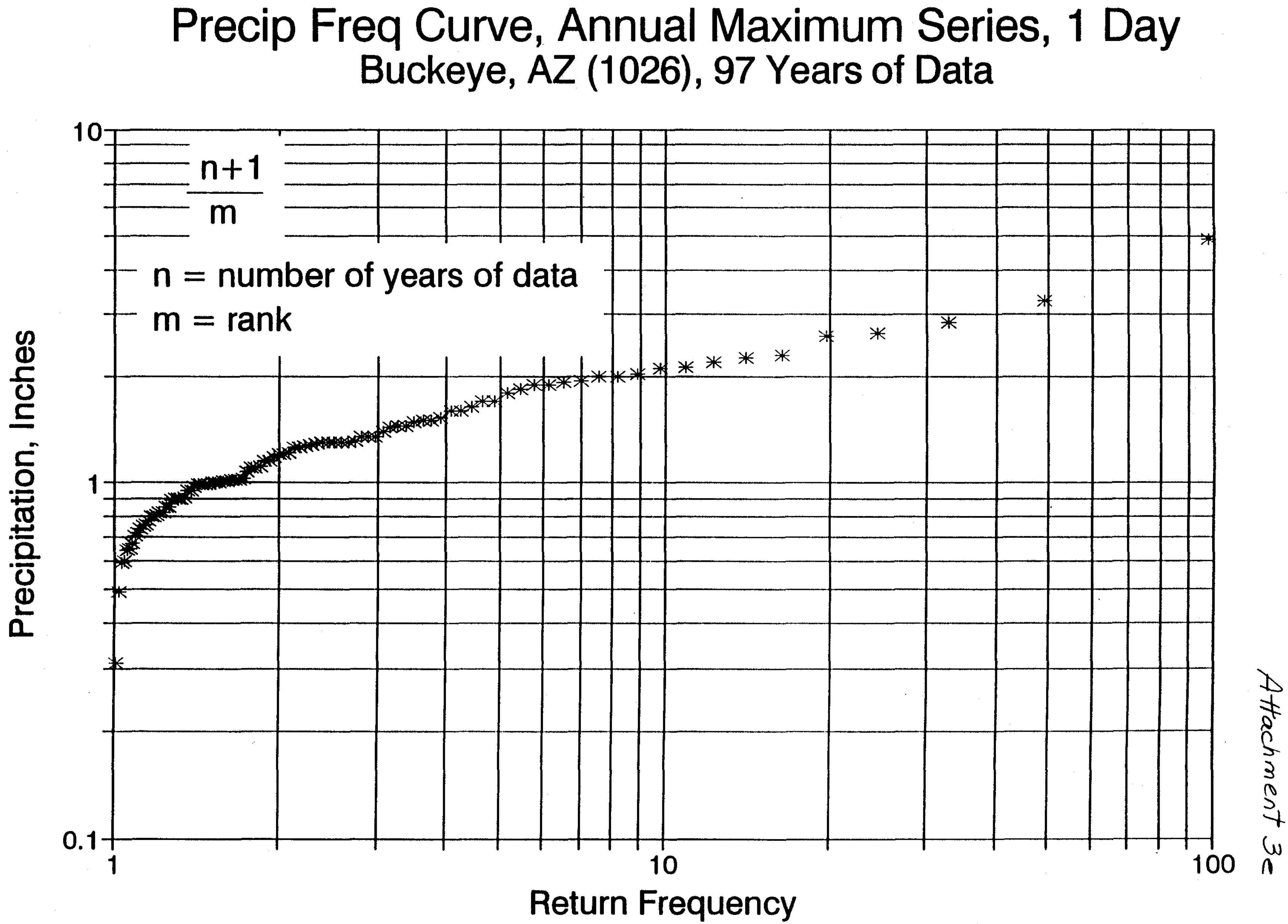
JMO 4/19/93

L-Skewness vs. L-CV

Partial Duration, 1-Day, Arizona - 277 stations



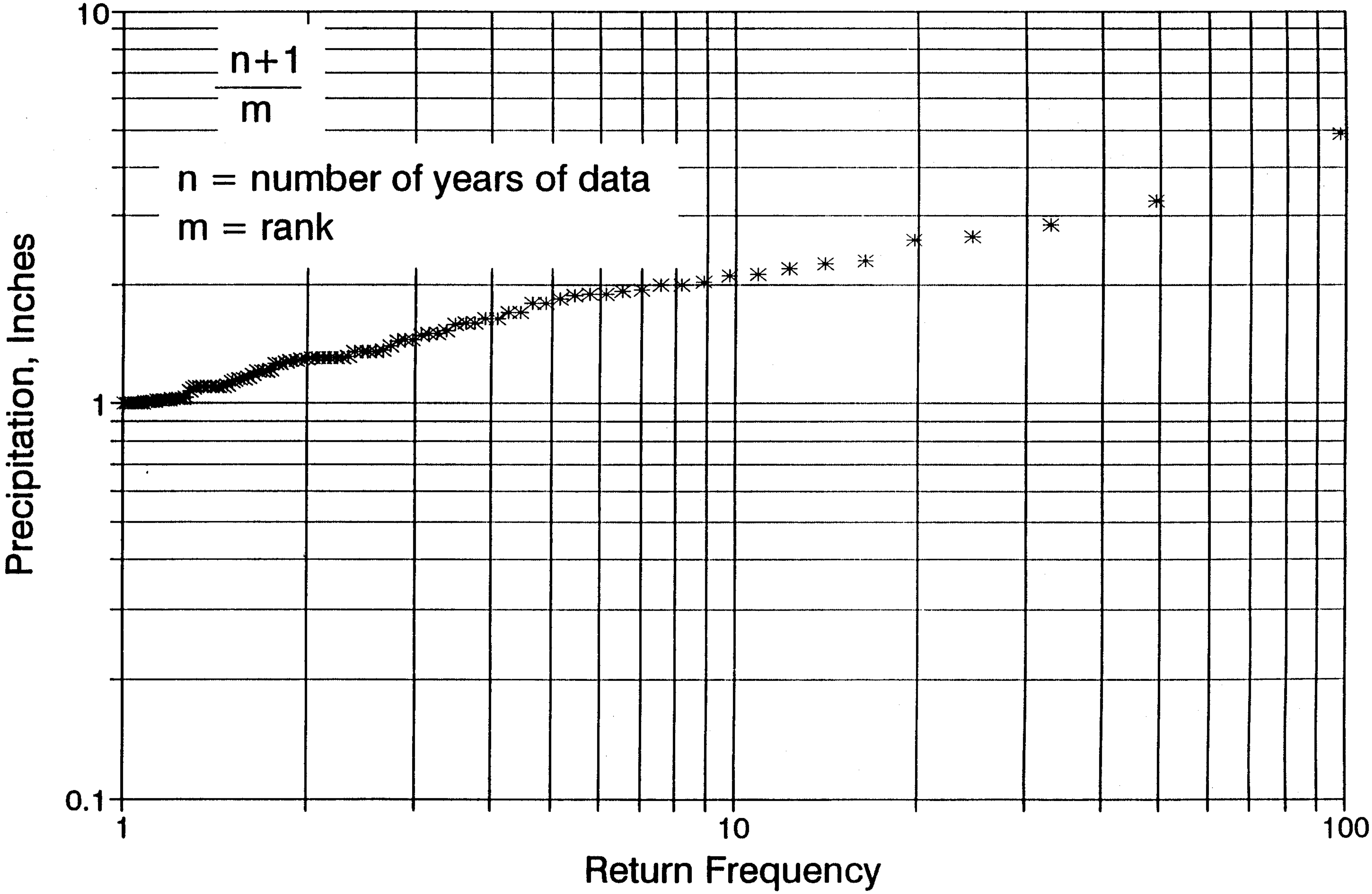
Attachment 3d


Precip Freq Curve, Annual Maximum Series, 1 Day
Buckeye, AZ (1026), 97 Years of Data
n+1 / m
n = number of years of data
m = rank
Precipitation, Inches
10
1
0.1
1
10
100
Return Frequency
Attachment 3e

JMO 4/15/93

Precip Freq Curve, Partial Duration Series, 1 Day

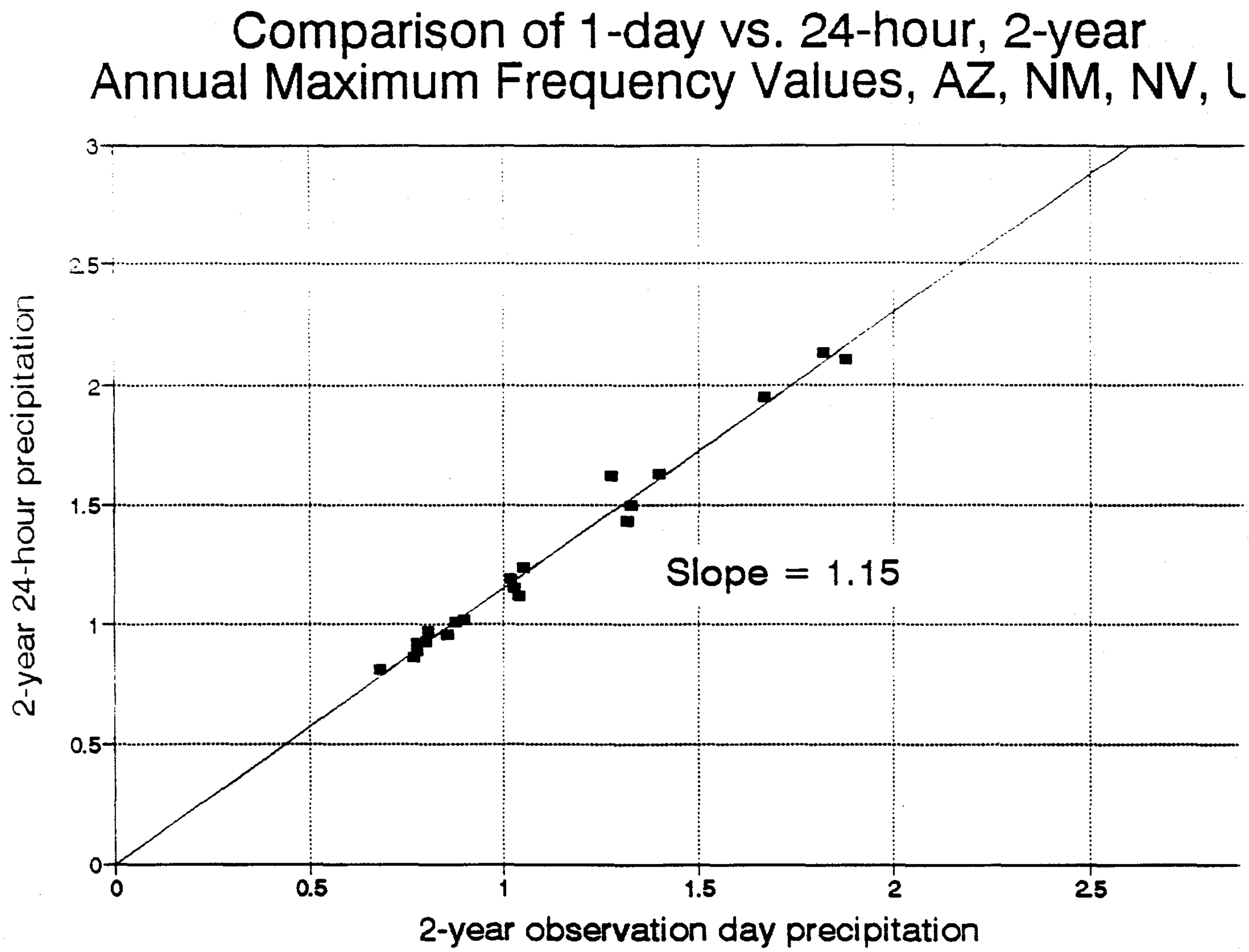
Buckeye, AZ (1026), 97 Years of Data



Attachment 3f

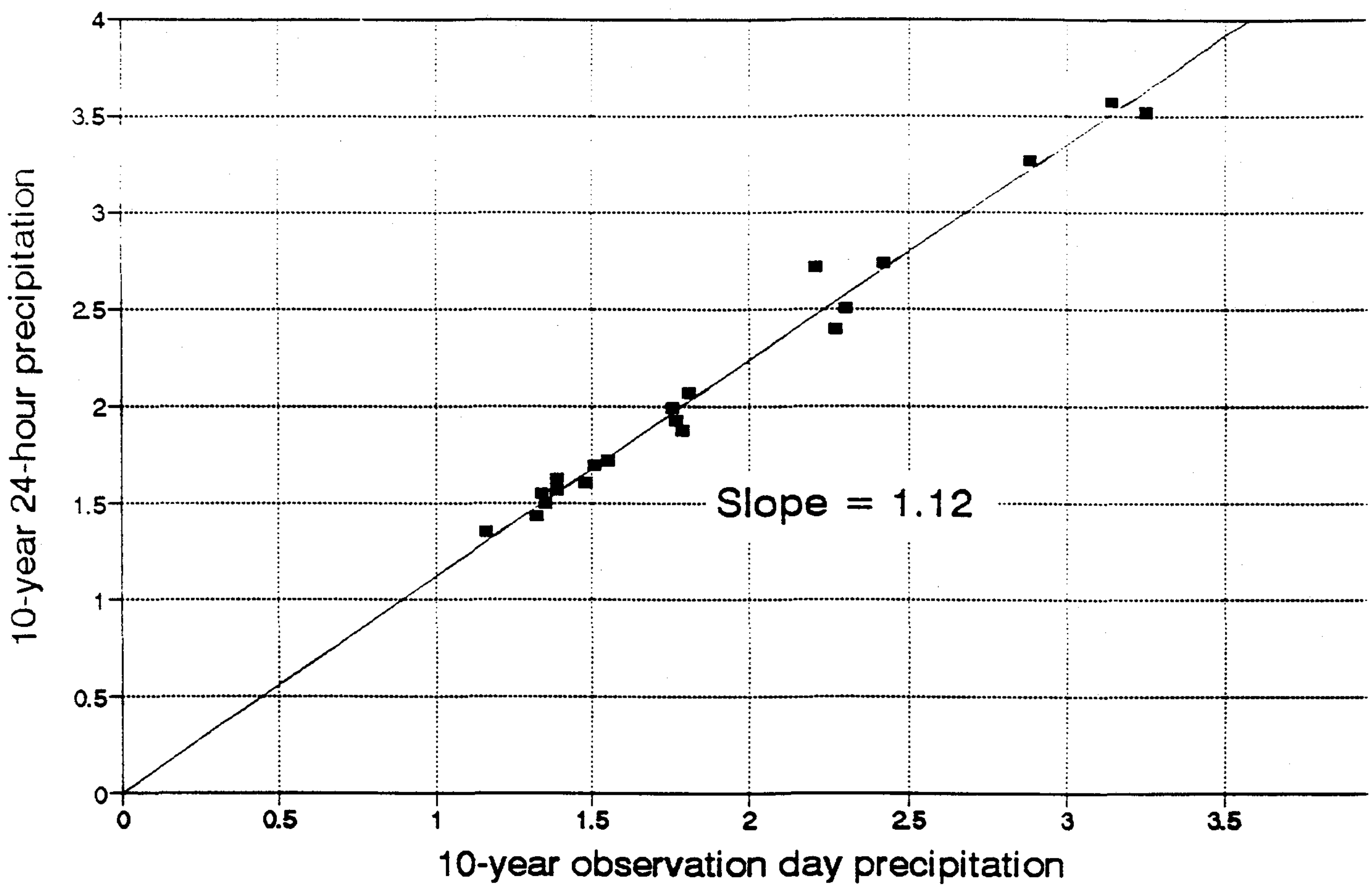
JMO 4/15/93

Attachment 4a



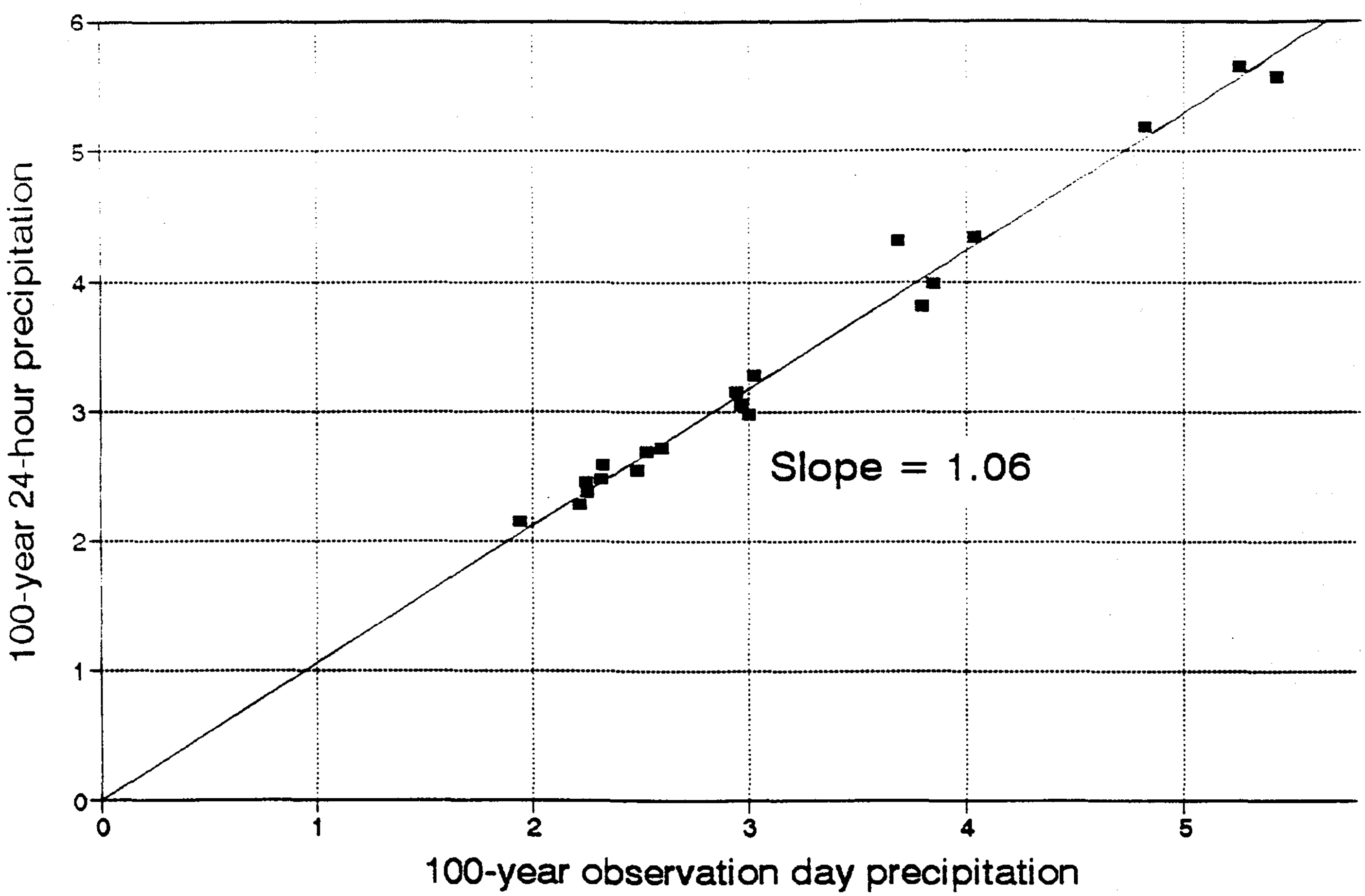
Attachment 4b

Comparison of 1-day vs. 24-hour, 10-year Annual Maximum Frequency Values, AZ, NM, NV, U



Attachment 4c

Comparison of 1-day vs. 24-hour, 100-year Annual Maximum Frequency Values, AZ, NM, NV, U



METHOD OF L-MOMENTS

a) robust, less sensitive to sampling errors and outliers
b) capable of characterizing a wide range of distributions
c) linear combination of order statistics

L-MOMENTS - DEFINITIONS

random variable X with cdf F(X) & quantile func X(F)

$$X_{1:n} \leq X_{2:n} \leq \cdots \leq X_{n:n}$$

L-MOMENT for r = 1, 2, · · · are:

$$\lambda_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} E\, X_{r-k:r}$$

$$\text{L-CV} = \lambda_2/\lambda_1$$

$$\text{L-SKEWNESS} = \lambda_3/\lambda_2$$

$$\text{L-KURTOSIS} = \lambda_4/\lambda_2$$

L-MOMENT TESTS

1. **DATA SCREENING--DISCORDANCY D_i**

Let $U_i = \left[t_2^{(i)}, t_3^{(i)}, t_4^{(i)}\right]^T$ be a vector for site i

$$\bar{U} = N^{-1} \sum_{i=1}^{N} U_i$$ -- unweighted group mean

THE DISCORDANCY FOR SITE i IS DEFINED:

$$D_i = \frac{1}{3}(U_i - \bar{U})^T S^{-1} (U_i - \bar{U})$$

where $S = (N-1)^{-1} \sum_{i=1}^{N} (U_i - \bar{U})(U_i - \bar{U})^T$

2. **HETEROGENEITY--H**

HOMOGENEOUS REGION - HETEROGENEITY, H: "IS THE BETWEEN-SITE DISPERSION OF THE SAMPLE L-MOMENTS FOR THE GROUP OF SITES LARGER THAN WOULD BE EXPECTED FROM A HOMOGENEOUS REGION?"

[(OBS. DISP) - (MEAN DISP BY SIMULATION)]/SD OF SIM DISP

SIMULATION: 4-PARAMETER KAPPA DISTRIBUTION

$$H = (V - \mu_V)/\sigma_V$$

WHERE V IS THE WEIGHTED SD AT EACH SITE

SAMPLE L-CV OR L-SKEW OR L-KURTOSIS

μ_V, σ_V FROM MONTE CARLO

3. **GOODNESS-OF-FIT Z**

$$Z^{GEV} = \frac{(\bar{t}_4 - \tau_4^{GEV})}{\sigma_4}$$

where $\bar{t}_4$ is the regional average L-Kurtosis.

τ_4 is the L-kurtosis of the fitted GEV distribution, and

σ_4 is the standard deviation of $\bar{t}_4$

AJO, ARIZONA 20080
PRECIPITATION MEANS AND PROBABILITIES FOR 1 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB O-T	0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
			PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION								
MAR 01	.24	53	24	22	18	12	9	5	3	1	
MAR 08	.16	76	26	24	20	15	11	7	4	2	
MAR 15	.25	73	25	23	19	14	10	6	4	2	
MAR 22	.12	60	25	22	17	10	6	3	2	1	
MAR 29	.04	83	19	17	12	6	3	1			
APR 05	.06	80	12	10	7	4	2				
APR 12	0.00	100	7	5	3	2	1				
APR 19	.02	83	[illegible]	8	4	1					
APR 26	.05	76	12	10	6	2					
MAY 03	0.00	100	[illegible]	6	4	1					
MAY 10	.03	80	8	5	3	1					
MAY 17	.01	93	6	4	1						
MAY 24	0.00	100	4	3	1						
MAY 31	.02	86	6	4	2						
JUN 07	0.00	100	3	2	1						
JUN 14	0.00	100	4	3	2	1					
JUN 21	.05	80	11	9	6	2	1				
JUN 28	.04	76	21	18	12	6	4	1	1		
JUL 05	.19	56	[illegible]	32	25	15	[illegible]	4	2	1	
JUL 12	.30	40	51	47	38	25	17	8	4	1	
JUL 19	.39	23	64	59	49	[illegible]	25	13	7	3	
JUL 26	.56	20	[illegible]	68	[illegible]	43	[illegible]	18	[illegible]	4	
AUG 02	.61	20	[illegible]	68	60	46	39	20	12	5	
AUG 09	.52	26	68	64	55	41	[illegible]	18	[illegible]	5	
AUG 16	.44	23	65	61	52	38	28	16	9	4	
AUG 23	.52	30	58	[illegible]	45	[illegible]	23	13	8	4	
AUG 30	.18	46	[illegible]	41	32	21	14	7	4	2	
SEP 06	.18	56	34	31	24	16	11	6	4	2	
SEP 13	.32	60	[illegible]	27	22	16	12	7	5	3	
SEP 20	.11	63	29	26	20	13	[illegible]	4	2	1	
SEP 27	.13	63	29	26	20	13	[illegible]	4	2		
OCT 04	.23	70	27	25	21	14	[illegible]	5	3	1	
OCT 11	.08	76	21	19	15	10	6	3	1		
OCT 18	.06	80	19	17	13	[illegible]	5	2	1		
OCT 25	.16	70	21	19	14	9	6	3	1		
NOV 01	.04	76	24	21	15	[illegible]	5	2	1		
NOV 08	.15	63	[illegible]	26	19	[illegible]	5	2	1		
NOV 15	.12	46	36	[illegible]	22	[illegible]	5	1			
NOV 22	.12	63	[illegible]	26	18	[illegible]	4	1			
NOV 29	.07	76	24	21	16	[illegible]	6	2	1		
DEC 06	.19	66	28	25	20	13	8	4	2		
DEC 13	.12	53	[illegible]	[illegible]	25	15	9	4	2		
DEC 20	.24	50	40	36	29	18	11	4	2		
DEC 27	.18	60	34	31	25	17	11	5	2	1	
JAN 03	.16	63	33	31	25	16	10	4	2	1	
JAN 10	.22	53	38	35	29	18	11	4	1		
JAN 17	.16	60	37	34	27	17	11	4	2		
JAN 24	.21	56	35	32	25	16	10	4	2		
JAN 31	.13	60	37	33	25	15	[illegible]	3	1		
FEB 07	.18	46	38	34	25	15	[illegible]	3	1		
FEB 14	.19	53	39	[illegible]	26	16	[illegible]	4	2	1	
FEB 21	.19	46	[illegible]	27	21	13	8	3	1		

AJO, ARIZONA 20080
PRECIPITATION MEANS AND PROBABILITIES FOR 2 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB O-T	0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
			PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION								
MAR 01	.40	46	36	33	28	22	17	11	7	4	1
MAR 15	.36	43	44	41	34	25	18	10	6	3	
MAR 29	.11	66	27	24	17	10	5	2			
APR 12	.03	83	18	15	8	3	1				
APR 26	.07	73	22	19	12	5	2				
MAY 10	.03	73	14	10	5	2					
MAY 24	.03	83	11	8	3						
JUN 07	0.00	100	8	7	4	1					
JUN 21	.09	60	30	26	18	9	5	2	1		
JUL 05	.49	16	71	66	56	40	29	15	8	3	
JUL 19	.95	0	91	87	79	64	52	34	23	12	2
AUG 02	1.13	10	90	88	83	72	61	43	29	18	2
AUG 16	.96	10	81	78	71	59	49	33	23	13	2
AUG 30	.36	33	57	53	44	33	26	16	10	6	1
SEP 13	.43	43	49	45	38	28	21	13	8	5	1
SEP 27	.36	36	49	46	38	26	19	10	5	2	
OCT 11	.14	66	32	30	25	17	12	6	3	1	
OCT 25	.20	56	38	35	28	18	12	8	2	1	
NOV 08	.27	33	53	48	36	22	13	8	2		
NOV 22	.18	53	45	41	32	19	12	5	2		
DEC 06	.32	43	51	48	40	28	19	9	4	2	
DEC 20	.42	30	59	55	46	33	24	12	6	2	
JAN 03	.30	36	57	53	45	32	23	11	6	2	
JAN 17	.37	33	59	55	46	32	22	11	5	2	
JAN 31	.31	30	59	54	44	29	19	9	4	1	
FEB 14	.38	23	57	51	41	27	19	9	5	2	

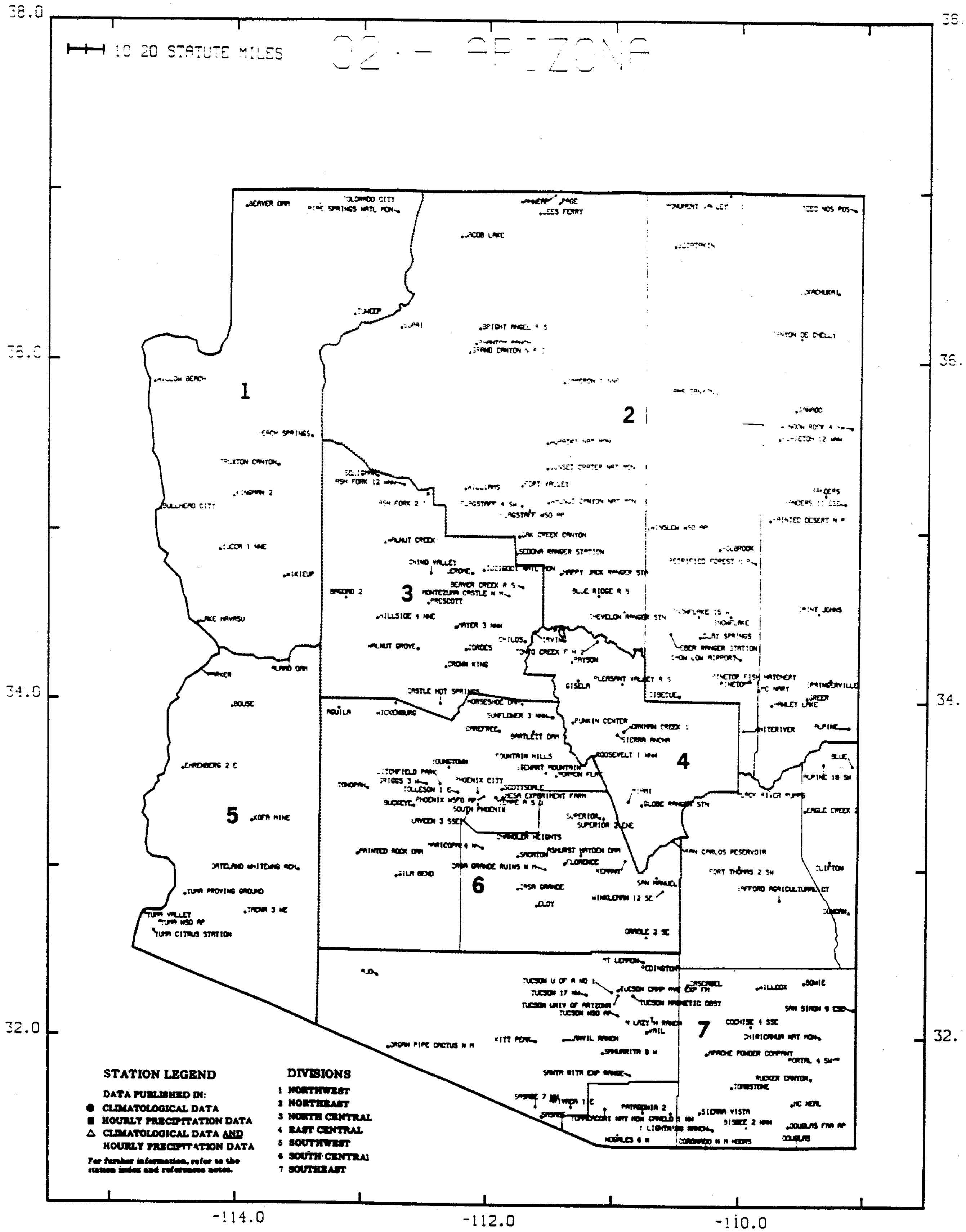
AJO, ARIZONA 20080
PRECIPITATION MEANS AND PROBABILITIES FOR 3 WEEK PERIODS

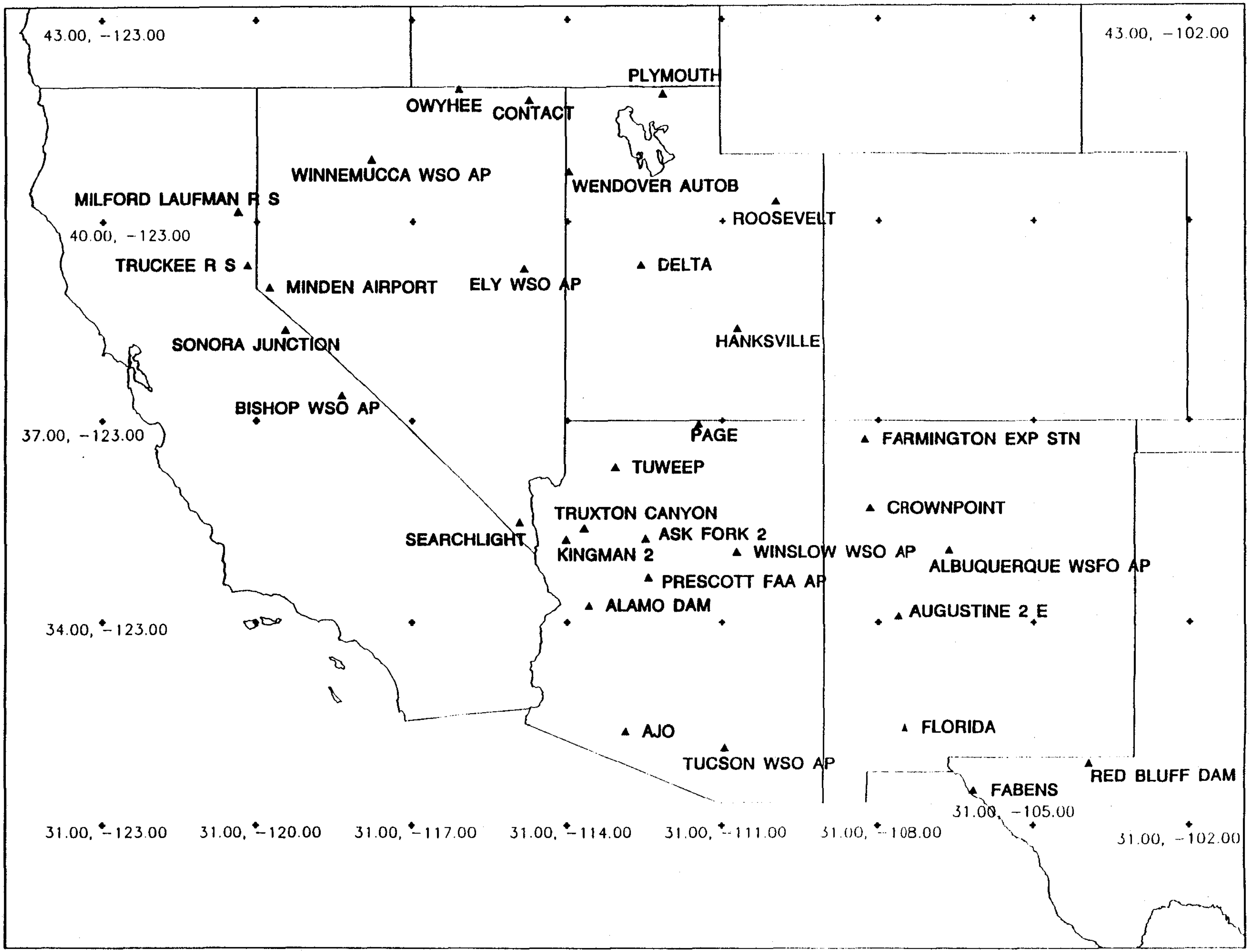
PERIOD BEGINS	MEAN PCPN	PROB O-T	0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
			PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION								
MAR 01	.64	40	49	46	40	31	25	17	12	7	1
MAR 22	.22	36	46	41	32	20	13	6	3	1	
APR 12	.07	63	30	25	15	8	2				
MAY 03	.05	70	23	18	11	4	2				
MAY 24	.03	83	15	11	5						
JUN 14	.09	56	34	29	20	11	6	2	1		
JUL 05	.88	6	89	86	77	62	49	32	21	11	2
JUL 26	1.69	0	97	96	93	85	77	60	46	30	6
AUG 16	1.15	6	88	85	79	68	59	43	31	19	4
SEP 06	.61	26	61	57	49	39	31	21	14	9	2
SEP 27	.48	30	60	56	47	34	26	14	8	4	
OCT 18	.26	50	47	43	35	25	17	9	5	2	
NOV 08	.38	30	61	56	45	30	20	9	4	1	
NOV 29	.38	26	64	60	50	36	26	13	7	3	
DEC 20	.58	23	70	67	59	45	35	20	11	5	
JAN 10	.59	23	73	69	61	46	35	19	10	4	
JAN 31	.50	20	73	68	57	41	30	17	10	4	

Attachment 6

Analysis of precipitation probabilities for ...

Attachment 7





Attachment 8

Attachment 9

EXTREME PRECIPITATION SEASONALITY ANALYSIS

* 2 SEASONS: COOL & WARM

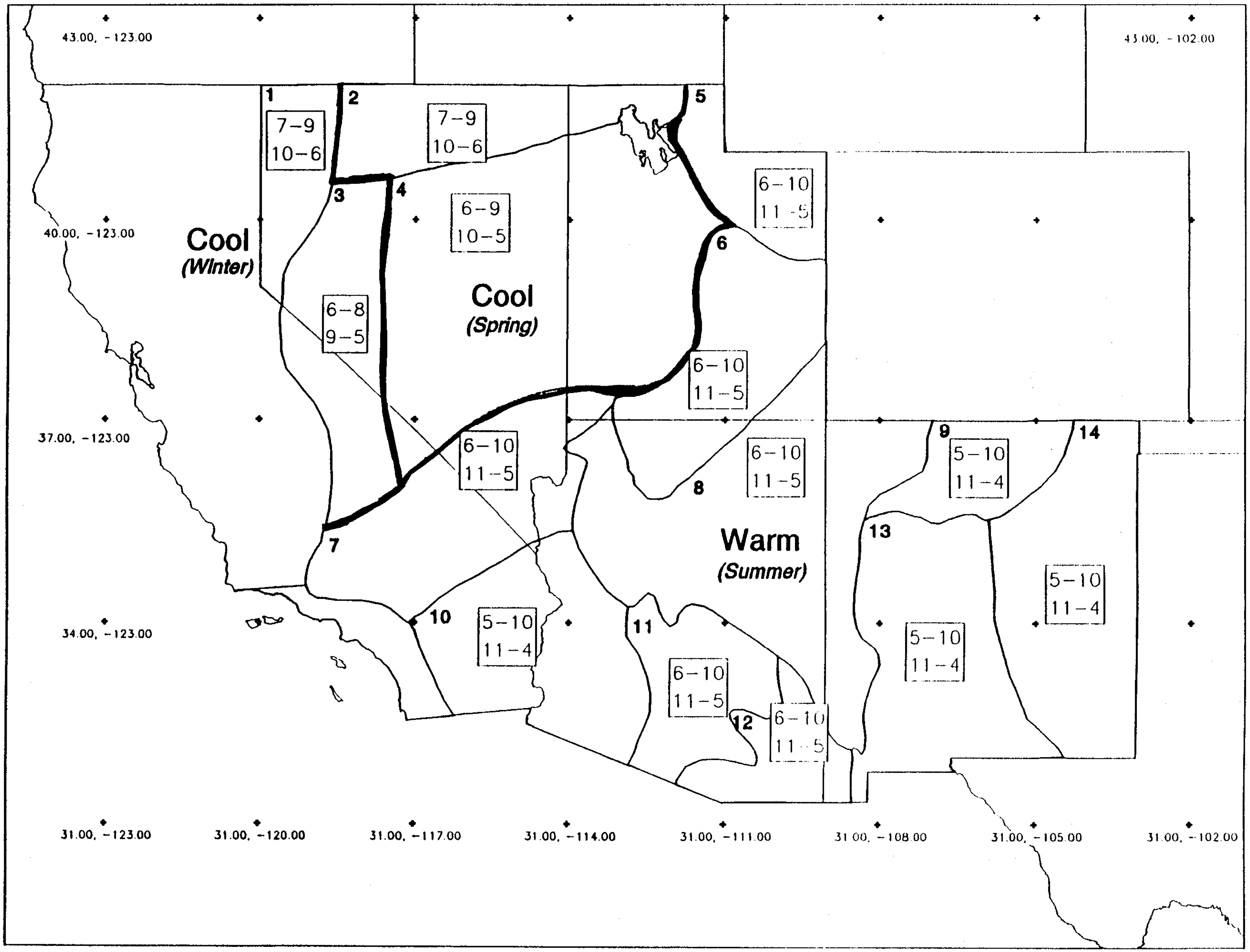
* PRECIPITATION SEASONS:

  # Winter (COOL)

  # Spring (COOL)

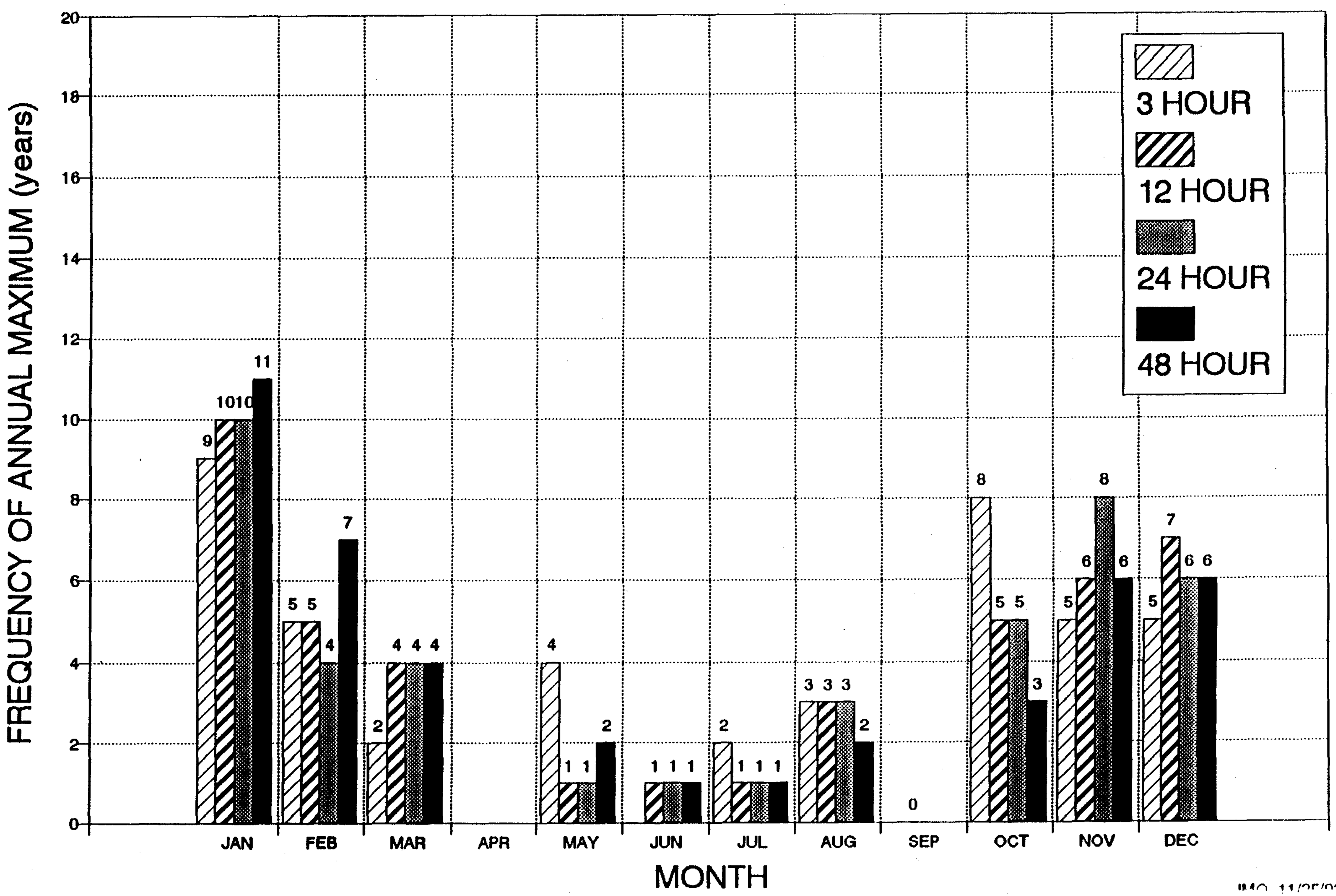
  # Summer (WARM)

  # October (IMPOSSIBLE)



Attachment 10

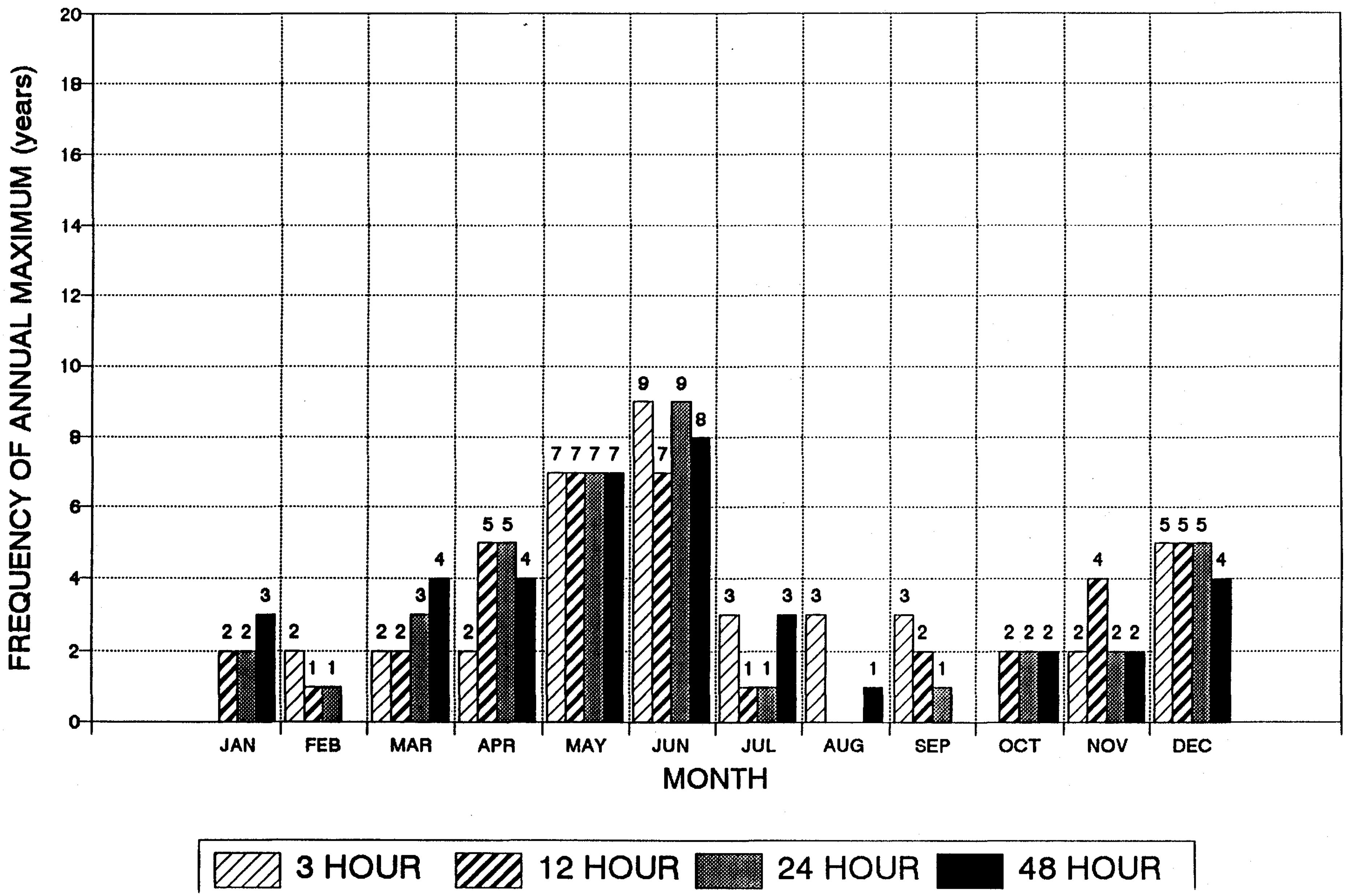
HISTOGRAM OF ANNUAL MAXIMUM
MINDEN AIRPORT, NEVADA n=43 years



Attachment 11a

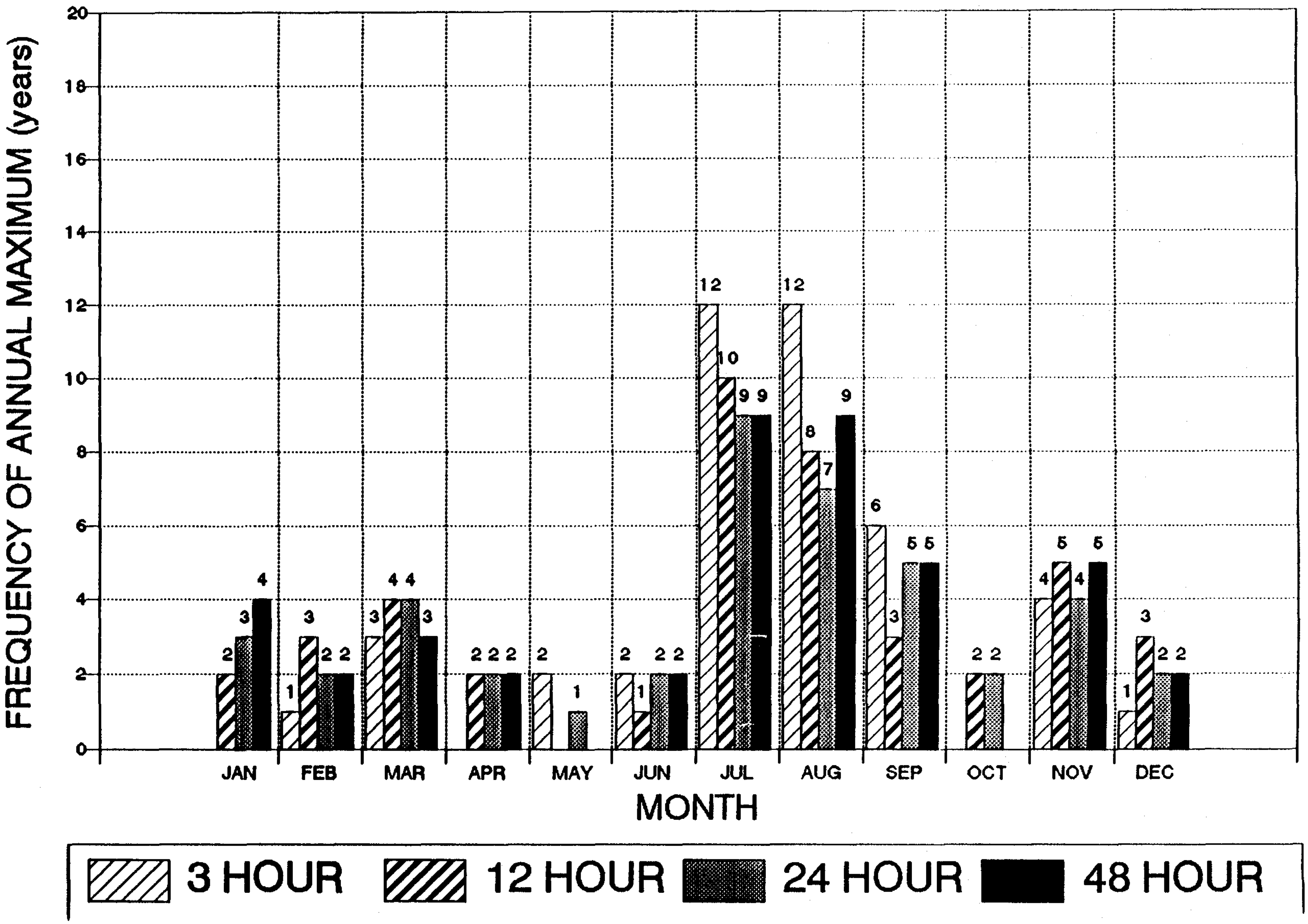
IMO 11/25/92

ANNUAL MAXIMUM HISTOGRAM
Owyhee (5869), Nevada n=38 years



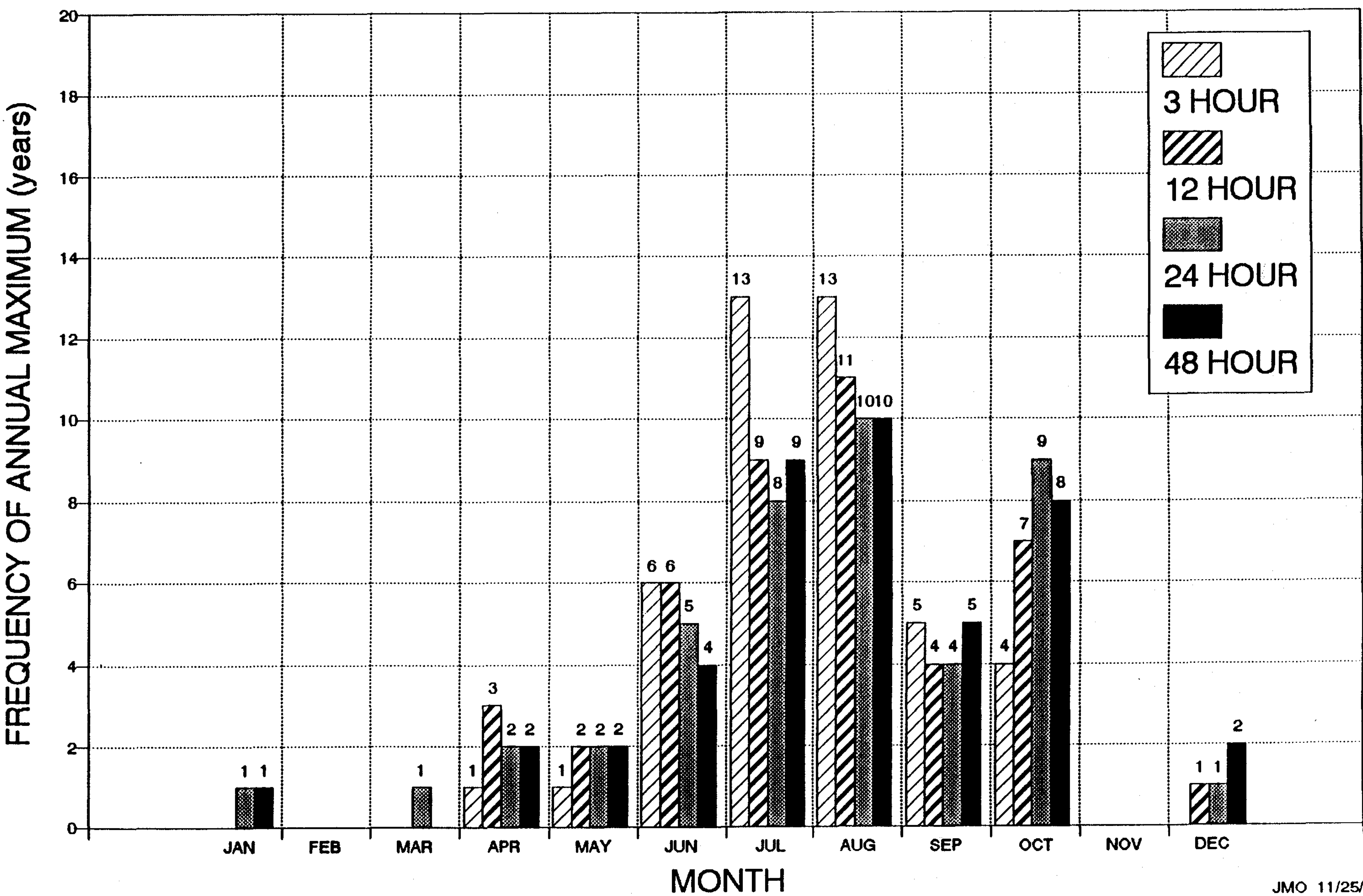
Attachment 11b

ANNUAL MAXIMUM HISTOGRAM
TUWEEP (8895), ARIZONA n=43 years



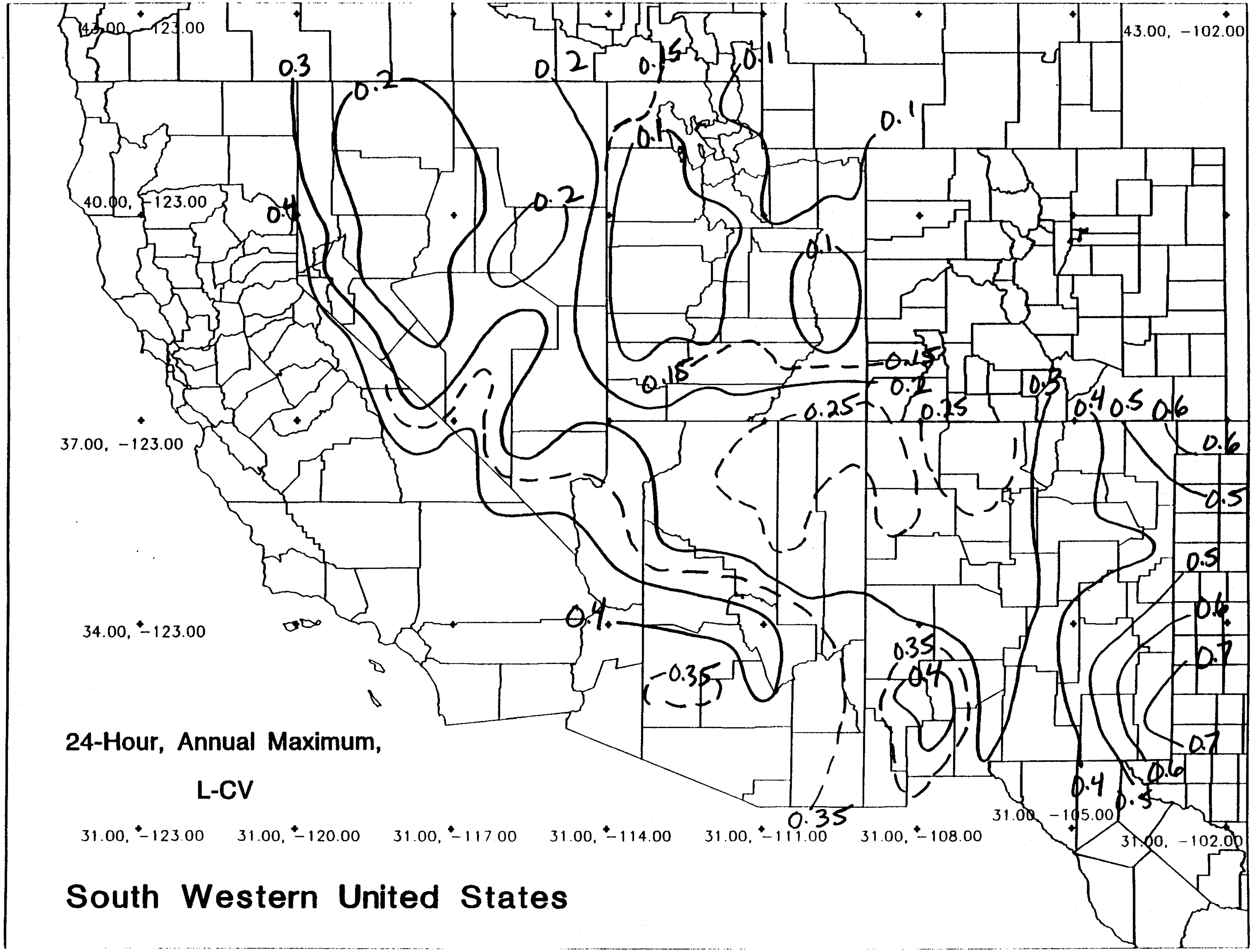
Attachment 11c

HISTOGRAM OF ANNUAL MAXIMUM
ALBUQUERQUE WSFO AP, NEW MEXICO n=43



JMO 11/25/92

Attachment 11d



24-Hour, Annual Maximum,

L-CV

South Western United States

Attachment 12

Attachment 13

24-hour, Annual Maximum, region 8 22 SITES

SITE	N	NAME	L-CV	L-SKEW	L-KURT	D(I)
1	42	02-0487 ANM	.2123	.1049	.1528	1.04
2	43	02-0808 ANM	.1623	.1866	.2074	.96
3	16	02-2754 ANM	.1650	.1575	.2226	.84
4	43	02-3010 ANM	.1804	.1264	.0415	1.34
5	43	02-4586 ANM	.2425	.1238	.1582	1.89
6	39	02-5325 ANM	.1920	.1972	.1126	.45
7	42	02-6323 ANM	.2344	.2991	.2352	.60
8	43	02-6468 ANM	.2315	.1631	.2008	.68
9	22	02-6801 ANM	.2246	.3101	.2903	1.07
10	18	02-7708 ANM	.1817	.1279	.2801	1.30
11	43	02-8778 ANM	.2434	.2459	.2066	.41
12	43	02-8895 ANM	.2087	.2475	.2144	.19
13	43	02-9271 ANM	.2076	.1639	.1311	.28
14	43	02-9439 ANM	.2099	.2701	.0844	1.44
15	43	29-0818 ANM	.2923	.3342	.2179	2.44
16	18	29-1018 ANM	.1767	.2131	.1358	.76
17	43	29-3142 ANM	.1715	.1606	.2002	.52
18	21	29-5273 ANM	.2294	.1726	.2537	.79
19	26	29-5800 ANM	.1873	.1459	.0633	.94
20	24	29-9897 ANM	.1911	.1622	.3402	1.93
21	41	42-0738 ANM	.2465	.3672	.2890	1.85
22	17	42-1308 ANM	.1920	.1863	.1300	.26
		WEIGHTED MEANS	.2121	.2072	.1836	

FLAGGED TEST VALUES

PARAMETERS OF REGIONAL KAPPA DISTRIBUTION .8567 .2507 -.1182 -.2792

***** HETEROGENEITY MEASURES *****
(NUMBER OF SIMULATIONS = 500)

OBSERVED S.D. OF GROUP L-CV = .0325
SIM. MEAN OF S.D. OF GROUP L-CV = .0292
SIM. S.D. OF S.D. OF GROUP L-CV = .0049
STANDARDIZED TEST VALUE = .67

OBSERVED AVE. OF L-CV / L-SKEW DISTANCE = .0729
SIM. MEAN OF AVE. L-CV / L-SKEW DISTANCE = .0817
SIM. S.D. OF AVE. L-CV / L-SKEW DISTANCE = .0124
STANDARDIZED TEST VALUE = -.71

OBSERVED AVE. OF L-SKEW/L-KURT DISTANCE = .0940
SIM. MEAN OF AVE. L-SKEW/L-KURT DISTANCE = .1042
SIM. S.D. OF AVE. L-SKEW/L-KURT DISTANCE = .0144
STANDARDIZED TEST VALUE = -.71

***** GOODNESS-OF-FIT MEASURES *****

GEN. LOGISTIC	L-KURTOSIS= .202	Z VALUE= .86	*
GEN. EXTREME VALUE	L-KURTOSIS= .166	Z VALUE= -1.31	*
GEN. LOG NORMAL	L-KURTOSIS= .156	Z VALUE= -1.87	
PEARSON TYPE III	L-KURTOSIS= .137	Z VALUE= -3.00	
GEN. PARETO	L-KURTOSIS= .081	Z VALUE= -6.30	

QUANTILE ESTIMATES FOR DISTRIBUTIONS ACCEPTED AT THE 90% LEVEL

	.100	.500	.800	.900	.960	.980	.990
GEN. LOGISTIC	.581	.929	1.246	1.479	1.817	2.111	2.446
GEN. EXTREME VALUE	.580	.923	1.269	1.511	1.832	2.081	2.339
WAKEBY	.561	.930	1.252	1.500	1.843	2.115	2.399

PARAMETERS:

GEN. LOGISTIC	.929	.197	-.207		
GEN. EXTREME VALUE	.816	.290	-.057		
WAKEBY	.399	1.564	4.953	.319	.058

Attachment 14

24-hour, Partial Duration, region 8 22 SITES

SITE	N	NAME	L-CV	L-SKEW	L-KURT	D(I)
1	42	02-0487 PD	.1433	.2711	.1321	.45
2	43	02-0808 PD	.1055	.4056	.2177	1.00
3	16	02-2754 PD	.1270	.3318	.1453	.32
4	43	02-3010 PD	.1169	.1822	.0538	1.61
5	43	02-4586 PD	.1418	.3646	.2066	.02
6	39	02-5325 PD	.1218	.3149	.1303	.45
7	42	02-6323 PD	.1785	.4677	.2724	1.05
8	43	02-6468 PD	.1521	.3776	.2345	.07
9	22	02-6801 PD	.1794	.4226	.2794	.79
10	18	02-7708 PD	.1019	.4205	.4174	2.56
11	43	02-8778 PD	.1464	.4320	.3256	.38
12	43	02-8895 PD	.1487	.4264	.2661	.18
13	43	02-9271 PD	.1259	.3119	.0570	1.39
14	43	02-9439 PD	.1646	.2855	.1369	.72
15	43	29-0818 PD	.2107	.3792	.2124	2.40
16	18	29-1018 PD	.1360	.2980	.1553	.21
17	43	29-3142 PD	.1152	.4250	.1968	1.22
18	21	29-5273 PD	.1309	.3680	.3685	1.76
19	26	29-5800 PD	.1327	.1947	.1756	2.34
20	24	29-9897 PD	.1168	.5030	.3813	1.48
21	41	42-0738 PD	.1722	.5092	.3425	1.19
22	17	42-1308 PD	.1245	.3473	.1518	.40
		WEIGHTED MEANS	.1430	.3662	.2129	

FLAGGED TEST VALUES

PARAMETERS OF REGIONAL KAPPA DISTRIBUTION .7751 .2122 -.1455 .7182

***** HETEROGENEITY MEASURES *****
(NUMBER OF SIMULATIONS = 500)

OBSERVED S.D. OF GROUP L-CV = .0271
SIM. MEAN OF S.D. OF GROUP L-CV = .0262
SIM. S.D. OF S.D. OF GROUP L-CV = .0049
STANDARDIZED TEST VALUE = .19

OBSERVED AVE. OF L-CV / L-SKEW DISTANCE = .0767
SIM. MEAN OF AVE. L-CV / L-SKEW DISTANCE = .0808
SIM. S.D. OF AVE. L-CV / L-SKEW DISTANCE = .0127
STANDARDIZED TEST VALUE = -.32

OBSERVED AVE. OF L-SKEW/L-KURT DISTANCE = .1087
SIM. MEAN OF AVE. L-SKEW/L-KURT DISTANCE = .1122
SIM. S.D. OF AVE. L-SKEW/L-KURT DISTANCE = .0170
STANDARDIZED TEST VALUE = -.21

***** GOODNESS-OF-FIT MEASURES *****

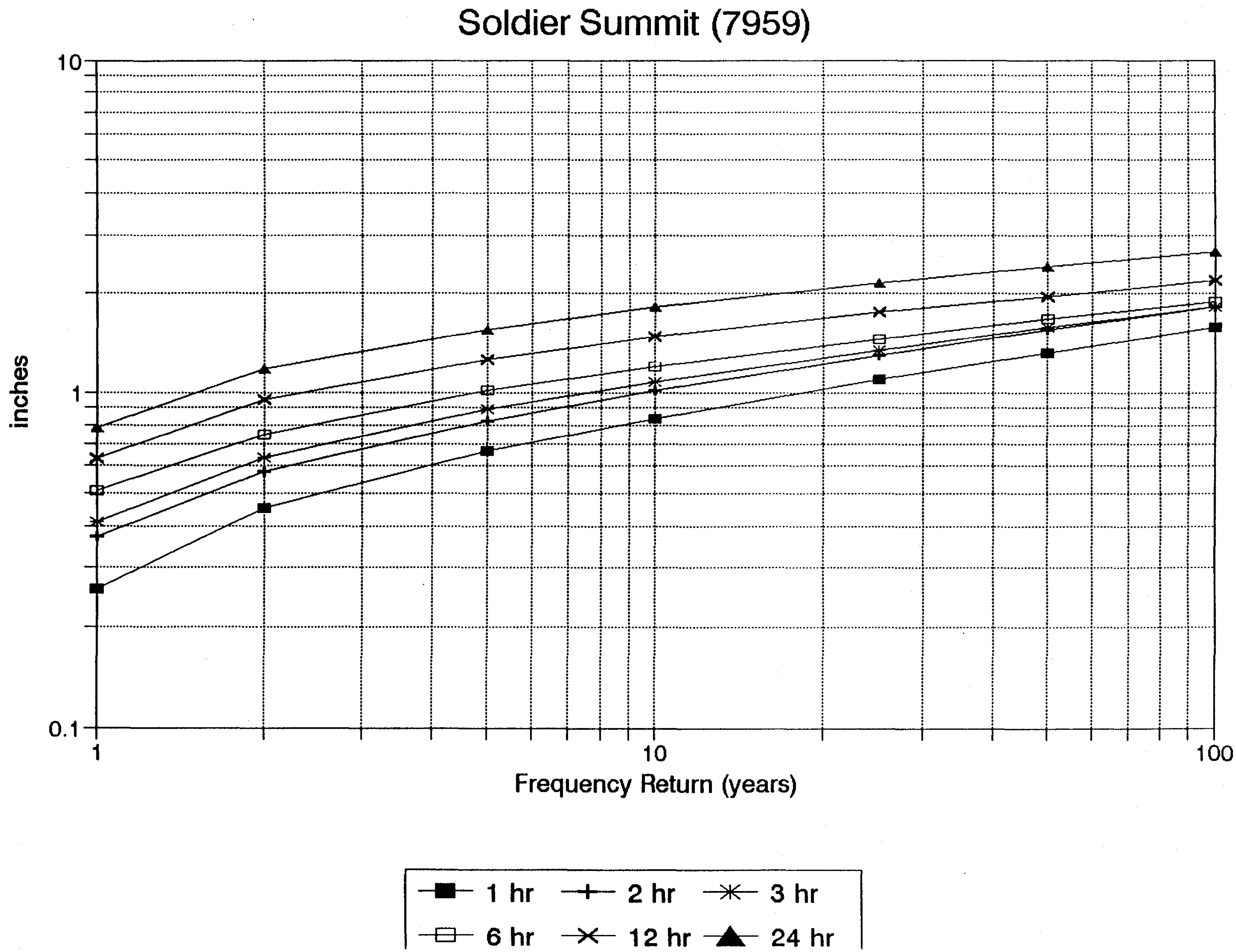
GEN. LOGISTIC	L-KURTOSIS= .278	Z VALUE= 2.66	
GEN. EXTREME VALUE	L-KURTOSIS= .258	Z VALUE= 1.69	
GEN. LOG NORMAL	L-KURTOSIS= .229	Z VALUE= .30	*
PEARSON TYPE III	L-KURTOSIS= .179	Z VALUE= -2.08	
GEN. PARETO	L-KURTOSIS= .193	Z VALUE= -1.38	*

QUANTILE ESTIMATES FOR DISTRIBUTIONS ACCEPTED AT THE 90% LEVEL

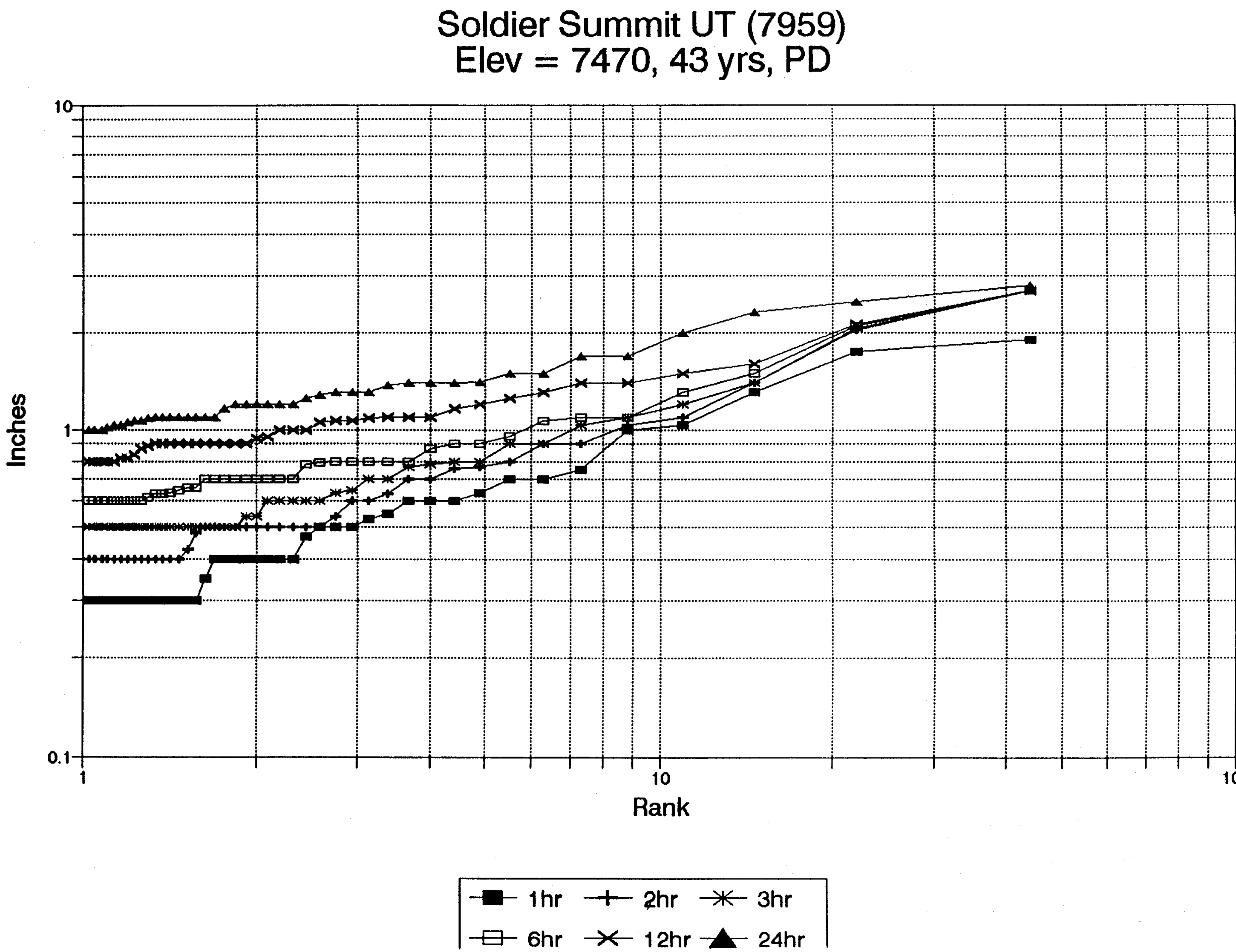
	.100	.500	.800	.900	.960	.980	.990
GEN. NORMAL	.751	.911	1.145	1.343	1.644	1.906	2.200
GEN. PARETO	.751	.906	1.161	1.365	1.651	1.880	2.122
WAKEBY	.749	.911	1.151	1.347	1.641	1.892	2.173

PARAMETERS:

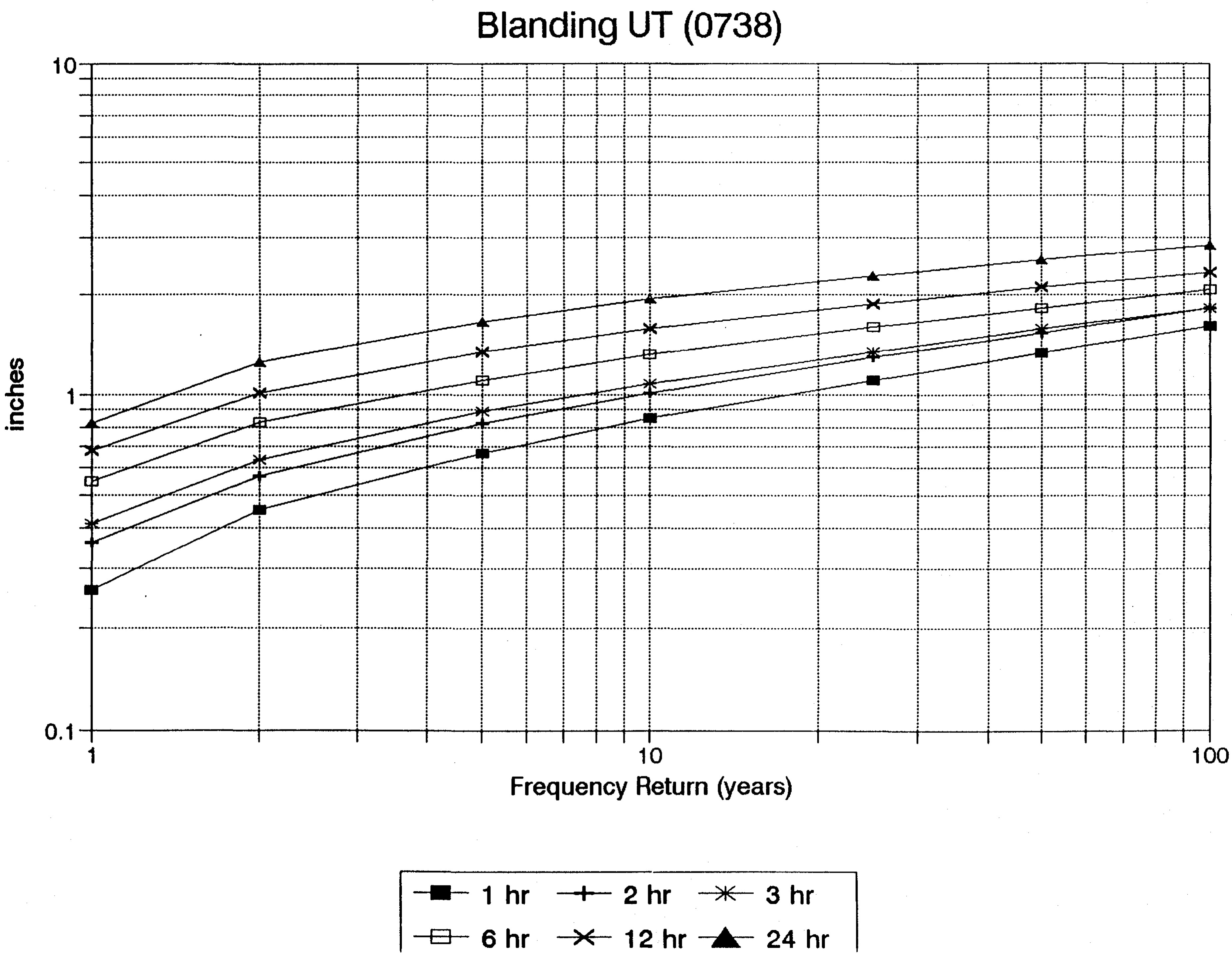
GEN. NORMAL	.911	.197	-.775		
GEN. PARETO	.724	.256	-.072		
WAKEBY	.716	.114	1.857	.205	.160



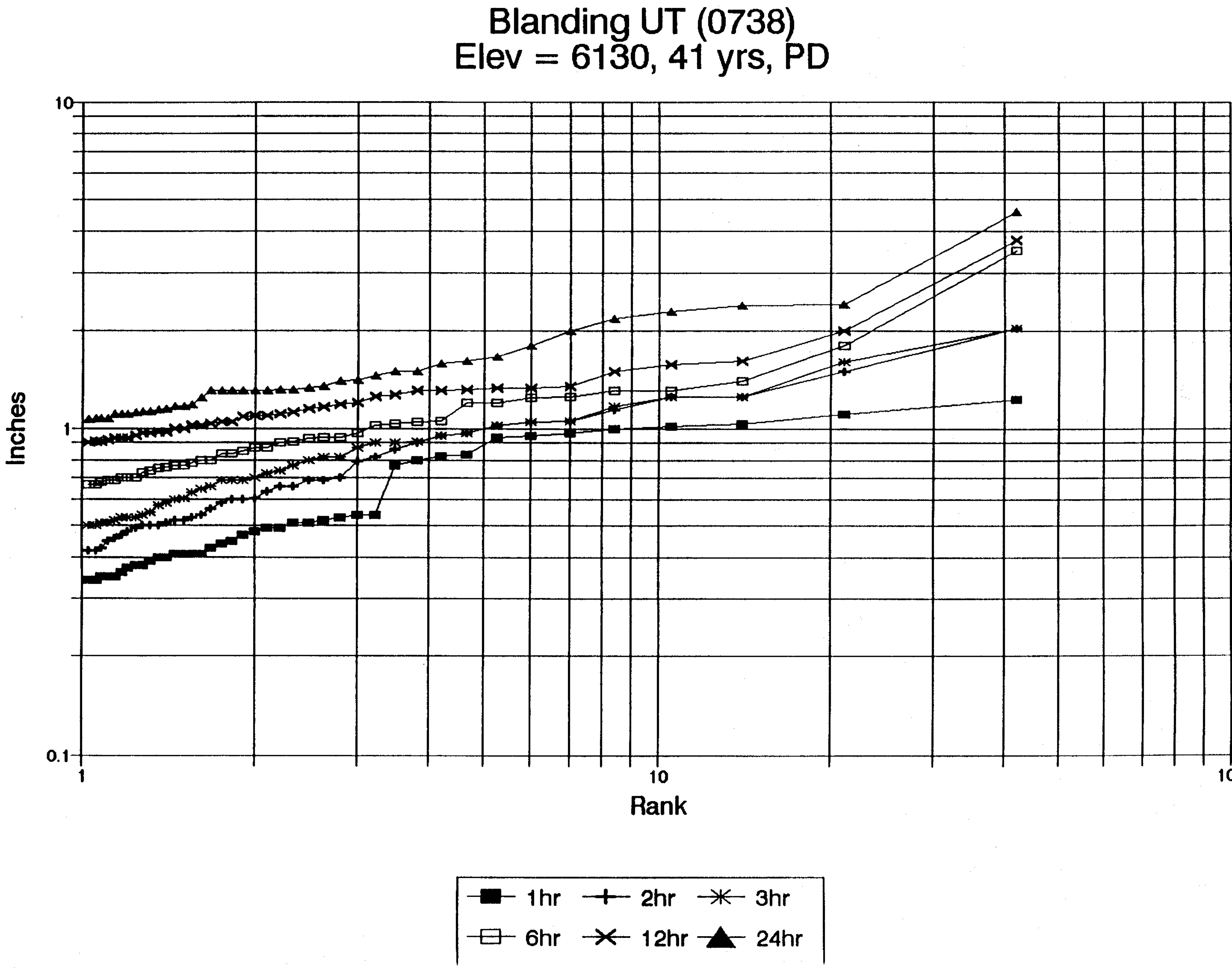
Attachment 15a



Attachment 15b



Attachment 16a

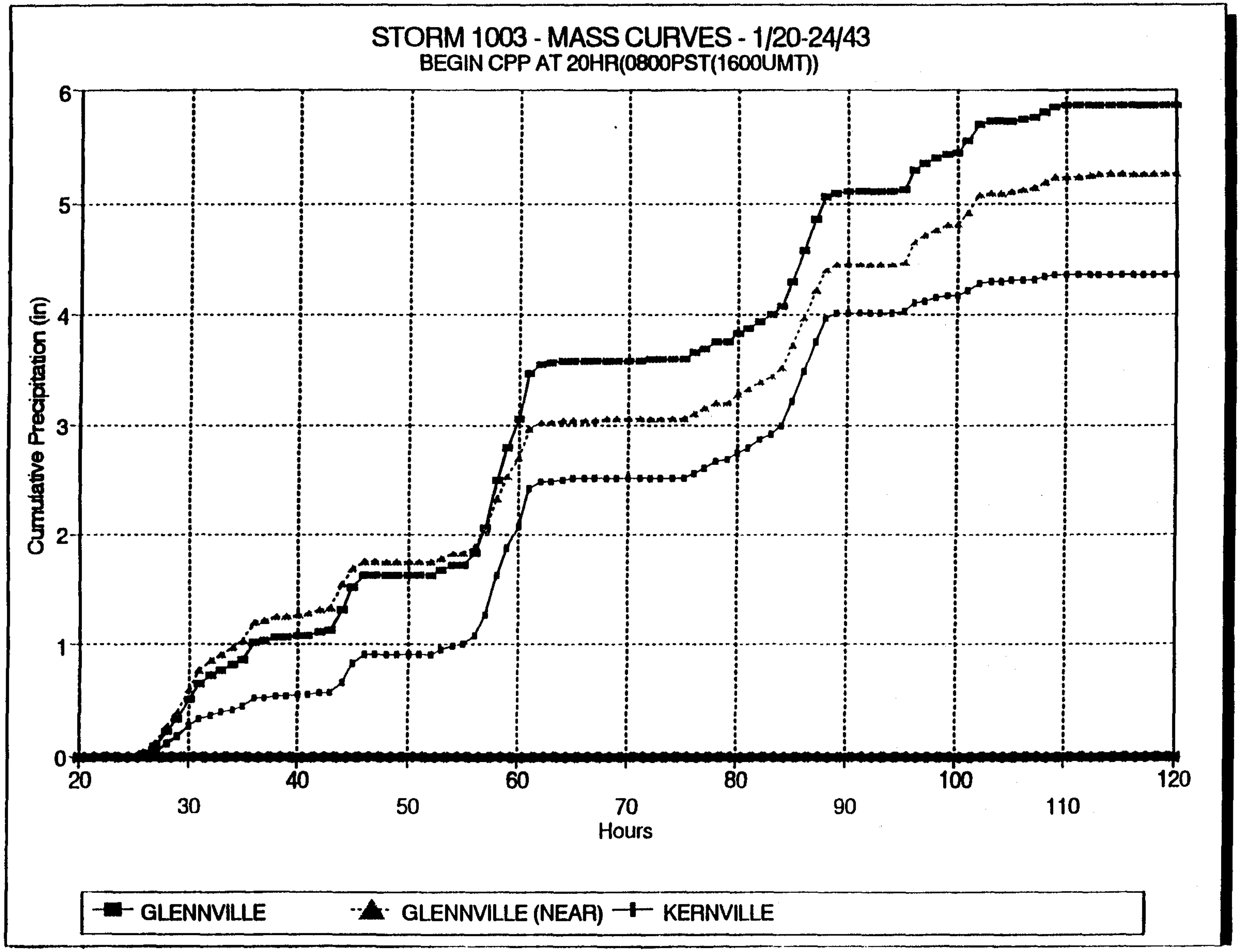


Attachment 16b

Attachment 17

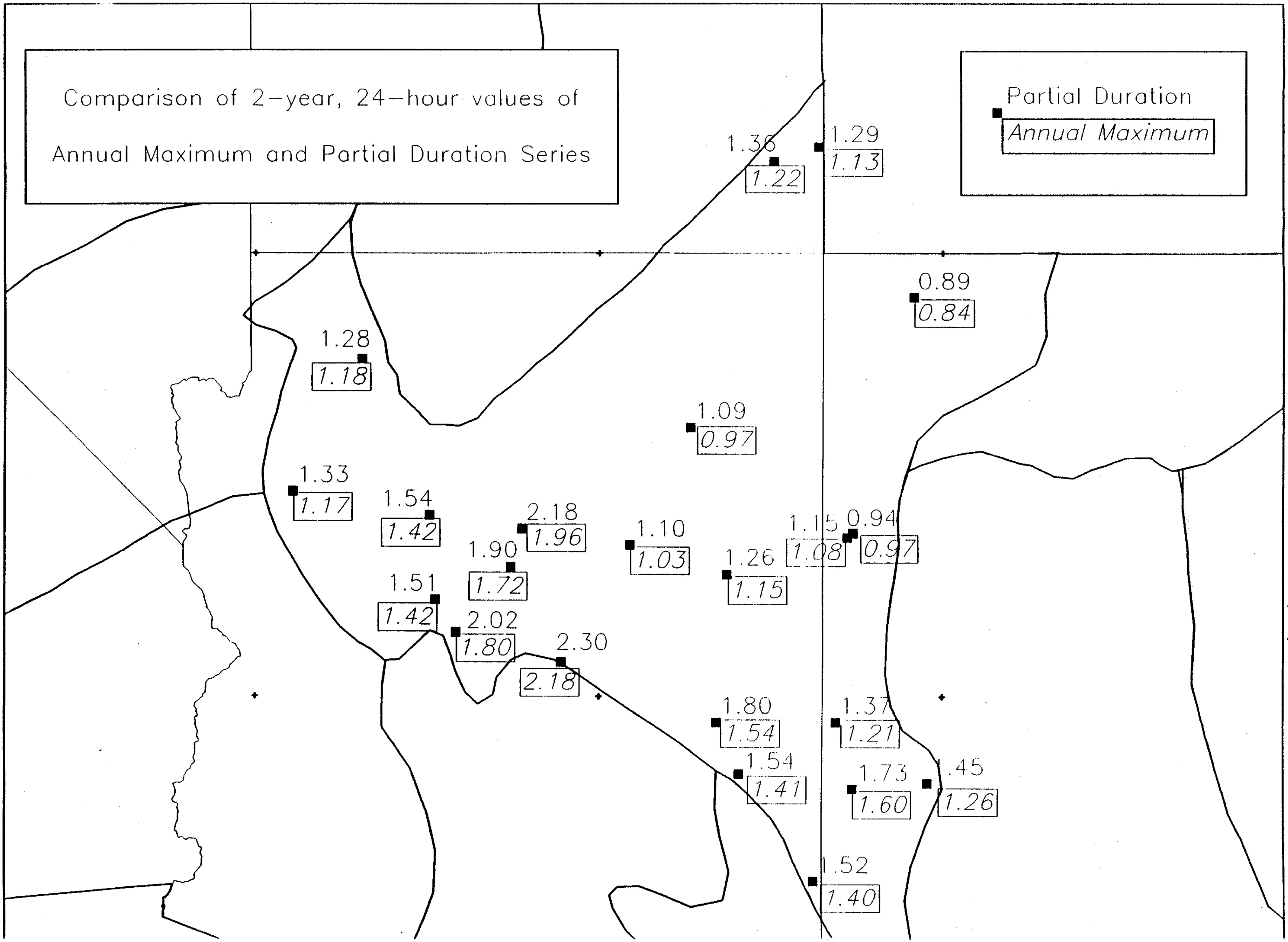
ORACLE 2 SE

02-611985	8	0.80	5149	1	0	0	0	5149
02-611985	8	1.00	5149	2	0	0	0	5149
02-611985	8	1.00	5149	3	0	0	0	5149
02-611985	8	1.20	5149	4	0	0	0	5149
02-611985	8	1.50	5149	6	0	0	0	5149
02-611985	8	1.50	5149	8	0	0	0	5149
02-611985	8	1.50	5149	12	0	0	0	5149
02-611985	8	1.50	5149	24	0	0	0	5149
02-611985	8	1.50	5149	48	0	0	0	5149
02-611985	8	1.60	5149	96	0	0	0	5127

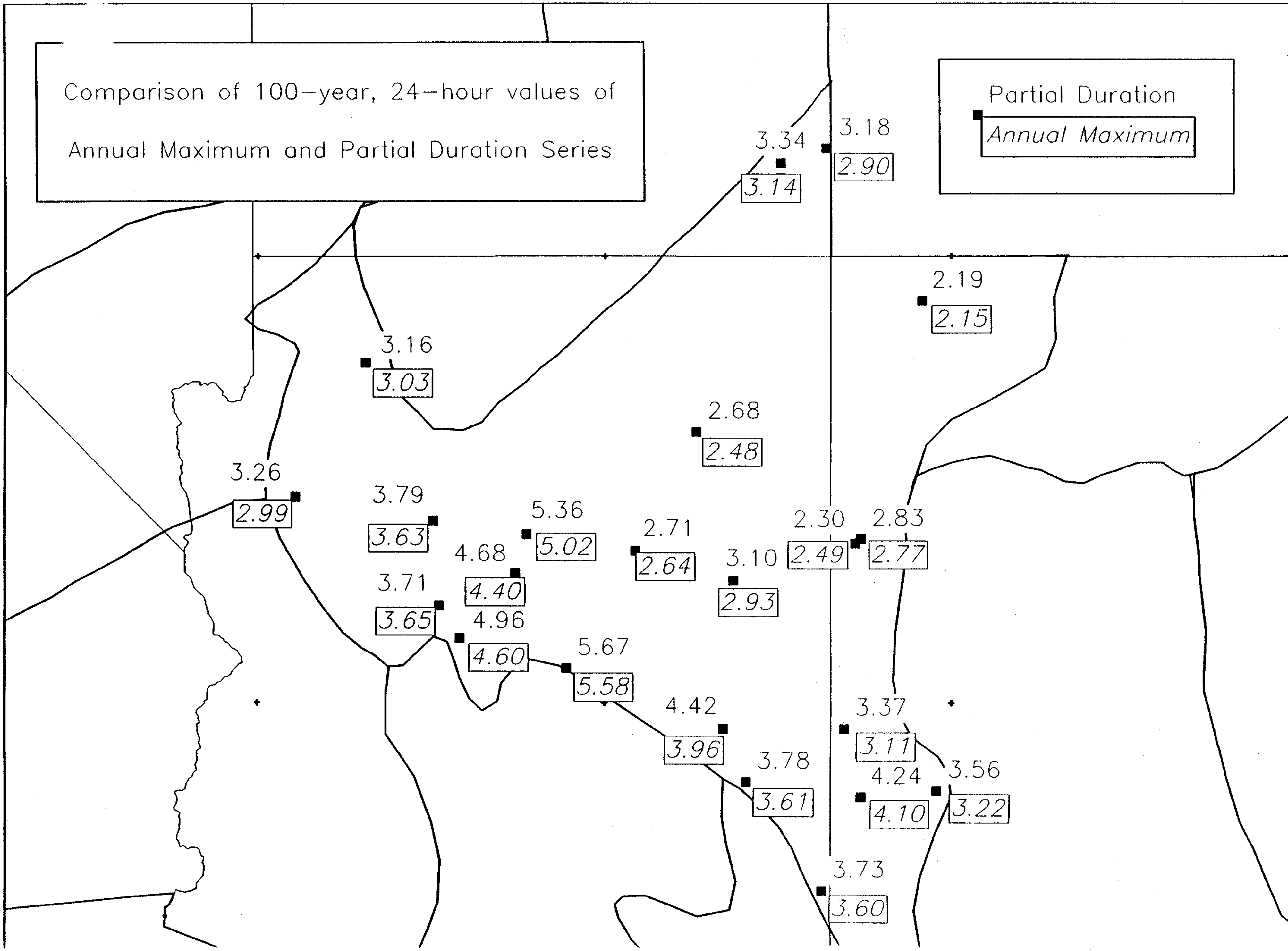


Attachment 18

Figure 19. Set of mass curves for a southern California storm from January 20 through 24, 1943.



Attachment 19a



Attachment 19b

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

January 25, 1995 W/OH5:LFT

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH5 - Lesley Tarleton

SUBJECT: Minutes: Semiannual Meeting for the Arizona Department of Transportation (ADOT), Tempe, Arizona, 28 November 1994

Enclosed is a copy of the Minutes for the Semiannual Meeting and report on the Semiarid Precipitation Frequency Project. The Minutes include copies of about 30 charts and graphs that were shown at the Meeting. Larry Scofield hosted the Meeting for ADOT and I made the presentation for the National Weather Service.

If you have any questions, comments, or suggestions, please feel free to call me at (301) 713-1669.

Enclosure

Minutes--Fifth Meeting
Semiarid Precipitation Frequency Project
Tempe, Arizona
7 November 1994

Attendance

Cliff Anderson	Smith Engineering for AMAFCA[1]	(505) 884-2215
Ching-Tai Chyan	ADOT[2]/Bridges	(602) 255-8613
David Creighton	ADWR[3]	(602) 542-1541
Javier O. Guana	ADOT[2]/Drainage	(602) 255-8610
Itty P. Itty	ADOT[2]/Drainage	(602) 255-7542
Ray Jordan	ADOT[2]/Drainage	(602) 255-7197
George Lopez-Cepero	ADOT[2]/Drainage	(602) 225-7481
George Sabol	GVSCE[4]	(602) 483-3368
Lou Schreiner	USBR[5]	(303) 236-3791
Larry Scofield	ADOT[2]/ATRC[6]	(602) 831-1353
Lesley Tarleton	NOAA/NWS	(301) 713-1669

INTRODUCTION

The Fifth Semiannual review meeting for the Semiarid Precipitation Frequency Project was convened at 9:00 AM November 7, 1994 at the Arizona Department of Transportation (ADOT) Research Center (ATRC) in Tempe, Arizona. Larry Scofield hosted the meeting for ADOT. Lesley Tarleton of the National Weather Service, Office of Hydrology presented the review. The agenda is included as Attachment 1. The report included discussion of various aspects of the final datasets, including partial duration (PD) versus annual maximum (AMX) series, daily to hourly conversion factors, a comparison with the amount of data used for NOAA Atlas 2 (Miller et al 1973), and the n-minute (short duration) data analysis. In addition, a regional study of the Salton Sea area (Imperial County, California) was presented. Some storm analysis results were presented, as well as 2- and 100-year, 24-hour frequency maps for Utah and southern Arizona and n-minute ratios for the study area. A list of Attachments is included. These are, in most part, the overheads that were shown at the meeting. The discussion included several useful suggestions for the final report, such as using the real-data-check to infer confidence-limits. Discussion included a number of questions from Lou Schreiner and others regarding the implications of new findings on final results and on the schedule

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1 Albuquerque Metropolitan Flood Control District
2 Arizona Department of Transportation
3 Arizona Department of Water Resources
4 George V. Sabol Consulting Engineers, Inc.
5 U.S. Bureau of Reclamation
6 ADOT Research Center

for completion. The summary includes the proposed final report and discussion of comments and questions. The format of these minutes will be a brief discussion on the attachments, ending with a summary. The attachments are at the end of the report.

ATTACHMENTS

1. Agenda

MAPS AND DATA

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3. Map of Semiarid stations
4. SNOTEL map
5. Comparison of number of stations used for Semiarid Study with NOAA Atlas 2
6. Conversion factors from daily to hourly data
7. Time series, Roosevelt 1 WNW, AZ (02-7281)
8. Real-data-check, Region 20

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9. N-minute stations in Semiarid study area
10. N-minute frequency by month:
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11. N-minute precipitation frequency maps:
    a. 5min 2yr, b. 5min 100yr, c. 30min 2yr, d. 30min 100yr
12. Imperial County, California station map

IMPERIAL COUNTY, CALIFORNIA

13. Imperial County frequency maps:
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14. Imperial County - Semiarid minus NOAA Atlas 2 (SA-NA2) maps:
    a. 2yr 24hr, b. 100yr 24hr
15. Gold Rock Ranch CA SA-NA2
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18. Map for SA storms 1019, 1020, 1021, and 1022
19. Mass curve - storm 1020
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21. Depth-area-duration curves - storm 1020

ANALYSIS

N-minute Ratios

22. Semiarid n-minute ratios by n-minute region
23. Comparison of SA n-minute ratios to NOAA Atlas 2 and Huff and Angel 1992

Precipitation Frequency Maps

24. Southern Arizona Index map - 2yr 24hr precipitation frequency map
25. Southern Arizona 100yr 24hr precipitation frequency map
26. SA-NA2 southern Arizona 100yr 24hr difference map
27. Utah Index map: 2yr 24hr precipitation frequency map
28. Utah: 100yr 24hr precipitation frequency map

SUMMARY

29. Dataset and analysis summary

Attachments 2-10: **MAPS AND DATA**

Daily and Hourly Data

The division of the project area into near-homogeneous subregions is essential to optimal use of L-moment statistical procedures for determining precipitation return frequencies (Hosking and Wallis 1991). Criteria for determination of homogeneity include precipitation regime, seasonality, orography, synoptic climatology, and other factors. The 24 near-homogeneous regions are shown on the map in Attachment 2. The final dataset is comprised of 1432 daily (including 147 SNOpack TELemetry (SNOTEL) and 108 Mexican) and 449 hourly stations. All the stations are shown on the map in Attachment 3. As the SNOTEL records have relatively short records, they were compared with longer term stations in the areas shown in Attachment 4. The SNOTEL data provide information at higher elevations, in locations where no data had been available previously. Attachment 5 shows a comparison of data used for the Semiarid Study compared with NOAA Atlas 2 . This updated study is using 357 more daily stations (19 or more years of record) and 87 more hourly stations (15 or more years of record) in the core states of Arizona, Nevada, New Mexico, and Utah. The 147 SNOTEL and 108 Mexican stations are also additions to the database that were not available to NOAA Atlas 2. Without counting the stations in the border states and California, additional and otherwise, the Semiarid study has an increase of 700, (well, 699, 357+87+147+108 = 699) stations over NOAA Atlas 2.

The data were quality-controlled in a variety of ways, and adjustments were calculated to convert daily observations into 24-hour data and the 2-day data into 48-hour data. The amount of adjustment needed decreases with increasing return frequency. The factors are shown in Attachment 6. The data were also examined for any trends, by comparing 10-year periods, using a Friedman test. No significant trends were found. An example of a time series for a long-term station is shown in Attachment 7. Although variable, there does not appear to be any change in the mean. Therefore, we assume that there is no climate change that is affecting the Semiarid dataset.

In order to evaluate different probability distributions, the data were compared to the results from several distributions and to the theoretical probability (real-data-check (RDC), Lin and Vogel (1993)). The theoretical probability is that for a 2-year return frequency value, 50 percent of the observations are above and 50 percent below the estimated value, for 5-year - 20 percent above, 10-year - 10 percent above, and so on to 100-year - with 1 percent above. The graph in Attachment 8 is a plot of the percentages (shown as probabilities in the graph) of the data above the various probability distribution estimates. For example, the 100-year theoretical value is 1 percent (.01 on the graph) and the percentage of data that is above the Gumbel estimate is 3.65 percent (.0365 on the graph). This means that 3.65 percent of the actual observed data are above the estimate of the Gumbel probability distribution, or in other words, at the 100-year return frequency in Region 20, the Gumbel estimate is low. It can also be seen on this graph that the Log-normal (LNO) and the Generalized Pareto (GPA) most closely fit the theoretical value.

N-minute Data

Attachment 9 shows the locations of the n-minute data stations. The 27 stations with n-minute data were collated from both digital and hard-copy sources, resulting in a dataset with records of 14 to nearly 100 years. Eight of these stations have more than 80 years of data. The regionalization of the n-minute data consists of seasonal clusters of the same regions used for the daily and hourly data analysis. Attachment 9 also shows the four n-minute regions: 1) Cool (winter), 2) Cool (spring), and 3) Warm (summer) - West, and 4) Warm (summer) - East. The boundary between the two Warm (summer) precipitation regimes is the Continental Divide in Colorado and New Mexico.

For seasonal analysis of the n-minute data, the seasons essentially coincide with those of the individual regions, and are also shown in Attachment 9. To determine seasonality of short-duration precipitation, the extremes were tabulated by the month of occurrence. Attachments 10a-10f show the seasonal distribution for various short-duration extreme precipitation events - 10a: Flagstaff AZ; 10b: Winslow AZ; 10c: Phoenix AZ; 10d: Tucson AZ; 10e: Yuma AZ; 10f: Albuquerque NM. For example, Phoenix (10c) is typical of most of the southwest with the convective storms of late summer contributing most of the high-intensity rainfall. This corroborates that the more intense storms are convective, rather than general in this part of the study area.

The n-minute data were quality-controlled, regionalized, and tested for discordancy, heterogeneity, and goodness-of-fit with L-moment statistical software. The best-fit probability distribution proved to be the Generalized Pareto (GPA), the same as for the hourly and daily data. The return frequencies were computed using partial duration series for six durations: 5, 15, 30, 60, 120, and 180 minutes, for 25 stations with monthly maximums. Examples of n-minute return frequencies **(DRAFT)** are shown in the maps in Attachments - 11a: 2-yr, 5-min; 11b: 100-yr, 5-min; 11c: 2-yr, 30-min; and 11d: 100-yr, 30-min. In general, the highest values are in the southeastern part of the study area, in Arizona and New Mexico, and the lowest values in the northwestern part of the area.

Attachments 12 - 16: **IMPERIAL COUNTY, CALIFORNIA**

Imperial County contains most of the Salton Sea and has about one-third of its area below sea level. In the interest of water resources, the question was asked, "How do the surrounding mountains fare in regard to rainfall?" as nearly the only rainfall occurs in the higher elevations in the county. The Salton Sea area is 'rain-shadowed' on three sides, and only opens to the southeast on a relatively narrow swath to the Gulf of California, thus it is no surprise that it is very dry. The map in Attachment 12 shows station names and numbers and elevations for Imperial County and surroundings. Six of the stations are below sea level, four of them 100 feet or more below sea level. All the stations that are above sea level (in Imperial County) are within the valley. The Chocolate Mountains rise to about 2000 to 3000 feet along the northeast side of the valley, although to the east of Gold Rock Ranch (490 feet), a relatively isolated peak rises to only 1500 feet. The mountain barrier that blocks the Pacific moisture from the west ranges from over 10,000 feet in the northern part of the range to about 5500 feet west of Crawford Ranch. Preliminary precipitation return frequency values, 2-year/24-hour and 100-year/24-hour, were mapped and are shown in Attachments 13a and 13b.

Although higher elevations generally have higher precipitation values, there is no direct linear relationship. For example, at 2-year/24-hour (Attachment 13a) Ocotillo (410 feet) has a value of 1.60 inches, but Coyote Wells (250 feet) and El Centro (-30 feet) have essentially the same value, 1.07 and 1.06, respectively. The 100-year/24-hour map (Attachment 13b) shows similar results. In Attachments 14a and 14b, the differences between the Semiarid study and NOAA Atlas 2 for 2-year/24-hour and 100-year/24-hour are given (Semiarid minus NOAA Atlas 2). In the 100-year return period, there are a few small increases, but most of the values decreased by several tenths of an inch. Only one decrease is more than 1 inch, at Ocotillo Wells which shows a decrease of 1.28 inches. Attachment 15 shows the differences between the 2 studies at Gold Rock Ranch, or rather it shows the lack of difference at nearly all return periods, except the 2-year, where the Semiarid L-moment values are slightly higher. Attachment 16 show a comparison of return frequencies at various elevations in Imperial county. Although the highest elevation station (Gold Rock Ranch, 490 ft) has the highest precipitation, and the lowest elevation (Brawley, -100 ft) has the lowest precipitation, the rest of the stations show essentially no correlation with elevation.

Attachments 17 - 20 **STORM ANALYSIS**

Attachment 17 shows the list of storms being analyzed for this study to develop depth-area-duration curves and area reduction curves. The analyses of the four storms (1019, 1020, 1021, 1022) of Fall 1983 (9/27-10/3), shown on the map in Attachment 18, have been completed and depth-area-duration (DAD) curves prepared. Two December 1992 storms (1040, 1041) are nearly complete. Additional DAD curves are available from other storm studies for Semiarid storms 1023 (August 1951), 1029 (September 1970), and 1030 (October 1972). Storm 1020 is used as example of the storm analysis process: Attachment 19, a set of mass curves; Attachment 20, an isohyetal analysis; and Attachment 21, DAD curves. The DAD curves illustrate the short-duration nature of many of the storm in the southwest. Although rain fell over a period of 90 hours, the additional time above 24 hours added only 20 percent to the 24-hour (66 more hours) amount at 10 mi^2. Furthermore, about 85 percent of the 24-hour total fell in six hours (coincident with 12 hours) at 10 mi^2.

Attachments 22 - 28 **ANALYSIS**

N-minute Ratios

To determine return frequencies for durations less than one hour (60 minutes), ratios to 60 minutes are used. Ratios are used for these shorter durations, because of the limited number of stations available, which precludes adequate spatial coverage for mapping. Attachment 22 shows the n-minute ratios (n-min/60-min) for each region. The ratios were computed for each region separately, but the largest difference between any two regions was 0.03. Therefore, the ratios for the entire area were considered to be essentially homogeneous across the whole Semiarid region. Furthermore, the ratios were found to be the essentially the same, regardless of return frequency. This confirms the findings in Hershfield 1961 Technical Paper 40 and adapted in NOAA Atlas 2. Attachment 23 shows the averages for the whole Semiarid study area and those reported in NOAA Atlas 2 for 5, 10, 15, and 30 minutes. Also shown in Attachment 23 are the ratios used by Huff and Angel (1992). The Semiarid ratios are .04 higher than the NOAA Atlas 2 values at 5 and 10 minutes and .03 higher at 15 and 30 minutes. The Huff and Angel values are the same as NOAA Atlas 2, except at 5-minutes, where their ratio is lower than both the Semiarid and NOAA Atlas 2 values. Further comparisons will be made with other short duration studies, such as Arkell and Richards (1986).

Isohyetal Maps

Isohyetal maps and/or ratios are used to represent return frequencies from 2-year to 100-year (also 200, 500, and 1000 year estimates) for durations from 5 minutes to 60 days. The index map for 2-year/24-hour return frequency has been plotted, hand-analyzed, and is being digitized into the GIS/GRASS computing system. An initial raster map has been generated and a vector (isohyetal) map generated from the raster map. The first draft of the 100-year/24-hour map for Utah and southern Arizona has been computer-generated from the 2-year index map, by multiplying the 2-year raster map by the Regional Growth Factors (RGFs), derived from the L-moment regional analysis. The other return frequencies will be computer-generated in the same way. However, this process will take additional consideration as the RGFs vary among the different regions; and how to best resolve any finite discontinuities between regions is still undecided. Possibly a spline-fitting technique may be developed for interpolation between regions. A linear interpolation between regions was successful on a study in Hayes County, Texas; but the area had only two regions, not 24, and the topography was not nearly as complex. Attachment 24 shows the southern Arizona Index Map, 2-year/24-hour, and Attachment 25 shows the 100-year/24-hour map of the same area. The 2-year map was hand-analyzed and digitized into GRASS, and the 100-year map was generated on the computer by multiplying the 2-year map by the 100-year Regional Growth Factors. Attachment 26 shows a 100-year/ 24-hour difference map, Semiarid minus NOAA Atlas 2. Attachments 27 and 28 show the 2-year/24-hour and the 100-year 24-hour maps for Utah.

SUMMARY

Attachment 29 summarizes the dataset for the Semiarid precipitation return frequency analysis for all durations from 5 minutes through 60 days. All data are prepared from partial duration series, using L-moment statistics. Return frequencies include 2 to 100 years, and also 200, 500, and 1000 years, as a result of user requests for the higher value return frequencies. Were we to map all these durations and return frequencies for annual, summer and winter precipitation seasons, it would result in 486 maps. This seems a bit much. Thus, a combination of maps, tables, and graphs will be used to present the required return frequencies in as accessible way as possible.

Discussion included a number of questions from Lou Schreiner and others regarding the implications of new findings on final results and on the schedule for completion. Also, the discussion included several useful suggestions for the final report, such as using the real-data-check to infer confidence-limits. Another request centered on the importance of the 1-hour return frequency and the preference for a map of this parameter. The suggestion was made that where values differ from NOAA Atlas 2 be noted in the final report.

Thus, included in the final report will be maps for the 1-hour and 24-hour durations for 2-, 5-, 10-, 25-, 50-, and 100-year return frequencies. Seasonal maps will also be developed for the same periods. The n-minute ratios are complete (see Attachments 22 and 23) and can be used directly with the 1-hour map. The 1-hour map will be primarily computer-generated using the ratios of 1-hour to 24-hour values with the 24-hour map. The longer durations, 2-day to 60-day values, and the higher value return frequencies (200-, 500-, and 1000-year) have been prepared, and will be presented in a combination of maps, graphs and/or tables. Confidence limits will be presented where appropriate, using a combination of real-data-check analysis and the boundaries formed by different probability distributions. In addition to return frequencies, the final report will include updated depth-area-duration curves determined for the southwestern United States, and temporal distributions. In regard to the questions regarding new values, it is planned to include information indicating areas of change from NOAA Atlas 2. Most of the differences are considered to have resulted from additional data, longer records, and observations in locations not available to NOAA Atlas 2, especially at higher elevations.

The question was raised regarding the implications of new values (different from NOAA Atlas 2) on Probable Maximum Precipitation (PMP). In this regard, if our results are different, and they will be in some areas, their ratio to current PMP values will be different. However, the range of the ratios for PMP to 24-hour, 100-year precipitation frequencies in

Colorado and New Mexico given in HMR 55A (Hansen et al 1988) varies from 4.2 to 8.8 and as long as the new values fall within that range they will be considered reasonable. Subsequent PMP studies will use the updated return frequency values for a reference base; but basically the development of PMP values is an independent process from the determination of return frequencies.

It is expected that draft maps for review will available in the spring. The results have been delayed due to computer software development, innovation in switching from hand-analysis to a combined (hand- and computer-) system, and staff shortages, among other causes. The Semiarid Project is considered, not only the essential update of NOAA Atlas 2 for the Southwest, but also as the prototype development for the update of frequency studies in the rest of the United States. In this, it is serving well, allowing the application of new technology, development of new software and mapping procedures, use of state-of-the-art extreme-value statistics, as well as scientific expertise.

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Lin, B., and J.L. Vogel, 1993: A comparison of L-moments with method of moments, Engineering Hydrology, Symposium Proceedings, ASCE, New York, 443-448.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973: Precipitation-frequency atlas of the western United States, NOAA Atlas 2, National Weather Service, Silver Spring, Md.

LIST OF ATTACHMENTS

ATTACHMENT 1

Semiarid Precipitation Frequency Study
Status Report

National Weather Service

Arizona Department of Transportation
Tempe, Arizona

November 7, 1994

AGENDA

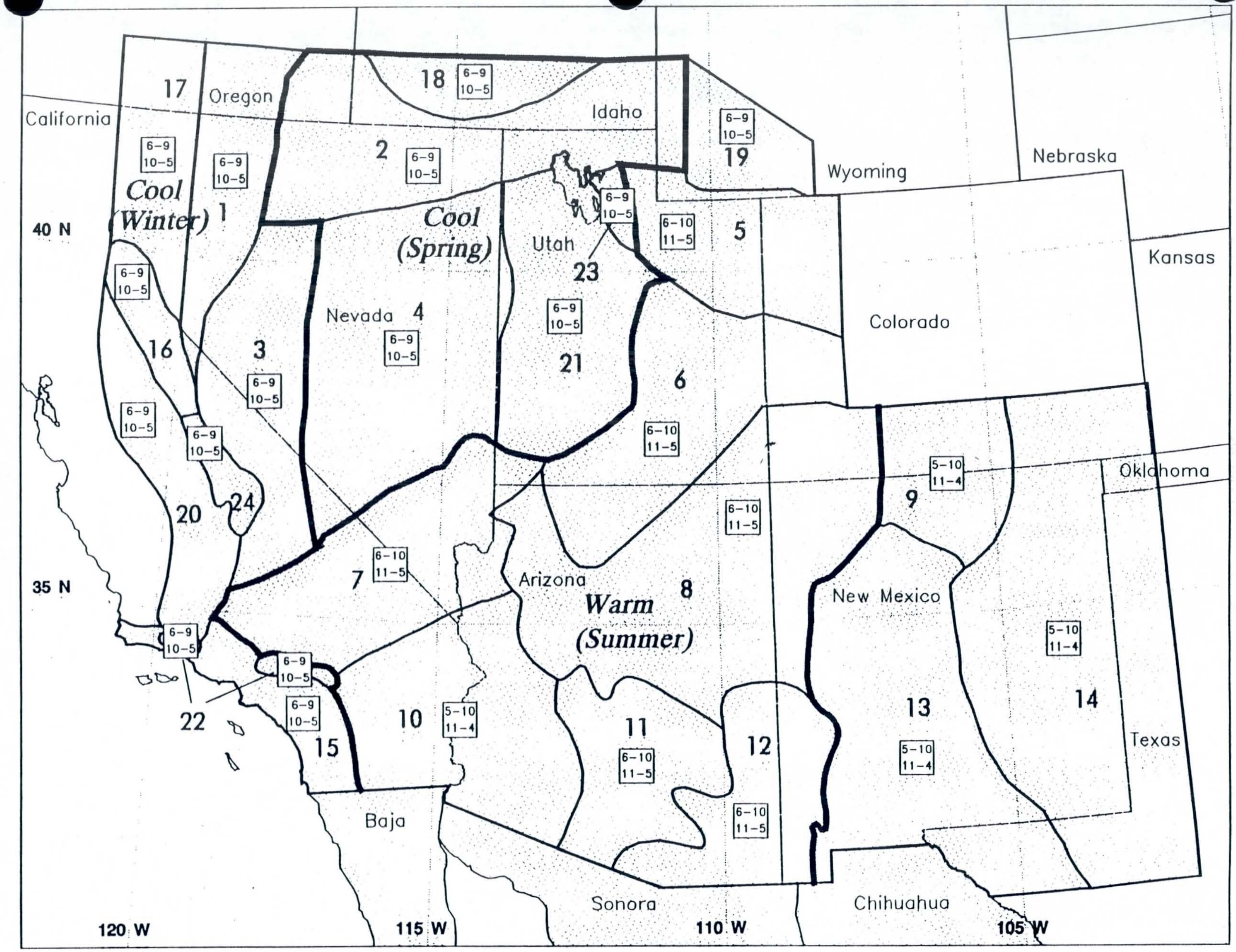
Data
- Comparisons with NOAA Atlas 2
- N-minute Data Analysis

Regional Analysis - Imperial County

Storm Analysis

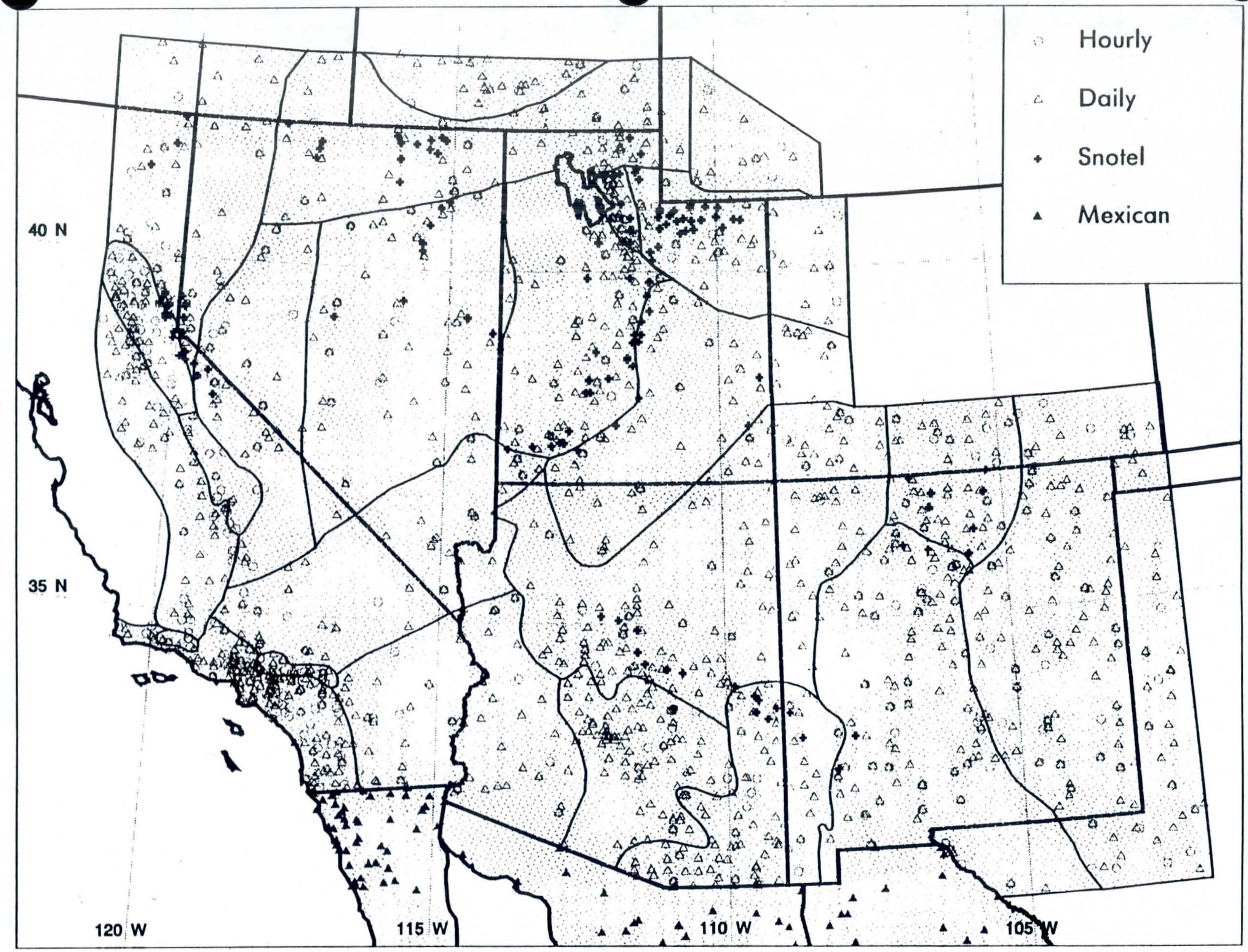
Results
- N-minute Ratios
- Precipitation Frequency Maps

Summary and Outlook



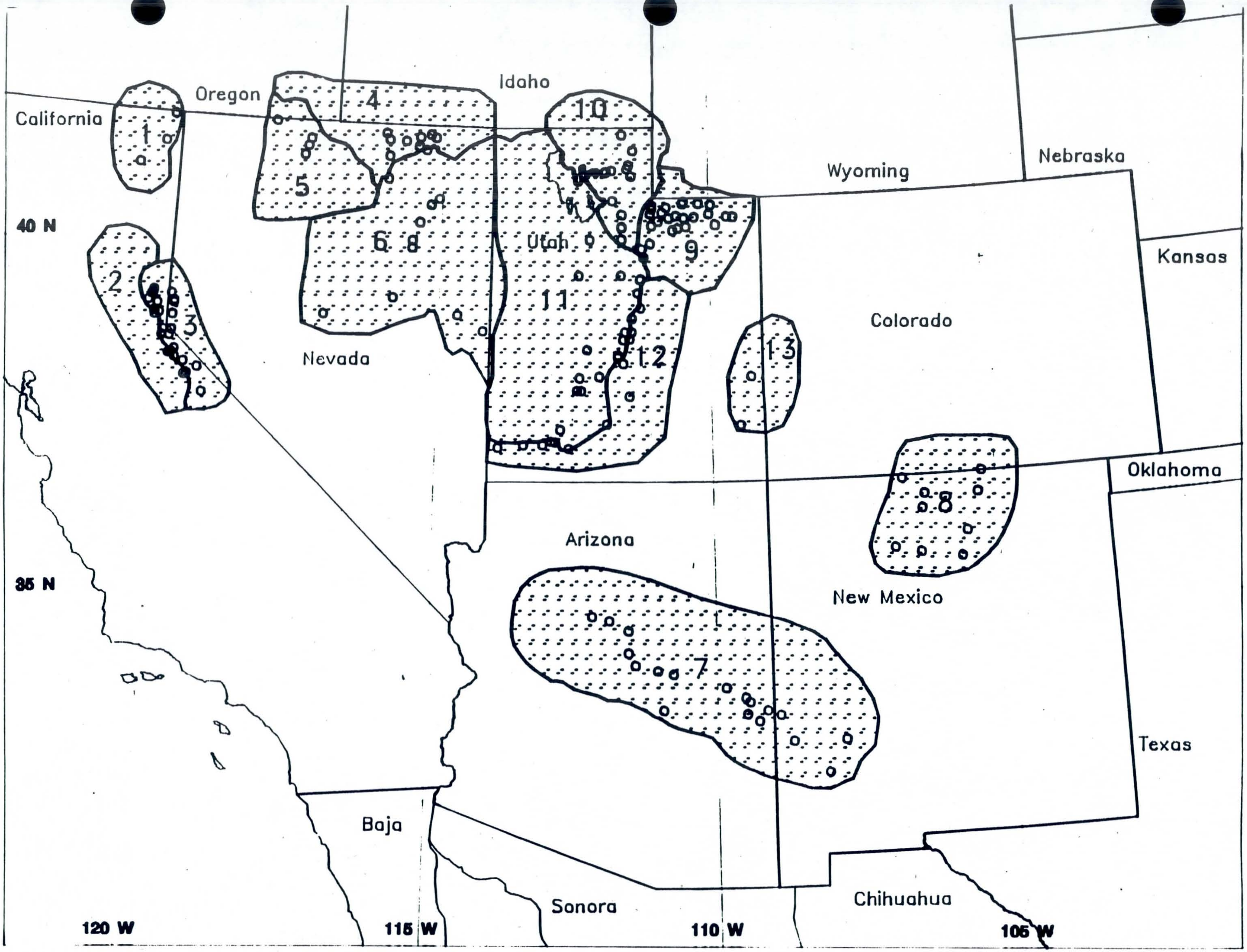
Semiarid study climatic regions.

ATTACHMENT 2



Semiarid study station locations.

ATTACHMENT 3



ATTACHMENT 4

ATTACHMENT 5

DAILY STATIONS WITH AT LEAST 19 YEARS OF DATA

Core States	Semiarid	NOAA Atlas 2	**Increase**
Arizona	267	125	**142**
Nevada	91	34	**57**
New Mexico	212	143	**69**
Utah	171	82	**89**
Total	741	384	**357**

Other Stations	
California	288
Border states	148
SNOTEL	147
Mexico	108
Total Other	691
TOTAL DAILY	1432

HOURLY STATIONS WITH AT LEAST 15 YEARS OF DATA

Core States	Semiarid	NOAA Atlas 2	**Increase**
Arizona	42	32	**10**
Nevada	41	27	**14**
New Mexico	81	42	**39**
Utah	44	20	**24**
Total	208	121	**87**

Other Stations	
California	182
Border states	59
Total Other	241
TOTAL HOURLY	449

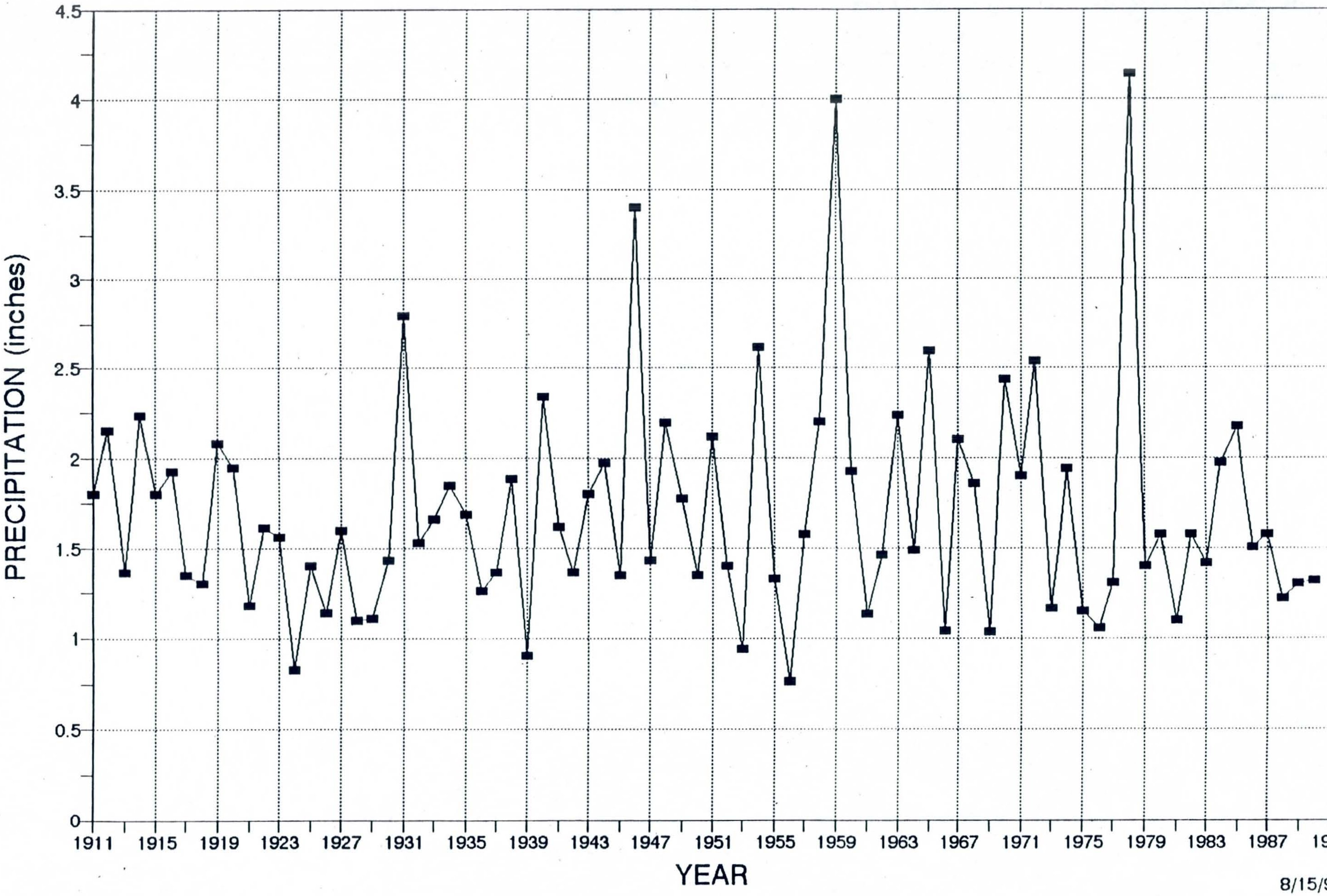
TOTALS	
DAILY	1432
HOURLY	449
TOTAL STATIONS	**1881**

Conversion Factors

Return Period	1-day to 24-hr	2-day to 48-hr
2-year	1.15	1.02
5-year	1.13	1.02
10-year	1.12	1.02
25-year	1.10	1.00
50-year	1.08	1.00
100-year	1.06	1.00
200-year	1.05	1.00
500-year	1.04	1.00
1000-year	1.02	1.00

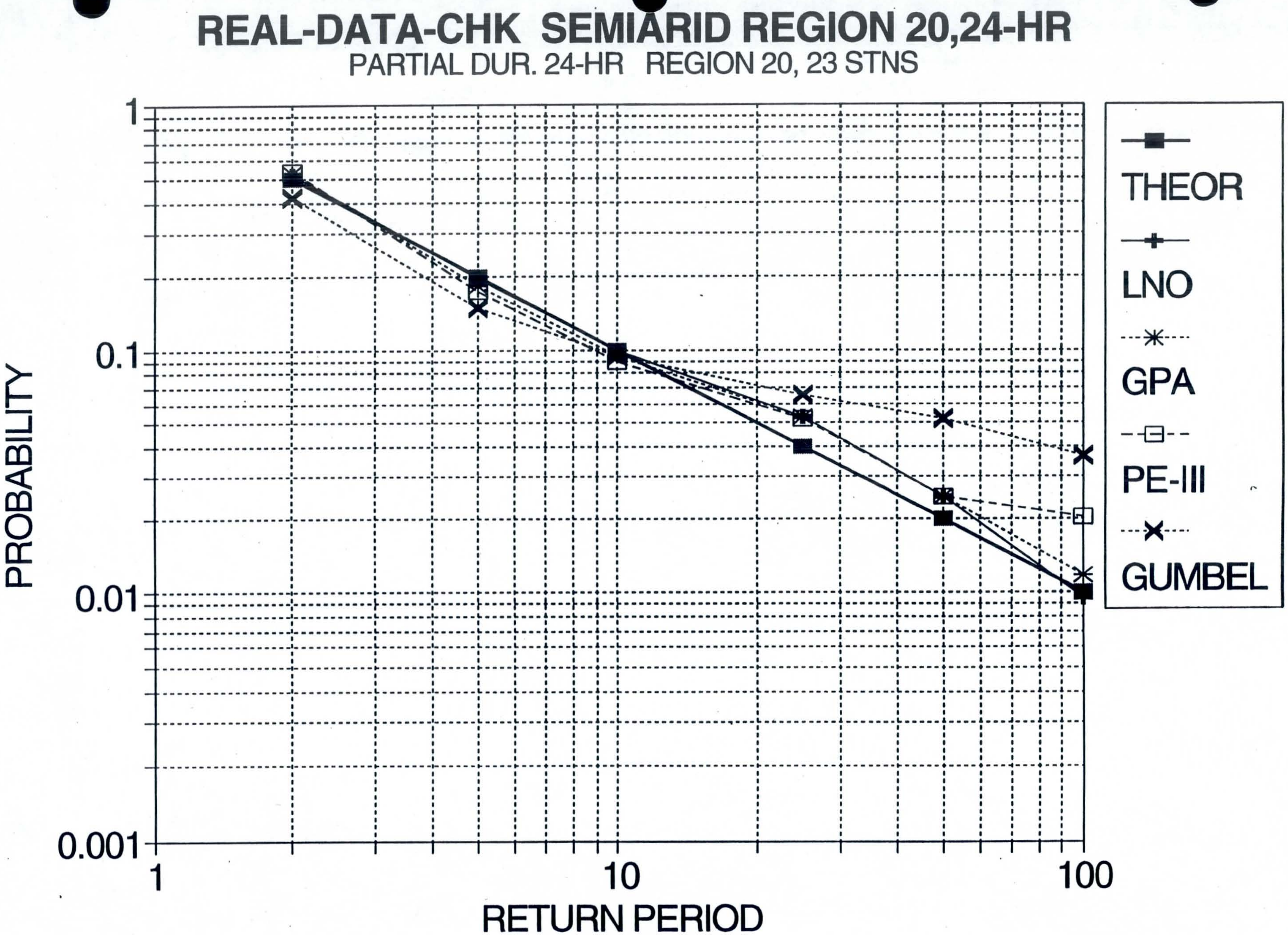
ATTACHMENT 6

ANNUAL MAXIMUM SERIES
Region 11, 02-7281



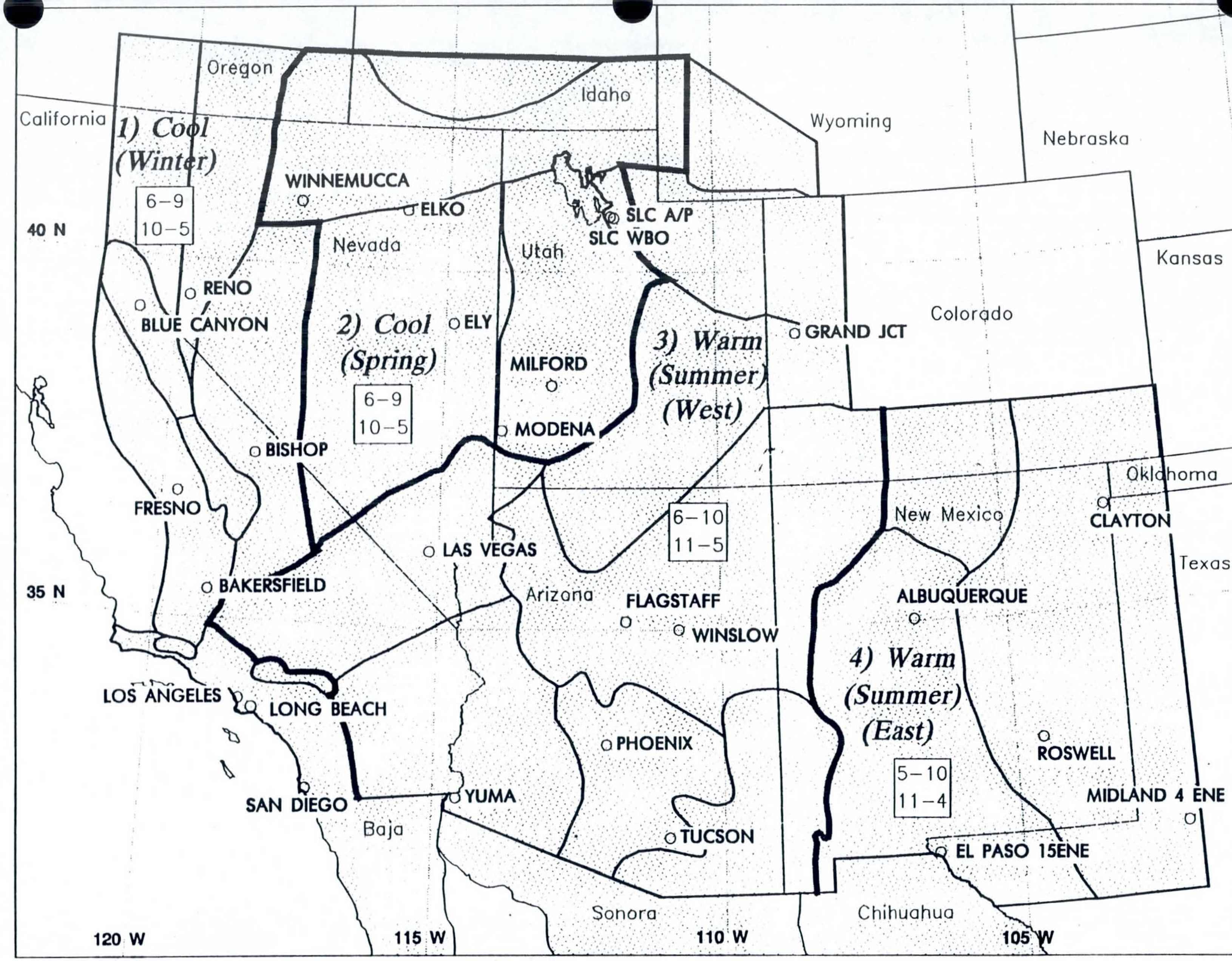
ATTACHMENT 7

8/15/94 JMO



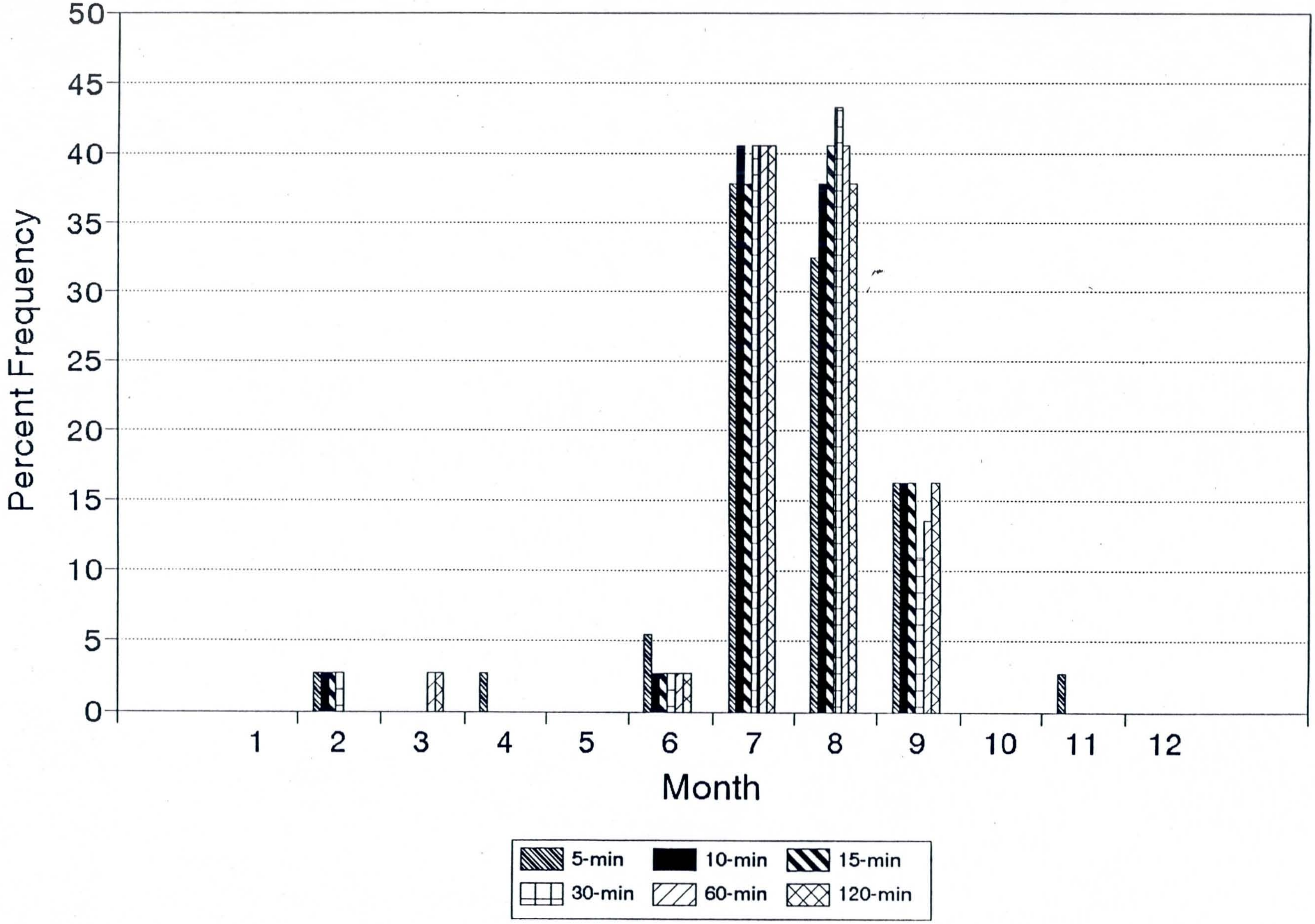
ATTACHMENT 8

ATTACHMENT 9



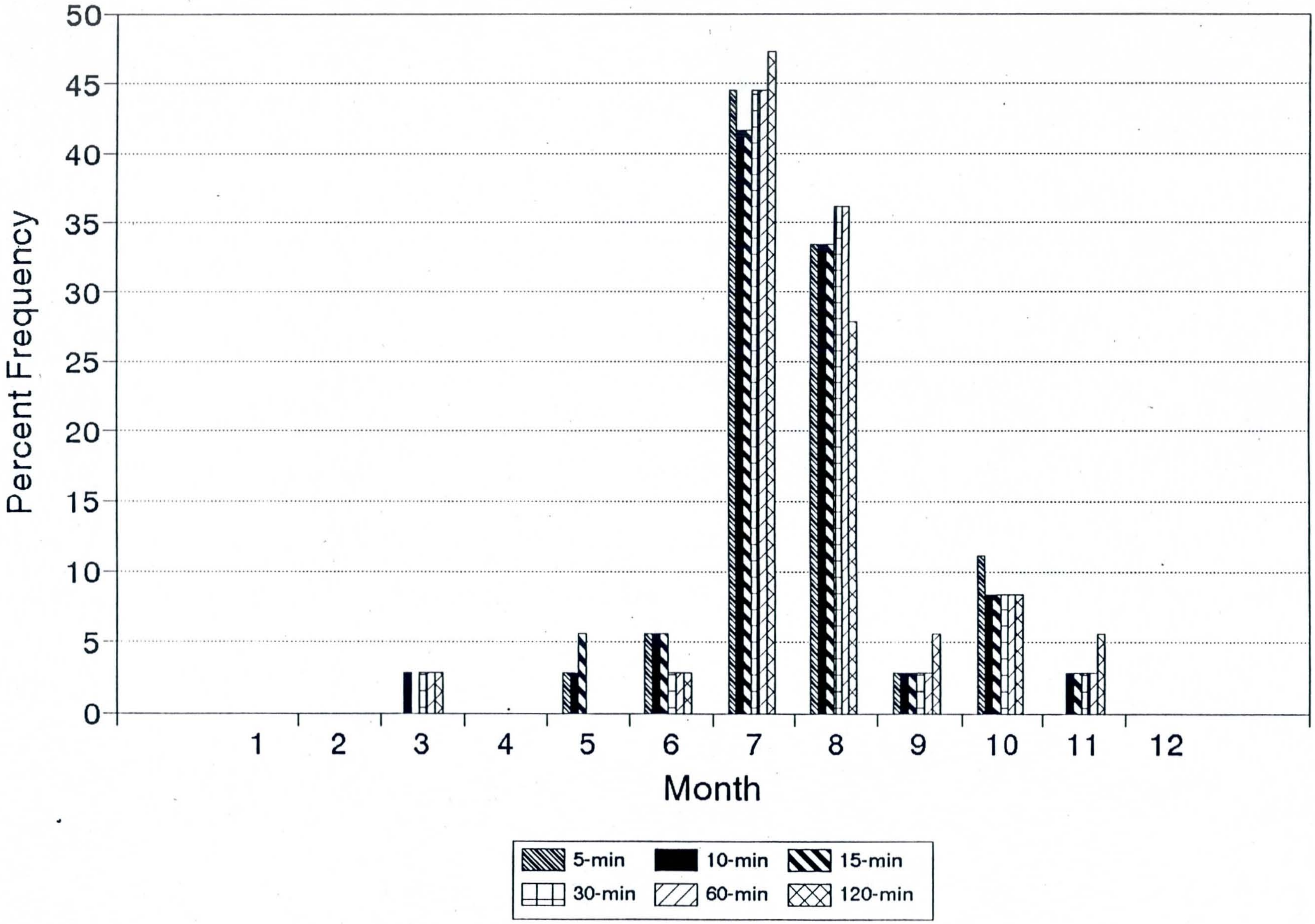
N-Minute stations in the Semiarid study area.

02-3010 Flagstaff, AZ 37 YOR
Percent Frequency of N-min max



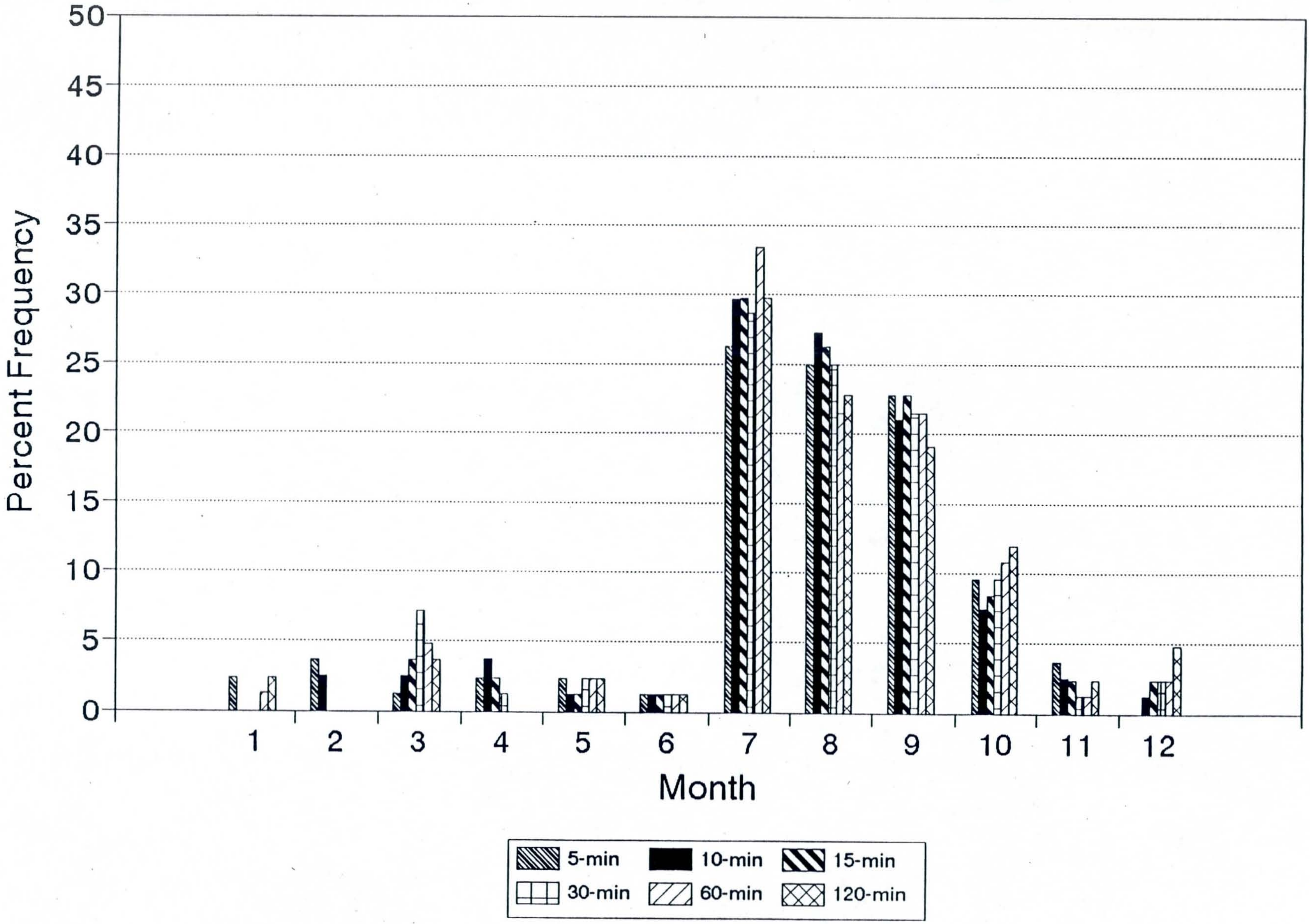
ATTACHMENT 10a

02-9439 Winslow, AZ 36 YOR
Percent Frequency of N-min max



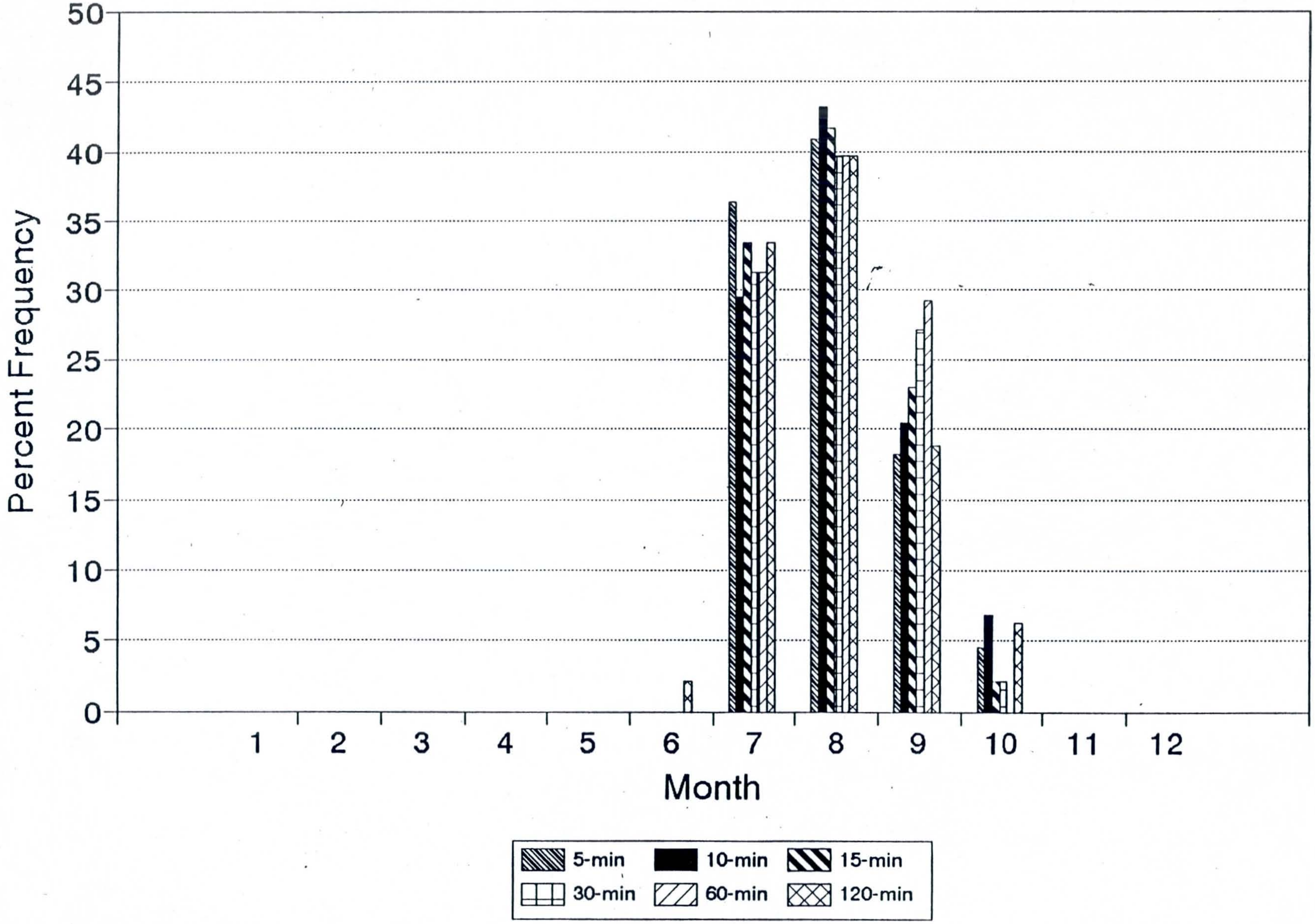
ATTACHMENT 10b

02-6481 Phoenix, AZ 84 YOR
Percent Frequency of N-min max



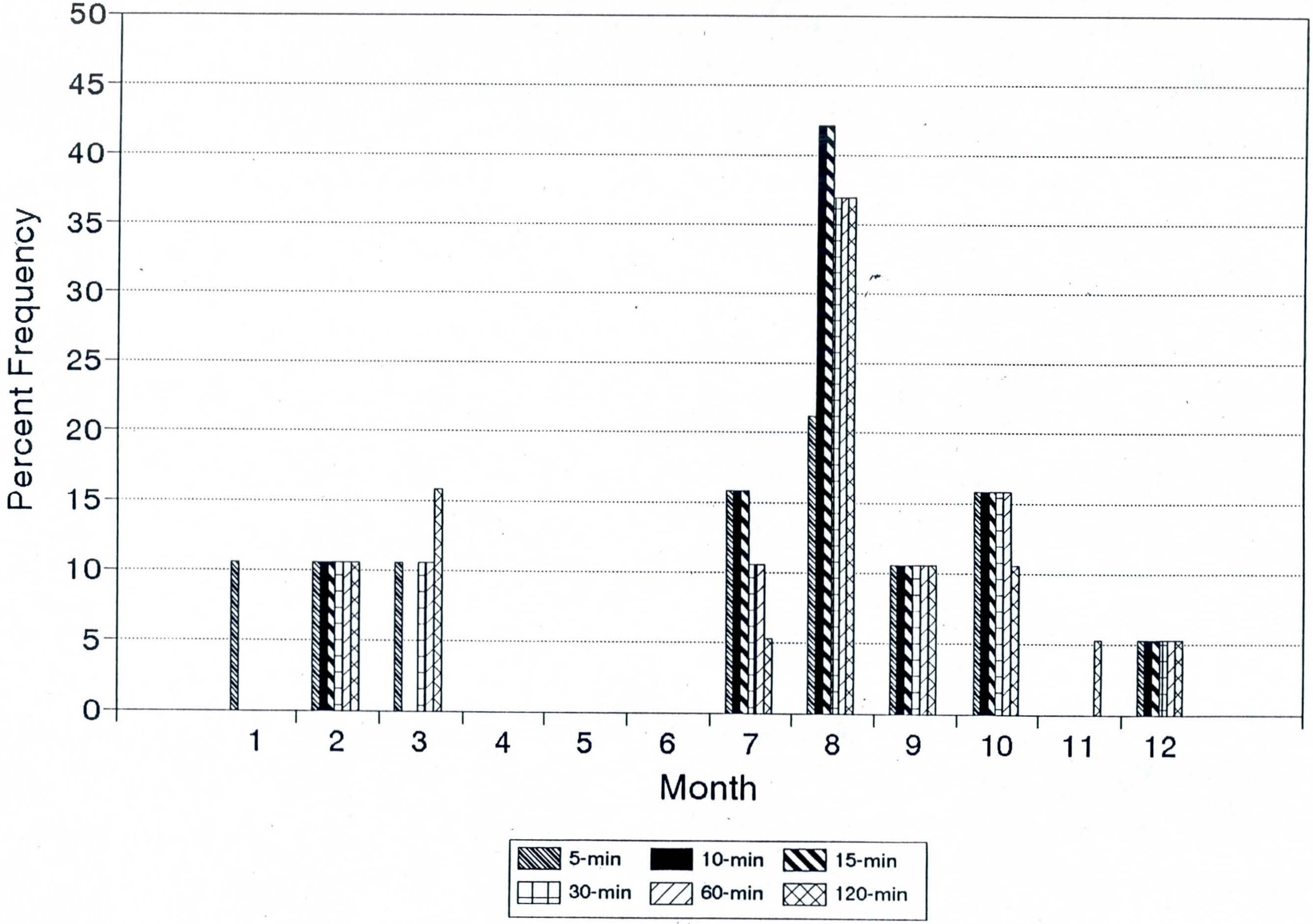
ATTACHMENT 10c

02-8820 Tucson, AZ 48 YOR
Percent Frequency of N-min max



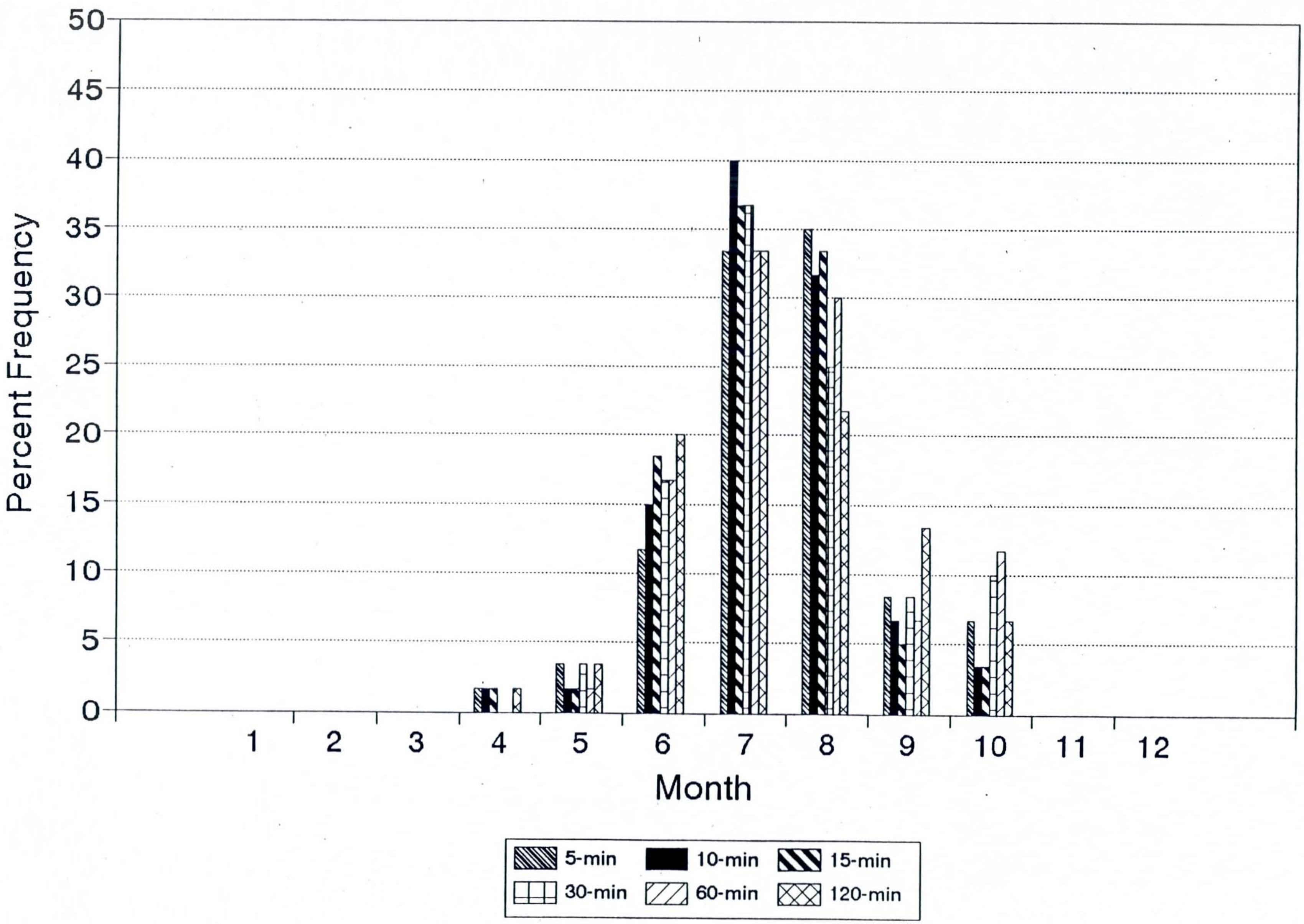
ATTACHMENT 10d

02-9660 Yuma, AZ 19 YOR
Percent Frequency of N-min max

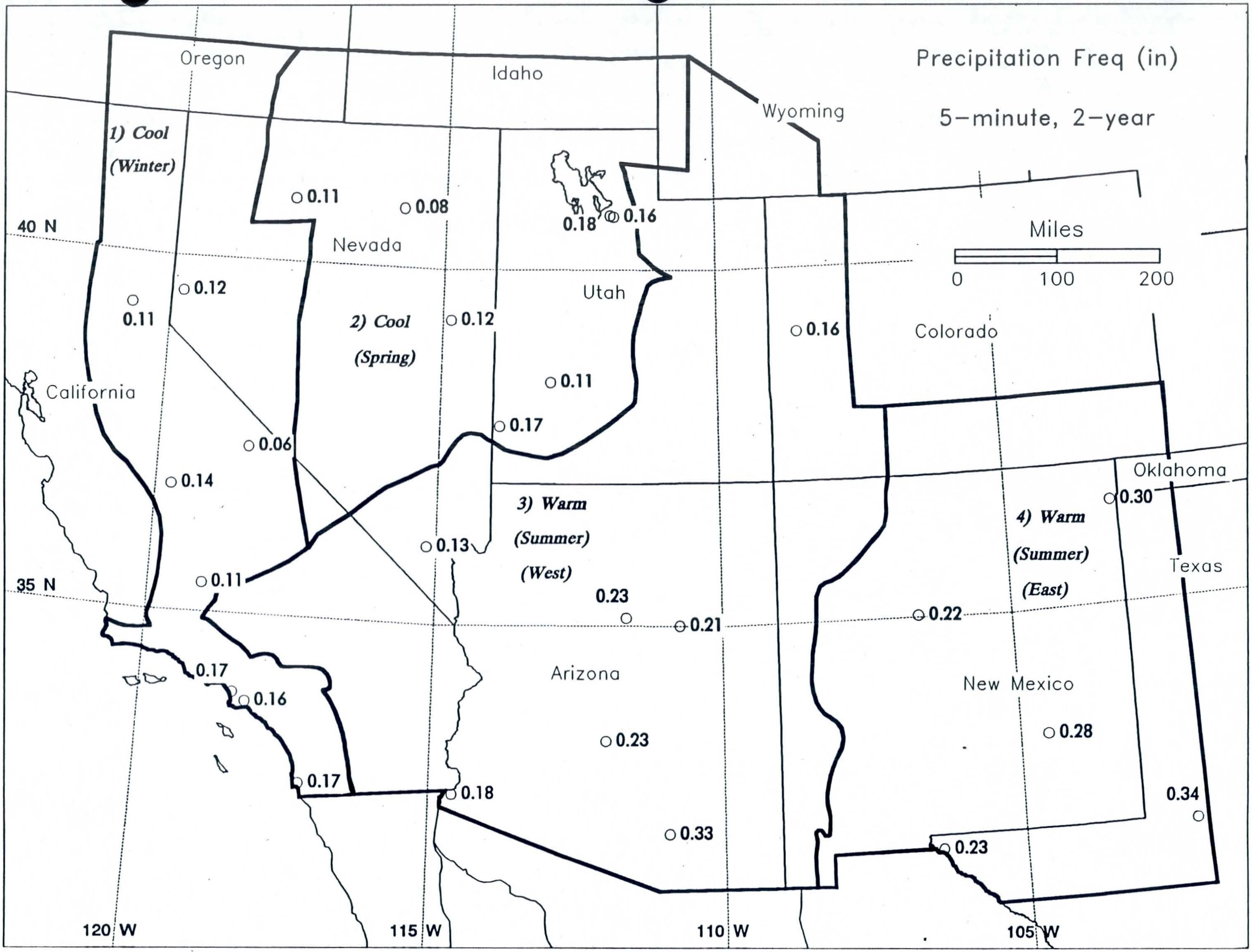


ATTACHMENT 10e

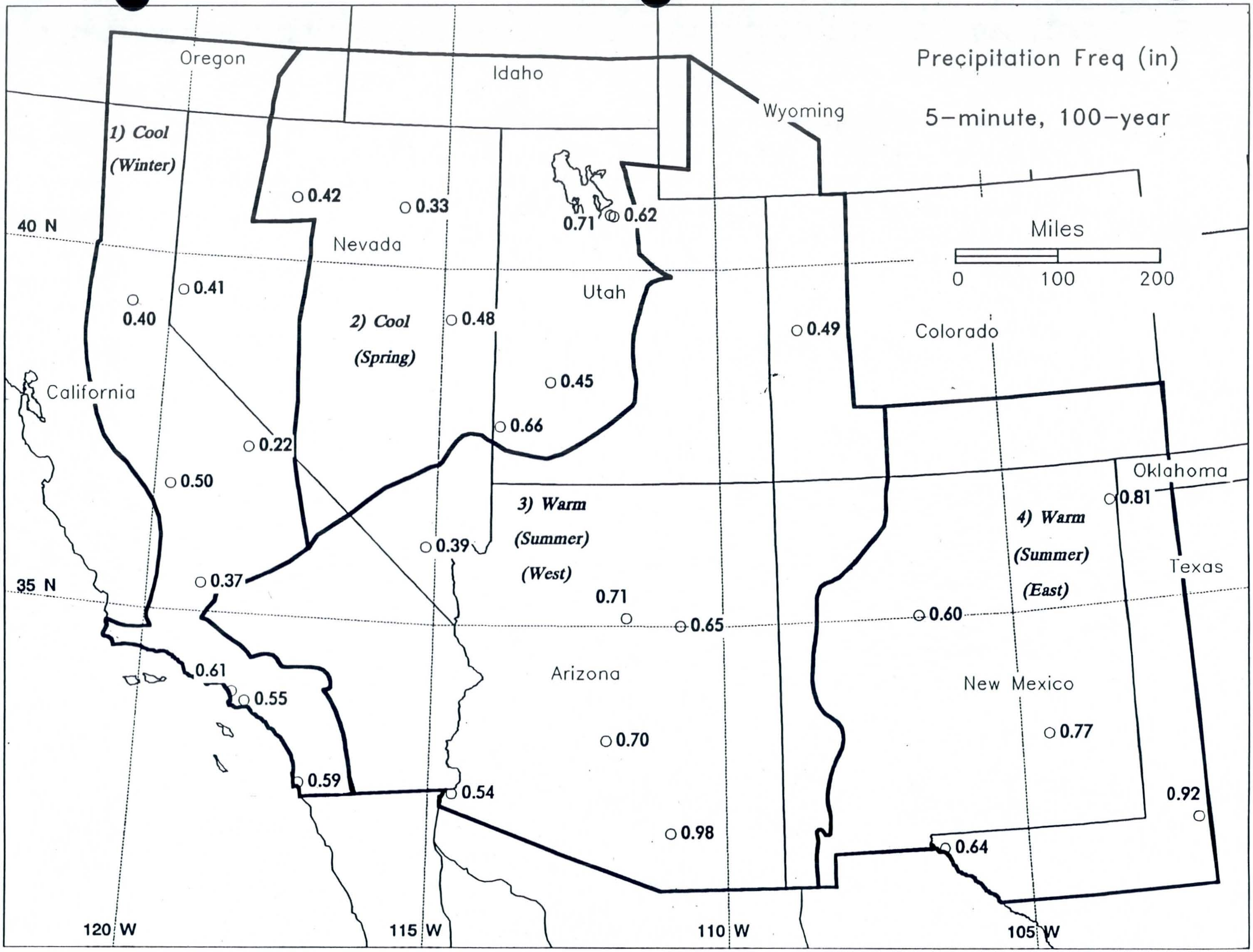
29-0234 Albuquerque NV 60 YOR
Percent Frequency of N-min max



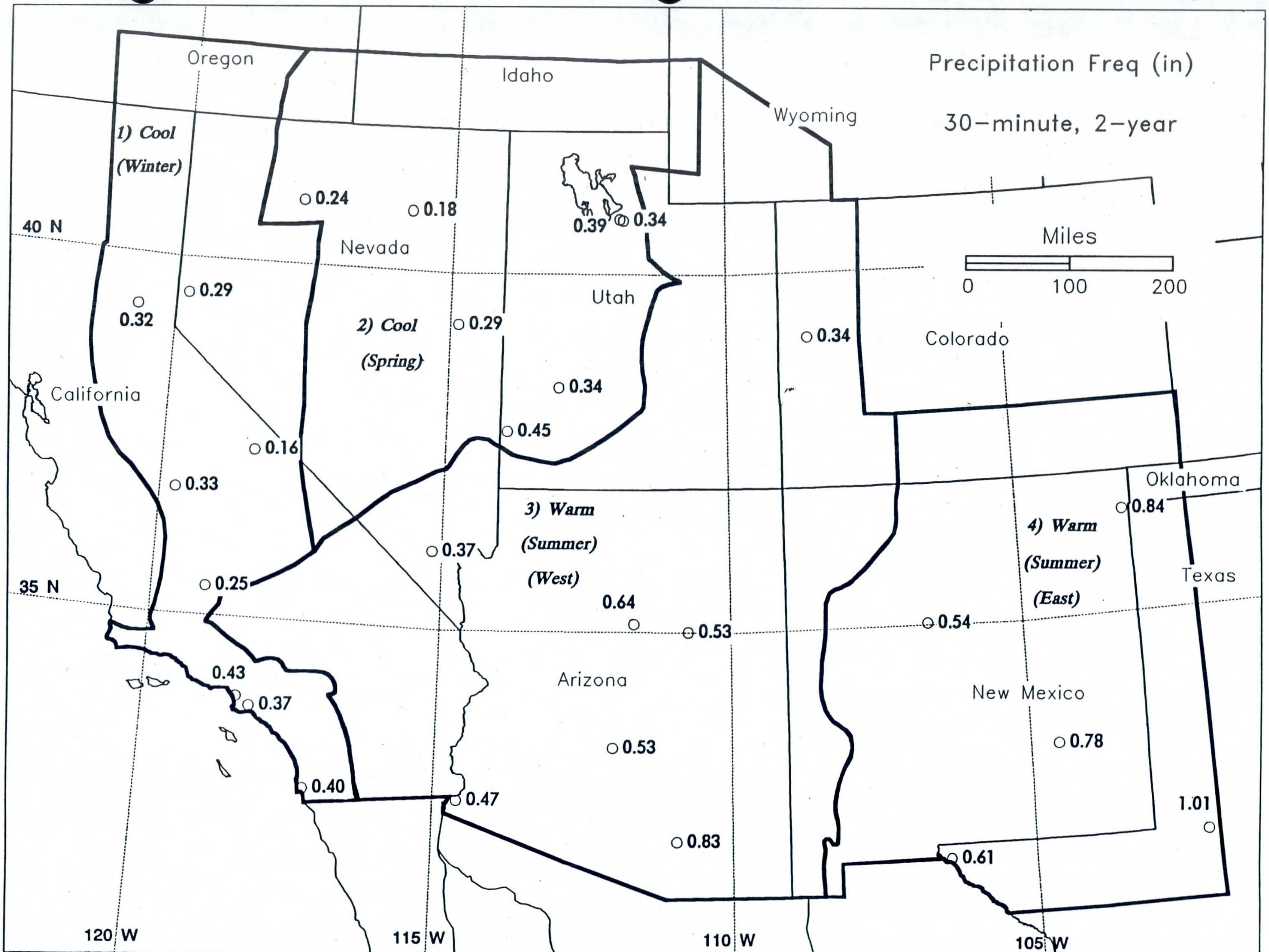
ATTACHMENT 10f



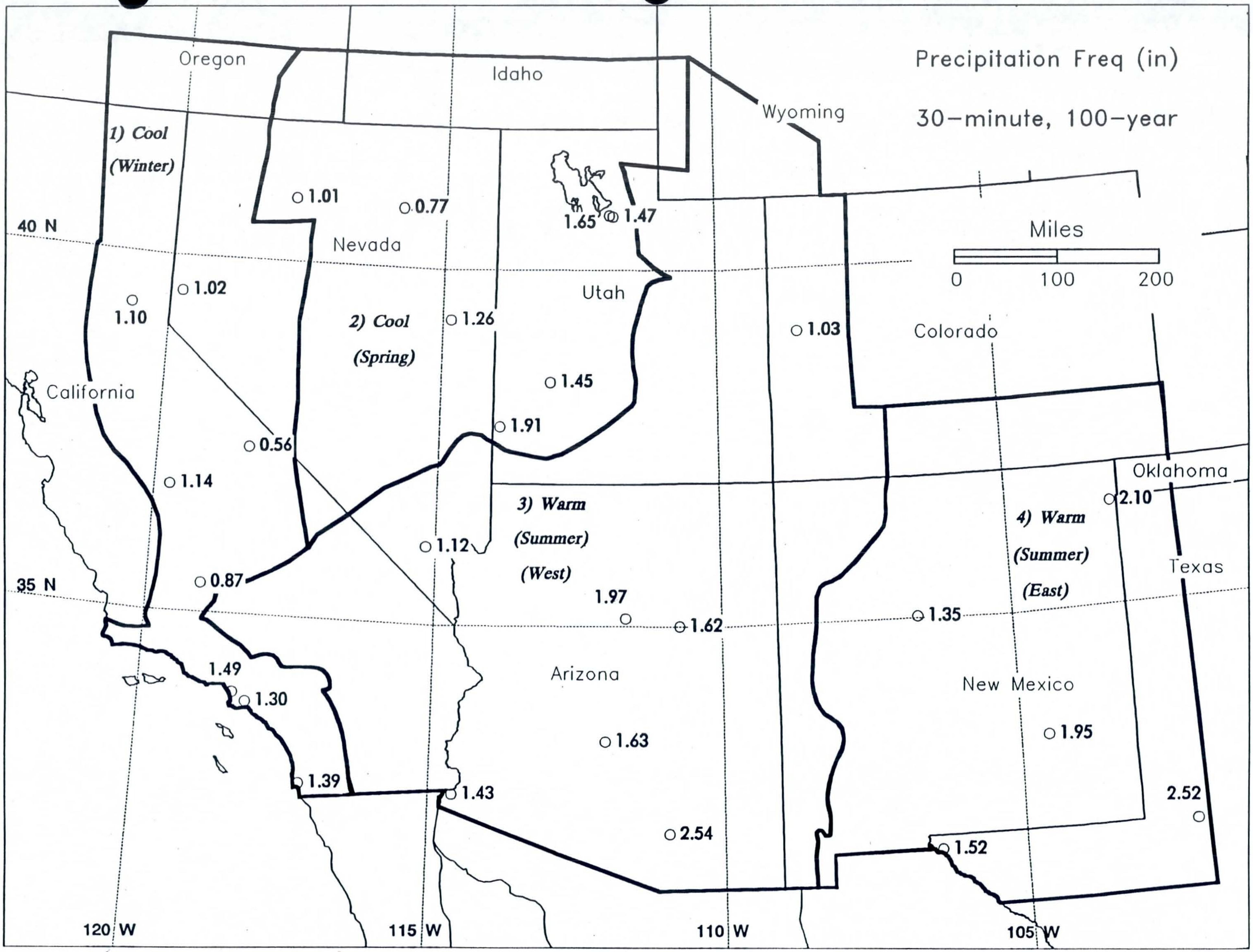
ATTACHMENT 11a



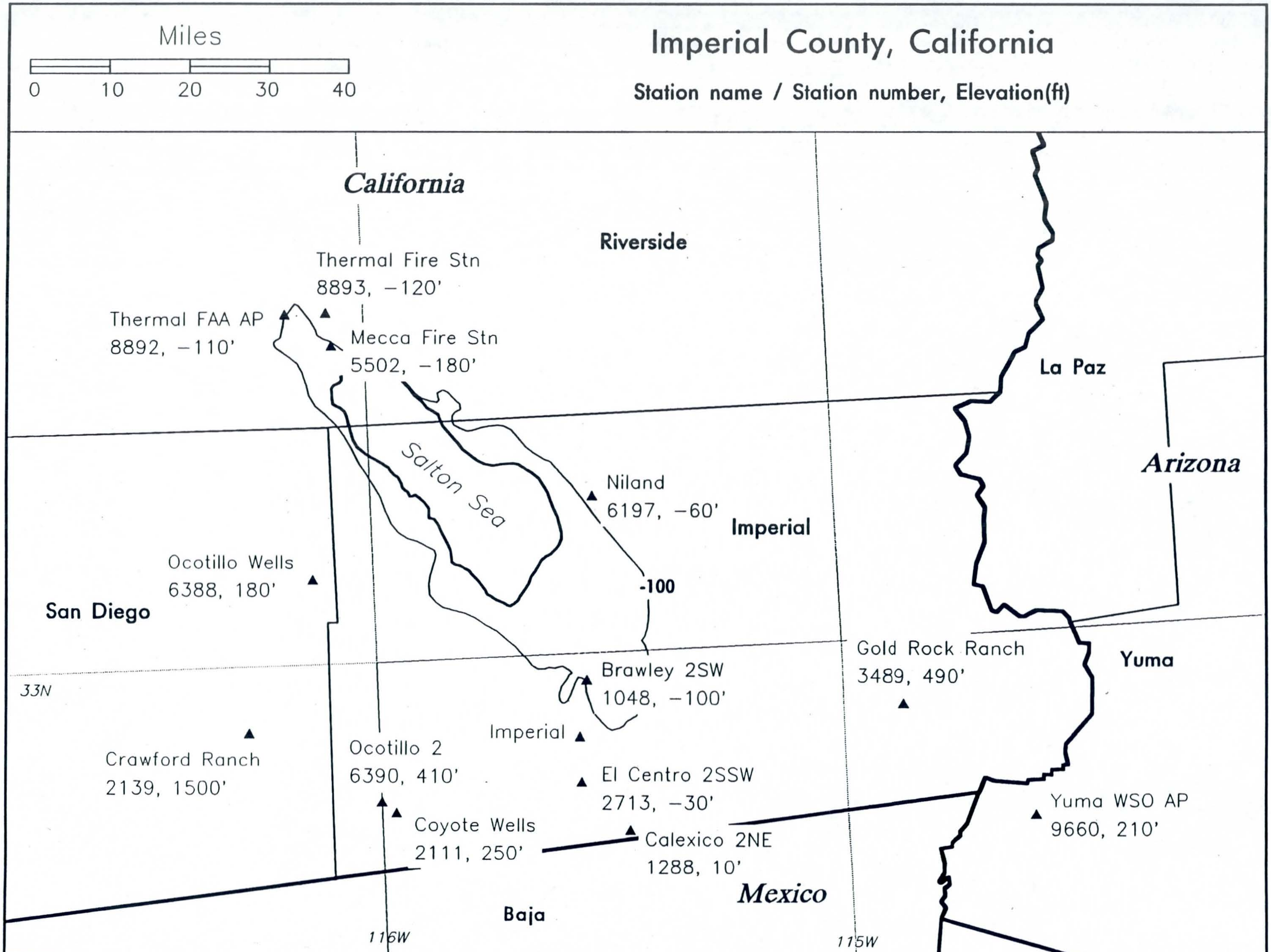
ATTACHMENT 11b



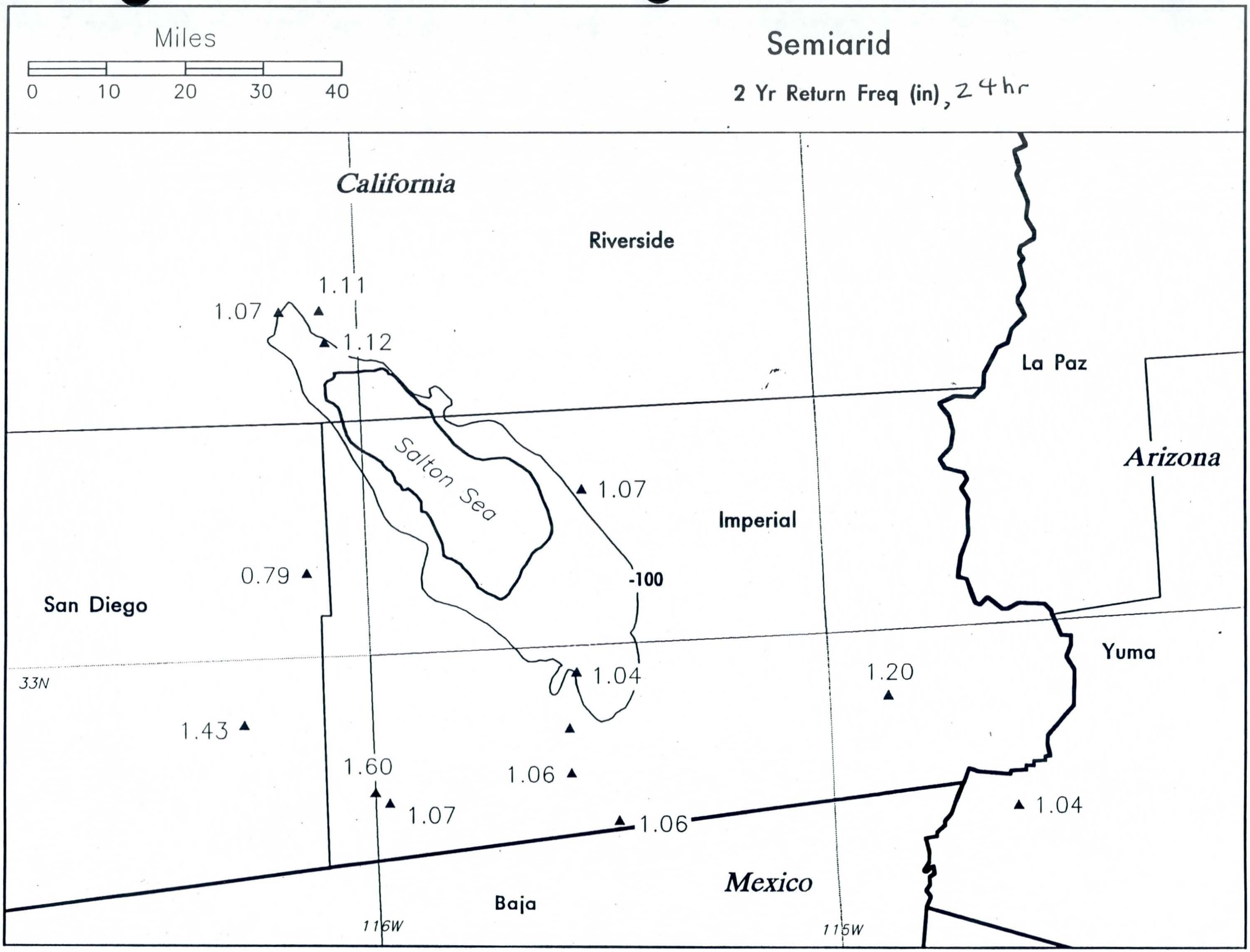
ATTACHMENT 11c



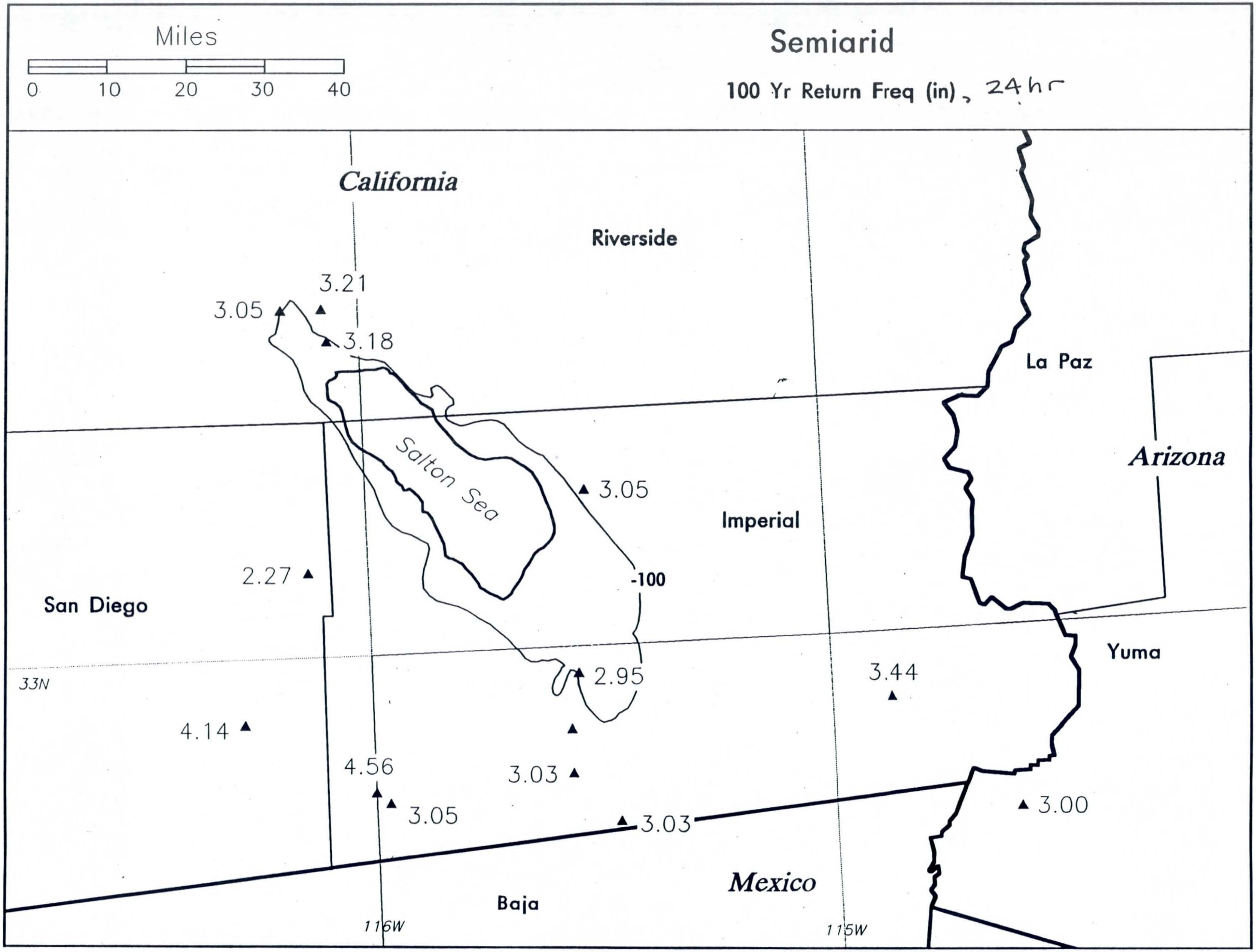
ATTACHMENT 11d



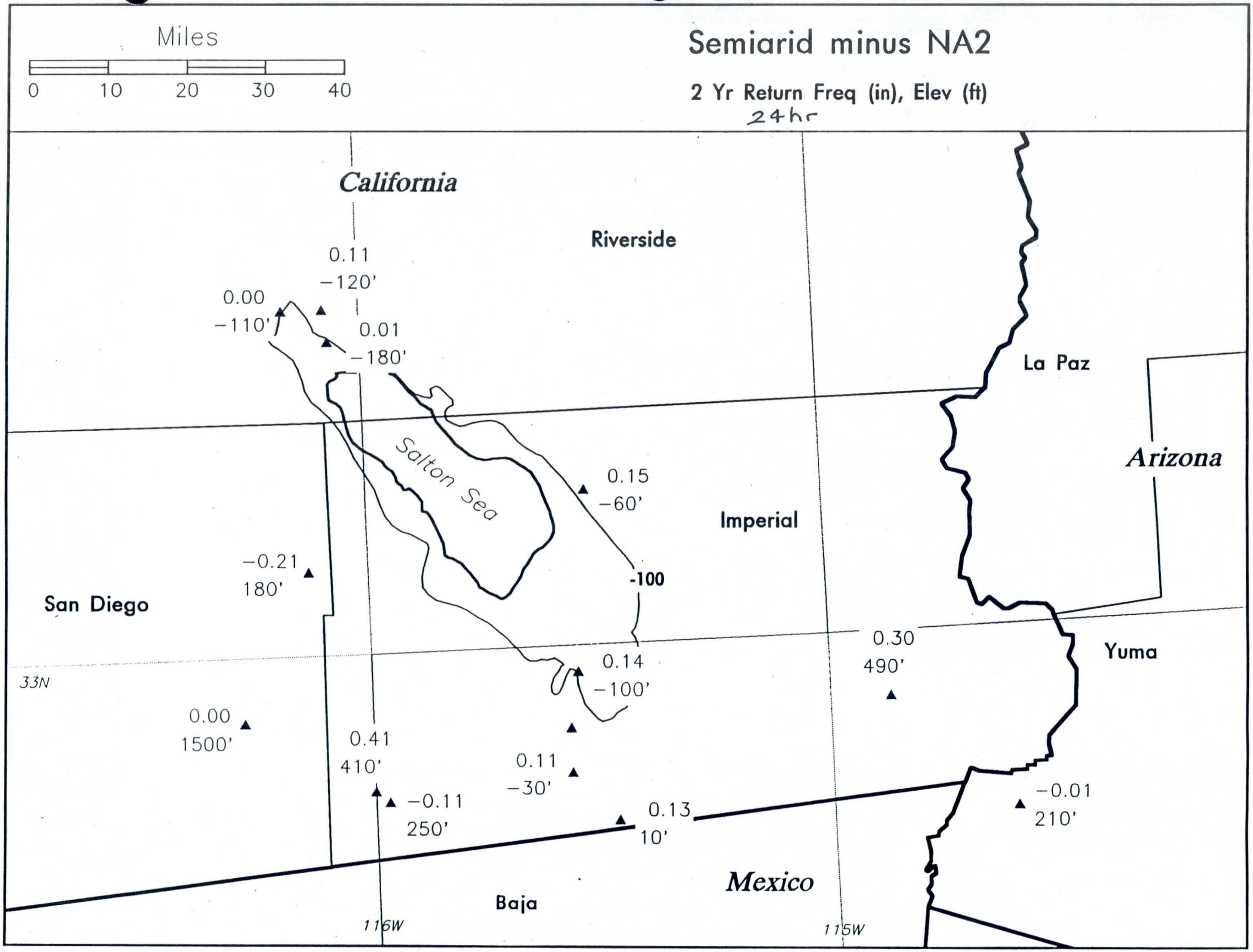
ATTACHMENT 12



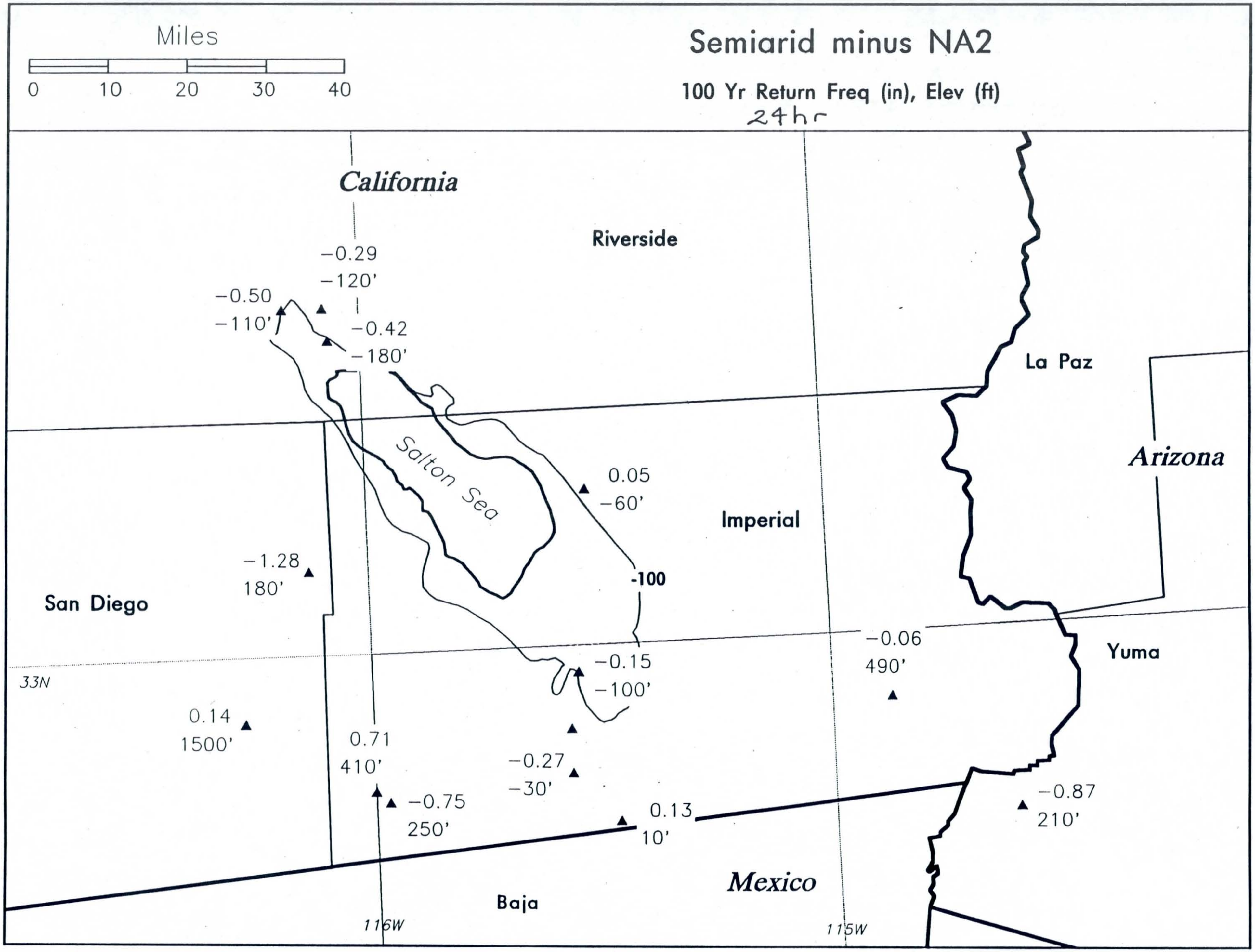
ATTACHMENT 13a



ATTACHMENT 13b

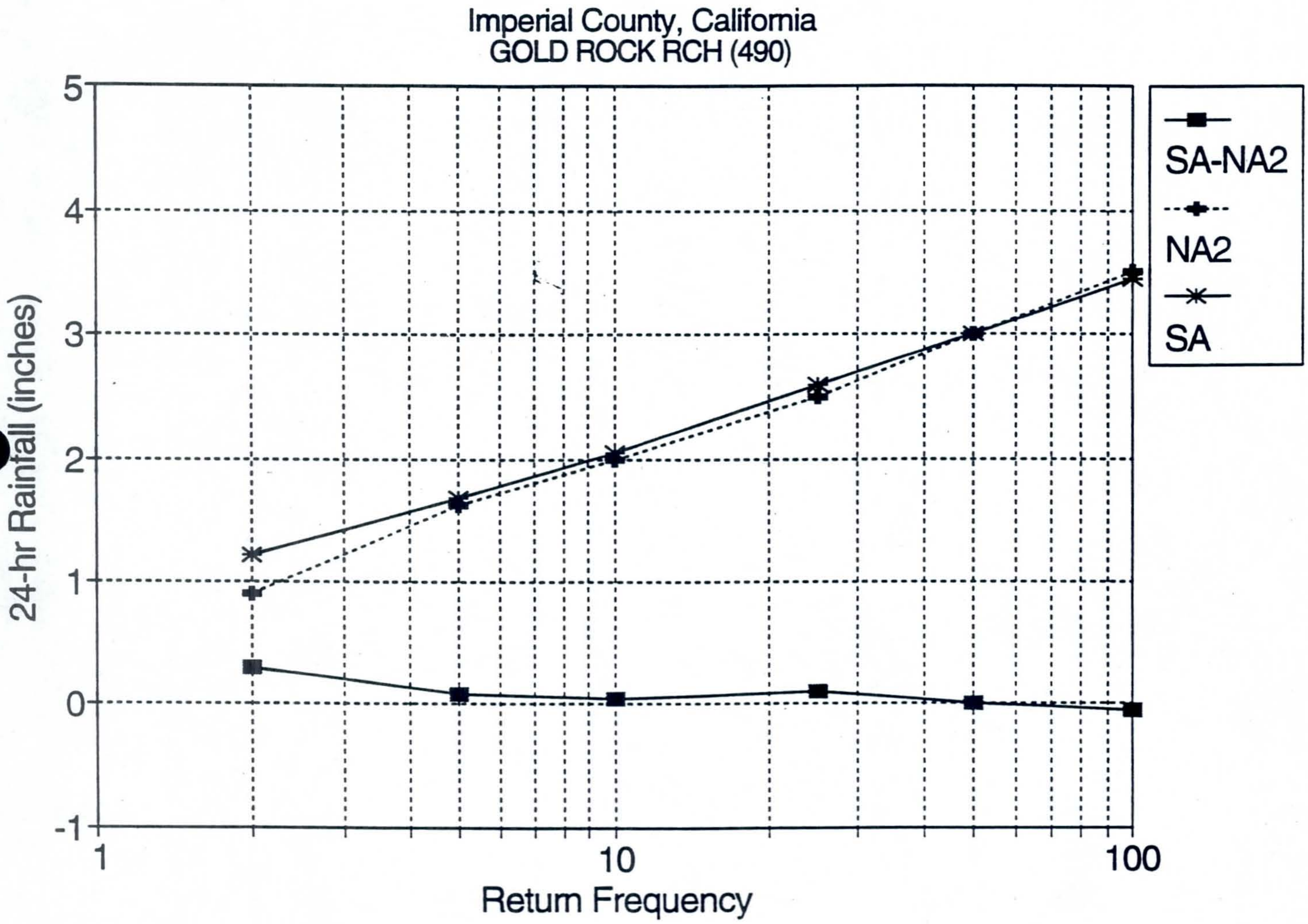


ATTACHMENT 14a

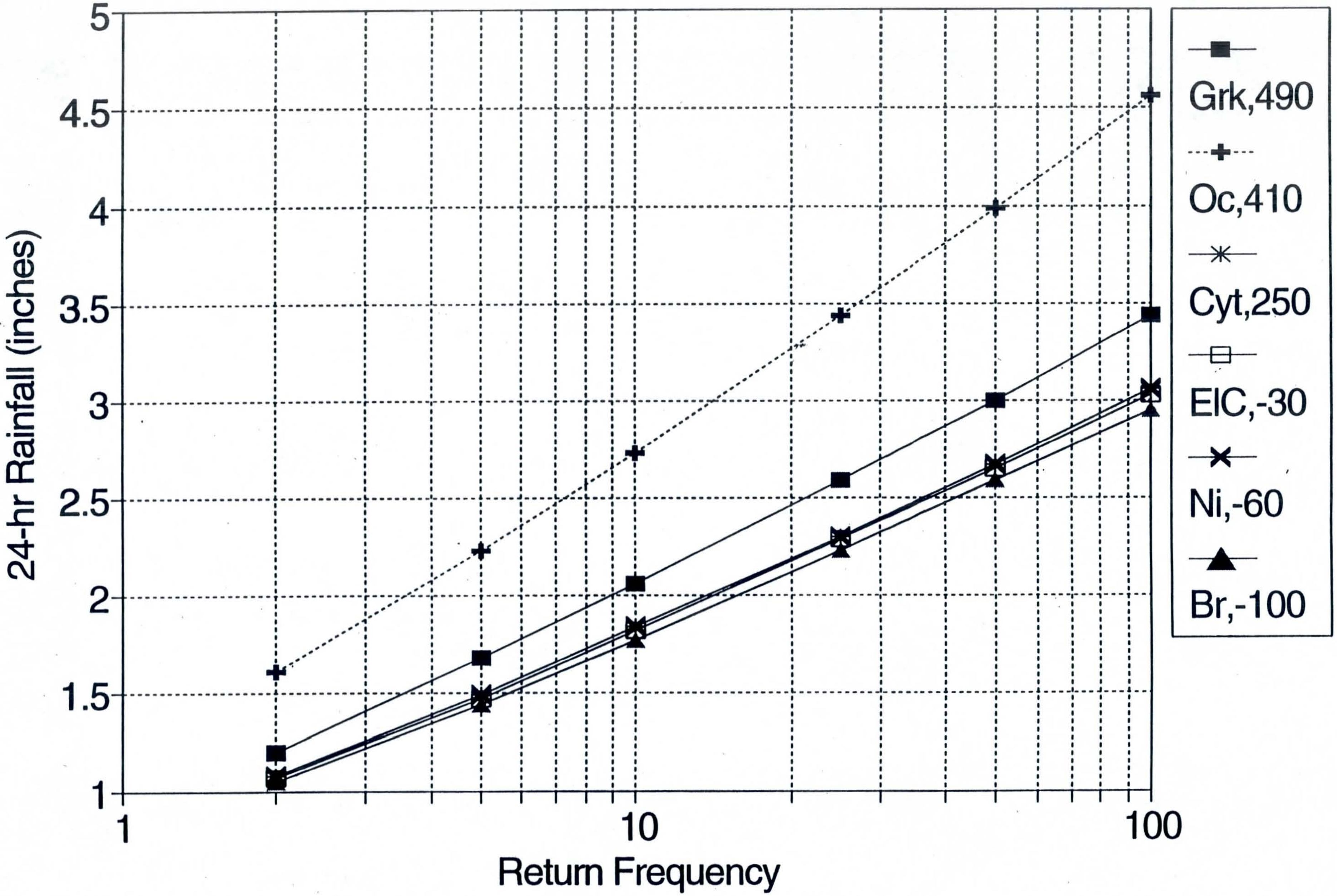


ATTACHMENT 14b

ATTACHMENT 15



Imperial County, California
SA Frequencies for Various Elevations



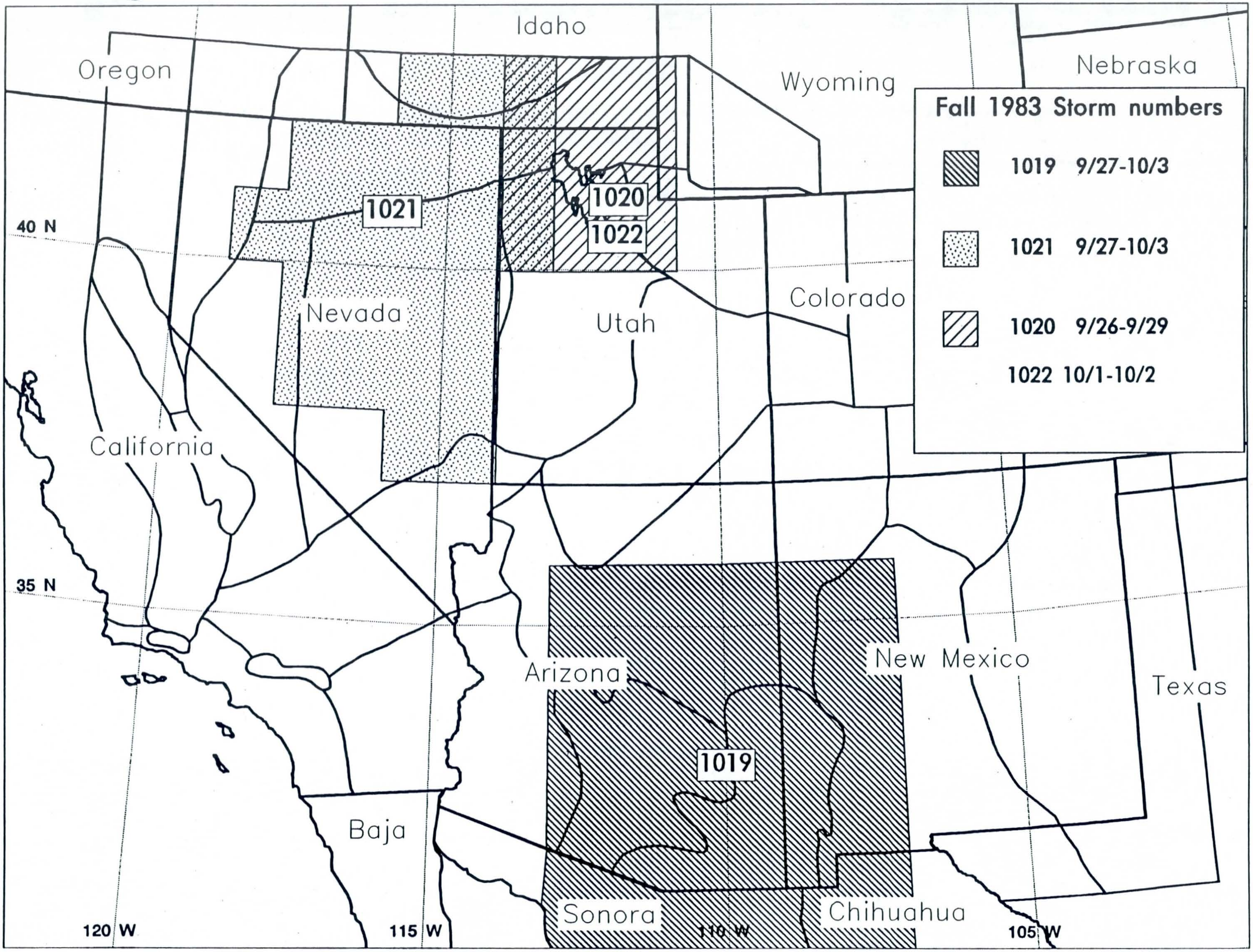
ATTACHMENT 16

Semiarid General Storms

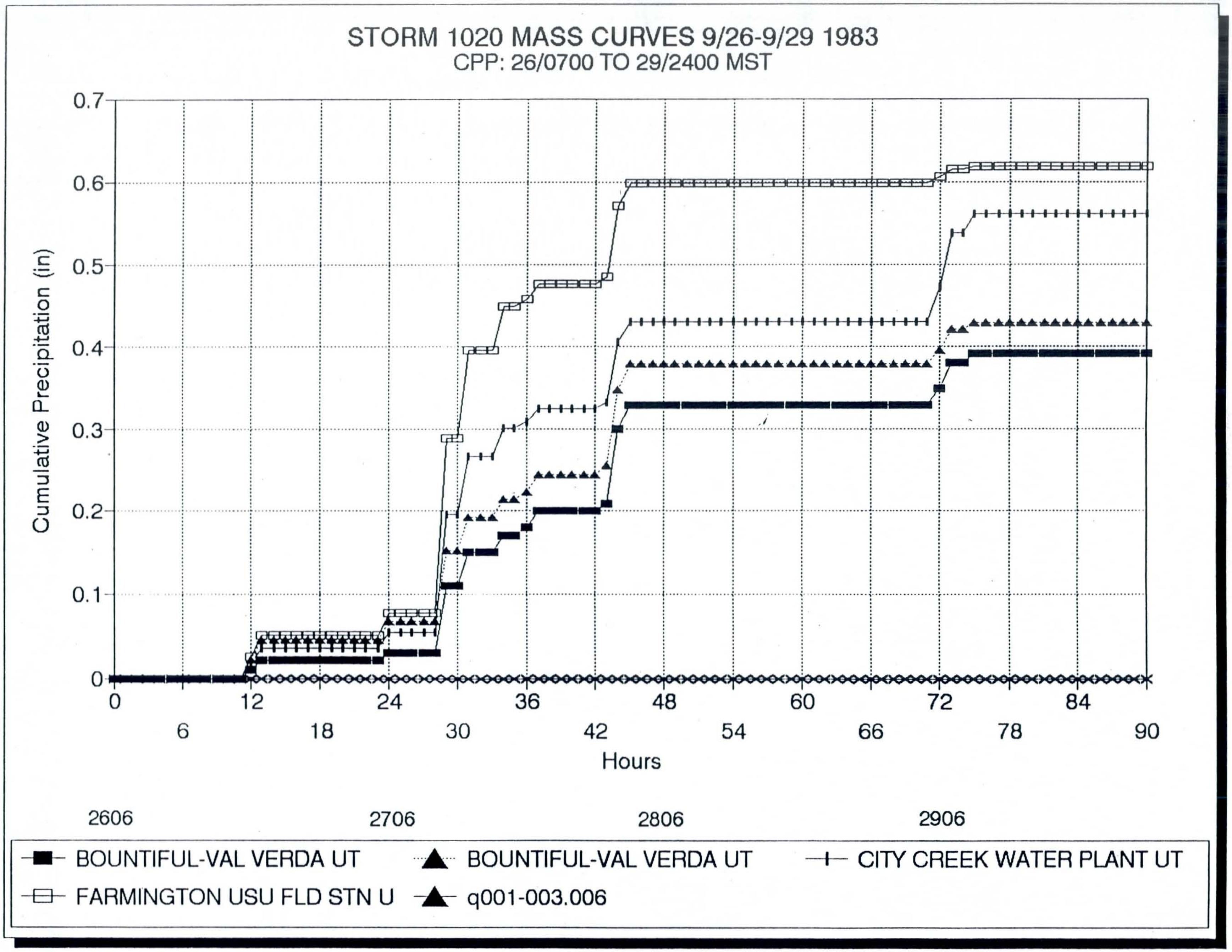
Storm #	Dates	Location
1019	9/27-10/3/83	AZ,NM,MX
1020	9/26-9/29/83	UT,ID
1021	9/27-10/3/83	NV,UT,ID
1022	10/1-10/2/83	UT,ID
1023	8/27-8/30/51	AZ,NM,UT,TX
1024	3/22-3/23/54	AZ,NM,UT,TX
1025	10/6-10/7/54	AZ,NM,UT,TX,CO
1026	5/18-5/19/55	NM,CO
1027	10/29-10/30/59	AZ,NM,NV,CA
1028	8/5-8/8/60	NM,TX
1029	9/4-9/6/70	AZ,NM,CO
1030	10/19/72	AZ,NM,TX
1031	9/12/75	NM,TX

Semiarid Winter Storms

Storm #	Dates	Location
1032	12/23/48	AZ,NM,CO
1033	12/30-12/31/51	AZ,NV,UT
1034	12/25/59	AZ,NV,UT
1035	12/10/65	AZ,NM,NV
1036	12/6/66	AZ,NV,UT,CO
1037	12/15-12/16/67	AZ,NV,UT,CA
1038	12/19-12/20/67	AZ,NM,UT
1039	12/17-12/20/78	AZ,NM,NV,UT
1040	12/4-12/5/92	AZ,NM,NV,CA,MX
1041	12/28-12/29/92	AZ,NV,CA,MX

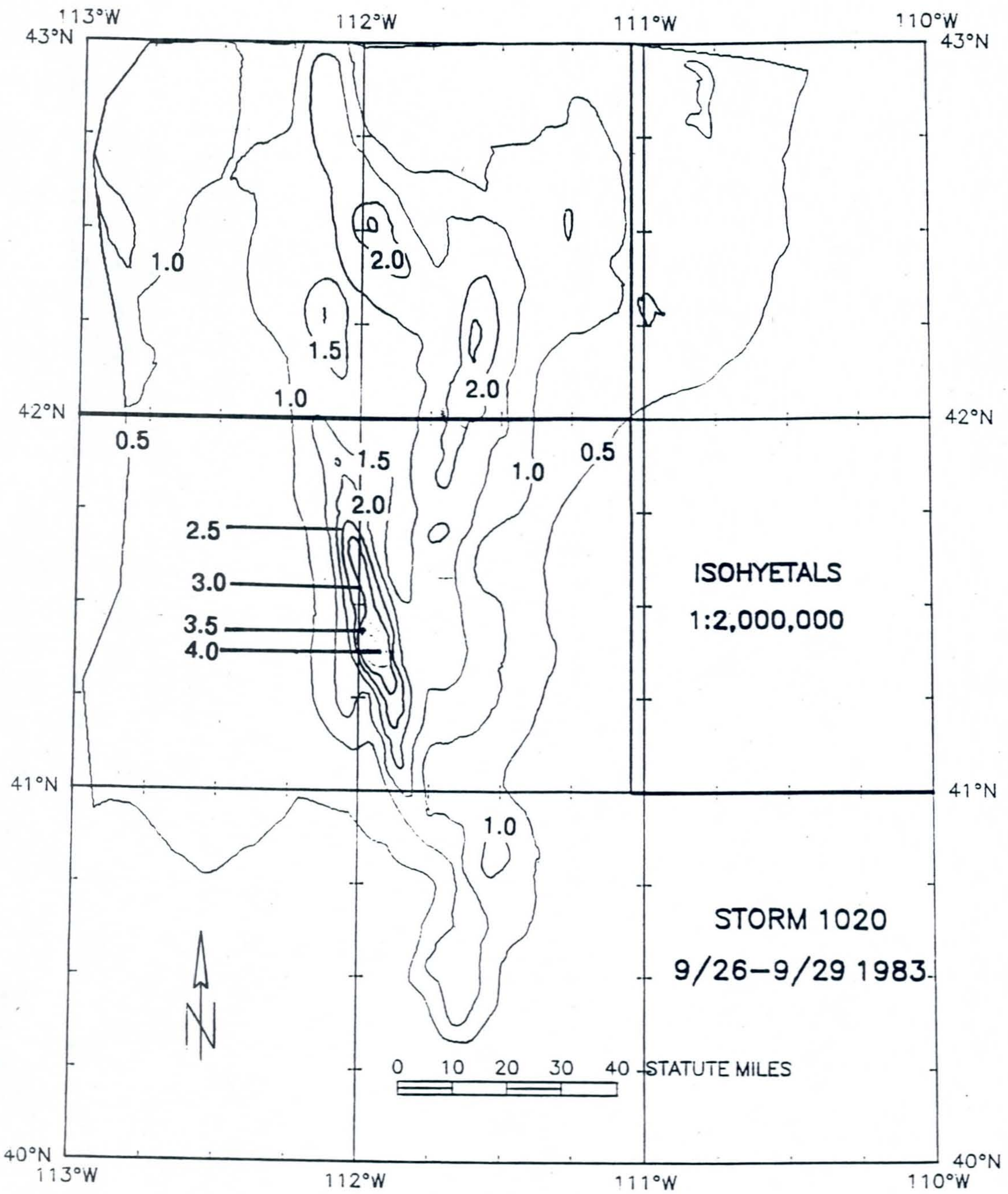


ATTACHMENT 18

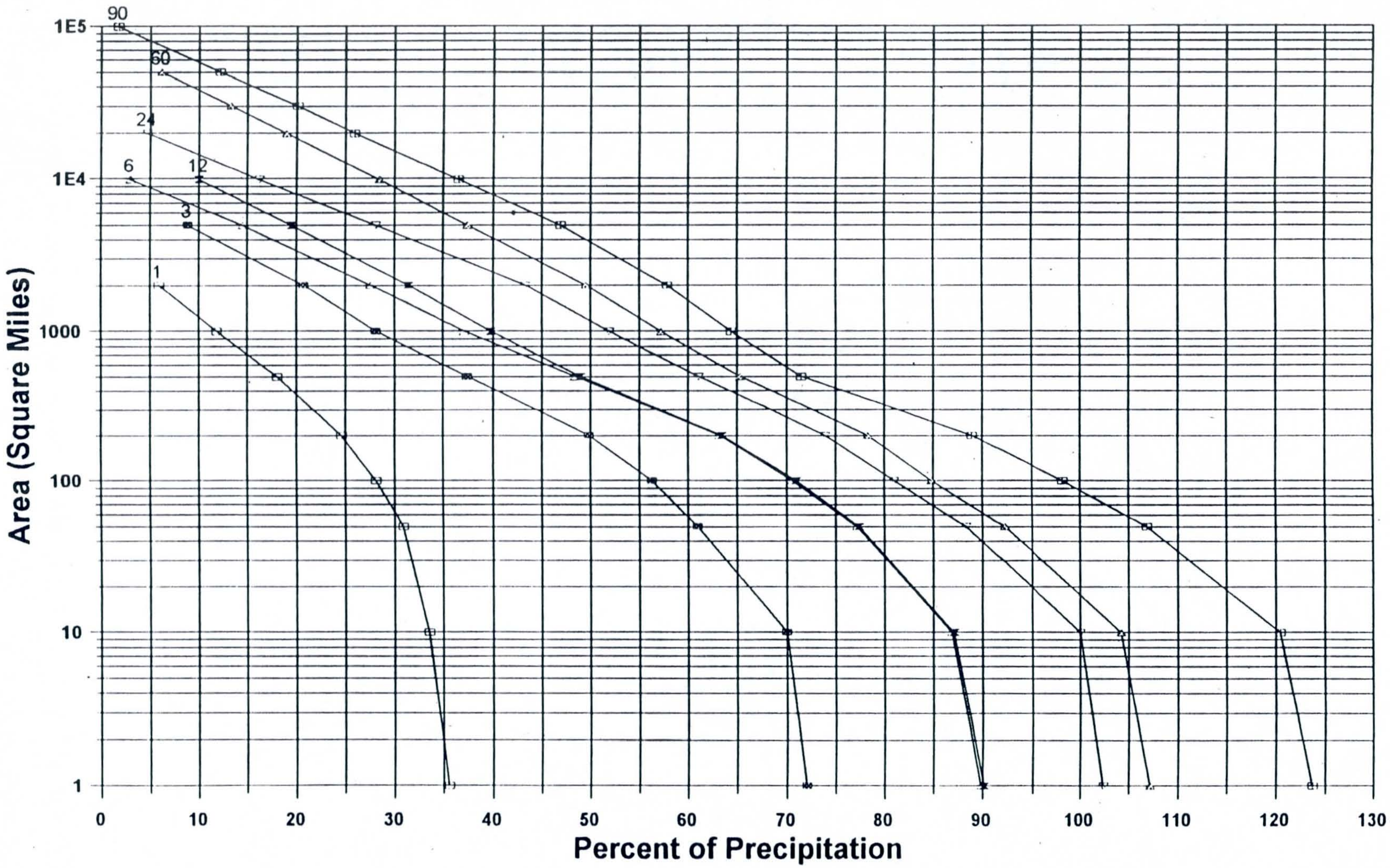


ATTACHMENT 19

ATTACHMENT 20



Depth-Area-Duration, normalized to the 10-square mile, 24-hour value
Storm 1020, 9/26-9/29 1983



ATTACHMENT 21

Semiarid n-minute ratios by region

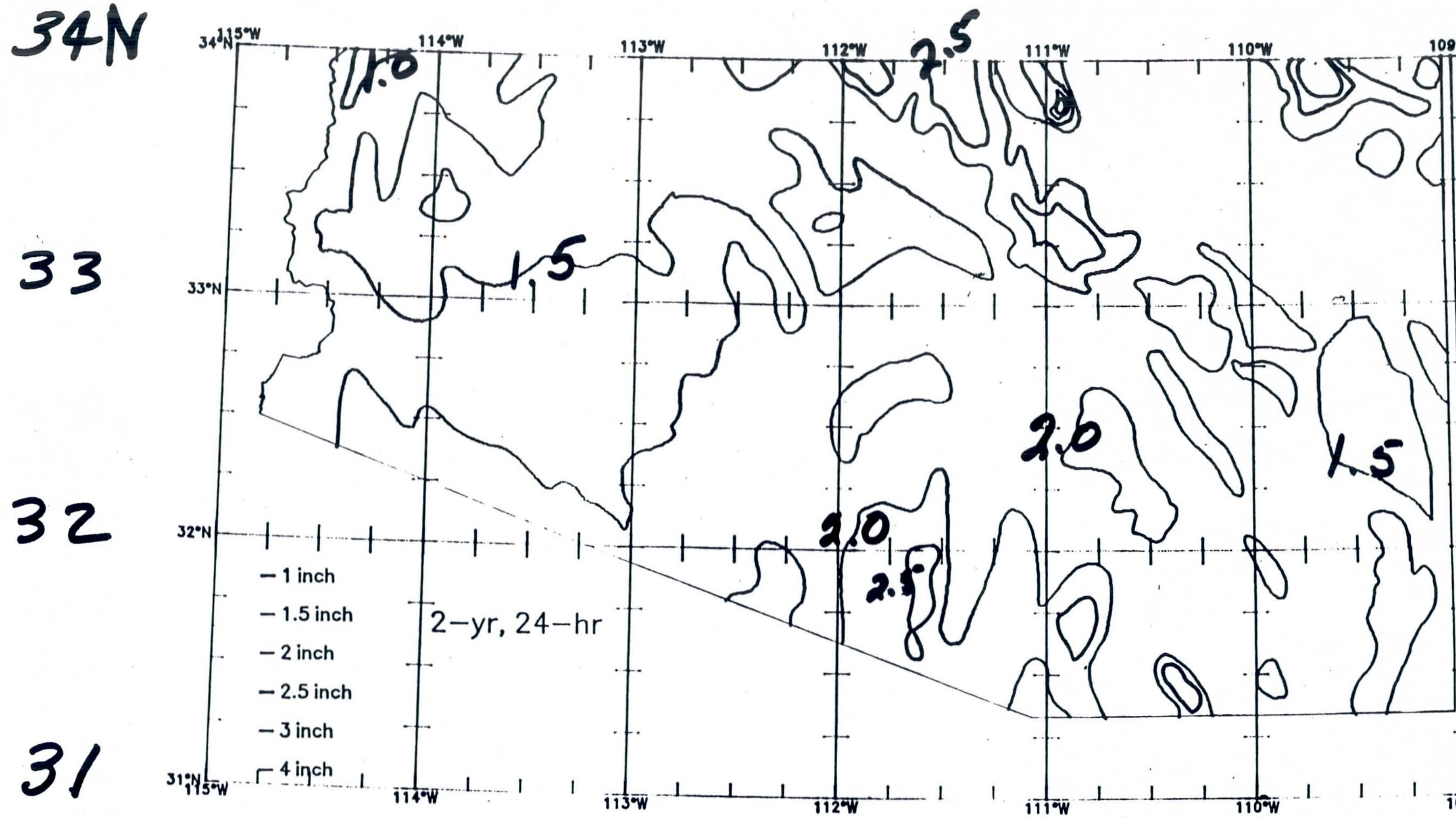
		5m	10m	15m	30m
1.	Cool (win)	0.34	0.49	0.61	0.81
2.	Cool (spr)	0.33	0.49	0.61	0.83
3.	Warm (sum) West	0.32	0.49	0.61	0.82
4.	Warm (sum) East	0.31	0.47	0.58	0.81
	Mean	0.33	0.49	0.60	0.82
	Std.Dev.	0.01	0.01	0.01	0.01
	Range	0.03	0.02	0.03	0.02
	Max.	0.34	0.49	0.61	0.83
	Min.	0.31	0.47	0.58	0.81

Comparison of Semiarid n-minute ratios to NOAA Atlas 2 ratios

	5-min	10-min	15-min	30-min
Semiarid Ratios	0.33	0.49	0.60	0.82
NOAA Atlas 2	0.29	0.45	0.57	0.79
Huff and Angel 1992	0.26	0.45	0.57	0.79
Difference	0.04 (.07)	0.04	0.03	0.03

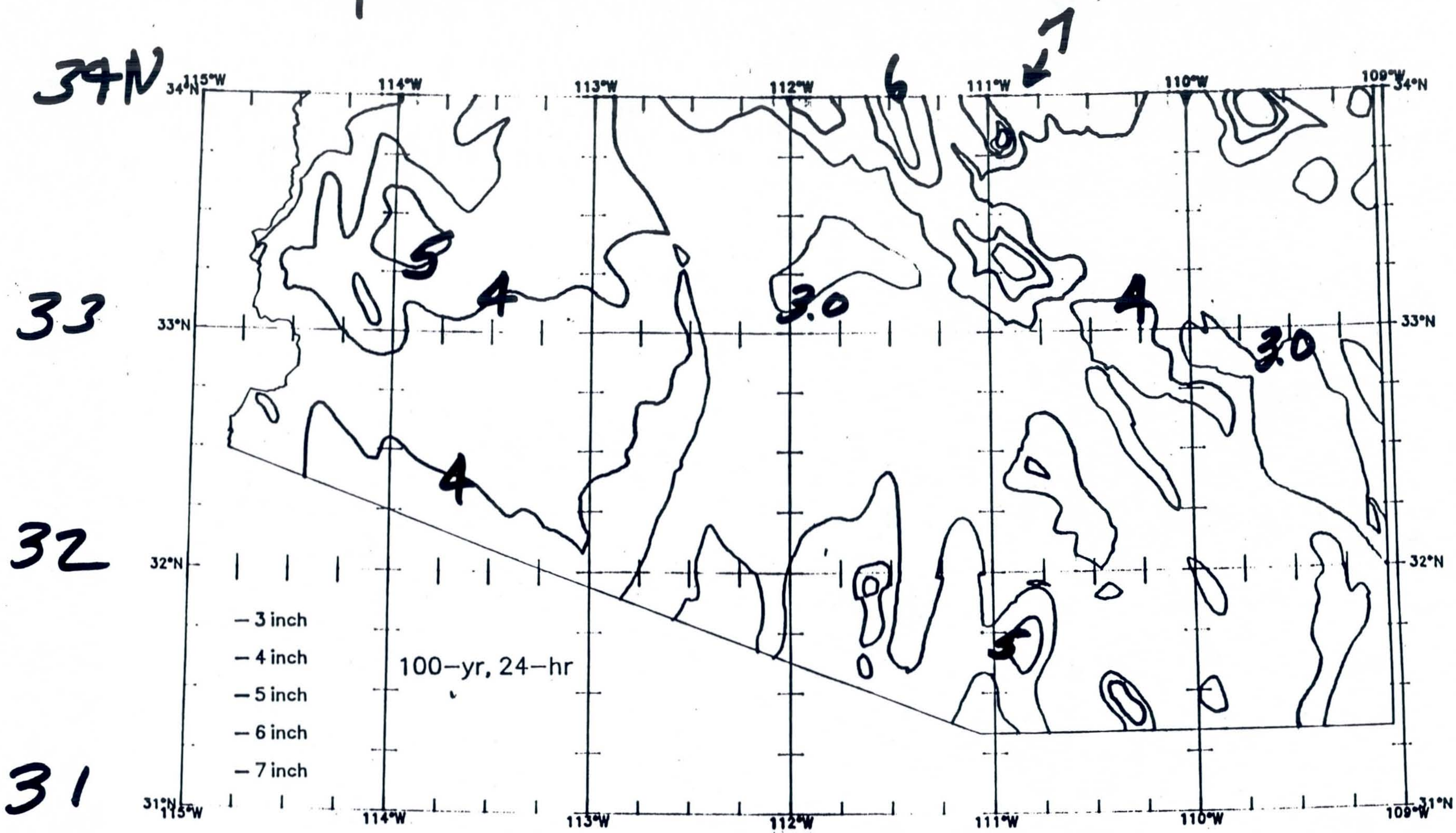
ATTACHMENT 23

2yr 24hr Precip Freq - Index Map



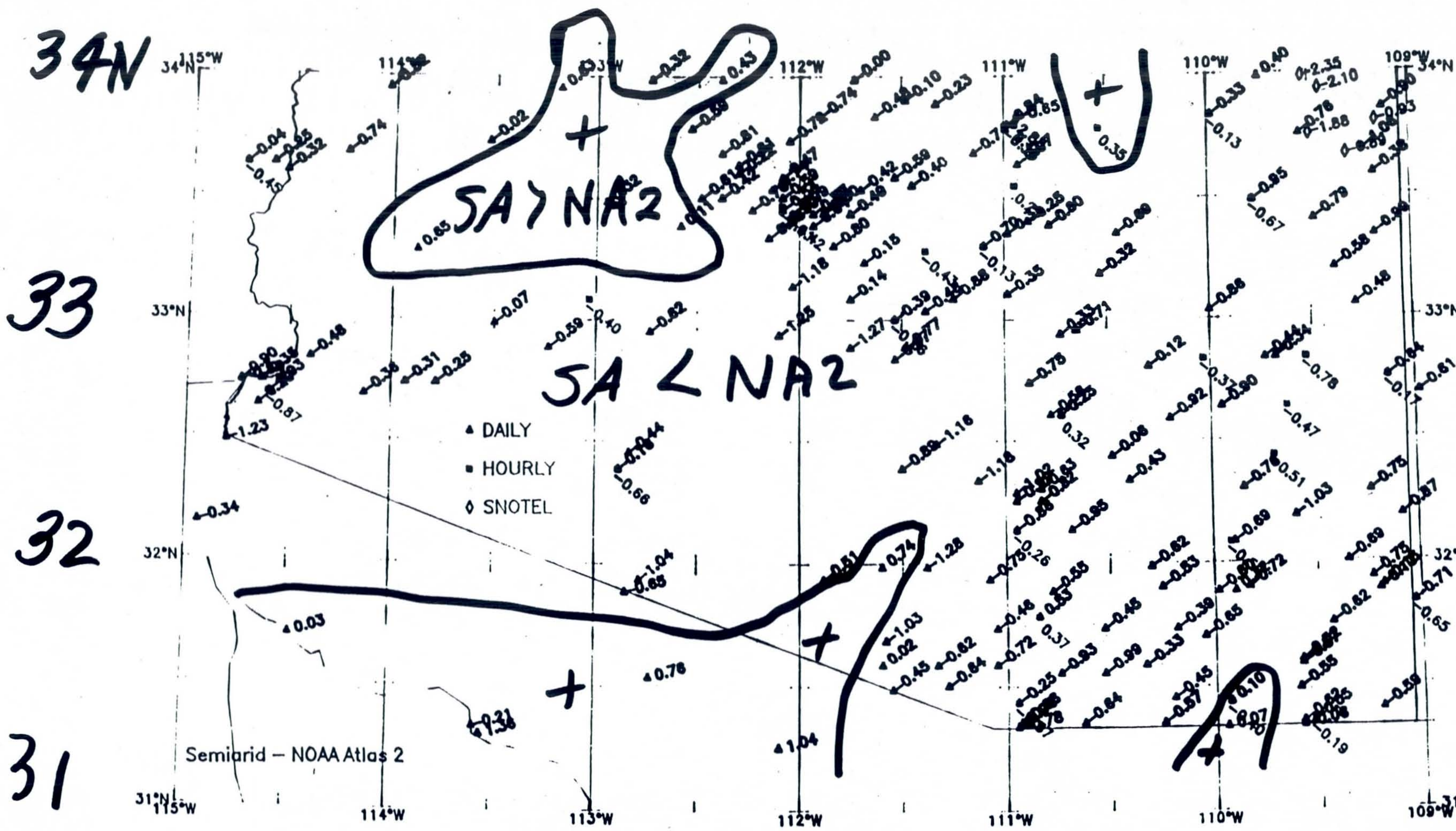
ATTACHMENT 24

100yr 24hr Precip Freq



ATTACHMENT 25

100yr 24hr SA minus NA2

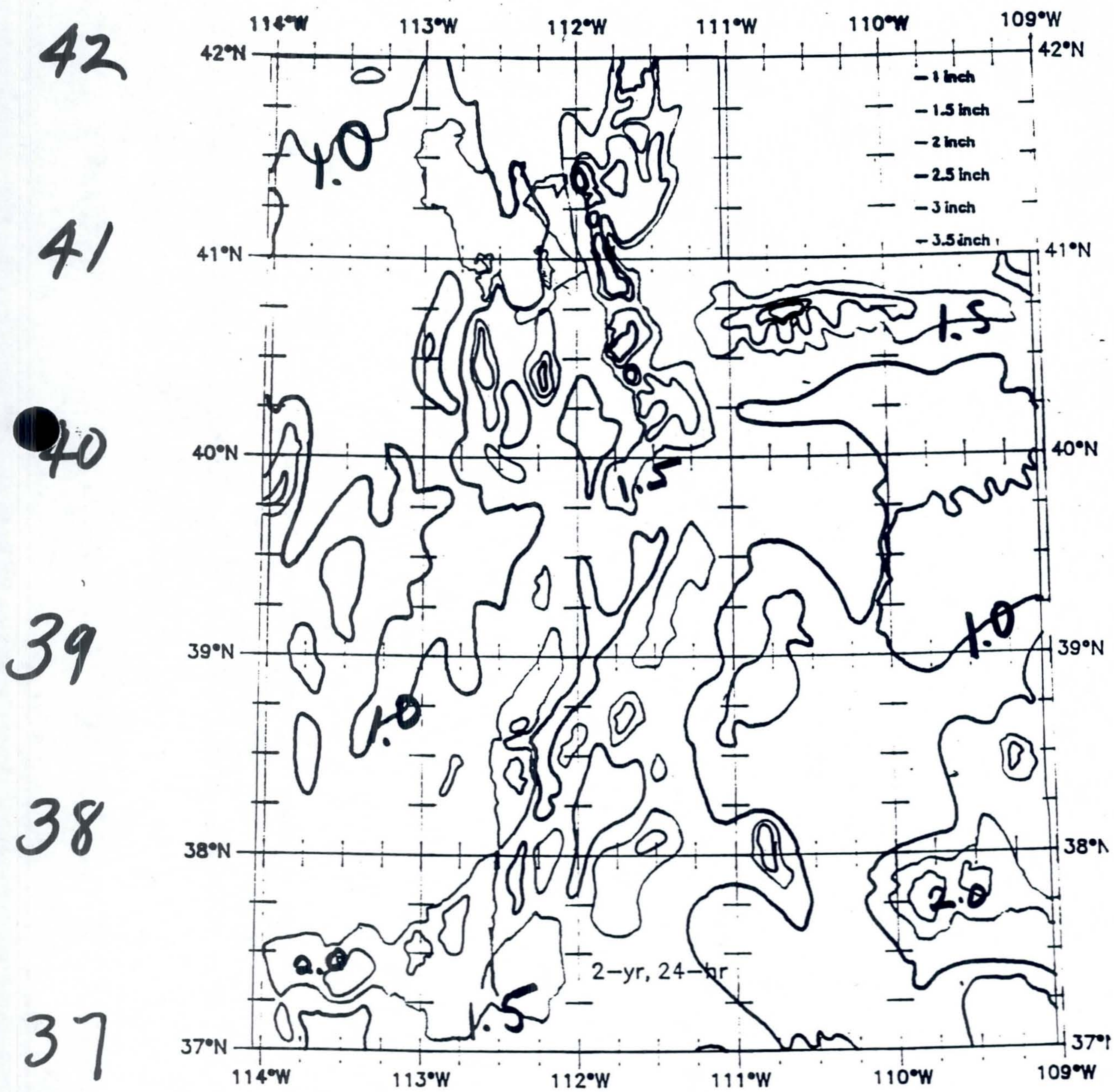


ATTACHMENT 26

ATTACHMENT 27

UTAH

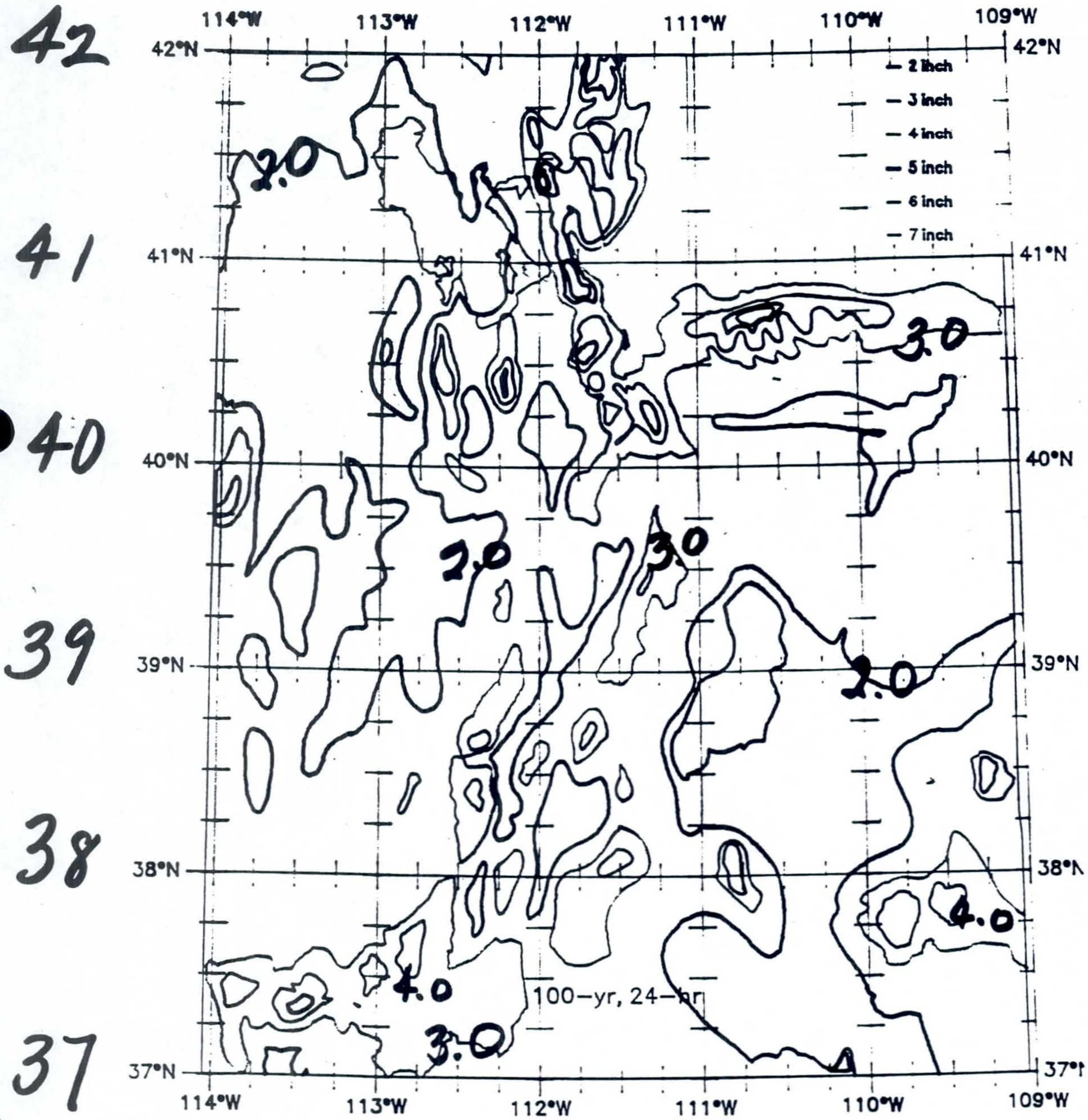
2yr 24hr Index Map



ATTACHMENT 28

UTAH

100yr 24hr



ATTACHMENT 29

Dataset and Analysis Summary

- L-moment statistics
- Partial duration series
- Generalized Pareto probability distribution
- 24 near-homogeneous regions (Daily, Hourly)
- 13 higher-elevation areas (SNOTEL)
- 3 Mexican states (Mexican Daily)
- 4 N-minute areas
- Daily data - Converted from 1-day to 24-hour, 2-day to 48-hour
- Hourly data - Converted from 1-hour to 60-minute
- N-minute data - Ratios to 60 minutes

Durations: 1 day (24 hours), 2 days (48 hours), 4, 7, 10, 20, 30, 45, and 60 days.

1, 2, 3, 6, 12, 24, and 48 hours;

5, 10, 15, 30, 60, 120, and 180 minutes.

Return frequencies: 2, 5, 10, 25, 50, 100, 200, 500, and 1000 years.

Map Scale: 1:1,000,000 for analysis (1:2,000,000 for publication).

Elevation Map: 1:1,000,000 computer-generated, with elevations from minus 100 feet to over 14,000 feet. Contours: -100, 1, 100, 200, 400, 600, 800, 1000, 1500, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 12000. (Although there are elevations above 14,000 ft, there are no 14,000-ft contours on the smoothed maps.)

LETTER OF TRANSMITTAL

TO:	
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY Ms. Carol H. Davis. 2801 Durango Road Phoenix, AZ 85009	ARIZONA DEPARTMENT OF TRANSPORTATION RESEARCH SECTION Arizona State University Engineering Research Center, Room 405 Tempe, AZ 85287-6306 Mail Drop 075R Phone: (602) 965-2368 Fax: (602) 965-9267
	CONTRACT NO. PROJ./TRACS NO.: HPR-3(018) RE: Quarterly Report

WE ARE SENDING: [X] ATTACHED [] UNDER SEPARATE COVER VIA

[] CONTRACT MODIFICATION [] PLANS [] VIDEO TAPE(S)
[] COPY OF LETTER(S) [] PHOTOS [] OTHER
[] LITERATURE [X] REPORT(S)
[] MEETING MINUTES [] SAMPLE(S)

COPIES	DATE	NO.	DESCRIPTION
1	February 24, 1992		First Quarterly Progress Report for Semi-Arid Precipitation Frequency Study

THESE ARE BEING SENT:

[X] FOR YOUR USE [] FOR YOUR INFORMATION
[] FOR YOUR REVIEW []
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[] FOR YOUR APPROVAL
[] FOR YOUR COMMENTS
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FLOOD CONTROL DISTRICT
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FEB 28 1992
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REMARKS

NOTES

COPY TO:
Project file
Project Monitor file

SIGNATURE
Joe Warren
TITLE Senior Research Engineer
DATE: February 24, 1992

FIRST QUARTERLY PROGRESS REPORT

for

SEMI-ARID PRECIPITATION FREQUENCY STUDY

by

John L. Vogel and Edwin H. Chin
Office of Hydrology
National Weather Service

Silver Spring, Maryland
February 1992

FIRST QUARTERLY PROGRESS REPORT
for
SEMI-ARID PRECIPITATION FREQUENCY STUDY

October 1 to December 31, 1991

Overview

During the 3-month period from October 1 through December 31, 1991, the first steps toward the processing of the data and the general organization of the Semi-Arid Precipitation Frequency study were undertaken. Some of the accomplishments during this period were: 1) software was developed to begin the data reduction of the hourly and daily data; 2) the initial processing of the daily and hourly data was begun; 3) an Independent Advisory Group was established; and 4) a meeting was held in Phoenix, Arizona, with representatives of the various Federal, state, and local groups involved with the project. More details of these accomplishments are discussed below.

Software Development

Initial analysis of the precipitation frequency values for Pennsylvania and West Virginia showed that the software for reducing the precipitation data from the individual stations had to treat accumulated data in a more organized way and to show how much and when data at a station were missing. For Pennsylvania and West Virginia, only annual maximum data were processed. One of the goals of the Semi-Arid Precipitation Frequency Project is to provide seasonal relations. So for the Semi-Arid study it was necessary to also obtain the maximum precipitation values for the various durations for each month. As a result, the development of new software for this project was begun. It is recognized that this will be a continuing process, for as the project progresses, new requirements will arise and additional software will be developed to meet these requirements.

The objectives of this initial software development was 1) to process data, 2) to provide a data base that could easily be verified for potential errors and 3) to ensure that the data within the data base were easily accessible. Software routines that had been previously developed to read the daily and hourly precipitation data from the National Climatic Data Center (NCDC) were reviewed and checked to ensure that the data was being retrieved correctly. The data formats for the first software development were the TD-3200 (daily data) and TD-3240 (hourly data) from NCDC. Initially, annual maximum data were obtained from the hourly data for durations of 1, 2, 3, 6, 12, and 24 hours; and monthly maximum data were acquired for 1-day durations. Examples of data files from these two different data sets are given in Tables 1 and 2.

The data shown in Table 1 is from Aguila (index number 02-0060) located in Maricopa County in west central Arizona at 2170 ft. Digital precipitation data from this daily station are available from June 1924 and continues through 1990. The data extracted for Table 1 covers the period from January 1941 through December 1943. The table emulates the manner in which the data are stored. Each line provides the station index, the year, month, and date of the maximum daily precipitation amount, the maximum daily precipitation amount (inches), the amount of any accumulated data (inches), the number of days with accumulated data, and the number of days with missing data.

During January 1941 the maximum daily amount was 0.69 inch recorded on the 24th. During this month there were no accumulated rainfalls, no days with accumulation, and data were recorded on all days. No precipitation fell in June of 1941, so a zero amount is recorded for this month.

The first month with any accumulated amount is November 1941, when there were two days of accumulated precipitation with a total of 0.62 inch. When this total is divided by two, the greatest daily total for November 1941 was 0.31 inch. This number represents the least possible maximum daily total for November. The logic here is quite simple, if 1.00 inch of rain falls on two days, there has to be at least a maximum of 0.50 inch of precipitation. This is not to say that 0.75 did not fall on one day and 0.25 on the second. However, from the record that is available there is no way of telling how much rain fell on individual days during this period. Rather, the least possible maximum daily total is 0.5 inch, or 1.0 divided by two. Also note that the accumulated amount is spread equally over the duration of the accumulation, so no single date can be designated as the date of occurrence, for convenience the last date of the month is listed. If one were to examine this data using the CD-ROM available from Earth Info, the accumulated amount does not show; rather it shows that the daily maximum amount was 0.62 inch, and this is wrong. During November 1941, no days with missing precipitation are indicated. The 0.62 inch was the only precipitation recorded for the month.

In January 1943 the greatest daily total was 0.64 inch on the 27th. However, during this month there were two days with an accumulated precipitation total of 1.19. When this value is divided by two, the least possible daily total would be 0.59 inch, so even though there are two days of accumulated precipitation, the daily maximum indicated for January 1943 will remain the 0.64 inch on the 27th.

Missing data are also shown in this file, as well as the number of day missing in a month. From May 1943 through December 1943, the data file shows that data are missing for 29 days in each month.

Table 1. Example of a Daily Maximum File for Aguila, Arizona

Station Index	Year	Month	Date	Daily Maximum	Accum. Amount	Accum. Days	Msg Days
02-0060	1941	01	24	0.69	0	0	0
02-0060	1941	02	20	0.64	0	0	0
02-0060	1941	03	13	1.85	0	0	0
02-0060	1941	04	11	1.39	0	0	0
02-0060	1941	05	23	0.11	0	0	0
02-0060	1941	06	30	0.00	0	0	0
02-0060	1941	07	24	0.59	0	0	0
02-0060	1941	08	15	0.85	0	0	0
02-0060	1941	09	13	0.82	0	0	0
02-0060	1941	10	20	0.65	0	0	0
02-0060	1941	11	30	0.31	62	2	0
02-0060	1941	12	11	1.12	0	0	0
02-0060	1942	01	01	0.25	8	2	0
02-0060	1942	02	27	0.67	0	0	0
02-0060	1942	03	14	0.44	0	0	0
02-0060	1942	04	23	0.28	0	0	0
02-0060	1942	05	31	0.00	0	0	0
02-0060	1942	06	30	0.00	0	0	0
02-0060	1942	07	16	0.30	0	0	0
02-0060	1942	08	17	0.71	0	0	0
02-0060	1942	09	30	0.00	0	0	0
02-0060	1942	10	13	0.05	0	0	0
02-0600	1942	11	30	0.00	0	0	0
02-0060	1942	12	26	0.15	0	0	0
02-0060	1943	01	27	0.64	119	2	0
02-0060	1943	02	09	0.18	0	0	0
02-0060	1943	03	11	0.36	0	0	0
02-0060	1943	04	06	0.29	0	0	0
02-0060	1943	05	0	-9.99	0	0	29
02-0060	1943	06	0	-9.99	0	0	29
02-0060	1943	07	0	-9.99	0	0	29
02-0060	1943	08	0	-9.99	0	0	29
02-0060	1943	09	0	-9.99	0	0	29
02-0060	1943	10	0	-9.99	0	0	29
02-0060	1943	11	0	-9.99	0	0	29
02-0060	1943	12	0	-9.99	0	0	29

Table 2 shows maximum annual hourly precipitation data for Ash Fork 2 (index number 02-0487) located in Yavapai County in north central Arizona at 5130 feet. Digital data for Ash Fork 2 are available from 1948 through 1990. The data shown in Table 2 ranges from 1961 through 1964. Similar to Table 1 the first column gives the station index number, followed by the year, the maximum for a given duration, the Julian hour beginning the string of hours, the duration, an accumulated amount, the number of hours represented by that accumulated amount, and the number of missing hours.

Table 2.Example of a Annual Hourly Maximum File for Ash Fork 2, Arizona

Station Index	Year	Hourly Amount	Julian Hour	Duration	Accum. Amount	Accum. Hours	Msg. Hours
02-0487	1961	0.76	6224	1	90	20	0
02-0487	1961	0.89	6224	2	90	20	0
02-0487	1961	0.99	6224	3	90	20	0
02-0487	1961	1.38	6224	6	90	20	0
02-0487	1961	1.73	6220	12	90	20	0
02-0487	1961	1.79	6206	24	70	31	0
02-0487	1962	0.53	6351	1	65	14	121
02-0487	1962	0.70	6351	2	65	14	121
02-0487	1962	0.88	6351	3	65	14	121
02-0487	1962	0.95	6351	6	65	14	121
02-0487	1962	0.95	6351	12	65	14	121
02-0487	1962	0.95	6351	24	45	26	121
02-0487	1963	0.39	5082	1	31	4	743
02-0487	1963	0.47	5081	2	31	4	743
02-0487	1963	0.53	7445	3	31	4	743
02-0487	1963	0.64	7445	6	0	0	743
02-0487	1963	0.68	7444	12	0	0	743
02-0487	1963	0.69	7444	24	0	0	743
02-0487	1964	-9.99	-999	1	0	0	8784
02-0487	1964	-9.99	-999	2	0	0	8784
02-0487	1964	-9.99	-999	3	0	0	8784
02-0487	1964	-9.99	-999	6	0	0	8784
02-0487	1964	-9.99	-999	12	0	0	8784
02-0487	1964	-9.99	-999	24	0	0	8784

The maximum 1-hour precipitation amount of 0.76 inch during 1961 is shown on the first line of Table 2. This occurred during the Julian hour 6224, or beginning at 7 am on September 15. Similarly the maximum 2-, 3-, 6-, 12-, and 24-hour duration totals range from 0.89 to 1.79 inches. All of these strings of data begin on either September 14 or September 15. For the durations from 1 through 12 hours, 20 hours of accumulated data are shown with a total amount of 0.90 inch. If the accumulated total divided by the number of hours had exceeded 0.76 inch for the 1-hour duration, then this value would have been given as the 1-hour maximum precipitation for 1961. However, 0.90 inch divided by 20 gives 0.045 inch. If this rate, when multiplied by the appropriate duration, had exceeded the indicated amount for any duration, then that value would be given as the maximum amount for that duration. For the 24-hour duration, a different accumulated value is shown. Once the duration exceeds the number of accumulated hours, then it is dropped from further consideration, unless the preceding or subsequent hours also have precipitation. Thus, for durations of 24 hours or more the number of accumulated hours must equal or exceed 24 hours. Since the accumulated amount of 0.70 inch is less than the 1.79 inches on September 14, the maximum 24-hour duration precipitation for 1961 remains at 1.79 inches.

The maximum hourly values in 1963 point out that the maximum hourly values do not always come from the same string of hours. The maximum values for durations of 1 and 2 hours began at Julian hours 5082 and 5081 respectively, or on July 29. While the maximum values for durations of 3 through 24 hours began at either Julian hours 7444 or 7445 or November 5. During 1963 there were 743 hours or nearly 31 days of data missing.

During 1964 no data were recorded, since there were 8784 hours or 366 days of data missing. Remember this is a leap year.

Data Processing

Arizona daily and hourly data have been processed. Monthly maximum values for 1-day data were obtained for all the daily data that are available in a digital format. Maximum values for durations of 1, 2, 3, 6, 12, and 24 hours have been obtained for each month for the Arizona data. Using this information a summary of the period of record were obtained for data available in a digital format from NCDC. These data were also stratified by elevation (feet), and are given in Tables 3 and 4.

Table 3. ARIZONA Daily Precipitation Data

Record Length (yr)	Station Elevation (ft) ≤1000	1001-3000	3001-5000	5001-7000	>7000	Sum
1-9	7	34	37	42	6	126
10-19	9	18	11	24	5	67
20-29	5	19	20	24	4	72
30-39	2	26	34	8	6	76
40-49	1	9	6	6	0	22
50-59	2	4	8	6	1	21
60-69	1	4	6	2	0	13
70-79	1	7	6	7	3	24
80-89	1	3	5	4	0	13
90	2	1	1	0	0	4
Sum	31	125	134	123	25	438

Table 4. ARIZONA Daily Precipitation Data

Record Length (yr)	Station Elevation (ft) ≤1000	1001-3000	3001-5000	5001-7000	>7000	Sum
1-9	1	3	12	7	1	24
10-19	0	7	16	5	0	28
20-29	1	1	3	3	0	8
30-39	1	2	7	7	1	18
40-49	0	2	1	0	0	3
Sum	3	15	39	22	2	83

The data processed extended through 1988, additional daily and hourly data through 1990 will be obtained and appended to this data set. In addition, daily and hourly data will be appended to these digital data using paper copies of annual and some monthly maximum data that were reduced previously for use in Technical Paper No. 40 (Hershfield, 1961) and NOAA Atlas 2 (Miller et al, 1973). Table 3 shows that there are 245 stations available on digital data with records lengths of 20 years or more. A preliminary survey of the available data on paper that can be used to lengthen the digital period of records shows that there are about 274 stations with 20 years of more of records. Similarly, the digital record only shows 97 stations with 40 years or more of record, the additional paper records provide 139 stations with 40 years or more of daily record. Increases in record length for the hourly data will be more limited. For most hourly stations no more than eight years of additional data are available, and often there are only two or three additional years of data.

The biggest cluster of data for a period of record greater than 20 years lies between elevations of 1000 through 7000 feet, and between 20 and 40 years. For elevations greater than 7000 feet, only 14 stations have 20 or more years of data and 19 have 10 years or more of data. Additional precipitation data above 7000 feet will be available from other sources. One of these sources will be the SNOTEL network operated by the Soil Conservation Service (SCS) of the U. S. Department of Agriculture. In Arizona this network has 14 stations, and 12 of these 14 stations are above 7000 feet. These stations will only have 11 to 12 years of daily data available. This network extends into other states in the Semi-Arid region, with an additional 29 stations in Nevada, 13 stations in New Mexico, and 77 stations in Utah. These data will be used to bolster the precipitation relations above 7000 feet.

Independent Advisory Group

An Independent Advisory Group was formed in an effort to assure that this study is using the latest techniques, to help determine strategies and preferred approaches, and to assist in the review of the study. This group is to provide expertise from various technical fields. The group consists of:

Dr. Robert A. Clark (Hydrology), University of Arizona, Department of Hydrology, Tucson, AZ

Dr. Kenneth Kunkel (Climatology), Illinois State Water Survey, Champaign, IL

Mr. V. Ottozawa-Chatupron (Engineering Applications), Arizona State Land Department, Phoenix, AZ

Dr. James R. Wallis (Statistical Applications), IBM Research Center, Yorktown Heights, NY

December 5, 1991 Meeting

The first meeting of the Interagency Support Group was held on December 5, 1991, at the Arizona Department of Transportation Offices in Phoenix, Arizona. The purpose of this meeting was to 1) meet all the parties contributing to this study, 2) review NWS experience in previous precipitation frequency studies, 3) present some results from recent studies by the NWS in Pennsylvania, West Virginia, and Louisiana, and 4) obtain input from the various users about their needs. Members from the various state, local and Federal agencies, and the Independent Advisory Group were present. Several Federal members were not able to attend because of other conflicts. A second meeting was planned for that group for early January 1992 to be held in Silver Spring, Maryland. In the discussion during the December 5 meeting a number of questions and concerns were raised relative to the final display of the data, confidence limits, area-depth curves, and temporal distribution of precipitation to highlight only some of the major questions. Not all of the concerns could be addressed at the meeting, but they will be considered as the Project progresses. Minutes for the meeting were distributed on January 8, 1992.

Bibliography

Hershfield, D. M., 1961: "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years." Technical Paper No. 40, U. S. Government Printing Office, Washington, DC, 61 pp.

Miller, J. F., R. H. Frederick, and R. J. Tracey, 1973: "Precipitation-Frequency Atlas of the Western United States." NOAA Atlas 2, U. S. Government Printing Office, Washington, DC, 11 Volumes.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administ
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

April 30, 1992

W/OH1

June 5, 92 [illegible]

MEMORANDUM FOR: Participants in the Southwest Arid Precipitation Frequency Study

FROM: W/OH1 - E. Marshall Hansen

SUBJECT: June Project Status Meeting

The next meeting of the participants supporting the Southwest Arid Precipitation Frequency Study is scheduled for Wednesday, June 10, 1992. Joe Warren plans to hold the meeting at the same location as the December 5, 1991 meeting--Arizona Department of Transportation Offices, 2612 South 46th Street, Executive Conference Room. For those of you coming from out of town, the Hilton Airport Inn (602) 894-1000) is quite convenient (walking distance) to the meeting site.

I believe we can start at 8:00 a.m. and probably complete business by 2:00 p.m., unless some lengthy discussion develops. The intent of the meeting is to review the interim progress by the National Weather Service and discuss any aspects of the project believed relevant by the participants. We have chosen not to invite the Independent Advisory Group to this meeting. John Vogel will explain this decision and present the NWS progress to date.

By coincidence, this announcement corresponds with release of the second quarterly progress report (enclosed). Hopefully, each of you will read this report prior to the meeting and should you have any questions, John will provide answers.

Talk to [illegible]
on 6-9-92 on
the Progress Report Crs.
has problems w/ Schedule
of Task(s) — No
progress — Data Analysis
should be completed by now.

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MAY 4 1992

ARIZONA TRANSPORTATIC
RESEARCH CENTER

SECOND QUARTERLY PROGRESS REPORT

for

SEMI-ARID PRECIPITATION FREQUENCY STUDY

by

John L. Vogel, Edwin H. Chin, and Michael Yekta
Office of Hydrology
National Weather Service

June 5, 92 GH

Silver Spring, Maryland
April 1992

SEMI-ARID PRECIPITATION FREQUENCY STUDY
Second Quarterly Progress Report
for the period from
January 1 through March 31, 1992

Overview

Software development continued throughout the second quarter. One of the goals of the Semi-Arid Precipitation Frequency Project is to develop annual and seasonal return frequencies. To accomplish this task it was decided to obtain the monthly maximum precipitation amounts for durations of less than 4 days, and the highest six independent precipitation amounts in each year for durations of 7 and 10 days. For longer durations up to 30 days the highest 2 to 5 independent precipitation amounts will be found for each year. The decision as to how many of the highest independent precipitation amounts in a year are to be selected will be made so that the seasonal relations for the durations can be defined. The major activity during this quarter was the continued refinement of the software for reducing the data.

Other activities during this quarter were 1) the acquisition of additional data from the National Climatic Data Center, and data for higher elevations and data-sparse regions in the Southwest United States; 2) the extension of data using previous paper tabulations of data; 3) the quality control of data; and 4) the recruitment of a project leader to assist in the day-to-day administration and research efforts of this project.

Software Development

Since one of the major thrusts of this project is the determination of not only annual return frequency relations but also seasonal return frequency relations, a decision had to be made as to how to characterize the timing of the various durations. This became especially important for determining which day, month, or year an event occurred. For example, if the maximum 6-hour duration began on the 22nd hour of the last day of the month, and extended through the 4th hour of the first day of the next month, it was necessary to define the month in which the maximum 6-hour event would be assigned. There are no set criteria and the decision can be entirely arbitrary. Some of the possible criteria are: 1) the first hour of the event, 2) the last hour of the event, 3) the maximum hour of occurrence, or 4) some other hour within the event, such as the middle or median hour. The same type of logic also applies to daily sequences that span beyond the end of a month or a year. As part of this process, it was agreed that as much information as possible would be retained to facilitate any additional studies of the data, such as the most likely hours of occurrence, or the most likely beginning time of the sequence. It was finally decided that the hour in the sequence with the maximum precipitation in one hour would determine in which month an hourly sequence would be assigned. In addition, the beginning hour of each sequence would also be saved for other studies. If the maximum precipitation within a sequence was equalled by another hour, then the first hour would be recorded as the maximum hour.

Similarly for daily data, the day with the maximum precipitation amount would be recorded, and this day would be used to identify the maximum occurrence for the month. In addition, the beginning day of the sequence would be saved for further analysis purposes. The previous software development had not considered these potential data problems for either daily or hourly data sequences that might extend beyond the end of a month. The software for both the hourly and daily precipitation data had to be modified to account for many possible alternatives. Some of these alternatives are caused by the randomness of the data; others are caused by missing or accumulated data, and are much harder to resolve.

The program for processing the hourly data was almost ready by the end of March. Hourly data will be processed for durations of 1, 2, 3, 6, 12, 24, and 48 hours. For each of these durations a line of data will be generated, and will identify the following information: 1) state, 2) station identification code, 3) date (year and month), 4) maximum monthly precipitation in hundredths of an inch for that duration, 5) Julian hour of the highest hourly precipitation value within that duration, 6) the duration, 7) accumulated amount (if any), 8) accumulated number of hours (if any), 9) number of missing hours (if any), and 10) the beginning hour of the event.

Daily precipitation data will be processed for durations of 1, 2, 4, 7, 10, 20, and 30 days. Some experimentation will also be done for durations of 45 and 60 days. Essentially the same information will be saved for the daily data as is being done for the hourly data, except the times will be saved as days instead of hours. This software was developed by the end of March for durations through 4 days, and it is anticipated that it will be completed for all durations about mid May.

Data

Hourly and daily digital data residing at the Office of Hydrology at the beginning of this project extended through 1988. This data base was extended through 1990 this quarter with the acquisition of hourly and daily data tapes from the National Climatic Data Center (NCDC). Fifteen-minute data were also obtained this quarter, so that the data base for 15-minute data extends from the beginning of the record through 1990. The beginning date for the 15-minute durations varies since this data is only acquired from Fischer-Porter rain gages. These are recording, weighing-bucket rain gages that record data on paper tapes with a resolution of a tenth of an inch. These rain gages were installed at various times, with the first data becoming available in about 1971 or 1972.

Contact was made with the Soil Conservation Service (SCS) in Portland, Oregon, to obtain the daily precipitation data from SNOTEL (SNOWpack TELemetry) rain gages in Arizona, California, Nevada, New Mexico, and Utah from the beginning of this record (1979) through 1991. These data are to be transferred via floppy disks, and are awaiting the final quality control for the 1991 data. The Western Regional Climate Center (WRCC) in Reno, Nevada, is the repository of the RAWS (Remote Automated Weather Stations) data set collected by the Forest Service and the Bureau of Land Management. These data are available in an hourly format since 1985, and the hourly precipitation data are being acquired through 1991. Both these data bases provide data for higher elevations and otherwise data-sparse regions of the West.

Much of the digital data available at NCDC does not extend prior to 1948, because this is the beginning year for the routine digitization of climatic data. Paper tabulations for previous precipitation-return frequencies (NOAA Atlas 2 and Technical Paper No. 40) can extend the period of record back in time. Hourly data can often be extended back to about 1940 for durations of 1 and 6 hours, and 1-day duration data are available for varying lengths of time, often to the beginning of the station. Generally, these data are available for the annual and monthly maximums. These data are currently being readied to be transferred to digital files for the states in the Semi-Arid Southwest Study. Also, quality control checks on some of the extreme daily data have been made by hand to verify unusually high values that are indicated on the digital data base.

A software routine has been developed to compare stations that have the same indicated latitude and longitude. Often times the station name changes as observers quit and others begin. There were 22 such pairs of daily stations in Arizona. For each of these pairs of records, the historical data base was examined using a digital file that details the history of each of the stations since 1948, and using Substation History files which were published in 1956 and documented the locations of the stations through 1955. This will allow us to merge data from different stations and to develop a longer period of record for a number of these pairs. In other cases, it was apparent that these stations had substantially different elevations (more than 100 feet) and needed to be treated as separate locations. Such an analysis will also be done for each state for both hourly and daily data.

Personnel

A vacancy announcement was issued in January to locate a person that could assist in the day-to-day leadership of the Semi-Arid Southwest Study. Four candidates were interviewed in late March, and a selection was made in April. It is anticipated that this person will be able to join the staff of the Hydrometeorological Branch in mid-June. An announcement of the person's name will be made as soon as all personnel procedures are completed.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

August 12, 1992 W/OH11:JLV

MEMORANDUM FOR: Southwest Semi-Arid Precipitation Frequency Study Group

FROM: W/OH11 - John L. Vogel

SUBJECT: Third Quarterly Progress Report

Enclosed is the Third Quarterly Progress Report for the period from April 1 through June 30, 1992. This report is an extension of the minutes of the June 10, 1992, semi-annual meeting in Phoenix. If you have any questions, please feel free to call me on (301) 713-1669.

Enclosure

THIRD QUARTERLY PROGRESS REPORT

for

SEMI-ARID PRECIPITATION FREQUENCY STUDY

by

John L. Vogel, Edwin H. Chin, Lesley Tarleton,
and Michael Yekta
Office of Hydrology
National Weather Service

Silver Spring, Maryland
August 1992

SEMI-ARID PRECIPITATION FREQUENCY STUDY
Third Quarterly Progress Report
for the period from
April 1 through June 30, 1992

Introduction

Software development and data acquisition continued to be the major work accomplished during the third quarter of the Semi-Arid Precipitation Frequency Project. As the software development for daily and hourly precipitation continued, more problems with the different ways in which missing and accumulated data were treated over the years were encountered. However by the end of the quarter, it was felt that most of the possible variations were solved. It was always recognized that there would have to be some hand checks of the data, and it is hoped that these have been minimized. Some work began on the seasonal analysis of data, and data were obtained for the SNOTEL (SNOwpack TELemetry) network of the Soil Conservation Service. Work also continued in extending the hourly and the daily precipitation data bases using paper tabulations of data that were used for the development of the Rainfall Frequency Atlas of the United States--Technical Paper No. 40 (Hershfield, 1961).

A major activity that continued during this quarter was the hiring of new personnel. In all three new people joined the Hydrometeorological Branch during June of this year. Prior to this time there were extensive amounts of paper work that were required to complete the recruitment activities for these new staff members.

Data Acquisition

Various data have been acquired during the past six months. The first data sets acquired were the 15-minute, hourly, and daily data from the cooperative observer climate network. These data were obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina. Hourly and daily data were obtained for the calendar years of 1989 and 1990, which augmented the data already available to the Water Management Information Division (WMID). This means that digital data from 1948 through 1990 are now available. Data prior to 1948 that have been digitized by states in a reciprocal agreement between NCDC and the individuals states are also available. The record length of the data prior to 1948 and the number of stations from each state vary. The 15-minute precipitation data were obtained from the time the processing of these data began (about 1971 or 1972) through 1990. The number of stations available in each state varies as the installation of the Fischer-Porter recording raingages progressed.

An important data source for remote regions in the West are the SNOTEL (SNOwpack TELemetry) network operated by the United States

Department of Agriculture's Soil Conservation Service (SCS). These data are collected and archived at the Western Regional Technical Center of the SCS at Portland, Oregon. About June 1, the SCS supplied daily precipitation and snow data from this network on floppy discs. These data were quality controlled by the SCS, and were forwarded as soon as the quality-controlled data became available through the end of the 1991 Water Year (September 1991). Data were obtained for the states of Arizona, California, New Mexico, Nevada, and Utah. These stations are usually sited at high altitudes. Table 1 shows the number of stations available for each state, and the number of stations that began in a particular water year. Of the 161 stations, 124 stations began between October 1978 (Water Year 1979) and October 1981 (Water Year 1982). These stations provide 10 to 13 years of data in high-altitude regions that are not normally available from the NCDC. Arizona is the only state that SNOTEL data did not begin until Water Year 1983 (October 1982). Figures 1 through 4 show how the SNOTEL sites (stars) will supplement the daily stations in Arizona, Nevada, New Mexico, and Nevada. The SNOTEL sites, because they are generally at higher altitudes, depict much of the higher altitudes in each state.

Table 1. Number of SNOTEL stations by state beginning by Water Year.

Water Year	Arizona	California	Nevada	New Mexico	Utah	Total
1979		12	8		28	48
1980		1	1	7	15	24
1981		11	14	5	11	41
1982			1	1	8	10
1983	12					12
1984		1	3			4
1985	2					2
1986					8	8
1987					1	1
1988					2	2
1989					3	3
1990		1		1	1	3
1991		1	1		1	3
Total	14	27	28	14	78	161

An example of the data format is given in Table 2. The data are for Frisco Divide, New Mexico (33°44'N/108°56'W) The data are accumulated from October 1, 1984, through September 30, 1985, in tenths of an inch. From October 1st to October 2nd 0.2 inch of precipitation fell, and an additional 0.6 inch of precipitation fell between the 2nd and 3rd of October. In all 29.8 inches of precipitation fell during the 1985 water year. These data are not unlike the data collected by the NCDC, in that there are problems

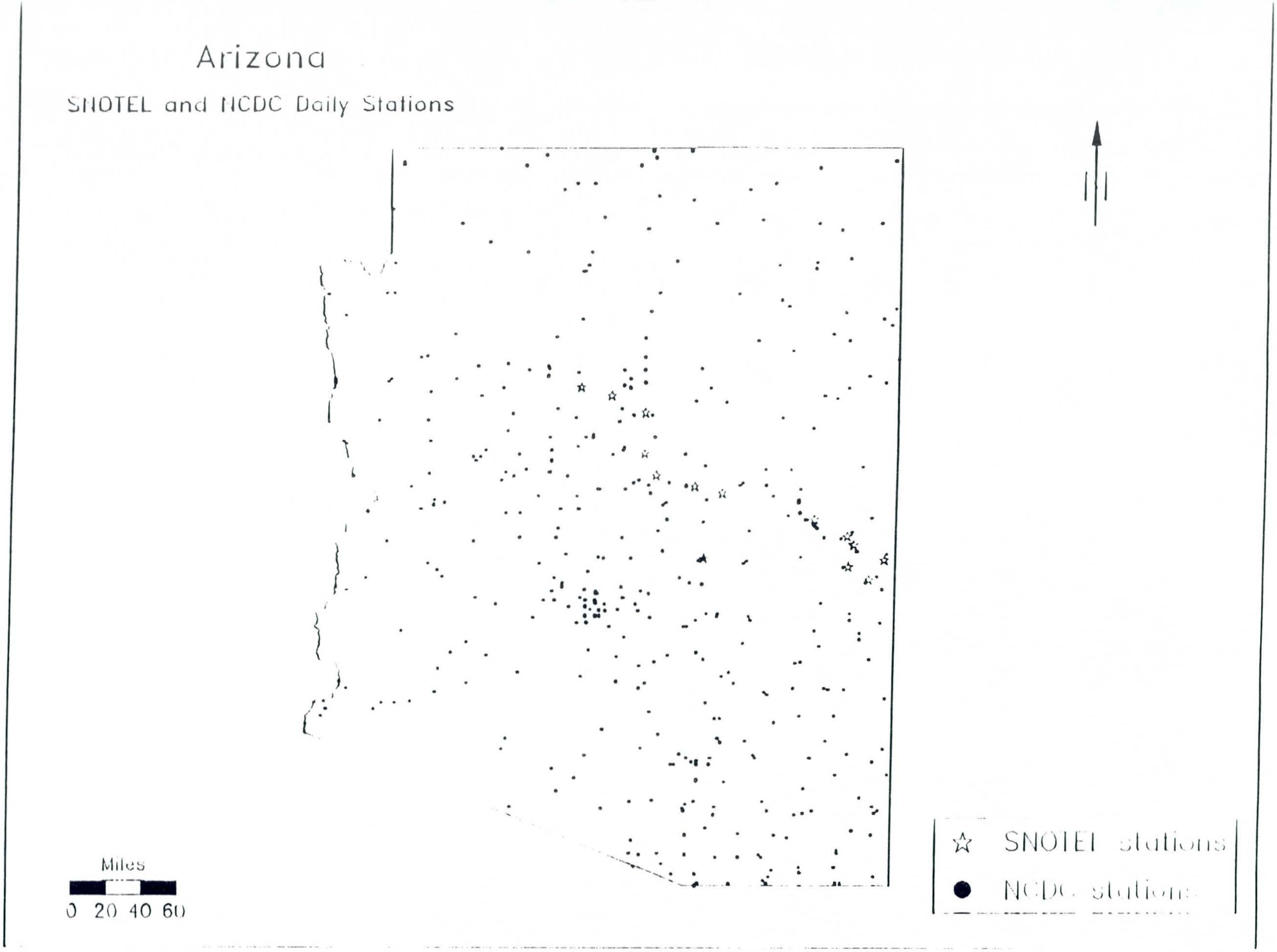


Figure 1. NCDC and SNOTEL Daily Stations for Arizona

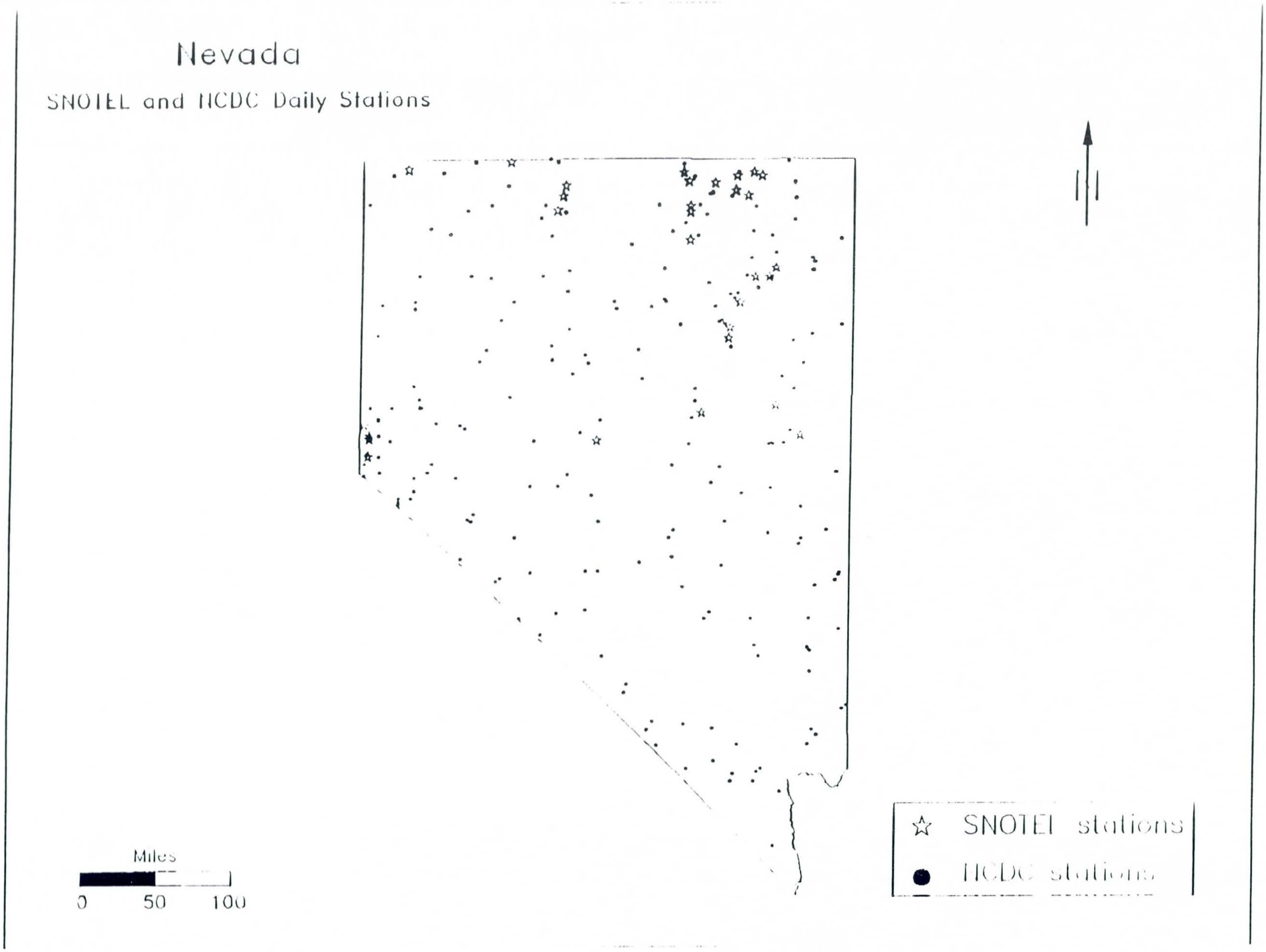


Figure 2. NCDC and SNOTEL Daily Stations for Nevada

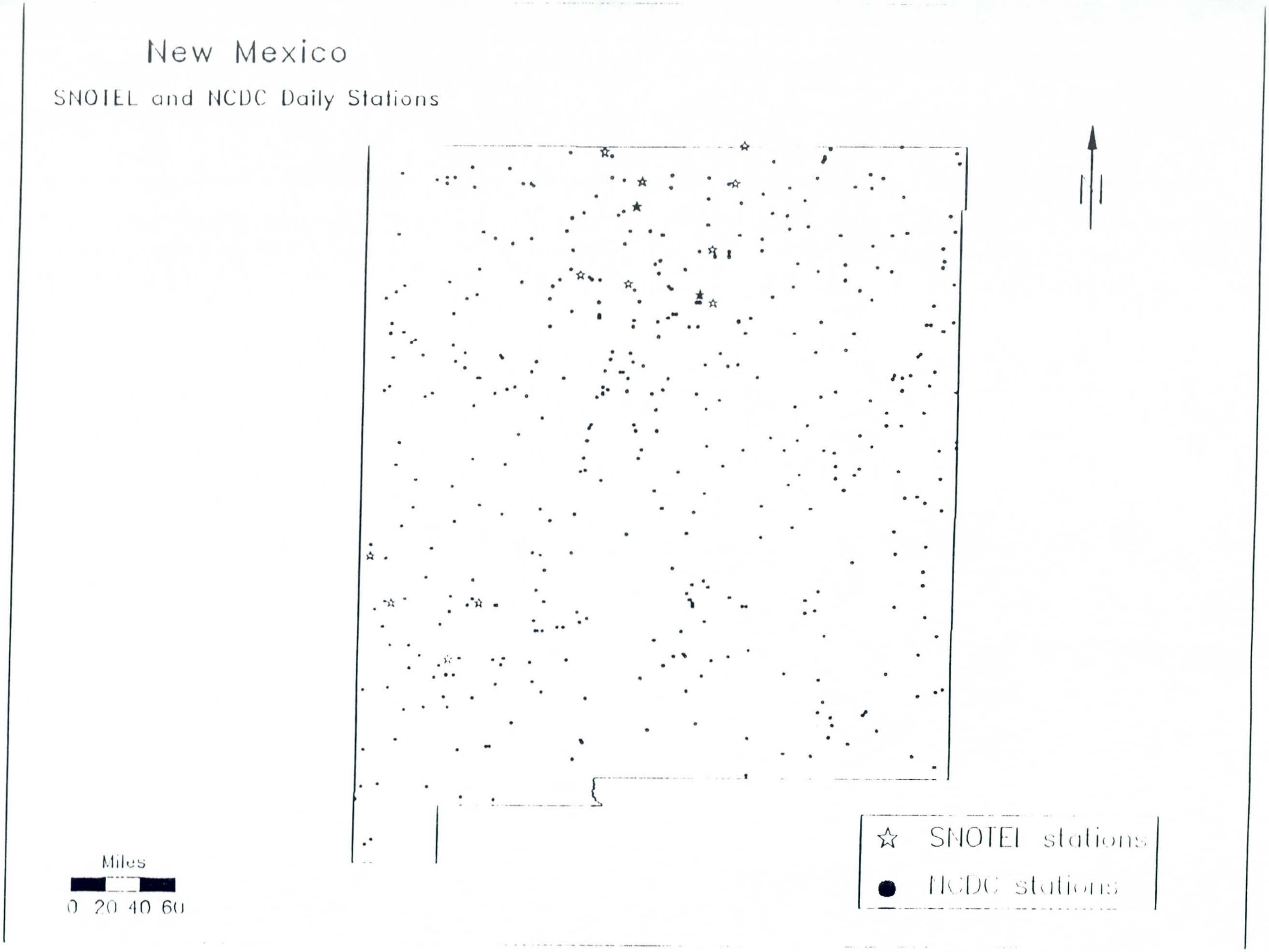


Figure 3. NCDC and SNOTEL Daily Stations for New Mexico

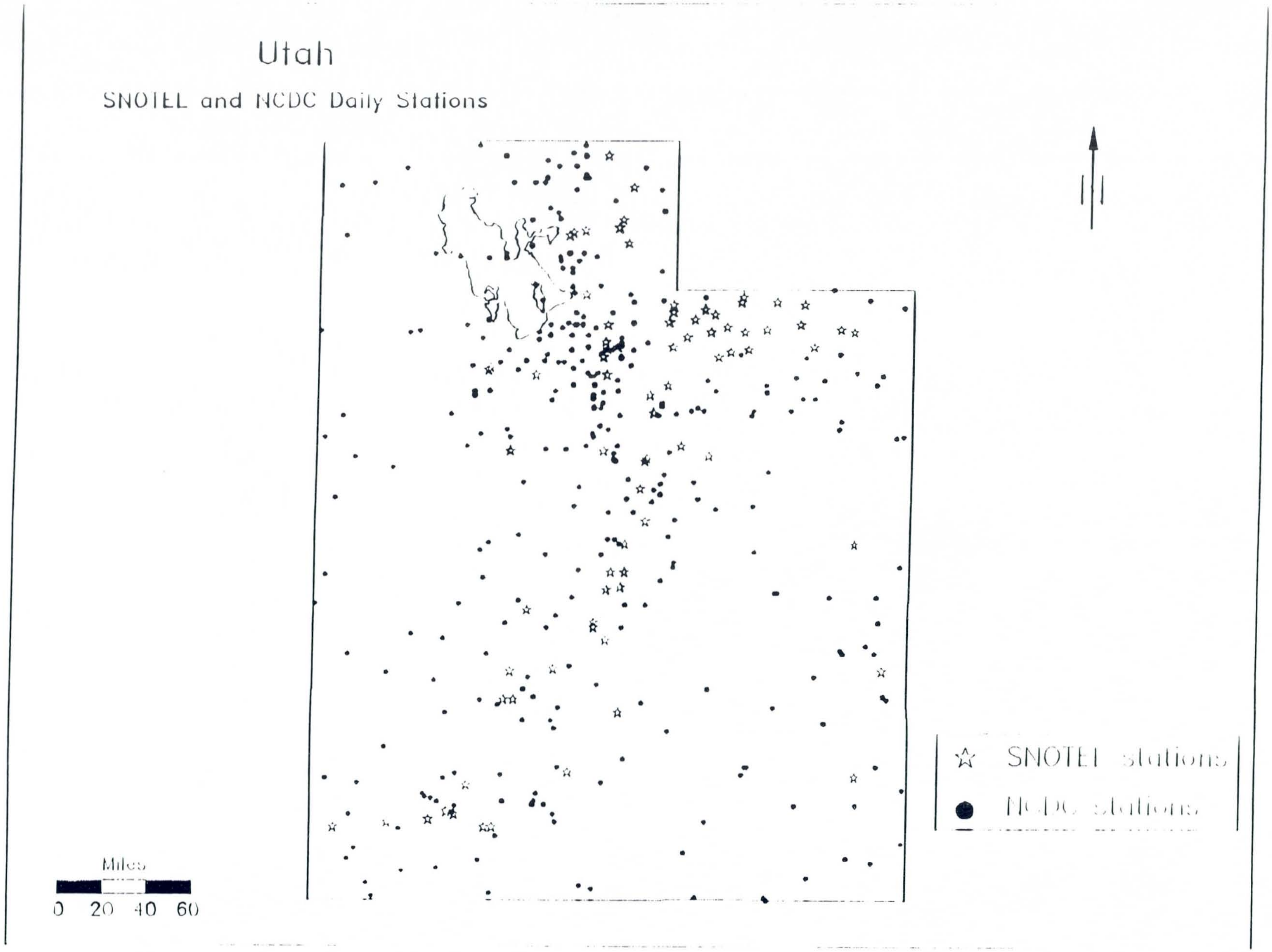


Figure 4. NCDC and SNOTEL Daily Stations for Utah

Table 2. SNOTEL Precipitation Data for Frisco Divide in Water Year 1958 (units: inches)

/cdb/nm/snot35 85 prec

Station : 08S01S, FRISCO DIVIDE
------- Unit = inches

day	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
1	0.0	3.3	3.7	9.4	12.6	13.0	15.3	17.8	18.1	19.1	22.3	26.5
2	0.2	3.3	3.7	9.4	12.6	13.0	15.4	17.8	18.1	19.1	22.3	26.5
3	0.8	3.3	3.7	9.4	12.6	13.0	15.4	17.8	18.1	19.1	22.6	26.5
4	1.3	3.3	4.2	9.4	12.6	13.0	15.4	17.8	18.1	19.1	22.6	26.5
5	1.6	3.3	4.7	9.6	12.6	13.2	15.4	18.1	18.1	19.1	22.8	26.5
6	1.7	3.3	4.7	9.6	12.6	13.3	15.4	18.1	18.3	19.1	23.1	26.5
7	1.8	3.3	4.7	9.6	12.6	13.3	15.4	18.1	18.3	19.1	23.1	26.5
8	1.8	3.3	4.7	9.6	12.6	13.3	15.4	18.1	18.5	19.1	23.5	26.5
9	1.8	3.3	4.7	9.9	12.6	13.3	15.4	18.1	18.5	19.1	23.6	26.5
10	1.8	3.3	4.7	9.9	12.6	13.3	16.6	18.1	18.5	19.1	23.8	26.5
11	1.8	3.3	5.2	9.9	12.6	13.3	16.6	18.1	18.5	19.1	24.6	26.5
12	2.1	3.3	5.6	10.3	12.6	13.9	16.6	18.1	18.5	19.5	25.5	26.5
13	2.1	3.3	6.0	10.3	12.6	14.0	16.6	18.1	18.5	19.5	25.5	26.5
14	2.1	3.3	6.4	10.3	12.6	14.1	16.6	18.1	18.5	19.5	25.5	26.6
15	2.1	3.3	6.8	10.3	12.6	14.4	16.6	18.1	18.5	19.6	25.5	26.8
16	2.1	3.3	6.9	10.3	12.6	14.7	16.6	18.1	18.5	19.6	25.5	26.9
17	2.3	3.3	7.0	10.3	12.6	14.9	16.6	18.1	18.5	19.6	25.5	26.9
18	2.3	3.3	7.0	10.3	12.6	14.9	16.6	18.1	18.5	19.6	25.5	27.0
19	2.3	3.3	7.0	10.4	12.6	14.9	16.6	18.1	18.5	19.6	25.5	28.2
20	2.3	3.3	7.2	10.4	12.6	14.9	16.6	18.1	18.5	20.0	25.5	28.4
21	2.3	3.3	7.2	10.4	12.6	15.1	16.6	18.1	18.8	20.8	25.5	29.4
22	2.5	3.3	7.2	10.4	12.7	15.1	16.6	18.1	18.8	21.1	25.5	29.4
23	2.6	3.4	7.3	10.4	12.7	15.1	16.8	18.1	19.0	21.1	26.3	28.4
24	2.9	3.4	7.4	10.7	12.7	15.1	16.8	18.1	19.1	21.1	26.3	28.4
25	3.3	3.6	7.5	10.7	12.9	15.1	17.0	18.1	19.1	21.1	26.5	28.4
26	3.3	3.6	7.6	11.0	13.0	15.1	17.0	18.1	19.1	21.3	26.5	28.4
27	3.3	3.6	7.7	11.0	13.0	15.1	17.1	18.1	19.1	21.3	26.5	28.5
28	3.3	3.7	9.2	11.0	13.0	15.1	17.3	18.1	19.1	21.3	26.5	28.8
29	3.3	3.7	9.4	11.2	---	15.1	17.6	18.1	19.1	21.6	26.5	29.0
30	3.3	3.7	9.4	11.2	---	15.1	17.8	18.1	19.1	21.8	26.5	29.8
31	3.3	---		11.2	---	15.3	---	18.1	---	22.1	26.5	---
mean	2.2	3.4	6.3	10.3	12.7	14.3	16.4	18.1	18.6	20.0	24.9	27.4
max	3.3	3.7	9.4	11.2	13.0	15.3	17.8	18.1	19.1	22.1	26.5	29.8
min	0.0	3.3	3.7	9.4	12.6	13.0	15.3	17.8	18.1	19.1	22.3	26.5

such as: missed transmissions resulting in accumulated data and missing data. When there is no rain for up to a month, evaporation can occur, and this appears as negative precipitation amounts as the cumulative precipitation amount decreases in value. For the computer software that has been developed, these data will be put into a format compatible with that of the NCDC daily data. Contact was made with the Western Regional Climate Center (WRCC) in Reno, Nevada, to acquire the hourly precipitation from the RAWS (Remote Automated Weather System) Network. This is one of the few networks with hourly precipitation data available at high altitudes. These data do not have the period of record that is normally wanted for a precipitation frequency study, but it does supply information in data sparse regions that would otherwise not be available. These data will be used to supplement hourly data in remote regions of the Southwest. Figure 5 gives the spatial distribution of these stations as described by Redmond (1991). It is anticipated that these data will be obtained from the WRCC during August.

Peter Corrigan and John Vogel visited the San Bernardino County Flood Control District on June 11 and the Riverside County Flood Control and Water Conservation District on June 12 to review available data resources. It was found that both groups had extensive data resources available for use in this study. Peter Corrigan on June 15 and 16 also visited the River Forecast Center of the National Weather Service at Sacramento, and the California Department of Water Resources (CDWR) to inquire about other data resources in California. The latter group archives some of the precipitation data from ALERT raingages in the SHEF format (Standard Hydrologic Exchange Format), and is willing to supply data. The CDWR also has available raingage data from a variety of other agencies that collect precipitation information in California. Contact has been continued to determine the extent of the data collection which resides at the CDWR.

During this same visit the Los Angeles and Sacramento Corps of Engineers District Offices were visited to examine various storm files. Both offices were able to supply supplementary data on various general and local storms. Especially pertinent were bucket survey data obtained for some local storms. Data on the spatial and temporal definitions of extreme local storms are very difficult to obtain, and this information will prove helpful in the future.

Software Development

Software development for processing the daily and hourly precipitation data continued during this quarter. As indicated in the Second Quarterly Progress Report, a major thrust of the project is to determine seasonal return frequency intensities, as well as the traditional, annual return frequency intensities. It becomes important to identify the month during which the precipitation occurred. As reported in the Second Quarterly Progress Report, it was decided that the hour (day) in the sequence with the maximum

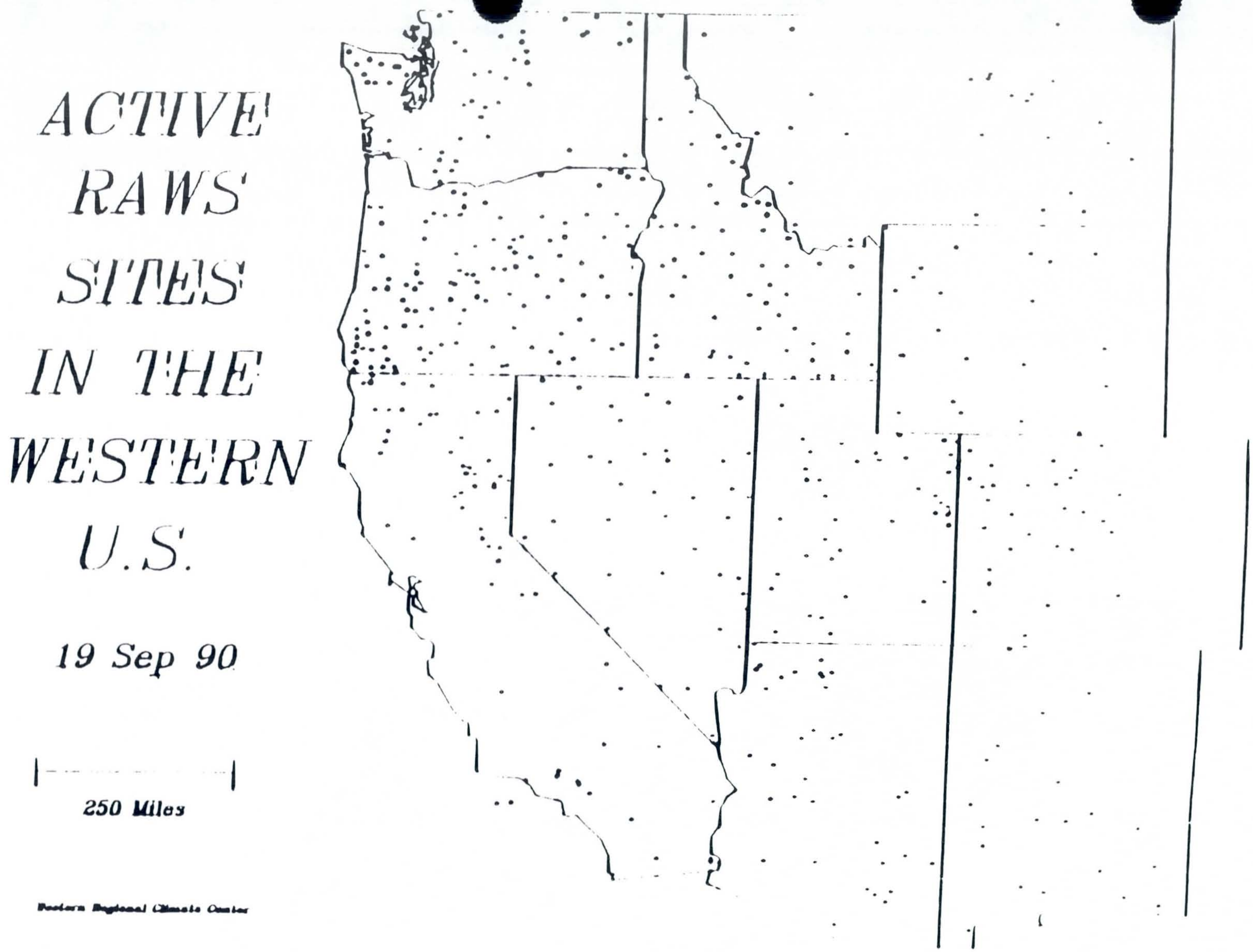


Figure 5. Map of RAWS Sites

precipitation would determine the month in which an hourly (daily) sequence would be assigned. It was also decided to retain as much information as possible with each hourly (daily) sequence, so that the beginning hour (day) of each sequence and the maximum hour (day) of each sequence would be retained for later analysis. In addition, the software for both the hourly and daily precipitation data had to be modified to accommodate the many alternatives of accumulated and missing data, and possible digitizing errors. Hourly data will be processed for durations of 1, 2, 3, 6, 12, 24, and 48 hours; daily data will be calculated for durations of 1, 2, 4, 7, 10, 20, 30, 45, and 60 days.

Table 3 shows processed data for the Tucson WSO Airport. As one reads across the first line the state of Arizona is indicated by 02; Tucson WSO airport is identified by its station number, 8820; the year (1958) is given by the 58 at the end of the station number; the month is July, 7; the maximum 1-hour intensity of 1.43 inches occurred in Julian hour 5022, July 29, hour ending at 0600 local standard time; the 1 shows that this is a 1-hour duration; the next three columns, all zeros, give the amount of accumulated precipitation (if any), the number of accumulated hours (if any), and the number of missing hours (if any) for the month of July 1958; and the last column provides the Julian hour (5022) during which the sequence began. For a 1-hour duration the maximum and the beginning hour coincide. During July 1958 the hour with the most precipitation for durations of 1-, 2-, 3-, 6-, 12-, 24-, and 48-hours are all Julian hour 5022. The beginning hour for all the durations only varies by two hours from the 1-hour duration through the 48-hour duration. Precipitation must fall during the beginning hour of any duration, so that it can be readily seen that most of the rain occurred between Julian hours 5021 and 5027.

A mixture of accumulated and real data for November 1966 are illustrated in Table 4 at Tuweep (station 8895), located in northwest Arizona. For durations of 1 and 2 hours, the maximum hourly precipitation was 0.12 inch at Julian hour 7481 (November 8, hour ending at 1700) with the 2-hour duration beginning at Julian hour 7480 (November 8, hour ending at 1600). The 3-hour precipitation intensity in November, is the same magnitude as the 2-hour duration intensity, 0.15 inch. The asterisk next to Julian hour 7456 (November 7, hour ending at 1600) indicates that this intensity value has accumulated values during the sequence. The 81 in the fourth to last column indicates that 0.81 inch of precipitation accumulated over 16 hours (third to last column). If the 0.81 inch is divided by 16, it gives an hourly average value of 0.050625 inch, which when summed over the 3-hour period from Julian hour 7456 gives a total accumulated precipitation of 0.15 inch. If there is a tie of two intensities within a month, the first value is given as the reported value, as was done here. Subsequent intensity values for November 1966 are calculated in a similar manner.

Table 3. Tucson, Arizona, Hourly Precipitation Intensities for 1 through 48 Hours in 1958

State	Station No. and Year	Month	Intensity	Max Hour	Duration	Acc Amt	No. of Acc Hours	No. of Msg Hours	Beginning Hour
02	882058	7	1.43	5022	1	0	0	0	5022
02	882058	7	2.39	5022	2	0	0	0	5021
02	882058	7	3.02	5022	3	0	0	0	5021
02	882058	7	3.66	5022	6	0	0	0	5021
02	882058	7	3.87	5022	12	0	0	0	5021
02	882058	7	3.93	5022	24	0	0	0	5020
02	882058	7	3.93	5022	48	0	0	0	5020

Table 4. Tuweep, Arizona, Hourly Precipitation Intensities for November and December 1966.

State / Station No. and Year / Month	Intensity	Max Hour	Duration	Acc Amt	No. of Acc Hours	No. of Msg Hours	Beginning Hour
02-88956611	0.12	7481	1	81	16	0	7481
02-88956611	0.15	7481	2	81	16	0	7480
02-88956611	0.15	7456	3	81	16	0	7456*
02-88956611	0.30	7456	6	81	16	0	7456*
02-88956611	0.61	7456	12	81	16	0	7456*
02-88956611	0.86	7481	24	0	0	0	7458*
02-88956611	0.96	7481	48	0	0	0	7456*
02-88956612	0.45	8157	1	0	0	0	8157
02-88956612	0.86	8157	2	0	0	0	8157
02-88956612	1.26	8157	3	0	0	0	8157
02-88956612	1.79	8157	6	0	0	0	8155
02-88956612	2.30	8157	12	0	0	0	8150
02-88956612	3.57	8157	24	0	0	0	8137
02-88956612	4.96	8157	48	0	0	0	8113

There is no missing data at Tuweep during December 1966 and Tuweep has a maximum of 0.45 inch recorded during Julian hour 8157 (December 6 in the hour ending at 2100). During the next hour an additional 0.41 inch was recorded and at the hour ending at 2300 on 0.40 inch was recorded giving a 1.26 inches over three hours. The 48-hour amount of 4.96 inches began on December 4 in the hour ending at 0100 (Julian hour 8113). Comparing the intensity of precipitation for the various durations in December 1966 with the same durations during July 1958, one can readily see the difference between warm-season and cold-season precipitation. The precipitation during the cold season is less intense, but persists through the period. On the other hand, most of the precipitation during July mostly occur during the six hours of 5021 through 5027. Clearly there are seasonal differences in the characteristics of the precipitation.

Examples of the annual maximum intensities determined from daily data are given in Table 5 for Abbott 1 SE, New Mexico. The 29 indicates the state of New Mexico; 0022 is the station number for Abbott 1 SE; the year is 1974; the Julian day is 210 or 7/29; the maximum precipitation is 1.45 inches; the 1 shows the relative position of the maximum day in the sequence (which for a 1-day duration is identical to the first day or Julian day 210) and the amount of precipitation on this day is 1.45 inches. The last five zeros are used for indicators, to define the amount of accumulated precipitation, or the accumulated number of days or missing days in a year. For example, if an accumulated amount was embedded as part of the 10- or 20-day duration intensities then the code, -8 (see second example, year 1980) would appear in the fifth last column, if part of the duration has some missing data the code, -9, would appear. The last three columns provide accumulated amount of precipitation (if any), the number of accumulated days (if any), and the number of missing days (if any) for the year. For the year 1974 there were no missing or accumulated days, therefore there was no accumulated precipitation.

The sixth line in Table 5 gives the precipitation intensity for the 20-day duration in 1974. The beginning day of the sequence is Julian day 202 or July 21 with a total of 5.27 inches of precipitation during the 20-day period. The day with the most precipitation is Julian day 210 or July 29, and this was the 9th day in the sequence (column 7). The maximum day for each duration in the sequence of days is given in the same manner.

For durations of seven days and greater, monthly maximum values are not being determined. Rather the top six to ten precipitation intensities for durations of seven days are being calculated. Enough of the top intensities for each duration greater than seven days will be calculated so that seasonal relations for these durations can be determined. Table 6 shows the top six durations for Abiquiu Dam (0041) in New Mexico for the years 1987 and 1988. Again the Julian day, date, and the precipitation intensity is

Table 5. Abbott 1SE, New Mexico, Annual Maximum Daily Precipitation Intensities for 1 Day through 60 Days for 1974 and 1980

State and Station No.	Year	Beginning Date			Intensity	Maximum Day in Sequence	Date			Intensity of Max Day	Duration	Indicator Acc	Indicator Msg	Acc Amt	No. of Days Acc	No. of Days Msg
29-0022	1974	210	7	29	145	1	210	7	29	145	1	0	0	0	0	0
29-0022	1974	213	8	1	193	1	213	8	1	113	2	0	0	0	0	0
29-0022	1974	210	7	29	263	1	210	7	29	145	4	0	0	0	0	0
29-0022	1974	210	7	29	396	1	210	7	29	145	7	0	0	0	0	0
29-0022	1974	209	7	28	474	2	210	7	29	145	10	0	0	0	0	0
29-0022	1974	202	7	21	527	9	210	7	29	145	20	0	0	0	0	0
29-0022	1974	207	7	26	583	4	210	7	29	145	30	0	0	0	0	0
29-0022	1974	189	7	8	626	22	210	7	29	145	45	0	0	0	0	0
29-0022	1974	205	7	24	848	6	210	7	29	145	60	0	0	0	0	0
29-0022	1980	118	4	27	240	1	118	4	27	240	1	0	0	0	0	1
29-0022	1980	118	4	27	240	1	118	4	27	240	2	0	0	0	0	1
29-0022	1980	115	4	24	260	4	118	4	27	240	4	0	0	0	0	1
29-0022	1980	115	4	24	260	4	118	4	27	240	7	0	0	0	0	1
29-0022	1980	115	4	24	260	4	118	4	27	240	10	0	0	0	0	1
29-0022	1980	118	4	27	435	1	118	4	27	240	20	-8	0	0	0	1
29-0022	1980	115	4	24	458	4	118	4	27	240	30	-8	0	0	0	1
29-0022	1980	93	4	2	475	26	118	4	27	240	45	-8	0	0	0	1
29-0022	1980	82	3	22	498	37	118	4	27	240	60	-8	0	0	0	1

Table 6. Top Six 10-day Precipitation Intensities at Abiquiu Dam, New Mexico for 1987 and 1988.

State and Station No.	Year	Beginning Date			Intensity	Duration and Rank	Acc Amt	No. Acc	of Days Msg
29-0041	1987	211	7	30	161	10-1	0	0	0
29-0041	1987	235	8	23	125	10-2	0	0	0
29-0041	1987	160	6	9	102	10-3	0	0	0
29-0041	1987	303	10	30	96	10-4	0	0	0
29-0041	1987	136	5	16	90	10-5	0	0	0
29-0041	1987	8	1	8	76	10-6	0	0	0
29-0041	1988	211	7	29	379	10-1	0	0	0
29-0041	1988	139	5	18	179	10-2	0	0	0
29-0041	1988	236	8	23	171	10-3	0	0	0
29-0041	1988	255	9	11	90	10-4	0	0	0
29-0041	1988	202	7	20	86	10-5	0	0	0
29-0041	1988	180	6	28	65	10-6	0	0	0

provided. Interestingly, the top three 10-day precipitation intensities in 1988 are greater than the maximum annual or the highest 10-day precipitation intensity for 1987.

Seasonality

Software development was begun during this quarter to examine possible seasonal relations of the precipitation intensities. Initially, the software examines the year beginning from January 1 in an effort to define those periods that are wet or dry. This survey will be done for varying durations beginning at 60 days. The preliminary version of this software only surveys one year at a time. However, the next version will survey two years at a time, and will begin the search with different months of the year.

Storm Analysis

A major thrust that will begin in the fourth quarter is the development of a storm analysis program on an IBM RISC 6000 work station. The Bureau of Reclamation (Lou Schreiner and Dick Stodt) developed a program for use on a main-frame computer to examine storms in orographic regions. This program provides a tool to analyze individual storms, and has been used to study extreme rainfall events over the Colorado River and the Pacific Northwest. This program gives a tool to analyze individual storms. The output from this program provides a total-storm isohyetal analysis, mass curves at individual stations, and depth-area-duration (DAD) curves. These results will be used to develop DAD curves and mass curves for use in conjunction with the point precipitation return frequencies.

Personnel

During the past six months a significant amount of time was spend developing vacancy announcements, interviewing potential new personnel, and completing paper work necessary to hire new personnel. Three new people have been hired and are currently on board. Some background about these three people is provided.

Lesley Tarleton joined the Hydrometeorological Branch as a Project Leader on June 29. Lesley came from Boulder, Colorado, where she was working with Dr. R. W. Katz of the Environmental and Societal Impacts Group at the National Center for Atmospheric Research (NCAR) on temperature variability associated with changes in climatic means. Lesley completed her Ph.D. at the University of Colorado in 1987, followed by a year of teaching at the University of Oklahoma in Norman. In 1988 she returned to Colorado where she worked as a meteorologist at Wright Water Engineers in Denver for two years. As a student Lesley had considerable experience in gathering data on a wide variety of field experiments. Lesley will serve as a project leader for the Semi-Arid Precipitation Frequency Project, and will take on much of the day-to-day administrative duties and research efforts.

Daniel Romberger transferred to the Hydrometeorological Branch as a Computer Specialist on June 1, from the Systems Development Branch of the National Geodetic Survey. Dan received a B.S. in Horticulture from the University of Maryland, and then decided that this was not his "thing." He returned to the University of Maryland and received a second B.S. in Information Systems Management in August 1988. Dan began working at the Systems Development Branch as a student, and when he left he was the technical lead of a project developing interactive applications on a large national data base. Dan will concentrate on developing a version of the storm analysis program on a work station. This program will be used for the Semi-Arid project and the development of probable maximum precipitation estimates for California.

Julie Olson was hired as a Physical Scientist, and began work on June 1. Julie received a B.S. with honors from the University of Maryland in May 1992. Her major was Geography. Three summers ago Julie worked for the Department of Defense, and did computer mapping on a SUN work station. During the last two summers, Julie assisted in the orientation of incoming freshmen and transfer students at the University of Maryland. Julie will be working on several projects. She will assist in the development of data bases, and provide support for mapping in this and other projects within the Branch.

References

Hershfield, D. M., 1961: Rainfall frequency atlas of the United States. Technical Paper No. 40, U. S. Weather Bureau, Washington, DC, 115 pp.

Redmond, K., 1991: A user's guide to RAWS products. Western Regional Climate Center, WRCC Report #91-02, Reno, NV, 28 pp + figs.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

W/OH11/lft

November 16, 1992

MEMORANDUM FOR: Semi-arid Precipitation Frequency Project Participants

FROM: John Vogel and Lesley Tarleton W/OH11

SUBJECT: Semi-arid Project 4th Quarterly Report: June 1 - September 30, 1992

Enclosed is a copy of the Fourth Quarterly Progress Report for the Semi-arid Precipitation Frequency Study for the southwestern United States. In this update, the work done on data base acquisition, data formatting and quality control is detailed. As of September 30, 1992, the data sets for all the states in the study (Arizona, Nevada, New Mexico, Utah, and southeastern California) were nearly complete. Other topics covered in the report are seasonality, use of L-moment statistics, and some of the computer resources being used, such as GRASS (Geographical Resources Analysis Support System) software.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMI-ARID PRECIPITATION FREQUENCY STUDY
Fourth Quarterly Progress Report
for the period from
July 1 through September 30, 1992

by

Lesley F. Tarleton, John L. Vogel, Julie M. Olson,
Edwin H. Chin, and Michael Yekta
Office of Hydrology
National Weather Service

Silver Spring, Maryland
November 1992

SEMI-ARID PRECIPITATION FREQUENCY STUDY
Fourth Quarterly Progress Report
for the period from
July 1 through September 30, 1992

Overview

The major work in the fourth quarter was software refinement, data processing and quality control. Except for some minor alterations in software because of some new data problems, the software for the reduction of hourly and daily precipitation data was completed in this quarter. Action taken as a result of quality control included deleting some stations and merging others. Consequently, data acquisition, formatting for processing, and basic quality control are nearly complete for both hourly and daily data. Some dense network data and specific storm data are still being sought. Seasonal and regional analyses have been started, using L-moment statistics and other analytic methods. GRASS GIS software was installed on an IBM RISC 6000 workstation in September, and several members of the staff received training from the Corps of Engineers GRASS staff from Champaign, Illinois.

Data Acquisition

Essentially all the National Climatic Data Center (NCDC) data, both hourly and daily, are now in the Semiarid Project data base and are formatted for statistical and return frequency analysis. In addition, Michael Yekta is working on software to put the SNOTEL (SNOwpack TELemetry) data in an NCDC-compatible format. The RAWS (Remote Automated Weather Stations) data set is being reformatted and will be sent to us as soon as it is available from the Western Regional Climate Center at Reno, Nevada.

Lesley Tarleton contacted the U.S. Geological Survey (USGS) in Reston, Virginia, for information about their recording precipitation gages, and received names and contacts for state USGS offices in the southwestern United States. As a result of contacting the New Mexico USGS office, a formal request for the Albuquerque area recording gage data was made. Additional contacts by phone and mail are being made to other federal, state, and local agencies.

Quality Control

Hourly data.

Quality control of hourly data and the collation of sufficiently long records continues. Among the methods used in evaluating the station data, are: 1) L-moment statistics (mapping and plots of L-skew versus L-coefficient of variation and L-skew versus L-kurtosis), 2) double-mass curves, and 3) checking proximity criteria (distance and elevation) to determine whether stations with short periods of record can be merged. Some examples will illustrate the processes and the decisions made to keep or discard data.

In the case of short records (less than five years) and the proximity of two or more stations, the procedure included a qualitative check for nearby stations and then a quantitative check on separation - distance and elevation. This is done to increase, if possible, the period of record by merging the data from two or more stations to make the total record more statistically robust. In Figure 1 the locations of the NCDC hourly stations for Arizona are shown. The names, station numbers, and periods of record are listed in Table 1. All stations that appeared close are circled in Figure 1 and were checked for length of record and nearness to others (criteria: less than five miles distant and less than 300 feet difference in elevation). Sixteen sets of stations were considered. Table 2 lists ten stations with short records and the comparisons and actions taken. The additional comparisons circled in Figure 1 included stations with records of more than five years.
An illustration of a successful comparison of stations is the Grand Canyon. The greatest distance between any of the three Grand Canyon stations: Grand Canyon (3581), Grand Canyon N P (3595), and Grand Canyon Natl Pk 2 (3596), was found to be about a mile with an elevation difference of 160 feet. As for record length, each station had from 10 to 20 years of data, with no overlap in time. The earliest and longest record is Grand Canyon (3581), beginning in July 1948, Therefore, if the records were representative of the same precipitation regime, three short records could possibly be combined to make a single time series of more than 30 years. This would be particularly important for a high-elevation station such as the Grand Canyon at 6900 feet, as there are relatively few observations at higher elevations. To test whether these three records were compatible, a double-mass curve of the three Grand Canyon stations was plotted against several adjacent long-term stations, as shown in Figure 2. The procedure for preparing a double-mass curve is to choose four or five adjacent long-term stations, find their average annual value, in this case the annual maximum precipitation, and plot the station of interest against the average of the other combined stations. Although the station numbers of some of the stations used for comparison are the same as the stations being evaluated,

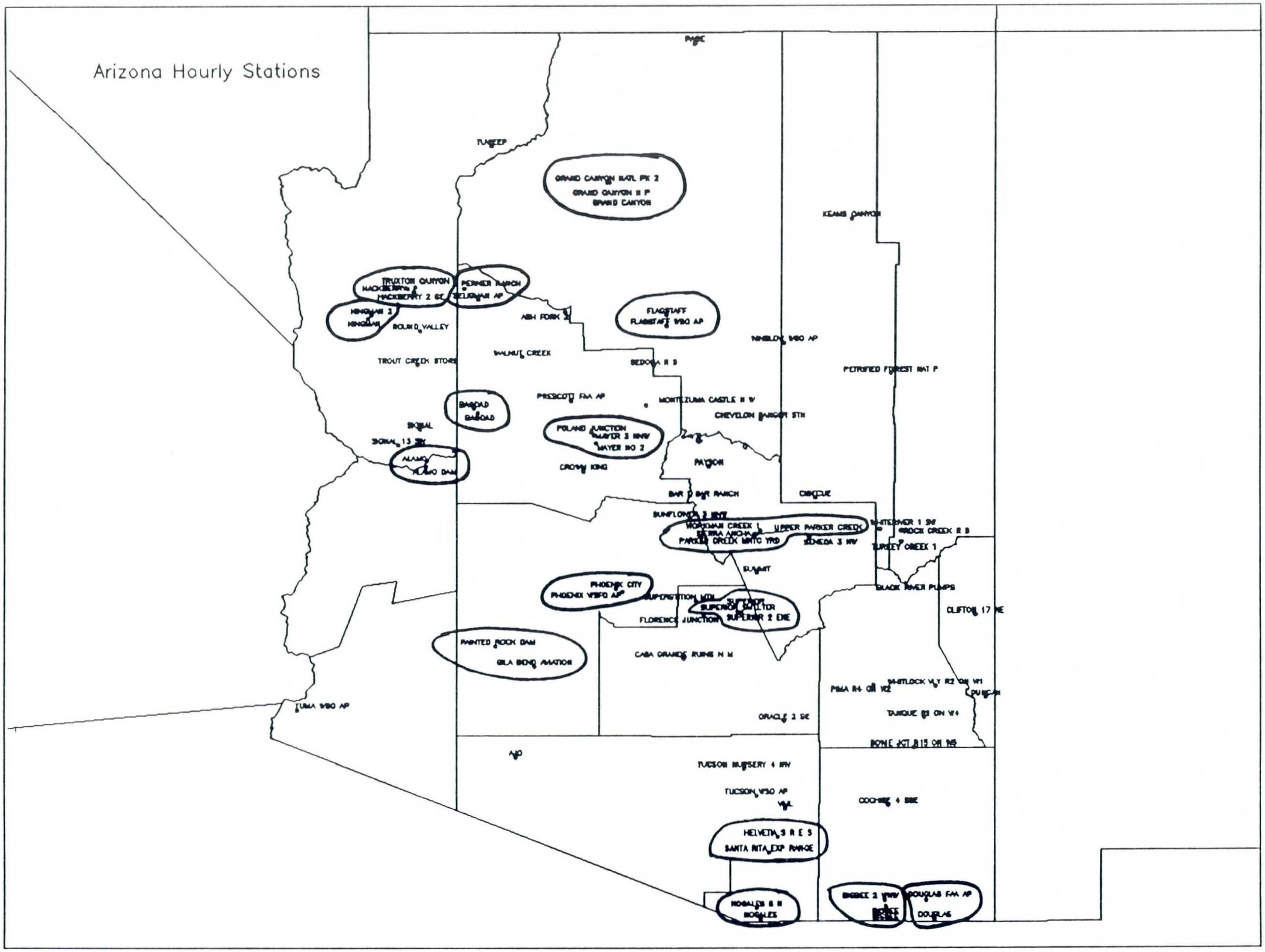

Arizona Hourly Stations
GRAND CANYON
FLAGSTAFF
FLAGSTAFF WSO AP
PAYSON
PHOENIX CITY
NOGALES
DOUGLAS
TUCSON WSO AP
YUMA WSO AP

Figure 1.

TABLE 1.

ARIZONA HOURLY STATIONS

NAME	SITE	LAT	LON	ELEV	POR
AJO	0080	32.37	-112.87	1800	7/1948-12/1990
ALAMO	0096	34.27	-113.57	1060	7/1948- 3/1965
ALAMO DAM	0100	34.23	-113.58	1290	3/1965-12/1990
ASH FORK 2	0487	35.22	-112.48	5080	7/1948-12/1990
BAGDAD	0582	34.60	-113.20	3200	7/1948-11/1949
BAGDAD	0586	34.57	-113.17	3710	12/1949-11/1969
BAR T BAR RANCH	0625	34.03	-111.37	3100	12/1976- 2/1980
BISBEE	0768	31.43	-109.92	5310	7/1948- 2/1985
BISBEE	0773	31.43	-109.92	5310	6/1961- 6/1982
BISBEE 2 WNW	0775	31.47	-109.93	5600	3/1985-12/1990
BLACK RIVER PUMPS	0808	33.48	-109.77	6040	7/1948-12/1990
BOWIE JCT R15 ON W5	0966	32.43	-109.70	4720	7/1948- 2/1967
CASA GRANDE RUINS N M	1314	33.00	-111.53	1420	7/1948-12/1990
CHEVELON RANGER STN	1574	34.53	-110.92	7010	12/1981-12/1990
CIBECUE	1749	34.03	-110.48	5050	6/1980-12/1990
CLIFTON 17 NE	1852	33.28	-109.20	4280	6/1978-12/1980
COCHISE 4 SSE	1870	32.07	-109.90	4180	7/1948-12/1990
CROWN KING	2329	34.20	-112.33	5920	6/1980-12/1990
DOUGLAS	2659	31.35	-109.53	4040	7/1948-12/1990
DOUGLAS FAA AP	2664	31.47	-109.60	4100	7/1948- 9/1951
DUNCAN	2754	32.75	-109.12	3660	8/1975-12/1990
FLAGSTAFF	3007	35.20	-111.67	6910	7/1948- 3/1951
FLAGSTAFF WSO AP	3010	35.13	-111.67	7010	1/1950-12/1990
FLORENCE JUNCTION	3035	33.28	-111.37	1880	1/1968- 9/1982
GILA BEND AVIATION	3398	32.95	-112.72	720	7/1948- 9/1951
GRAND CANYON	3581	36.05	-112.13	6910	7/1948- 8/1957
GRAND CANYON N P	3595	36.05	-112.13	6950	8/1957- 5/1976
GRAND CANYON NATL PK 2	3596	36.05	-112.15	6790	5/1976-12/1990
HACKBERRY	3788	35.37	-113.73	3580	7/1948- 1/1959
HACKBERRY 2 SE	3790	35.35	-113.68	3700	1/1959- 7/1970
HELVETIA S R E S	3981	31.87	-110.78	4300	7/1948- 4/1950
KEAMS CANYON	4586	35.82	-110.20	6210	7/1948-12/1990
KINGMAN	4639	35.18	-114.05	3360	7/1948- 8/1967
KINGMAN 2	4645	35.20	-114.02	3540	8/1967-12/1990
MAYER 3 NNW	5325	34.43	-112.25	4640	3/1969-11/1986
MAYER NO 2	5344	34.38	-112.23	340	1/1986-12/1990
MONTEZUMA CASTLE N W	5635	34.62	-111.83	3180	7/1979-12/1990
NOGALES	5921	31.35	-110.92	3810	7/1948-12/1983
NOGALES 6 N	5924	31.42	-110.95	3560	8/1983-12/1990
ORACLE 2 SE	6119	32.60	-110.73	4510	2/1950-12/1990

NAME	SITE	LAT	LON	ELEV	POR
PAGE	6180	36.93	-111.45	4270	10/1957-12/1983
PAINTED ROCK DAM	6194	33.08	-113.03	550	1/1962-12/1990
PARKER CREEK MNTC YRD	6260	33.78	-110.97	4990	6/1972-12/1975
PAYSON	6323	34.23	-111.33	4910	5/1949-12/1990
PERNER RANCH	6434	35.37	-113.28	5600	4/1952-11/1969
PETRIFIED FOREST NAT P	6468	34.82	-109.88	5450	7/1948-12/1990
PHOENIX WSFO AP	6481	33.43	-112.02	1110	7/1948-12/1990
PHOENIX CITY	6486	33.45	-112.07	1080	7/1948- 8/1968
PIMA R4 ON W2	6546	32.83	-110.02	3770	7/1948- 2/1967
POLAND JUNCTION	6676	34.45	-112.27	4900	7/1948- 3/1969
PRESCOTT FAA AP	6801	34.65	-112.43	5020	7/1948-11/1969
ROCK CREEK R S	7210	33.82	-109.80	3630	6/1955- 3/1966
ROUND VALLEY	7311	35.10	-113.63	3740	7/1948-11/1969
SANTA RITA EXP RANGE	7593	31.77	-110.85	4300	5/1950-12/1990
SEDONA R S	7708	34.87	-111.77	4220	4/1973-12/1990
SELIGMAN AP	7718	35.30	-113.17	5580	7/1948- 6/1951
SENECA 3 NW	7741	33.78	-110.53	4920	7/1948-11/1965
SIERRA ANCHA	7876	33.80	-110.97	5100	1/1976-12/1990
SIGNAL	7884	34.47	-113.63	1520	7/1948- 6/1952
SIGNAL 13 SW	7888	34.37	-113.80	2510	6/1952- 7/1961
SUMMIT	8264	33.55	-110.95	3650	10/1951- 5/1977
SUNFLOWER 3 NNW	8273	33.90	-111.48	3720	7/1980-12/1990
SUPERIOR	8348	33.30	-111.10	3000	6/1959-10/1978
SUPERIOR 2 ENE	8349	33.30	-111.07	4160	10/1978-12/1990
SUPERIOR SMELTER	8351	33.30	-111.10	2790	9/1948- 2/1958
SUPERSTITION MTN	8356	33.37	-111.43	1960	7/1948- 1/1968
TANQUE R9 ON W4	8409	32.62	-109.62	3560	7/1948- 2/1967
TROUT CREEK STORE	8762	34.88	-113.65	2850	7/1948-11/1969
TRUXTON CANYON	8778	35.38	-113.67	3820	7/1970-12/1990
TUCSON NURSERY 4 NW	8810	32.30	-111.05	2250	7/1948- 2/1965
TUCSON WSO AP	8820	32.13	-110.95	2580	7/1948-12/1990
TURKEY CREEK 1	8875	33.75	-109.80	6750	6/1955- 3/1966
TUWEEP	8895	36.28	-113.07	4780	7/1948-12/1990
UPPER PARKER CREEK	8940	33.80	-110.95	5500	7/1948- 3/1972
VAIL	8995	32.05	-110.72	3230	9/1977-12/1990
WALNUT CREEK	9158	34.93	-112.82	5090	7/1979-12/1990
WHITERIVER 1 SW	9271	33.83	-109.97	5120	7/1948-12/1990
WHITLOCK VLY R2 ON W1	9279	32.82	-109.52	3290	7/1948- 2/1967
WINSLOW WSO AP	9439	35.02	-110.73	4890	7/1948-12/1990
WORKMAN CREEK 1	9534	33.82	-110.92	6970	7/1948- 2/1986
YUMA WSO AP	9660	32.67	-114.60	210	9/1948-12/1990

Table 2.

Arizona Hourly Stations - Quality Control/Deletions & Combinations
Stations with short records (<5 years):

Station Name	Station Number	Calendar Years	Action Taken	Comment Dates of Record
1. Bar T Bar Ranch	0625	3	delete	12/76-2/80, record too short, no nearby station with which to combine
2. Bisbee 2 WNW	0775	4	delete	3/85-12/88, no complete years of record
Bisbee	0768	38	combine	7/48-2/85
Bisbee	0773	2	combine	6/61-6/82, 20 years of '0's, 2 years of data
3. Clifton	1852	3	delete	6/78-12/80, record too short, no nearby station with which to combine
4. Douglas FAA AP	2664	4	delete	7/48-9/51, record too short, more than 5 miles from Douglas/2659 and coincident in time
5. Flagstaff	3007	4	combine	7/48-3/51, within 5 miles and within 300 feet elevation of Flagstaff WSO AP/3010
Flagstaff WSO AP	3010	39	combine	1/50-12/88, add 7/48-12/49 of Flagstaff/3007 to 3010 to make total record of nearly 41 years
6. Gila Bend Aviation	3398	4	delete	7/48-9/51, record too short, more than 5 miles from nearest station, Painted Rock Dam/6194
7. Helvetia SRES	3981	3	delete	7/48-4/50, record too short (<2 years), slightly more than 5 miles from Santa Rita Lodge/7593
8. Mayer No 2	5344	3	delete	1/86-12/88, record incomplete
Mayer 3 NW	5325	18	combine	3/69-11/86, within 5 miles and 300 feet of Poland Junction/6676
Poland Junction	6676	22	combine	7/48-3/69, within 5 miles and 300 feet of Mayer 3 NW/5325
9. Parker Creek MNTC YRD	6260	4	combine	6/72-12/75, within 5 miles and 300 feet of Sierra Ancha/7876
Sierra Ancha	7876	13	combine	1/76-12/88, within 5 miles & 300 feet of Parker Creek MNTC YRD/6260
Upper Parker Creek	8940	25	keep separate	7/48-3/72, within 5 miles, but over 400 feet above Parker Creek MNTC YRD/6260 and Sierra Ancha/7876
Workman Creek 1	9534	39	keep separate	7/48-2/86, 2000-foot elevation difference, long record, do not combine
10. Seligman AP	7718	4	delete	7/48-6/51, record too short, more than 5 miles from Perner Ranch/6434
Perner Ranch	6434	18	keep	4/52-11/69, more than 5 miles from Seligman Ranch/7718

DOUBLE MASS CURVE (1949-1979)
Stations 3581, 3595, 3596

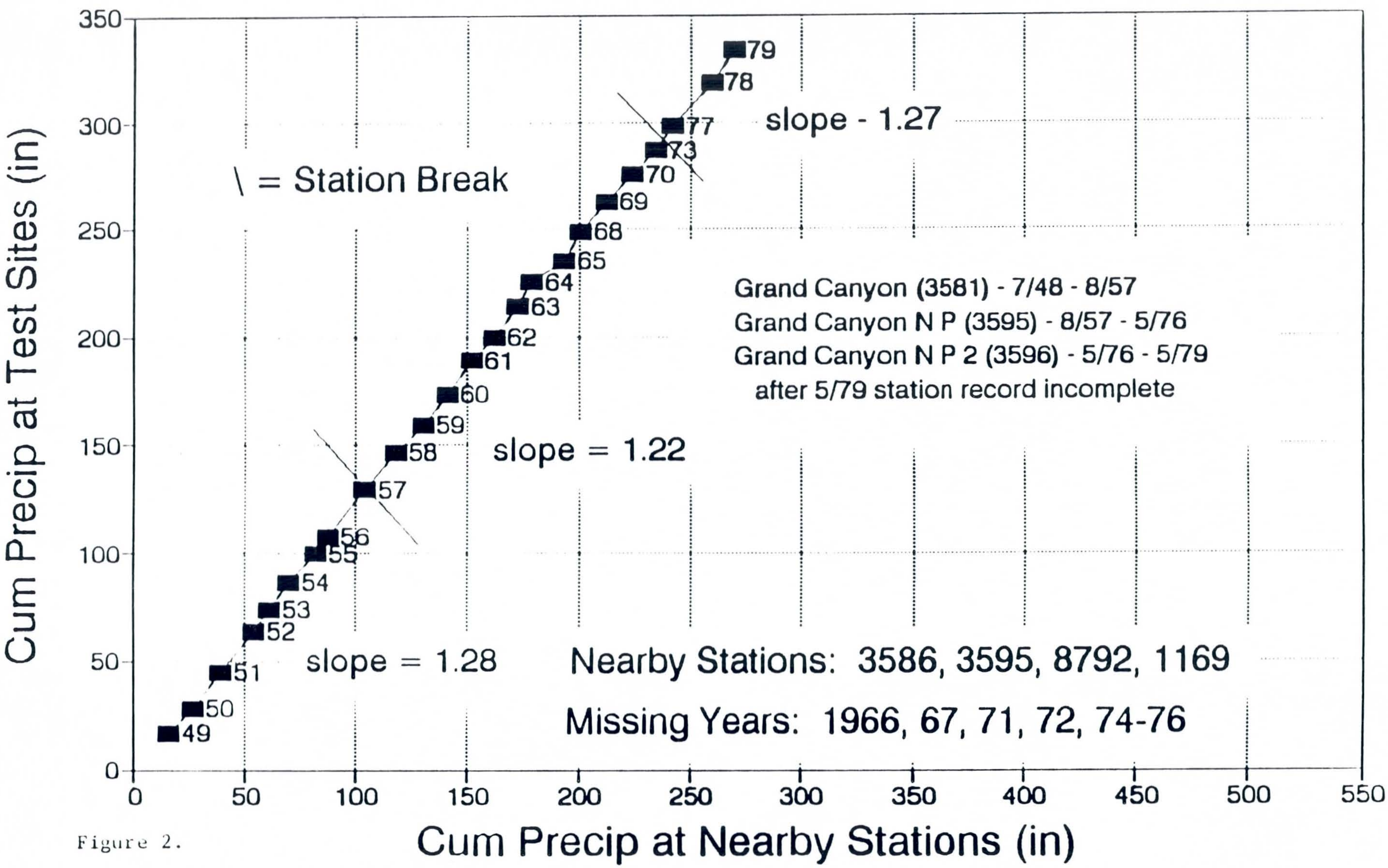


Figure 2.

the comparable stations are separate daily records being compared with the hourly records of interest here. The slanted lines on the graph indicate the temporal boundaries between stations. The data show an essentially straight-line relationship (straight-line criterion is for slopes to be within +/- 0.10) among the Grand Canyon stations and nearby stations. The slopes differ by less than 0.10, (0.06 in this case). No apparent effect from site re-location was noted; therefore, the decision was made to composite these stations. Other combinations of stations - after similar evaluations - included: 1) Hackberry, Hackberry 2 SE, and Truxton Canyon; 2) Poland Junction and Mayer 3NNW; 3) Parker Creek MNTC YRD, and Sierra Ancha; and 4) Nogales 6N and Nogales among others. The double mass-curve for Truxton Canyon is shown in Figure 3. As the slope for Truxton differs by 0.10 to 0.11 from those of the two Hackberry stations, this combination is still tentative. Further testing will be done on these records. Note that although most long-term stations have data through 1990 (Table 1), the double-mass curves are plotted only to the early 1980s. As a result of a change in record-keeping methods, no annual maximum values are available if there are any missing months of data. Prior to the change, even if a few months were missing, the annual maximum was estimated from the record; after that time, if even a single month were missing, the annual maximum is also missing.

In the case of two stations at Alamo (Alamo (0096) and Alamo Dam (0100)), the double mass-curve in Figure 4 shows a change in slope from 0.94 to 0.77 at the time of the station change; therefore, the stations were not combined. Both records, Alamo (1949-1964) and Alamo Dam (1965-1990) are being kept for further analysis. Table 3 lists the stations that were combined as of 9/30/92. There will be further quality control on all stations, including those in Table 3.

Another quality control measure uses L-moment statistics. The characteristics of these linear statistics enable one to determine whether a set of observations are consistent and likely to be a representative data sample. They also may indicate data problems within a record such as too many missing data and/or recording errors. For example, in Figure 5 (1-hour annual maximum precipitation, L-skew versus L-coefficient of variation) and Figure 6 (L-skew versus L-kurtosis), the stations Oracle (6119) and Bar T Bar Ranch (0625) are 'way out' from the rest of the data. Therefore, the original data were examined for potential causes. Figure 7 shows a time series of the one-hour annual maximum precipitation for Oracle. The 1957-value of 10.2 inches was found to be erroneous; it is a key punch error due to an 'overpunch'. A review of the published data showed that the maximum hourly amount for 1957 is 0.40 inch. That value is also shown on the plot. In the case of Bar T Bar Ranch, although the original list indicated five years of data, the actual record ran from 12/76 to 2/80, five calendar years, but only three years and

DOUBLE MASS CURVE (1949-1981)

Stations 3788, 3790, 8778

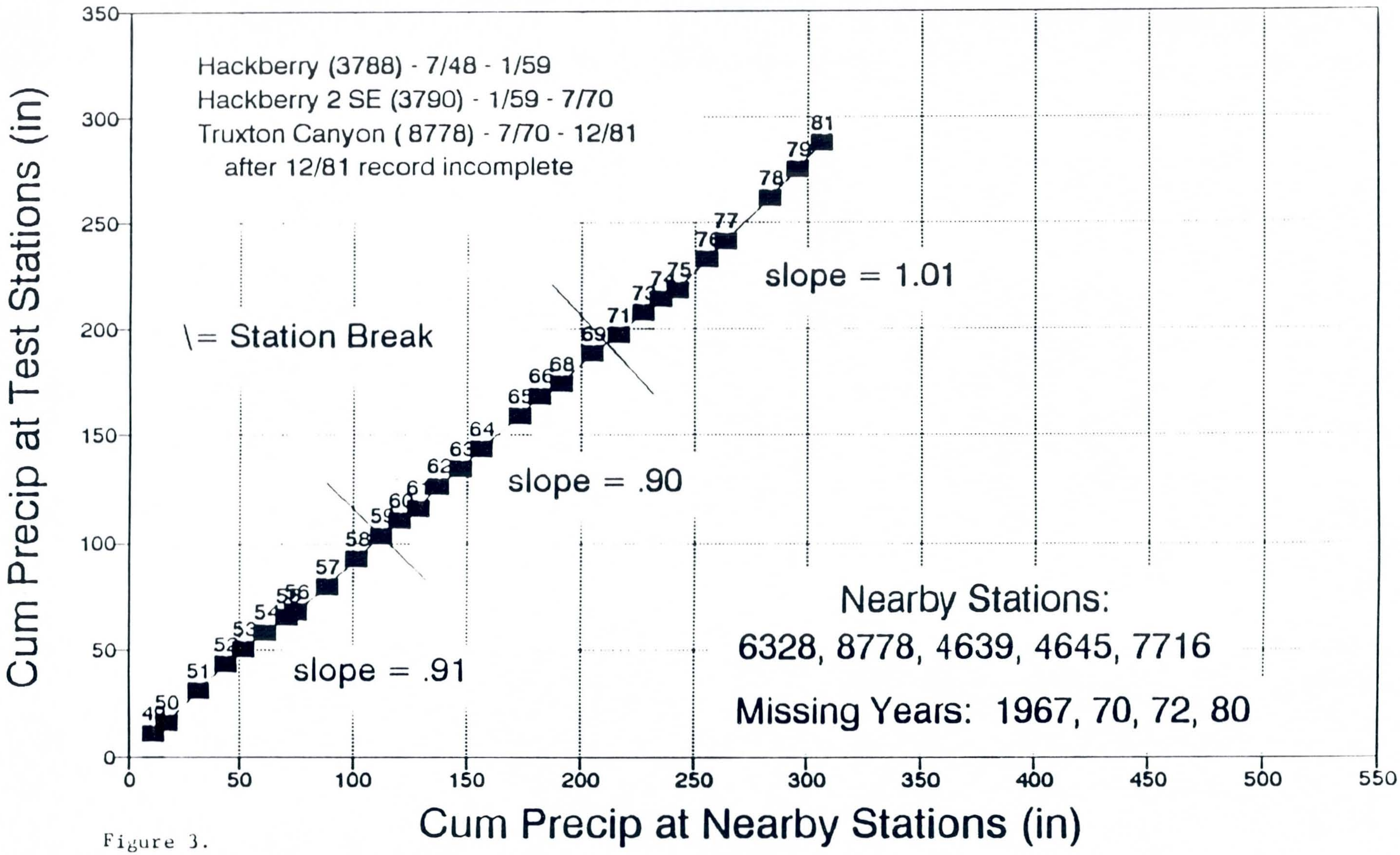


Figure 3.

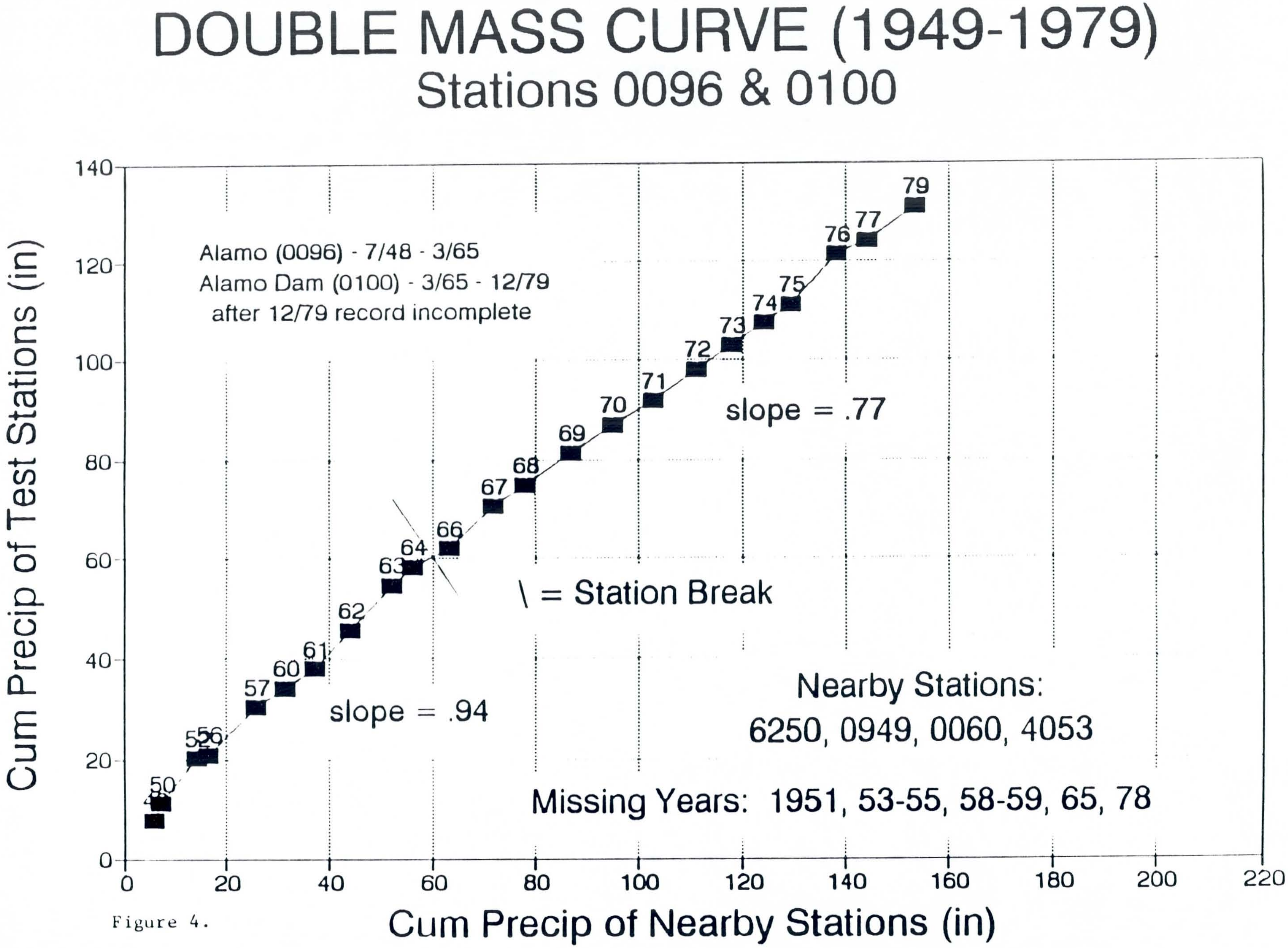

DOUBLE MASS CURVE (1949-1979)
Stations 0096 & 0100
Alamo (0096) - 7/48 - 3/65
Alamo Dam (0100) - 3/65 - 12/79
after 12/79 record incomplete
slope = .77
\ = Station Break
slope = .94
Nearby Stations:
6250, 0949, 0060, 4053
Missing Years: 1951, 53-55, 58-59, 65, 78
Cum Precip of Test Stations (in)
Cum Precip of Nearby Stations (in)

Figure 4.

Table 3.

Arizona Hourly Stations/Combinations
As of 9/30/92

1. Grand Canyon/3581 (7/48-7/57), Grand Canyon N P/3595 (8/57-4/76), and Grand Canyon Natl Pk 2/3596 (5/76-12/90); new name: **Grand Canyon Natl Pk 2/3596.**

2. Hackberry/3788 (7/48-12/58), Hackberry 2 SE/3790 (1/59-6/70), and Truxton Canyon/8778 (7/70-12/90); new name: **Truxton Canyon/8778.**

3. Kingman/4639 (7/48-8/67) and Kingman 2/4645 (7/67-12/90); new name: **Kingman 2/4645.**

4. Flagstaff/3007 (7/48-3/51) and Flagstaff WSO AP/3010 (1/50-12/90); **Flagstaff WSO AP.**

5. Bagdad/0582 (7/48-11/49) and Bagdad/0586 (12/49-11/69); new name: **Bagdad/0586.**

6. Poland Junction/6676 (7/48-2/69) and Mayer 3 NNW/5325 (3/69-11/86); new name: **Mayer 3 NNW/5325.**

7. Parker Creek Mntc Yrd/6260 (6/72-12/75), and Sierra Ancha/7876 (1/76-12/90); new name: **Sierra Ancha/7876.**

8. Nogales/5921 (7/48-7/83) and Nogales 6 N/5924 (8/83-12/90); new name: **Nogales 6 N/5924.**

9. Bisbee/0768 (7/48-5/61, 7/62-2/85) and Bisbee/0773 (6/61-6/62); new name: **Bisbee/0768.**

RELATION OF L-CV & L-SKEW
1-HOUR ANNUAL MAXIMUM FOR ARIZONA

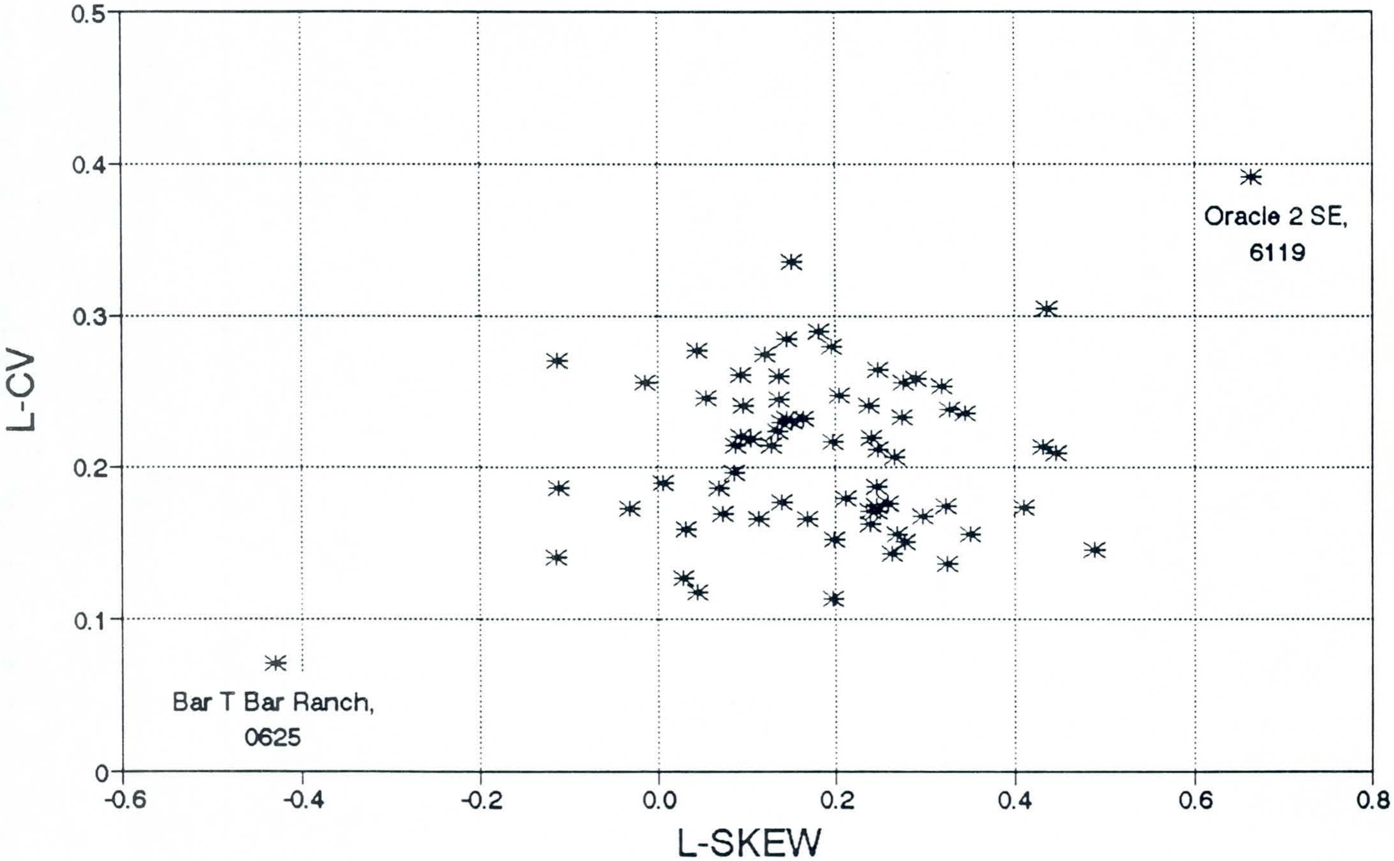


Figure 5.

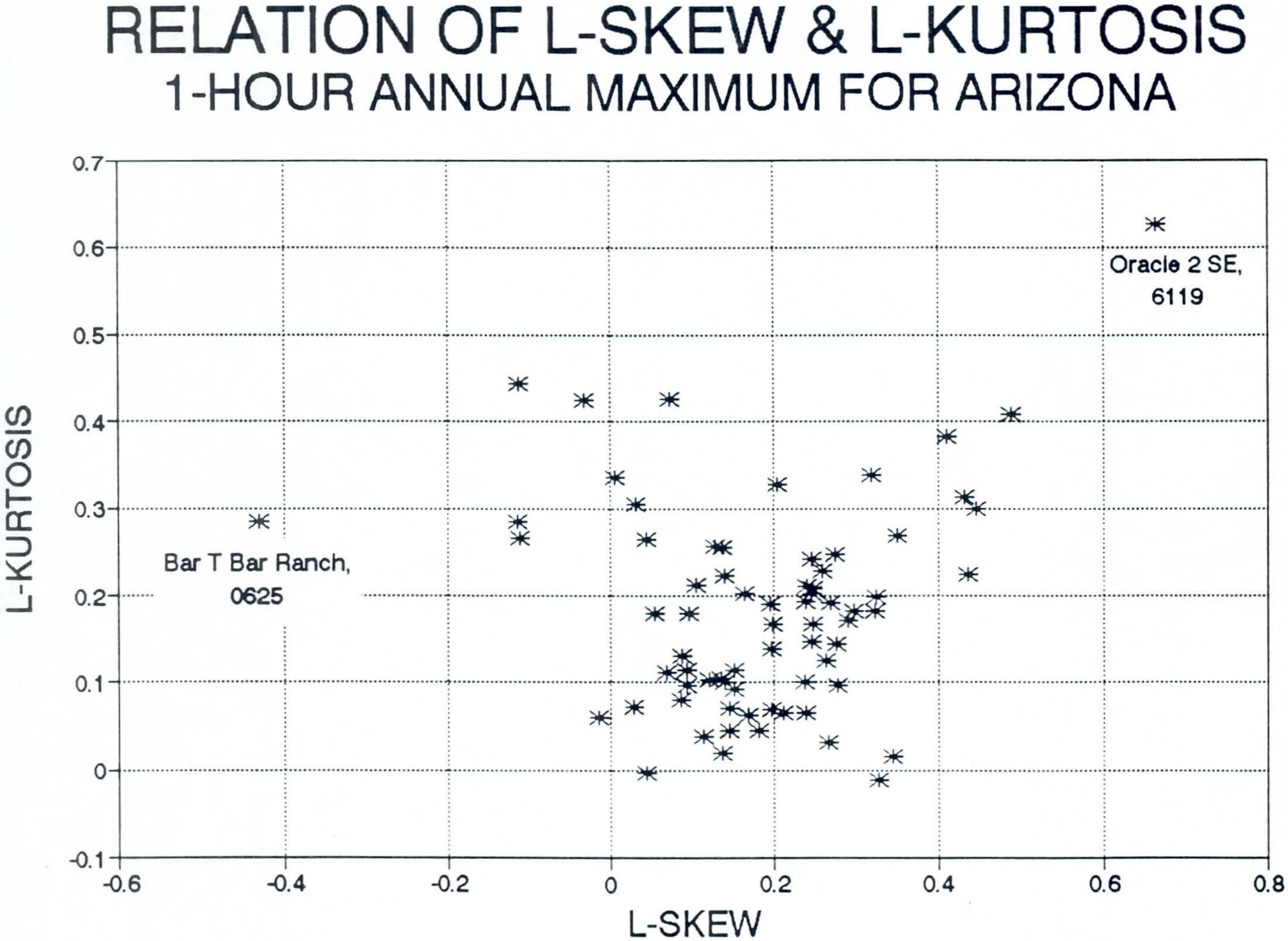

RELATION OF L-SKEW & L-KURTOSIS
1-HOUR ANNUAL MAXIMUM FOR ARIZONA
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
L-KURTOSIS
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
L-SKEW
Oracle 2 SE,
6119
Bar T Bar Ranch,
0625

Figure 6.

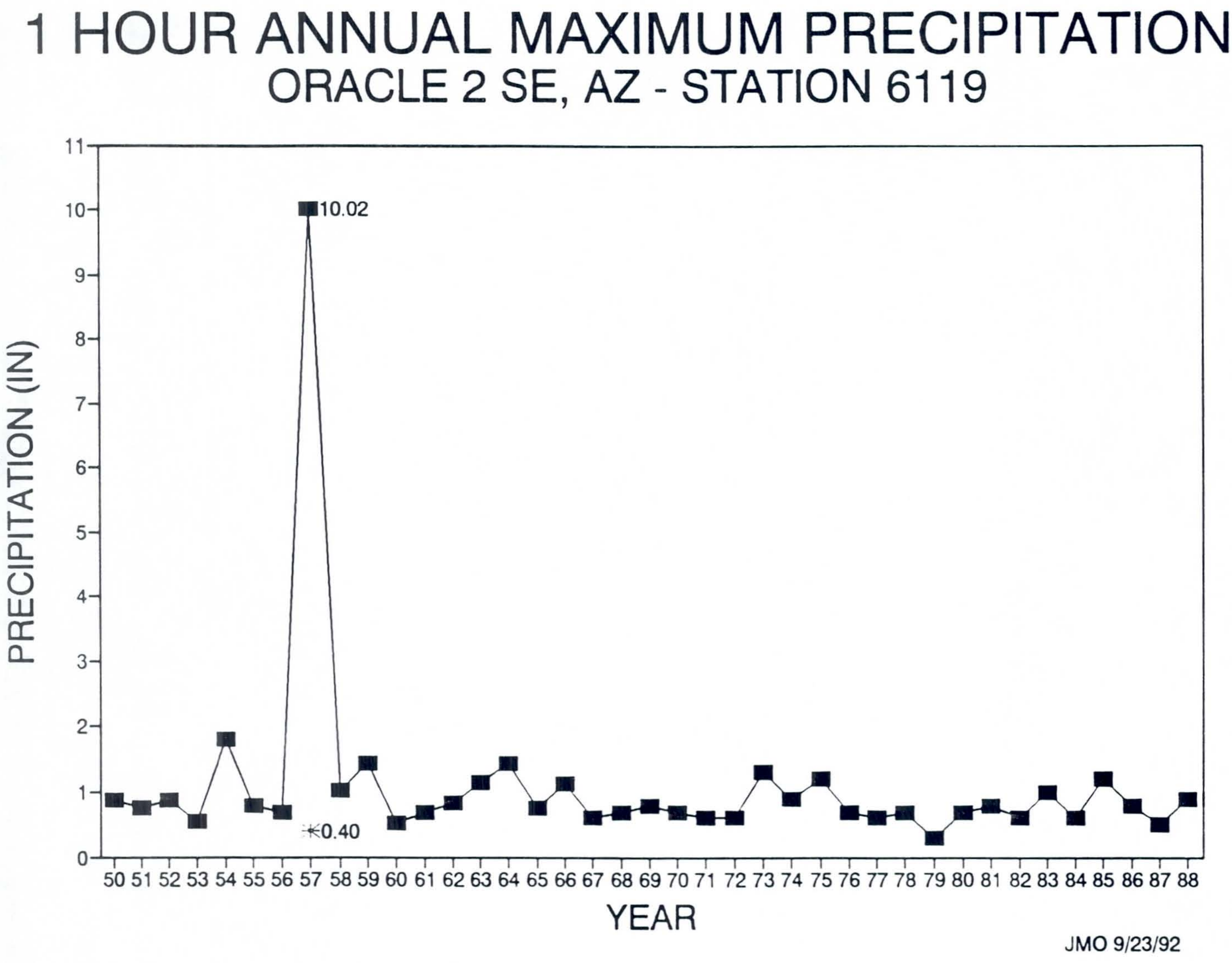

1 HOUR ANNUAL MAXIMUM PRECIPITATION
ORACLE 2 SE, AZ - STATION 6119
PRECIPITATION (IN)
10.02
0.40
0
1
2
3
4
5
6
7
8
9
10
11
50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88
YEAR
JMO 9/23/92

Figure 7.

three months of data. Thus, this record was deleted because it is too short for analysis.

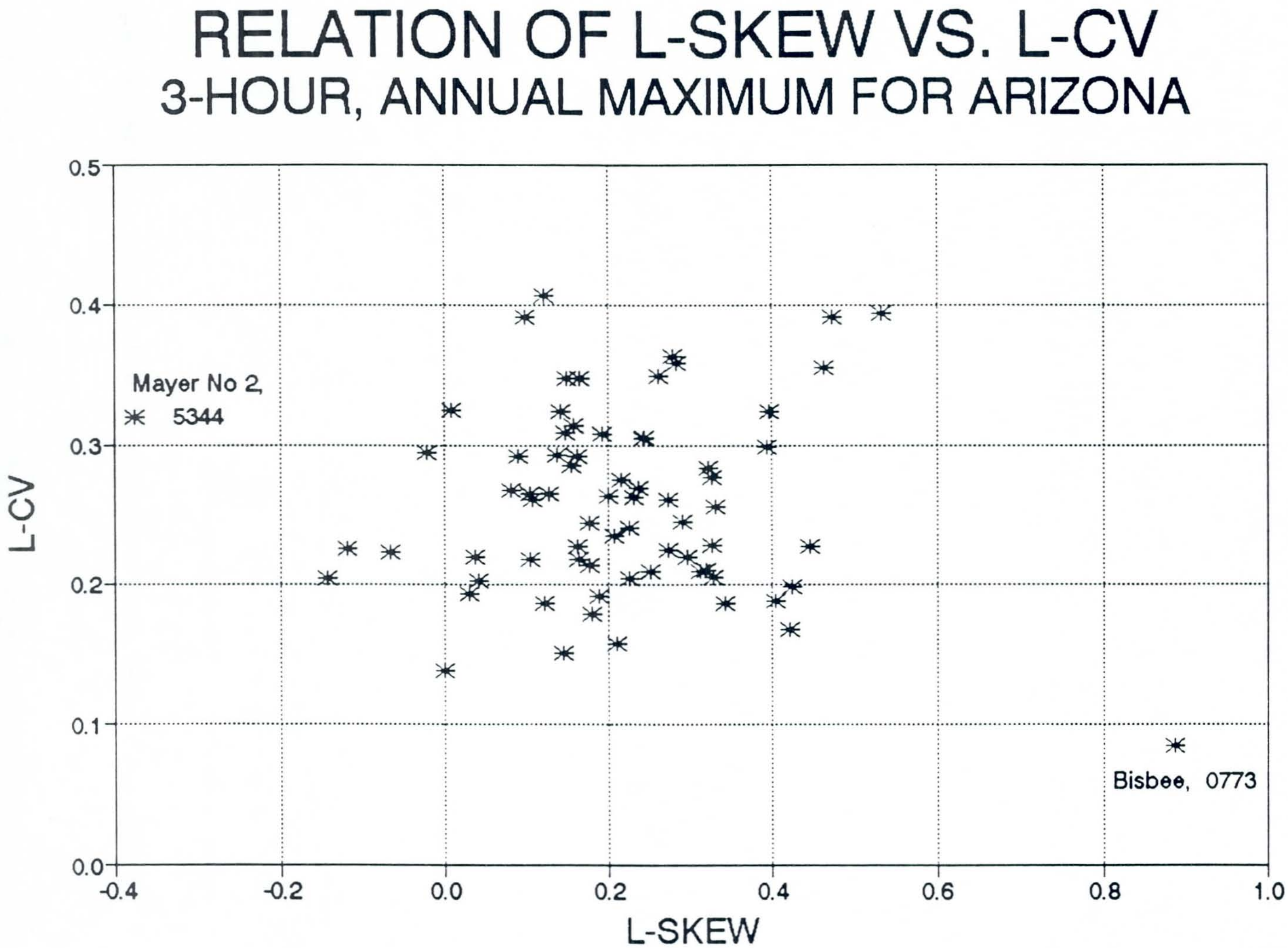
A further indication of the screening value of L-moment statistics is shown in Figures 8 and 9, the same type of plots as Figures 5 and 6, but for the 3-hour annual maxima. In these plots, stations Mayer No 2 (5344) and Bisbee (0773) are far distant from the main cluster. Mayer No 2 has, not only a short record, but many gaps as well. Mayer No 2 was deleted. Note that these two stations are not marked on the one-hour plots; Mayer No 2 (5344) fell nearer the cluster, and Bisbee (0733) had been deleted prior to making the one-hour plots and then re-inserted for testing the effect of the zeros in the record.

As for Bisbee, it was noted to have 22 years of data, but the file included 20 years of zeros. A first-round data check had shown that there were 20 years of zeros in the 0773 record, but it was decided to determine how L-moment statistics would act if this had not been found in a preliminary examination of the hourly data. The L-moment plot confirmed the data problems in the Bisbee (0773) record. Bisbee (0773) (after deleting the zeros) was combined with Bisbee (0768).

Although the City of Phoenix has two stations, Phoenix City and Phoenix WSFO AP, they have both been kept in the data base, as each has a record of more than 20 years and the two records overlap in time.

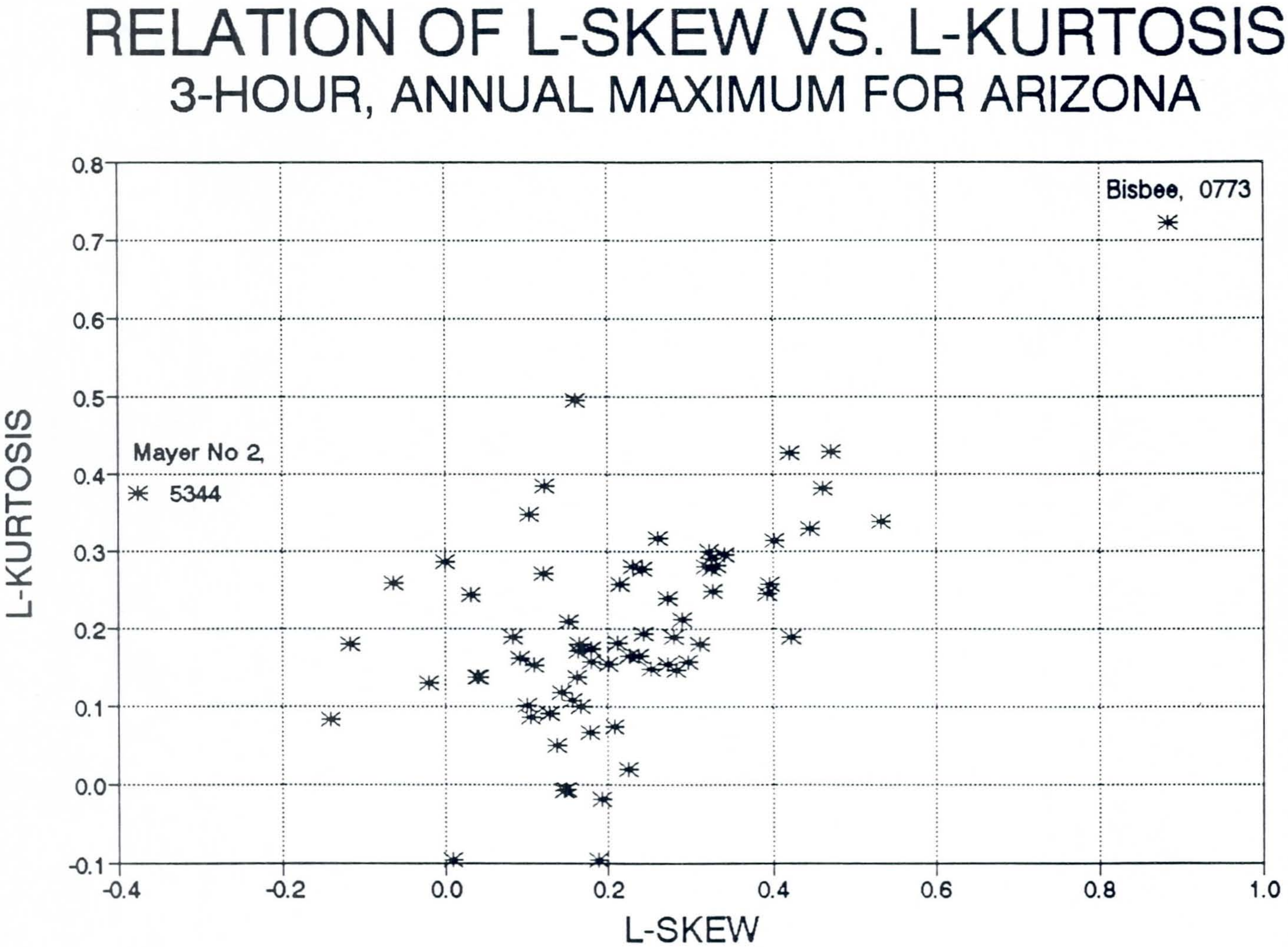
Further analysis, using L-moments (e.g. Hosking and Wallis, 1991) will include mapping of L-statistics to help determine regionality, to test homogeneity of records, and to choose the best-fit distribution for frequency analysis. L-skew plots, such as Figures 10 and 11 (same as Figures 8 and 9 except Bisbee (0773) has been combined with Bisbee (0768) and Mayer No 2 (5344) has been deleted) will be considered further, as the stations that are not within a well-defined cluster need to be checked for frequency analysis suitability.

In summary, as a result of the various quality assessments of the Arizona hourly observations, nine sets of stations were combined and eight stations deleted, as of 30 September 1992. The combinations are listed in Table 3. However, in some of the combinations where the records do not appear compatible, e.g. Kingman (not shown), further testing will be done. Note in Table 3 that the new name of the station is that of the most recent station. The deletions are noted in Table 4.



RELATION OF L-SKEW VS. L-CV
3-HOUR, ANNUAL MAXIMUM FOR ARIZONA
L-CV
0.5
0.4
0.3
0.2
0.1
0.0
Mayer No 2,
5344
Bisbee, 0773
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
L-SKEW

Figure 8.



RELATION OF L-SKEW VS. L-KURTOSIS
3-HOUR, ANNUAL MAXIMUM FOR ARIZONA
Bisbee, 0773
Mayer No 2,
5344
L-KURTOSIS
L-SKEW
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0

Figure 9.

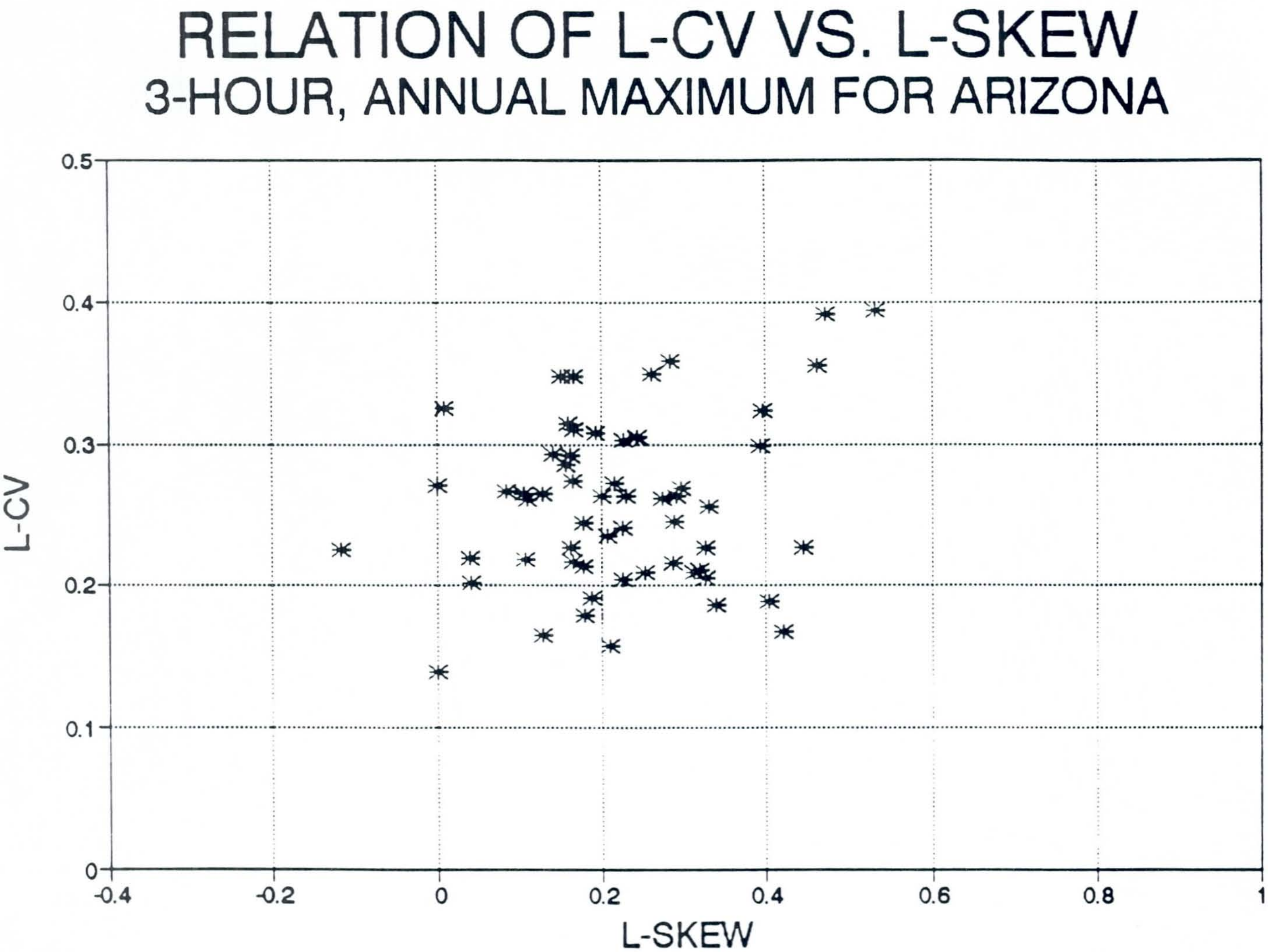

RELATION OF L-CV VS. L-SKEW
3-HOUR, ANNUAL MAXIMUM FOR ARIZONA
0.5
0.4
0.3
0.2
0.1
0
L-CV
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
L-SKEW

Figure 10.

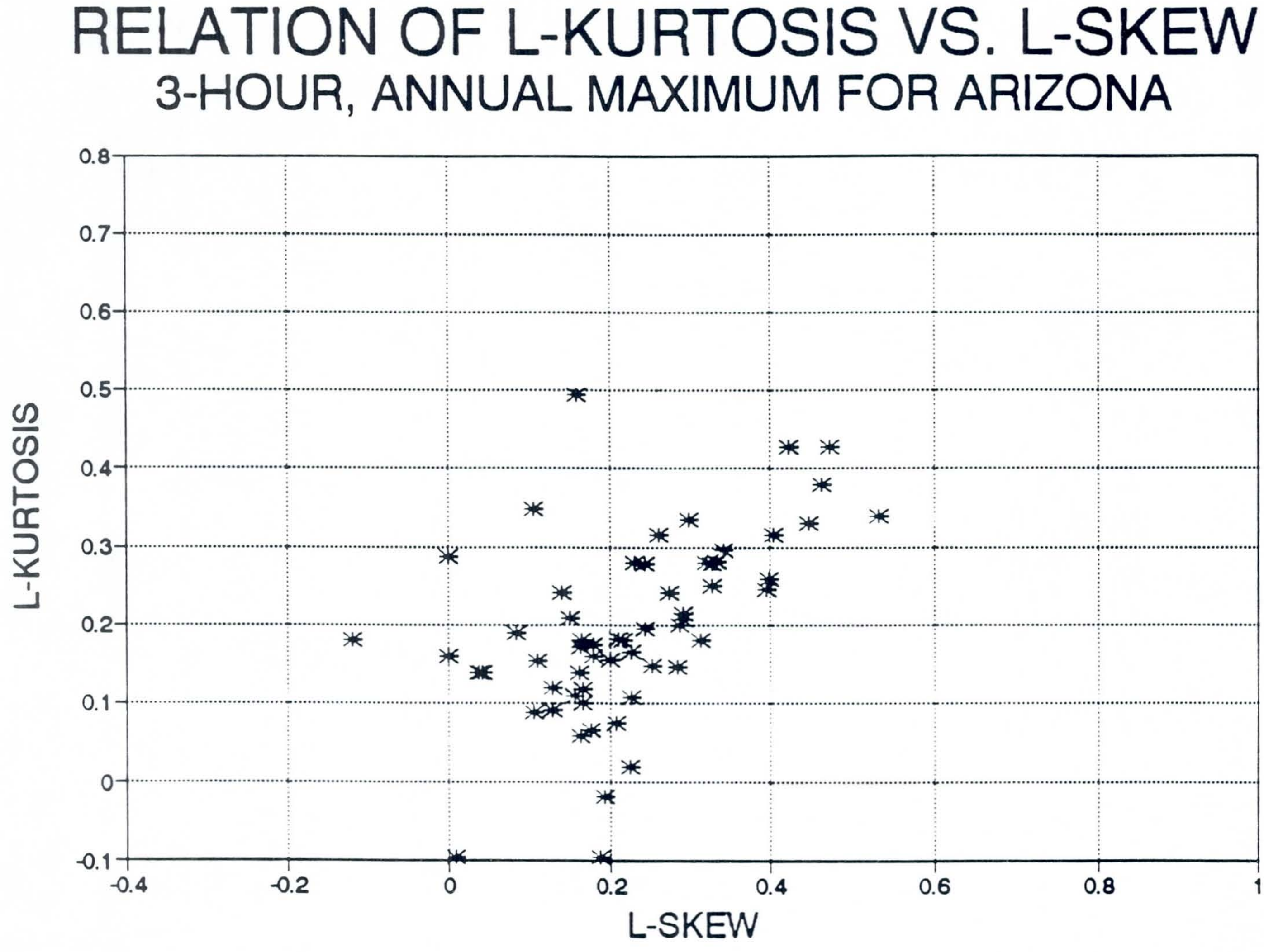

RELATION OF L-KURTOSIS VS. L-SKEW
3-HOUR, ANNUAL MAXIMUM FOR ARIZONA
L-KURTOSIS
L-SKEW
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

Figure 11.

Table 4.

Arizona Hourly Stations
Stations Deleted as of 9/30/92

Stations		
Bar T Bar	0625	Short period of record, no adjacent station to composite.
Bisbee 2 WNW	0775	Short and incomplete record, combined Bisbee (0773) and Bisbee (0768) for same time.
Clifton	1852	Short period of record, no adjacent station to composite.
Douglas FAA AP	2664	Short record, more than 5 miles from Douglas (2659), coincident in time with 2659.
Gila Bend Aviation	3398	Short period of record, no adjacent station to composite.
Helvetia SRES	3981	Less than 2 years of record.
Mayer No 2	5344	Short and incomplete record, combined Mayer 3 NW and Poland Junction for same location.
Seligman AP	7718	Short period of record, no adjacent station to composite.

Daily Data.
Ed Chin has completed appending the 1989 and 1990 daily precipitation data for Nevada and Utah, and finished data quality assurance procedures. Processing has begun with these data, using L-moment statistics and return frequency analysis. In addition to the NCDC taped data, the TP40 (Technical Paper No. 40, 1961) data have been added to the records. These data were hand-copied, keyed into the data base, and then concatenated with the later data, resulting in some records of nearly 90 years. In most cases, long records were made longer by this process rather than increasing the number of long records (i.e., 'carrying coals to Newcastle'). Although most TP40 stations added only about ten to twenty years to the recent (1948-1990) data, a few records now start as early as 1880.

Initially, in the interest of considering all possible data, all stations with at least one full year of data were included in the data base. From the original 282 NCDC stations in Nevada, 211 were left after discarding those stations that had no latitude and longitude indicated, or those that had less than one year of data. In the remaining data base, there are 105 stations with 19 or more years of data and 83 stations with 25 or more years of record. In an effort to evaluate whether the record lengths are sufficient for return frequency analysis, comparisons using L-moment statistics were made between stations with 10-year (132 sites) and 30-year (57 sites) records. The L-moments of skewness and kurtosis for the period of record were computed and plotted (L-skew versus L-kurtosis). The scatter, or rather the clustering, of the points is a measure of the stability of the data. Figure 12 shows the 'shotgun' pattern of 132 sites with 10 years of record. Figure 13 (30-year records (57 sites)) shows some scatter, but far less than the 10-year records. A count of the number of stations outside the 0.0-0.4 box in each figure, shows that 33 percent of the 10-year sites fall outside the main cluster; whereas only 16 percent of the 30-year sites lie outside the cluster. Furthermore, the data in Figures 12 and 13 appear to be in two clusters, even within the limited area of the 0.0-0.4 box. It may be that these two clusters represent two different regimes or geographic regions. This will be investigated further.

As most of the records in the data base have 19 or more years of data, record lengths of 19 and 25 years will be tested in the same manner to determine the optimum use of available data.

As for daily data for Arizona and New Mexico, the Arizona data base has been completed and is in the quality assurance phase, and the New Mexico data base will be completed shortly. Ken Kunkel, former New Mexico state climatologist, now with the Illinois State Water Survey, has provided digital data for the pre-1948 period. The complete data bases include NCDC data from 1948 to 1990 and as many earlier records as possible.

L-skewness vs. L-kurtosis for Observed Annual Maximum 1-day Precipitation in Nevada (132 sites)

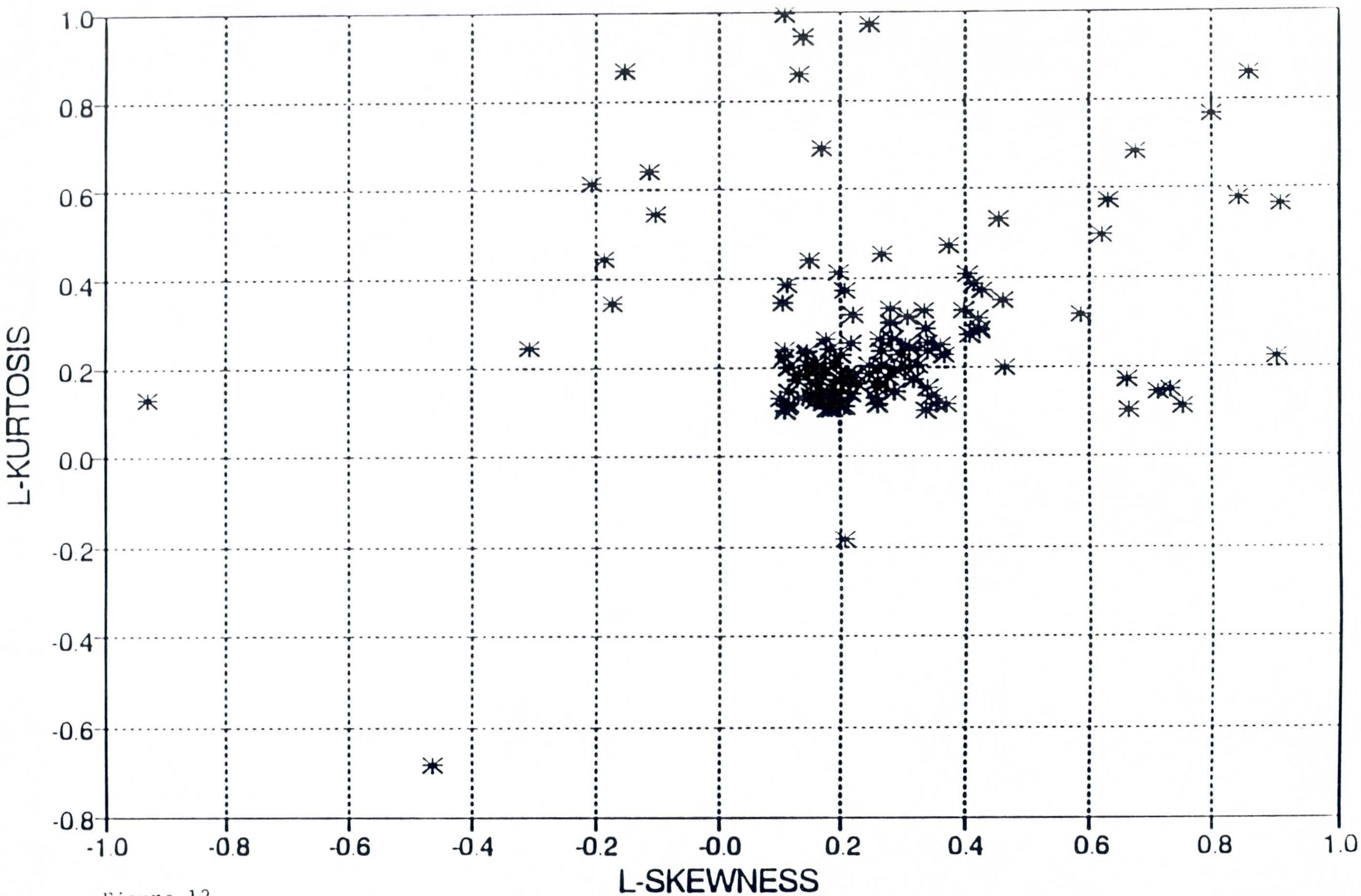
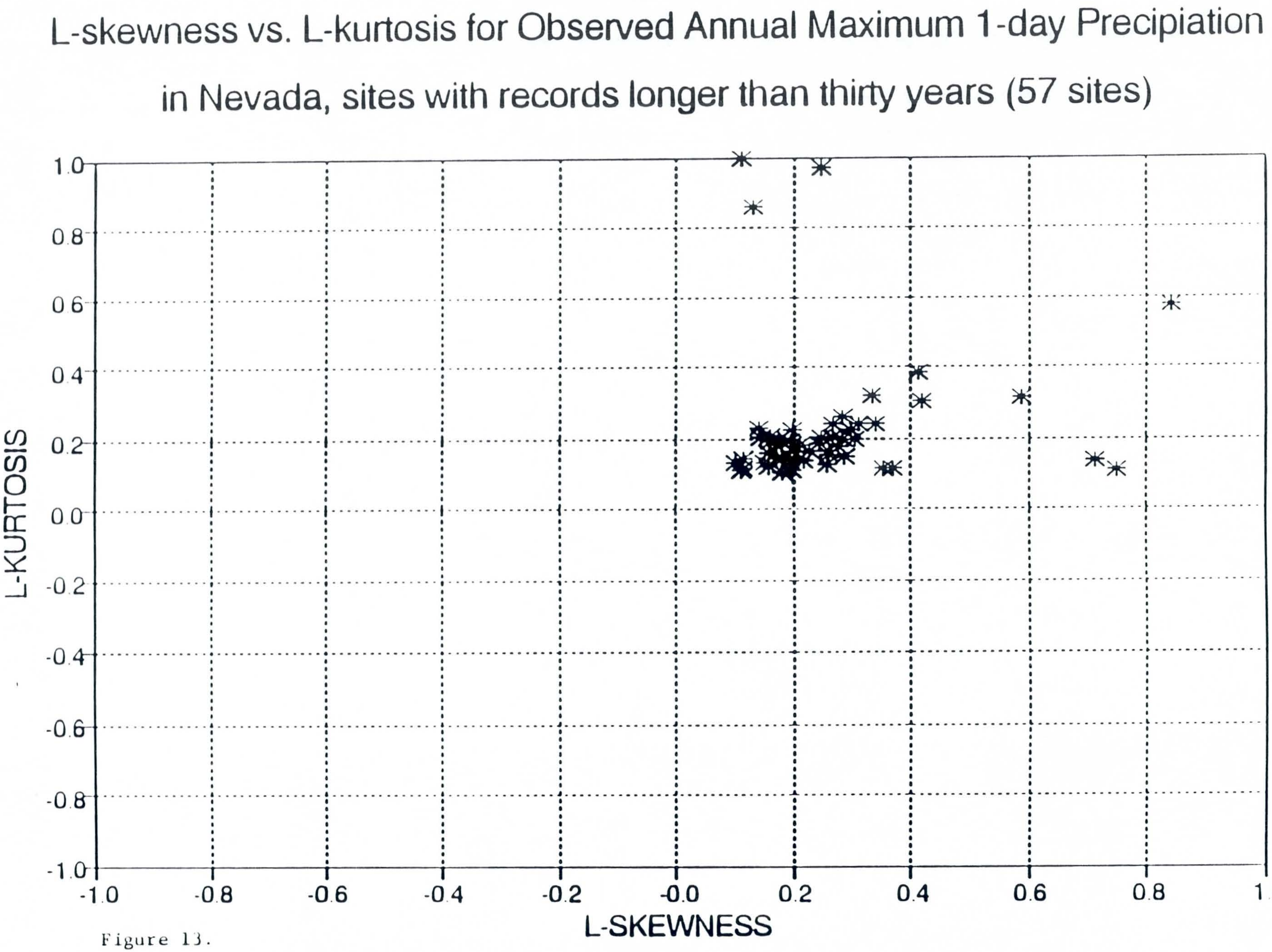


Figure 12.



L-skewness vs. L-kurtosis for Observed Annual Maximum 1-day Precipiation
in Nevada, sites with records longer than thirty years (57 sites)
L-KURTOSIS
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.0
-0.8
-0.6
-0.4
-0.2
-0.0
0.2
0.4
0.6
0.8
1.0
L-SKEWNESS

Figure 13.

Seasonality and Regionalization

Various approaches have been started to determine the appropriate seasons and homogeneous regions for the southwest. One approach is to determine consecutive 90- or 120-day dry periods. Another uses a Western Regional Research Publication (Gifford et al., 1967), which has analyzed weekly rainfall probabilities for selected stations in the western United States.

Computing Facilities

GRASS (Geographical Resources Analysis Support System) software was installed during September on an IBM RISC 6000 workstation in our Resource Center. GRASS is a GIS (Geographical Information Systems) mapping and analysis system, that will be used for storm analysis, development of depth-area duration curves and other procedures in the Southwest Precipitation Frequency Project. Three GRASS experts from the Corps of Engineers Research Laboratory (CERL) in Champaign, Illinois, presented three days of training for project staff. This training was supplied as part of another research project that we began this summer for determining the probable maximum precipitation in California. CERL is continuing to work closely with Office of Hydrology staff in the development and adaptation of GRASS to the specific needs of precipitation analysis. It is expected that this system will be a mainstay in, not only analysis and mapping, but in production of the final documents. Several advantages of the GRASS software include: 1) it is in the public domain with active interchange of ideas and development among users, 2) it is hardware 'independent', and 3) it uses the powerful UNIX operating system.

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Gifford, R.O., Ashcroft, G. L., and Magnuson, M.D., 1967: Probability of selected precipitation amounts in the Western Region of the United States. T-8, Ag. Exper. Station, Univ. of Nevada, Western Regional Research Publication, USDA, DOC, ~150pp.

Hershfield, D.M., 1961: Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years, Weather Bureau Technical Paper No. 40, U.S. Weather Bureau, Washington, D.C., 115 pp.

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Hosking, J.R.M. and Wallis, J.R., 1991: Some statistics useful in regional frequency analysis, Research Report, RC 17096, IBM Res. Div., Yorktown Heights, N.Y., 23 pp.

Vogel, John L. and Lin, Bingzhang, 1992: Precipitation return frequencies and L-moment statistics, Preprint, 12th Conference on Probability and Statistics in Atmospheric Sciences, Toronto, Canada, Amer. Meteo. Soc., Boston, 251-254.

Wallis, J.R., 1989: Regional frequency studies using L-moments, IBM Research Division RC 14597 (#65218), Yorktown Heights, NY, 17 pp.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

February 26, 1993 W/OH11/lft

MEMORANDUM FOR: Southwest Semi-Arid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Fifth Quarterly Report - Semi-Arid Precipitation Frequency Project, October 1 - December 31, 1992

Enclosed is a copy of the Fifth Quarterly Progress Report for the Semi-Arid Precipitation Frequency Study for the southwestern United States. In this update, the report summarizes the work done on data, data analysis, and computer storm analysis techniques. In addition, the report covers in detail L-moment statistics, including distribution fitting, and homogeneity and discordancy test procedures. Another area covered in detail is the seasonality analysis and the various diagnostic approaches used to identify seasons and regions.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMI-ARID PRECIPITATION FREQUENCY STUDY

Fifth Quarterly Progress Report
for the period from
October 1 through December 31, 1992

John L. Vogel, Lesley F. Tarleton, Julie M. Olson,
Edwin H. Chin, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
February 1993

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SEMI-ARID PRECIPITATION FREQUENCY STUDY

Fifth Quarterly Progress Report
for the period from
October 1 through December 31, 1992

OVERVIEW

This quarterly report summarizes the work for the October 1 - December 31, 1992 period for the Semi-Arid Precipitation Frequency Project in four general areas: data and data analysis; computing facilities, including storm analysis; statistical procedures; and seasonality, including regionalization.

Data acquisition, quality control, and data sets are discussed. The Remote Automated Weather Stations (RAWS) data has been received and transferred to our system; the SNOpack TELemetry (SNOTEL) data are formatted and in the quality control process; the NCDC daily and hourly data are essentially complete (all four core states, southeast California and 60 nautical miles into adjacent border states). Partial duration series are being prepared and will be used for the frequency analysis. In regard to other data sets, these will be used to supplement the National Climatic Data Center (NCDC) and SNOTEL sets. In particular, the dense networks (e.g., ARS-Walnut Creek, Phoenix-Salt River, Albuquerque-USGS) will be used for storm analysis and depth-area-duration curves.

The RISC 6000/GRASS system software development is nearing completion; NOAA Atlas 2 (Miller et al, 1973) for the 100-year return frequency is on the system; and the RISC 6000 is being used to prepare mass curves for California storms. Identification of storms in the other semi-arid states has begun.

The L-moment statistics continue to be a mainstay in our quality control, as well as in other aspects of data analysis. The L-moment statistical procedures are discussed in detail in their use for quality control, homogeneity, and distribution-fitting.

One of the most important developments in this quarter is the first-scan determination of seasonality and regionality. We used three different approaches and the results appear to be quite consistent, therefore validating the proposed regional definitions. Additionally, Ed Chin's work using Hosking's measures for Discordancy (D), Heterogeneity (H), and Goodness-of-Fit (Z) give us solid, objective measures that can further define climatic regions, as well as determine the optimum distributions for frequency analysis.

Much of the this Southwest Semi-Arid Precipitation Frequency Project Fifth Quarterly Report for the period October 1 through December 31, 1992 was presented at the Third Semi-Annual review meeting held on December 7 at the Arizona Department of Transportation in Phoenix. The list of participants and the agenda for the meeting are included as Attachments A and B. Lesley Tarleton and John Vogel of the Office of Hydrology, Water Management Information Division (WMID) presented the review.

Various people have worked on these projects. The data processing, quality control of data, and data for future storm analyses have been done in part by Ed Chin, Doug Kluck, Julie Olson, Lesley Tarleton, John Vogel, and Mike Yekta. Seasonality has been tackled by Ed Chin, Julie Olson, Lesley Tarleton, and John Vogel. The frequency calculations has been accomplished by Ed Chin, Julie Olson, and John Vogel. In September Doug Kluck, a meteorologist, joined the WMID staff. Although Doug is primarily working on another project, he is assisting in the development of storm data for the Semi-Arid Southwest.

DATA

A map showing the distribution of daily and hourly stations from the NCDC, and the SNOTEL data from the SCS is given in Figure 1. Note how the SNOTEL data (starred stations) supplement the data from the NCDC, especially in the high-altitude region.

Hourly Data

The software for data reduction and quality-control procedures are now in place and in routine use. Figure 2 summarizes the data reduction of the hourly precipitation data from NCDC from 1948 through 1990 for the core states in the Semi-Arid Project. Due to missing data, the combination of nearby stations, short record periods, and inconsistencies in the data set, the actual number of stations, from those that have taken data for the past 45 years, was reduced by 50 percent or more for the final analysis.

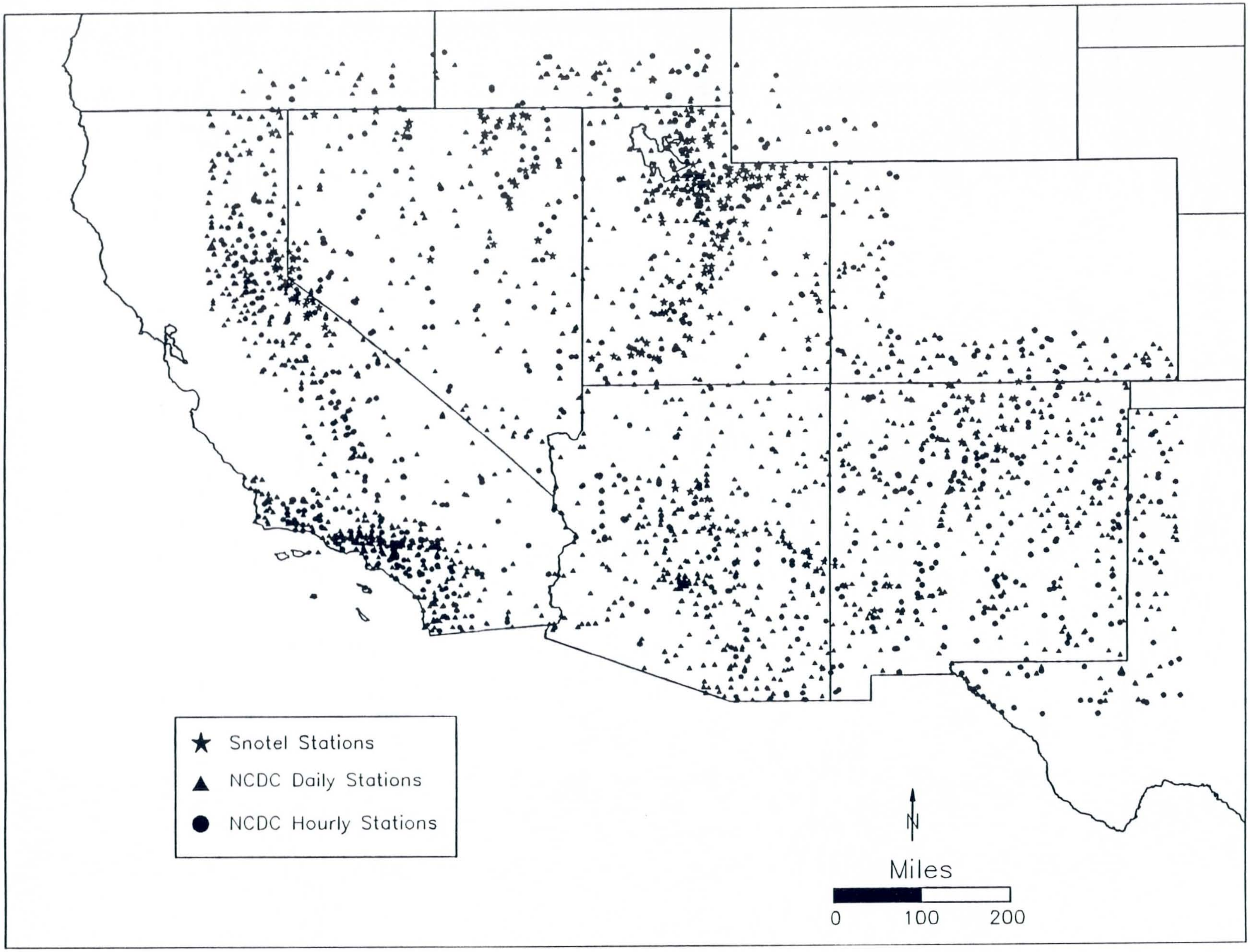

Figure 1. Hourly and Daily Stations used in the Semi-Arid Precipitation Frequency Project.

Semi-Arid Precipitation Frequency

Summary Of Hourly Stations
(as of 12/2/92)

	Arizona	Nevada	New Mexico	Utah
Orginal Number of Stations	81	73	141	91
delete <5 yrs	-3	-4	-25	-17
"loss" to combinations	-11	-6	-24e	-9e
Other Deletions i.e. (L-Moments)	-8	-6e	-8e	-7e
Total	59	57	84	78
Next Step				
delete <15 yrs	-11	-11	-30	-17
TOTAL	48	46	54	61

e = estimated

Figure 2. Summary of deletion and combinations for NCDC hourly stations.

Daily Data

The daily data have been treated in a similar manner, and the number of stations with at least 19 years of data is shown in Table 1. Data for New Mexico were obtained from Ken Kunkel, the former State Climatologist for New Mexico. This is a very valuable data set, since it extends the data base prior to 1948 to the beginning year of the station. However, the format for these data is slightly different from the format used by the National Climatic Data Center, making it difficult to differentiate between accumulated and missing data (Figures 3a and 3b). Some additional software is being developed to incorporate these differences. New software has been prepared to reduce the daily data from the SNOTEL (SNOw TELemetry) network maintained by the Soil Conservation Service. These data are usually in remote and/or high-elevation sites in the various states, and will provide information for generally data-sparse regions.

Other Data Sets

A variety of other data are being examined, including precipitation data for input into the storm analysis program. Initially, this will be for the post-1948 era and for Southeast California. Table 2 provides a list of those groups who have supplied or indicated that they will supply precipitation data for the Southwest Semi-Arid project. California storm data from Jim Goodridge have been obtained, and are being examined and inventoried.

N-minute data

The N-minute data (rainfall amounts for durations from 5 to 1440 minutes) have been examined and inventoried. Table 3 shows the stations and years of record for Arizona, New Mexico, Nevada, and Utah. Although some of the records go back as early as 1881 (Yuma, Arizona), the data set needs to be updated to include the data from 1979 to 1990.

Remote Automated Weather Stations (RAWS)

The RAWS data have been received from the Western Regional Climate Center in Reno, Nevada, and have been entered on our computing system. These data are tipping bucket observations, measured to 0.01 inches at over 100 stations, 1985-1990. The 1991 and 1992 data should be available in the spring of 1993 and will be added to our data base at that time. RAWS locations are shown in Figure 4.

Table 1.

Data Reduction of the NCDC daily precipitation data for the four core states of the Semi-Arid Precipitation Frequency Project.

Daily
- NCDC + TP40
- Records mostly 1948-1990
- Some as early as 1880

Core States	Initial	≥ 19 yrs
Arizona	438	276
Nevada	211	105
Utah	316	186
New Mexico	*	
California	447	
Border States	462	

SNOTEL (SNOpack TELemetry)
- 163 stations for area
- Software complete

New Mexico Daily Data
Format Problems

Missing Data

	-99 ...	-99	-99	-99	-99	-99 .. ..
	-99 ...	-99	-99	**99**	**99**	
Date:	21 ...	28	29	30	31	

Note: last 2 days of month 99 instead of -99

-99 = missing data

Solution: write program to change 99 at ends of month to -99

Figure 3a. New Mexico Format Problems for Missing Data.

New Mexico Daily Data
Format Problems

Accumulated Data

...0 0 0 -99 **110** 0 0 .. .

Note: Accumulated data is <u>not</u> coded -88 in this data set, it is coded -99, same as <u>missing</u>.

-88 = Accumulated data

Solution: Distribute data over days with -99 prior to observation.

Example:	-99	110	(1.10)	
	55	55	(.55	.55)

. gure 3b. New Mexico Format Problems for A umulated Data.

Table 2.

Data sets for the Semi-Arid Frequency Project.

NCDC	National Climatic Data Center	NOAA
SNOTEL	SNOwpack TELemetry	USDA/SCS
RAWS	Remote Automated Weather Station	USDA/BLM/ & FS
ARS	Agricultural Research Service	USDA/ARS
USGS	U.S. Geological Survey	Dept. of Interior
Supplementary	Dept. of Water Resources	California
Supplementary	San Bernardino County, Ca	
Supplementary	Riverside County, Ca	
ALERT	Automated Local Evaluation in Real Time	
	California Storm Data	J. Goodridge
	New Mexico Climate Data	Ken Kunkel

TABLE 3.

N-MINUTE DATA BASE

Durations: 5-, 10-, 15-, 30-, 60-, 120-, 1440- minutes
Maximum precipitation for each duration for each year.[1]

Arizona:		
Flagstaff	1951-1978	(all)
	1898-1978	(1440-min)
Phoenix	1906-1978	(all)
	1898-1978	(1440-min)
Tucson	1943-1978	(all)
	1924-1978	(1440-min)
Winslow	1951-1978	(all)
	1881-1978	(1440-min)
Yuma	1881-1978	(1440-min)
New Mexico:		
Albuquerque	1931-1978	(all)
Roswell	1905-1978	(all)
Nevada:		
Reno	1906-1978	(all)
Winnemucca	1906-1978	(all)
	1884-1978	(1440-min)
Utah:		
Modena	1904-1944	(all)
	1904-1947	(1440-min)
Salt Lake City AP	1936-1978	(all)
	1929-1978	(1440-min)
Salt Lake City WBO	1896-1951	(5-,10-,60-min)
	1903-1951	(15-,120-min)
	1882-1953	(1440-min)

[1] Note: There are a few years missing in the 1960s in New Mexico, Nevada, and Utah.

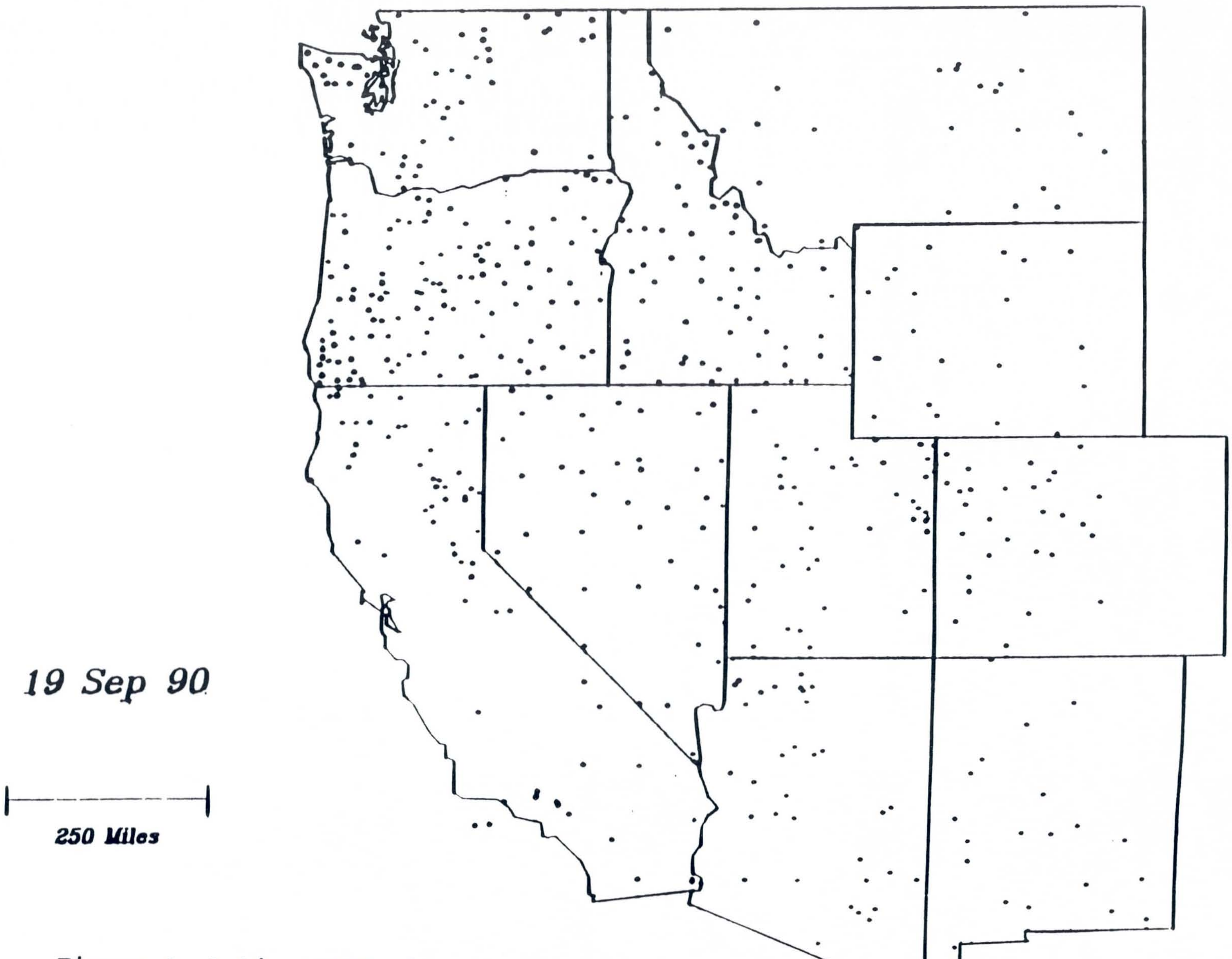

Figure 4. Active RAWS sites in the Western U.S.

Agricultural Research Service (ARS)
John Vogel met with Leonard Lane at the U. S. Department of Agriculture Southwest Watershed Research Center in Tucson, Arizona, on Friday and Saturday, December 4-5, 1992. Leonard briefed John on the availability of precipitation data from Walnut Gulch, Arizona, and Alamogordo Creek, New Mexico, Experimental Watersheds. Although some precipitation data had been obtained previously through the Agricultural Research Service (ARS) in Beltsville, MD, Leonard indicated that more data were available for the Walnut Gulch Experimental Watershed. Leonard offered to supply daily data for six to nine of the raingages in the dense raingage network. These gages have been shown by statistical analysis to be reasonably independent of each other. Later in the year, when a new data processing system becomes available at the Southwest Watershed Research Center, breakpoint data for the same gages will also be made available. This will give valuable information about short-duration rainfalls.

COMPUTING FACILITIES AND STORM ANALYSIS

The RISC 6000/GRASS system software development is nearing completion. This storm analysis software will be used to develop area-depth, depth-duration, and mass-curve relations for storms in the Semi-Arid regions of the Southwest. The first working version on our system is expected early in 1993. An important part of storm analysis is the comparison of individual storms to the NOAA Atlas 2 100-year return frequencies. These 100-year return frequencies have been entered on the computer system. Refinements of the software will continue in the future in an effort to develop more objective analysis schemes. Work has begun on reducing data for some storms in the Southwest.

The RISC 6000 workstations will also be used to assist in mapping the precipitation fields, and to assist in statistical-physical modeling of the precipitation intensities.

L-MOMENT STATISTICS AND OTHER PROCEDURES

L-Moment Quality Control

The L-moment program requires at least five years of data to run the software, but more importantly at least 15 years, preferably 20 years, of record are required to obtain reliable frequency data. Figure 5 shows initial processing criteria. For instance, the outlier stations (from L-skewness versus L-kurtosis plots) were sorted against years of record (not shown), with a strong positive relationship (i.e., short records = outliers). This supports the need to use longer records for frequency analysis. We have set the lower limit at 15 years for stations to be used in the frequency analysis.

L-moment statistics have also been found to be a powerful technique for quality control of the data (Vogel and Lin, 1992). After determining the maximum annual intensity for various durations, the data are processed using L-moment statistics. As part of this process, the mean, L-coefficient of variation, L-skewness, L-kurtosis, and the fifth moment are calculated. For example when using L-moment statistics if the L-skewness and the L-kurtosis points for a number of stations are plotted in a scatter diagram, a cluster of points is expected. If several points are not near this cluster, this usually means that some data for this station need to be examined carefully. The steps are outlined in Figure 6. For annual maximum precipitation values, it could mean that one of the years was incorrectly entered, and needs to be corrected; or that there are missing data that have been given a zero value and were not coded as missing. These are but a few examples.

L-moment statistics provide a new way of examining data, and our experience shows that it is a very powerful tool. Previously, the analysis of the return frequency of precipitation has used various fitting procedures. For NOAA Atlas 2 (Miller et al, 1973) the method of moments was used, and others more recently have used the method of maximum likelihood, which is more cumbersome. L-moments use probability-weighted moments (Hosking, 1990). This technique 1) supplies a more robust analysis which is less sensitive to sampling errors and outliers, 2) uses linear combinations of order statistics, and 3) is capable of characterizing a wide range of statistical distributions. The L-moment process is summarized in Figures 7a, b, and c. Using L-coefficient of variation, L-skewness, and L-kurtosis, Hosking and Wallis (1991) developed a measure of discordancy (D_i), which can be used to detect possible non-homogeneities within the data set (Figure 7c).

CRITERIA

To Run L-Moment

- Need at least 5 years

To Combine

- ≤ 5 miles
- ≤ 300 feet difference in elevation

For Frequency Analysis

- "within" cluster of L-skew vs. L-kurtosis plot
  - i.e., not 'real far out'
- 15 years for frequency analysis

Figure 5. Initial Processing Criteria.

PROCESS

- Use Formatted Statewide Data Set
- Run L-Moment FORTRAN program {MN,CV,SK,K,5th}
  (without < 5-year stations)
- Plot L-skewness vs. L-kurtosis, check outliers for erroneous data, if outliers:
  correct, if necessary
  combine, if possible
  delete, otherwise
- Check proximity for merging
  < 5 miles
  < 300 feet
  (especially to combine 2 or more short records to make 1 long record)

Figure 6. Process of quality control using L-moment statistics.

OBSERVED DATA--PROBABILITY DISTRIBUTIONS

1. METHOD OF MOMENTS

2. METHOD OF MAXIMUM LIKELIHOOD

   LET $f(x_i;\ \theta_1, \theta_2, \ldots)$ BE THE pdf, THEN

$$L = \prod_{i=1}^{n} f(x_i; \theta_1, \theta_2 \ldots) \quad \text{Likelihood Function}$$

$$\frac{\partial L}{\partial \theta_i} \quad \text{solve for } \theta_i$$

3. METHOD OF L-MOMENTS

   a) robust, less sensitive to sampling errors and outliers

   b) capable of characterizing a wide range of distributions

   c) linear combination of order statistics

Figure 7a. Statistical methods for fitting data to probability distributions.

L-MOMENTS

random variable X with cdf F(X) & quantile func X(F)

$$X_{1:n} \preceq X_{2:n} \preceq \cdots \preceq X_{n:n}$$

L-MOMENT for r = 1, 2, · · · are:

$$\lambda_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} E\, X_{r-k:r}$$

$$\text{L-CV} = \lambda_2/\lambda_1$$

$$\text{L-SKEWNESS} = \lambda_3/\lambda_2$$

$$\text{L-KURTOSIS} = \lambda_4/\lambda_3$$

Figure 7b. Definition of L-moments.

DATA SCREENING--DISCORDANCY D_i

Let $\bar{U}_i = \left[t_2^{(i)}, t_3^{(i)}, t_4^{(i)}\right]^T$ be a vector for site i

$$\bar{U} = N^{-1}\sum_{i=1}^{N}\bar{U}_i$$ -- unweighted group mean

THE DISCORDANCY FOR SITE i IS DEFINED:

$$D_i = \frac{1}{3}(\bar{U}_i - \bar{U})^T \bar{S}^{-1}(\bar{U}_i - \bar{U})$$

where $\bar{S} = (N - 1)^{-1} \sum_{i=1}^{N} (\bar{U}_i - \bar{U})(\bar{U}_i - \bar{U})^T$

Figure 7c. Discordancy measure developed by Hosking and Wallis (1991).

This discordancy measure was tested on 1-day duration precipitation data using the annual maximum series for 276 daily stations in Arizona which had been previously quality controlled. Thirteen stations were found to have D_i values of 3 or greater, indicating that these stations had some unusual data points (Table 4, page 26). Several of these stations had relatively low periods of record (< 25 years); however, many of the stations had long periods of record and these stations are generally considered to be more stable. Discordancy indicates the need to verify the data, but does not indicate that the data are wrong, just different from most of the stations within the data set. Subsequent verification of the data for the long-term stations indicated that the values in the annual maximum series were valid. The short-term stations may provide valuable information for return frequencies of less than 10 years, but for estimation of frequencies in excess of 10 years, caution will be required.

Double-Mass Curves

The use of double-mass curves was discussed in some detail in an earlier quarterly (QR4). However, as it is another powerful technique that can be used to examine the reliability of precipitation data, further mention is warranted. For our analysis, we compare the accumulated annual maximum rainfall at a station to the average annual rainfall at several nearby stations that are known to be reliable. This technique can be used to determine graphically if there has been any significant change in the exposure of the raingage, and to examine the potential merging of nearby raingages with short records into a longer record period. Figure 8a shows a double-mass curve for Beatty, Nevada, which indicates that there may be a problem with the 1978 maximum value. Figure 8b is the same plot without the 1978 point and the slope is smooth; thus, the data for 1978 for this station need to be re-examined. It is important to note that this data point may be a valid observation; but it needs to be verified against other documentation, and for reasonableness within the local precipitation regime.

In addition to L-moments and double-mass curves, a variety of other data analyses are planned. These include comparisons of 1) the annual maximum series and the partial duration series for various durations, 2) daily rainfall amounts and 24-hour amounts, and 3) hourly and shorter durations rainfall amounts.

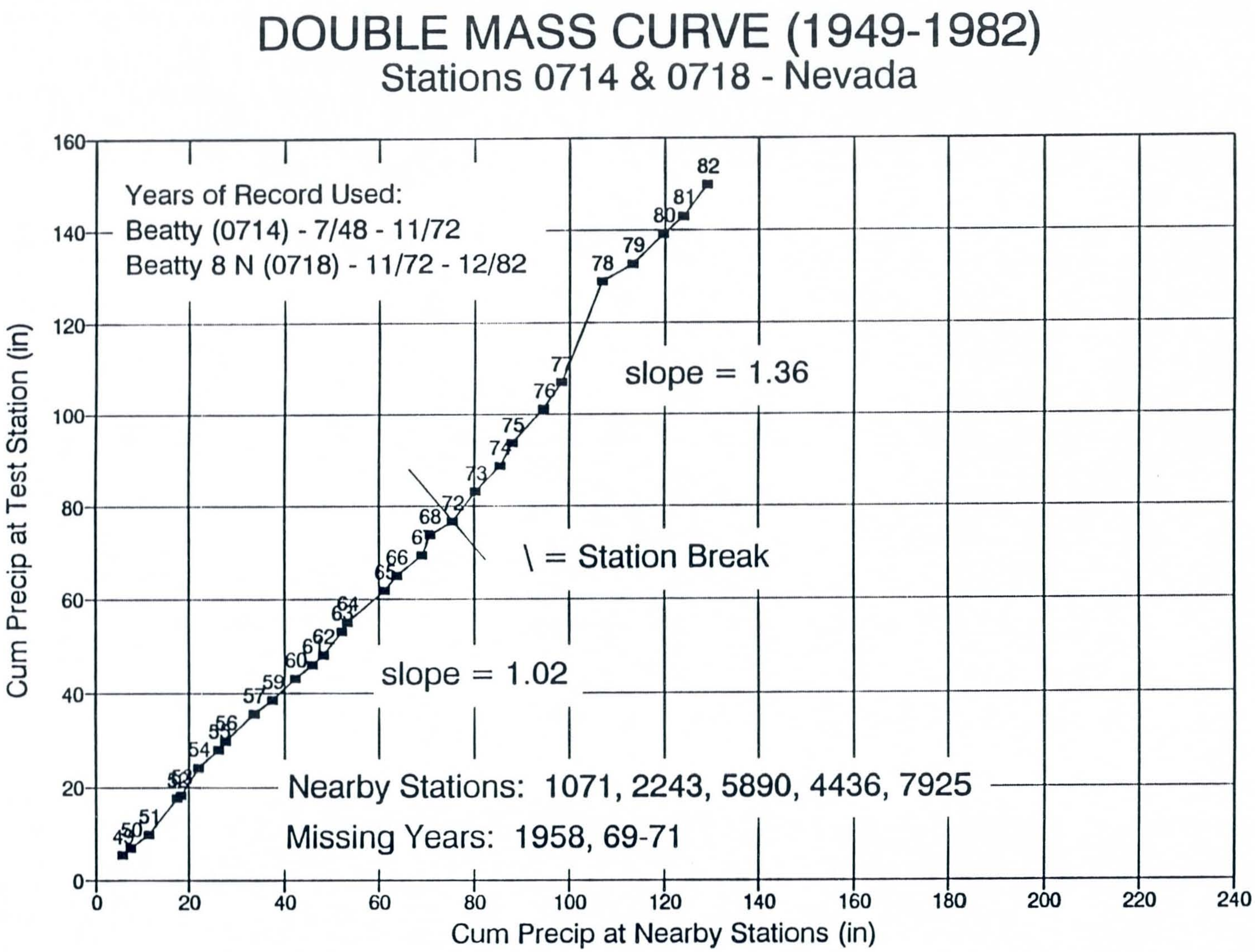

Figure 8a. Double Mass Curve of Beatty and Beatty 8 N, Nevada.

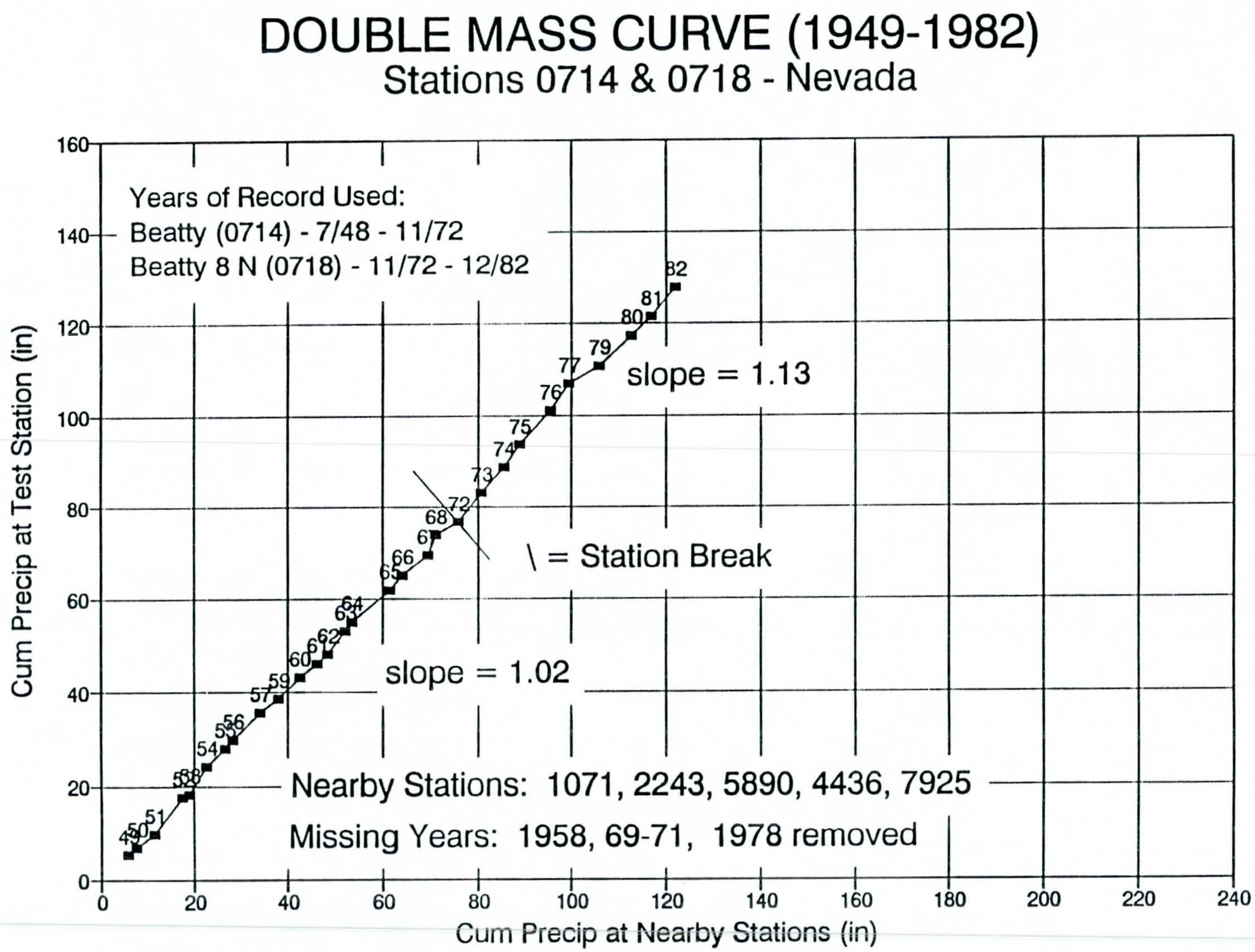

Figure 8b. Double Mass Curve of Beatty and Beatty 8 N, Nevada, with 1978 removed.

Frequency Calculations

An important part of determining the intensity of the frequency relations for the various durations using L-moments is to determine if the data in the physical regions that are being defined are homogeneous or non-homogeneous (heterogeneous). Hosking and Wallis (1991) have developed a test that examines heterogeneity, H. This measure of H "compares the between-site variations in sample L-moments for the group of sites with what would be expected for a homogeneous region" (see Figure 9a). This technique essentially uses the graphical property of anticipating a close cluster of points around some central value for a plot of the L-coefficient of variation and the L-skewness. If the points are closely clustered around a central point then the region might be considered to be homogeneous; but if the points are scattered then the region is considered to be heterogenous.

As a numerical measure of heterogeneity Hosking and Wallis determine the average distance from a site's plotted point to the group average point that would be expected of a "homogeneous region." The expected value of the homogeneous region is obtained by simulating the expected values of a homogeneous region using a 4-parameter kappa distribution. The 4-parameter kappa distribution was chosen, so that a particular distribution for the data is not forced. After the simulation a comparison between the observed and simulated dispersion is made, using the appropriate statistics, as follows:

$$\frac{\text{(observed dispersion)} - \text{(mean of simulation)}}{\text{(standard deviation of simulation)}}$$

This can be done for the L-coefficient of variation, the combination of L-coefficient of variation and L-skewness, or the combination of L-skewness and L-kurtosis. The farther one gets from only using the L-coefficient of variation, the more tolerance on what is considered to be homogeneous.

HOMOGENEOUS REGION - HETEROGENEITY, H: "IS THE BETWEEN-SITE DISPERSION OF THE L-MOMENTS FOR THE GROUP OF SITES LARGER THAN WOULD BE EXPECTED FROM A HOMOGENEOUS REGION?"

[(OBS. DISP) - (MEAN DISP BY SIMULATION)]/SD OF SIM DISP

SIMULATION: 4-PARAMETER KAPPA DISTRIBUTION

$$H = (V - \mu_V)/\sigma_V$$

WHERE V IS THE WEIGHTED SD AT EACH SITE

SAMPLE L-CV OR L-SKEW OR L-KURTOSIS

μ_V, σ_V FROM MONTE CARLO

Figure 9a. Heterogeneity test developed by Hosking and Wallis (1991).

As a crude first investigation an analysis was performed using the 276 daily stations in Arizona (Figure 9b). For this data set the threshold was 3.0; i.e., if the measure of heterogeneity (H) is greater than 3.0, then the data are not homogeneous, but if H is less than 3.0 than the data are homogeneous. This analysis showed that if only the L-coefficient of variation is used the Arizona daily data are not homogeneous; if the L-coefficient and the L-skewness are used the daily data are not homogeneous; but if the L-skewness and the L-kurtosis are used then H equals 0.01 and the data are homogeneous. This means that in a gross sense the daily data from Arizona are homogeneous, but one should expect other physical divisions if one expects to have a truly homogeneous data set.

Another important part of any frequency investigation is the determination of the optimum frequency distribution for the data set. Hosking and Wallis (1991) developed a goodness-of-fit measure, Z, (Figure 9c) which can be used to determine the optimum frequency distribution for a given data set. Again the 276 daily stations for 1-day durations and an annual-maximum series were chosen for a test run of this measure. The closer the absolute value of Z is to zero, the better the frequency distribution. The results from this test run are shown in Table 5. They indicate that the GEV or the Generalized Extreme Value distribution, with a Z value of -2.06, is the optimum distribution for a duration of one-day for Arizona. This is the same result that was found for precipitation data over West Virginia and Pennsylvania. The next best frequency distribution is the generalized normal distribution with a Z value of -4.62. The generalized logistic is third with an absolute value of Z equal to 7.30.

SEASONALITY

An important part of the initial analysis is determining the seasonality of intense precipitation occurrences. In just about any region of the world there are particular months or periods of months which dominate the intensity of the return frequency. During these periods more than half of all the highest intensity rainfalls can be expected. The other periods can have significance for other reasons, and it is important that the precipitation return frequencies for these other seasons also be defined. In addition, the seasonality will delineate the physical first cut of the regionalization of the Semi-Arid Southwest.

*** HETROGENEITY MEASURES ***

SIMULATIONS = 500

OBSERVED SD OF GROUP L-CV	0.0769
SIM. MEAN OF SD OF GROUP L-CV	0.0351
SIM. SD OF SD OF GROUP L-CV	0.0015
STANDARIZED TEST VALUE	27.38**

OBSERVED AVG OF L-CV/L-SKEW DIST	0.0[illegible]
SIM MEAN OF AVE L-CV/L-SKEW DIST	0.0717
SIM SD OF AVE L-CV/L-SKEW DIST	0.0028
STANDARDIZED TEST VALUE	7.68**

OBSERVED AVG OF L-SKEW/L-KURT DIST	0.0860
SIM MEAN OF AVG L-SKEW/L-KURT DIST	0.0860
SIM SD OF AVG L-SKEW/L-KURT DIST	0.0033
STANDARDIZED TEST VALUE	0.01

Figure 9b. Heterogeneity test results from 276 daily stations in Arizona.

GOODNESS-OF-FIT Z

$$Z^{GEV} = \frac{(\bar{t}_4 - \tau_4^{GEV})}{\sigma_4}$$

where $\bar{t}_4$ is the regional average L-Kurtosis.

τ_4 is the L-kurtosis of the fitted GEV distribution, and

σ_4 is the standard deviation of $\bar{t}_4$

Figure 9c. Goodness-of-fit measure developed by Hosking and Wallis (1991.)

Table 4.

Discordancy Measures

ARIZONA 276 SITES

N	NAME	L-CV	L-SKEW	L-KURT	D(I)
62	0060	.3701	.3096	.1531	1.10
77	0080	.3219	.2578	.2595	0.43
23	0625	.6247	.3033	.0599	6.97**
27	1169	.5143	.3350	.1190	3.54*
20	1248	.3579	.5132	.5364	7.33**
78	2329	.6048	.2209	.1396	4.45**
96	3595	.3050	.3651	.4777	5.51**
22	3926	.6020	.2393	.2772	5.34**
43	4182	.5953	.3706	.2278	4.21**
41	4586	.4228	.5015	.4345	4.59**
31	4675	.5143	.2027	.0470	3.29**
25	8184	.3878	.2024	.3303	3.07*
36	8273	.6879	.3359	.2568	6.84**
21	8329	.2380	.1023	.1926	1.36
31	8649	.4440	.1948	.2993	3.02*
30	9114	.2876	.4463	.4276	4.11**
MEAN		.3204	.2107	.1726	

Table 5.

Goodness-of-fit Measures

GEN LOGISTIC	L-KURTOSIS	=	0.204	Z VALUE	=	7.30
GEV	L-KURTOSIS	=	0.167	Z VALUE	=	-2.06
GEN NORMAL	L-KURTOSIS	=	0.157	Z VALUE	=	-4.62
PEARSON TY III	L-KURTOSIS	=	0.138	Z VALUE	=	-9.7
GEN PARETO	L-KURTOSIS	=	0.083	Z VALUE	=	-23.7

Three different sets of data are being examined to define the seasonality for this project. They are 1) the initial month of 120-day dry periods, 2) the probability of precipitation amounts expected during particular weeks of the year, and 3) a monthly frequency count of the annual maximum rainfall intensity for particular durations.

Figure 10 shows an analysis of the monthly beginning dates of the driest 120 consecutive days for 2-year periods in Arizona, New Mexico, Nevada, and Utah. No attempt at stratifying the data by regions within the state was made at this point, rather for each state all the data for the whole state were lumped together. The highest spike in these data occurs during the month of March for Arizona. It indicates that nearly half of all the 120-day dry periods in Arizona begin during March, and that less than 10% of the dry periods in Arizona begin in other months except for February. This means that over 60% of all the 120-day dry periods begin in March or February. Consequently, the wet period can be expected to maximize during the months from June through August, or during the monsoon season.

In New Mexico the dry periods generally begin during the months of January through March and September through December. The wet period in New Mexico can be characterized as the period from April through August. Nevada and Utah show that the 120-day dry periods begin mainly from May through September, and that the wet period can be expected from October through February or April.

A second way of exploring seasonality relations is to examine some statistics that provide more detailed information, and at the same time integrate some of the characteristics of the weather systems which characterize different periods of the year. During the 1960s the Western Region Technical Committee of the U. S. Agriculture Department Experiment Stations developed a climatology of the percent probability of selected precipitation amounts within various weeks of the year beginning with March 1, or the climatic year (Gifford et al, 1967). These data were analyzed for the stations shown in Figure 11a with an example of this data set shown in Figure 11b for Ajo, Arizona. The first column shows the beginning of each one-week period starting with March 1. The next column gives the mean precipitation amount for that week. The third column provides the probability of no rain or only a trace of precipitation within the week, and the next eight columns provides the probability of receiving a precipitation amount equal to or in excess of a given amount. These values vary according to average annual precipitation at each station. If the station averages less than 30 inches of precipitation in a year, it is considered dry; if more than 30 inches, it is considered wet.

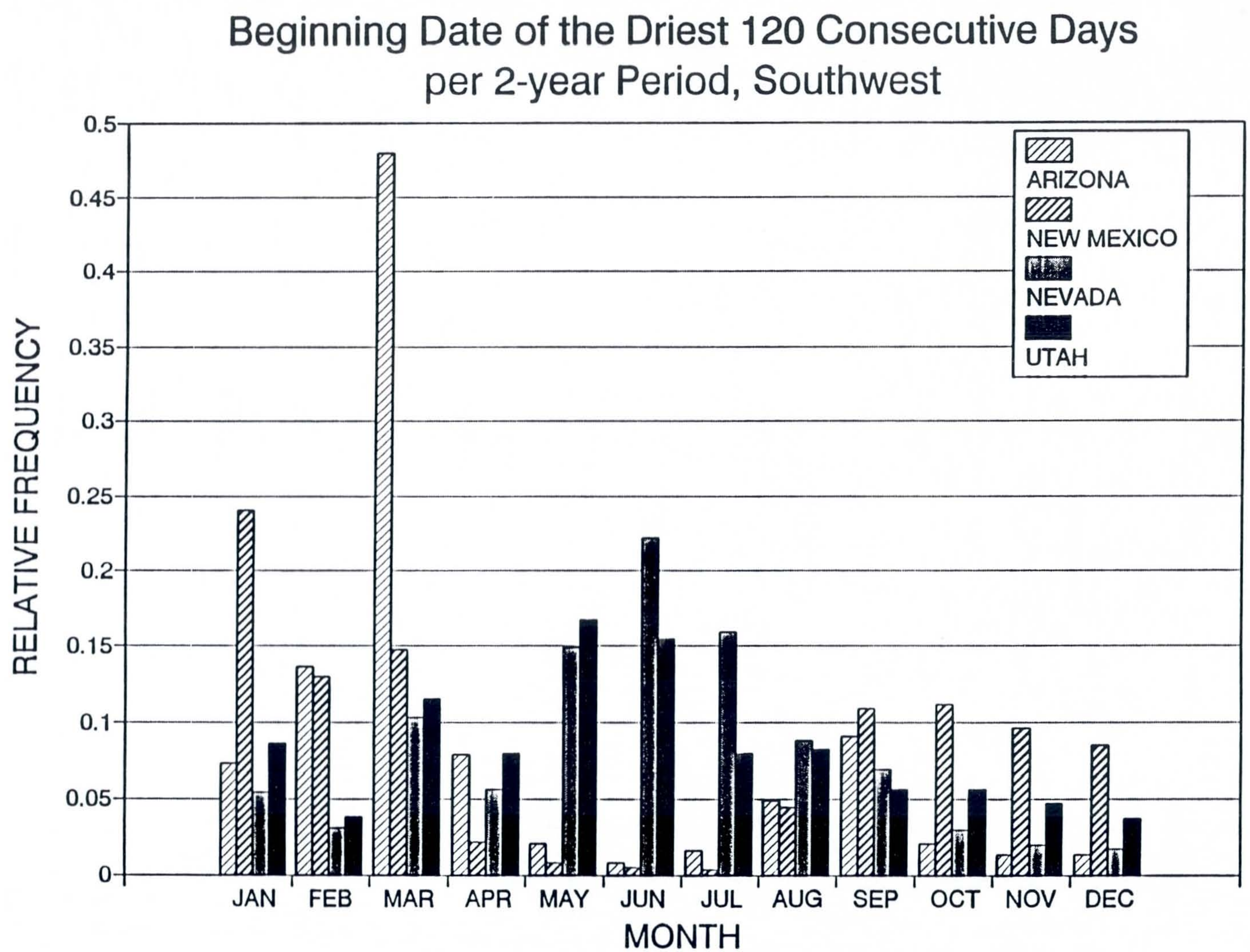

Figure 10. Monthly beginning dates of the driest 120 consecutive days for 2-year periods for Arizona, New Mexico, Nevada, and Utah.

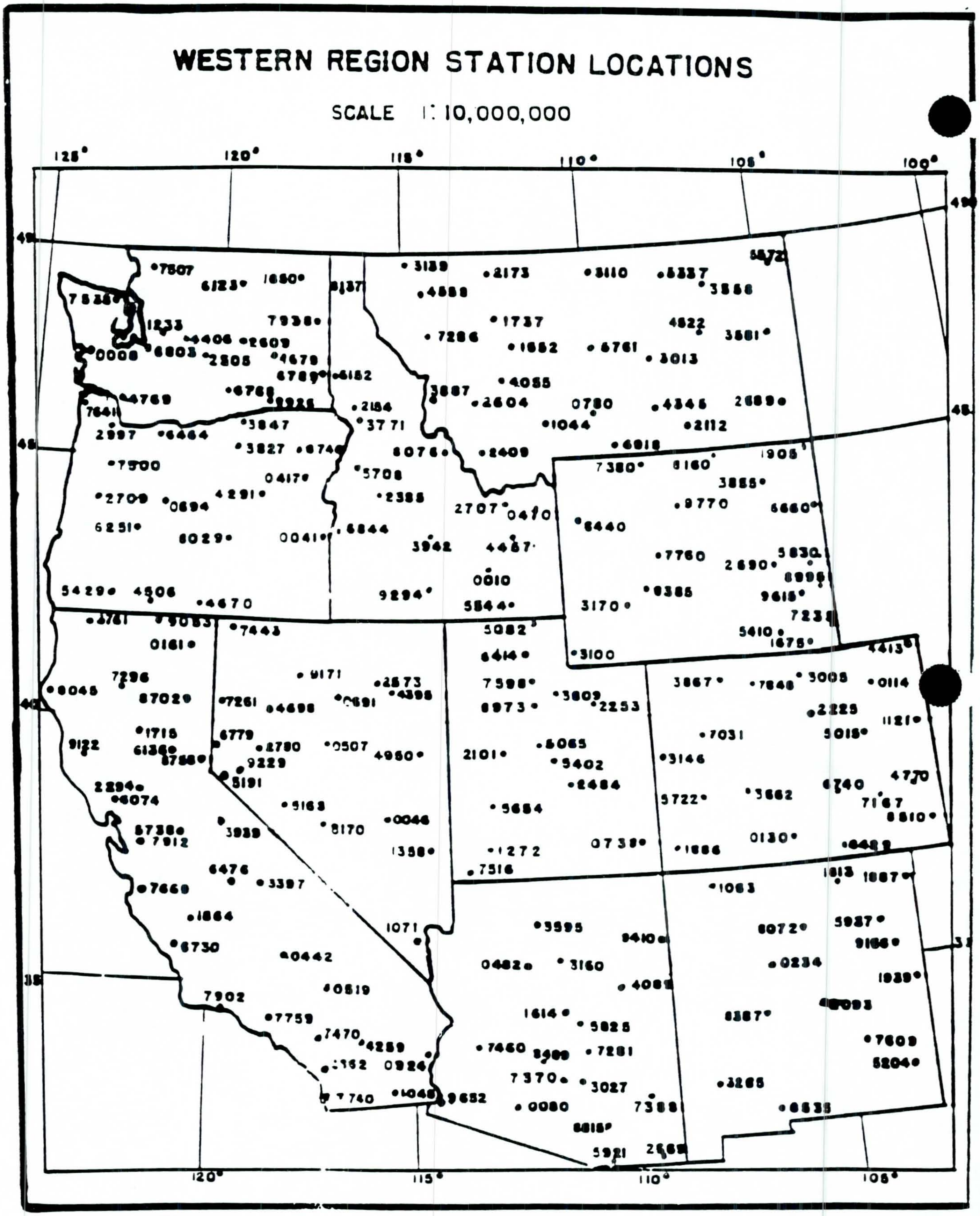

Figure 11a. Stations for which precipitation probabilities were calculated.

AJO, ARIZONA 20080
PRECIPITATION MEANS AND PROBABILITIES FOR 1 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.24	53	24	22	18	12	9	5	3	1	
MAR 08	.16	76	26	24	20	15	11	7	4	2	
MAR 15	.25	73	25	23	19	14	10	6	4	2	
MAR 22	.12	60	25	22	17	10	6	3	2	1	
MAR 29	.04	83	19	17	12	6	3	1			
APR 05	.06	80	12	10	7	4	2				
APR 12	0.00	100	7	5	3	2	1				
APR 19	.02	83	10	8	4	1					
APR 26	.05	76	12	10	6	2					
MAY 03	0.00	100	8	6	4	1					
MAY 10	.03	80	8	5	3	1					
MAY 17	.01	93	6	4	1						
MAY 24	0.00	100	4	3	1						
MAY 31	.02	86	6	4	2						
JUN 07	0.00	100	3	2	1						
JUN 14	0.00	100	4	3	2	1					
JUN 21	.05	80	11	9	6	2	1				
JUN 28	.04	76	21	18	12	6	4	1	1		
JUL 05	.19	56	33	32	25	15	10	4	2	1	
JUL 12	.30	40	51	47	38	25	17	8	4	1	
JUL 19	.39	23	64	59	49	34	25	13	7	3	
JUL 26	.56	20	73	68	58	43	31	18	10	4	
AUG 02	.61	20	72	68	60	46	35	20	12	5	
AUG 09	.52	26	68	64	55	41	31	18	10	5	
AUG 16	.44	23	65	61	52	38	28	16	9	4	
AUG 23	.52	30	58	54	45	32	23	13	8	4	
AUG 30	.18	46	45	41	32	21	14	7	4	2	
SEP 06	.18	56	34	31	24	16	11	6	4	2	
SEP 13	.32	60	30	27	22	16	12	7	5	3	
SEP 20	.11	63	29	26	20	13	8	4	2	1	
SEP 27	.13	63	29	26	20	13	8	4	2		
OCT 04	.23	70	27	25	21	14	10	5	3	1	
OCT 11	.08	76	21	19	15	10	6	3	1		
OCT 18	.06	80	19	17	13	8	5	2	1		
OCT 25	.16	70	21	19	14	9	6	3	1		
NOV 01	.04	76	24	21	15	9	5	2	1		
NOV 08	.15	63	30	26	19	10	5	2	1		
NOV 15	.12	46	36	31	22	10	5	1			
NOV 22	.12	63	30	26	18	9	4	1			
NOV 29	.07	76	24	21	16	10	6	2	1		
DEC 06	.19	66	28	25	20	13	8	4	2		
DEC 13	.12	53	35	32	25	15	9	4	2		
DEC 20	.24	50	40	36	29	18	11	4	2		
DEC 27	.18	60	34	31	25	17	11	5	2	1	
JAN 03	.16	63	33	31	25	16	10	4	2	1	
JAN 10	.22	53	38	35	29	18	11	4	1		
JAN 17	.16	60	37	34	27	17	11	4	2		
JAN 24	.21	56	35	32	25	16	10	4	2		
JAN 31	.13	60	37	33	25	15	9	3	1		
FEB 07	.18	46	38	34	25	15	9	3	1		
FEB 14	.19	53	39	34	26	16	10	4	2	1	
FEB 21	.19	46	30	27	21	13	8	3	1		

AJO, ARIZONA 20080
PRECIPITATION MEANS AND PROBABILITIES FOR 2 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.40	46	36	33	28	22	17	11	7	4	1
MAR 15	.36	43	44	41	34	25	18	10	6	3	
MAR 29	.11	66	27	24	17	10	5	2			
APR 12	.03	83	18	15	8	3	1				
APR 26	.07	73	22	19	12	5	2				
MAY 10	.03	73	14	10	5	2					
MAY 24	.03	83	11	8	3						
JUN 07	0.00	100	8	7	4	1					
JUN 21	.09	60	30	26	18	9	5	2	1		
JUL 05	.49	16	71	66	56	40	29	15	8	3	
JUL 19	.95	0	91	87	79	64	52	34	23	12	2
AUG 02	1.13	10	90	88	83	72	61	43	29	16	2
AUG 16	.96	10	81	78	71	59	49	33	23	13	2
AUG 30	.36	33	57	53	44	33	26	16	10	6	1
SEP 13	.43	43	49	45	38	28	21	13	8	5	1
SEP 27	.36	36	49	46	38	26	19	10	5	2	
OCT 11	.14	66	32	30	25	17	12	6	3	1	
OCT 25	.20	56	38	35	28	18	12	5	2	1	
NOV 08	.27	33	53	48	36	22	13	5	2		
NOV 22	.18	53	45	41	32	19	12	5	2		
DEC 06	.32	43	51	48	40	28	19	9	4	2	
DEC 20	.42	30	59	55	46	33	24	12	6	2	
JAN 03	.38	36	57	53	45	32	23	11	6	2	
JAN 17	.37	33	59	55	46	32	22	11	5	2	
JAN 31	.31	30	59	54	44	29	19	9	4	1	
FEB 14	.38	23	57	51	41	27	19	9	5	2	

AJO, ARIZONA 20080
PRECIPITATION MEANS AND PROBABILITIES FOR 3 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.64	40	49	46	40	31	25	17	12	7	1
MAR 22	.22	36	46	41	32	20	13	6	3	1	
APR 12	.07	63	30	25	15	5	2				
MAY 03	.05	70	23	18	11	4	2				
MAY 24	.03	83	15	11	5						
JUN 14	.09	56	34	29	20	11	6	2	1		
JUL 05	.88	6	89	86	77	62	49	32	21	11	2
JUL 26	1.69	0	97	96	93	85	77	60	46	30	6
AUG 16	1.15	6	88	85	79	68	59	43	31	19	4
SEP 06	.61	26	61	57	49	39	31	21	14	9	2
SEP 27	.48	30	60	56	47	34	26	14	8	4	
OCT 18	.26	50	47	43	35	25	17	9	5	2	
NOV 08	.38	30	61	56	45	30	20	9	4	1	
NOV 29	.38	26	64	60	50	36	26	13	7	3	
DEC 20	.58	23	70	67	59	45	35	20	11	5	
JAN 10	.59	23	73	69	61	46	35	19	10	4	
JAN 31	.50	20	73	68	57	41	30	17	10	4	

Figure 11b. Analysis of precipitation probabilities for Ajo, Arizona.

For each station in the Semi-Arid Southwest region an isopercental analysis was done, as shown in Figure 11b. The isopercental analysis for one-week periods at Ajo, Arizona, clearly shows a maximum beginning about June 21 and ending about September 20. This maximum also corresponds to some of the highest weekly average precipitation amounts and some of the lowest probabilities of zero or trace rainfall amounts during a week. In this instance the monsoon season is at its peak, and is characterized by convective rainshowers. A second maximum begins about November 1 and continues through the middle or last part of March. The mean rainfall amounts during these weeks are less than those experienced during the warmer months, and represent a secondary maximum of mean rainfall. The third period, middle or late March through mid June, is characterized by very low rainfall amounts and high probabilities of zero or trace rainfall amounts.

A similar analysis was done for all the stations in the Semi-Arid region. For our analysis no attempt is being made to divide the seasons into less than a one-month period. The preliminary analysis of these data, Figure 11c, indicates that Arizona and New Mexico west of the Continental Divide can be characterized by three seasons: 1) July through October (primarily the Monsoon Season, 2) November through February (a period characterized by large-scale general storms), and 3) March through June (a relatively dry period). New Mexico east of the Continental Divide can be depicted by two seasons. The eastern most region can be divided into a warm season (April through October) and a cold season (November through March). A second region is south-central New Mexico, where the seasons appear to be defined by June through October (warm season) and November through May (cold season). For Nevada and Utah the seasonality is not clearly defined from the preliminary analysis. The northern parts of Nevada and Utah appear to be divided into two seasons: a dry period beginning in June or July through September, and a wet period from October through May or June. The central and southern regions of Nevada and New Mexico are portrayed by transitional periods between northern Nevada and New Mexico and Arizona-New Mexico.

WESTERN REGION STATION LOCATIONS

SCALE 1:10,000,000

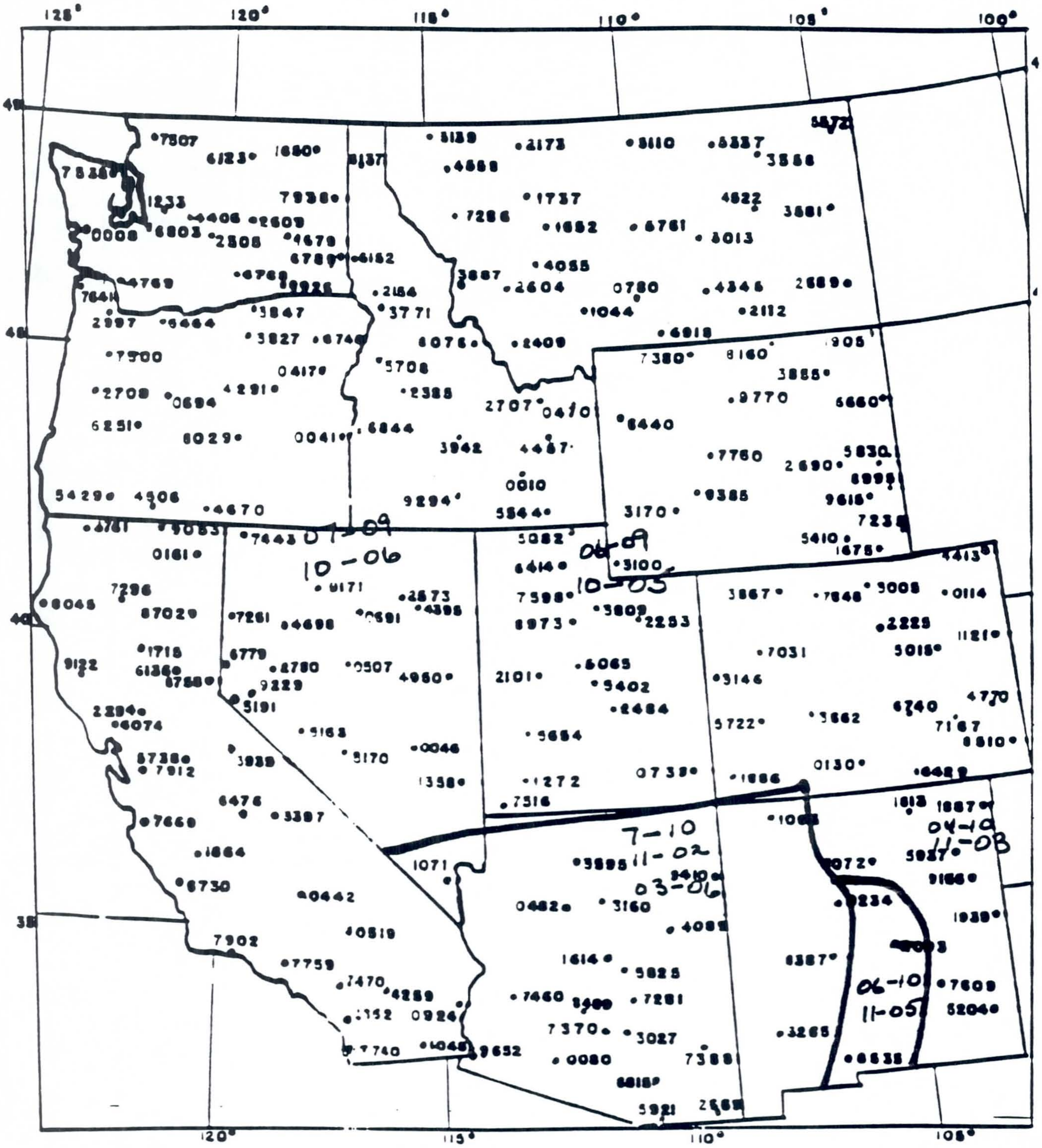

Figure 11c. Preliminary analysis of seasonality for the Semi-Arid Precipitation Frequency Project.

The third data set is a frequency count of the months in which the annual maximum intensity occurred for durations of 3, 12, 24, and 48 hours. Thirteen stations have been chosen for the initial analysis (Figure 12a). The frequency counts by months for Ajo, Arizona, is shown in Figure 12b. July through September dominate the maximum annual occurrence for all durations through 48 hours, with a dry period from April through June. This analysis is in agreement with the results found from the other two data sets, which indicate a wet period from July through October, a secondary maximum from November through February or March, and a dry period from April through June. The analysis for the other stations show similar results for the various reasons, including some sort of a transitional period over central and southern portions of Nevada and Utah. There are minor differences in the results from this preliminary analysis of the three data sets, but these three data sets should be sufficient to define the seasonality of the Semi-Arid Southwest.

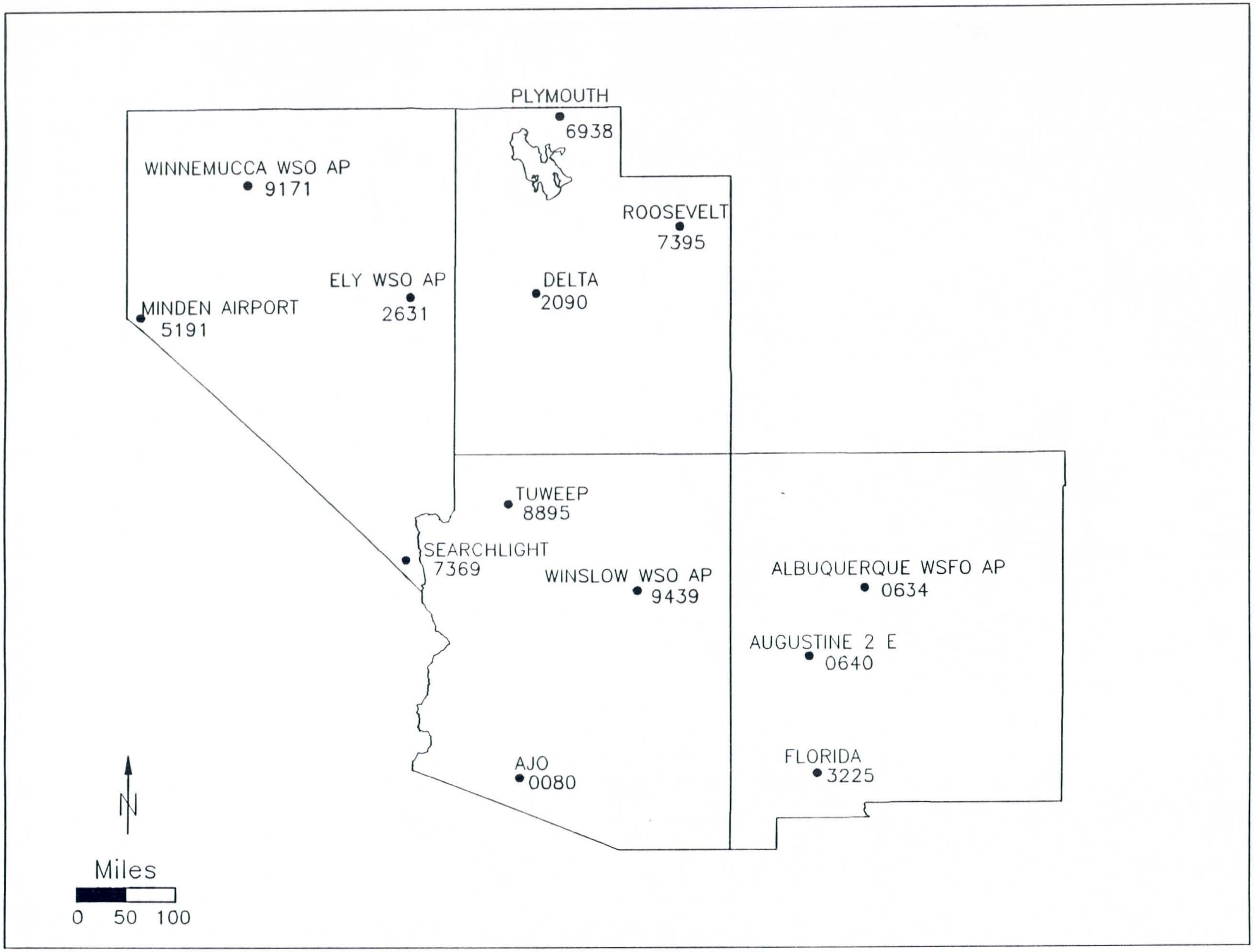

Figure 12a. Stations chosen for seasonality analysis.

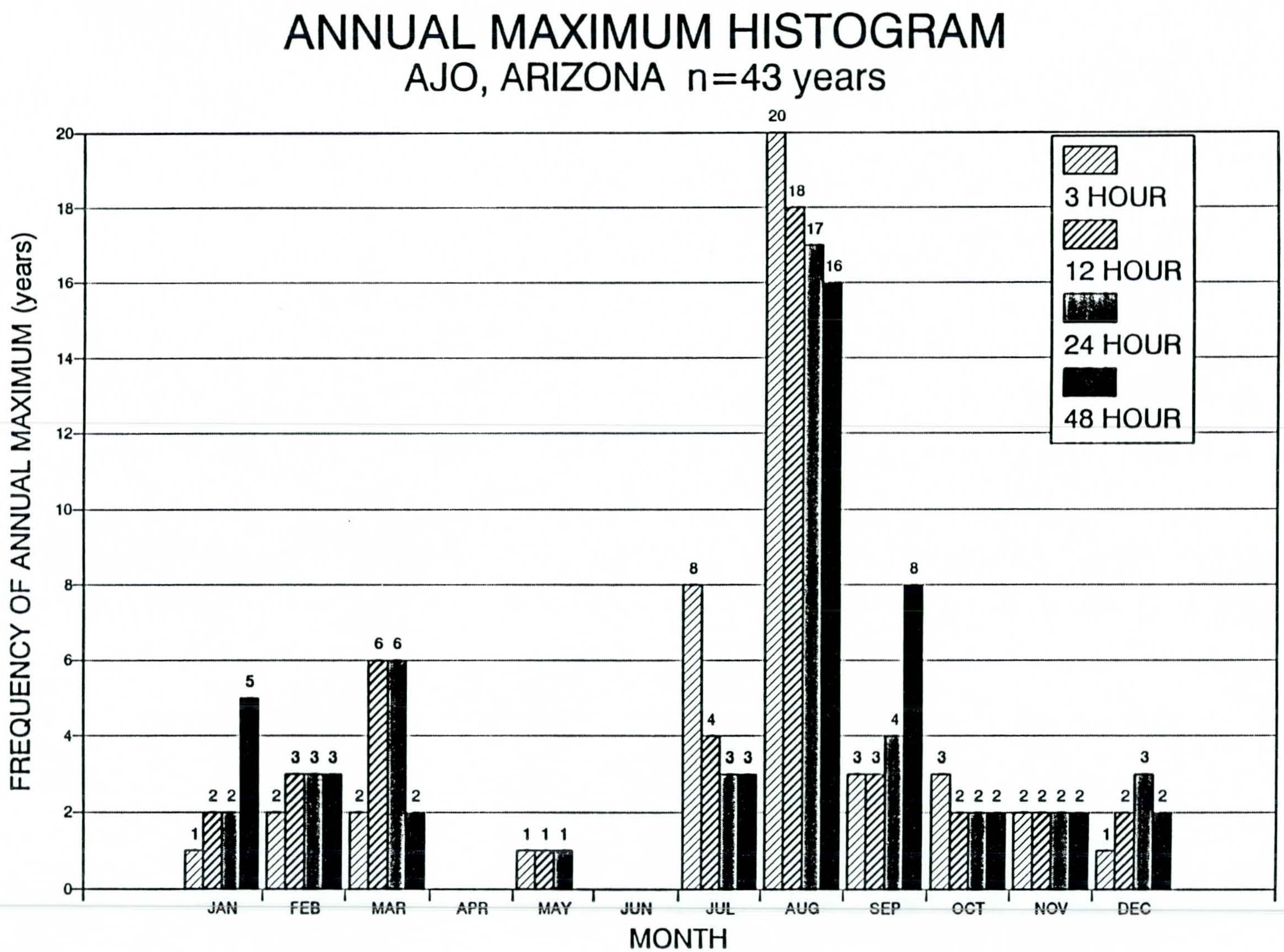

Figure 12b. Intensity of annual maximum by month for durations of 3, 12, 24, and 48 hours at Ajo, Ari[illegible]a.

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ATTACHMENT A

Third Meeting
Semi-Arid Precipitation Frequency Study
Phoenix, Arizona
December 7, 1992

The Third Semi-Annual review meeting for the Southwest Semi-Arid Precipitation Frequency Project was convened at 9 AM at the Arizona Department of Transportation Administration offices in Phoenix. Joe Warren served as the host. The agenda for the meeting is included as Attachment B. Lesley Tarleton and John Vogel of the Office of Hydrology, Water Management Information Division (WMID) presented the review. John Vogel led off by summarizing some general progress of the project.

Attendance

Joe Warren	ADOT[1]	(602) 831-0662
Ray Jordan	ADOT	(602) 255-7197
Tony Brazel	ASU[2]	(602) 965-6265
George Lopez Cepero	ADOT	(602) 255-7481
Cliff Anderson	AMAFCA[3]	(505) 884-2215
Stephen Waters	Maricopa FCD	(602) 506-1501
Jess Romero	Yavapai FCD	(602) 771-3196
Lesley Tarleton	NOAA/NWS	(301) 713-1669
John Vogel	NOAA/NWS	(301) 713-1669

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[1] Arizona Department of Transportation

[2] Arizona State University, Office of Climate

[3] Albuquerque Metropolitan Arroyo Flood Control District

ATTACHMENT B

Agenda for Semi-Annual Meeting of the Semi-Arid Precipitation Frequency Project

December 7, 1992

I. Welcome and Overview

II. Data

- A. Data Reduction
  - 1. Progress of hourly and daily data processing
  - 2. Merging/Deletion of stations
- B. Data Acquisition
- C. Data Quality Control
  - 1. L-Moments
  - 2. Mass Curves
- D. Data Comparisons Planned

III. Seasonality

- A. Dry Periods
- B. Probability of Precipitation Amounts
- C. Frequency of Annual Maximum Values

IV. Frequency Calculations

V. Storm Analysis

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

April 15, 1993 W/OH11/lft

MEMORANDUM FOR: Southwest Semi-Arid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Sixth Quarterly Report - Semi-Arid Precipitation Frequency Project, January 1 - March 31, 1993

Enclosed is a copy of the Sixth Quarterly Progress Report for the Semi-Arid Precipitation Frequency Project for the southwestern United States. In this update, the report contains listings of the quality-controlled data sets for the core states; lists of the border state hourly stations, and lists of the stations for which there are co-located hourly and daily stations. The latter is for comparisons of daily and 24-hour data so that a combined data set can be used for frequency analysis where appropriate. Also included is an initial analysis of the Walnut Gulch, Arizona, dense raingage network.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMI-ARID PRECIPITATION FREQUENCY STUDY

Sixth Quarterly Progress Report
for the period from
January 1 through March 31, 1993

Lesley F. Tarleton, Julie M. Olson,
Edwin H. Chin, John L. Vogel, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
April 1993

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SEMI-ARID PRECIPITATION FREQUENCY STUDY

Sixth Quarterly Progress Report
for the period from
January 1 through March 31, 1993

OVERVIEW

This Sixth Quarterly Report summarizes the work for the Semi-Arid Precipitation Frequency Project for the period January 1 through March 31, 1993. Station lists and maps of the quality-controlled hourly data sets are given in the Appendices. Among these are the hourly data for the core states - Arizona, Nevada, New Mexico, and Utah, and the stations which have both hourly and daily observations for at least 15 years of record. The station lists for the bordering states are also given in the Appendices. In addition, the station list for California, which is both a 'border' state and part of the core study area (southeastern California) is included in this report. Comparison of annual and partial duration series procedures for daily data is discussed, as well as comparison of daily and 24-hour data. Some analyses of the Walnut Gulch dense raingage network are included.

DATA

Hourly Data

Core area

In the quality-control process, the number of hourly stations for the four core states, Arizona, Nevada, New Mexico, and Utah, has been decreased about 45 percent. Short station records from adjacent stations have been merged; stations with less than five years of data have been deleted, as they cannot be processed in the L-moment programs; stations with less than 15 years of data are insufficient for frequency analysis and have been removed from the data base. Appendices 1a - 1d show the revised station lists for the states of Arizona, Nevada, New Mexico, and Utah, respectively. Appendices 2a - 2d list the station merges for each of the states. Figures 1a - 1d are maps of the revised stations for each state. As a result of the quality assurance process, all the stations on these lists and maps have at least 15 years of record. These data are being used for initial frequency analysis, and for comparison and evaluation of relationships between data sets and between various procedures.

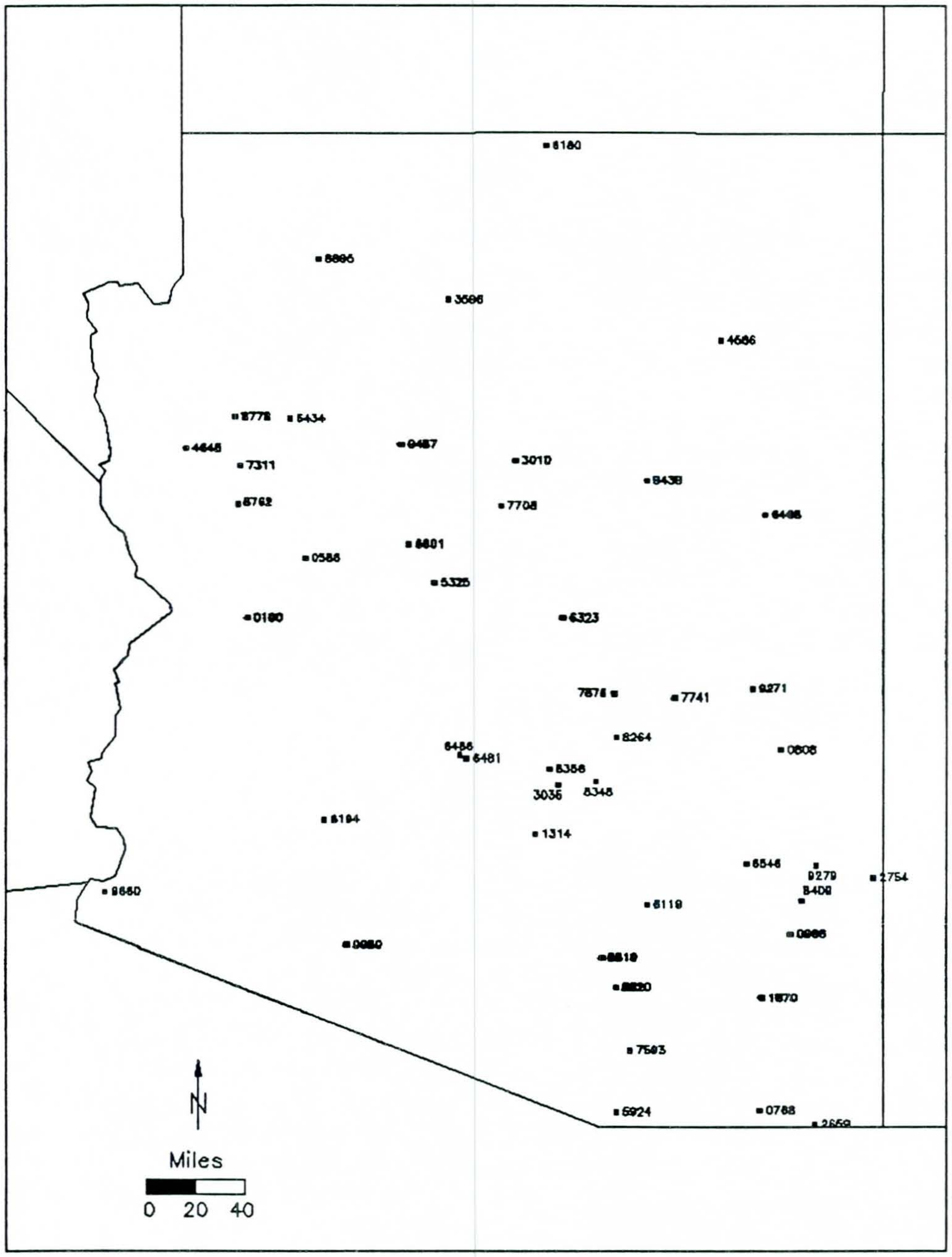

Figure 1a. Arizona hourly stations after quality control, station number.

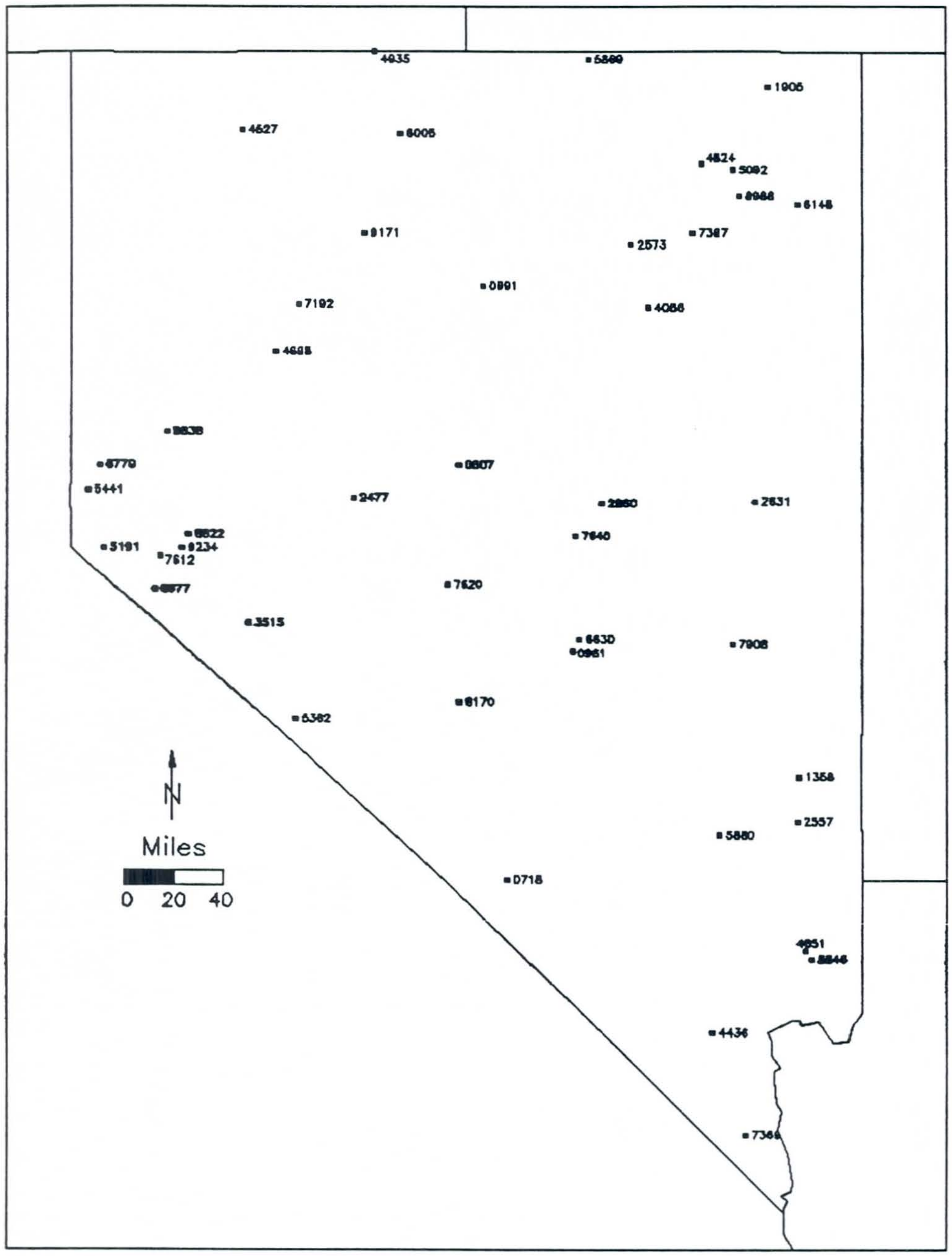

Figure 1b. Nevada hourly stations after quality control, station number.

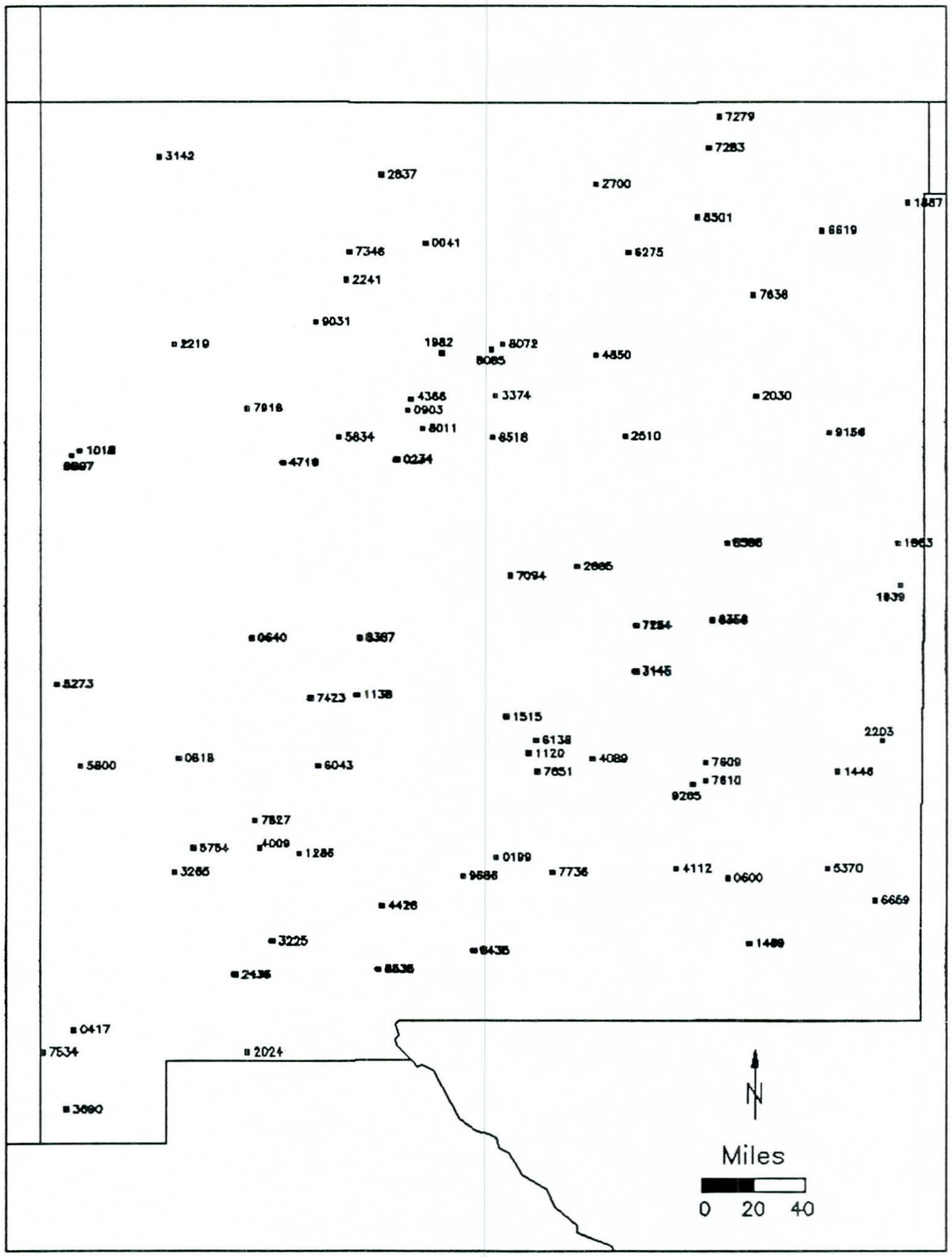

Figure 1c. New Mexico hourly stations after quality control, station number.

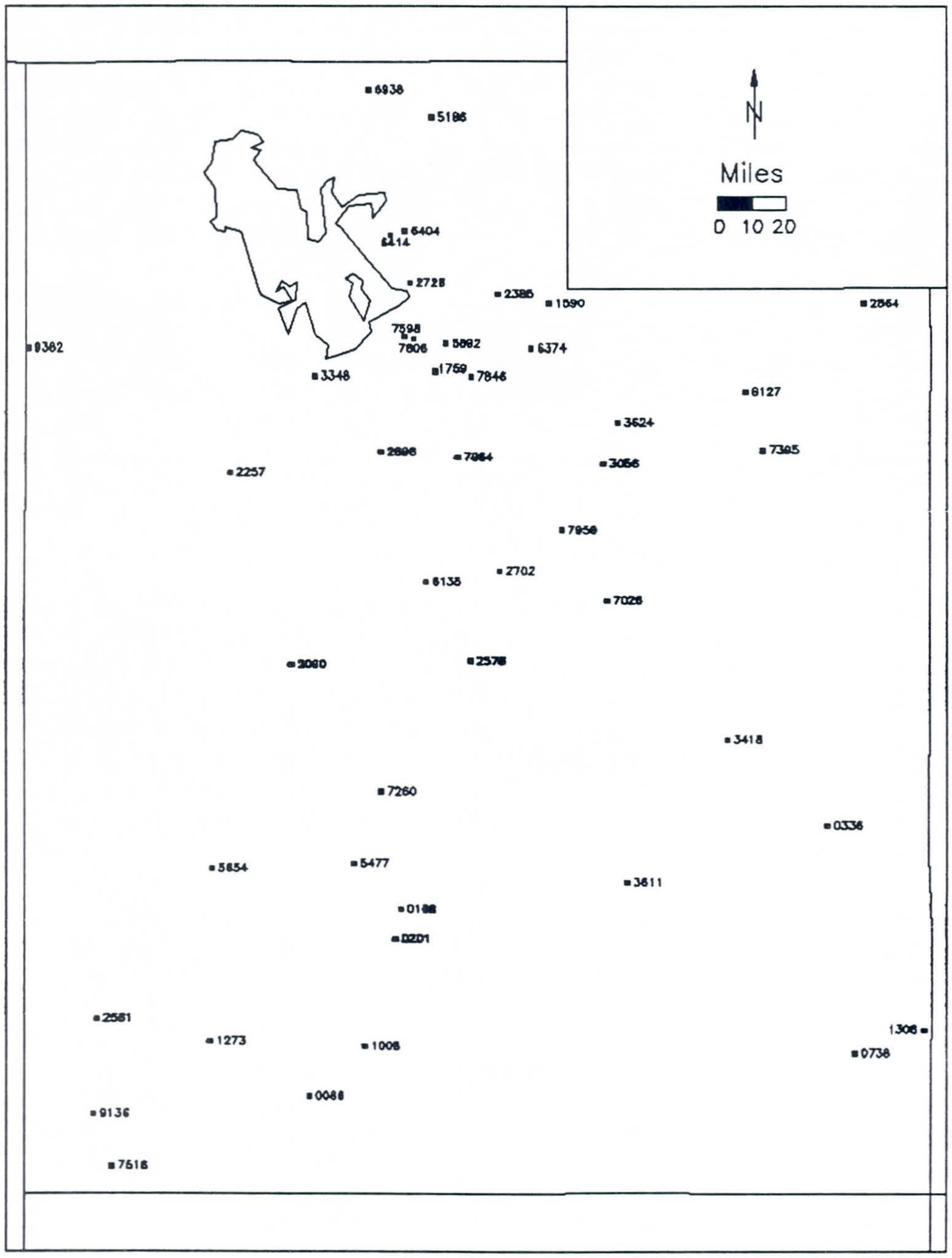

Figure 1d. Utah hourly stations after quality control, station number.

Border States and California

In order to make the analyses consistent with adjacent areas and not 'break' at state boundaries, precipitation data are being analyzed for a distance of one degree of latitude (60 nautical miles) into the states around the study area. Appendices 3a - 3e list the stations within that distance for Colorado, Idaho, Oregon, Texas, and Wyoming. California is a special case as southeastern California is part of the study area, the rest of southern California borders the study area, and northeastern California borders the core state of Nevada. Figure 2 shows the map of the entire study area, including the border states. Appendix 4 lists the initial 270 California hourly stations being used for this study. The quality control techniques for the border states and California stations are the same as those used for the other states, including L-moments, double-mass curves, time series, station histories, and so on. These procedures have been described in detail in earlier Semiarid Study Quarterly Reports (QR4, Jun-Aug 1992; and QR5, Oct-Dec 1992).

Daily Data

The daily data stations being used in the study have at least 19 years of record, with 276 stations in Arizona, 105 in Nevada, and 186 in Utah. New Mexico has 430 stations with at least one year of data, but has been processed somewhat differently. The data prior to 1948 for the other states was hand-entered into the digital data base. Fortunately, for New Mexico the complete digital records of pre-1948 daily data were obtained from Ken Kunkel, the former State Climatologist for New Mexico. This valuable data set extends the data base to the beginning year of each station. However, these digital data needed reformatting in order to match the rest of the New Mexico observations. Jennifer Hanson programmed the software during this quarter and the reformatting is expected to be complete in early April.

Fifteen-minute Data

Fifteen-minute precipitation data tapes from the National Climate Data Center (NCDC) have been read and put on the RISC 6000. Station lists for the 15-minute data in the core and border states have been prepared. There are 47 stations in Arizona, 47 in Nevada, 73 in New Mexico, and 70 in Utah. As an sample, Table 1 shows the Arizona station list and other information for 15-minute data for that state. Information given for each station includes station name and number, latitude and longitude, elevation, and years of record. The code PP15 indicates 15-minute data, and E18234 is the tape number.

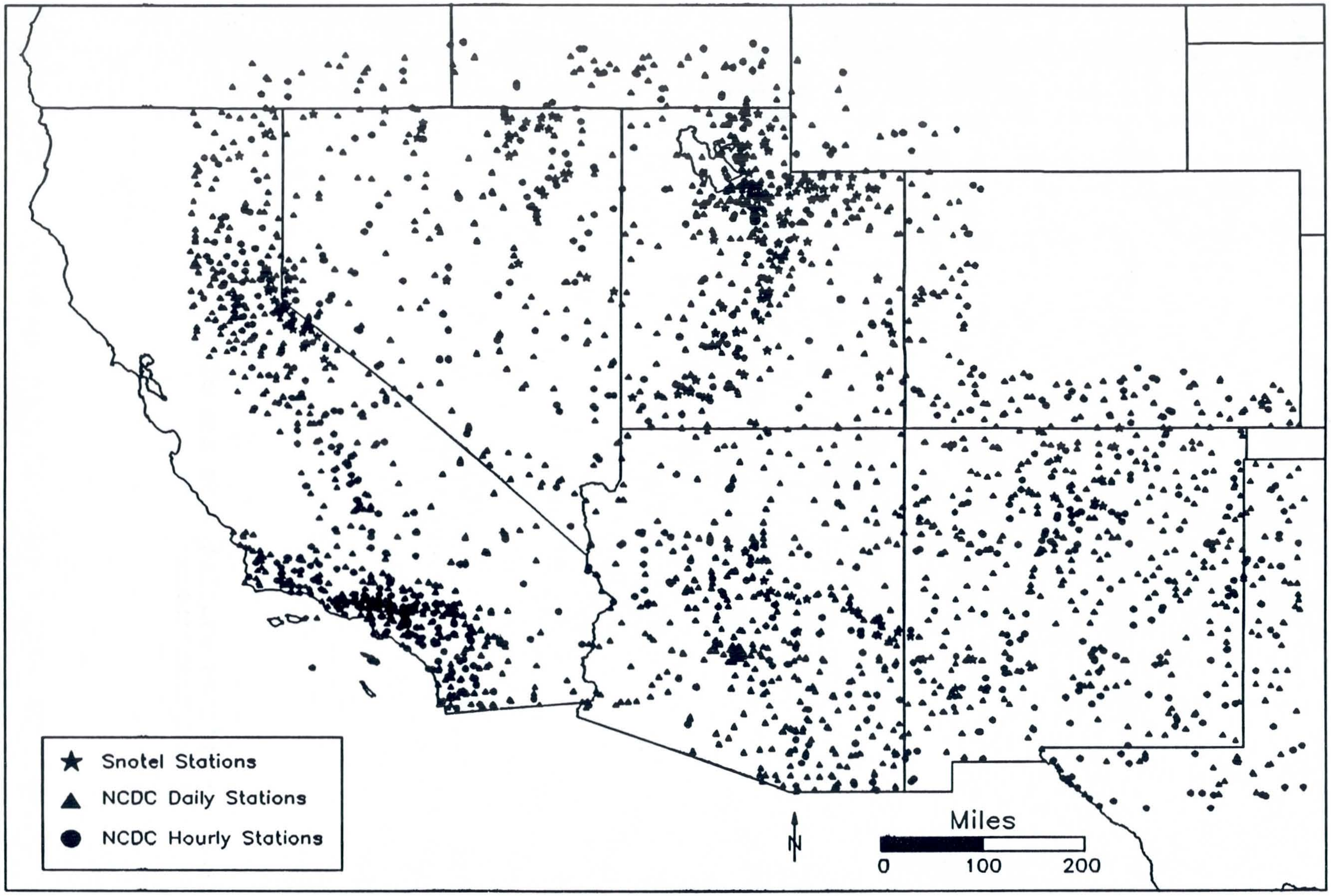

Figure 2. Stations used in the Southwestern Semi-Arid Precipitation Frequency Study.

Table 1. 15-minute Data

	AZ	-STATION NAME MISSING-		02-0008	0.00	0.00
0		7/1984 - 7/1984	PP15		E18234	
	AZ	AJO		02-0080	32.37	112.87
1800		5/1971 - 12/1987	PP15		E18234	
	AZ	ALAMO DAM		02-0100	34.23	113.58
1290		1/1984 - 12/1987	PP15		E18234	
	AZ	ASH FORK 2		02-0487	35.22	112.48
5080		5/1971 - 12/1987	PP15		E18234	
	AZ	BAR T BAR RANCH		02-0625	34.03	111.37
3100		12/1976 - 2/1980	PP15		E18234	
	AZ	BISBEE		02-0768	31.43	109.92
5310		6/1971 - 2/1985	PP15		E18234	
	AZ	BISBEE		02-0773	31.43	109.92
5310		3/1982 - 6/1982	PP15		E18234	
	AZ	BISBEE 2 WNW		02-0775	31.47	109.93
5600		3/1985 - 12/1987	PP15		E18234	
	AZ	BLACK RIVER PUMPS		02-0808	33.48	109.77
6040		6/1971 - 12/1987	PP15		E18234	
	AZ	CASA GRANDE RUINS N M		02-1314	33.00	111.53
1420		5/1971 - 12/1987	PP15		E18234	
	AZ	CHEVELON RANGER STN		02-1574	34.53	110.92
7010		12/1981 - 12/1987	PP15		E18234	
	AZ	CIBECUE		02-1749	34.03	110.48
5050		6/1980 - 12/1987	PP15		E18234	
	AZ	CLIFTON 17 NE		02-1852	33.28	109.20
4280		6/1978 - 12/1980	PP15		E18234	
	AZ	COCHISE 4 SSE		02-1870	32.07	109.90
4180		4/1972 - 12/1987	PP15		E18234	
	AZ	CROWN KING		02-2329	34.20	112.33
5920		6/1980 - 12/1987	PP15		E18234	
	AZ	DOUGLAS		02-2659	31.35	109.53
4040		5/1971 - 12/1987	PP15		E18234	
	AZ	DUNCAN		02-2754	32.75	109.12
3660		8/1975 - 12/1987	PP15		E18234	
	AZ	FLAGSTAFF WSO AP		02-3010	35.13	111.67
7010		1/1984 - 12/1987	PP15		E18234	
	AZ	FLORENCE JUNCTION		02-3035	33.28	111.37
1880		5/1971 - 9/1982	PP15		E18234	
	AZ	GRAND CANYON NATL PK 2		02-3596	36.05	112.15
6790		1/1984 - 12/1987	PP15		E18234	
	AZ	KEAMS CANYON		02-4586	35.82	110.20
6210		5/1971 - 12/1987	PP15		E18234	
	AZ	KINGMAN 2		02-4645	35.20	114.02
3540		5/1971 - 12/1987	PP15		E18234	
	AZ	MAYER 3 NNW		02-5325	34.43	112.25
4640		5/1971 - 11/1986	PP15		E18234	
	AZ	MAYER NO. 2		02-5344	34.38	112.23
4340		11/1986 - 12/1987	PP15		E18234	
	AZ	MONTEZUMA CASTLE N W		02-5635	34.62	111.83
3180		7/1979 - 12/1987	PP15		E18234	
	AZ	NOGALES		02-5921	31.35	110.92
3810		5/1971 - 12/1983	PP15		E18234	
	AZ	NOGALES 6 N		02-5924	31.42	110.95
3560		8/1983 - 12/1987	PP15		E18234	

Table 1. (cont)

	AZ	ORACLE 2 SE		02-6119	32.60	110.73
4510	5/1971 - 12/1987		PP15		E18234	
	AZ	PAINTED ROCK DAM		02-6194	33.08	113.03
550	1/1984 - 12/1987		PP15		E18234	
	AZ	PARKER CREEK MNTC YRD		02-6260	33.78	110.97
4990	3/1972 - 12/1975		PP15		E18234	
	AZ	PAYSON		02-6323	34.23	111.33
4910	5/1971 - 12/1987		PP15		E18234	
	AZ	PETRIFIED FOREST NAT P		02-6468	34.82	109.88
5450	3/1972 - 12/1987		PP15		E18234	
	AZ	PHOENIX WSFO AP		02-6481	33.43	112.02
1110	1/1984 - 12/1987		PP15		E18234	
	AZ	SANTA RITA EXP RANGE		02-7593	31.77	110.85
4300	3/1972 - 12/1987		PP15		E18234	
	AZ	SEDONA R S		02-7708	34.87	111.77
4220	4/1973 - 12/1987		PP15		E18234	
	AZ	SIERRA ANCHA		02-7876	33.80	110.97
5100	12/1975 - 12/1987		PP15		E18234	
	AZ	SUNFLOWER 3 NNW		02-8273	33.90	111.48
3720	7/1980 - 12/1987		PP15		E18234	
	AZ	SUPERIOR		02-8348	33.30	111.10
3000	3/1973 - 10/1978		PP15		E18234	
	AZ	SUPERIOR 2 ENE		02-8349	33.30	111.07
4160	10/1978 - 12/1987		PP15		E18234	
	AZ	TRUXTON CANYON		02-8778	35.38	113.67
3820	7/1972 - 12/1987		PP15		E18234	
	AZ	TUCSON WSO AP		02-8820	32.13	110.95
2580	1/1984 - 12/1987		PP15		E18234	
	AZ	TUWEEP		02-8895	36.28	113.07
4780	10/1972 - 12/1987		PP15		E18234	
	AZ	VAIL		02-8995	32.05	110.72
3230	9/1977 - 12/1987		PP15		E18234	
	AZ	WALNUT CREEK		02-9158	34.93	112.82
5090	7/1979 - 12/1987		PP15		E18234	
	AZ	WHITERIVER 1 SW		02-9271	33.83	109.97
5120	4/1973 - 12/1987		PP15		E18234	
	AZ	WINSLOW WSO AP		02-9439	35.02	110.73
4890	1/1984 - 12/1987		PP15		E18234	
	AZ	WORKMAN CREEK 1		02-9534	33.82	110.92
6970	10/1972 - 2/1986		PP15		E18234	
	AZ	YUMA WSO AP		02-9660	32.67	114.60
210	1/1984 - 12/1987		PP15		E18234	

ANALYSIS

Annual Versus Partial Duration Series

Using daily data, Dr. Edwin Chin is evaluating the relationship between return frequencies calculated from annual series and ones based on partial duration series. An annual series consists of the highest precipitation amount for each duration in each year; whereas a partial duration series consists of the **n** highest amounts, where **n** is the number of years of record, regardless of year of occurrence. Dr. Chin is using over 200 daily stations in Arizona, and preparing the annual and partial duration series for each station. All stations have at least 19 years of record, and most stations have about 35 years of data. Some stations have nearly 100 years of observations, with the longest records at Clifton (1849; 33.05N, 109.28W) and Parker 6 NE (6250; 34.18N,114.22W), each with 98 years of observations. When the data base is complete, the return frequencies will be calculated, using L-moment statistics and the Generalized Extreme Value (GEV) distribution, for each series separately. The results will be compared and contrasted; and the results applied to the analysis of other states in the study.

Comparison of Daily and 24-Hour Data

In order to use the maximum amount of available data, it is necessary to understand and adjust for the differences between data collected daily and that collected hourly. All stations that have at least 15 years of data and have co-located daily and hourly observations have been put into a separate data base for statistical testing. The stations that meet these criteria for Arizona, Nevada, New Mexico, and Utah are listed in Appendices 5a - 5d. The evaluation of relationships between these two types of observations will permit the use of a much larger data base for the preparation of return frequency estimates. Julie Olson and Michael Yekta prepared the data sets and have begun processing the data.

Border States - Quality Control

The stations in the border areas (Appendices 3a - 3e) are being checked for missing or erroneous data, proximity to other stations, and otherwise checked for quality control. In addition to L-moment plots of L-skewness (L-SKEW) versus L-kurtosis (L-KURT) (or L-coefficient of variation (L-CV)), and double-mass curves, discussed in detail in earlier quarterly reports; maps of the L-statistics are being used to evaluate consistency and reasonableness of all station data. For example, the Texas hourly stations being considered for this study are shown on the map in Figure 3. Note the circled stations Pep and Pettit 4 NE, which appear geographically close. For these two stations, several things need to be considered: the distance between them, the elevation difference, and whether the L-statistics are similar to other stations in the area. The L-statistics (mean, L-CV, L-SKEW) for the six-hour annual maxima for the Texas stations are mapped in Figures 4, 5, and 6. Looking again at Pep and Pettit 4 NE, there are notable differences in the values for the means and L-CV's for this pair of stations:

	Pep	Pettit
Mean	2.16	1.44
L-CV	0.57	0.59
L-SK	0.22	0.10

In order to evaluate this type of inconsistency, both stations need to be checked for things such as: missing data, short records, wrong data values, as well as elevation differences, aspect, etc. The data may be good, but confirmation is needed and potential problems eliminated. Another point to look for through mapping is a 'bulls-eye'. This is where a single station stands out from all the surrounding stations and does not fit in with the general pattern. Any station that is a 'bulls-eye' needs checking. This is the same process that has been used in quality control for the core states.

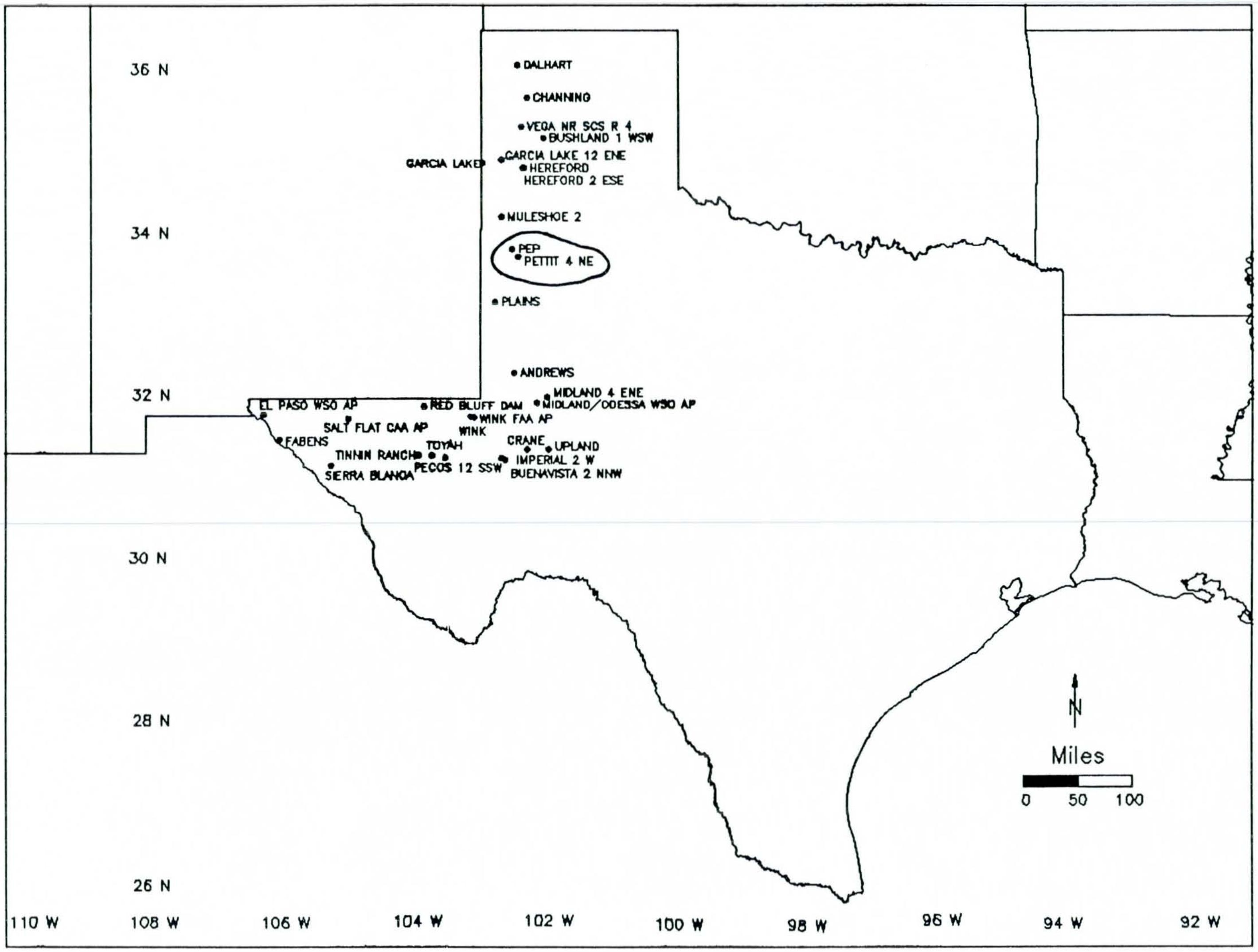

Figure 3. Texas Hourly Stations.

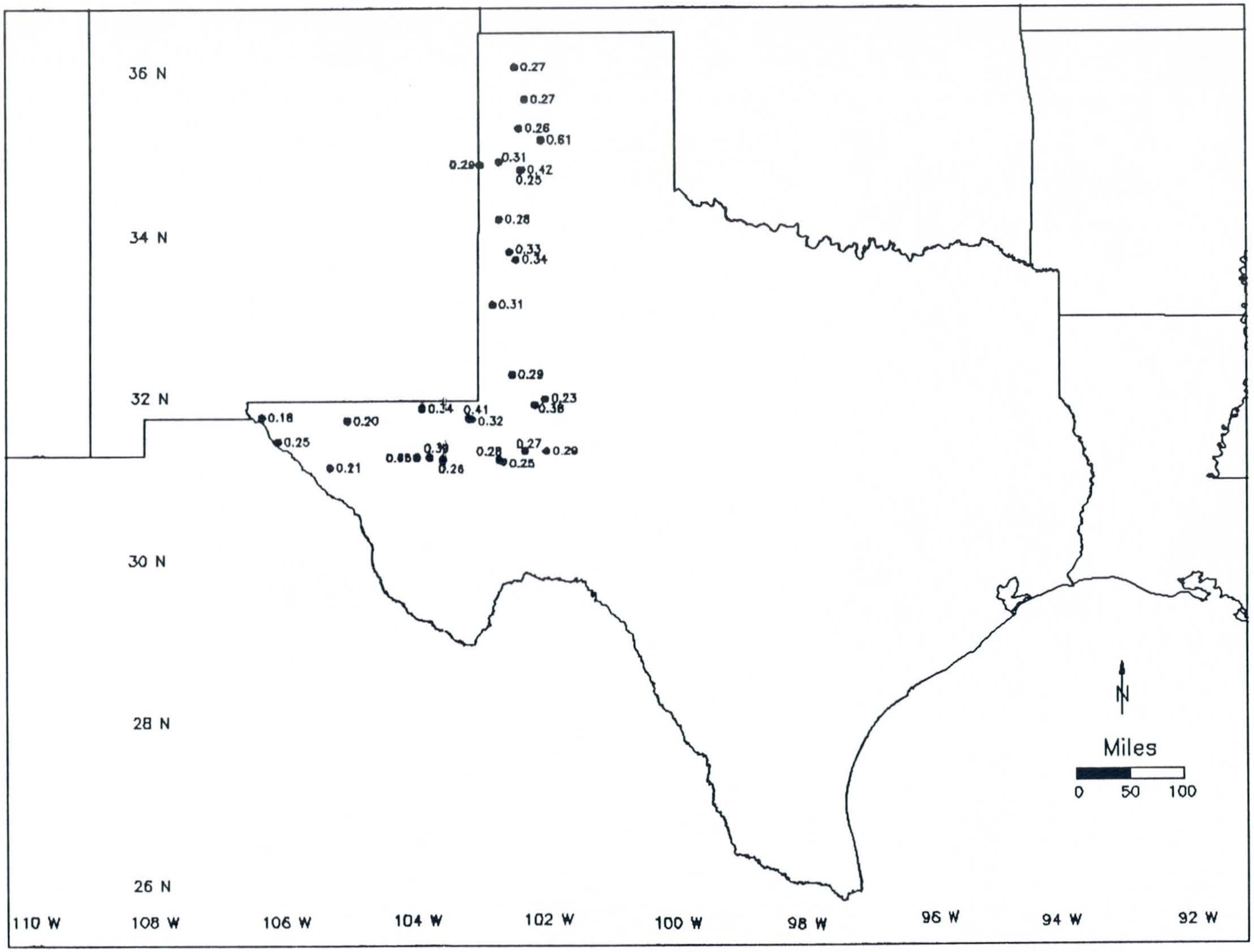

Figure 4. Texas Hourly Stations, 6-Hour, Annual Maximum Mean

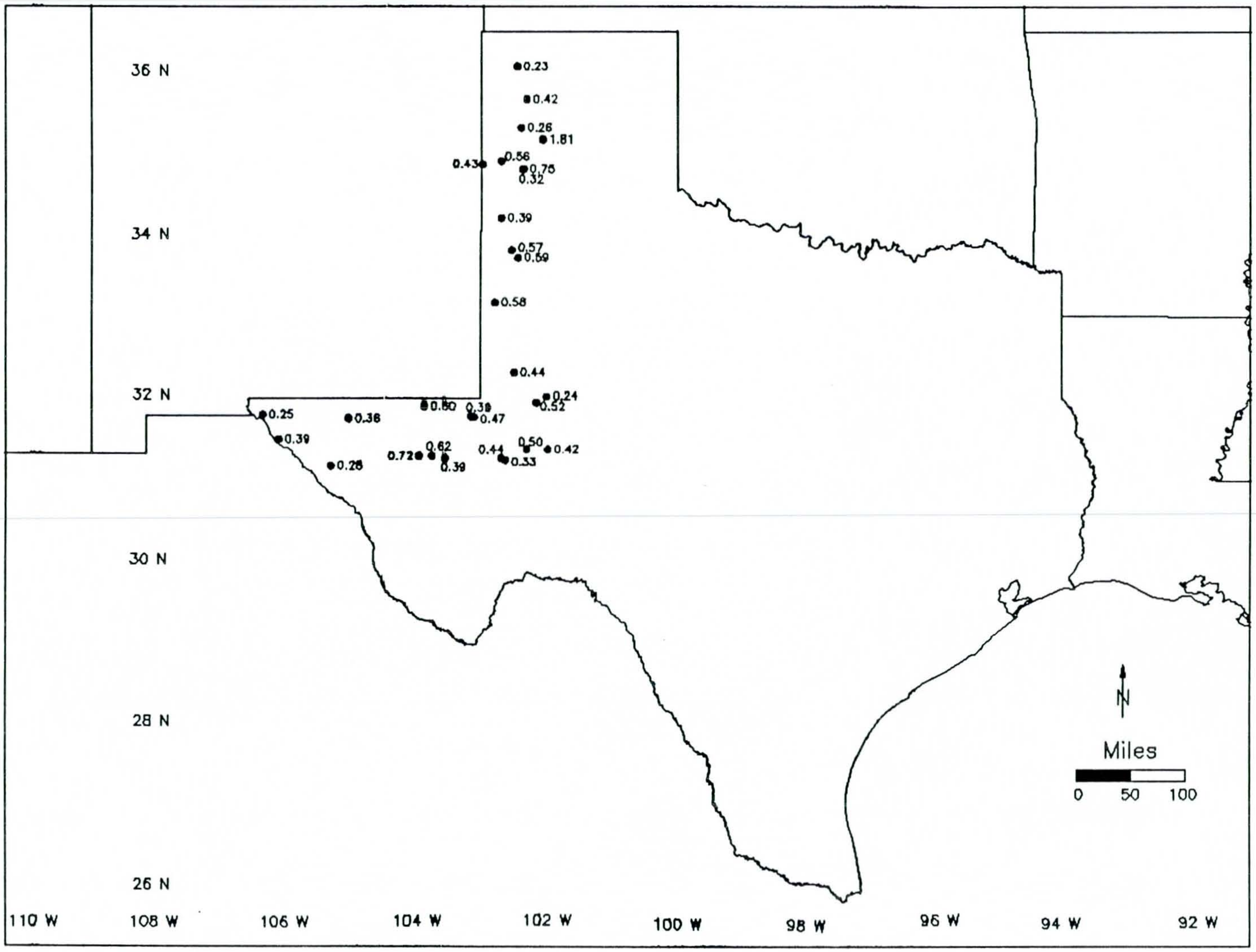

Figure 5. Texas Hourly Stations. 6-Hour, Annual Maximum L-CV

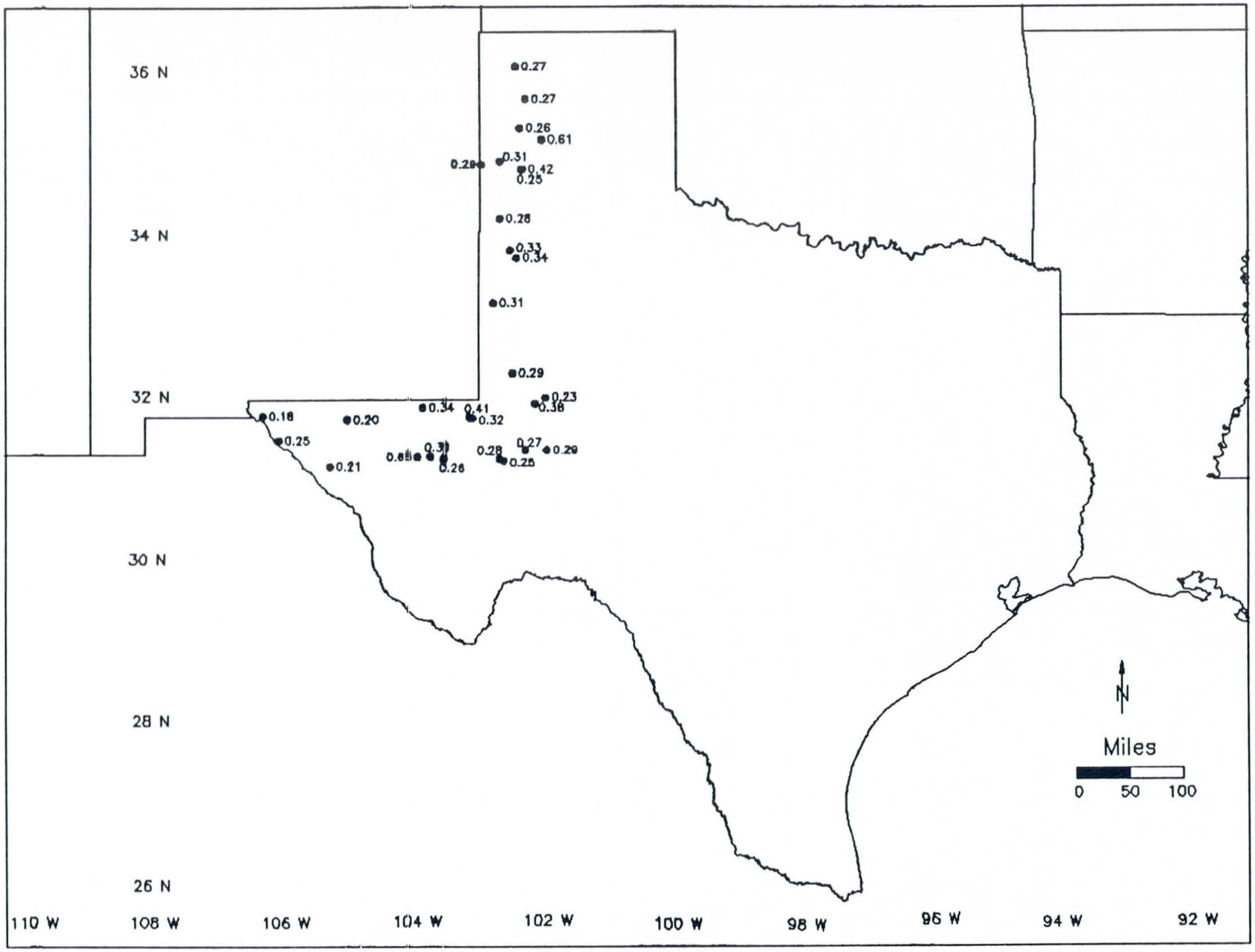

Figure 6. Texas Hourly Stations, 6-Hour, Annual Maximum L-Skewness

Walnut Gulch, Arizona

Agricultural Research Service (ARS)
Leonard Lane, Cathy Manetsch, and Mary Nichols of the Agricultural Research Service, Tucson, Arizona, have provided 35 years (1956-1990) of daily data from six gages in the ARS Walnut Gulch dense raingage network. Walnut Gulch is southeast of Tucson near Tombstone, Arizona. The network consists of about 85 recording gages in a 58 mi^2 (150 km^2) drainage basin, with elevations varying from about 4180 to 5200 feet (1275 to 1585 meters). An outline map of the basin with the gage locations is shown in Figure 7. An initial investigation with the data confirms the expectation that most of the extreme rainfall occurs in the late summer and, therefore, is convective and/or monsoonal. Figure 8 show a histogram of the percent frequency of the occurrence of precipitation of one-inch or greater amounts at any of the six gages. Eighty-five percent of the one-inch or higher rainfalls occur in July, August, or September. If October is included, over 90 percent of the rainfall is taken into account.

Many studies have been made over the years as this data base has grown longer and, thus, has become more valuable. These reference papers are an important resource, in addition to the basic data. Among the studies are ones on timing and duration of rainfall (Osborn 1983), and on stochastic models of rainfall in the basin (Osborn et al. 1971). Later in the year, when a new data processing system becomes available at ARS, breakpoint data for the same gages will be made available. This will give valuable information about short-duration rainfalls.

Figure 7. Walnut Gulch Precipitation Gauges

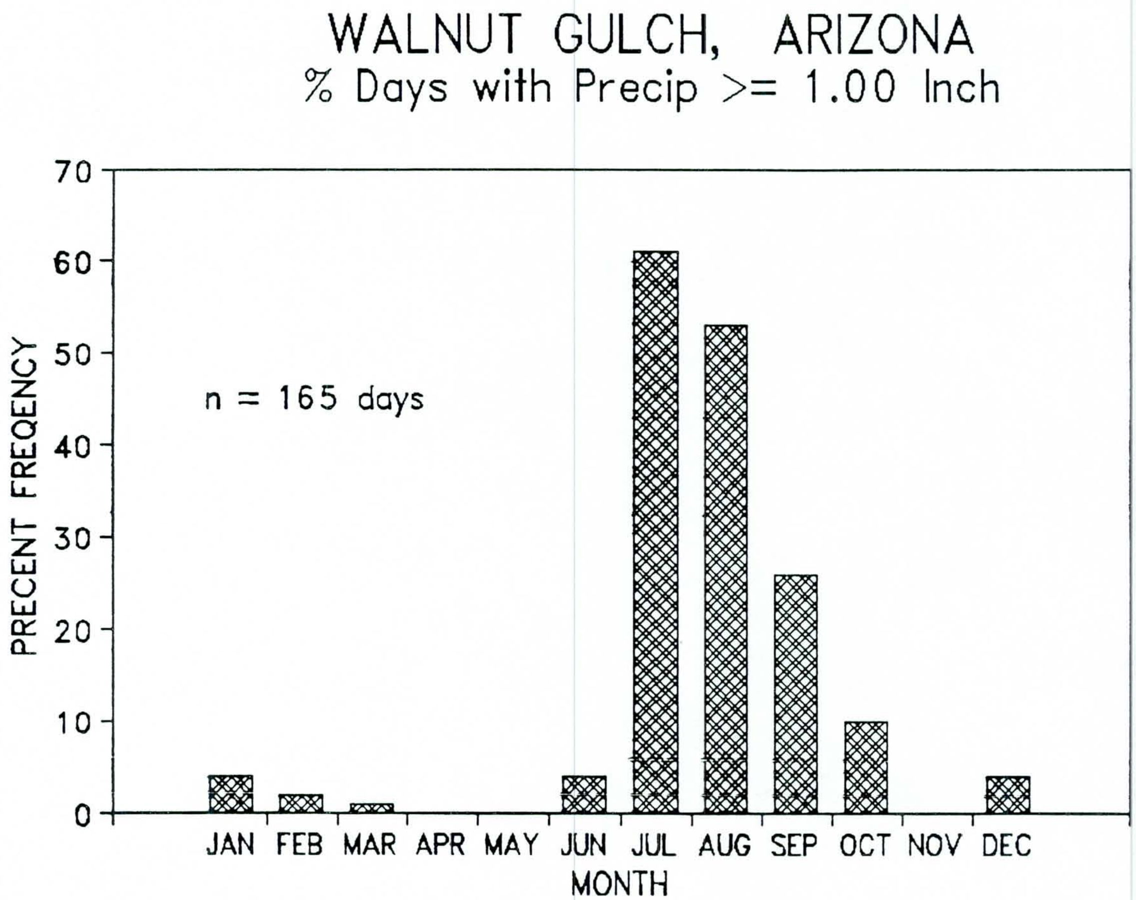

Figure 8. Percent of days with precipitation greater than equal to one inch at Walnut Gulch, Arizona.

REFERENCES

Osborn, Herbert B., 1983: Timing and duration of high rainfall rates in the Southwestern United States, Water Resources Research, 19:1036-1042.

Osborn, Herbert B., L.J. Lane, and R.S. Kagan, 1971: Stochastic models of spatial and temporal distribution of thunderstorm rainfall, Symposium on Statistical Hydrology, USDA Misc. Pub. #1275.

APPENDICES

Appendix 1a.

ARIZONA HOURLY STATIONS - AS OF 3/30/93

	NAME	STN#	LAT	LON	ELEV	PERIOD OF REC
1	AJO	0080	32.37	112.87	1800	7/1948-12/1990
2	ALAMO DAM	0100	34.23	113.58	1290	3/1965-12/1990
3	ASH FORK 2	0487	35.22	112.48	5080	7/1948-12/1990
4	BAGDAD	0586	34.57	113.17	3710	7/1948-11/1969
5	BISBEE	0768	31.43	109.92	5310	7/1948- 2/1985
6	BLACK RIVER PUMPS	0808	33.48	109.77	6040	7/1948-12/1990
7	BOWIE JCT R15 ON W5	0966	32.43	109.70	4720	7/1948- 2/1967
8	CASA GRANDE RUINS N M	1314	33.00	111.53	1420	7/1948-12/1990
9	COCHISE 4 SSE	1870	32.07	109.90	4180	7/1948-12/1990
10	DOUGLAS	2659	31.35	109.53	4040	7/1948-12/1990
11	DUNCAN	2754	32.75	109.12	3660	8/1975-12/1990
12	FLAGSTAFF WSO AP	3010	35.13	111.67	7010	7/1948-12/1990
13	FLORENCE JUNCTION	3035	33.28	111.37	1880	1/1968- 9/1982
14	GRAND CANYON NATL PK 2	3596	36.05	112.15	6790	7/1948-12/1990
15	KEAMS CANYON	4586	35.82	110.20	6210	7/1948-12/1990
16	KINGMAN 2	4645	35.20	114.02	3540	7/1948-12/1990
17	MAYER 3 NNW	5325	34.43	112.25	4640	7/1948-11/1986
18	NOGALES 6 N	5924	31.42	110.95	3560	7/1948-12/1990
19	ORACLE 2 SE	6119	32.60	110.73	4510	2/1950-12/1990
20	PAGE	6180	36.93	111.45	4270	10/1957-12/1983
21	PAINTED ROCK DAM	6194	33.08	113.03	550	1/1962-12/1990
22	PAYSON	6323	34.23	111.33	4910	5/1949-12/1990
23	PERNER RANCH	6434	35.37	113.28	5600	4/1952-11/1969
24	PETRIFIED FOREST NAT P	6468	34.82	109.88	5450	7/1948-12/1990
25	PHOENIX WSFO AP	6481	33.43	112.02	1110	7/1948-12/1990
26	PHOENIX CITY	6486	33.45	112.07	1080	7/1948- 8/1968
27	PIMA R4 ON W2	6546	32.83	110.02	3770	7/1948- 2/1967
28	PRESCOTT FAA AP	6801	34.65	112.43	5020	7/1948-11/1969
29	ROUND VALLEY	7311	35.10	113.63	3740	7/1948-11/1969
30	SANTA RITA EXP RANGE	7593	31.77	110.85	4300	5/1950-12/1990
31	SEDONA R S	7708	34.87	111.77	4220	4/1973-12/1990
32	SENECA 3 NW	7741	33.78	110.53	4920	7/1948-11/1965
33	SIERRA ANCHA	7876	33.80	110.97	5100	6/1972-12/1990
34	SUMMIT	8264	33.55	110.95	3650	10/1951- 5/1977
35	SUPERIOR	8348	33.30	111.10	3000	9/1948-10/1978
36	SUPERSTITION MTN	8356	33.37	111.43	1960	7/1948- 1/1968
37	TANQUE R9 ON W4	8409	32.62	109.62	3560	7/1948- 2/1967
38	TROUT CREEK STORE	8762	34.88	113.65	2850	7/1948-11/1969
39	TRUXTON CANYON	8778	35.38	113.67	3820	7/1948-12/1990

Appendix 1a (cont).

ARIZONA HOURLY STATIONS - AS OF 3/30/93

40	TUCSON NURSERY 4 NW	8810	32.30	111.05	2250	7/1948- 2/1965
41	TUCSON WSO AP	8820	32.13	110.95	2580	7/1948-12/1990
42	TUWEEP	8895	36.28	113.07	4780	7/1948-12/1990
43	UPPER PARKER CREEK	8940	33.80	110.95	5500	7/1948- 3/1972
44	WHITERIVER 1 SW	9271	33.83	109.97	5120	7/1948-12/1990
45	WHITLOCK VLY R2 ON W1	9279	32.82	109.52	3290	7/1948- 2/1967
46	WINSLOW WSO AP	9439	35.02	110.73	4890	7/1948-12/1990
47	WORKMAN CREEK 1	9534	33.82	110.92	6970	7/1948- 2/1986
48	YUMA WSO AP	9660	32.67	114.60	210	9/1948-12/1990

Appendix 1b.

NEVADA HOURLY STATIONS - AS OF 3/30/93

	NAME	STN#	LAT	LON	ELEV	PERIOD OF REC
1	AUSTIN	0507	39.50	117.08	6610	7/1948-12/1990
2	BATTLE MOUNTAIN AP	0691	40.58	116.90	4540	7/1948-12/1990
3	BEATTY 8 N	0718	37.00	116.72	3550	7/1948-12/1990
4	BLUE JAY HWY STN	0961	38.38	116.22	5320	5/1963- 4/1985
5	CALIENTE	1358	37.62	114.52	4400	7/1948-11/1976
6	CONTACT	1905	41.78	114.75	5370	7/1948-12/1990
7	EASTGATE	2477	39.30	117.88	5020	7/1948- 7/1969
8	ELGIN	2557	37.35	114.53	3390	3/1951-12/1990
9	ELKO FAA AP	2573	40.83	115.78	5080	7/1948-12/1990
10	ELY WSO AP	2631	39.28	114.85	6260	7/1948-12/1990
11	FISH CREEK RANCH	2860	39.27	116.00	6050	7/1948- 8/1966
12	HAWTHORNE AP	3515	38.55	118.67	4220	7/1948-12/1990
13	JIGGS 3 N	4086	40.45	115.65	5420	7/1948- 3/1972
14	LAS VEGAS WSO AP	4436	36.08	115.17	2160	1/1949-12/1990
15	LEONARD CREEK RANCH	4527	41.52	118.72	4220	12/1954-12/1990
16	LOGANDALE UN EXP FARM	4651	36.57	114.47	1320	2/1968-12/1990
17	LOVELOCK	4698	40.18	118.47	3980	9/1952-12/1990
18	MALA VISTA RANCH	4824	41.32	115.25	5590	3/1950- 4/1968
19	MC DERMITT	4935	42.00	117.72	4530	3/1950-12/1990
20	METROPOLIS	5092	41.28	115.02	5800	3/1968-12/1990
21	MINDEN AIRPORT	5191	39.00	119.75	4710	7/1948-12/1990
22	MONTOGMERY MNTC STN	5362	37.97	118.32	7100	5/1960- 8/1984
23	MT ROSE CHRISTMAS TREE	5441	39.35	119.87	7240	1/1971-12/1990
24	OVERTON	5846	36.52	114.42	1220	7/1948-12/1988
25	OWYHEE	5869	41.95	116.10	5400	7/1948- 6/1985
26	PAHRANAGAT WILDLIFE RE	5880	37.27	115.12	3400	4/1965-12/1990
27	PARADISE VALLEY 1 NW	6005	41.50	117.53	4680	7/1948- 1/1964
28	PEQUOP	6148	41.07	114.53	6300	7/1948- 8/1988
29	RATTLESNAKE	6630	38.45	116.17	5910	7/1948- 5/1963
30	RENO WSFO AP	6779	39.50	119.78	4400	7/1948-12/1990
31	RYE PATCH DAM	7192	40.47	118.30	4140	7/1948-12/1990
32	SEARCHLIGHT	7369	35.47	114.92	3540	7/1948-12/1990
33	SEVENTY-ONE RANCH	7397	40.90	115.32	5450	12/1949-9/1978
34	SMITH 6 N	7612	38.95	119.33	5000	7/1973-12/1990
35	SMOKEY VALLEY	7620	38.78	117.17	5630	5/1953-12/1990
36	SNOWBALL RANCH	7640	39.07	116.20	7160	9/1966-12/1990
37	SUNNYSIDE	7908	38.42	115.02	5300	7/1948-12/1990

Appendix 1b (cont).

NEVADA HOURLY STATIONS - AS OF 3/30/93

38	TONOPAH AIRPORT	8170	38.07	117.08	5430	6/1954- 3/1977
39	WABUSKA 5 SE	8822	39.08	119.12	4300	2/1972-12/1990
40	WADSWORTH 4 N	8838	39.70	119.28	4200	7/1948-12/1990
41	WELLINGTON R S	8977	38.75	119.37	4840	7/1948- 5/1973
42	WELLS	8988	41.12	114.97	5650	7/1948-12/1990
43	WINNEMUCCA WSO AP	9171	40.90	117.80	4300	7/1948-12/1990
44	YERINGTON 2	9234	39.00	119.17	4380	7/1948-12/1971

Appendix 1c.

NEW MEXICO HOURLY STATIONS - AS OF 3/30/92

	NAME	STN#	LAT	LON	ELEV	PERIOD OF REC
1	ABIQUIU DAM	0041	36.23	106.43	6380	10/1963-12/1990
2	ALAMOGORDO	0199	32.88	105.95	4350	9/1968-12/1990
3	ALBUQUERQUE WSFO AP	0234	35.05	106.62	5310	10/1947-12/1990
4	ANIMAS	0417	31.95	108.82	4420	11/1969-12/1990
5	ARTESIA 6 S	0600	32.77	104.38	3320	10/1947-12/1990
6	AUGUSTINE 2 E	0640	34.08	107.62	7000	10/1947-12/1990
7	BEAVERHEAD R S	0818	33.42	108.12	6670	7/1948-12/1990
8	BERNALILLO	0903	35.32	106.55	5060	10/1947- 9/1982
9	BLACK ROCK	1018	35.10	108.78	6450	7/1948-12/1974
10	BONITO DAM	1120	33.45	105.73	7280	10/1947-12/1990
11	BOSQUE DEL APACHE	1138	33.77	106.90	4510	9/1950-10/1970
12	CABALLO DAM	1286	32.90	107.30	4190	10/1947-12/1990
13	CAPROCK 6 SE	1446	33.35	103.63	4270	10/1947-12/1971
14	CARLSBAD	1469	32.42	104.23	3120	10/1947-12/1990
15	CARRIZOZO	1515	33.65	105.88	5420	10/1947-12/1990
16	CLAYTON WSO AP	1887	36.45	103.15	4970	10/1947-12/1990
17	CLOVIS 3 SSW	1939	34.37	103.20	4280	10/1947-12/1990
18	CLOVIS 13 N	1963	34.60	103.22	4440	7/1949-12/1990
19	COCHITI DAM	1982	35.63	106.32	5560	5/1959-12/1990
20	COLUMBUS	2024	31.83	107.65	4160	10/1947-12/1990
21	CONCHAS DAM	2030	35.40	104.18	4240	10/1947-12/1990
22	CROSSROADS	2203	33.52	103.33	4150	12/1971-12/1990
23	CROWNPOINT	2219	35.68	108.15	6960	7/1948-11/1969
24	CUBA	2241	36.03	106.97	7050	7/1970-12/1990
25	DEMING	2436	32.25	107.73	4300	4/1961-12/1990
26	DILIA	2510	35.18	105.07	5200	10/1947-12/1990
27	DURAN	2665	34.47	105.40	6280	10/1947-12/1990
28	EAGLE NEST	2700	36.55	105.27	8260	10/1947-12/1990
29	EL VADO DAM	2837	36.60	106.73	6740	10/1947-12/1990
30	FARMINGTON EXP STN	3142	36.70	108.25	5630	7/1948-12/1990
31	FARNSWORTH RANCH	3145	33.90	105.00	5400	5/1953- 5/1980
32	FLORIDA	3225	32.43	107.48	4450	10/1947-12/1990
33	FORT BAYARD	3265	32.80	108.15	6140	9/1968-12/1990
34	GALISTEO	3374	35.40	105.95	6090	1/1958-12/1977
35	GRAY RANCH	3690	31.52	108.87	5100	7/1948- 9/1969
36	HILLSBORO	4009	32.93	107.57	5270	10/1947-12/1990
37	HONDO 2 NW	4089	33.42	105.30	5300	10/1947-12/1990
38	HOPE	4112	32.82	104.73	4100	5/1965-12/1990
39	JEMEZ DAM	4366	35.38	106.53	5390	10/1953-12/1990
40	JORNADA EXP RANGE	4426	32.62	106.73	4270	11/1947-12/1990
41	LAGUNA	4719	35.03	107.40	5800	10/1948-12/1990
42	LAS VEGAS 2 NW	4850	35.62	105.27	6600	11/1954- 6/1983
43	LUNA RANGER STN	5273	33.83	108.93	7050	7/1948- 1/1970
44	MALJAMAR 4 SE	5370	32.82	103.70	4000	2/1948-12/1990

Appendix 1c (Cont).

NEW MEXICO HOURLY STATIONS - AS OF 3/30/92

45	MIMBRES RANGER STN	5754	32.93	108.02	6240	11/1952-12/1990
46	MOGOLLON	5800	33.38	108.78	6800	7/1948-10/1973
47	MONTANO GRANT	5834	35.17	107.02	5930	1/1948-10/1967
48	NARROWS	6043	33.38	107.17	4400	1/1948- 4/1969
49	NOGAL LAKE 1 S	6138	33.52	105.68	7110	11/1947- 5/1970
50	OCATE 1 N	6275	36.18	105.05	7670	8/1960-12/1990
51	OROGRANDE	6435	32.38	106.10	4180	11/1947-12/1990
52	PASAMONTE	6619	36.30	103.73	5650	11/1947- 3/1965
53	PEARL	6659	32.65	103.38	3800	11/1947-12/1990
54	PROGRESSO	7094	34.42	105.85	6300	11/1947-12/1990
55	RAMON 8 SW	7254	34.15	105.00	5330	6/1969-12/1990
56	RATON FILTER PLANT	7279	36.92	104.43	6930	/1953-12/1990
57	RATON WB AP	7283	36.75	104.50	6380	11/1947-11/1968
58	REGINA	7346	36.18	106.95	7450	11/1947- 9/1969
59	RIENHARDT RANCH	7423	33.75	107.22	5450	10/1951-12/1990
60	RODEO	7534	31.83	109.03	4110	1/1954- 4/1978
61	ROSWELL WSO AP	7609	33.40	104.53	3640	12/1947-12/1972
62	ROSWELL FAA AP	7610	33.30	104.53	3670	1/1973-12/1990
63	ROY	7638	35.95	104.20	5880	11/1947-12/1990
64	RUIDOSO 2	7651	33.35	105.67	6940	11/1947-12/1990
65	SACRAMENTO 2	7736	32.80	105.57	7550	11/1947-12/1990
66	SAN FIDEL 2 E	7827	33.08	107.60	6160	11/1947-12/1976
67	SAN MATEO	7918	35.33	107.65	7240	11/1947- 3/1988
68	SANDIA CREST	8011	35.22	106.45	10680	10/1953- 7/1969
69	SANTA FE	8072	35.68	105.90	7200	11/1947- 3/1972
70	SANTA FE 2	8085	35.65	105.98	6720	3/1972-12/1990
71	SKIPWORTH RANCH	8358	34.18	104.48	4180	11/1947- 1/1969
72	SOCORRO	8387	34.08	106.88	4590	7/1948-12/1990
73	SPRINGER	8501	36.37	104.58	5950	11/1947-12/1990
74	STANLEY 1 NNE	8518	35.17	105.97	6380	12/1954-12/1990
75	STATE UNIV	8535	32.28	106.75	3880	11/1947-12/1990
76	SUMNER LAKE	8596	34.60	104.38	4310	10/1947-12/1990
77	TORREON NAVAJO MISSION	9031	35.80	107.18	6700	1/1961-12/1990
78	TUCUMCARI 4 NE	9156	35.20	103.68	4090	11/1947-12/1990
79	TWO RIVERS RESERVOIR	9265	33.28	104.62	4060	7/1963- 8/1982
80	WHITE SANDS NATL N M	9686	32.78	106.18	4000	11/1947-12/1990
81	ZUNI	9897	35.07	108.83	6310	3/1949-12/1990

Appendix 1d.

UTAH HOURLY STATIONS - AS OF 3/30/93

	NAME	STN#	LAT	LON	ELEV	PERIOD OF REC
1	ALTON	0086	37.43	112.48	7040	12/1971-12/1990
2	ANGLE	0168	38.25	111.97	6400	11/1975-12/1990
3	ANTIMONY	0201	38.12	112.00	6460	7/1948-11/1975
4	ARCHES N P HQRS	0336	38.62	109.62	4130	7/1948-12/1990
5	BLANDING	0738	37.62	109.47	6130	7/1948-12/1990
6	BRYCE CANYON NP HQ	1008	37.65	112.17	7920	6/1959-12/1990
7	CEDAR CITY STEAM PLANT	1273	37.67	113.03	6000	12/1961- 2/1984
8	CEDAR POINT	1308	37.72	109.08	6760	7/1974-12/1990
9	COALVILLE 13 E	1590	40.93	111.15	6510	11/1974-12/1990
10	COTTONWOOD WEIR	1759	40.62	111.78	4960	7/1948-12/1990
11	DELTA	2090	39.33	112.58	4620	7/1948-12/1990
12	DUGWAY	2257	40.18	112.92	4340	3/1951-12/1990
13	ECHO DAM	2385	40.97	111.43	5470	11/1949-12/1990
14	ENTERPRISE BERYL JCT	2561	37.77	113.65	5150	7/1948-12/1990
15	EPHRAIM SORENSENS FIEL	2578	39.35	111.58	5670	9/1949-12/1990
16	FAIRFIELD	2696	40.27	112.08	4880	7/1948-12/1990
17	FAIRVIEW 8 N	2702	39.75	111.42	6750	7/1974-12/1990
18	FARMINGTON USU FLD STN	2726	41.02	111.92	4340	8/1948- 2/1968
19	FLAMING GORGE	2864	40.93	109.42	6270	2/1958-12/1990
20	FRUITLAND	3056	40.22	110.85	6620	8/1948- 7/1965
21	GRANTSVILLE	3348	40.60	112.45	4290	6/1956-12/1990
22	GREEN RIVER AVN	3418	39.00	110.17	4070	7/1948-12/1990
23	HANKSVILLE	3611	38.37	110.72	4310	7/1948-12/1990
24	HANNA	3624	40.40	110.77	6750	7/1965-12/1990
25	LOGAN UTAH ST U	5186	41.75	111.80	4790	7/1948-12/1990
26	MARYSVALE	5477	38.45	112.23	5910	7/1948-12/1990
27	MILFORD WSMO	5654	38.43	113.02	5030	7/1948-12/1990
28	MOUNTAIN DELL DAM	5892	40.75	111.72	5420	10/1967-12/1990
29	NEOLA 8 N	6127	40.53	110.07	6910	12/1971-12/1990
30	NEPHI	6135	39.70	111.83	5130	8/1948-12/1990
31	OAKLEY 3 NE	6374	40.73	111.25	6650	2/1971-12/1990
32	OGDEN PIONEER P H	6404	41.25	111.95	4350	10/1971-12/1990
33	OGDEN SUGAR FACTORY	6414	41.23	112.03	4280	7/1948-12/1990
34	PLYMOUTH	6938	41.87	112.15	4470	7/1948-12/1990
35	PRICE WAREHOUSES	7026	39.62	110.83	5680	7/1948-12/1990
36	PROVO B Y U	7064	40.25	111.65	4570	7/1948-12/1990
37	RICHFIELD RADIO KSVC	7260	38.77	112.08	5270	8/1948-12/1990

Appendix 1d (cont).

UTAH HOURLY STATIONS - AS OF 3/30/93

38	ROOSEVELT	7395	40.28	109.97	5010	7/1948-12/1990
39	ST GEORGE	7516	37.12	113.57	2760	7/1948-12/1990
40	SALT LAKE CITY NWSFO A	7598	40.78	111.95	4220	7/1948-12/1990
41	SALT LAKE TRIAD CENTER	7606	40.77	111.90	4280	7/1948- 4/1984
42	SILVER LAKE BRIGHTON	7846	40.60	111.58	8740	7/1948-12/1990
43	SOLDIER SUMMIT	7959	39.93	111.08	7470	7/1948-12/1990
44	VEYO POWER HOUSE	9136	37.35	113.67	4600	3/1974-12/1990
45	WENDOVER AUTOB	9382	40.73	114.03	4240	7/1948- 1/1977

Appendix 2a.

Arizona Hourly Stations/Combinations

1. Poland Junction/6676 (7/48-3/69) and Mayer No 3/5325 (3/69-11/86); new name: **Mayer No 3/5325.**

2. Upper Parker Creek/8940 (7/48-3/72), Parker Creek Mntc Yrd/6260 (6/72-12/75), and Sierra Ancha/7876 (1/76-12/88); new name: **Sierra Ancha/7876.**

3. Nogales/5921 (7/48-12/83) and Nogales 6 N/5924 (8/83-12/88); new name: **Nogales 6 N/5924.**

4. Grand Canyon/3581 (7/48-8/57), Grand Canyon N P/3595 (8/57-5/76), and Grand Canyon Natl Pk/3596 (5/76-12/88); new name: **Grand Canyon Natl Pk/3596.**

5. Hackberry/3788 (7/48-1/59), Hackbery 2 SE/3790 (1/59-7/70), and Truxton Canyon/8778 (7/70-12/88); new name: **Truxton Canyon/8778.**

6. Bagdad/0582 (7/48-11/49) and Bagdad/0586 (12/49-11/69); new name: **Bagdad/0586.**

7. Flagstaff/3007 (7/48-3/51) and Flagstaff WSO AP/3010 (1/50-12/88); **Flagstaff WSO AP.**

8. Bisbee/0768 (7/48-5/61, 7/62-2/85) and Bisbee/0773 (6/61-7/62); new name: **Bisbee/0768.**

9. Kingman/4639 (7/48-8/67) and Kingman 2/4645 (8/67-12/88); new name: **Kingman 2/4645.**

Appendix 2b.

Nevada Station Merges
As of 3/8/93

1. Beatty/0714 (7/48-11/72), and Beatty 8 N/0718 (11/72-12/90); new name: **Beatty 8 N/0718.**

3. Fernley Mntnc Stn/2849 (7/48-7/54), Fernley/2840 (7/54-8/74), and Wadsworth 4 N/8838 (8/74-12/90); new name: **Wadsworth 4 N/8838.**

2. Paradise Valley/6000 (7/48-7/51), and Paradise Valley 1 NW/6005 (7/51-1/64); new name: **Paradise Valley 1 NW/6005.**

4. Yerington 2/9234 (7/48-12/71), Yerington/9229 (3/65-4/67); new name: **Yerington 2/9234.**

Appendix 2c.

New Mexico Station Merges
As of 3/8/93

1. Agricultural College/0131 (11/47-3/59), and State University/8535 (4/59-12/90); new name: **State University/8535.**

2. Alamogordo Dam/0205 (10/47-1/75), and Sumner Lake/8596 (1/75-12/90); new name: **Sumner Lake/8596.**

3. Clovis 3 W/1956 (10/47-6/49), and Clovis 3 SSW/1939 (7/49-12/88); new name: **Clovis 3 SSW/1939.**

4. Crossroads #2/2207 (12/71-3/77), and Crossroads/2203 (3/77-12/90); new name: **Crossroads/2203.**

5. Deming FAA AP/2440 (4/61-6/82), and Deming/2436 (7/82-12/90); new name: **Deming/2436.**

6. Dunlap 4 NE/2625 (11/47-12/61), and Skipworth Ranch/8358 (1/62-1/69); new name: **Skipworth Ranch/8358.**

7. Eicks Ranch/2757 (7/48-6/62), and Gray Ranch/3690 (9/62-9/69); new name: **Gray Ranch/3690.**

8. Farmington 4 NE/3134 (7/48-3/78), and Farmington Exp Stn/3142 (4/78 - 12/90); new name: **Farmington Exp Stn/3142.**

9. Pena Blanca/6693 (5/59-2/68), and Cochiti Dam/1982 (4/67-12/90); new name: **Conchiti Dam/1982.**

10. Ruidoso 2 NNE/7649 (11/47-6/87), and Ruidoso 2/7651 (7/87-12/90); new name: **Ruidoso 2/7651.**

11. Sacramento/7735 (11/47-11/74), and Sacramento 2/7736 (11/74-12/90); new name: **Sacramento 2/7736.**

Appendix 2d.

Utah Station Merges
as of 3/8/93

1. Fairfield CAA AP/2697 (7/48-7/50), and Fairfield/2696 (9/50-12/90); new name: **Fairfield/2696.**

2. Greenriver/3413 (7/48-10/49), and Green River AVN/3418 (11/49-12/90); new name: **Green River AVN/3418.**

3. Moab 4 NW/5733 (7/48-5/80), and Arches NP HQRS/0336 (6/80-12/90); new name: **Arches NP HQRS/0336.**

4. Ogden FAA AP/6424 (7/48-5/52), and Ogden Sugar Factory/6414 (6/53-12/90); new name: **Ogden Sugar Factory/6414.**

5. Otter Creek Dam/6558 (11/75-6/81), and Angle/0168 (7/81-12/90); new name: **Angle/0168.**

6. Price Game Farm/7015 (7/48-7/68), and Price Warehouses/7026 (7/68-12/90); new name: **Price Warehouses/7026.**

7. Provo AP/7061 (7/48-4/52), Provo Radio KAYK/7068 (4/52-2/77), and Provo BYU/7064 (9/80-12/90); new name: **Provo BYU/7064.**

8. Salt Lake City WSO CI/7603 (7/48-11/73), and Salt Lake City Triad Center/7606 (3/73-4/84); new name: **Salt Lake City Triad Center/7606.**

Appendix 3a.
Colorado Hourly Stations

Rec#	STATE	NAME	STNO STN#	LAT	LON	ELEV	POR
1	CO	ALAMOSA WSO AP	05-0130	37.45	105.87	7540	9/1948 - 12/1990
2	CO	ARTESIA 2 E	05-0354	40.23	108.97	5920	8/1948 - 5/1965
3	CO	ATKINSON RANCH	05-0381	37.60	108.88	-99	8/1948 - 11/1949
4	CO	CEDAREDGE	05-1440	38.90	107.93	6240	8/1948 - 12/1990
5	CO	CUCHARAS DAM	05-2040	37.75	104.60	5770	8/1948 -4/1988
6	CO	CUCHARAS DAM 4 NW	05-2042	37.78	104.67	6010	11/1982 - 8/1984
7	CO	DINOSAUR NATL MONUMENT	05-2286	40.23	108.97	5920	6/1965 - 12/1990
8	CO	DURANGO	05-2432	37.28	107.88	6600	8/1948 -9/1980
9	CO	GRAND JUNCTION WSO AP	05-3488	39.10	108.55	4850	8/1948 - 12/1990
10	CO	GREAT DIVIDE	05-3538	40.78	107.83	6870	8/1948 -7/1954
11	CO	GREAT DIVIDE 8 SE	05-3539	40.72	107.70	7030	7/1954 -2/1975
12	CO	HOEHNE	05-4047	37.27	104.38	5700	12/1955-10/1968
13	CO	KIM 15 NNE	05-4538	37.45	103.32	5150	8/1948 - 12/1990
14	CO	MEEKER	05-5484	40.03	107.90	6240	8/1948 - 10/1970
15	CO	MEEKER 2	05-5487	40.03	107.92	6350	10/1970 -12/1990
16	CO	MESA VERDE NATL PARK	05-5531	37.20	108.48	7120	8/1948 -12/1990
17	CO	MONTE VISTA 1 E	05-5706	37.57	106.08	7640	8/1948 -5/1965
18	CO	MONTE VISTA REFUGE	05-5711	37.48	106.15	7680	5/1965 -12/1990
19	CO	MULE SHOE LODGE 1 SSE	05-5819	37.58	105.18	8870	8/1948 -2/1986
20	CO	PLATORO	05-6559	37.35	106.53	9840	12/1950 -6/1959
21	CO	PLEASANT VIEW 2 W	05-6591	37.58	108.80	6840	8/1950 - 12/1990
22	CO	RIFLE	05-7031	39.53	107.80	5320	8/1948 - 12/1990
23	CO	RYE SCHOOL	05-7320	37.93	104.93	6750	7/1985 - 12/1990
24	CO	SAN LUIS	05-7428	37.20	105.42	7990	8/1948 - 12/1990
25	CO	SHEEP MOUNTAIN	05-7572	37.72	105.23	7750	1/1988 - 12/1990
26	CO	SILVERTON	05-7656	37.82	107.67	9270	8/1948 - 4/1986
27	CO	SPRINGFIELD 7 WSW	05-7866	37.38	102.73	4580	5/1972 - 12/1990
28	CO	SPRINGFIELD 8 S	05-7867	37.28	102.62	4500	8/1948 -5/1972
29	CO	SUMMITVILLE	05-8092	37.43	106.60	11350	8/1948 - 11/1949
30	CO	TELLURIDE	05-8204	37.93	107.82	8800	8/1948 - 12/1990
31	CO	TERCIO 4 NW	05-8220	37.08	105.05	8270	8/1948 - 12/1990
32	CO	TRINIDAD	05-8429	37.17	104.48	6030	5/1973 - 12/1990
33	CO	TRINIDAD FAA AP	05-8434	37.25	104.33	5750	8/1948 -4/1973
34	CO	WAGON WHEEL GAP 3 N	05-8742	37.80	106.83	8500	8/1948 -2/1975
35	CO	WALSENBURG	05-8781	37.63	104.78	6150	8/1948 - 12/1990
36	CO	WHITE ROCK	05-8997	37.87	104.12	4730	8/1948 - 12/1990

Appendix 3b.

Idaho Hourly Stations

Rec	ST	NAME	STNO	STATN	LAT	LON	ELEV	POR
1	ID	BANCROFT	10-	0563	42.72	111.90	5290	7/1948-11/1952
2	ID	BLACKFOOT DAM	10-	0920	43.00	111.72	6200	7/1948-9/1971
3	ID	BRIDGE	10-	1156	42.13	113.35	4700	4/1949-11/1952
4	ID	BURLEY FACTORY	10-	1298	42.55	113.80	4140	7/1948-5/1978
5	ID	BURLEY FAA AP	10-	1303	42.53	113.77	4160	8/1948-1/1953
6	ID	GOODING 1 S	10-	3677	42.92	114.70	3560	9/1952-12/1990
7	ID	GOODING AP	10-	3682	42.92	114.77	3690	7/1948-8/1952
8	ID	GRACE	10-	3732	42.58	111.73	5550	11/1952-12/1990
9	ID	GRASMERE	10-	3809	42.38	115.88	5130	4/1961-3/1963
10	ID	GRASMERE 3 S	10-	3811	42.33	115.88	5140	4/1963-12/1990
11	ID	HENRY	10-	4230	42.90	111.50	6140	9/1971-12/1990
12	ID	MALAD	10-	5544	42.20	112.27	4580	7/1948-5/1978
13	ID	MALAD CITY	10-	5559	42.17	112.28	4470	7/1948-9/1951
14	ID	MALTA AVIATION	10-	5567	42.30	113.33	4540	11/1952-12/1990
15	ID	MURPHY HOT SPRINGS	10-	6250	42.03	115.35	5160	12/1987-12/1990
16	ID	POCATELLO WSO AP	10-	7211	42.92	112.60	4450	7/1948-12/1990
17	ID	SILVER CITY 5 W	10-	8412	43.02	116.82	6160	12/1982-12/199[illegible]
18	ID	THREE CREEK	10-	9119	42.08	115.25	5460	4/1961-11/19[illegible]
19	ID	TOPAZ	10-	9158	42.63	112.08	4920	5/1978-12/19[illegible]
20	ID	TWIN FALLS WSO	10-	9303	42.55	114.35	3960	6/1978-12/1990

Appendix 3c.

Oregon Hourly Stations

Rec	ST	NAME	STNO	STATN	LAT	LON	ELEV	POR
1	OR	ADEL	35-	0036	42.18	119.90	4580	10/1968-5/1975
2	OR	JORDAN VALLEY	35-	4321	42.98	117.05	4390	10/1948-12/1990
3	OR	LAKEVIEW 2 NNW	35-	4670	42.22	120.37	4780	10/1948-12/1990
4	OR	PLUSH	35-	6717	42.42	119.90	4510	4/1961-3/1963
5	OR	ROME CAA AP	35-	7312	42.58	117.88	4040	10/1949-10/1950

Appendix 3d.

Texas Hourly Stations

Rec	ST	NAME	STNO	STATN	LAT	LON	ELEV	POR
1	TX	ANDREWS	41-	0248	32.32	102.53	3170	7/1942-12/1990
2	TX	BUENAVISTA 2 NNW	41-	1185	31.25	102.67	2510	8/1942-9/1963
3	TX	BUSHLAND 1 WSW	41-	1267	35.18	102.08	3820	2/1940-5/1953
4	TX	CHANNING	41-	1646	35.68	102.33	3800	1/1941-12/1990
5	TX	COTTONWOOD DAM 1	41-	2042	31.55	106.08	3850	10/1947-7/1949
6	TX	COUNTY LINE	41-	2053	31.38	105.98	3550	3/1942-7/1942
7	TX	CRANE	41-	2082	31.38	102.33	2630	8/1943-12/1990
8	TX	DALHART	41-	2238	36.08	102.48	4000	1/1941-12/1946
9	TX	DALHART FAA AP	41-	2240	36.02	102.55	3990	4/1950-9/1951
10	TX	DELL CITY 5 SSW	41-	2354	31.90	105.22	3770	5/1955-9/1957
11	TX	EL PASO 15 ENE	41-	2794	31.83	105.93	5240	7/1947-9/1947
12	TX	EL PASO WSO AP	41-	2797	31.80	106.40	3920	8/1942-12/1990
13	TX	FABENS	41-	3033	31.50	106.15	3610	2/1953-9/1977
14	TX	FABENS 2	41-	3034	31.52	106.15	3650	7/1949-4/1951
15	TX	FORT QUITMAN	41-	3272	31.10	105.60	3430	2/1942-7/1942
16	TX	GARCIA LAKE	41-	3441	34.88	103.02	4200	10/1947-8/1953
17	TX	GARCIA LAKE 12 ENE	41-	3442	34.92	102.73	4130	11/1943-5/1971
18	TX	GUADALUPE PASS CAA AP	41-	3789	31.83	104.80	5450	7/1948-8/1950
19	TX	HEREFORD	41-	4098	34.82	102.40	3820	5/1955-12/1990
20	TX	HEREFORD 2 ESE	41-	4100	34.82	102.38	3800	7/1941-5/1955
21	TX	IMPERIAL 2 W	41-	4425	31.27	102.73	2400	9/1963-12/1990
22	TX	ISLAND STATION	41-	4498	31.53	106.23	3630	1/1942-7/1942
23	TX	MADDEN ARROYO	41-	5471	31.22	105.77	3500	2/1942-7/1942
24	TX	MIDLAND/ODESSA WSO AP	41-	5890	31.95	102.18	2860	2/1941-12/1990
25	TX	MIDLAND 4 ENE	41-	5891	32.02	102.02	2740	10/1947-10/1953
26	TX	MULESHOE 2	41-	6136	34.22	102.73	3800	6/1941-12/1990
27	TX	PECOS 12 SSW	41-	6893	31.27	103.60	2640	3/1960-12/1990
28	TX	PEP	41-	6935	33.82	102.57	3660	8/1956-12/1990
29	TX	PETTIT 4 NE	41-	6981	33.73	102.47	3550	6/1941-7/1956
30	TX	PLAINS	41-	7074	33.18	102.83	3680	7/1942-12/1990
31	TX	RED BLUFF DAM	41-	7481	31.90	103.92	2800	7/1942-12/1990
32	TX	SALT FLAT CAA AP	41-	7922	31.75	105.08	3710	7/1942-3/1955
33	TX	SARAGOSA NR	41-	8068	31.07	103.65	2990	7/1942-12/1945

Appendix 3d (cont).

Texas Hourly Stations

34	TX	SIERRA BLANCA	41-	8305	31.18	105.35	4590	7/1942-12/1990
35	TX	TINNIN RANCH	41-	9037	31.30	104.00	3230	7/1942-12/1969
36	TX	TOYAH	41-	9106	31.30	103.80	2810	12/1969-5/1977
37	TX	UPLAND	41-	9248	31.38	102.00	2600	8/1942-7/1948
38	TX	VAN HORN	41-	9295	31.07	104.78	3960	7/1948-9/1951
39	TX	VEGA NR SCS R 4	41-	9328	35.32	102.42	3930	3/1940-2/1944
40	TX	VEGA SCS 101-2-46	41-	9329	35.25	102.43	4020	1/1941-5/1941
41	TX	WALCOTT	41-	9435	34.93	102.98	4110	5/1971-2/1975
42	TX	WINK	41-	9829	31.77	103.15	2790	7/1942-12/1990
43	TX	WINK FAA AP	41-	9830	31.78	103.20	2810	10/1947-11/1952

Appendix 3e.

Wyoming Hourly Stations

Rec	ST	NAME	STNO	STATN	LAT	LON	ELEV	POR
1	WY	BIG PINEY	48-	0695	42.55	110.12	6820	8/1948-12/1990
2	WY	CRESTON	48-	2175	41.73	108.73	7040	8/1948-2/1984
3	WY	EVANSTON 1 E	48-	3100	41.27	110.95	6810	8/1948-12/1990
4	WY	FORT BRIDGER AP	48-	3430	41.40	110.42	7020	8/1948-3/1966
5	WY	LYMAN	48-	5836	41.33	110.30	6700	10/1956-3/1960
6	WY	MOUNTAIN VIEW	48-	6555	41.27	110.35	6800	3/1966-12/1990
7	WY	MUD SPRINGS	48-	6597	41.32	108.92	6740	5/1953-12/1990
8	WY	ROCK SPRINGS	48-	7840	41.58	109.22	6370	4/1954-5/1979
9	WY	ROCK SPRINGS FAA AP	48-	7845	41.60	109.07	6740	8/1948-12/1990
10	WY	WAMSUTTER 8 W	48-	9460	41.65	108.12	0	8/1948-6/1951

Appendix 4.

California Hourly Stations

Rec	ST	NAME	STATE	STN#	LAT	LON	ELEV	POR
1	CA	ACTON-ESDO CYN FC261F	04-	0014	34.50	118.27	2960	7/1948-12/1990
2	CA	ALISO CANYON OAT MT FC	04-	0115	34.32	118.55	2370	7/1948-12/1990
3	CA	ALTURAS R S	04-	0161	41.50	120.55	4400	7/1948-12/1990
4	CA	AMBOY	04-	0176	34.57	115.75	640	7/1948-11/1974
5	CA	APACHE CAMP	04-	0239	34.87	119.33	4970	7/1948-11/1971
6	CA	BADGER	04-	0422	36.63	119.02	3050	7/1948-12/1990
7	CA	BAKER	04-	0436	35.27	116.07	940	11/1953-12/1989
8	CA	BAKERSFIELD WSO AP	04-	0442	35.42	119.05	500	7/1948-12/1990
9	CA	BALCH POWER HOUSE	04-	0449	36.92	119.08	1720	2/1950-12/1990
10	CA	BEAUMONT	04-	0606	33.93	116.97	2610	10/1957-12/1990
11	CA	BEAUMONT 1 E	04-	0609	33.93	116.97	2600	7/1948-10/1957
12	CA	BEL AIR FC-10A	04-	0619	34.08	118.45	540	7/1948-2/1984
13	CA	BELL CANYON PLATT RCH	04-	0625	34.20	118.65	920	7/1948-9/1956
14	CA	BIEBER	04-	0731	41.12	121.13	4130	7/1948-12/1990
15	CA	BIG BEAR LAKE DAM	04-	0742	34.23	116.97	6820	7/1948-12/1990
16	CA	BIG PINES PARK FC 83 B	04-	0779	34.38	117.68	6850	7/1948-12/1990
17	CA	BIRMINGHAM GEN HOSP	04-	0818	34.18	118.50	720	7/1948-5/1977
18	CA	BISHOP WSO AP	04-	0822	37.37	118.37	4110	7/1948-12/1990
19	CA	BLODGETT EXP FOREST	04-	0883	38.92	120.67	4410	10/1969-12/1990
20	CA	BLUE CANYON WSMO	04-	0897	39.28	120.70	5280	7/1948-12/1990
21	CA	BLYTHE 7 W	04-	0925	33.62	114.72	390	2/1953-12/1990
22	CA	BLYTHE FAA AP	04-	0927	33.62	114.72	390	7/1948-2/1953
23	CA	BORON	04-	0979	35.00	117.65	2460	12/1959-12/1990
24	CA	BOWMAN DAM	04-	1018	39.45	120.65	5370	7/1948-12/1990
25	CA	BREA DAM	04-	1057	33.88	117.93	280	7/1948-12/1990
26	CA	BRIDGEPORT	04-	1072	38.25	119.23	6470	7/1948-6/1950
27	CA	BRIDGEPORT R S	04-	1076	38.25	119.23	6440	6/1950-12/1990
28	CA	BRUSH CREEK R S	04-	1130	39.68	121.33	3560	7/1948-12/1990
29	CA	BUCKS LAKE	04-	1161	39.90	121.20	5200	7/1948-11/1969
30	CA	BUMBLEBEE TRAILER PARK	04-	1187	38.20	120.00	5760	2/1964-11/1964
31	CA	BURBANK VALLEY PMP PLT	04-	1194	34.18	118.35	660	7/1948-12/1990

Appendix 4 (cont).

California Hourly Stations

32	CA	CACHUMA DAM	04-	1253	34.58	119.98	780	10/1951-12/1990
33	CA	CAJON WEST SUMMIT	04-	1272	34.38	117.57	4780	7/1948-12/1990
34	CA	CALAVERAS BIG TREES	04-	1277	38.28	120.32	4700	7/1986-12/1990
35	CA	CALIF HOT SPRINGS R S	04-	1300	35.88	118.68	2950	7/1948-3/1965
36	CA	CAMARILLO 2 SE	04-	1336	34.20	119.02	120	1/1956-6/1958
37	CA	CAMARILLO 4 NNW	04-	1338	34.27	119.08	350	1/1956-6/1958
38	CA	CAMP ANGELUS	04-	1369	34.15	116.98	5760	7/1948-12/1990
39	CA	CAMP BALDY FC 85 F	04-	1373	34.23	117.67	4300	7/1948-4/1958
40	CA	CAMP HI HILL OPIDS 57B	04-	1404	34.25	118.10	4250	2/1969-12/1978
41	CA	CAMP PARDEE	04-	1428	38.25	120.85	660	7/1948-12/1990
42	CA	CAMPTONVILLE R S	04-	1462	39.45	121.05	2760	7/1948-12/1990
43	CA	CAMP WISHON	04-	1470	36.18	118.67	3800	7/1948-12/1960
44	CA	CANYON DAM	04-	1497	40.17	121.08	4560	10/1975-12/1990
45	CA	CARBON CANYON DAM	04-	1517	33.92	117.83	400	9/1972-7/1977
46	CA	CARBON CANYON GILMAN	04-	1518	33.92	117.78	1620	6/1955-12/1990
47	CA	CARBON CYN WORKMAN	04-	1520	33.97	117.78	1180	9/1949-12/1990
48	CA	CARPINTERIA RESERVOIR	04-	1540	34.40	119.48	390	11/1968-12/1990
49	CA	CATHEYS VLY BULL R RCH	04-	1588	37.40	120.05	1430	7/1948-5/1977
50	CA	CHATSWORTH RESERVOIR	04-	1682	34.23	118.62	910	7/1948-12/1990
51	CA	CHUCHUPATE R S	04-	1754	34.80	119.02	5260	7/1948-12/1990
52	CA	COACHELLA INDIO CAA	04-	1860	33.68	116.17	-70	7/1948-5/1950
53	CA	CORCORAN	04-	2009	36.10	119.55	200	7/1948-1/1956
54	CA	CORCORAN IRRIG DIST OF	04-	2012	36.10	119.57	200	1/1956-12/1990
55	CA	CRAWFORD RANCH	04-	2139	32.88	116.28	1500	7/1948-7/1985
56	CA	CRESTLINE	04-	2162	34.25	117.30	4870	7/1948-10/1952
57	CA	CRESTLINE LAKE GREGORY	04-	2163	34.23	117.27	4530	10/1952-4/1966
58	CA	CRESTLINE FIRE STN 2	04-	2164	34.23	117.30	4900	4/1966-12/1990
59	CA	CUYAMACA	04-	2239	32.98	116.58	4640	8/1967-12/1990

Appendix 4 (cont).

California Hourly Stations

60	CA	CUYAMA RANCH	04-	2248	34.98	119.67	2170	7/1948-5/1970
61	CA	CUYAMA R S	04-	2249	34.85	119.48	2750	7/1948-3/1967
62	CA	DAGGETT EDISON PLT	04-	2255	34.87	116.87	1970	3/1953-12/1990
63	CA	DAGGETT FAA AP	04-	2257	34.87	116.78	1920	7/1948-3/1953
64	CA	DAY	04-	2306	41.22	121.38	3680	7/1948-12/1990
65	CA	DEEP SPRINGS 11 NW	04-	2330	37.43	118.17	10500	7/1948-8/1951
66	CA	DIAMOND BAR	04-	2432	34.00	117.80	880	7/1948-11/1985
67	CA	DONNER SUMMIT CAA	04-	2470	39.33	120.37	7190	7/1948-9/1951
68	CA	DOWNIEVILLE	04-	2500	39.57	120.83	2920	7/1948-12/1990
69	CA	DUNLAP SHINGLE MILL	04-	2559	36.72	119.12	2000	7/1948-5/1949
70	CA	EL CAPITAN DAM	04-	2709	32.88	116.82	600	5/1956-12/1990
71	CA	EL CENTRO 2 SSW	04-	2713	32.77	115.57	-30	7/1948-12/1990
72	CA	EL MODENA	04-	2775	33.80	117.78	460	7/1948-10/1977
73	CA	ELSINORE	04-	2805	33.67	117.33	1290	2/1966-12/1990
74	CA	ELSINORE 4 SE	04-	2811	33.63	117.27	1450	7/1948-11/1956
75	CA	ELSINORE 4 SSE	04-	2812	33.62	117.32	1310	11/1956-1/1966
76	CA	ESCONDIDO 2	04-	2863	33.12	117.08	600	11/1964-12/1990
77	CA	ESCONDIDO PARK HILL	04-	2869	33.12	117.07	850	5/1958-11/1964
78	CA	ESCONDIDO CHURCH RCH	04-	2871	33.10	117.08	720	7/1948-5/1958
79	CA	ETIWANDA	04-	2895	34.13	117.52	1390	7/1948-12/1990
80	CA	EXETER FAUVER RCH	04-	2922	36.35	119.07	440	7/1948-8/1990
81	CA	FALLBROOK	04-	2958	33.35	117.25	540	7/1948-12/1990
82	CA	FEATHER FALLS	04-	2994	39.60	121.27	2970	1/1958-6/1975
83	CA	FIDDLETOWN DEXTER RCH	04-	3038	38.53	120.70	2160	7/1948-12/1990
84	CA	FIGUEROA MTN	04-	3048	34.73	120.00	3200	7/1948-12/1990
85	CA	FLORENCE LAKE	04-	3093	37.27	118.97	7330	7/1948-12/1990
86	CA	FRESNO WSO AP	04-	3257	36.77	119.72	330	7/1948-12/1990
87	CA	FRIANT GOVT CAMP	04-	3261	36.98	119.72	410	7/1948-5/1952
88	CA	FULLERTON DAM	04-	3285	33.90	117.88	340	7/1948-12/1990
89	CA	GEORGETOWN	04-	3381	38.92	120.83	2720	7/1948-12/1967
90	CA	GEORGETOWN R S	04-	3384	38.92	120.78	3000	11/1967-12/1990
91	CA	GIANT FOREST	04-	3397	36.57	118.77	6410	7/1948-12/1968

Appendix 4 (cont).

California Hourly Stations

92	CA	GIBRALTAR DAM 2	04-	3402	34.52	119.68	1550	5/1970-12/1990
93	CA	GLENNVILLE FULTON R S	04-	3465	35.73	118.67	3500	7/1948-12/1990
94	CA	GRANT GROVE	04-	3551	36.73	118.97	6600	7/1948-9/1990
95	CA	GRASS VALLEY	04-	3571	39.22	121.07	2640	7/1962-9/1966
96	CA	GRASS VALLEY 2 NNE	04-	3572	39.23	121.03	2710	10/1950-10/1960
97	CA	GRASS VALLEY 2	04-	3573	39.22	121.07	2400	9/1966-12/1990
98	CA	GRASS VALLEY NID	04-	3574	39.22	121.07	2420	10/1960-7/1962
99	CA	GRIZZLY FLATS	04-	3649	38.63	120.52	3860	7/1948-11/1967
100	CA	GROVELAND 2	04-	3669	37.83	120.23	2880	7/1948-12/1990
101	CA	HAMILTON BRANCH V FD	04-	3725	40.27	121.08	4560	4/1953-10/1985
102	CA	HANSEN DAM	04-	3751	34.27	118.40	1100	7/1948-12/1990
103	CA	HAYFIELD PUMPING PLANT	04-	3855	33.70	115.63	1370	7/1948-12/1990
104	CA	HELL HOLE	04-	3891	39.07	120.42	4850	1/1954-12/1990
105	CA	HEMET RESERVOIR	04-	3899	33.67	116.67	4360	7/1948-6/1961
106	CA	HENSHAW DAM	04-	3914	33.23	116.77	2700	7/1948-12/1990
107	CA	HETCH HETCHY	04-	3939	37.95	119.78	3870	7/1948-12/1990
108	CA	HORSE CANYON	04-	4113	34.62	119.85	1550	7/1948-6/1958
109	CA	HUNTINGTON LAKE	04-	4176	37.23	119.22	7020	7/1948-12/1990
110	CA	HURKEY CREEK PARK	04-	4181	33.68	116.68	4390	6/1961-12/1990
11	CA	IDYLLWILD	04-	4208	33.75	116.70	5390	7/1948-6/1952
112	CA	IDYLLWILD FIRE DEPT	04-	4211	33.75	116.72	5400	6/1952-12/1990
113	CA	INDEPENDENCE	04-	4232	36.80	118.20	3950	7/1948-12/1990
114	CA	INDEPENDENCE ONION VLY	04-	4235	36.77	118.33	9180	12/1948-5/1971
115	CA	INYOKERN ARMITAGE	04-	4280	35.68	117.68	2220	7/1948-9/1951
116	CA	IRON MTN	04-	4297	34.13	115.13	920	7/1948-12/1990
117	CA	JULIAN	04-	4412	33.08	116.60	4220	9/1949-4/1966
118	CA	KYBURZ STRAWBERRY	04-	4616	38.80	120.15	5700	7/1948-4/1980
119	CA	LAGUNA BEACH 2	04-	4650	33.55	117.80	210	7/1948-12/1990
120	CA	LAKE WOHLFORD	04-	4726	33.17	117.00	1500	7/1948-12/1990

Appendix 4 (cont).

California Hourly Stations

121	CA	LA PORTE	04-	4773	39.68	120.98	4980	11/1958-9/1977
122	CA	LECHUZA PT STN FC 352B	04-	4867	34.08	118.88	1600	7/1948-12/1990
123	CA	LITTLE TUJUNGA GLD CR	04-	4986	34.32	118.30	2750	7/1948-5/1970
124	CA	LONG BARN EXP STN	04-	5078	38.18	120.02	5200	7/1948-2/1964
125	CA	LONG BEACH WSO AP	04-	5085	33.82	118.15	30	8/1968-12/1990
126	CA	LORAINE	04-	5098	35.30	118.43	2720	7/1948-4/1987
127	CA	LORAINE 5 NNE	04-	5100	35.38	118.42	4150	5/1987-12/1990
128	CA	LOS ANGELES 6TH MAIN	04-	5111	34.05	118.25	410	7/1948-6/1953
129	CA	LOS ANGELES WSO AP	04-	5114	33.93	118.40	110	7/1948-12/1990
130	CA	LOS ANGELES CIVIC CTR	04-	5115	34.05	118.23	270	7/1948-12/1990
131	CA	LOWER OTAY RESERVOIR	04-	5162	32.62	116.93	540	7/1948-12/1990
132	CA	LYTLE CR FTHILL BLVD	04-	5212	34.10	117.33	1160	7/1948-12/1990
133	CA	LYTLE CREEK R S	04-	5218	34.23	117.48	2730	1/1949-12/1990
134	CA	MAGIC MOUNTAIN	04-	5256	34.40	118.28	4450	7/1948-5/1962
135	CA	MANZANA SCHOOL	04-	5308	34.82	120.00	1200	8/1965-5/1971
136	CA	MANZANITA MOUNTAIN	04-	5314	34.90	120.08	3130	7/1948-6/1958
137	CA	MARCH FIELD	04-	5326	33.87	117.25	1490	7/1948-9/1951
138	CA	MARKLEEVILLE	04-	5356	38.70	119.78	5500	7/1948-9/1978
139	CA	MATILIJA DAM	04-	5417	34.48	119.30	1060	3/1969-12/1990
140	CA	MERCED 2	04-	5535	37.32	120.48	170	7/1948-12/1990
141	CA	MICHIGAN BLUFF	04-	5586	39.05	120.73	3480	7/1948-10/1985
142	CA	MILFORD LAUFMAN R S	04-	5623	40.13	120.35	4860	7/1948-12/1990
143	CA	MILL CREEK INTAKE	04-	5632	34.08	116.93	4950	7/1948-12/1990
144	CA	MILL CREEK SUMMIT R S	04-	5637	34.38	118.08	4990	1/1972-12/1990
145	CA	MILO 5 NE	04-	5669	36.27	118.77	3100	1/1957-12/1990
146	CA	MOJAVE	04-	5756	35.05	118.17	2740	11/1959-12/1990
147	CA	MOORPARK 3 SE	04-	5825	34.25	118.85	640	1/1956-6/1958

Appendix 4 (cont).

California Hourly Stations

148	CA	MOORPARK 3 NNW	04-	5826	34.33	118.90	1050	1/1956-6/1958
149	CA	MORENA DAM	04-	5840	32.68	116.52	3080	7/1948-12/1990
150	CA	MT BALDY FC85G	04-	5900	34.23	117.65	4280	5/1958-9/1976
151	CA	MOUNT DANAHER	04-	5909	38.75	120.67	3410	7/1948-4/1975
152	CA	MT GIVENS	04-	5927	37.28	119.08	9500	12/1964-5/1969
153	CA	MT WILSON 2	04-	6006	34.23	118.07	5710	7/1948-6/1972
154	CA	MUSICK CREEK GUARD STN	04-	6048	37.10	119.32	5520	12/1967-10/1971
155	CA	NEEDLES	04-	6115	34.83	114.60	480	2/1953-12/1990
156	CA	NEEDLES FAA AP	04-	6118	34.77	114.62	910	7/1948-2/1953
157	CA	NEVADA CITY	04-	6136	39.25	121.03	2780	4/1949-10/1950
158	CA	NEVADA CITY 1 N	04-	6139	39.27	121.02	2850	7/1948-3/1949
159	CA	NEWBURY PARK 2 WNW	04-	6147	34.18	118.95	680	1/1956-6/1958
160	CA	NEW CUYAMA FIRE STN	04-	6154	34.95	119.68	2160	12/1973-12/1990
161	CA	NEWHALL SOLEDAD FC 32C	04-	6162	34.38	118.53	1240	7/1968-12/1990
162	CA	NEWHALL US R S	04-	6164	34.37	118.52	1340	10/1949-6/1968
163	CA	NEW MELONES DAM	04-	6172	37.95	120.53	780	2/1979-12/1990
164	CA	NORTH BLOOMFIELD	04-	6232	39.37	120.90	3280	10/1969-12/1990
165	CA	OAK GROVE R S	04-	6319	33.38	116.80	2750	5/1978-12/1990
166	CA	OCEANSIDE CAA	04-	6378	33.23	117.42	20	7/1948-2/1952
167	CA	OCEANSIDE PUMPING PLAN	04-	6379	33.22	117.35	30	2/1952-12/1990
168	CA	OPIDS CAMP FC 57 BE	04-	6465	34.25	118.10	4250	7/1948-5/1969
169	CA	ORANGE COUNTY RES	04-	6473	33.93	117.88	660	7/1948-12/1990
170	CA	OZENA GUARD STN	04-	6577	34.68	119.35	3590	11/1972-12/1990
171	CA	PACIFIC COLO FC 356B	04-	6594	34.05	117.82	690	7/1948-5/1956
172	CA	PALMDALE	04-	6624	34.58	118.10	2600	2/1963-12/1990
173	CA	PALMDALE 2 NE	04-	6625	34.60	118.10	2580	3/1953-2/1963
174	CA	PALMDALE FAA AP	04-	6627	34.63	118.08	2520	7/1948-3/1953
175	CA	PALOMAR MTN OBSY	04-	6657	33.35	116.87	5550	7/1948-12/1990

Appendix 4 (cont).

California Hourly Stations

176	CA	PARKER RESERVOIR	04-	6699	34.28	114.17	740	7/1948-12/1990
177	CA	PINECREST SUMMIT R S	04-	6893	38.25	120.00	5600	11/1964-12/1990
178	CA	PINE MOUNTAIN	04-	6908	34.63	119.37	4680	4/1966-1/1968
179	CA	PINE MOUNTAIN INN	04-	6910	34.60	119.35	4200	1/1965-12/1990
180	CA	PIRU TELEMETERING	04-	6942	34.40	118.70	800	6/1971-12/1990
181	CA	PLACERVILLE 1 W	04-	6963	38.73	120.82	1790	7/1948-6/1963
182	CA	PLACERVILLE DISPOSAL P	04-	6964	38.73	120.85	1560	6/1963-12/1990
183	CA	PLUMAS EUREKA STATE PK	04-	6998	39.75	120.70	5170	5/1964-12/1990
184	CA	POINT ARGUELLO WB AP	04-	7015	34.67	120.58	370	7/1959-6/1964
185	CA	PORTOLA	04-	7085	39.80	120.47	4850	10/1954-12/1990
186	CA	PORTOLA 2	04-	7088	39.80	120.48	4830	7/1948-10/1954
187	CA	POTRERO SECO	04-	7105	34.63	119.43	4860	7/1948-6/1958
188	CA	PRADO DAM	04-	7123	33.88	117.63	560	7/1948-12/1990
189	CA	RANDSBURG	04-	7253	35.37	117.65	3570	9/1949-1/1957
190	CA	RED MTN	04-	7314	35.37	117.63	3700	7/1948-1/1949
191	CA	RIVERSIDE CIT EXP STN	04-	7473	33.97	117.35	990	7/1948-12/1990
192	CA	ROBBS PEAK P H	04-	7489	38.90	120.37	5120	2/1967-12/1990
193	CA	RUNNING SPRINGS 1 E	04-	7600	34.20	117.08	5970	7/1948-12/1990
194	CA	SAN ANTONIO DAM	04-	7712	34.17	117.67	2130	9/1972-8/1977
195	CA	SANDBERG WSMO	04-	7735	34.75	118.73	4520	7/1948-5/1983
196	CA	SAN DIEGO WSO AP	04-	7740	32.73	117.17	10	7/1948-12/1990
197	CA	SAN DIMAS TANBARK FLAT	04-	7750	34.20	117.77	2890	7/1948-11/1985
198	CA	SAN FERNANDO P H 3	04-	7762	34.32	118.50	1250	7/1948-12/1990
199	CA	SN GABR DAM FC 425 B E	04-	7779	34.20	117.87	1480	7/1948-12/1990
200	CA	SAN JACINTO R S	04-	7813	33.78	116.97	1560	7/1948-12/1990
201	CA	SAN JUAN G S	04-	7837	33.60	117.52	730	7/1948-12/1990
202	CA	SAN MARCOS PASS	04-	7859	34.52	119.82	2300	12/1967-12/1990

Appendix 4 (cont).

California Hourly Stations

203	CA	SAN MARCOS RANCH	04-	7861	34.55	119.87	800	10/1951-5/1960
204	CA	SAN NICOLAS ISLAND	04-	7870	33.25	119.45	500	7/1948-12/1976
205	CA	SANTA ANA RIVER P H 3	04-	7891	34.10	117.10	1970	7/1948-12/1990
206	CA	SANTA BARBARA	04-	7902	34.42	119.68	10	7/1948-12/1990
207	CA	SANTA BARBARA FAA AP	04-	7905	34.43	119.83	10	7/1948-9/1951
208	CA	SANTA BARBARA POTRERO	04-	7908	34.78	119.65	5200	7/1948-6/1958
209	CA	SANTA CATALINA WB AP	04-	7910	33.40	118.42	1570	7/1948-12/1967
210	CA	SANTA FE DAM	04-	7926	34.12	117.97	430	7/1948-12/1990
211	CA	SANTA MARIA WSO AP	04-	7946	34.90	120.45	250	7/1948-12/1990
212	CA	SANTA PAULA 3 SE	04-	7959	34.33	119.02	2250	2/1956-6/1958
213	CA	SANTA SUSANA 4 NNE	04-	7973	34.33	118.70	1520	2/1956-6/1958
214	CA	SANTA YNEZ	04-	7976	34.62	120.08	600	7/1948-12/1990
215	CA	SANTIAGO DAM	04-	7987	33.78	117.72	860	7/1948-12/1990
216	CA	SANTIAGO PEAK	04-	7993	33.72	117.53	5640	7/1971-12/199[illegible]
217	CA	SEPULVEDA DAM	04-	8092	34.17	118.47	670	7/1948-12/1990
218	CA	SIERRAVILLE R S	04-	8218	39.58	120.37	4980	7/1948-12/1990
219	CA	SIGNAL HILL FC 415	04-	8230	33.80	118.17	100	7/1948-12/1990
220	CA	SILVERADO R S	04-	8243	33.75	117.65	1100	7/1948-12/1990
221	CA	SILVER LAKE AP	04-	8250	35.33	116.08	920	7/1948-11/1953
222	CA	SIMI 3 E	04-	8258	34.27	118.73	920	12/1956-6/1958
223	CA	SIMI SANITATION PLANT	04-	8261	34.28	118.82	660	10/1975-12/1990
224	CA	SISQUOC SOUTH FORK CAM	04-	8266	34.77	119.77	2500	7/1948-8/1965
225	CA	SLOAT	04-	8292	39.87	120.73	4120	6/1958-10/1962
226	CA	SNOW LAB CEN SIERRA	04-	8320	39.32	120.37	6890	7/1948-6/1961
227	CA	SODA SPRINGS	04-	8331	39.32	120.38	6750	7/1948-12/1958
228	CA	SODA SPRINGS 1 E	04-	8332	39.32	120.37	6890	7/1961-12/1990
229	CA	SOMERSET 5 ESE	04-	8344	38.62	120.60	3160	11/1967-10/1977
230	CA	SOMIS 2 NNW	04-	8347	34.28	119.00	510	1/1956-6/1958

Appendix 4 (cont).

California Hourly Stations

231	CA	SOMIS 5 WNW	04-	8350	34.28	119.07	520	1/1956-6/1958
232	CA	SONORA JUNCTION	04-	8355	38.35	119.45	6890	9/1959-12/1990
233	CA	SPADRA-PAC COL FC 356	04-	8436	34.05	117.82	680	1/1955-12/1990
234	CA	SPRINGVILLE R S	04-	8460	36.13	118.80	1050	7/1948-12/1990
235	CA	SPRINGVILLE TULE HDWKS	04-	8463	36.20	118.65	4070	10/1956-12/1990
236	CA	SURF 2 ENE	04-	8697	34.68	120.57	110	7/1948-12/1990
237	CA	SUSANVILLE AP	04-	8702	40.37	120.57	4150	7/1948-5/1949
238	CA	SUSANVILLE 1 WNW	04-	8703	40.43	120.67	4560	9/1952-12/1990
239	CA	SUSANVILLE STATE R S	04-	8705	40.40	120.67	4560	6/1949-9/1952
240	CA	TAFT	04-	8752	35.15	119.47	1030	7/1948-12/1988
241	CA	TEHACHAPI AIRPORT	04-	8832	35.13	118.43	3960	7/1948-12/1990
242	CA	TEMECULA	04-	8844	33.50	117.15	1020	9/1971-12/1990
243	CA	TERMO 1 E	04-	8873	40.52	120.26	5300	7/1948-12/1990
244	CA	THERMAL FAA AP	04-	8892	33.63	116.17	-110	6/1950-11/1972
245	CA	THERMAL FIRE STN 39	04-	8893	33.63	116.08	-120	11/1972-12/1990
246	CA	THREE RIVERS 6 SE	04-	8912	36.42	118.83	1980	1/1957-12/1990
247	CA	THREE RVR EDISON P H 1	04-	8917	36.47	118.87	1140	7/1948-12/1990
248	CA	TIGER CREEK P H	04-	8928	38.45	120.48	2360	7/1948-12/1990
249	CA	TRABUCO CANYON	04-	8992	33.65	117.60	970	7/1948-12/1990
250	CA	TRUCKEE R S	04-	9043	39.33	120.18	6020	7/1948-12/1990
251	CA	TUJUNGA MILL FC 470	04-	9049	34.38	118.08	4650	7/1948-6/1976
252	CA	TUJUNGA SUMMIT FC 1029	04-	9050	34.38	118.08	4950	11/1949-4/1951
253	CA	UHL RANGER STATION	04-	9120	35.88	118.65	3730	1/1965-12/1990
254	CA	USONA 2 N	04-	9193	37.48	119.82	3150	4/1972-5/1981
255	CA	VENTUCOPA R S	04-	9283	34.85	119.48	2750	3/1967-11/1972
256	CA	VICTORVILLE PUMP PLANT	04-	9325	34.53	117.30	2860	7/1948-12/1990
257	CA	WARNER SPRINGS	04-	9447	33.28	116.63	3180	7/948-5/1978

Appendix 4 (cont).

California Hourly Stations

258	CA	WASIOJA FORBES RANCH	04-	9456	34.97	119.87	2360	7/1948-11/1955
259	CA	WASIOJA PATTERSON RANC	04-	9457	34.98	119.90	2180	11/1955-7/1960
260	CA	WASIOJA PHOENIX RANCH	04-	9458	34.98	119.90	2370	7/1960-12/1973
261	CA	WAWONA R S	04-	9482	37.55	119.65	3990	7/1948-12/1990
262	CA	WELDON 1 WSW	04-	9512	35.67	118.30	2680	7/1948-3/1986
263	CA	WESTWOOD	04-	9599	40.30	121.00	5070	7/1948-4/1953
264	CA	WHEATLAND 2 NE		04-	9605	39.03	121.381107/1948-12/1990	
265	CA	WHEELER SPRINGS 2 SSW	04-	9615	34.48	119.30	880	7/1948-1/1969
266	CA	WHEELER SPRINGS 7 N	04-	9618	34.60	119.33	4150	7/1948-1/1965
267	CA	WHITTIER NARROWS DAM	04-	9666	34.02	118.08	240	9/1972-12/1990
268	CA	WINCHESTER	04-	9722	33.72	117.08	1480	7/1948-8/1971
269	CA	WOODFORDS	04-	9775	38.78	119.82	5670	2/1979-12/1989
270	CA	YOSEMITE PARK HDQ	04-	9855	37.75	119.58	3970	7/1948-12/1990

Appendix 5a.

ARIZONA HOURLY AND DAILY STATIONS
STATIONS AN WITH OVERLAP OF AT LEAST 15 YEARS

	NAME	STN#	LAT	LON	ELEV	OVERLAP
1	AJO	0080	32.37	112.87	1800	7/1948-12/1990
2	ALAMO DAM	0100	34.23	113.58	1290	7/1975-12/1990
3	ASH FORK 2	0487	35.22	112.48	5080	7/1948-12/1990
4	BAGDAD	0586	34.57	113.17	3710	7/1948-11/1969
5	BISBEE	0768	31.43	109.92	5310	7/1948- 2/1985
6	BLACK RIVER PUMPS	0808	33.48	109.77	6040	7/1948-12/1990
7	CASA GRANDE RUINS N M	1314	33.00	111.53	1420	7/1948-12/1990
8	DOUGLAS	2659	31.35	109.53	4040	7/1948-12/1990
9	DUNCAN	2754	32.75	109.12	3660	8/1975-12/1990
10	FLAGSTAFF WSO AP	3010	35.13	111.67	7010	1/1950-12/1990
11	GRAND CANYON NATL PK 2	3596	36.05	112.15	6790	5/1976-12/1990
12	KEAMS CANYON	4586	35.82	110.20	6210	8/1948-12/1990
13	KINGMAN 2	4645	35.20	114.02	3540	9/1967-12/1990
14	NOGALES 6 N	5924	31.42	110.95	3560	10/1952-12/1990
15	ORACLE 2 SE	6119	32.60	110.73	4510	2/1950-12/1990
16	PAGE	6180	36.93	111.45	4270	10/1957-12/1983
17	PAYSON	6323	34.23	111.33	4910	5/1949-12/1990
18	PETRIFIED FOREST NAT P	6468	34.82	109.88	5450	7/1948-12/1990
19	PHOENIX WSFO AP	6481	33.43	112.02	1110	7/1948-12/1990
20	PHOENIX CITY	6486	33.45	112.07	1080	7/1948- 8/1968
21	PRESCOTT FAA AP	6801	34.65	112.43	5020	7/1948-11/1969
22	SANTA RITA EXP RANGE	7593	31.77	110.85	4300	5/1950-12/1990
23	SEDONA R S	7708	34.87	111.77	4220	4/1973-12/1990
24	SUPERIOR	8348	33.30	111.10	3000	9/1948-10/1978
25	TRUXTON CANYON	8778	35.38	113.67	3820	7/1948- 3/1980
26	TUCSON WSO AP	8820	32.13	110.95	2580	7/1948-12/1990
27	TUWEEP	8895	36.28	113.07	4780	7/1948-12/1985
28	WHITERIVER 1 SW	9271	33.83	109.97	5120	7/1948-12/1990
29	WINSLOW WSO AP	9439	35.02	110.73	4890	7/1948-12/1990
30	YUMA WSO AP	9660	32.67	114.60	210	9/1948-12/1990

Appendix 5b.

NEVADA HOURLY AND DAILY STATIONS WITH AN OVERLAP OF AT LEAST 15 YEARS

	NAME	STN#	LAT	LON	ELEV	OVERLAP
1	AUSTIN	0507	39.50	117.08	6610	7/1948-12/1990
2	BATTLE MOUNTAIN AP	0691	40.58	116.90	4540	7/1948-12/1990
3	BEATTY 8 N	0718	37.00	116.72	3550	12/1972-12/1990
4	BLUE JAY HWY STN	0961	38.38	116.22	5320	5/1963- 4/1984
5	CALIENTE	1358	37.62	114.52	4400	7/1948-11/1976
6	CONTACT	1905	41.78	114.75	5370	7/1948-12/1990
7	EASTGATE	2477	39.30	117.88	5020	7/1948- 6/1964
8	ELGIN	2557	37.35	114.53	3390	3/1951-12/1990
9	ELKO FAA AP	2573	40.83	115.78	5080	7/1948-12/1990
10	ELY WSO AP	2631	39.28	114.85	6260	7/1948-12/1990
11	FISH CREEK RANCH	2860	39.27	116.00	6050	7/1948-12/1964
12	HAWTHORNE AP	3515	38.55	118.67	4220	7/1948-12/1990
13	JIGGS 3 N	4086	40.45	115.65	5420	7/1948- 3/1972
14	LAS VEGAS WSO AP	4436	36.08	115.17	2160	1/1949-12/1990
15	LEONARD CREEK RANCH	4527	41.52	118.72	4220	12/1954-12/1990
16	LOGANDALE UN EXP FARM	4651	36.57	114.47	1320	2/1968-12/1990
17	LOVELOCK	4698	40.18	118.47	3980	9/1952-12/1990
18	MALA VISTA RANCH	4824	41.32	115.25	5590	3/1950- 6/1965
19	MC DERMITT	4935	42.00	117.72	4530	3/1950-12/1990
20	METROPOLIS	5092	41.28	115.02	5800	3/1968-12/1990
21	MINDEN AIRPORT	5191	39.00	119.75	4710	7/1948-12/1990
22	MONTOGMERY MNTC STN	5362	37.97	118.32	7100	5/1960- 5/1980
23	OVERTON	5846	36.52	114.42	1220	7/1948-12/1988
24	OWYHEE	5869	41.95	116.10	5400	7/1948- 1/1985
25	PAHRANAGAT WILDLIFE RE	5880	37.27	115.12	3400	4/1965-12/1990
26	PARADISE VALLEY 1 NW	6005	41.50	117.53	4680	7/1948- 1/1964
27	PEQUOP	6148	41.07	114.53	6300	7/1948- 7/1985
28	RATTLESNAKE	6630	38.45	116.17	5910	7/1948- 5/1963
29	RENO WSFO AP	6779	39.50	119.78	4400	7/1948-12/1990
30	RYE PATCH DAM	7192	40.47	118.30	4140	7/1948-12/1990
31	SEARCHLIGHT	7369	35.47	114.92	3540	7/1948-12/1990
32	SMITH 6 N	7612	38.95	119.33	5000	7/1973-12/1990
33	SMOKEY VALLEY	7620	38.78	117.17	5630	5/1953-12/1990
34	SNOWBALL RANCH	7640	39.07	116.20	7160	9/1966-12/1990
35	SUNNYSIDE	7908	38.42	115.02	5300	7/1948-12/1990
36	TONOPAH AIRPORT	8170	38.07	117.08	5430	6/1954- 3/1977
37	WABUSKA 5 SE	8822	39.08	119.12	4300	6/1972-12/1990
38	WADSWORTH 4 N	8838	39.70	119.28	4200	7/1948-12/1990
39	WELLINGTON R S	8977	38.75	119.37	4840	7/1948- 4/1973
40	WELLS	8988	41.12	114.97	5650	7/1948-12/1990
41	WINNEMUCCA WSO AP	9171	40.90	117.80	4300	7/1948-12/1990

Appendix 5c.

NEW MEXICO HOURLY AND DAILY STATIONS
STATIONS WITH AN OVERLAP OF AT LEAST 15 YEARS

	NAME	STATION NO.	LAT	LON	ELEV	OVERLAP
1	ABIQUIU DAM	0041	36.23	106.43	6380	10/1963-12/1990
2	ALAMOGORDO	0199	32.88	105.95	4350	9/1968-12/1990
3	ALBUQUERQUE WSFO AP	0234	35.05	106.62	5310	10/1947-12/1990
4	ANIMAS	0417	31.95	108.82	4420	11/1969-12/1990
5	ARTESIA 6 S	0600	32.77	104.38	3320	1/1948-12/1990
6	AUGUSTINE 2 E	0640	34.08	107.62	7000	1/1948-12/1990
7	BEAVERHEAD R S	0818	33.42	108.12	6670	7/1948-12/1990
8	BERNALILLO	0903	35.32	106.55	5060	1/1948- 9/1982
9	BOSQUE DEL APACHE	1138	33.77	106.90	4510	9/1950-10/1970
10	CABALLO DAM	1286	32.90	107.30	4190	1/1948-12/1990
11	CARLSBAD	1469	32.42	104.23	3120	1/1948-12/1990
12	CARRIZOZO	1515	33.65	105.88	5420	1/1948-12/1990
13	CLAYTON WSO AP	1887	36.45	103.15	4970	10/1947-12/1990
14	CLOVIS 3 SSW	1939	34.37	103.20	4280	10/1947-12/1990
15	CLOVIS 13 N	1963	34.60	103.22	4440	7/1949-12/1990
16	COCHITI DAM	1982	35.63	106.32	5560	2/1975-12/1990
17	COLUMBUS	2024	31.83	107.65	4160	1/1948-12/1990
18	CONCHAS DAM	2030	35.40	104.18	4240	1/1948-12/1990
19	CROSSROADS	2203	33.52	103.33	4150	12/1971-12/1990
20	CROWNPOINT	2219	35.68	108.15	6960	7/1948-11/1969
21	CUBA	2241	36.03	106.97	7050	7/1970-12/1990
22	DEMING	2436	32.25	107.73	4300	4/1961-12/1990
23	DILIA	2510	35.18	105.07	5200	1/1948-12/1990
24	EAGLE NEST	2700	36.55	105.27	8260	1/1948-12/1990
25	EL VADO DAM	2837	36.60	106.73	6740	1/1948-12/1990
26	FARNSWORTH RANCH	3145	33.90	105.00	5400	5/1953- 5/1980
27	FLORIDA	3225	32.43	107.48	4450	1/1948-12/1990
28	FORT BAYARD	3265	32.80	108.15	6140	9/1968-12/1990
29	HILLSBORO	4009	32.93	107.57	5270	1/1948-12/1990
30	HOPE	4112	32.82	104.73	4100	4/1966-12/1990
31	JORNADA EXP RANGE	4426	32.62	106.73	4270	1/1953-12/1990
32	LAGUNA	4719	35.03	107.40	5800	10/1948-12/1990
33	LUNA RANGER STN	5273	33.83	108.93	7050	7/1948- 1/1970
34	MALJAMAR 4 SE	5370	32.82	103.70	4000	2/1948-12/1990
35	MIMBRES RANGER STN	5754	32.93	108.02	6240	11/1952-12/1990
36	NARROWS	6043	33.38	107.17	4400	1/1948- 7/1964
37	OCATE 1 N	6275	36.18	105.05	7670	8/1960-12/1990
38	OROGRANDE	6435	32.38	106.10	4180	1/1948-12/1990
39	PASAMONTE	6619	36.30	103.73	5650	1/1948- 3/1965
40	PEARL	6659	32.65	103.38	3800	1/1948-12/1990
41	PROGRESSO	7094	34.42	105.85	6300	1/1948-12/1990
42	RAMON 8 SW	7254	34.15	105.00	5330	6/1969-12/1990

Appendix 5c (cont).

NEW MEXICO HOURLY AND DAILY STATIONS
STATIONS WITH AN OVERLAP OF AT LEAST 15 YEARS

43	RATON WB AP	7283	36.75	104.50	6380	1/1948-11/1968
44	REGINA	7346	36.18	106.95	7450	1/1948- 9/1969
45	RIENHARDT RANCH	7423	33.75	107.22	5450	10/1951-12/1990
46	RODEO	7534	31.83	109.03	4110	1/1954- 4/1978
47	ROSWELL WSO AP	7609	33.40	104.53	3640	12/1947-11/1972
48	ROSWELL FAA AP	7610	33.30	104.53	3670	1/1973-12/1990
49	ROY	7638	35.95	104.20	5880	1/1948-12/1990
50	SAN FIDEL 2 E	7827	33.08	107.60	6160	1/1948-12/1976
51	SAN MATEO	7918	35.33	107.65	7240	6/1948- 2/1988
52	SANDIA CREST	8011	35.22	106.45	680	10/1953- 7/1969
53	SANTA FE	8072	35.68	105.90	7200	11/1947- 3/1972
54	SANTA FE 2	8085	35.65	105.98	6720	4/1972-12/1990
55	SOCORRO	8387	34.08	106.88	4590	7/1948-12/1990
56	SPRINGER	8501	36.37	104.58	5950	1/1948-12/1990
57	STANLEY 1 NNE	8518	35.17	105.97	6380	12/1954-12/1990
58	STATE UNIV	8535	32.28	106.75	3880	4/1959-12/1990
59	SUMNER LAKE	8596	34.60	104.38	4310	3/1975-12/1990
60	TORREON NAVAJO MISSION	9031	35.80	107.18	6700	1/1961-12/1990
61	TUCUMCARI 4 NE	9156	35.20	103.68	4090	11/1947-12/1990
62	WHITE SANDS NATL N M	9686	32.78	106.18	4000	1/1948-12/1990
63	ZUNI	9897	35.07	108.83	6310	3/1949-12/1990

Appendix 5d.

UTAH HOURLY AND DAILY STATIONS
STATIONS WITH AN OVERLAP OF AT LEAST 15 YEARS

	NAME	STN#	LAT	LON	ELEV	OVERLAP
1	ALTON	0086	37.43	112.48	7040	12/1971-12/1990
2	ANTIMONY	0201	38.12	112.00	6460	9/1948-11/1975
3	BLANDING	0738	37.62	109.47	6130	7/1948-12/1990
4	BRYCE CANYON NP HQ	1008	37.65	112.17	7920	6/1959-12/1990
5	CEDAR CITY STEAM PLANT	1273	37.67	113.03	6000	12/1961- 2/1983
6	CEDAR POINT	1308	37.72	109.08	6760	7/1974-12/1990
7	COALVILLE 13 E	1590	40.93	111.15	6510	11/1974-12/1990
8	COTTONWOOD WEIR	1759	40.62	111.78	4960	7/1948-12/1990
9	DELTA	2090	39.33	112.58	4620	7/1948-12/1990
10	DUGWAY	2257	40.18	112.92	4340	3/1951-12/1990
11	ECHO DAM	2385	40.97	111.43	5470	11/1949-12/1990
12	ENTERPRISE BERYL JCT	2561	37.77	113.65	5150	7/1948-12/1990
13	EPHRAIM SORENSENS FIEL	2578	39.35	111.58	5670	9/1949-12/1990
14	FAIRFIELD	2696	40.27	112.08	4880	10/1950-12/1990
15	FAIRVIEW 8 N	2702	39.75	111.42	6750	5/1975-12/1990
16	FARMINGTON USU FLD STN	2726	41.02	111.92	4340	8/1948- 2/1968
17	FLAMING GORGE	2864	40.93	109.42	6270	2/1958-12/1990
18	FRUITLAND	3056	40.22	110.85	6620	8/1948- 7/1965
19	GRANTSVILLE	3348	40.60	112.45	4290	6/1956-12/1990
20	GREEN RIVER AVN	3418	39.00	110.17	4070	7/1948-12/1990
21	HANKSVILLE	3611	38.37	110.72	4310	7/1948-12/1990
22	HANNA	3624	40.40	110.77	6750	7/1965-12/1990
23	LOGAN UTAH ST U	5186	41.75	111.80	4790	7/1948-12/1990
24	MARYSVALE	5477	38.45	112.23	5910	7/1948-12/1990
25	MILFORD WSMO	5654	38.43	113.02	5030	7/1948-12/1990
26	MOUNTAIN DELL DAM	5892	40.75	111.72	5420	10/1967-12/1990
27	NEPHI	6135	39.70	111.83	5130	8/1948-12/1990
28	OGDEN PIONEER P H	6404	41.25	111.95	4350	10/1971-12/1990
29	OGDEN SUGAR FACTORY	6414	41.23	112.03	4280	7/1948-12/1990
30	PLYMOUTH	6938	41.87	112.15	4470	7/1948-12/1990
31	PRICE WAREHOUSES	7026	39.62	110.83	5680	9/1968-12/1990
32	RICHFIELD RADIO KSVC	7260	38.77	112.08	5270	8/1948-12/1990
33	ROOSEVELT	7395	40.28	109.97	5010	7/1948-12/1990
34	ST GEORGE	7516	37.12	113.57	2760	7/1948-12/1990

Appendix 5d (cont).

UTAH HOURLY AND DAILY STATIONS
STATIONS WITH AN OVERLAP OF AT LEAST 15 YEARS

35	SALT LAKE CITY NWSFO A	7598	40.78	111.95	4220	7/1948-12/1990
36	SILVER LAKE BRIGHTON	7846	40.60	111.58	8740	7/1948-12/1990
37	SOLDIER SUMMIT	7959	39.93	111.08	7470	7/1948-12/1990
38	VEYO POWER HOUSE	9136	37.35	113.67	4600	3/1974-12/1990
39	WENDOVER AUTOB	9382	40.73	114.03	4240	7/1948- 1/1977

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

July 29, 1993 W/OH11:LFT

MEMORANDUM FOR: Southwest Semi-Arid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Seventh Quarterly Report - Semi-Arid Precipitation Frequency Project, April 1 - June 30, 1993

Enclosed is a copy of the Seventh Quarterly Progress Report for the Semi-Arid Precipitation Frequency Project for the southwestern United States. This update contains an initial examination of the differences between annual maximum and partial duration series and the implications for frequency analysis. Comparisons of daily and 24-hour data for the Southwest are discussed. Also included is an analysis of the regionality and seasonality for the entire project area and a map of the preliminary regions to be used for frequency analysis.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

2. HETEROGENEITY--H

HOMOGENEOUS REGION - HETEROGENEITY, H: "IS THE BETWEEN-SITE DISPERSION OF THE SAMPLE L-MOMENTS FOR THE GROUP OF SITES LARGER THAN WOULD BE EXPECTED FROM A HOMOGENEOUS REGION?"

[(OBS. DISP) - (MEAN DISP BY SIMULATION)]/SD OF SIM DISP

SIMULATION: 4-PARAMETER KAPPA DISTRIBUTION

$$H = (V - \mu_V)/\sigma_V$$

WHERE V IS THE WEIGHTED SD AT EACH SITE

SAMPLE L-CV OR L-SKEW OR L-KURTOSIS

μ_V, σ_V FROM MONTE CARLO

3. GOODNESS-OF-FIT Z

$$Z^{GEV} = \frac{(\bar{t}_4 - \tau_4^{GEV})}{\sigma_4}$$

where $\bar{t}_4$ is the regional average L-Kurtosis.

τ_4 is the L-kurtosis of the fitted GEV distribution, and

σ_4 is the standard deviation of $\bar{t}_4$

APPENDIX D

Annual Maximum

	REGION 1, 5 sites				REGION 2, 8 sites				REGION 3, 15 sites				REGION 4, 39 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0	0	0	0	0	0	1	1	0	1	0	3	2
H1 L-C	2.58	2.53	0.21	0.81	-0.20	-0.51	0.42	1.37	0.22	0.63	3.67	3.69	3.18	3.86	4.48	2.45
H2 L-S	1.41	0.82	0.39	1.58	-1.46	-1.28	0.09	-0.12	0.83	0.06	-0.13	1.41	1.82	1.68	0.62	-0.82
H3 L-K	0.94	0.32	0.33	0.94	-2.10	-1.15	0.26	0.25	0.40	-0.41	-0.83	0.83	1.49	1.40	-0.30	-1.27
GLO	0.50	0.98	0.40	-0.13	-0.35	-0.03	0.23	1.76	-0.34	-0.16	1.07	0.06	1.05	0.97	1.94	1.11
GEV	-0.35	-0.21	-0.53	-1.02	-1.17	-1.08	-1.09	0.07	-1.48	-1.40	-0.50	-1.20	-1.09	-1.55	-1.14	-1.80
LNO	-0.73	-0.42	-0.85	-1.30	-1.71	-1.53	-1.41	-0.16	-2.10	-1.97	-0.99	-1.79	-2.23	-2.46	-1.81	-2.49
P III	-1.42	-0.91	-1.46	-1.85	-2.64	-2.53	-2.06	-0.76	-3.19	-3.01	-1.92	-2.84	-4.26	-4.17	-3.25	-3.93
GPA	-2.45	-2.87	-2.75	-3.11	-3.33	-3.64	-4.13	-3.66	-4.35	-4.46	-4.20	-4.31	-6.50	-7.58	-8.14	-8.46

	REGION 5, 11 sites				REGION 6, 7 sites				REGION 7, 30 sites				REGION 8, 22 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0	0	0	0	0	2	1	1	2	0	2	0	0
H1 L-C	0.63	2.13	1.67	1.78	2.49	1.05	1.82	1.16	4.22	3.94	1.24	1.78	-1.55	-0.37	0.67	0.58
H2 L-S	-1.27	-0.59	0.25	-0.14	1.86	3.31	0.46	0.08	1.54	2.20	-0.11	0.59	-0.37	-0.29	-0.71	-0.28
H3 L-K	-1.57	-0.28	0.43	0.04	2.28	3.74	0.08	-0.54	-0.57	0.57	-0.48	-0.20	-0.03	-0.47	-0.71	-0.36
GLO	-0.28	0.80	2.98	1.00	0.59	0.36	2.21	1.66	0.76	0.99	1.43	3.05	1.44	0.33	0.86	0.71
GEV	-1.16	-0.62	0.83	-0.55	-0.51	-0.81	0.64	0.45	-1.74	-1.53	-1.10	0.59	-0.60	-1.60	-1.31	-1.36
LNO	-1.71	-0.94	0.84	-0.81	-0.88	-1.12	0.43	0.05	-2.41	-2.21	-1.82	-0.33	-1.29	-2.25	-1.87	-1.96
P III	-2.67	-1.62	0.44	-1.42	-1.59	-1.74	-0.14	-0.72	-3.75	-3.57	-3.24	-2.03	-2.61	-3.47	-3.00	-3.14
GPA	-3.43	-3.87	-3.64	-3.98	-3.12	-3.51	-2.80	-2.43	-7.52	-7.37	-6.98	-5.30	-5.45	-6.17	-6.30	-6.19

Annual Maximum (continued)

	REGION 9, 14 sites				REGION 10, 20 sites				REGION 11, 12 sites				REGION 12, 12 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0
H1 L-C	-0.47	-0.83	-1.11	-0.08	6.41	5.35	4.65	4.12	0.50	0.72	-0.18	-0.54	1.36	0.39	0.25	0.70
H2 L-S	0.95	0.56	-1.29	0.14	3.32	2.79	1.93	0.28	-0.14	0.67	-0.02	-0.86	-0.16	0.37	-1.50	-1.61
H3 L-K	1.13	0.73	-0.62	0.69	1.22	1.36	-0.45	-0.98	0.45	1.00	0.08	-0.44	-0.76	-0.67	-1.45	0.01
GLO	1.19	0.39	0.50	-1.16	1.38	0.45	1.14	1.14	2.25	1.48	0.43	1.44	0.98	0.89	0.55	0.62
GEV	-0.23	-0.98	-1.14	-2.54	-0.44	-1.15	-0.89	-0.82	0.44	-0.15	-0.58	0.25	-0.83	-0.73	-1.26	-1.19
LNO	-0.73	-1.44	-1.43	-2.90	-1.26	-2.15	-1.56	-1.53	0.19	-0.46	-1.20	-0.34	-1.05	-1.07	-1.44	-1.38
PER III	-1.67	-2.30	-2.11	-3.62	-2.73	-3.37	-2.83	-2.86	-0.46	-1.16	-2.27	-1.40	-1.67	-1.82	-2.01	-1.95
GPA	-3.60	-4.23	-4.80	-5.73	-4.91	-6.13	-5.70	-5.51	-3.54	-3.83	-3.19	-2.74	-4.79	-4.41	-5.17	-5.12

	REGION 13, 33 sites				REGION 14, 25 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	1	3	1	0	0	2	1
H1 L-CV	2.73	1.93	1.54	1.24	0.00	-0.11	2.98	4.36
H2 L-SK	0.52	-0.10	0.47	0.29	0.30	-0.33	0.25	0.83
H3 L-KT	0.04	0.25	-0.01	0.39	0.18	-0.86	-0.67	0.59
GLO	2.78	1.64	3.22	3.97	0.95	1.92	3.77	3.90
GEV	-0.26	-1.49	-0.43	0.22	-1.10	-0.28	1.24	1.54
LNO	-0.88	-1.93	-0.68	-0.03	-1.85	-1.05	0.51	0.68
P III	-2.24	-3.08	-1.67	-1.04	-3.25	-2.49	-0.94	-0.93
GPA	-7.13	-8.40	-8.25	-7.82	-6.01	-5.50	-4.66	-4.10

APPENDIX E

Partial Duration

	REGION 1, 5 sites				REGION 2, 8 sites				REGION 3, 15 sites				REGION 4, 39 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2
H1 L-C	1.66	2.09	1.11	1.72	-0.93	-0.87	1.50	0.65	0.60	-0.23	3.19	3.62	3.34	2.34	2.34	0.15
H2 L-S	1.23	0.89	0.28	0.32	-1.98	-1.59	2.20	2.28	1.12	-0.13	0.07	2.11	2.56	2.32	1.86	0.13
H3 L-K	0.51	0.30	0.92	-0.10	-1.66	-1.78	1.58	1.55	-0.10	-0.61	0.23	1.84	2.19	2.57	1.94	-0.10
GLO	0.69	1.76	3.93	2.31	0.77	1.40	3.26	2.69	1.41	1.45	2.77	2.30	4.89	3.81	4.88	3.79
GEV	0.33	1.20	3.39	1.77	0.35	0.89	2.55	1.83	0.92	0.88	2.00	1.70	3.77	2.56	3.43	2.49
LNO	-0.33	0.53	2.52	1.04	-0.51	0.01	1.59	1.00	-0.22	-0.22	0.89	0.54	1.70	0.66	1.52	0.62
P III	-1.46	-0.60	1.04	-0.20	-1.97	-1.48	-0.04	-0.40	-2.16	-2.10	-1.02	-1.45	-1.84	-2.57	-1.73	-2.58
GPA	-0.89	-0.47	1.62	0.09	-1.14	-0.80	0.33	-0.62	-0.90	-1.12	-0.44	-0.39	-0.07	-1.49	-1.04	-1.61

	REGION 5, 11 sites				REGION 6, 7 sites				REGION 7, 30 sites				REGION 8, 22 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0
H1 L-C	0.16	0.87	3.28	2.15	2.39	0.90	1.40	1.13	3.04	1.30	0.31	1.06	-1.57	-0.93	0.19	0.09
H2 L-S	-0.15	-0.62	1.66	0.26	3.67	4.08	0.49	-0.93	-0.94	0.24	-0.66	-0.27	-0.08	-0.23	-0.32	0.68
H3 L-K	-0.50	-0.12	1.09	0.19	3.59	3.64	0.41	-0.53	-1.70	-0.40	-0.66	-0.53	-0.30	-0.78	-0.21	0.67
GLO	1.29	1.97	4.15	2.64	1.85	0.76	3.04	3.50	3.30	2.65	4.08	4.96	4.14	3.27	2.66	4.09
GEV	0.92	1.29	3.05	1.94	1.35	0.17	2.10	2.80	2.21	1.45	2.92	3.75	3.09	2.36	1.69	3.09
LNO	-0.03	0.43	2.24	1.03	0.53	-0.51	1.41	1.93	0.52	-0.12	1.19	1.96	1.59	0.88	0.30	1.57
P III	-1.66	-1.05	0.85	-0.54	-0.87	-1.65	0.23	0.45	-2.36	-2.80	-1.77	-1.09	-0.96	-1.64	-2.08	-1.01
GPA	-0.52	-0.78	0.11	-0.20	-0.32	-1.60	-0.42	0.68	-1.31	-2.24	-0.78	-0.13	-0.24	-0.63	-1.38	-0.14

Partial Duration (continued)

	REGION 9, 14 sites				REGION 10, 20 sites				REGION 11, 12 sites				REGION 12, 12 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1
H1 L-C	0.99	0.35	-0.45	0.45	5.42	4.72	3.47	2.54	-0.43	-0.46	-1.33	-1.31	1.15	-0.25	0.20	0.68
H2 L-S	0.80	0.90	-1.34	0.53	2.10	2.23	0.86	-0.39	-1.08	-0.17	-1.00	-1.26	-0.62	-0.47	-0.93	-0.43
H3 L-K	0.93	0.89	-0.76	0.58	0.42	1.04	-0.03	-0.44	-0.62	0.01	-0.61	-0.90	-0.87	-1.07	-0.62	0.43
GLO	3.51	2.37	1.81	1.28	3.61	2.68	3.51	3.02	4.11	3.38	2.01	3.30	2.94	2.80	3.02	3.41
GEV	2.75	1.69	1.11	0.71	2.78	1.80	2.46	2.10	3.12	2.58	1.42	2.63	1.96	1.97	2.20	2.64
LNO	1.65	0.65	0.13	-0.29	1.23	0.37	1.03	0.65	2.19	1.60	0.44	1.58	1.04	0.98	1.18	1.55
P III	-0.22	-1.12	-1.53	-1.99	-1.41	-2.08	-1.42	-1.82	0.61	-0.07	-1.22	-0.20	-0.54	-0.72	-0.57	-0.29
GPA	0.36	-0.51	-1.10	-1.21	-0.07	-1.08	-0.80	-0.89	0.31	0.16	-0.54	0.45	-0.81	-0.52	-0.28	0.21

	REGION 13, 33 sites				REGION 14, 25 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	2	0	1	0	2	2	1	1
H1 L-C	2.02	0.37	0.94	0.95	0.53	-0.14	2.17	3.91
H2 L-S	-0.34	0.81	0.01	1.03	0.60	-0.32	-0.80	0.38
H3 L-K	-0.49	0.81	-0.40	1.14	0.21	0.16	-0.69	0.38
GLO	5.53	4.29	5.75	6.99	3.41	3.50	5.39	5.32
GEV	4.04	2.86	3.98	5.01	2.32	2.37	3.94	3.95
LNO	2.26	1.17	2.33	3.37	0.78	0.85	2.39	2.37
P III	-0.77	-1.72	-0.48	0.57	-1.84	-1.75	-0.24	-0.33
GPA	-0.44	-1.42	-1.02	-0.43	-1.10	-1.13	-0.28	-0.13

SEMIARID PRECIPITATION FREQUENCY STUDY

Seventh Quarterly Progress Report
for the period from
April 1 through June 30, 1993

Lesley F. Tarleton, Julie M. Olson, Jennifer Hanson,
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Office of Hydrology
National Weather Service
Silver Spring, Maryland

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SEMIARID PRECIPITATION FREQUENCY STUDY

Seventh Quarterly Progress Report
for the period from
April 1 through June 30, 1993

OVERVIEW

This Seventh Quarterly Report summarizes the work for the Semiarid Precipitation Frequency Project for the period April 1 through June 30, 1993. In this period the seasonality and the first trial regionalization of the entire study area have been outlined. The criteria for choosing regional boundaries include, among others, the types of storms that cause extreme precipitation in the region, the topography, and the season of maximum precipitation. Comparisons of annual and partial data duration series are shown and the implications for frequency analysis are discussed. The development of storm analysis software is described.

DATA

Hourly and Daily Datasets

Database.

Although data quality assessment will continue until the final analysis, the hourly and daily precipitation databases have had the last 'odds and ends' brought on line. In particular, the 'cleanup' of the New Mexico digitized daily data records has added 271 stations to the database, all with records of at least 19 years and some with records dating into the last century. Also, 325 California daily stations with at least 19 years of record are now included within the project area. Southeastern California is a part of the core study area; northeastern California is part of the border area. As for the other border states, 114 hourly stations have been added to the database. The border states include one degree of latitude (60 nautical miles) of the surrounding states of Oregon, Idaho, Wyoming, Colorado, and Texas. Table 1 shows the numbers of daily and hourly stations for each state in the current database. These stations, which have been subjected to a variety of quality control procedures, have at least 15 years of record for hourly stations, and at least 19 years of data for daily stations.

Table 1.

	Daily	Hourly
Arizona	276	42
Nevada	105	41
New Mexico	271	81
Utah	186	42
California	325	242
Border States	140	114
Totals	1303	561

Discordancy test examples.

In regard to quality assurance, one of the most effective techniques is a discordancy test (Hosking and Wallis,1991). The discordancy test was described in the Fifth Quarterly Progress Report for the Semiarid Project (Oct-Dec 1992) and the definition for Discordancy is repeated here, as follows:

Let $U_i = \left[t_2^{(i)}, t_3^{(i)}, t_4^{(i)}\right]^T$ be a vector for site *i*,

where *t* = the L-moments,

$$\overline{U} = N^{-1}\sum_{i=1}^{N} U_i$$ the unweighted group mean

Then the Discordancy (D_i) for the site *i* is defined:

$$D_i = \frac{1}{3}(U_i-\overline{U})^T S^{-1}(U_i-\overline{U})$$

where $$S = (N-1)^{-1}\sum_{i=1}^{N}(U_i-\overline{U})(U_i-\overline{U})^T$$

S = sample covariance matrix

Several examples will illustrate its functionality in flagging data series that contain erroneous data. In the list in Table 2 of Arizona annual maximum data, each record had a high discordancy score. The data were examined for extreme outliers - which were found - and, going back to original data sources (e.g., microfiche, climate summaries, etc.), the correct annual maximums were found. The station numbers, errors, and corrections are given in Table 2.

Table 2.

Station #	Error	Comment	Correct Value
29-8015	70.02	(.02) wrong	1.80
29-3128	11.10	should be trace	1.04
29-5490	40.15	should be 0.15	2.29
29-9496	0.04	should be missing	
29-3511	13.00	should be missing	0.83
29-1063	8.00	should be 0.00	0.38
29-1403	11.10	should be trace	1.43

ANALYSIS

Annual Versus Partial Duration Series

Dr. Edwin Chin is evaluating the relationship between annual maximum series (AMX) and partial duration series (PD). An annual maximum series consists of the highest precipitation amount for each duration in each year. A partial duration series consists of the **n** highest amounts, where **n** is the number of years of record, regardless of year of occurrence. The partial duration series of daily data was developed from the monthly maximums for each station, thereby insuring independent events. Using 277 Arizona daily station records, the partial duration and annual maximum series were compared in several different ways. All the stations have at least 19 years of record, most have about 35 years; and some have nearly 100 years of record. Intuitively, one realizes that the highest values will be the same in both series, and that the differences will be that the partial duration series have fewer low values and a smaller range. The comparisons are as follows:

- o Figure 1 shows box-and-whisker plots for two stations in Arizona, Buckeye-1026 (97 years) and Clifton-1849 (98 years). The 'box' contains the middle 50 percent, while the 'whiskers' show the range of the data. The line inside the box is the median line. As expected, the partial duration series has a much smaller range for both stations, and, in fact, the lowest partial duration values are <u>greater</u> than the lowest quartile of the annual maximum series.
- o The same information is illustrated in another way in Figure 2, with an x-y plot of the partial duration and annual maximum series at Clifton. <u>No</u> partial duration value is less than 1.1, and <u>more than 20</u> annual maximum values are less than 1.1.

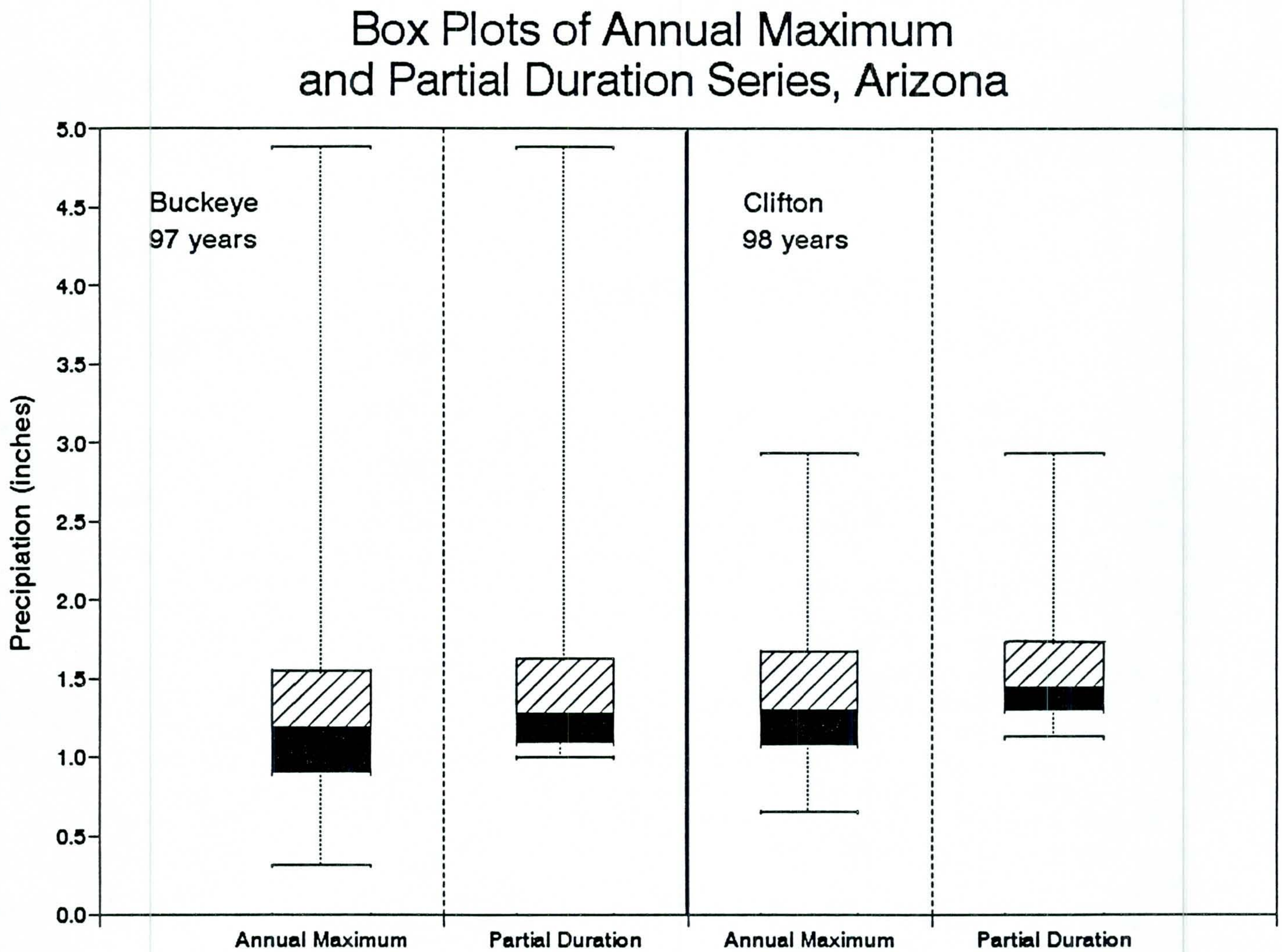

Figure 1. Box-and-whisker plots showing Annual Maximum and Partial Duration Series of Buckeye (1026) and Clifton (1849) Arziona.

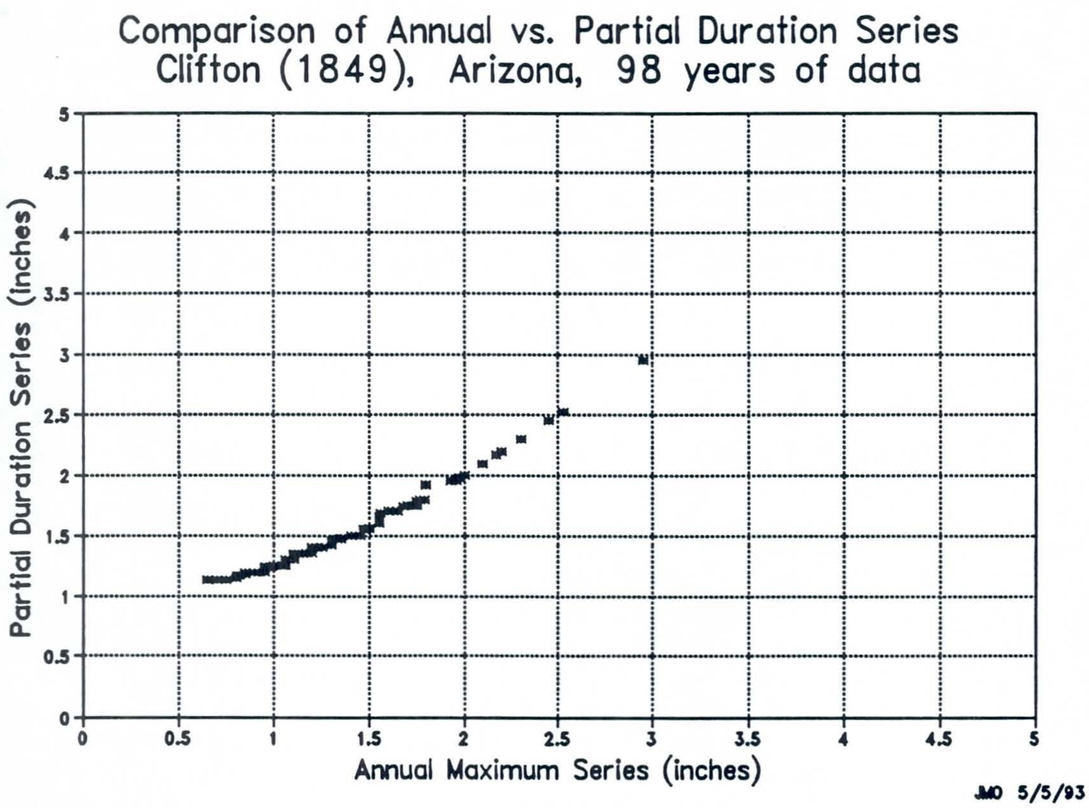

Figure 2. Comparison of Annual Maximum and Partial Duration Series Data for Clifton, Arizona.

- In another analysis the L-statistics were calculated for 277 Arizona stations, and plotted with the L-coefficient of variation (L-CV) against the L-skewness (L-SK) for the AMX (Figure 3) and the PD (Figure 4). Comparing the two, one sees that the AMX has higher variability (higher L-CV) and less skewness (L-SK) than the PD. Plots of L-skewness and L-kurtosis (not shown) also confirmed differences between AMX and PD.

Differences between annual maximum series and partial duration series are important for at least two reasons: 1) for the determination of the best-fit distribution, and 2) for possible differences in the frequency analysis results. For example, implications for frequency analysis are shown in the log-log plots of precipitation and return frequency in Figures 5 and 6. The AMX (Figure 5) gives much lower estimates, ranging from 0.80 to not quite 2.00 inches for the 1- to 2-year return frequencies. The estimates from the PD series (Figure 6) range from 1.80 to more than 2 inches for the same return periods.

Comparison of Daily and 24-hour Data.

Both NOAA Atlas 2, 1973, and Technical Paper 40 (Hershfield, 1961) use the empirically derived value of 1.13 to convert daily data to 24-hour data. This is necessary because of the varying observation times for daily data, and the unfortunate and uncooperative tendency of rainfall to fall not in the 'prescribed' daily observation period, but irregularly throughout the day. As the factor was computed many years ago and applied universally to the whole country, it was decided to compute an empirical factor based on only southwestern data. The initial results are based on the first order stations that have co-located hourly and daily raingages. These results from 20 stations in Arizona, Nevada, New Mexico, and Utah are shown in Figures 7, 8, and 9, for 2-year, 10-year, and 100-year return periods. The values of 1.15 (2-year) and 1.12 (10-year) suggest that at the 2- to 10-year return frequencies the factor for the southwest is comparable to the 1.13 used in earlier studies. However, the 100-year return frequency factor of 1.06 needs to be investigated further. TP-40 and NOAA Atlas 2 give no information on this factor for return frequencies greater than two years.

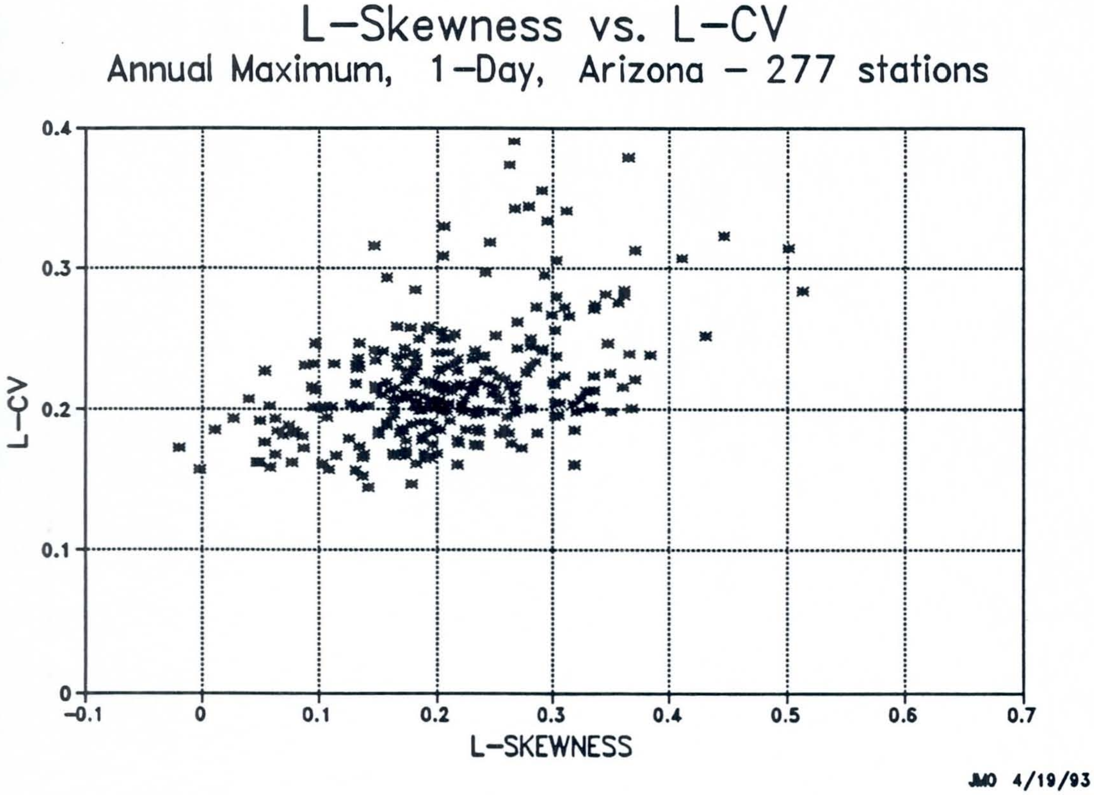

Figure 3. L-Skewness vs. L-CV of Annual Maximum Daily Data in Arizona.

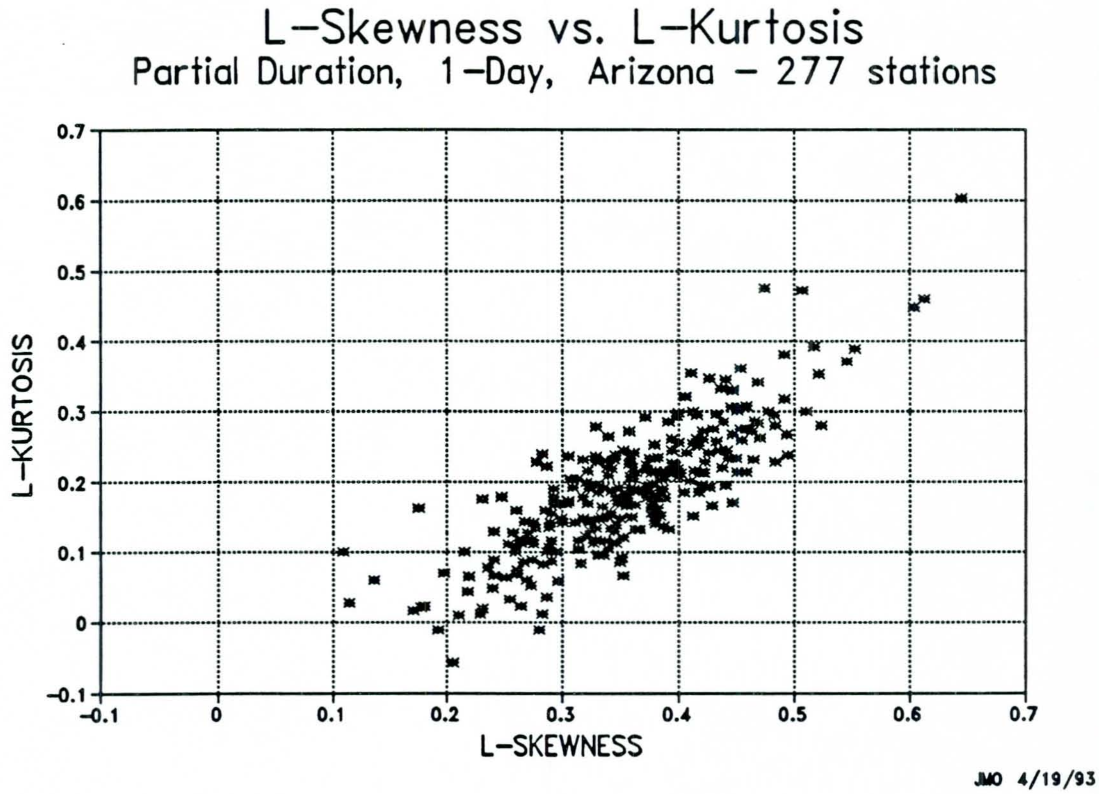

Figure 4. L-Skewness vs. L-Kurtosis of Partial Duration Series Daily Data in Arizona.

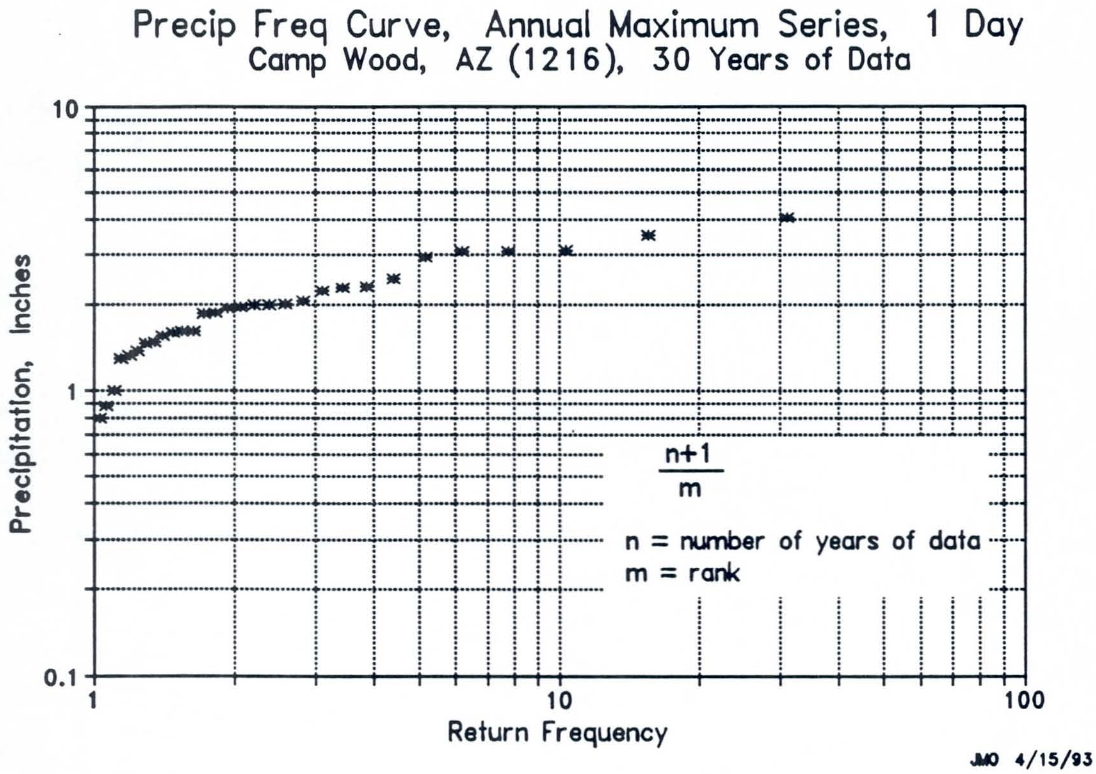

Figure 5. Precipitation Frequency Curve of 1-Day Annual Maximum Series Data for Camp Wood, Arizona.

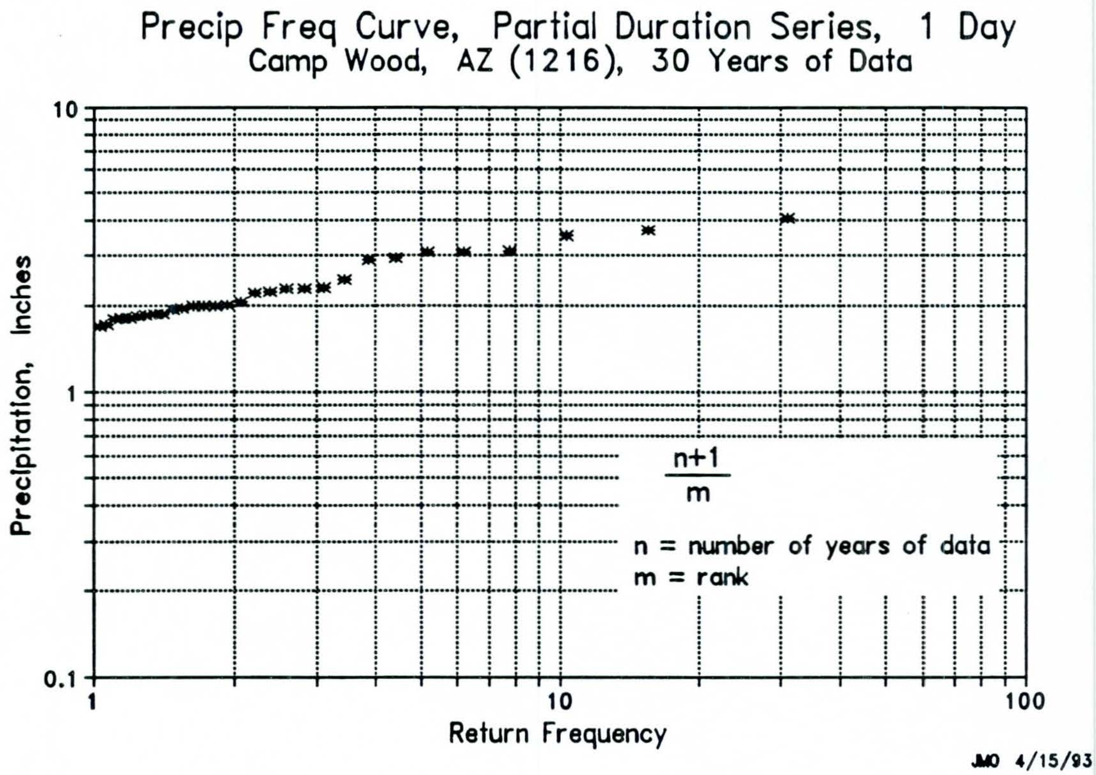

Figure 6. Precipitation Frequency Curve of 1-Day Partial Duration Series Data for Camp Wood, Arizona.

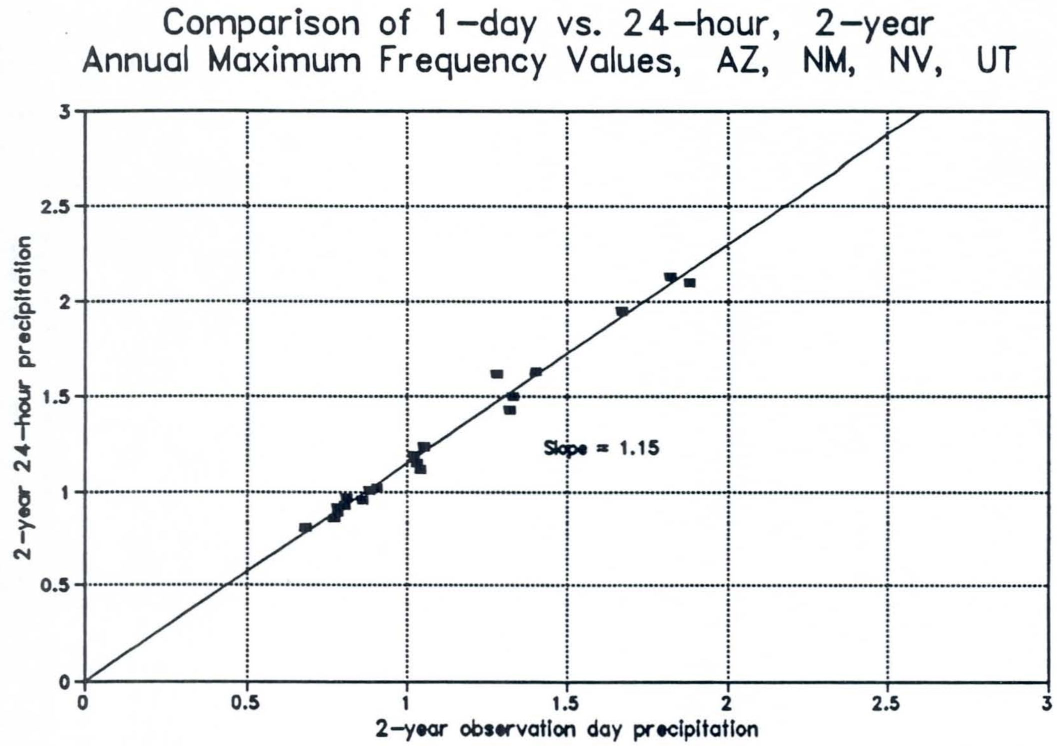

Figure 7. Comparison of 2-year daily vs. 24-hour annual maximum precipitation values.

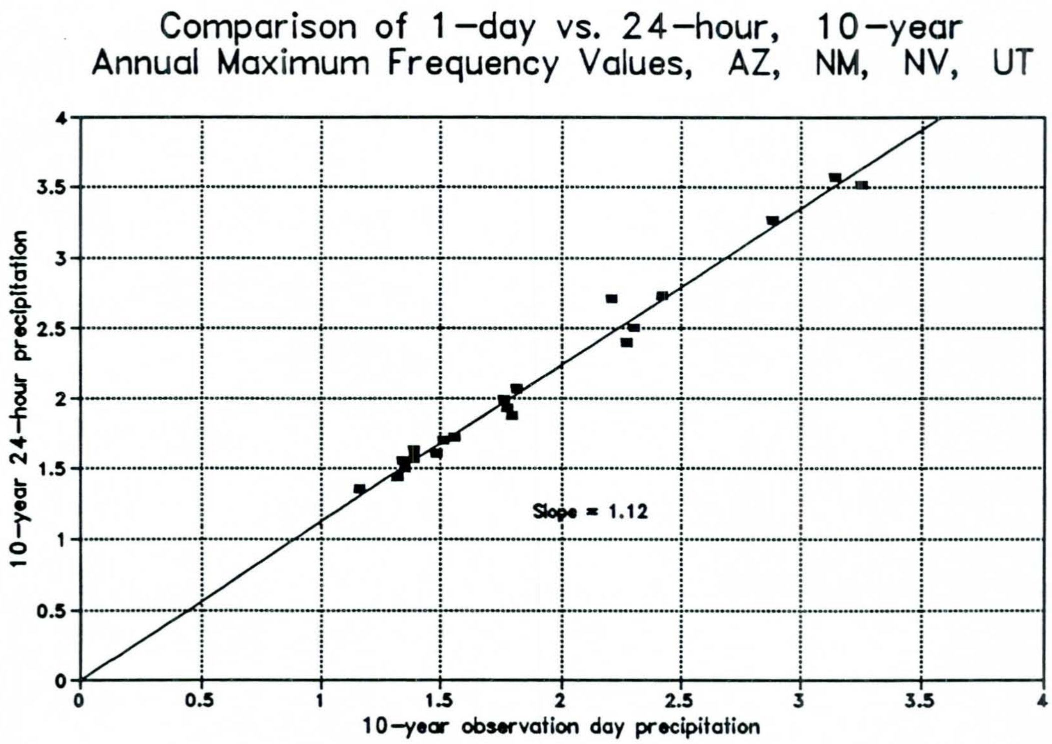

Figure 8. Comparison of 10-year daily vs. 24-hour annual maximum precipitation values.

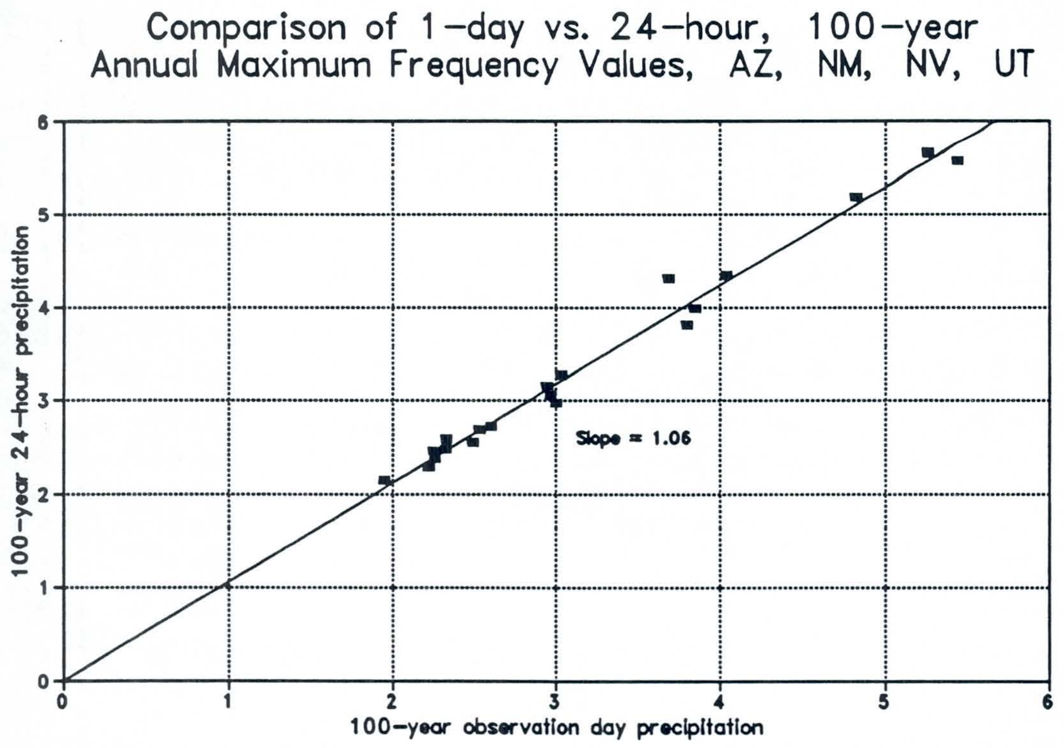

Figure 9. Comparison of 100-year daily vs. 24-hour annual maximum precipitation values.

Seasonality and Regionality

Regions.

In order to choose appropriate regions for analysis with L-moment statistics, several criteria need to be considered. Among these are: the season (or seasons) of highest precipitation, the type of precipitation (e.g., general storm, convective, monsoon, decayed tropical storms or decayed hurricanes, or a combination), the climate, the topography (especially as it interacts with the weather systems), and the homogeneity of these factors in a single area.

Seasons.

An analysis of the seasonality of each station was based on several sources: 1) Gifford et al, 1967, a report on the weekly probabilities of various precipitation amounts (.01,...,1.00,2.00 inches) for over 200 stations in the Western United States, 2) the National Weather Service (NWS) regions from the Climate Data Summaries (NOAA, 1989); and 3) histograms of the frequencies of the maximum precipitation for various durations by month. The analysis using Gifford et al, 1967 was described in the Semiarid Project Fifth Quarterly Report (10/1/92-12/31/92). The example used in that report is repeated in Figure 10, which illustrates the high precipitation in July and August in Ajo, Arizona. The second source noted is the NWS climate regions. As an illustration, the NWS Arizona climate regions are shown in Figure 11. The third method, using monthly histograms, is described below. However, a discussion of the 'naming' of the seasons precedes the details of the seasonal analysis.

A discussion of the problems of naming seasons seems appropriate. In meteorological terms we commonly define precipitation as 'summer precipitation' or 'winter precipitation" meaning of course, the type of rain or snow most commonly associated with that season. It is important to note that the various types of precipitation may occur nearly any time of year, but are usually more common in a particular season. In summer, showery precipitation, short-term and intense is prevalent. The thunderstorm exemplifies the most common summer convective precipitation. In general, winter precipitation is of the general storm type, widespread in area, and with durations of one to several days. However, the use of the words winter and summer may not suggest southwestern precipitation types. For example, the word winter may conjure up blizzards and deep snow, which may and do occur in the northern part of the southwest; but the emphasis needed here is that of the precipitation climate or precipitation regime appropriate to various areas of the southwest. Therefore, the terms, warm and cool, are used to designate the two precipitation seasons into which we have divided the subregions.

AJO, ARIZONA 20080

PRECIPITATION MEANS AND PROBABILITIES FOR 1 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	.40	2.00	4.00
MAR 01	.24	53	24	22	18	12	9	5	3	1	
MAR 08	.16	76	26	24	20	15	[illegible]	7	4	2	
MAR 15	.25	73	25	23	19	14	[illegible]	6	4	2	
MAR 22	.12	60	25	22	17	10	6	3	2	1	
MAR 29	.04	83	19	17	12	6	3	1			
APR 05	.06	80	12	10	7	4	2				
APR 12	0.00	100	7	5	3	2	1				
APR 19	.02	83	10	8	4	1					
APR 26	.05	76	12	10	6	2					
MAY 03	0.00	100	8	6	4	1					
MAY 10	.03	80	8	5	3	1					
MAY 17	.01	93	6	4	1						
MAY 24	0.00	100	4	3	1						
MAY 31	.02	86	6	4	2						
JUN 07	0.00	100	3	2	1						
JUN 14	0.00	100	4	3	2	1					
JUN 21	.05	80	11	9	6	2	1				
JUN 28	.04	76	21	18	12	6	4	1	1		
JUL 05	.19	50	33	32	25	15	10	4	2	1	
JUL 12	.30	40	51	47	38	25	17	8	4	1	
JUL 19	.39	23	64	59	49	34	25	13	7	3	
JUL 26	.56	20	72	68	58	43	38	18	10	4	
AUG 02	.61	20	72	68	60	46	35	20	12	5	
AUG 09	.52	26	68	64	55	41	32	18	10	5	
AUG 16	.44	23	65	61	52	38	28	16	9	4	
AUG 23	.52	30	58	54	45	32	23	13	8	4	
AUG 30	.18	46	45	41	32	21	14	7	4	2	
SEP 06	.18	56	34	31	24	16	11	6	4	2	
SEP 13	.32	60	30	27	22	16	12	7	5	3	
SEP 20	.11	63	29	26	20	13	8	4	2	1	
SEP 27	.13	63	29	26	20	13	8	4	2		
OCT 04	.23	70	27	25	21	14	[illegible]	5	3	1	
OCT 11	.08	76	21	19	15	10	8	3	1		
OCT 18	.06	80	19	17	13	8	5	2	1		
OCT 25	.16	70	21	19	14	9	6	3	1		
NOV 01	.04	76	24	21	15	8	5	2	1		
NOV 08	.15	63	38	26	19	[illegible]	5	2	1		
NOV 15	.12	46	36	31	22	[illegible]	5	1			
NOV 22	.12	63	38	26	18	8	4	1			
NOV 29	.07	76	24	21	16	[illegible]	6	2	1		
DEC 06	.19	66	28	25	20	13	8	4	2		
DEC 13	.12	53	35	32	25	15	9	4	2		
DEC 20	.24	50	40	36	29	18	11	4	2		
DEC 27	.18	60	34	31	25	17	11	5	2	1	
JAN 03	.16	63	33	31	25	16	10	4	2	1	
JAN 10	.22	53	38	35	29	18	11	4	1		
JAN 17	.16	60	37	34	27	17	11	4	2		
JAN 24	.21	56	35	32	25	16	10	4	2		
JAN 31	.13	60	37	33	25	15	9	3	1		
FEB 07	.18	46	38	34	25	15	9	3	1		
FEB 14	.19	53	39	34	26	16	[illegible]	4	2	1	
FEB 21	.19	46	30	27	21	13	8	3	1		

AJO, ARIZONA 20080

PRECIPITATION MEANS AND PROBABILITIES FOR 2 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.40	46	36	33	28	22	17	11	7	4	1
MAR 15	.36	43	44	41	34	25	18	10	6	3	
MAR 29	.11	66	27	24	17	10	5	2			
APR 12	.03	83	18	15	8	3	1				
APR 26	.07	73	22	19	12	5	2				
MAY 10	.03	73	14	10	5	2					
MAY 24	.03	83	11	8	3						
JUN 07	0.00	100	8	7	4	1					
JUN 21	.09	60	30	26	18	9	5	2	1		
JUL 05	.49	16	71	66	56	40	29	15	8	3	
JUL 19	.95	0	91	87	79	64	52	34	23	12	2
AUG 02	1.13	10	90	88	83	72	61	43	29	16	2
AUG 16	.96	10	81	78	71	59	49	33	23	13	2
AUG 30	.36	33	57	53	44	33	26	16	10	6	1
SEP 13	.43	43	49	45	38	28	21	13	8	5	1
SEP 27	.36	36	49	46	38	26	19	10	5	2	
OCT 11	.14	66	32	30	25	17	12	6	3	1	
OCT 25	.20	56	38	35	28	18	12	5	2	1	
NOV 08	.27	33	53	48	36	22	13	5	2		
NOV 22	.18	53	45	41	32	19	12	5	2		
DEC 06	.32	43	51	48	40	28	19	9	4	2	
DEC 20	.42	30	59	55	46	33	24	12	6	2	
JAN 03	.38	36	57	53	45	32	23	11	6	2	
JAN 17	.37	33	59	55	46	32	22	11	5	2	
JAN 31	.31	30	59	54	44	29	19	9	4	1	
FEB 14	.30	23	57	51	41	27	19	9	5	2	

AJO, ARIZONA 20080

PRECIPITATION MEANS AND PROBABILITIES FOR 3 WEEK PERIODS

PERIOD BEGINS	MEAN PCPN	PROB 0-T	PROBABILITY (PERCENT) OF RECEIVING AT LEAST THE FOLLOWING AMOUNTS (IN) OF PRECIPITATION 0.06	0.10	0.20	0.40	0.60	1.00	1.40	2.00	4.00
MAR 01	.64	40	49	46	40	31	25	17	12	7	1
MAR 22	.22	36	46	41	32	20	13	6	3	1	
APR 12	.07	63	30	25	15	5	2				
MAY 03	.05	70	23	18	11	4	2				
MAY 24	.03	83	15	11	5						
JUN 14	.09	56	34	29	20	11	6	2	1		
JUL 05	.88	6	89	86	77	62	49	32	21	11	2
JUL 26	1.69	0	97	96	93	85	77	60	46	30	6
AUG 16	1.15	6	88	85	79	68	59	43	31	19	4
SEP 06	.61	26	61	57	49	39	31	21	14	9	2
SEP 27	.48	30	60	56	47	34	26	14	8	4	
OCT 18	.26	50	47	43	35	25	17	9	5	2	
NOV 08	.38	30	61	56	45	30	20	9	4	1	
NOV 29	.38	28	64	60	50	36	26	13	7	3	
DEC 20	.58	23	70	67	59	45	35	20	11	5	
JAN 10	.59	23	73	69	61	46	35	19	10	4	
JAN 31	.50	20	73	68	57	41	30	17	10	4	

Figure 10. Analysis from Gifford et al, 1967, illustrating the high precipitation in July and August at Ajo, Arizona.

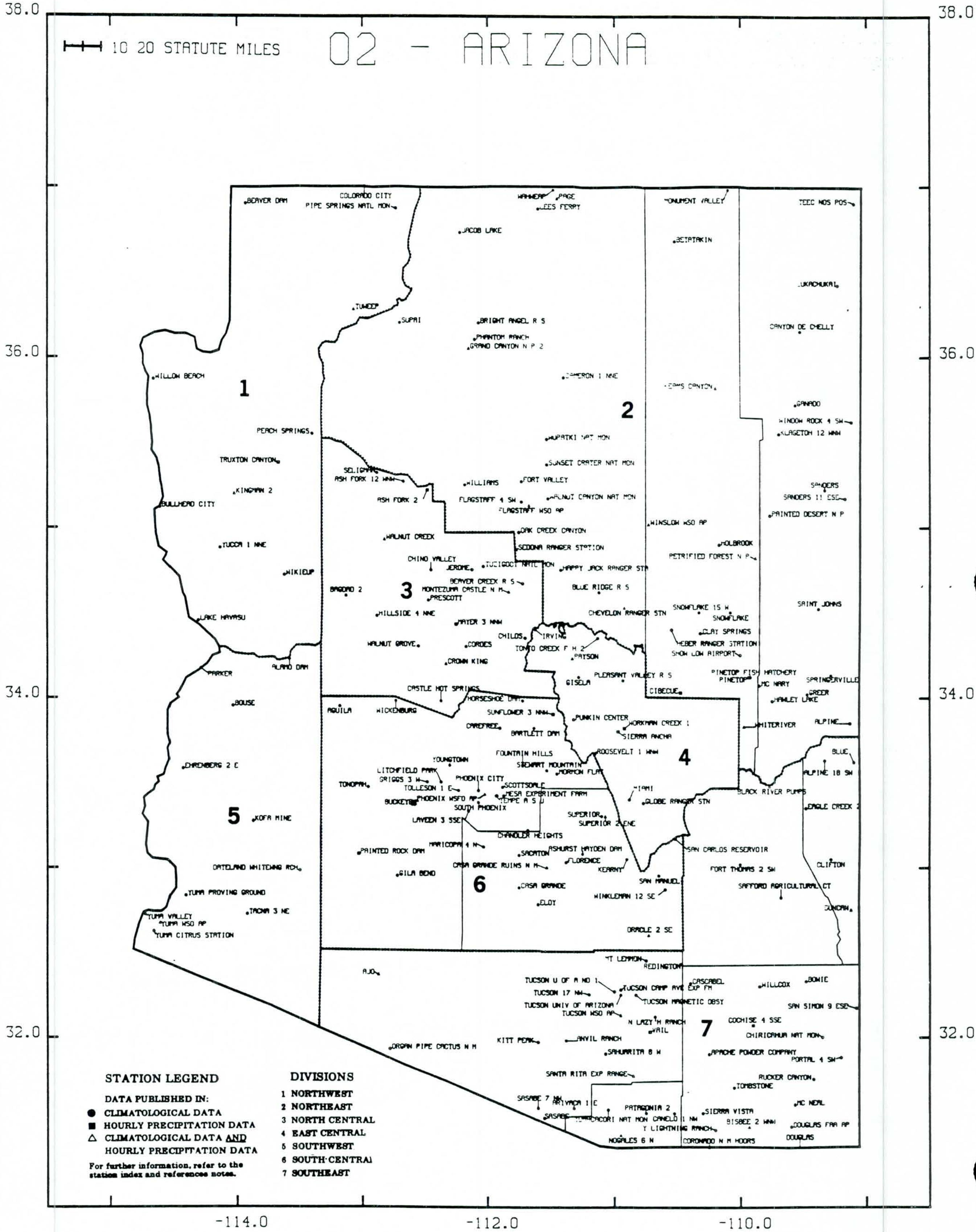

Figure 11. NWS climate regions from Climate Data Summaries (NOAA, 1989).

The stations used to develop seasonal histograms are shown in the map in Figure 12. The map in Figure 13 shows the initial 14 regions defined within the bounds of the four core states and southeastern California. The dates of the two seasons for each region are outlined within each area on the map. In Figure 14 the regions are grouped with regard to the season of maximum precipitation. After determining the maximum season, the next consideration was to separate a secondary maximum into the 'other' season. Therefore, months of few or no extremes are scarcely considered and can be included in either of the two seasons. However, dry months can be used to separate cool and warm regimes. Although each region has been divided into only two seasons, warm and cool; the bounds of warm and cool are different in different regions. They vary from warm = May-October (5-10) and cool = November-April (11-4), to warm = August-September (7-9) and cool = October-June (10-6). Also, the length of a season may vary from a minimum of three months to its complement, a maximum of nine months. Note also, that there are two cool seasons, 'winter' and 'spring'. To clarify, spring precipitation in the southwest is most commonly of a general storm type, similar to cool weather precipitation. Therefore, in regions 2 and 4, with spring maximums, the cool seasons run from October to May or June and include the spring months. On the other hand, convective summertime (warm) type precipitation may run into the fall. In this situation, we have included the fall months with summer. Thus far, a primary maximum has not been found in the fall. To illustrate the seasonal precipitation distribution, Figures 15, 16, 17, and 18 show representative histograms for the seasons.

Cool (winter). The histogram for Bishop WSO AP, California (Figure 15) shows the prevalence of extreme precipitation in the cool season (October-February), with relatively little activity in the other months of the year.

Cool (spring). A spring maximum in region 2 is illustrated with the Owyhee, Nevada histogram (Figure 16) with a warm season (July-September) and a cool one (October-June). The transition from winter to spring precipitation maximums is gradual and 'moves' eastward from northern California across Nevada, with an increase toward spring the farther east one goes.

Warm (summer). Two different warm maximum regimes are illustrated with Tuweep, Arizona in region 8 (Figure 17), and Albuquerque, New Mexico in region 13 (Figures 18). Although both stations have most of their extremes in July and August, Tuweep has some extremes throughout the year, including in winter. On the other hand, Albuquerque's precipitation extends later into the fall and has almost no extremes in the winter (November-March). Note October, particularly: Albuquerque has an October frequency nearly equal to the highest months of July and August; Tuweep has almost no October occurrences.

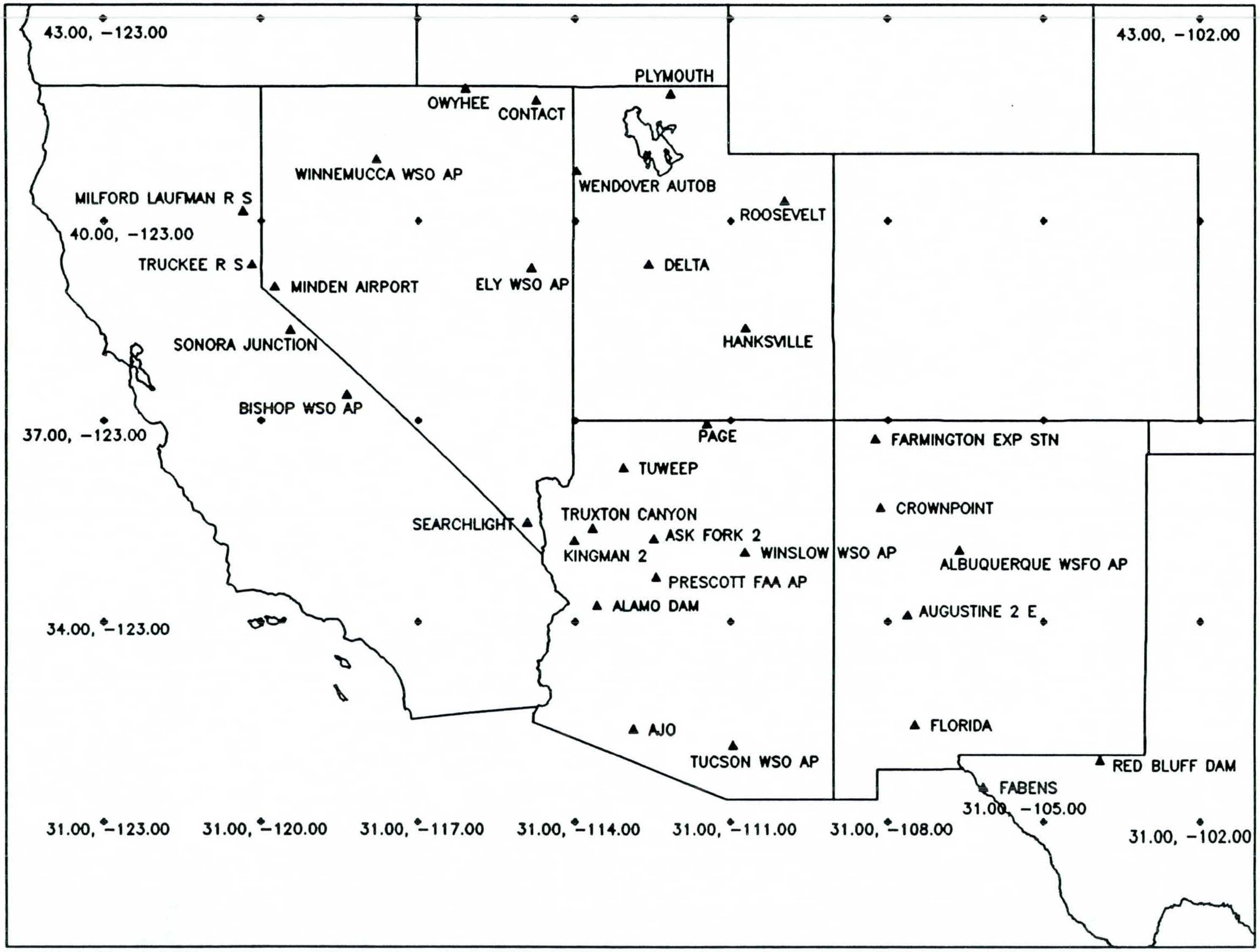

Figure 12. Stations used to develop seasonal histograms.

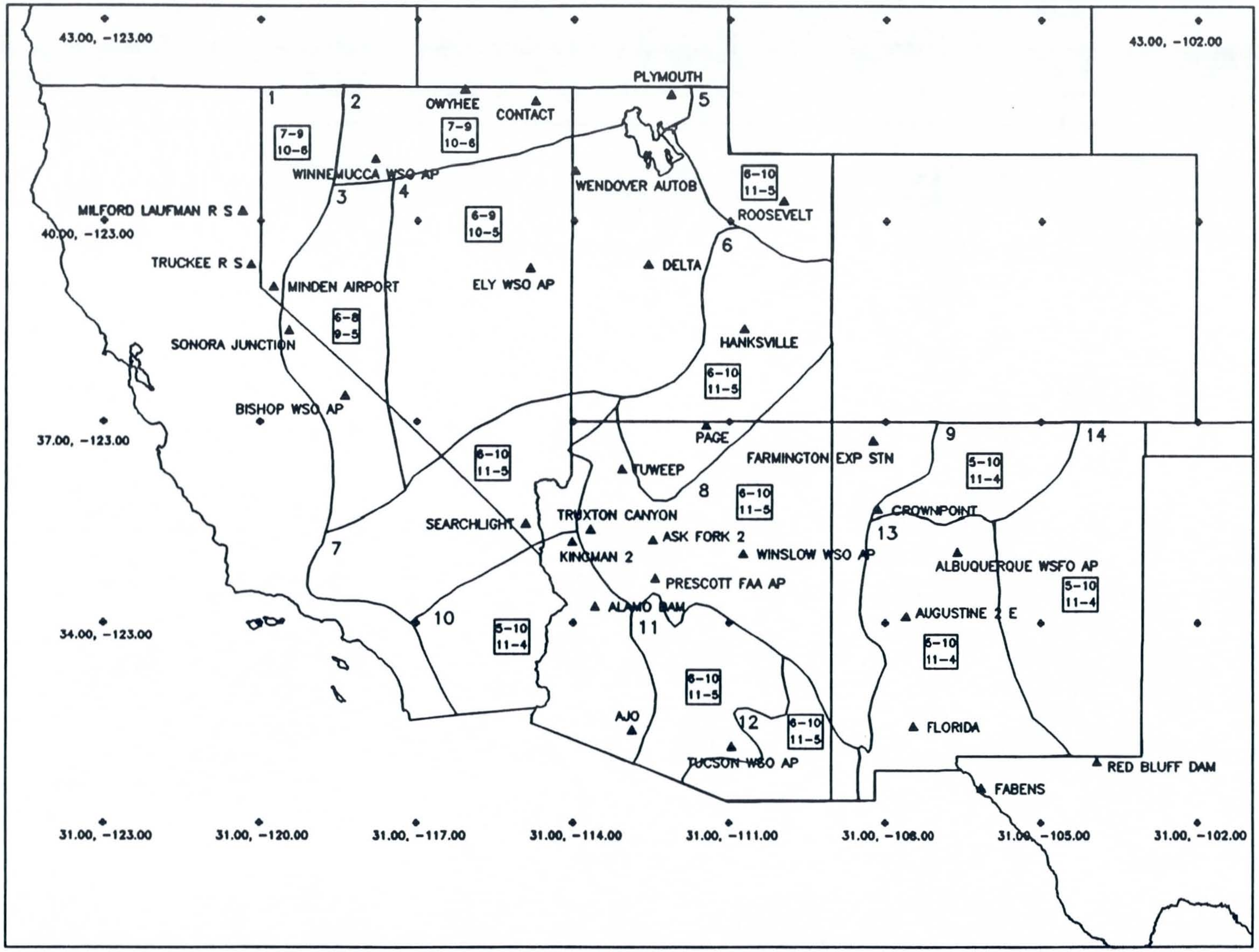

Figure 13. Climatic regions of the Southwestern United States, Preliminary 6/30/93.

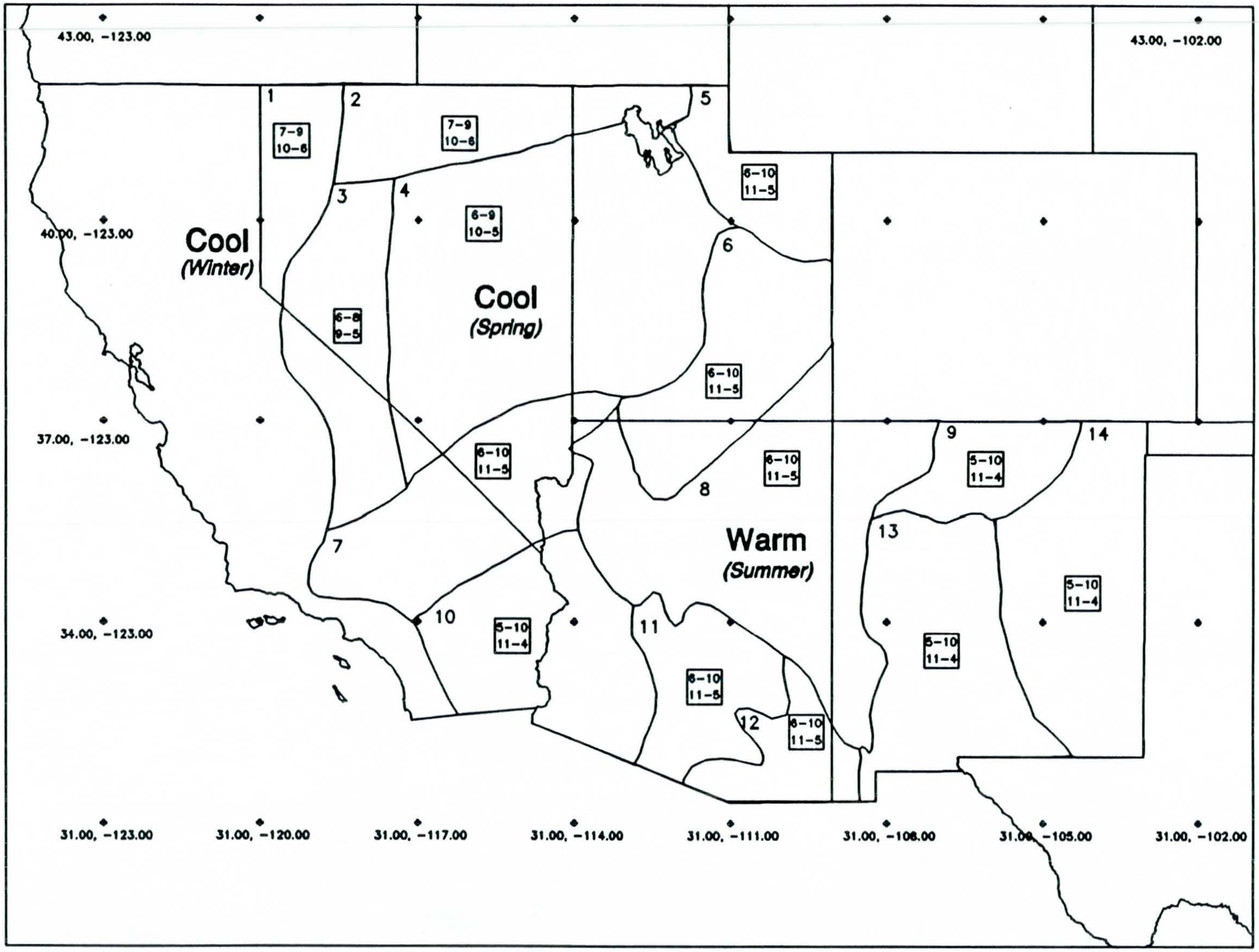

Figure 14. Seasons of Maximum Precipitation, Preliminary 6/30/93.

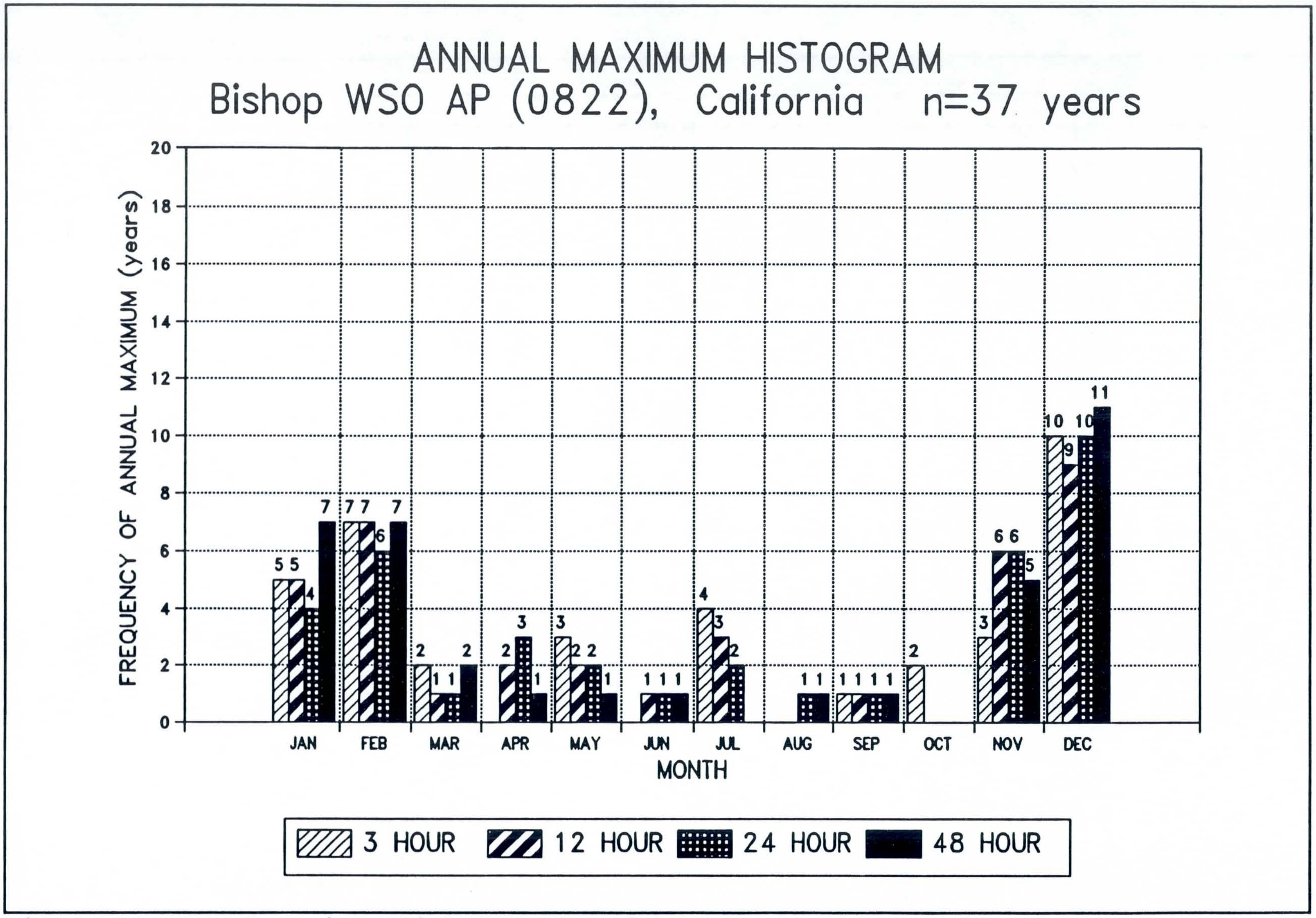

Figure 15. Annual Maximum Histogram for Bishop WSO AP, CA.

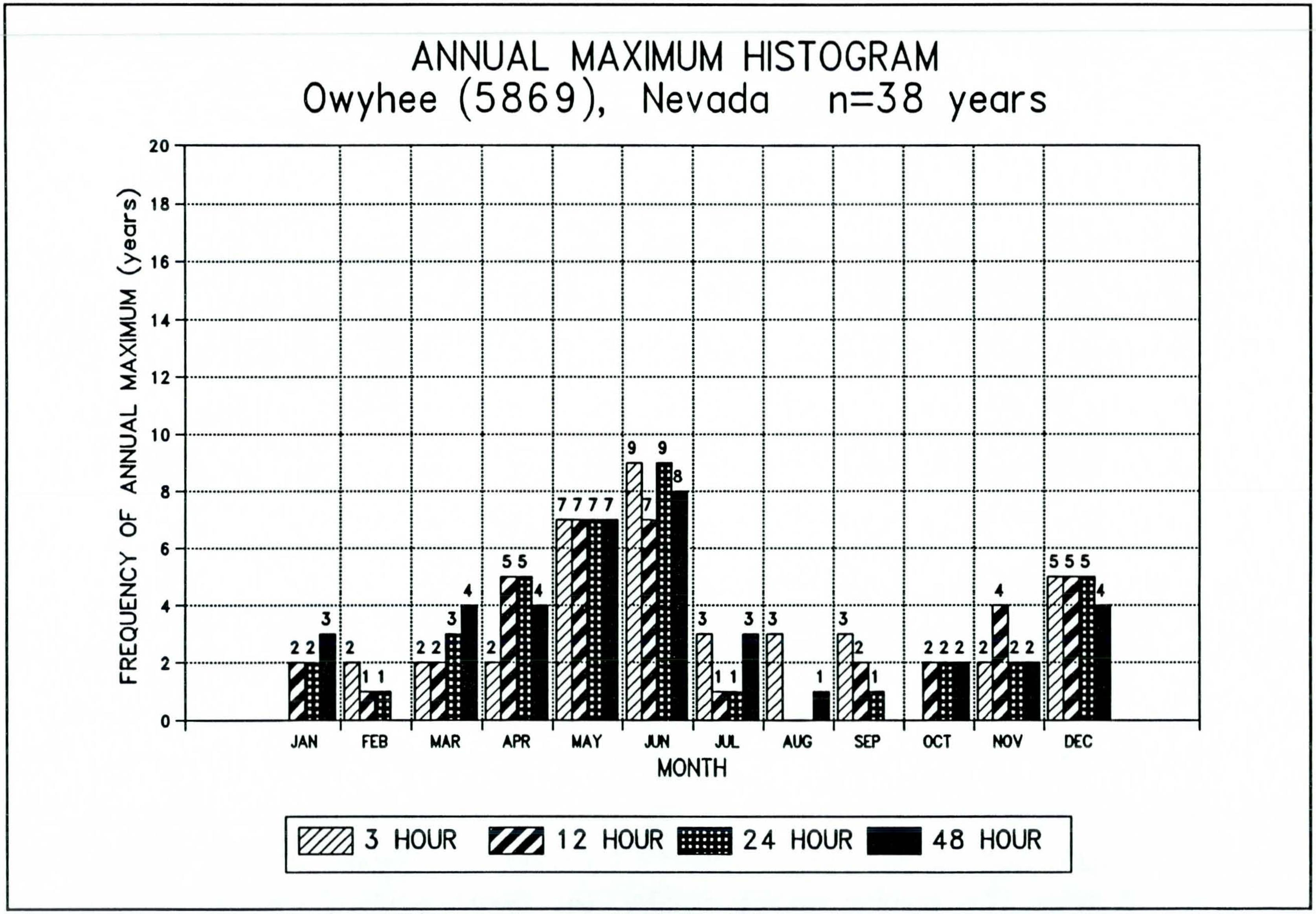

Figure 16. Annual Maximum Histogram for Owyhee, NV.

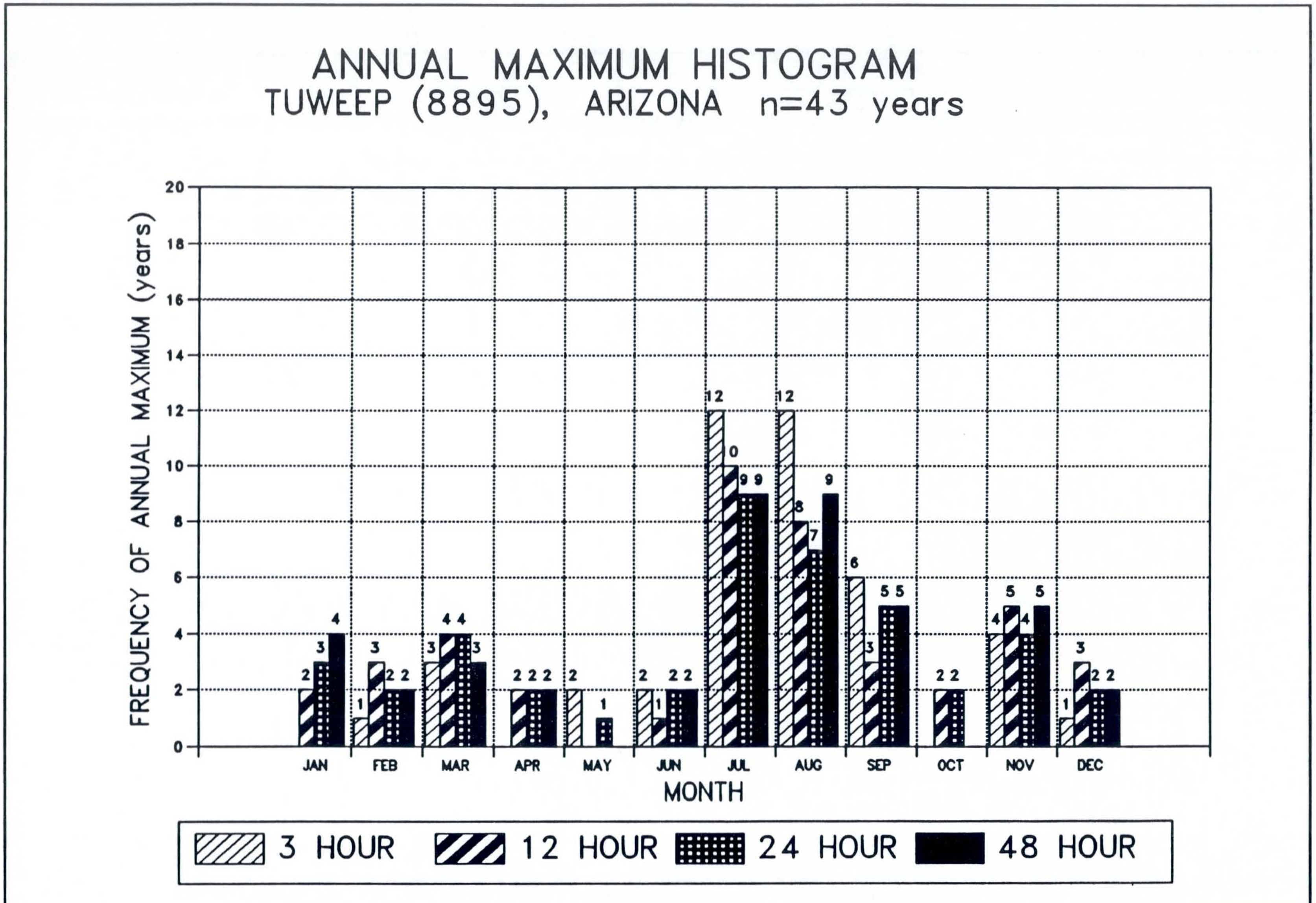

Figure 17. Annual Maximum Histgram for Tuweep, AZ.

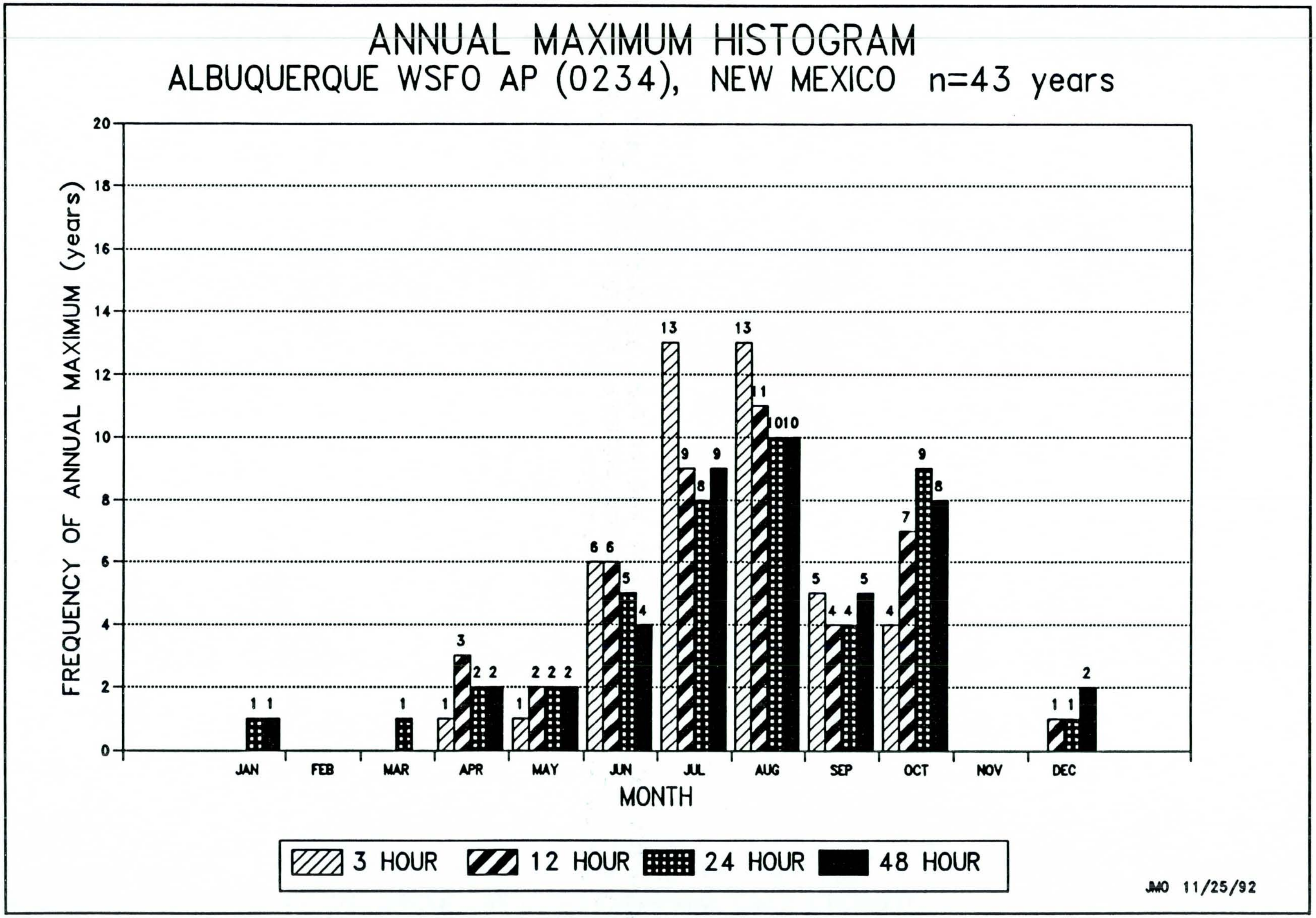

Figure 18. Annual Maximum Histogram for Albuquerque, NM.

October. In general, October has proved to be extremely difficult to categorize in several regions of the southwest. It is not only transitional between summer and winter; it is possible, even likely, to have several varieties of precipitation - warm convection, monsoon, decaying tropical storm, general storm, or a combination of these at a single station. On the other hand, October may be routinely a dry month, as at Tuweep (Figure 17).

Other regional factors.

After determining two seasons for each station, the stations were grouped on the basis of seasons and physiography, using a satellite map of the United States (Thelin and Pike, 1991). Consideration was given to barriers, synoptic climatology, homogeneity, precipitation climatology, among other parameters. It must be emphasized that these are 'first trial' regions, to be confirmed by the L-moment analysis, or to be brought into question, and final regions to be determined through an iterative analytic process.

Storm Analysis

Depth-area duration.

Area-depth and depth-duration curves are an integral part of storm analysis. Data from major storms in the Semiarid Southwest will be used to develop these curves. The various software components are being developed using the GRASS GIS system on a workstation environment. The process includes data extraction from a digital database and pairing the daily stations with an hourly station to establish a mass curve for the storm duration. The mass curve software is complete, and a sample set of curves is shown in Figure 19 for a southern California storm on January 20 through 24, 1943. The hourly station for this set of stations is Glenville, and the two daily stations that are timed are Glenville (near) and Kernville. The data are verified to determine whether the assigned daily and hourly stations are compatible. If there is a problem a new hourly station is sought for the daily station or a composite of several hourly stations is used to define an hourly station that best fits the daily values. A spreadsheet is being used as the base software for this work.

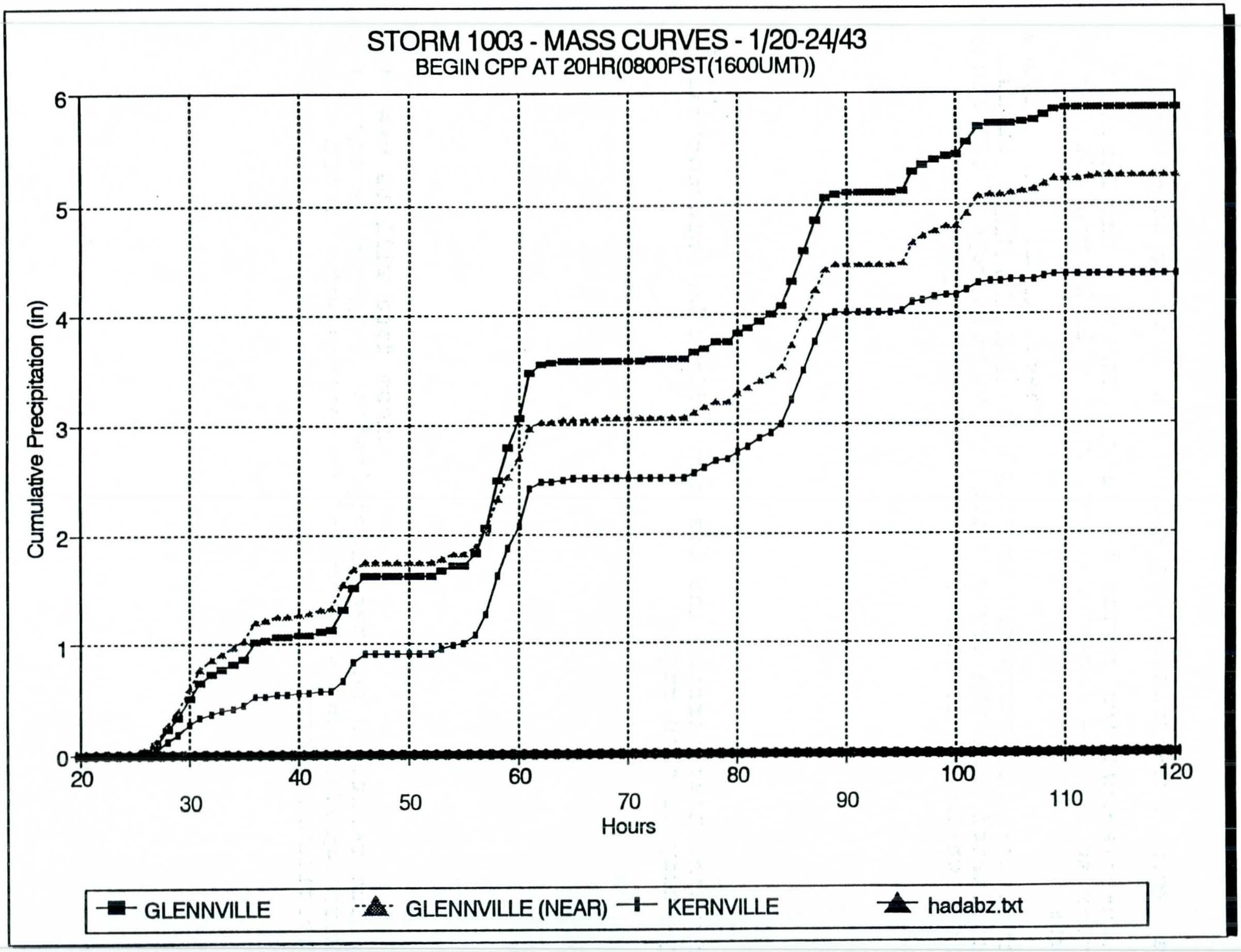

Figure 19. Set of mass curves for a southern California storm from January 20 through 24, 1943.

After the mass curves are defined, ratios between the observed values and the NOAA Atlas 2 (Miller et al, 1973) 100-year return values are calculated. These percents are plotted and an isopercental analysis is made with these data. The isopercental map is then transformed into an isohyetal analysis. From this analysis, depth-area-duration curves are developed. Currently, the depth-area-duration curve software is being developed.

Depth-area-duration curves for major storms in the Semiarid Southwest will be developed, and these will be provided to the users. Users will then be able to define the volume of precipitation within major storms. These curves will replace the curves that are currently provided in NOAA Atlas 2. It is anticipated that the curves will extend well beyond 400 square-miles, which is all that is available in NOAA Atlas 2.

Elevation data.

Rugged terrain covers much of the Semiarid Southwest. Such terrain often augments precipitation on the windward side, and causes lower moisture conditions on the leeward side. Thus, the intensities of the return frequencies in such regions can be directly affected by elevations, aspects, and slopes. It is important that terrain and its many effect be incorporated into any study of this region. Digital terrain elevation data have been obtained from the Defense Mapping Agency on a CDRom in binary format. These data are being extracted in meters with a resolution of 3 arc/sec or roughly a data point every 90 meters, and are being stored in units of 1 degree by 1 degree. Software has been developed to convert from binary to ASCII format, which places the data in a 1201 x 1201 matrix of points. The data are then imported into the GRASS GIS system for further use.

Future work will experiment with the spacing necessary for resolving the elevation data for use in the mapping of precipitation intensities. Also, these data will be used to develop relations so that precipitation intensities for different return periods can be estimated in regions with little or no precipitation data. Elevation, slope, and aspect will be important inputs into these analyses and the GRASS GIS system will be used to examine possible relations among precipitation, aspect, slope, and elevation. Other parameters, such as the distance from moisture sources will also be considered.

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Thelin, Gail P. and Richard J. Pike, 1991: Landforms of the conterminous United States, a digital shaded-relief portrayal, Miscel. Investigation Series, Map I-2206, USGS, Reston, Virginia.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

October 28, 1993 W/OH11:LFT

MEMORANDUM FOR: Southwest Semi-Arid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Eighth Quarterly Report - Semi-Arid Precipitation Frequency Project, July 1 - September 30, 1993

Enclosed is a copy of the Eighth Quarterly Progress Report for the Semi-Arid Precipitation Frequency Project for the southwestern United States. This update contains an L-moment analysis of the initial 14 regions, which were defined in the Seventh Quarterly Report. In addition, the regions have been extended to include border areas, resulting in 19 regions. After evaluation of the revised regions, the return frequency analysis will be run on the entire study area.

Also included are two corrected pages for the Seventh Quarterly Report to replace Figure 8 (wrong figure) and Figure 14 (incomplete).

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

Enclosures

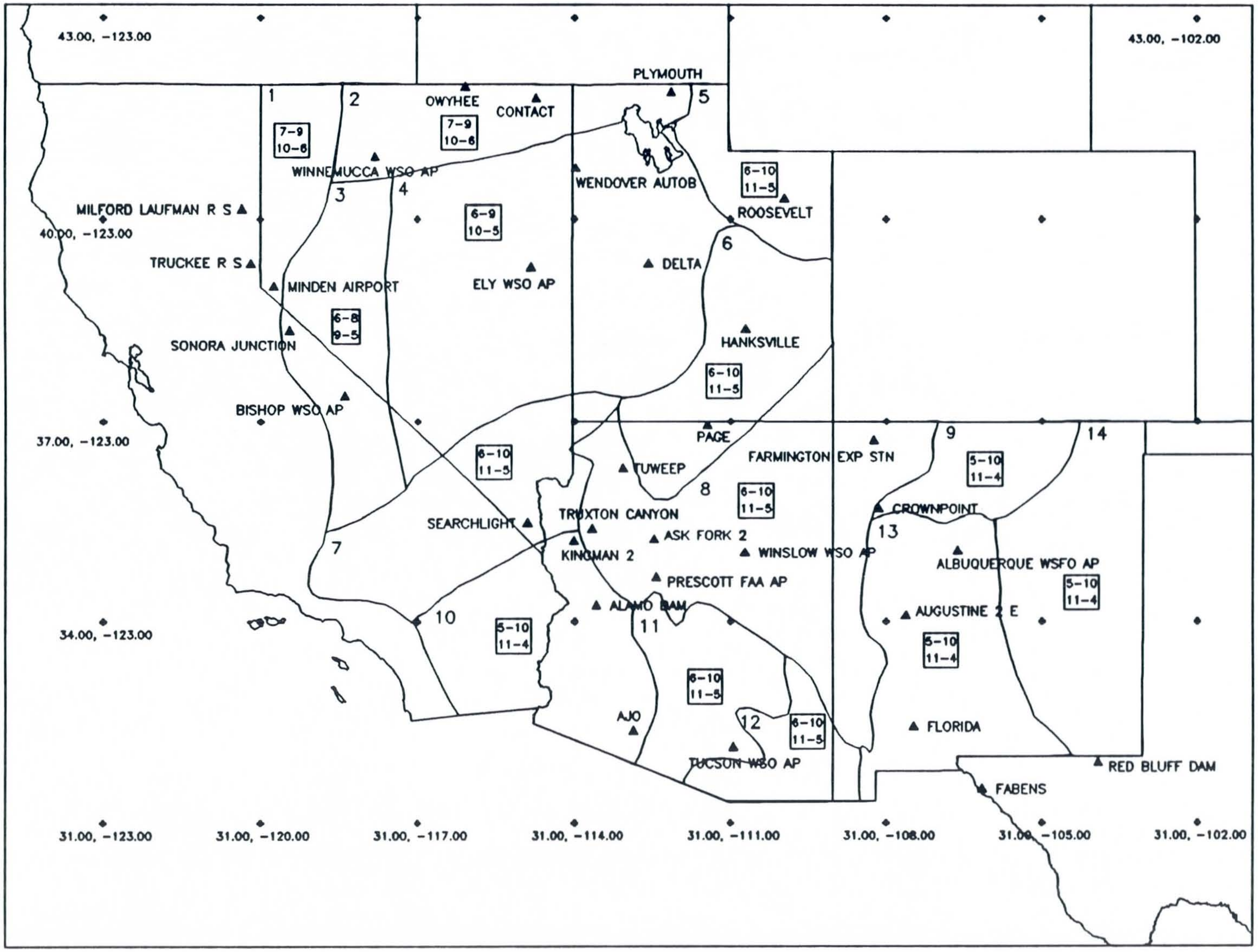

Figure 13. Climatic regions of the Southwestern United States, Preliminary 6/30/93.

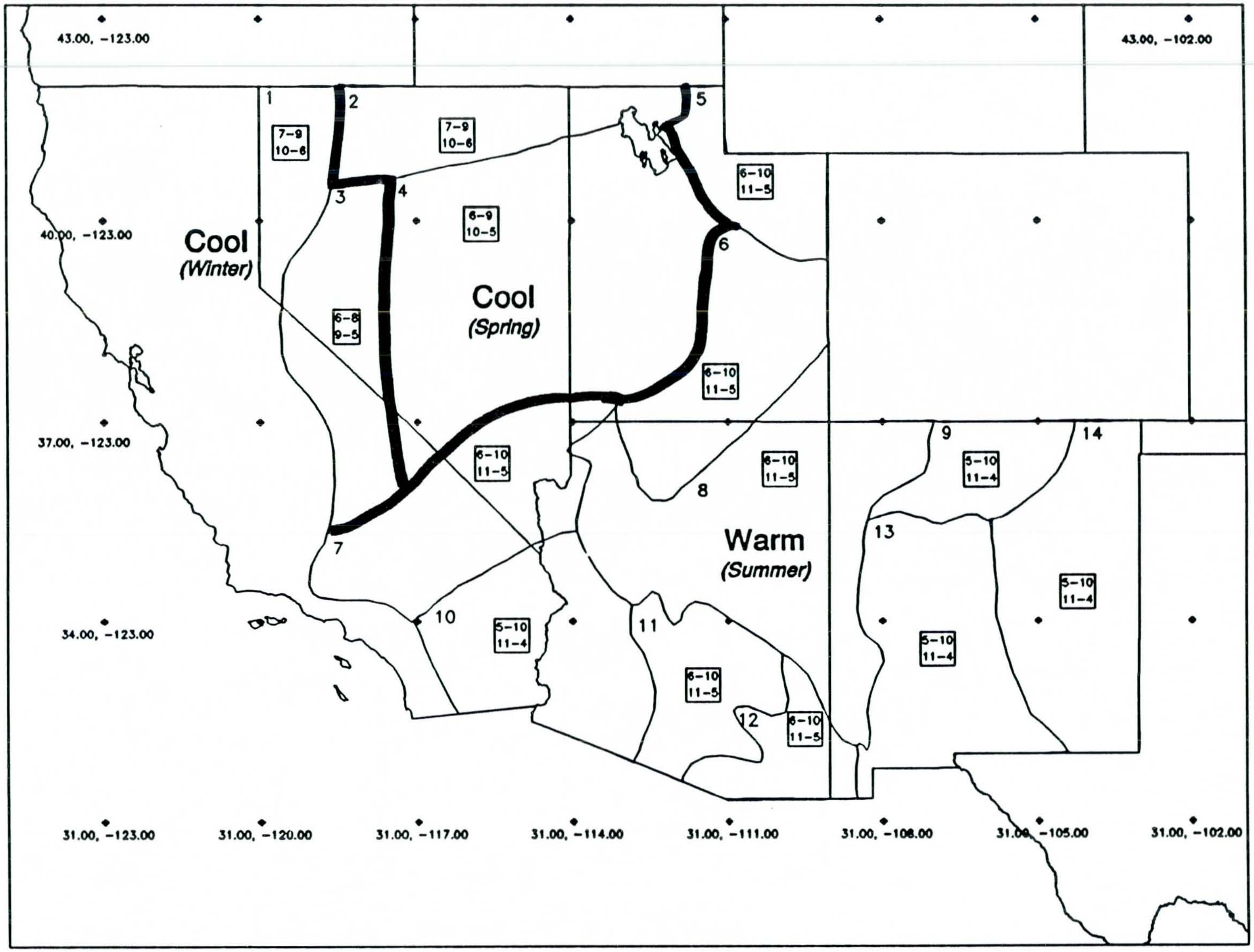

Figure 14. Seasons of Maximum Precipitation, Preliminary 6/30/93.

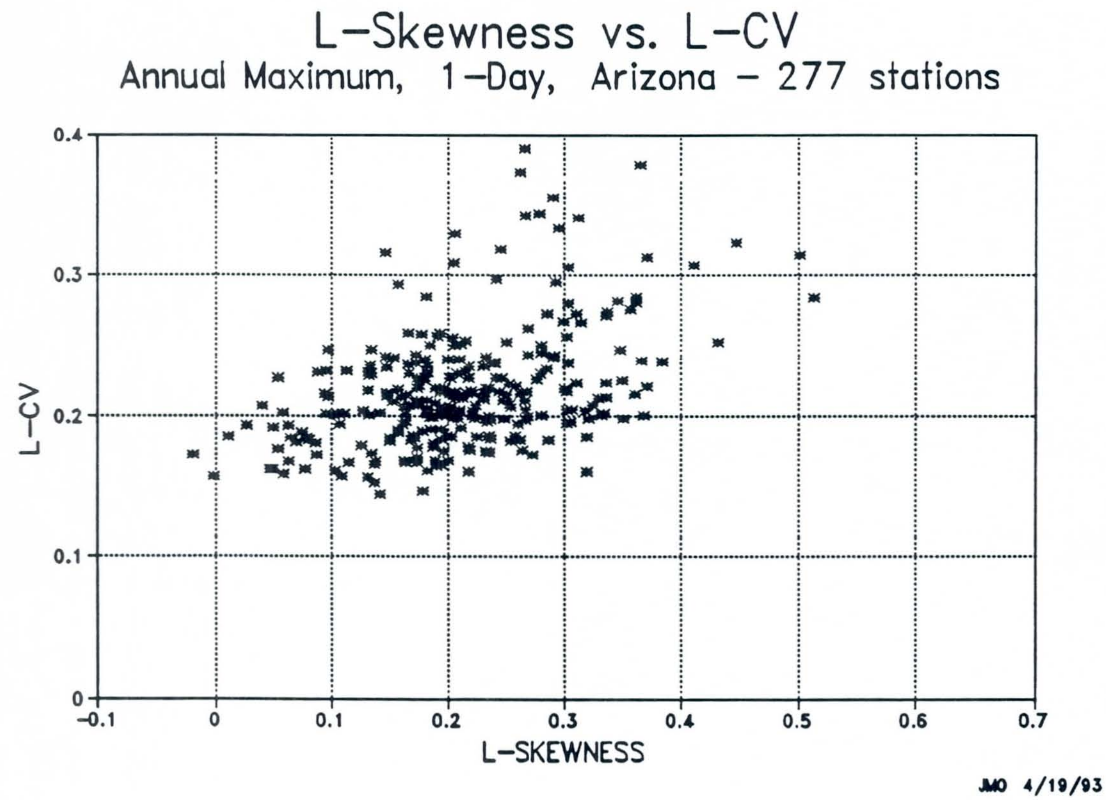

Figure 3. L-Skewness vs. L-CV of Annual Maximum Daily Data in Arizona.

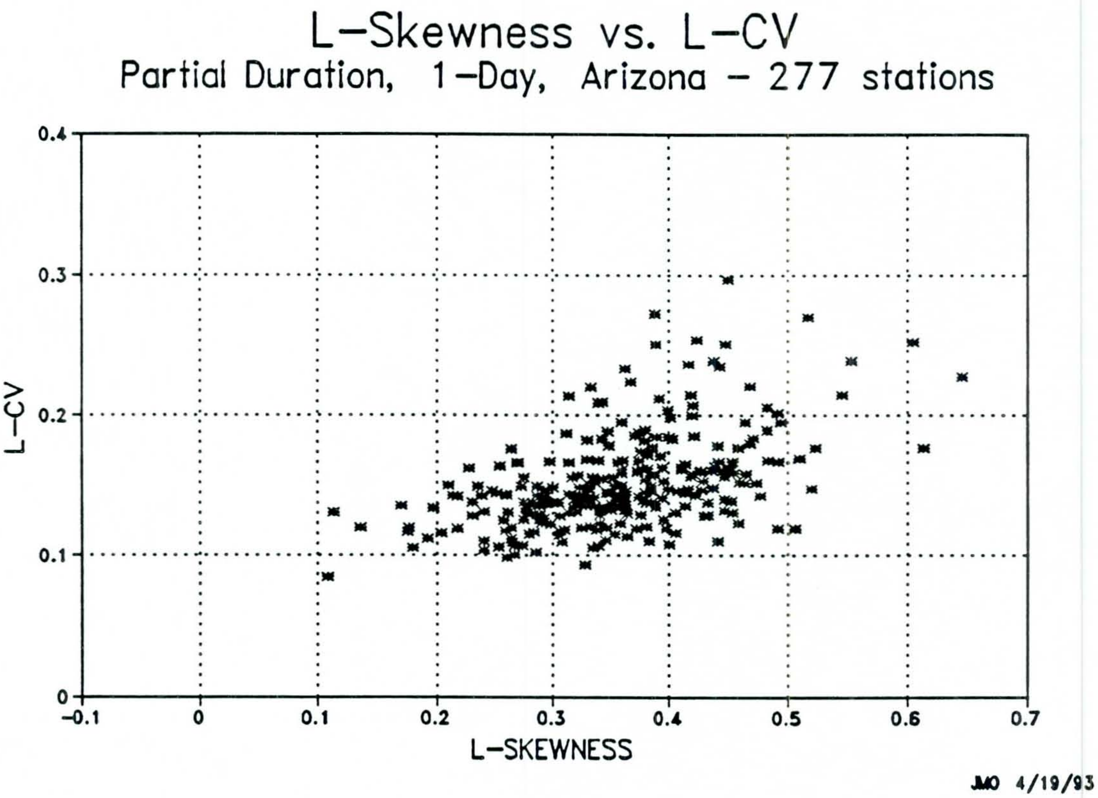

Figure 4. L-Skewness vs. L-CV of Partial Duration Series Daily Data in Arizona.

SEMIARID PRECIPITATION FREQUENCY STUDY

Eighth Quarterly Progress Report
for the period from
June 1 through September 30, 1993

Lesley F. Tarleton, Julie M. Olson,
Edwin H. Chin, and John L. Vogel

Office of Hydrology
National Weather Service
Silver Spring, Maryland
October 1993

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SEMIARID PRECIPITATION FREQUENCY STUDY

Eighth Quarterly Progress Report
for the period from
July 1 through September 30, 1993

OVERVIEW

This Eighth Quarterly Report summarizes the work for the Semiarid Precipitation Frequency Project for the period July 1 through September 30, 1993. In particular, the L-moment analysis of regions which were defined in the Seventh Quarterly Report (QR7) provides the largest part of the report. The initial 14 regions have been subjected to Discordancy (D), Heterogeneity (H), and Goodness-of-Fit tests, according to L-moment procedures described by Hosking and Wallis (1991). Furthermore, the study area regions have been expanded to include border areas, extending the number of regions to 19. The criteria for choosing regional boundaries included, among others, the types of storms that cause extreme precipitation in the region, the topography, and the season of maximum precipitation. A brief review of seasonality and regionalization of the study area, including definitions and use of L-moment tests, is included in the report.

On September 9, 1993, Lesley Tarleton, National Weather Service, Office of Hydrology, made a semiannual report on the Semiarid Project at the Arizona Department of Transportation, Phoenix, Arizona. The agenda and list of participants is given in Appendix A and B.

DATA

Hourly and Daily Datasets

Database.

Table 1 shows the numbers of daily and hourly stations for each state in the current database. These stations, which have been subjected to a variety of quality control procedures, have at least 15 years of record for hourly stations, and at least 19 years of data for daily stations. Southeastern California is in the core study area, while other California stations are included as part of the border. The border states include one degree of latitude (60 nautical miles) of the surrounding states of Oregon, Idaho, Wyoming, Colorado, and Texas.

Table 1.

	Daily	Hourly
Arizona	277	42
Nevada	102	41
New Mexico	271	81
Utah	185	44
California[1]	324	185
Border States	148	59
Totals	1307	452

[1]Note: California includes SE California and the part of California bordering the core area, including many stations in the Los Angeles area.

SEASONALITY AND REGIONALITY

Regions

In order to choose appropriate regions for analysis with L-moment statistics, several criteria were considered. Among these were: the season (or seasons) of highest precipitation, precipitation type (e.g., general storm, convection, monsoon, decayed tropical storms or decayed hurricanes, or a combination), climate, topography (especially as it interacts with the weather systems), and the homogeneity of these factors in a single area.

Seasons

As described in earlier quarterly reports (QR5 & QR7), analysis of the seasonality of each station was based on several sources: 1) Gifford et al.(1967), a report on weekly probabilities of various precipitation amounts (.01,...,1.00,2.00 inches) for over 200 stations in the Western United States; 2) the National Weather Service (NWS) regions from Climate Data Summaries (NOAA, 1989); 3) Hirschboeck (1991), a U.S. Geological Survey study on moisture sources and transfer; 4) Thelin and Pike (1991), a digital shaded-relief map of the United States; and 5) histograms of the frequencies of the maximum precipitation for various durations by month, among others.

As this report emphasizes further analysis of the regions, the discussion of the 'naming' of the seasons (Semiarid Project Seventh Quarterly Report (4/1/93-6/31/93)) is repeated here. In meteorological terms we commonly define precipitation as 'summer precipitation' or 'winter precipitation" meaning of course, the type of rain or snow most commonly associated with that season. It is important to note that the various types of precipitation may occur nearly any time of year, but are usually more common in a particular season. In summer, showery precipitation, short-term and intense, is prevalent. The thunderstorm exemplifies the most common summer convective precipitation. In general, winter precipitation is the general storm type, widespread in area, and with durations of one to several days. However, the use of the words winter and summer may not suggest southwestern precipitation types. For example, the word winter may conjure up blizzards and deep snow, which may and do occur in the northern part of the southwest; but the emphasis needed here is that of the precipitation climate or precipitation regime appropriate to various areas of the southwest. Therefore, the terms, warm and cool, are used to designate the two precipitation seasons into which we have divided the subregions.

The map in Figure 1 shows the initial 14 regions defined within the bounds of the four core states and southeastern California. Seasonal histograms from over 30 stations noted on the map were used to help define precipitation seasons and determine regional boundaries. The dates of two precipitation seasons for each region are outlined within each area on the map. Although each region has been divided into only two seasons, warm and cool; the bounds of warm and cool vary among regions. They differ from warm = May-October (5-10) and cool = November-April (11-4), to warm = August-September (7-9) and cool = October-June (10-6). Also, the length of a season may vary from a minimum of three months to its complement, a maximum of nine months. Note also, that there are two cool seasons, 'winter' and 'spring' (Figure 2). To clarify, spring precipitation in the southwest is most commonly of a general storm type, similar to winter weather

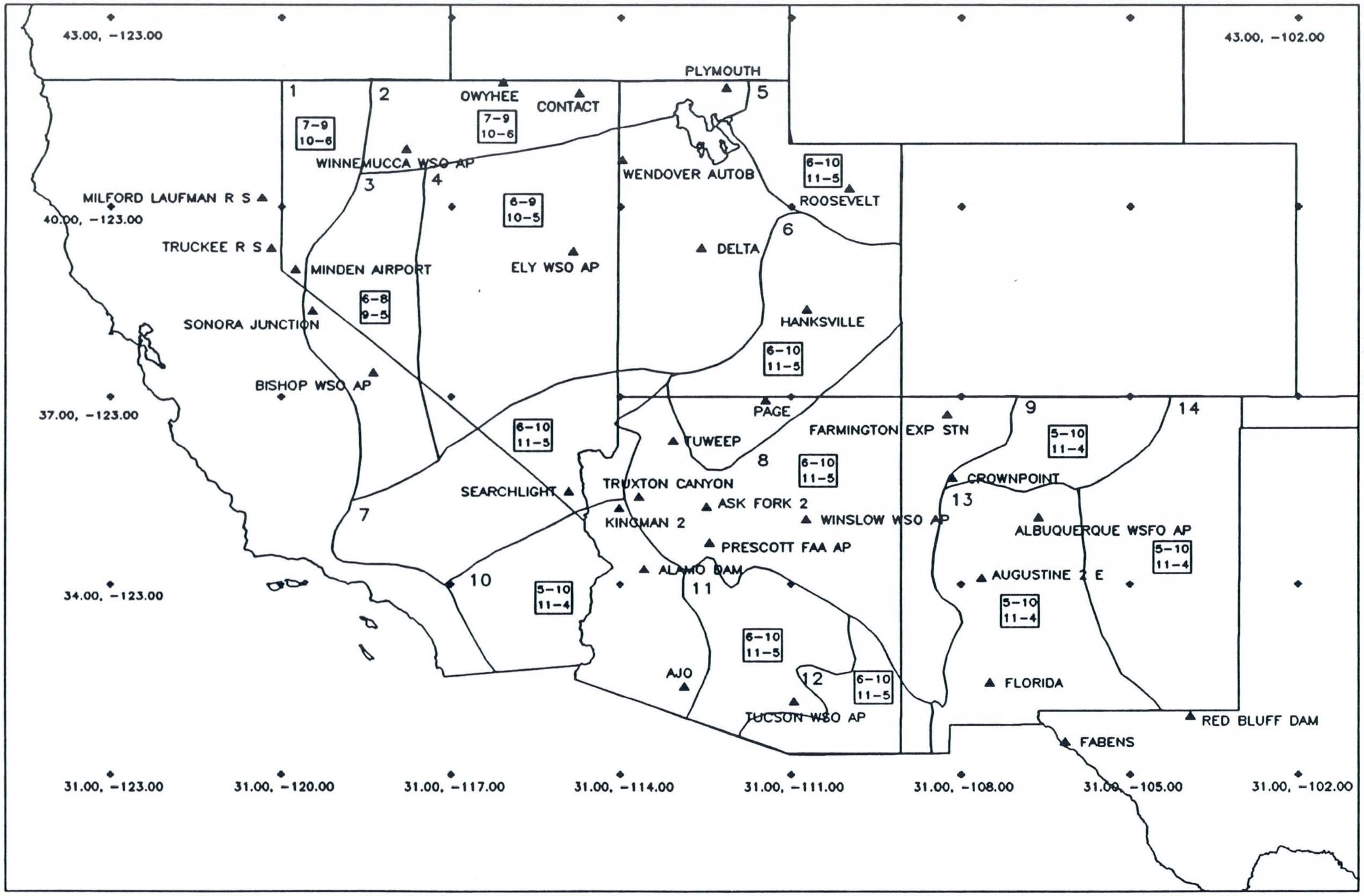

Figure 1. Climatic regions of the southwestern United States, Preliminary 6/30/93.

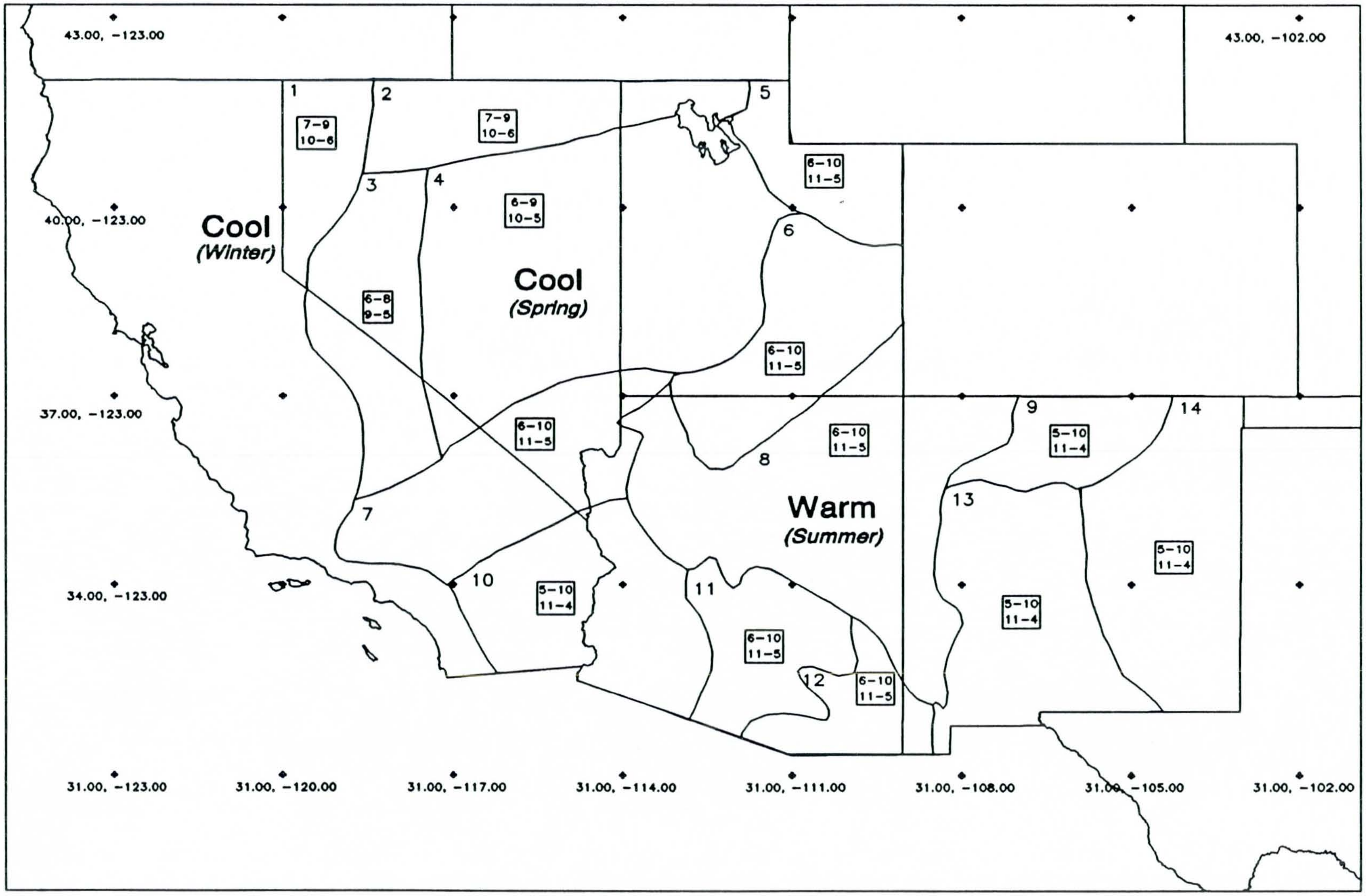

Figure 2. Seasons of maximum precipitation, Preliminary 6/30/93.

precipitation. Therefore, in regions 2 and 4, with spring maximums, the cool seasons run from October to May or June and include the spring months. On the other hand, convective summertime (warm) type precipitation may run into the fall. In this situation, we have included the fall months with summer. Thus far, a primary maximum has not been found in the fall. The seasons are summarized as follows:

Cool (winter).
In regions designated Cool (winter), extreme precipitation is prevalent in winter months, November-February, with relatively little activity in the other months of the year.

Cool (spring).
A Cool (spring) designation indicates a spring maximum, March or April to possibly as late as June, with a secondary precipitation season in the warm season, usually July to September. The transition from winter to spring precipitation maximums is gradual and 'moves' eastward from northern California across Nevada, with an increase toward spring maximums the farther east one goes.

Warm (summer).
In the Warm (summer) category, at least two different types of warm maximum regimes occur. Tuweep, Arizona in region 8 and Albuquerque, New Mexico in region 13 are examples of the two types. Although both stations have most of their extremes in July and August, Tuweep has some extremes throughout the year, including winter. On the other hand, Albuquerque's precipitation extends later into the fall and has almost no extremes in the winter (November-March). October is particularly interesting: Albuquerque has an October frequency nearly equal to the highest months of July and August; Tuweep has almost no October occurrences.

October.
In general, October has proved to be extremely difficult to categorize in several regions of the southwest. It is not only transitional between summer and winter; it is possible, even likely, to have several varieties of precipitation - warm convection, monsoon, decaying tropical storm, general storm, or a combination of these at a single station. On the other hand, October may be routinely a dry month, as at Tuweep.

ANALYSIS

Regional Update

Using the same criteria, the initial regions defined in QR7 have been expanded to include the border states, resulting in 19 regions, as shown in Figure 3. The primary precipitation seasons - winter, spring, and summer - are also noted on the map. L-moment analysis is underway on the revised regions. The updated regionalization and hourly stations and daily stations are shown in Figures 4 and 5, respectively.

L-moment Analysis

The main purpose of the L-moment analysis at this stage is to determine the homogeneity of the regions, and to make any necessary adjustments to improve a region's homogeneity. L-moment definitions and tests for Discordancy (D), Heterogeneity (H), and Goodness-of-fit are given in Appendix C.

L-moment analyses for the initial 14 regions for hourly stations have been run and a tabulation is given for annual maximum series (AMX) in Appendix D and for partial duration series (PD) in Appendix E. The regionalized daily data have also been analyzed, using the same L-moment statistical software. Discussion will center on the analysis of the initial regions. Test results for Discordancy, Heterogeneity, and Goodness-of-Fit are discussed for both hourly and daily data. All analyses were run on partial duration series and on annual maximum series. The updated regions will evaluated in the same way, before proceeding with the frequency analysis.

Hourly.

Discordancy. Initially, the discordancy measure was used for data checking and quality control. However, in evaluating regions, it is used to determine if a site has been assigned to the appropriate region. It is based on L-moments (L-coefficient-of-variation (L-CV), L-skewness (L-SK), and L-kurtosis (L-KT)), which represent a point in 3-dimensional space, for each site. Then, discordancy (D) is a function of the distance from the 'cloud' of points for the sites in the region being tested. The 'cloud center' is in fact the unweighted mean of the three moments for the sites within the region being tested. Sites with a discordancy value of 3 or greater are considered discordant, and should be examined to see if they possibly belong in another region or have a data problem. The threshold value of 3 is not a rigorous test, but a reasonable level to be expected within a homogeneous region.

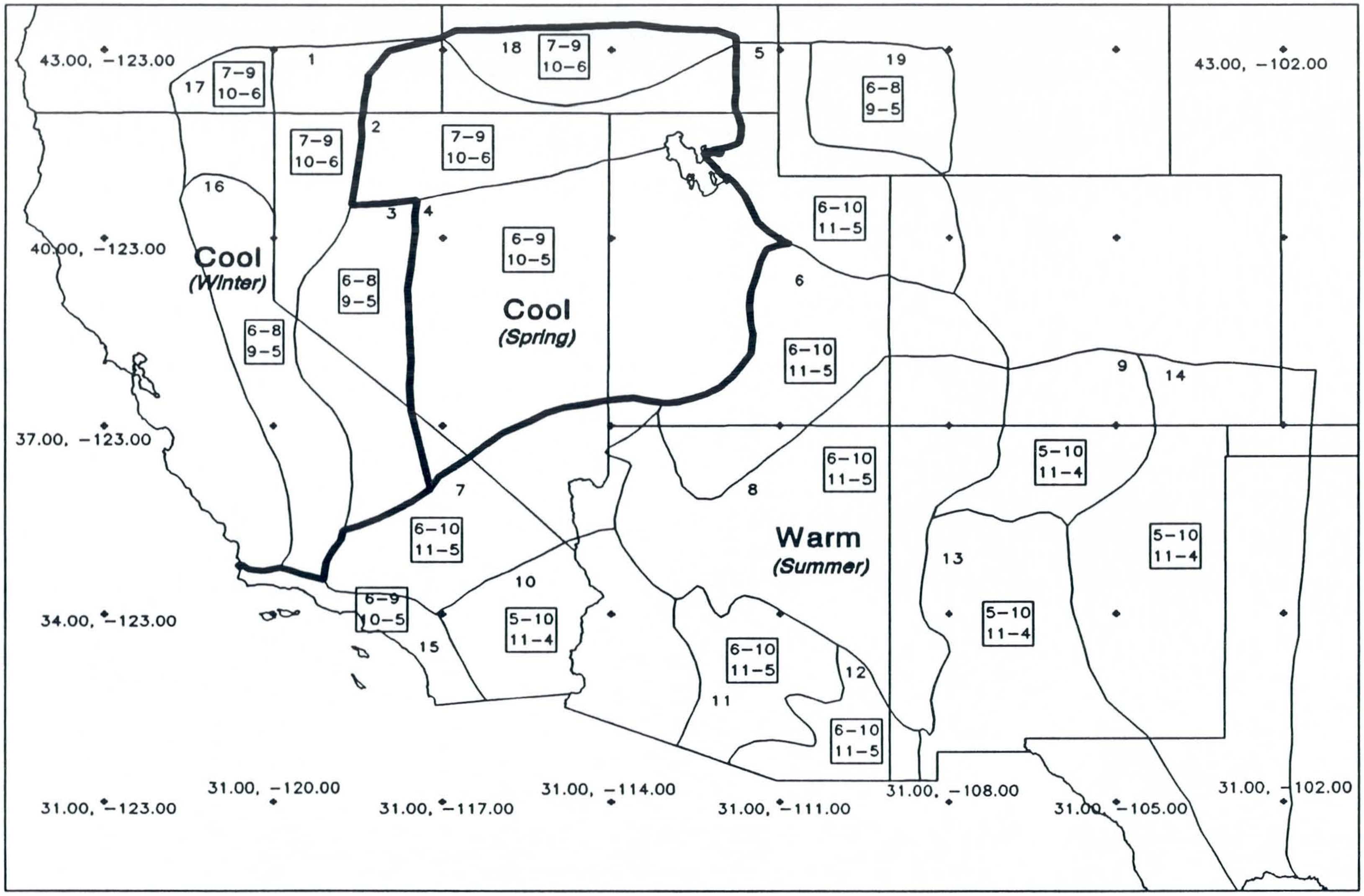

Figure 3. Climatic regions and seasons of maximum precipitation, Updated 9/30/93.

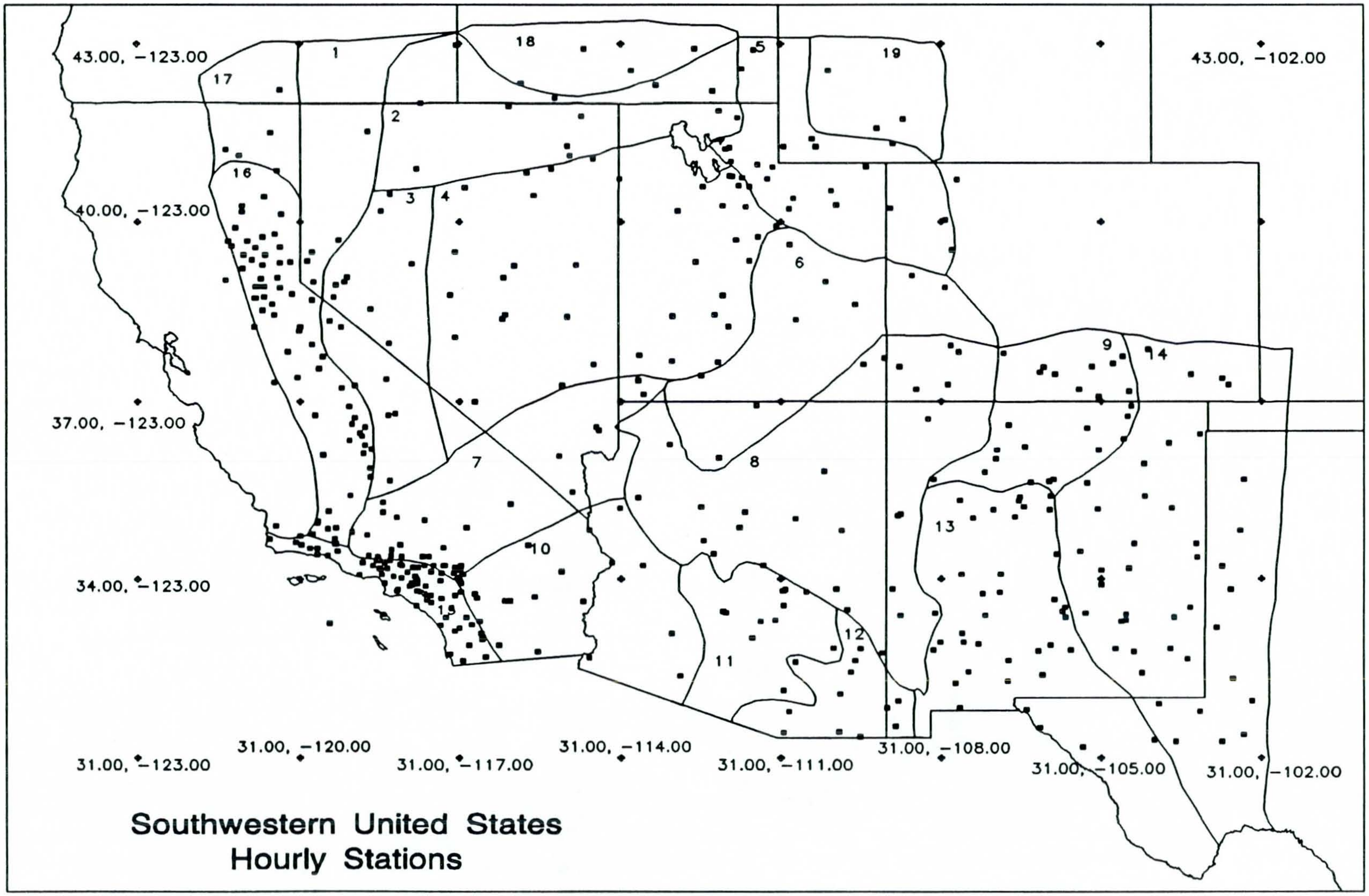

Figure 4. Hourly stations located in the updated climatic regions.

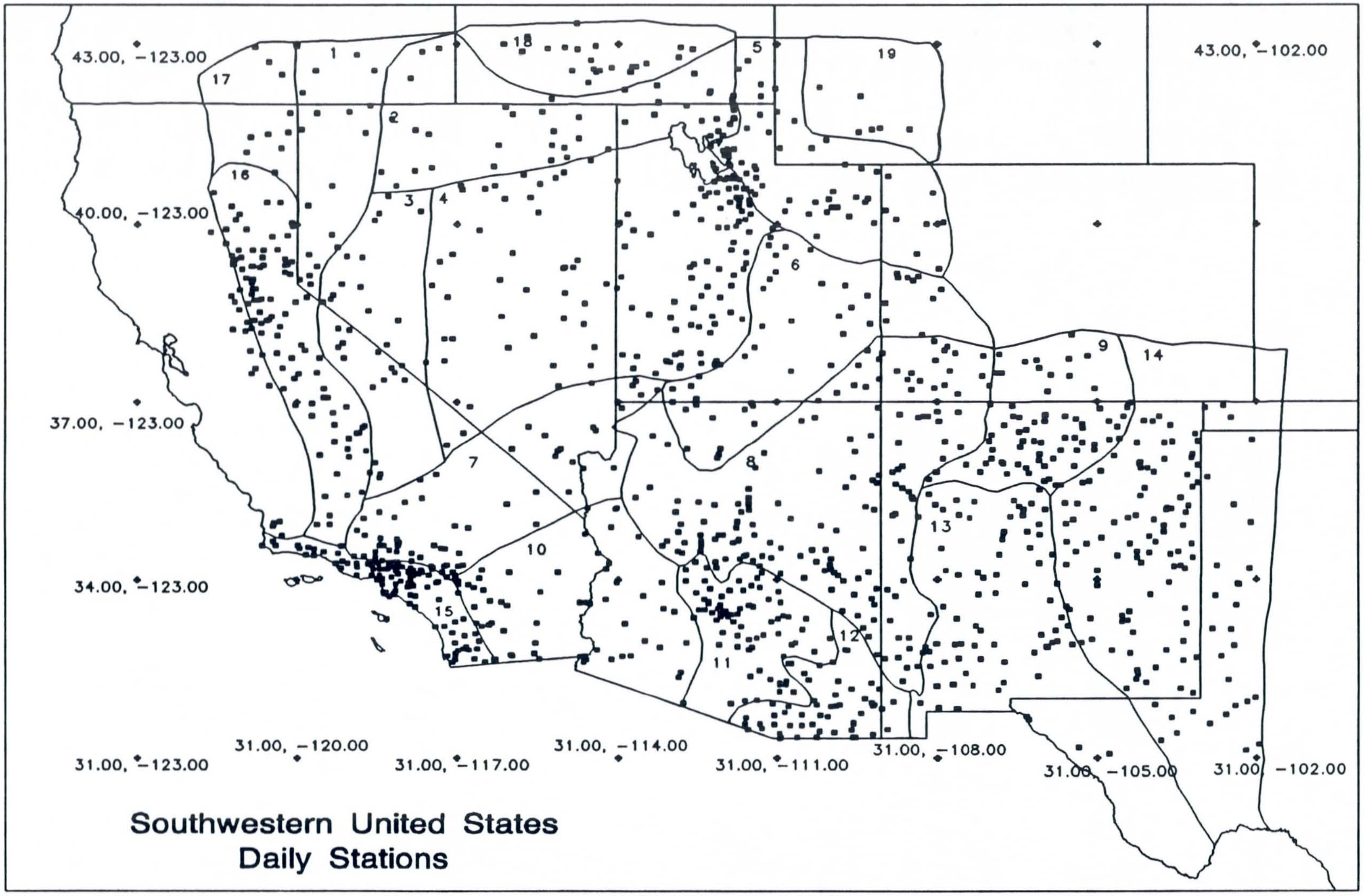

Figure 5. Daily stations located in the updated climatic regions.

Each region was analyzed for four durations: 3-, 6-, 24-, and 48-hour. In Appendices D and E, the first row of numbers below the headings contains the number of occurrences of D>3 for that duration for that region. Between PD and AMX, 29 out of 253 sites were tagged as discordant, with no particular preferred durations. The discordant stations were in seven regions in each (PD and AMX) analysis, although not all the same ones (10 regions had D>3 in either PD or AMX or both). Several stations were discordant at more than one duration. All of these stations are being checked. Possible outcomes include: 1/ error found and corrected; 2/ site belongs in another region; 3/ no error and no change in region. It is important to remember that a finding of D>3 may mean that a very rare event has occurred at that station, and it is not necessarily an error.

In Table 2, regions (PD only) with more than one occurrence of D>3 are listed. Region 10 has only one instance of D>3 and is included for reasons discussed below. The asterisks by regions 4 and 10 indicate that these two regions also have heterogeneity (H) values above the threshold. By the discordancy test, the regionization for a partial duration series looks quite good as nine regions show no discordancy and a tenth has only one.

Table 2.
Partial Duration Series

Region	(# sites)	Discordancy (D) # occurrences (D>3)
* 4	(39)	5
7	(30)	3
*10	(20)	1
13	(33)	3
14	(25)	6

Heterogeneity. Actually, the heterogeneity test (Appendix C) consists of three parts, one (H-1) based on L-CV, the second (H-2) based on L-CV and L-SK, and the third (H-3) based on L-SK and L-KT. As in the discordancy test, there is also a threshold value; Hosking and Wallis (1991) recommend a threshold of 1. However, they used wind data in establishing this threshold, and later conversations with Wallis (personal communication 1993) indicate that a threshold of 2 is reasonable, especially for precipitation data. Therefore, for each H-test, a value greater than 2 indicates heterogeneity (H>2), rather than homogeneity (H<2). The heterogeneity results are listed by region and duration in Appendix D (AMX) and Appendix E (PD). In general, H-1, based on L-coefficient of variation (L-CV) is most stringent. Thus, 17 of 30 occurrences (PD series) and 19 of 24 occurrences (AMX series) of H>2 (all 3 tests) are from the L-CV test. As precipitation data are highly variable in any case, the heterogeneity results were considered with and without the L-CV criterion. Table 3 (PD) shows that without the L-CV test, only 5 regions have H>2. Also shown is the number of occurrences of H>2 for all three H-tests for the five regions. Only two regions (4 and 10) have both discordant sites and occurrences of H>2. These are noted with an asterisk in Table 3. The use of these tests helps refine regional boundaries and may also indicate the need for additional regions.

Table 3.
Partial Duration Series

Region (# sites)	Heterogeneity ($H_{L\text{-}cv+sk+kt}$) # occurrences (H>2)	Heterogeneity ($H_{L\text{-}sk+kt}$) # occurrences (H>2)
2 (8)	2	2
3 (15)	3	1
* 4 (39)	7	4
6 (7)	5	4
*10 (20)	6	2

Goodness-of-fit. This test measures the "distance" of L-moment statistical parameters of a dataset from various theoretical probability distributions. The threshold for goodness-of-fit tests is 1.64 (absolute value), and 'best-fit' values are those less than the threshold. From the Goodness-of-Fit (Z) statistics for AMX (Appendix D), the 'best-fit' distributions for most durations are Generalized Extreme Value (GEV), Generalized Logistic (GLO), and Generalized Log Normal (LNO). For PD (Appendix E), Generalized Log Normal (LNO), Pearson Log III (PIII), and Generalized Pareto (GPA) are acceptable distributions for most durations. The final choice of distribution will depend on these tests and a real-data-check, Lin and Vogel (1993).

Daily data.

The daily data have been subject to the same regionalization and L-moment tests as the hourly. Durations of 1-, 2-, 4-, 10-, and 30-day periods have been analyzed. As an example, the results from region 5 for an annual maximum series of daily data are shown in Table 4. In regard to **Discordancy**, only four stations exceed the threshold, and at only one duration each. The **Heterogeneity** test exceeds the threshold of 2 for the L-CV test for 1-day and 2-day durations. All other durations and other H-tests are below the threshold, thus indicating an essentially homogeneous region. **Goodness-of-Fit** results indicate that Generalized Extreme Value (GEV) distribution is best for annual maximum (AMX) daily data, as it is for AMX hourly data discussed above.

Table 4.
Daily Data

Annual Maximum Precipitation Series, Region 5, 36 sites

	1-DAY	2-DAY	4-DAY	10-DAY	30-DAY
Discord	1	1	0	0	2
H1 L-CV	3.14	2.16	1.26	0.06	-0.03
H2 L-Skew	0.26	2.15	1.33	1.90	-0.85
H3 L-Kurt	-0.48	1.65	0.46	1.09	-0.71
Z Values					
GLO	1.77	2.81	1.67	2.04	3.66
GEV	-1.72	-0.32	-1.55	-1.37	-0.46
LNO	-2.55	-1.22	-2.22	-1.97	-0.78
PR III	-4.28	-2.98	-3.69	-3.36	-1.95
GPA	-9.70	-7.61	-8.85	-9.00	-9.31
Z MIN	GEV	GEV	GEV	GEV	GEV

SUMMARY

This Eighth Quarterly Report shows the revised regionalization including border areas into 19 subregions, and summarizes the L-moment analysis of regions for the Semiarid study area. The initial 14 regions described in the Seventh Quarterly Report (QR7) have been subjected to Discordancy (D), Heterogeneity (H), and Goodness-of-Fit tests, according to L-moment procedures described by Hosking and Wallis (1991). A brief review of seasonality and regionalization of the study area, including definitions and use of L-moment tests, was included in the report. The L-moment tests show 10 of 14 regions with no or only one discordancy, and only two regions (PD series) having both discordancies and limited homogeneity. Thus, it appears that although the initial regionalization needs some refinement, it is overall quite good. The next steps are being taken and include:

- o Check all discordant stations and correct data and/or adjust regions as necessary.
- o Review boundaries of heterogeneous regions and adjust or divide as appropriate.
- o Run L-moment tests on revised regions and evaluate results.
- o Compute return frequencies and compare with theoretical distributions with a real-data-check, Lin and Vogel (1993).

The precipitation frequency analysis for the Semiarid project will be based on the best regionalization possible and 'best-fit' probability distribution as determined from the above analytic process.

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APPENDICES

APPENDIX A

Agenda for Semiannual Meeting
of the Semiarid Precipitation Frequency Project
Phoenix, Arizona

9 September 1993

I. Welcome and Overview

II. Data

- A. Datasets
- B. Annual maximum versus partial duration series
- C. Comparisons of daily and 24-hour data

III. Analysis

- A. Seasonality
- B. Regionality - criteria, statistical tests, etc.
- C. Regional frequency analysis
- D. Precipitation-elevation relationships

IV. Storm Analysis

V. Discussion and Comment

APPENDIX B

Semiannual Meeting
of the Semiarid Precipitation Frequency Project
Phoenix, Arizona

9 September 1993

Attendance

George Lopez-Cepero	ADOT[1]	(602) 225-7481
Joe Warren	Pinal County FCD	(602) 868-6501
David Creighton	ADWR[2]	(602) 542-1541
Patrick J. Ellison	Cella Barr Assc.	(602) 242-2999
Lou Schreiner	USBR[3]	(303) 236-3791
Cliff Anderson	AMAFCA[4]	(505) 884-2215
Steve Waters	Maricopa County FCD	(602) 506-1501
Lesley Tarleton	NOAA/NWS	(301) 713-1669

1 Arizona Department of Transportation

2 Arizona Department of Water Resources

3 U.S. Bureau of Reclamation

4 Albuquerque Metropolitan Flood Control District

APPENDIX C
METHOD OF L-MOMENTS

a) robust, less sensitive to sampling errors and outliers
b) capable of characterizing a wide range of distributions
c) linear combination of order statistics

L-MOMENTS - DEFINITIONS

random variable X with cdf F(X) & quantile func X(F)

$$X_{1:n} \preceq X_{2:n} \preceq \cdots \preceq X_{n:n}$$

L-MOMENT for r = 1, 2, · · · are:

$$\lambda_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} E\, X_{r-k:r}$$

$$\text{L-CV} = \lambda_2/\lambda_1$$

$$\text{L-SKEWNESS} = \lambda_3/\lambda_2$$

$$\text{L-KURTOSIS} = \lambda_4/\lambda_2$$

L-MOMENT TESTS

1. **DATA SCREENING--DISCORDANCY D_i**

Let $\bar{U}_i = \left[t_2^{(i)}, t_3^{(i)}, t_4^{(i)}\right]^T$ be a vector for site i

$$\bar{U} = N^{-1} \sum_{i=1}^{N} \bar{U}_i \quad \text{-- unweighted group mean}$$

THE DISCORDANCY FOR SITE i IS DEFINED:

$$D_i = \frac{1}{3} (\bar{U}_i - \bar{U})^T \bar{S}^{-1} (\bar{U}_i - \bar{U})$$

$$\text{where } \bar{S} = (N-1)^{-1} \sum_{i=1}^{N} (\bar{U}_i - \bar{U})(\bar{U}_i - \bar{U})^T$$

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

January 31, 1994 W/OH11/LFT

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Ninth Quarterly Report - Semiarid Precipitation Frequency Project, October 1 - December 31, 1993

Enclosed is a copy of the Ninth Quarterly Progress Report for the Semiarid Precipitation Frequency Project for the southwestern United States. This update contains the final regions for return frequency analysis, procedures for choice of probability distribution, conversion factors for daily to 24-hour data for the Southwest, a list of storms for storm analysis, and other information.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMIARID PRECIPITATION FREQUENCY STUDY

Ninth Quarterly Progress Report
for the period from
October 1 through December 31, 1993

Lesley F. Tarleton, Julie M. Olson, Edwin H. Chin,
Susan M. Gillette, John L. Vogel, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
January 1994

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SEMIARID PRECIPITATION FREQUENCY STUDY

Ninth Quarterly Progress Report
for the period from
October 1 through December 31, 1993

OVERVIEW

This Ninth Quarterly Report summarizes the work for the Semiarid Precipitation Frequency Project for the period October 1 through December 31, 1993. It is important to develop climatologically homogeneous regions so that the power of L-moment statistics can be realized in the development of precipitation frequencies. To this end, the final array of 24 near-homogeneous regions is complete. The Eighth Quarterly Report showed only 19 regions including border areas. Further refinement was based primarily on discordancies between mountainous areas and adjacent lower elevation areas.

The hourly data at several durations have been subjected to a real-data-check (RDC), which compares theoretical distributions with observed values, Lin and Vogel (1993). Format problems with the daily data (some, but not all stations have a duplicate October 1990 on the computer file from the National Climatic Data Center (NCDC)), have slowed the analysis of the daily data, so that a real-data-check has not been completed. The optimum probability distribution for precipitation frequency analysis for the Southwest is being determined from real-data-check (RDC) comparisons, and on the 'best-fit' probability distribution as determined from L-moment Goodness-of-fit procedures (Hosking and Wallis 1991).

In addition to the NCDC daily and hourly data, SNOpack TELemetry (SNOTEL) data are ready for frequency analysis and will augment the daily data at higher elevations. Furthermore, ratios of various durations of hourly data to 24-hour data for all regions have been computed. Application of these ratios to daily data will extend the use of daily data to shorter durations. In addition, conversion factors from daily to 24-hour data for all return periods have been determined.

Other data sets that are being analyzed for the project are 15-minute, n-minute, and the U.S. Geological Survey (USGS) dense raingage network for the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA).

DATA

Hourly Dataset

The hourly dataset includes both an annual maximum series and a partial duration series. As a result of numerous statistical tests and other analytic techniques, the hourly data are ready for inclusion in all analyses to develop the final frequency analysis. For the final process, a partial duration series is being used. The hourly data have been used for all-season, summer, and winter frequency analyses for various durations: 1, 2, 3, 6, 12, 24, and 48 hours. In addition, the hourly data have been used to develop ratios to daily data to extend the daily dataset to shorter durations, and to develop conversion factors from daily to 24-hour data. There are 449 hourly stations in the semiarid study area, all with 15 to 43 years of data, with an average of about 35 years of record.

Daily Dataset

The daily data have also been processed using an annual maximum series and partial duration series. However, as there are many more stations (about 1300 stations) and much longer records (19 to nearly 100 years), data preparations have been much more tedious and time-consuming. In addition, recent obstructions included format problems with the daily data (some, but not all stations have a duplicate October 1990 on the computer file from NCDC). This 'extra October' problem must be solved in order to use the 1990-1992 data. As soon as 'October' is corrected in mid-January, partial duration series for 1, 2, 4, 7, 10, 20, 30, 45, and 60 days will be prepared. Frequency analyses for all durations will be developed from this daily dataset and the hourly dataset, described above. The software (L-moment) is all in place.

SNOTEL

SNOTEL (SNOpack TELemetry) data have been processed for the five core states, which includes 153 stations for about 10-12 years of record up through the 1991 water year. NCDC data in high-altitude regions in the west are very sparse, therefore the SNOTEL dataset is an important data source. Initial return frequencies for these high-altitude data have been generated, using an annual maximum series and L-moment software. A partial duration series is being prepared for the final frequency analysis. Furthermore, the return frequencies from select SNOTEL stations are being compared to nearby NCDC daily and hourly stations of similar elevation and period of record to determine the relationship between the two datasets. Also, the SNOTEL stations will be compared to NCDC stations at lower elevations in order to use the relationship between the two datasets to determine values for other high-altitude, data-scarce regions.

N-Minute Data

Format problems have plagued the access of n-minute data. These data are not requested very often from NCDC and, therefore, have not been processed as thoroughly as the more commonly used hourly and daily datasets. The n-minute data are needed for calculating return frequencies of less than one-hour durations. Fifteen-minute data are also being processed for short duration analysis. However, it is anticipated that once the format problems are resolved, the data will need little or no quality control.

Other Data

Data from the U.S. Geological Survey (USGS) dense raingage network for the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) have been sent to us by telnet. These data are 5-minute recorder data from 12 to 15 gages in the Albuquerque metropolitan area. These are invaluable for evaluation on small scales, both temporally and spatially.

ANALYSIS

Regionalization

Final Regions

The final division of the Semiarid Project area into 24 regions for frequency analysis is shown in Figure 1. The months that define the two seasons for each region are given in a box within each region. In Figure 1, the regions are further grouped with regard to the season of maximum precipitation - Cool(winter), Cool(spring), and Warm(summer). Although each region has been divided into only two seasons, warm and cool; the bounds of warm and cool are different in different regions. They vary from warm = May-October (5-10) and cool = November-April (11-4), to warm = June-September (6-9) and cool = October-May (10-5). Also, the length of a season may vary from a minimum of four months to its complement, a maximum of eight months. Note also, that there are two cool seasons, 'winter' and 'spring'. To clarify, spring precipitation in the southwest is most commonly of a general storm type, similar to cool weather precipitation. Therefore, in regions 2, 4, 18, and 21, with spring maximums, the cool season runs from October to May and includes the spring months. On the other hand, convective summertime (warm) type precipitation may run into the fall. In this situation, the fall months are included with summer. In this study, a primary maximum has not been found in the fall.

The results of the L-moment Discordancy (D), Heterogeneity (H), and Goodness-of-Fit tests on the hourly data (Hosking and Wallis 1991) are summarized for durations of 3, 6, 24, and 48 hours for the final regions in Table 1. A detailed discussion of D, H, and Goodness-of-fit test is given in the Appendix.

Each region was analyzed for four durations: 3, 6, 24, and 48 hours. In Table 1, the first row of numbers below the headings contains the number of occurrences of D>3 for that duration for that region. In this final set of regions, nearly all regions have no, or only one or two discordancies. Those with higher numbers of D>3, e.g., region 15, have low heterogeneity (H<2). It is important to remember that a finding of D>3 may mean that a very rare event has occurred at that station, and it is not necessarily an error. Heterogeneity results are given in the lines marked L-CV, L-SK, and L-KT. The Goodness-of-fit results are shown in the last five lines. Values ≤ 1.64 (absolute) are considered a 'good fit' for the respective probability distributions.

All frequency calculations are based on L-moment regional analysis of the stations within each region, thus taking advantage of the physical similarities or near-homogeneity within each region to strengthen the statistics.

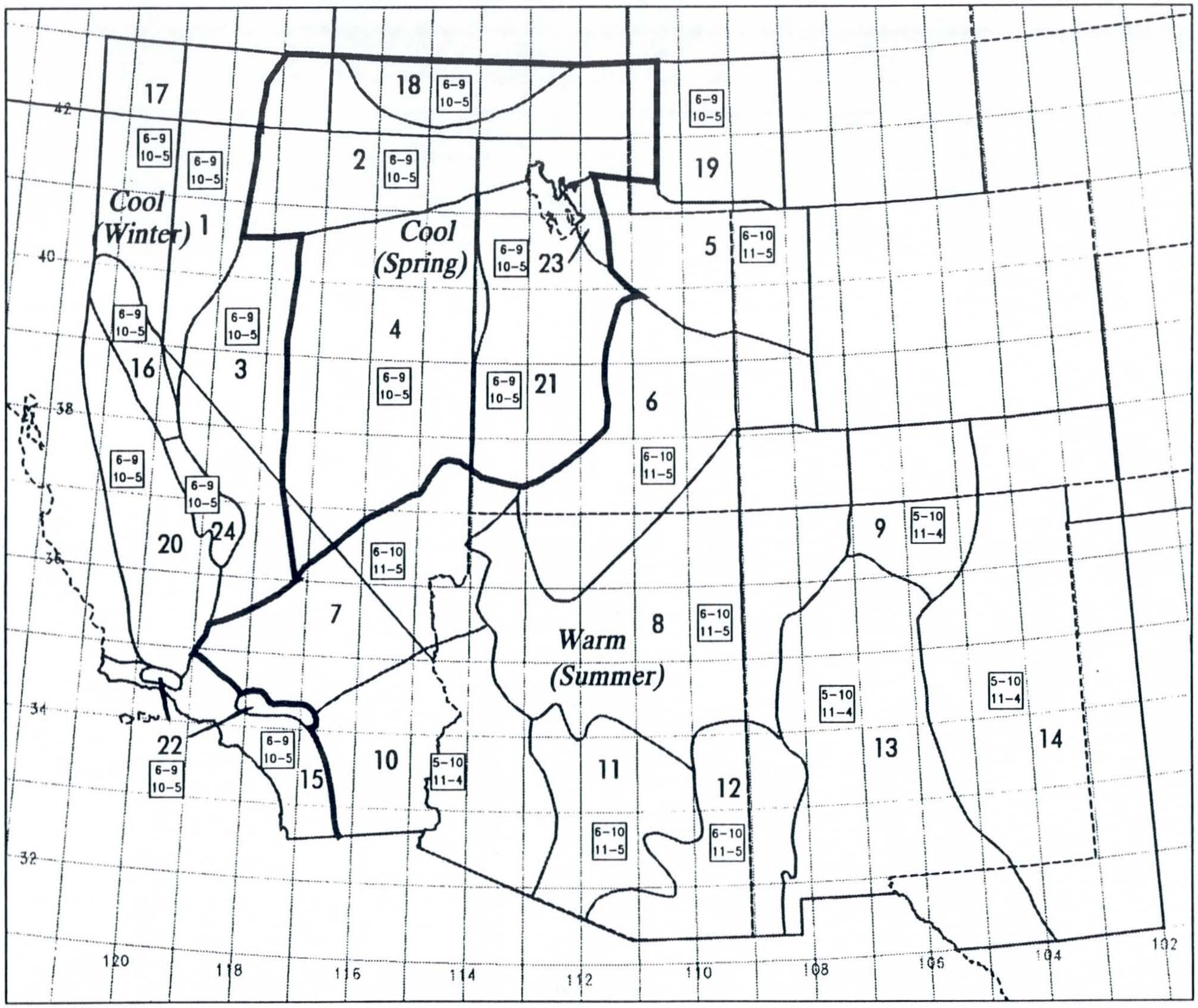

Figure 1. Climatic regions and precipitation seasons.

Table 1

Partial Duration 12/17/93 Final Revisions

	REGION 1, 6 sites				REGION 2, 14 sites				REGION 3, 14 sites				REGION 4, 17 sites				REGION 5, 13 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
L-CV	2.17	2.51	0.79	1.42	-1.55	-1.30	0.90	0.65	0.59	-0.36	2.28	3.15	1.27	0.71	0.26	-0.26	-0.95	-0.78	2.99	0.38
L-SK	1.32	0.76	0.04	0.61	-1.94	-1.08	1.28	2.65	1.30	-0.08	-0.18	1.89	2.69	2.61	1.20	0.96	-1.05	-1.51	1.10	1.41
L-KT	0.76	0.25	0.48	-0.08	-1.71	-0.17	0.60	2.14	0.20	-0.51	-0.28	1.51	2.14	2.34	1.09	0.54	-0.85	-0.96	0.73	1.77
GLO	1.12	2.14	4.00	2.69	1.67	3.20	3.44	3.96	1.47	1.46	2.19	2.00	2.96	2.15	2.18	2.84	-0.08	1.07	4.06	2.03
GEV	0.67	1.45	3.45	2.14	1.02	2.45	2.55	2.89	0.98	0.90	1.46	1.44	2.22	1.37	1.27	1.95	-0.47	0.56	3.00	1.36
LNO	-0.08	0.73	2.50	1.29	-0.11	1.21	1.35	1.74	-0.16	-0.21	0.37	0.28	0.96	0.19	0.16	0.77	-1.46	-0.47	1.98	0.32
P III	-1.35	-0.50	0.88	-0.14	-2.05	-0.92	-0.68	-0.23	-2.11	-2.11	-1.48	-1.69	-1.20	-1.81	-1.74	-1.24	-3.14	-2.23	0.24	-1.46
GPA	-0.82	-0.54	1.60	0.36	-1.17	-0.02	-0.22	-0.22	-0.85	-1.07	-0.88	-0.58	-0.25	-1.15	-1.47	-0.79	-1.97	-1.26	-0.01	-0.81

	REGION 6, 10 sites				REGION 7, 16 sites				REGION 8, 21 sites				REGION 9, 12 sites				REGION 10, 16 sites			
	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0
L-CV	1.56	0.90	2.13	2.22	0.94	-0.28	0.55	1.37	-0.62	-0.66	-0.44	0.55	1.11	0.16	0.46	0.78	2.60	3.13	3.18	2.42
L-SK	2.65	3.19	0.24	-0.49	-1.82	-0.31	-1.02	-0.50	0.46	-0.42	0.39	1.51	0.63	0.27	-1.60	-0.90	0.79	1.69	1.12	0.06
L-KT	2.29	2.81	-0.11	-0.01	-2.22	-0.49	-1.01	-0.98	0.26	-0.73	0.26	1.75	1.51	-0.22	-1.94	-1.63	-0.50	0.59	0.31	-0.21
GLO	1.88	0.87	4.41	5.82	1.87	1.43	2.37	2.93	4.37	3.26	3.38	4.65	2.84	1.90	2.07	1.83	3.18	2.86	2.85	2.25
GEV	1.37	0.18	3.18	4.70	1.22	0.74	1.54	2.07	3.32	2.43	2.38	3.49	2.14	1.26	1.37	1.18	2.48	2.12	1.99	1.49
LNO	0.29	-0.72	2.26	3.60	-0.03	-0.45	0.32	0.81	1.75	0.87	0.89	1.95	0.99	0.18	0.30	0.11	1.09	0.78	0.71	0.22
P III	-1.55	-2.25	0.67	1.73	-2.18	-2.50	-1.74	-1.32	-0.92	-1.79	-1.66	-0.67	-0.96	-1.66	-1.52	-1.71	-1.28	-1.50	-1.48	-1.94
GPA	-0.47	-1.93	-0.14	1.51	-1.04	-1.57	-1.12	-0.67	-0.05	-0.45	-0.82	-0.08	-0.16	-0.86	-0.89	-0.96	0.01	-0.42	-0.77	-1.02

DISC Number of Discordant Stations	Distribution Tests
	GLO Generalized Logistic
Heterogeneity Tests	GEV Generalized Extreme-Value
L-CV L-Moment Coefficient of Variation	LNO Generalized Log-Normal
L-SK L-Moment Skew	PIII Pearson Type III
L-KT L-Moment Kurtosis	GPA Generalized Pareto

Table 1 (cont.)

Partial Duration

REGION 11, 12 sites

	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	1
L-CV	-0.43	-0.46	-1.33	-1.31
L-SK	-1.08	-0.17	-1.00	-1.26
L-KT	-0.62	0.01	-0.61	-0.90
GLO	4.11	3.38	2.01	3.30
GEV	3.12	2.58	1.42	2.63
LNO	2.19	1.60	0.44	1.58
P III	0.61	-0.07	-1.22	-0.20
GPA	0.31	0.16	-0.54	0.45

REGION 12, 18 sites

	3-hr	6-hr	24-hr	48-hr
DISC	0	1	0	0
L-CV	-0.01	-0.64	1.38	1.54
L-SK	0.00	-0.63	-1.09	-0.16
L-KT	-0.31	-1.28	-0.72	0.60
GLO	3.21	3.11	3.63	4.44
GEV	2.12	2.15	2.59	3.40
LNO	0.91	0.89	1.32	2.05
P III	-1.13	-1.26	-0.84	-0.24
GPA	-1.09	-0.81	-0.55	0.19

REGION 13, 42 sites

	3-hr	6-hr	24-hr	48-hr
DISC	2	1	1	0
L-CV	1.72	0.72	1.23	1.17
L-SK	0.03	1.47	0.78	1.67
L-KT	-0.16	1.44	0.36	1.99
GLO	6.00	4.87	5.71	6.13
GEV	4.38	3.30	3.85	4.20
LNO	2.42	1.42	2.05	2.41
P III	-0.92	-1.78	-1.03	-0.67
GPA	-0.50	-1.42	-1.43	-1.23

REGION 14, 47 sites

	3-hr	6-hr	24-hr	48-hr
DISC	2	3	3	3
L-CV	0.88	0.08	0.95	2.34
L-SK	0.06	-0.58	-1.43	-0.70
L-KT	-0.46	-0.16	-1.38	-0.30
GLO	4.68	4.39	5.91	5.53
GEV	3.35	3.02	4.29	4.02
LNO	1.32	1.04	2.16	1.87
P III	-2.15	-2.34	-1.48	-1.79
GPA	-0.93	-1.33	-0.69	-0.73

REGION 15, 67 sites

	3-hr	6-hr	24-hr	48-hr
DISC	4	3	4	1
L-CV	1.46	1.24	0.30	-0.16
L-SK	0.09	-0.31	-1.55	-0.04
L-KT	0.12	0.24	-0.92	-0.68
GLO	5.97	7.52	9.40	9.00
GEV	4.21	5.33	6.90	6.88
LNO	1.71	2.91	4.47	4.27
P III	-2.53	-1.22	0.32	-0.16
GPA	-1.34	-1.11	-0.21	0.46

REGION 16, 25 sites

	3-hr	6-hr	24-hr	48-hr
DISC	2	2	1	1
L-CV	1.23	2.69	2.04	0.49
L-SK	3.30	0.84	0.91	-1.25
L-KT	3.28	0.92	0.85	-1.18
GLO	2.64	3.41	7.72	5.42
GEV	1.59	2.11	6.21	4.46
LNO	0.21	0.80	4.68	2.79
P III	-2.13	-1.44	2.07	-0.04
GPA	-1.66	-1.62	1.85	1.23

REGION 17, 12 sites

	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0
L-CV	2.39	4.24	0.98	0.37
L-SK	-0.59	1.15	-0.55	-0.33
L-KT	-0.77	0.75	-0.06	-0.60
GLO	2.89	4.00	1.96	2.09
GEV	2.18	2.95	1.34	1.56
LNO	1.01	1.84	0.22	0.39
P III	-1.00	-0.06	-1.69	-1.62
GPA	-0.17	-0.10	-0.79	-0.38

REGION 18, 4 sites

	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0
L-CV	1.13	2.52	-0.21	-1.76
L-SK	-0.35	0.23	-0.59	1.12
L-KT	-1.14	-0.24	-0.65	1.51
GLO	1.89	2.32	2.06	2.76
GEV	1.47	1.86	1.60	2.11
LNO	0.80	1.17	0.94	1.49
P III	-0.33	0.00	-0.18	0.43
GPA	0.11	0.39	0.13	0.26

REGION 19, 6 sites

	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0
L-CV	1.01	1.78	2.42	1.98
L-SK	-1.22	-0.73	-0.15	-0.88
L-KT	-0.99	-0.22	-0.18	-0.94
GLO	2.92	3.16	5.15	5.26
GEV	2.41	2.56	4.12	4.14
LNO	1.62	1.80	3.53	3.60
P III	0.28	0.51	2.49	2.64
GPA	0.75	0.73	1.49	1.37

REGION 20, 23 sites

	3-hr	6-hr	24-hr	48-hr
DISC	2	2	0	2
L-CV	0.96	1.63	1.34	0.17
L-SK	0.41	0.89	1.68	-1.22
L-KT	0.19	0.46	1.29	-1.32
GLO	1.86	2.43	2.21	2.14
GEV	1.08	1.63	1.44	1.56
LNO	-0.35	0.15	-0.03	0.02
P III	-2.79	-2.37	-2.54	-2.62
GPA	-1.61	-1.12	-1.22	-0.74

REGION 21, 15 sites

	3-hr	6-hr	24-hr	48-hr
DISC	1	0	0	1
L-CV	3.99	2.57	0.01	-0.92
L-SK	1.22	1.57	1.57	-0.70
L-KT	0.77	2.09	1.71	-0.09
GLO	3.74	3.05	3.79	2.53
GEV	2.99	2.20	2.77	1.60
LNO	1.62	0.95	1.53	0.45
P III	-0.71	-1.17	-0.59	-1.52
GPA	0.43	-0.52	-0.30	-1.22

REGION 22, 20 sites

	3-hr	6-hr	24-hr	48-hr
DISC	1	1	0	0
L-CV	0.71	0.24	0.23	0.62
L-SK	-0.41	-0.98	-0.15	-0.57
L-KT	-0.46	-0.68	-0.17	-0.81
GLO	3.96	3.66	2.83	2.91
GEV	2.82	2.48	1.89	1.98
LNO	1.52	1.22	0.58	0.67
P III	-0.70	-0.91	-1.63	-1.57
GPA	-0.55	-0.96	-1.06	-0.95

REGION 23, 8 sites

	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0
L-CV	0.16	0.28	0.69	-0.40
L-SK	2.46	1.35	1.42	-0.45
L-KT	1.98	1.45	1.34	-0.61
GLO	2.59	2.74	3.41	1.44
GEV	2.12	2.00	2.64	0.95
LNO	1.14	1.14	1.74	0.09
P III	-0.54	-0.32	0.19	-1.39
GPA	0.42	-0.21	0.36	-0.69

REGION 24, 11 sites

	3-hr	6-hr	24-hr	48-hr
DISC	0	0	0	0
L-CV	1.78	1.23	0.37	0.00
L-SK	-0.74	-0.99	-0.95	-1.14
L-KT	-0.21	-1.72	-0.46	-0.92
GLO	2.99	2.92	2.51	1.44
GEV	2.31	2.13	1.97	1.06
LNO	1.15	1.03	0.79	-0.08
P III	-0.83	-0.84	-1.21	-2.02
GPA	0.03	-0.33	-0.01	-0.51

Regional means

For a general look at the regions, the mean for the 24-hour partial duration series of hourly data for all stations within a region and mean L-moment Coefficient of Variation (L-CV) were calculated for 'all season' and 'summer' and 'winter' precipitation seasons. The average precipitation amount and the mean L-CV for all stations in each region are shown in the maps in Figures 2a-c, for all-season, summer, and winter, respectively. As would be expected from the prevailing weather patterns, winter maximum precipitation is much greater than summer in the northern and western parts of the study area; while, summer maximum precipitation is greater than winter in the southeast part of the region (Figures 2b and 2c) . This is because winter and spring storms dominate in the north and west, with only sporadic convection during the warm season; whereas, in summer organized convective systems dominate in the southeast, and winter precipitation is minimized. For example, region 20 has a winter mean value nearly five times the summer value. Furthermore, in regions that have a marked precipitation season the maximum seasonal values are nearly equal to the all-season values. Region 16 (winter precipitation season) has a mean all-season value of 4.64 inches (Figure 2a) and a winter value of 4.62 inches (Figure 2c). Region 14 is an example with a summer maximum that has an all-season value of 2.25 inches and a summer value of 2.21 inches (Figure 2b). Regions in the central part of the study area, such as regions 6, 8, and 21 have fairly similar values in summer and winter and their all-season values are only slightly higher. This reflects a climate with two almost comparable - in amount, but not in type - precipitation seasons.

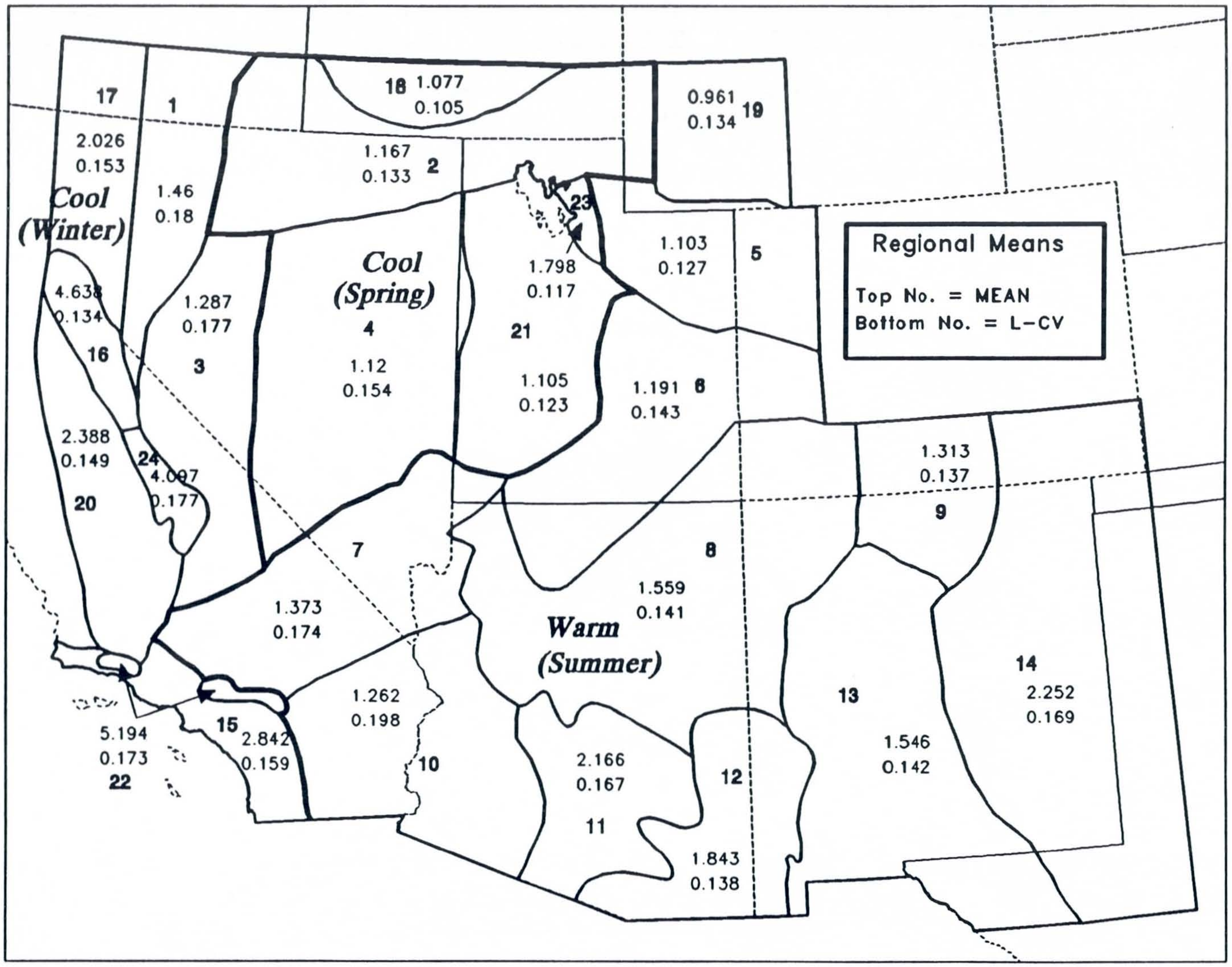

Figure 2a. All season regional mean precipitation (inches) and L-CV of the 24-hr partial duration series hourly data set.

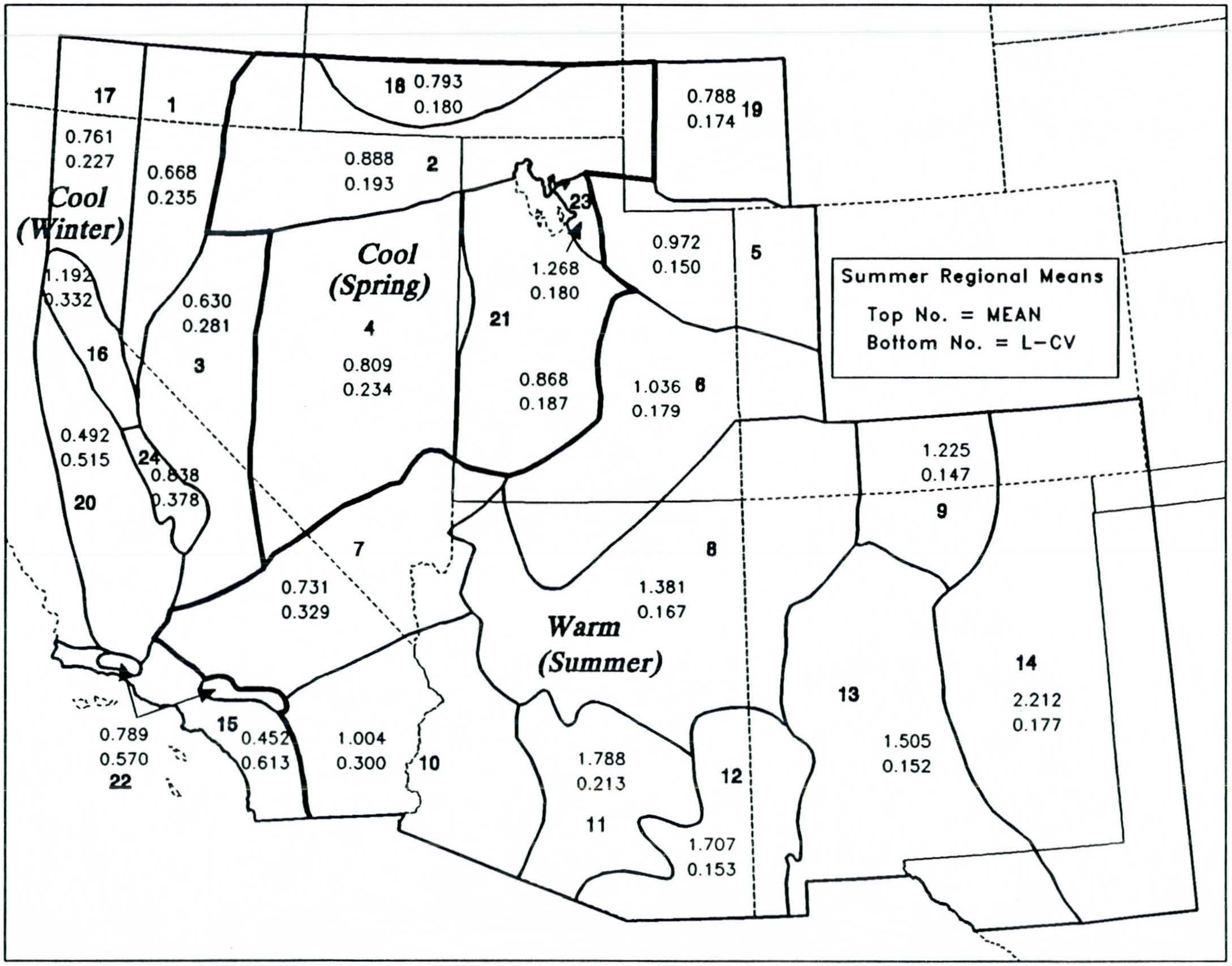

Figure 2b. Summer regional mean precipitation (inches) and L-CV of the 24-hr partial duration series hourly data set.

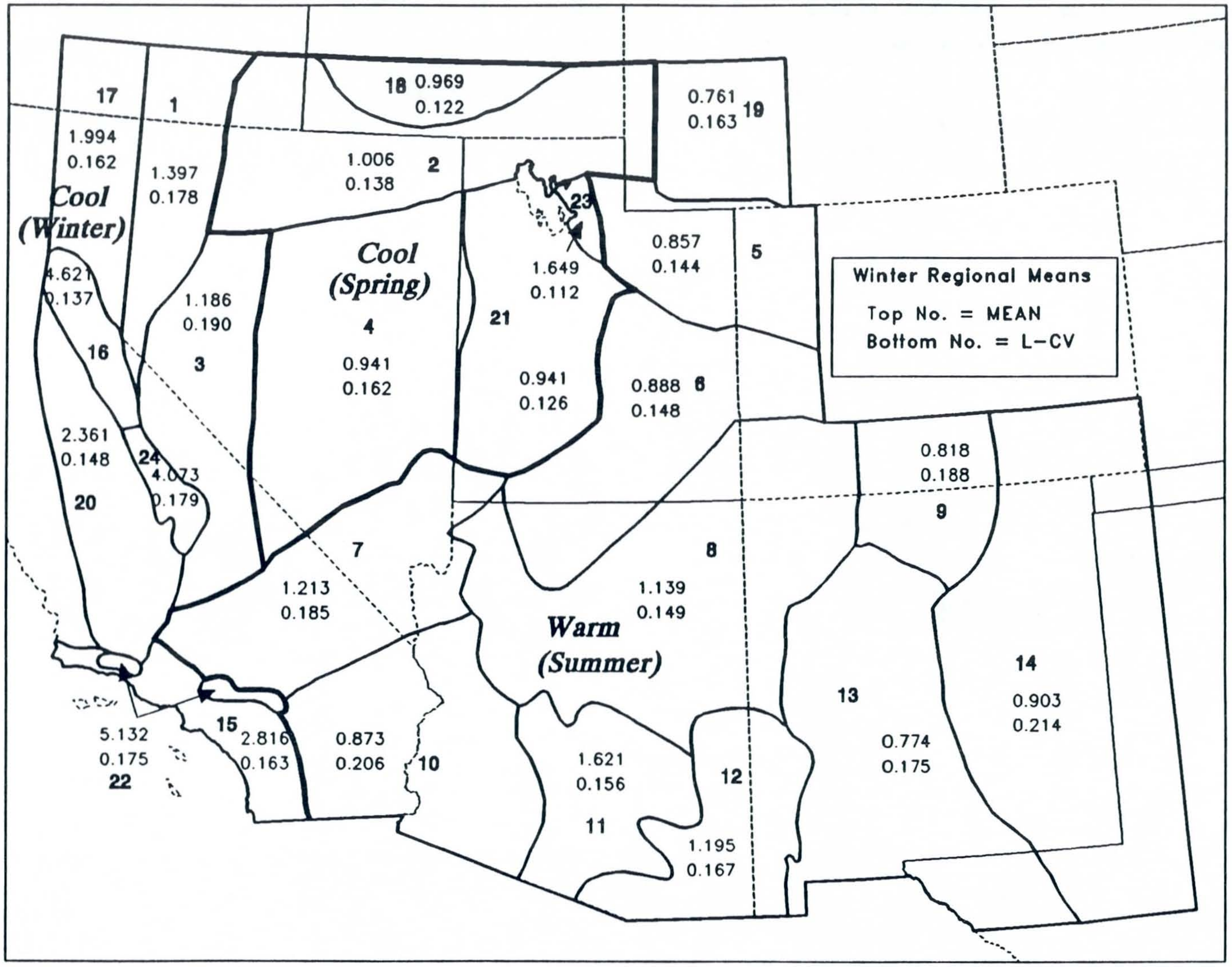

Figure 2c. Winter regional mean precipitation (inches) and L-CV of the 24-hr partial duration series hourly data set.

Probability distributions

Traditionally, the Gumbel probability distribution has been used for extreme-value return frequency calculations. With L-moment statistical routines, it is possible to test for acceptable fit for many different probability distributions. Also, in the past, i.e., 'the olden days' prior to computer processing, the datasets were assembled 'by hand' and the computations done with pencil and graph paper. Thus, annual maximum series were easier to prepare (the highest value for each year), than a partial duration series (the n-year top values), and computer testing of 'best-fit' was not an option. For this project, both annual maximum and partial duration series have been prepared and compared. Discussion of comparisons were given in the Seventh Semiarid Quarterly Report (3/1/93-6/30/93). One of the not-so-surprising differences between partial duration series and annual maximum series is that the probability distributions differ. The decision has been made to use partial duration (PD) series, as PD is more representative of extreme events, and with present computing facilities, no more difficult to prepare. For NOAA Atlas 2 (Miller et al. 1973), the calculations were done using an annual maximum series, and an across-the-board conversion from annual-maximum results to partial duration numbers. Using a partial duration series to start with avoids the blanket conversion. Now, which distribution to use? Two criteria are important: 1) a 'best-fit' distribution, i.e., a distribution where the data come closest to the theoretical; and 2) conservatively high.

Goodness-of-fit

In Table 1, the Goodness-of-fit results are given for various durations using a PD series of hourly data for five probability distributions: Generalized Logistic (GLO), Generalized Extreme-Value (GEV), Log-Normal (LNO), Pearson Log-III (PIII), and Generalized Pareto (GPA). Values ≤ 1.64 (absolute) are considered a 'good fit' to the probability distribution. The LNO, PIII, and GPA have reasonable fit at most durations for this partial duration series, while the GLO and GEV distributions test values exceed the threshold in most cases (in nearly all cases for GEV). Tests on annual maximum series show the reverse, with GEV having the best fit and GPA the worst. Now how to choose among those with a 'reasonable fit'? On to the next section about real-data-check.

Real-data-check

Two criteria should be met for the optimum choice of distribution for return frequency computations:

- that the theoretical distribution be close to the observed data, and
- that where the fit is not exact, that the results be conservatively high.

Therefore, a real-data-check (RDC) was run on the hourly data (3, 6, 24, and 48 hours) and will be run shortly on the daily data to compare the observations with various theoretical distributions. In the RDC procedure, the actual percentage of occurrences is compared with the theoretical probability. For example, theoretically, the 2-year return value is the median, and, therefore, 50 percent of the events should be greater and 50 percent less than the median value. The theoretical thresholds for the other return periods are: 5-yr, 20%; 10-yr, 5%; 25-yr, 4%; 50-yr, 2%; and 100-yr, 1%. The RDC was run on four distributions: LNO, GPA, PIII, and Gumbel (GUM). Although GUM does not provide a good fit for partial duration series, it was the distribution used for NOAA Atlas 2, and was included for evaluation and comparison purposes. LNO and GPA ranked closest to the observations, and PIII was third. GUM was a distant fourth. If one includes the second criterion, then LNO fares slightly better than the GPA. The daily data will be tested in January and the final distribution will be chosen.

Daily to 24-hour Conversion

In order to make the daily and hourly data comparable, a conversion is necessary from 'observation day' to 24 hours.

Both NOAA Atlas 2 (Miller et al. 1973) and Technical Paper 40 (Hershfield 1961) use the empirically derived value of 1.13 to convert daily data to 24-hour data. A conversion is necessary because of the varying observation times for daily data, and the unfortunate and uncooperative tendency of rainfall to fall not in the 'prescribed' daily observation period, but irregularly throughout the day. As the factor was computed many years ago and applied universally to the whole country, it was decided to examine an empirical factor based on only southwestern data. Results are based on 20 First-Order Stations in Arizona, Nevada, New Mexico, and Utah that have co-located hourly and daily raingages. The results are shown in Figures 3a-f and are summarized in Figure 4, for 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year return periods. The factors shown in Figures 3 and 4 will be used for the conversion in this Southwest frequency analysis. The values are listed in Table 2.

Table 2.

Return Period	Conversion Factor
2-year	1.15
5-year	1.13
10-year	1.12
25-year	1.10
50-year	1.08
100-year	1.06

Technical Paper 40 and NOAA Atlas 2 give no information on this factor for return frequencies greater than two years. In NOAA Atlas 2, 1.13 was used at all return periods.

It is physically consistent for the conversion factors to decrease with larger return periods. The extreme events in a series are more likely to have occurred over a 24-hour period, which is reflected closely in the daily observations.

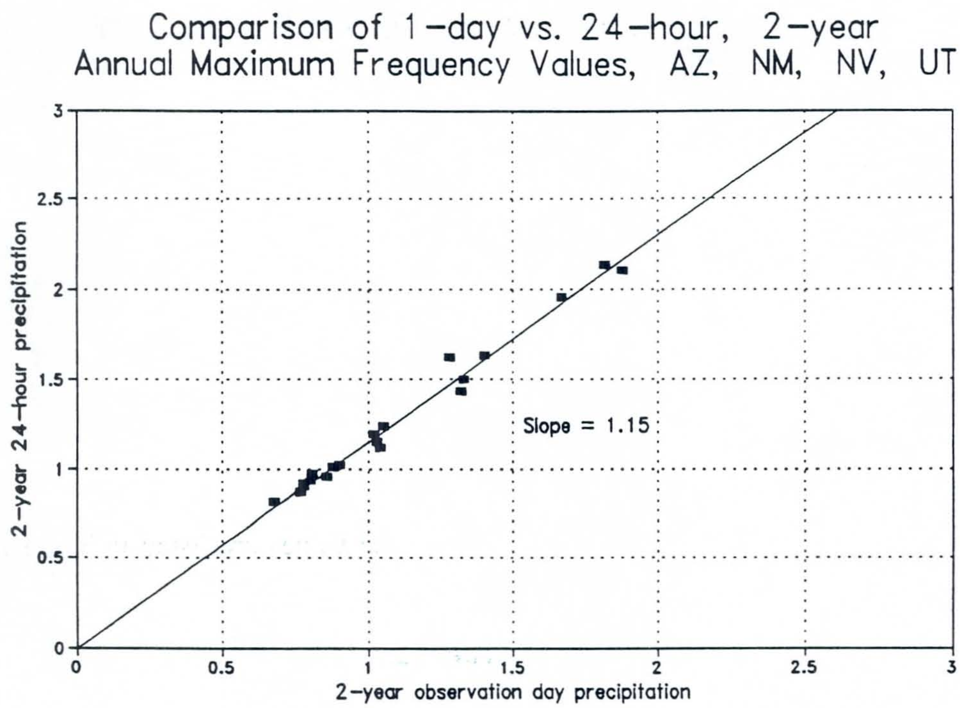

Figure 3a. Comparison of 2-year, 1 day vs. 24-hour values.

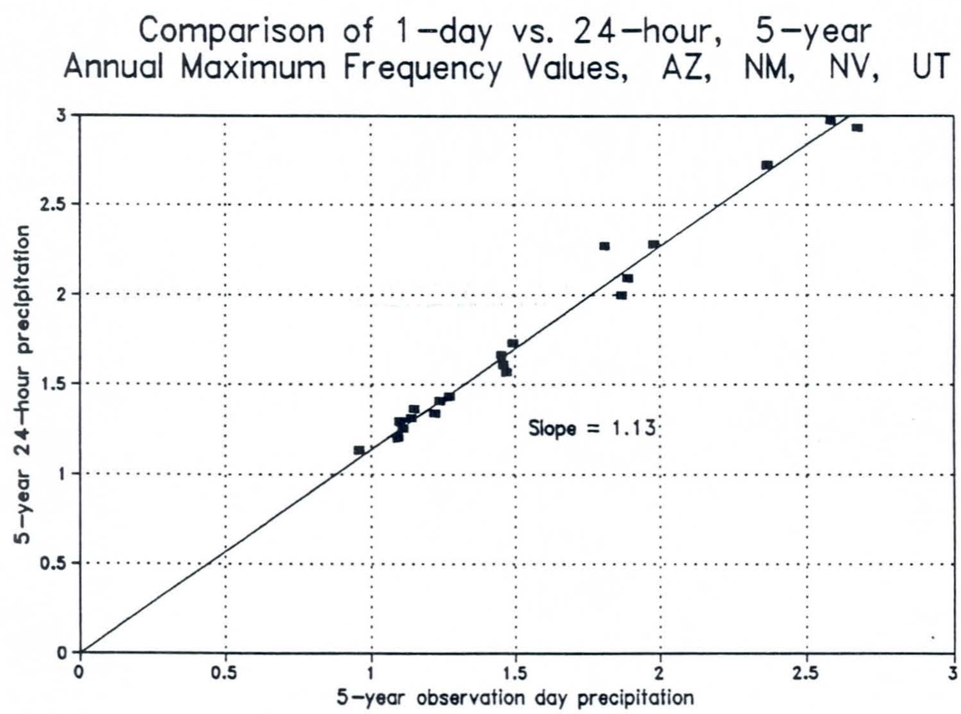

Figure 3b. Comparison of 5-year, 1 day vs. 24-hour values.

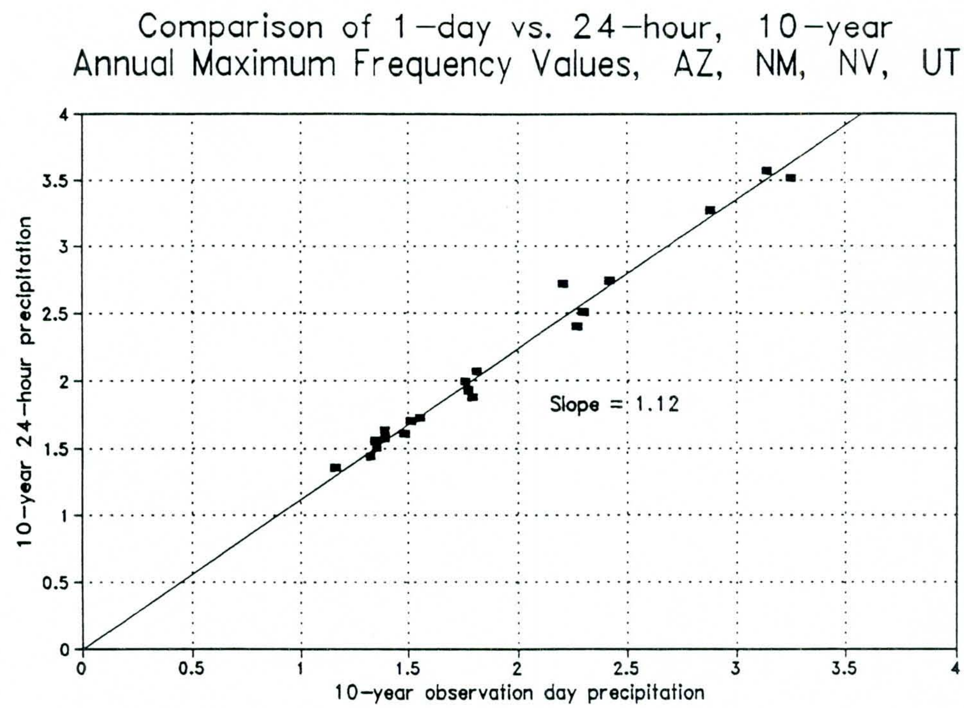

Figure 3c. Comparison of 10-year, 1 day vs. 24-hour values.

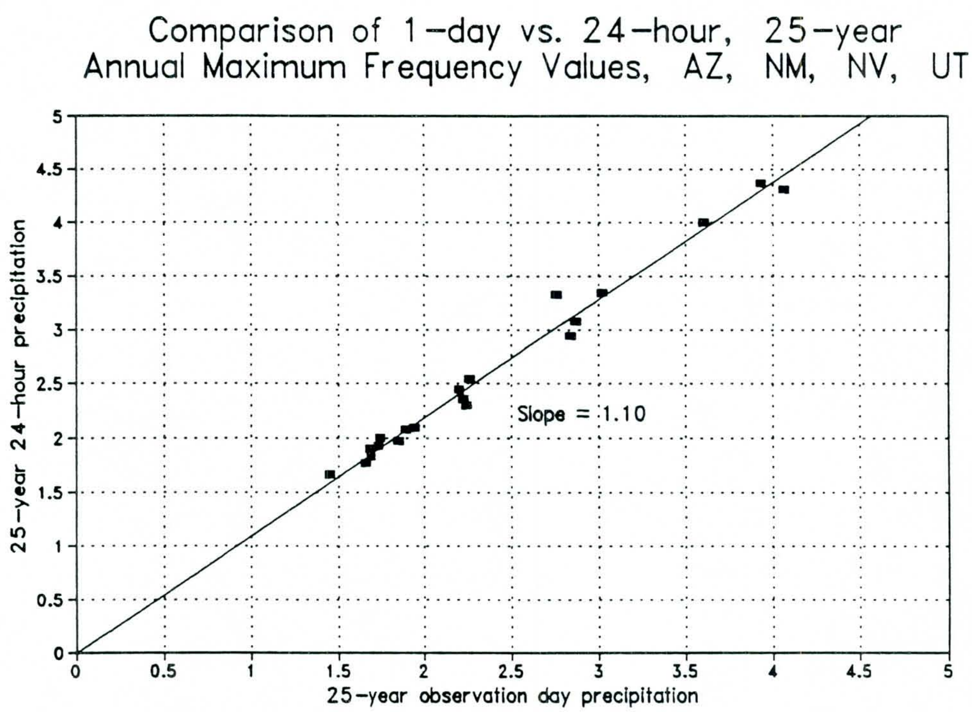

Figure 3d. Comparison of 25-year, 1 day vs. 24-hour values.

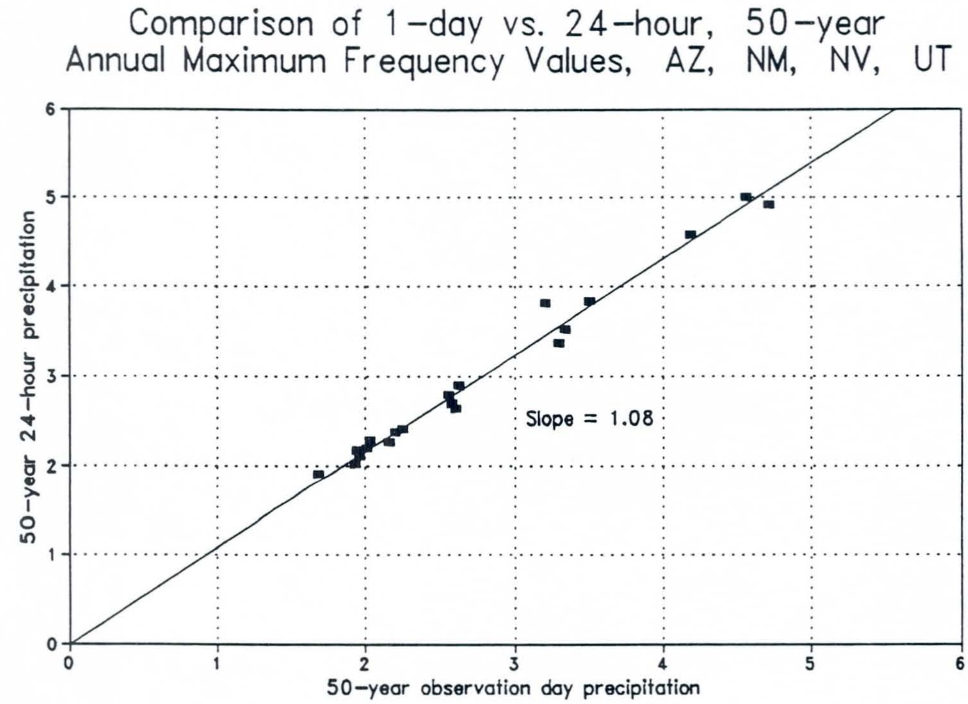

Figure 3e. Comparison of 50-year, 1 day vs. 24-hour values.

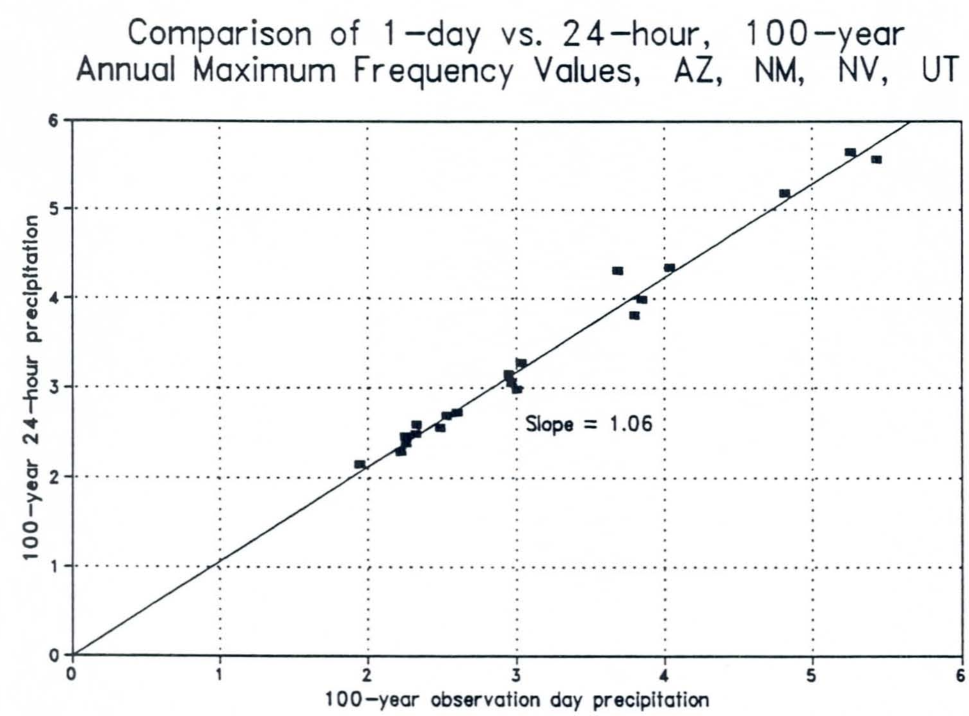

Figure 3f. Comparison of 100-yr, 1 day vs. 24-hour values.

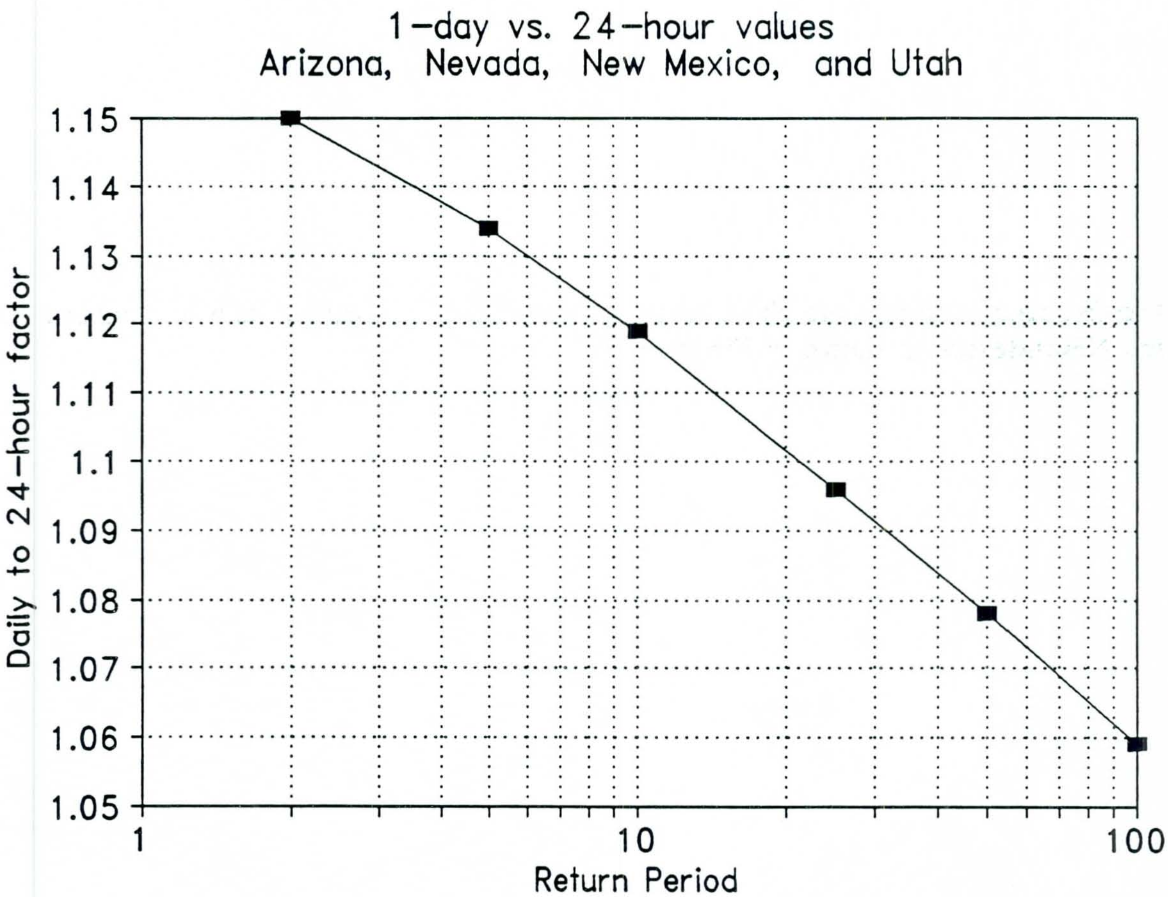

Figure 4. 2-year to 100-year comparisons.

N-hour ratios

Ratios of durations: 1, 2, 3, 6, 12, and 48 hours to 24 hours for all return periods were computed for all hourly stations in the project area for all-season, and for summer and winter seasons. From an initial review of the ratios, it appears that the shorter durations are the major contributors to extreme events of all durations. Within individual regions, there is reasonable spatial continuity. Examples of seasonal 3-hr/24-hr, 2-year ratios for two regions, region 8 (summer maximum) and region 16 (winter maximum) are shown in Figures 5a-d. In both cases the summer ratios are greater than the winter ratios, but there is a real difference in magnitude between the regions. For region 8, the 3-hr/24-hr ratios average about 0.60 in summer (Figure 5a) and about 0.40 in winter (Figure 5b); whereas, in region 16 the 3-hr/24-hr ratios average about 0.55 in summer (Figure 5c) and about 0.25 in winter (Figure 5d).

Frequency Analysis

The frequency analyses are about ready for production. A sample map of southern Arizona and New Mexico is shown in Figure 6. The 100-year, 24-hour, return frequency values of hourly data are plotted on this map. The complete plotted map will have daily stations (converted to 24-hour values), SNOTEL stations (also converted to 24-hour values), and topographic background. The maps will be computer-plotted, hand-analyzed, and then digitized for computer mapping.

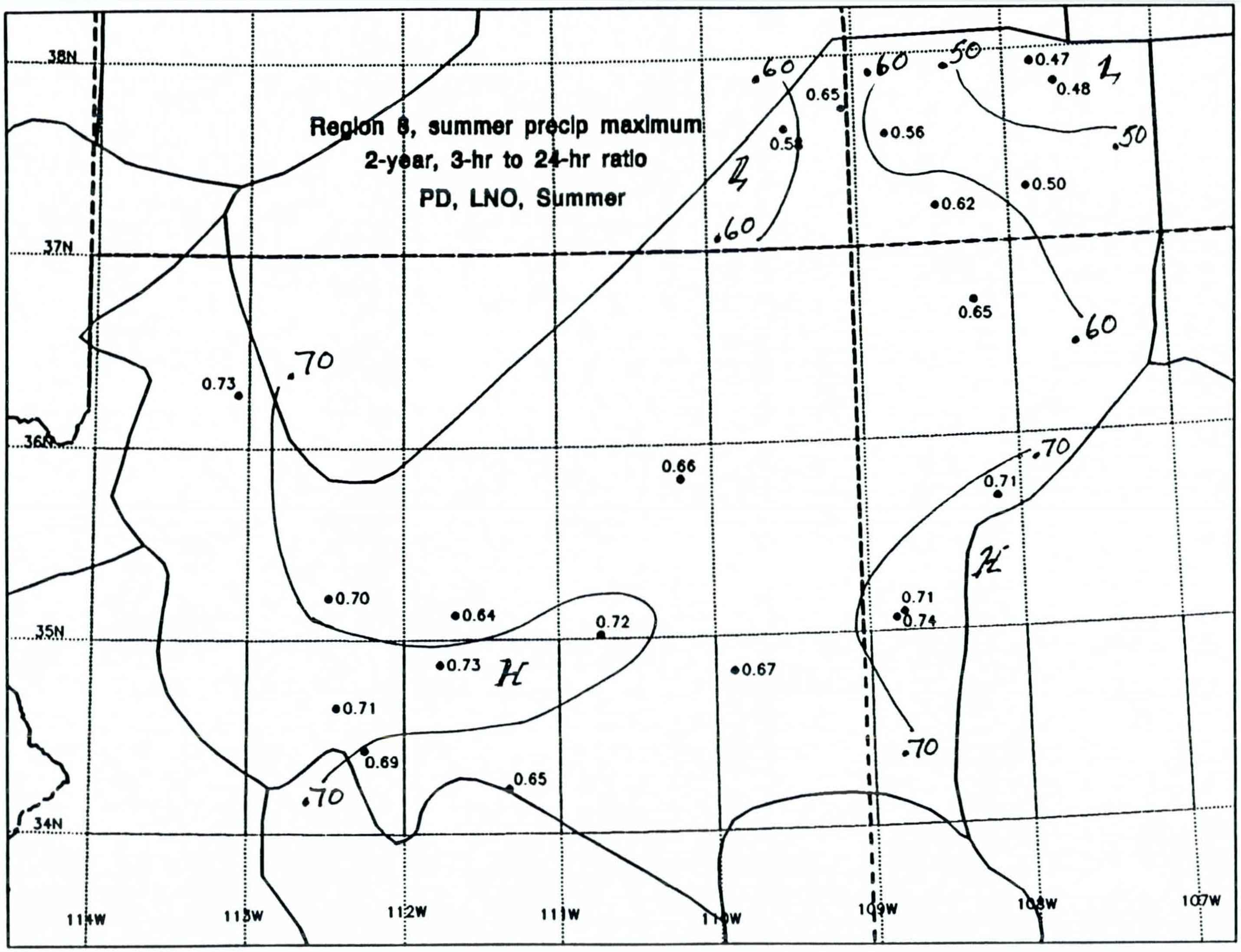

Figure 5a. Region 8, hourly stations. Summer ratios for 2-year, 3-hr to 24-hr. Ratios vary from 0.47 to 0.74, a range of 0.27.

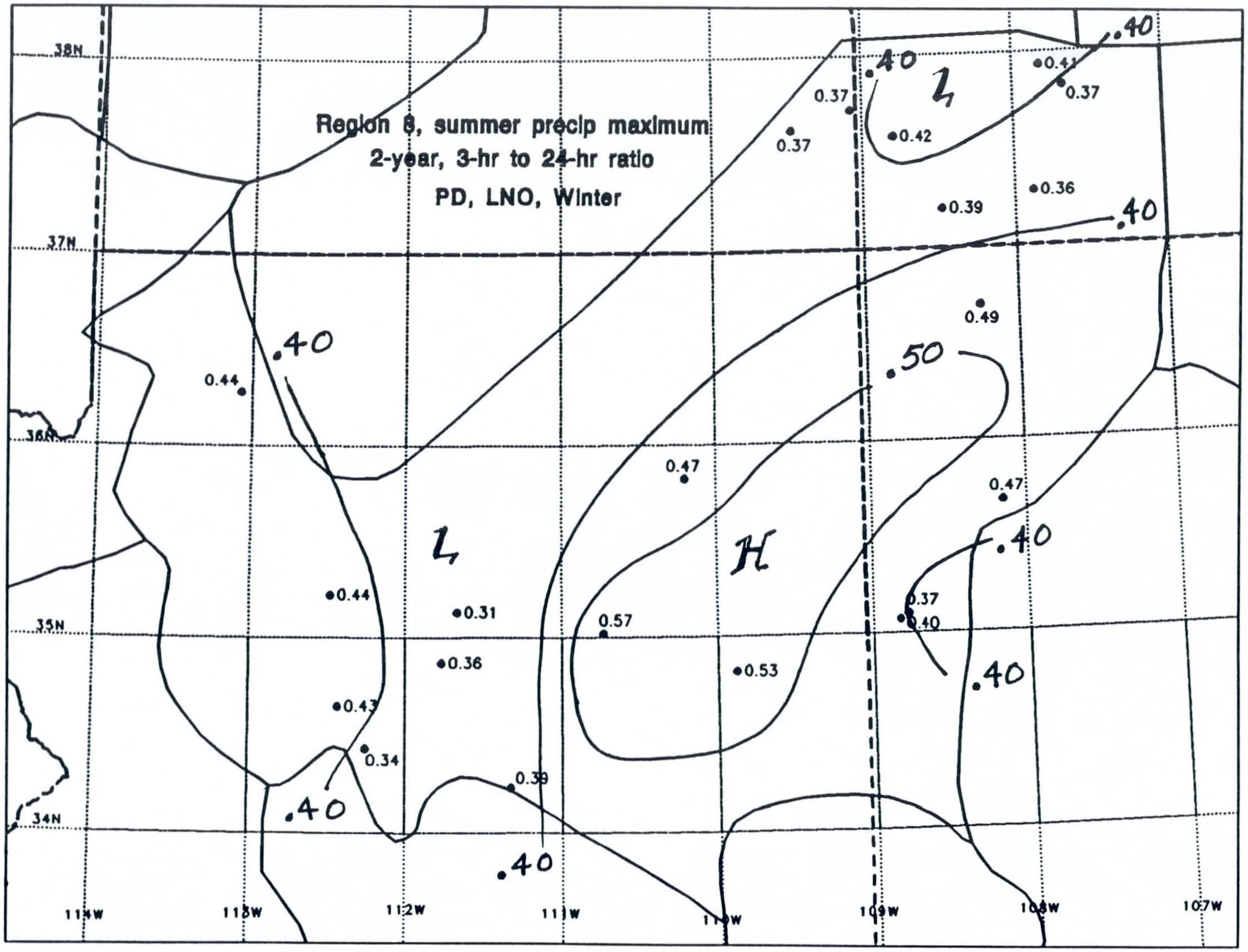

Figure 5b. Region 8, hourly stations. Winter ratios for 2-year, 3-hr to 24-hr. Ratios vary from 0.31 to 0.57, a range of 0.26.

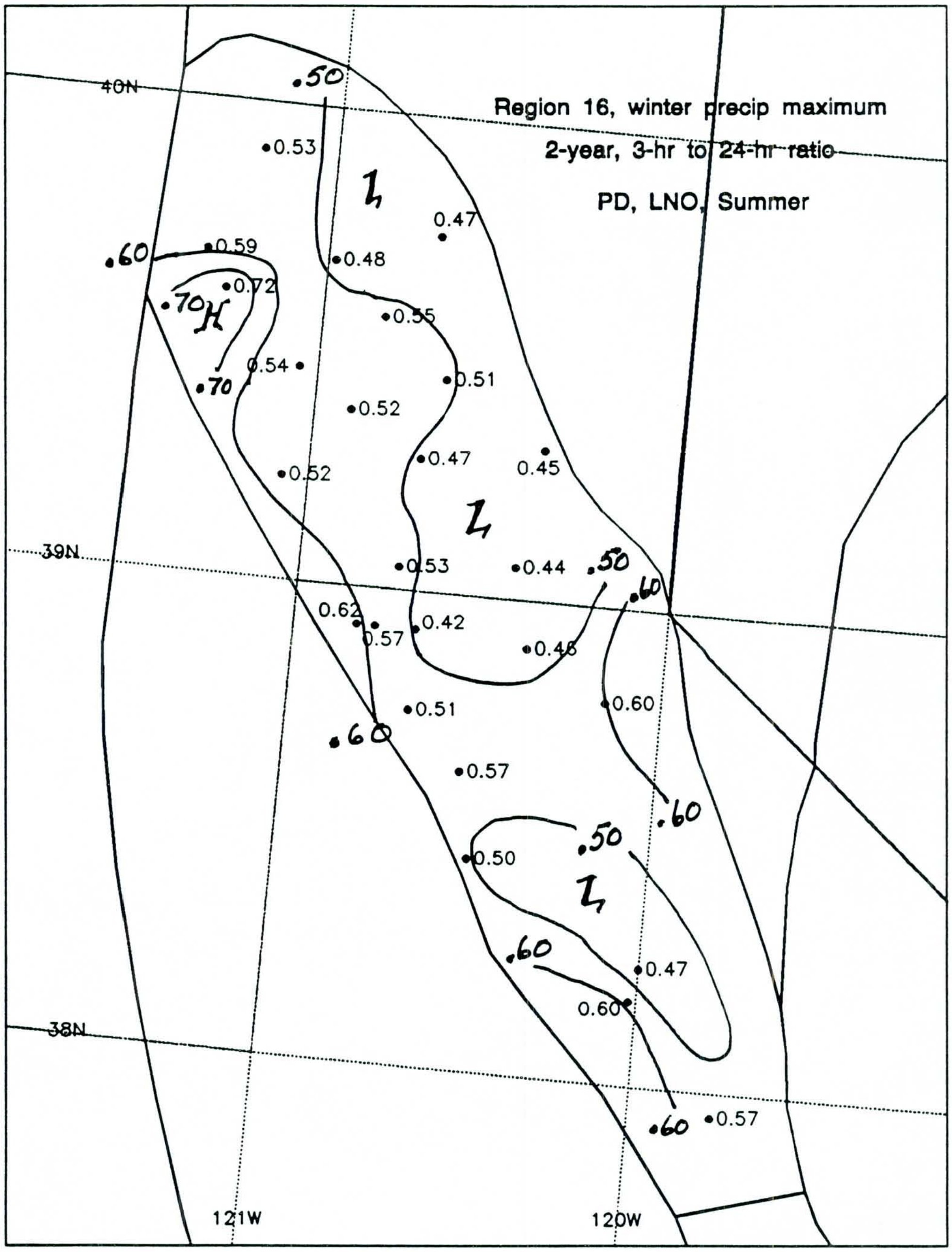

Figure 5c. Region 16, hourly stations. Summer ratios for 2-yr, 3-hr to 24-hr. Ratios vary from 0.44 to 0.72, a range of 0.28.

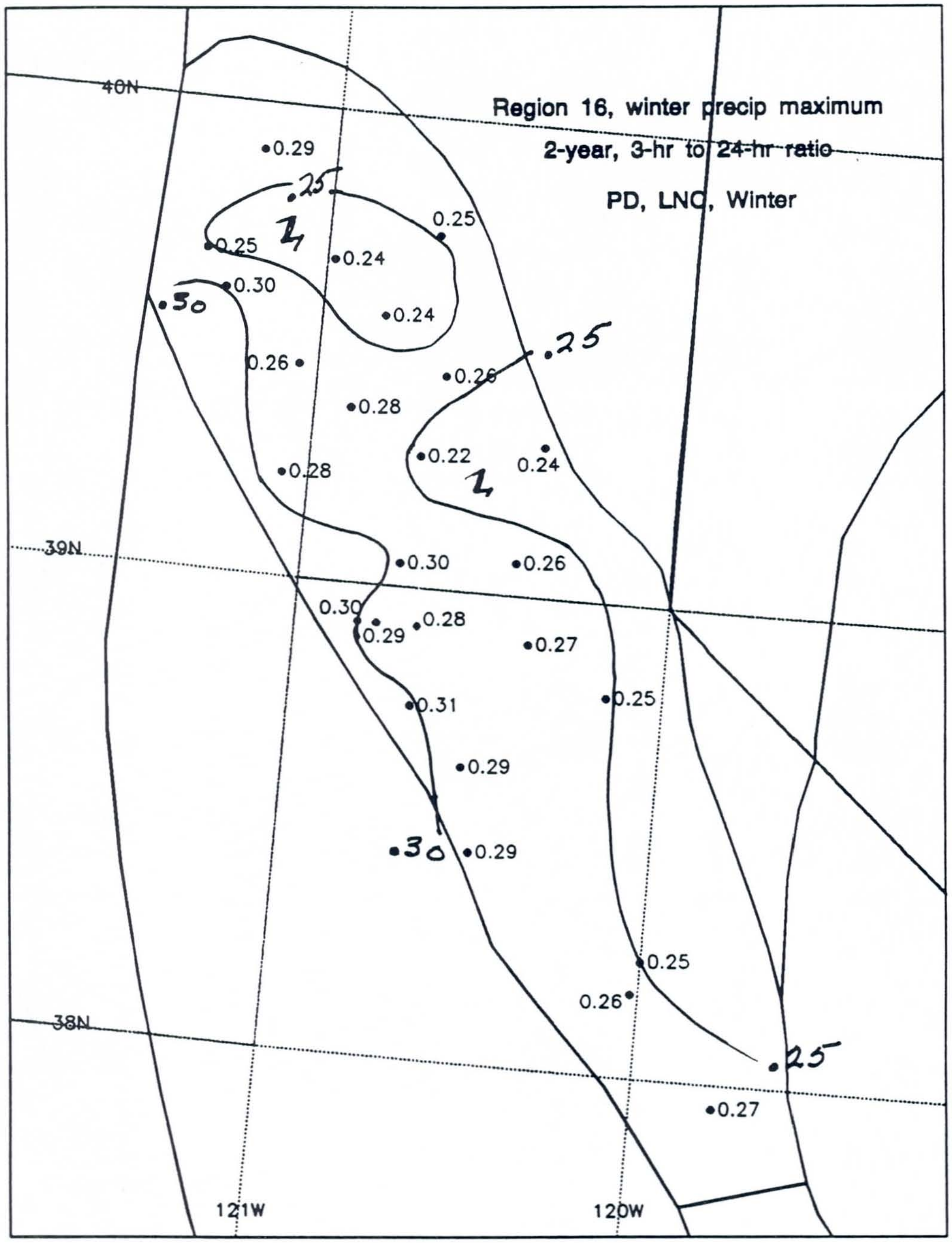

Figure 5d. Region 16, hourly stations. Winter ratios for 2-year, 3-hr to 24-hr. Ratios vary from 0.22 to 0.31, a range of 0.09.

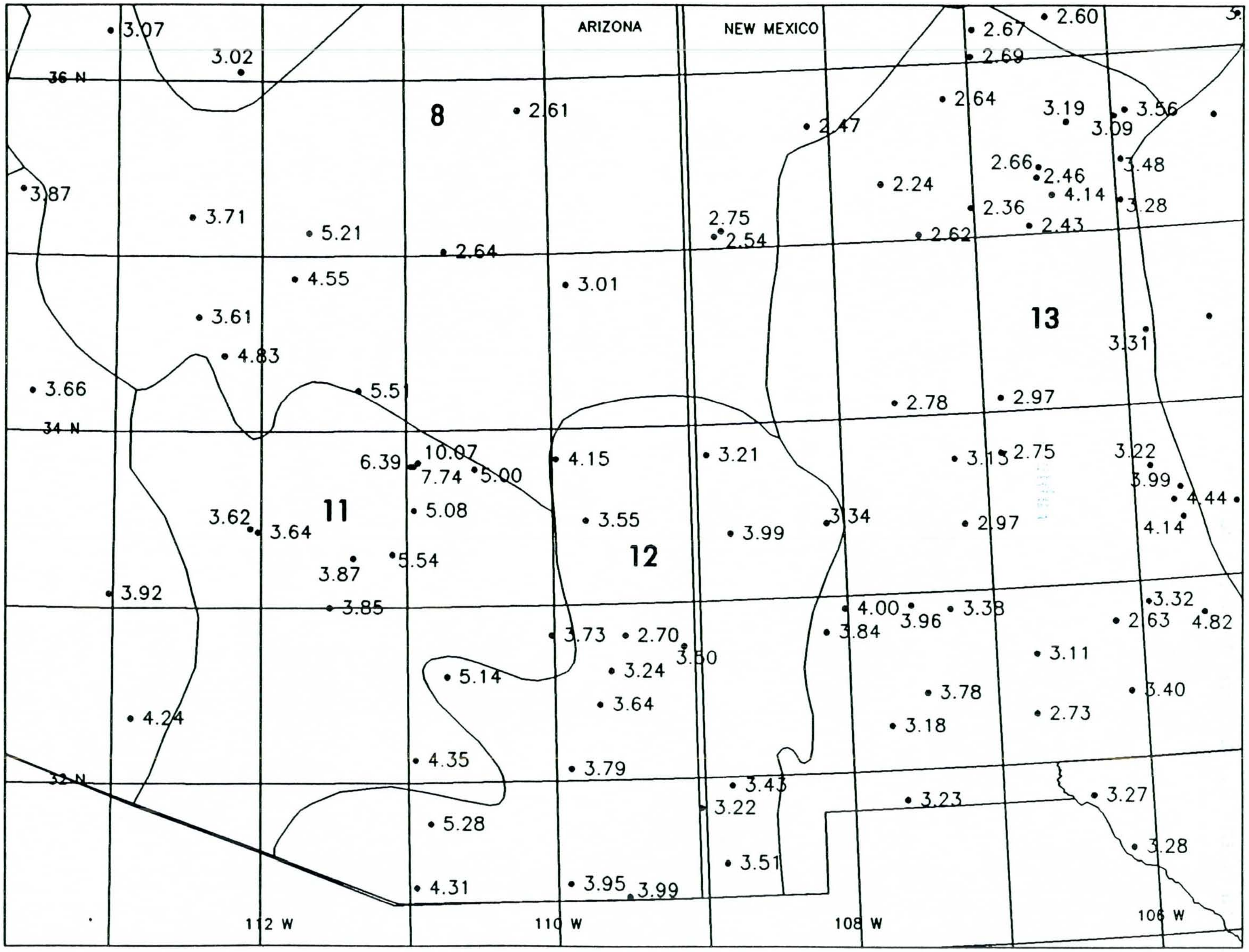

Figure 6. 100-year, 24-hour partial duration, frequency values (inches) for hourly stations, DRAFT.

STORM ANALYSIS

An initial storm list has been prepared and is presented in Table 3. Some local storms, and some storms that have been analyzed for other studies may be added to the list. The first storm being analyzed occurred September 26 - October 4, 1984 and covers nearly the entire study area.

Table 3.

All-Season			Winter		
Date		States	Date		States
8/27-29/	1951	AZ,NM,UT	12/23/	1948	AZ
3/22-23/	1954	AZ	12/30-31/	1951	AZ,TX,UT
10/6-7/	1954	NM	12/25/	1959	AZ
5/18-19/	1955	NM	12/10/	1965	AZ
10/29-30/	1959	AZ,CA	12/6/	1966	AZ
7/5-8/	1960	NM	12/15-16/	1967	AZ,CA
9/5-6/	1970	AZ,UT	12/19-20/	1967	AZ
10/19/	1972	AZ	12/17-20/	1978	AZ,CO,NM,UT
9/12/	1975	NM,UT	Nov-Dec/	1992	AZ
9/28-10/2/	1983	AZ,NV,NM			

SUMMARY AND OUTLOOK

Daily and hourly datasets are essentially in order for analysis. Computer programs - L-moment and other software for data preparation, testing, analysis, computer mapping, etc. - have been developed, modified, and tested, and are operational. Ratios for shorter durations and multi-day partial duration series are nearly complete. Digital elevation data are ready on the computing system at a resolution of three arc-sec (about 90 meters). As a result, return frequency analyses are nearly ready for production for varying durations from 1 hour to 1 day to 60 days.

The storm analysis study is proceeding. The procedures are in place and the first storms are being analyzed. Initially, emphasis will be placed on all-season storms. In other studies, storms have been limited to 1- to 5-day events. In this analysis, longer duration storms will also be evaluated.

N-minute data have been assembled. This took much longer than originally anticipated. The n-minute data are seldom used. Even when acquiring the data from NCDC, it took much time and effort to have people recover these data. Furthermore, the tape formats that were supposed to be associated with these data were wrong and we had to decipher the proper format.

Development of relationships between SNOTEL (higher elevation data) and data with longer records from NCDC and other groups is continuing. This will provide return-frequency information at higher elevations, that has not been previously available in southwestern United States.

REFERENCES

Hershfield, D.M., 1961: Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years, Weather Bureau Technical Paper No. 40, U.S. Weather Bureau, Washington, D.C., 115 pp.

Hosking, J.R.M. and Wallis, J.R., 1991: Some statistics useful in regional frequency analysis, Research Report, RC 17096, IBM Res. Div., Yorktown Heights, N.Y., 23 pp.

Lin, B., and Vogel, J.L., 1993: A comparison of L-moments with method of moments, Engineering Hydrology, Symposium Proceedings, ASCE, New York, 443-448.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973: Precipitation-frequency atlas of the western United States, NOAA Atlas 2, National Weather Service, Silver Spring, Md.

APPENDIX

Discordancy

Initially, the discordancy measure was used for data checking and quality control. However, in evaluating regions, it is used to determine if a site has been assigned to the appropriate region. It is based on L-moments (L-coefficient-of-variation (L-CV), L-skewness (L-SK), and L-kurtosis (L-KT)), which represent a point in 3-dimensional space, for each site. Then, discordancy (D) is a function of the distance from the cluster of points for the sites in the region being tested. The cluster center is in fact the unweighted mean of the three moments for the sites within the region being tested. Sites with a discordancy value of 3 or greater are considered discordant, and should be examined to see if they possibly belong in another region or have a data problem. The threshold value of 3 is not a rigorous test, but a reasonable level to be expected within a homogeneous region.

Heterogeneity

Actually, the heterogeneity test consists of three parts, one (H-1) based on L-CV, the second (H-2) based on L-CV and L-SK, and the third (H-3) based on L-SK and L-KT. As in the discordancy test, there is also a threshold value; Hosking and Wallis (1991) recommend a threshold of 1. However, they used wind data in establishing this threshold, and later conversations with Wallis (personal communication 1993) indicate that a threshold of 2 is reasonable, especially for precipitation data. Therefore, for each H-test, a value greater than 2 indicates heterogeneity (H>2), rather than homogeneity (H<2). In general, H-1, based on L-coefficient of variation (L-CV) is most stringent. As precipitation data are highly variable in any case, the heterogeneity results were considered giving less weight to the L-CV criterion.

Goodness-of-fit

This test measures the "distance" of L-moment statistical parameters of a dataset from various theoretical probability distributions. The threshold for goodness-of-fit tests is 1.64 (absolute value), and 'best-fit' values are those less than or equal to the threshold. For partial duration, Generalized Log-Normal (LNO), Pearson Log-III (PIII), and Generalized Pareto (GPA) are acceptable distributions for most durations.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

May 11, 1994 W/OH11/LFT

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Tenth Quarterly Report - Semiarid Precipitation Frequency Project, January 1 - March 31, 1993

Enclosed is a copy of the Tenth Quarterly Progress Report for the Semiarid Precipitation Frequency Project for the southwestern United States. This update outlines final production procedures for the return frequency maps and storm analyses. These procedures are in current use. The report includes the periods of record for the final datasets (daily, hourly, SNOTEL, and Mexican); and also a complete list of Semiarid storms being analyzed. Presently, we are concentrating on finalizing the return frequncies for the Southwest. In addition, we are examining various storms using the strom-analysis program over the Southwest to develop new insights into depth-area-duration and storm mass curves.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMIARID PRECIPITATION FREQUENCY STUDY

Tenth Quarterly Progress Report
for the period from
January 1 through March 31, 1994

Lesley F. Tarleton, Julie M. Olson, Edwin H. Chin,
Susan M. Gillette, John L. Vogel, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
April 1994

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SEMIARID PRECIPITATION FREQUENCY STUDY

Tenth Quarterly Progress Report
for the period from
January 1 through March 31, 1994

OVERVIEW

This Tenth Quarterly Report summarizes the work for the Semiarid Precipitation Frequency Project for the period January 1 through March 31, 1994.

The dataset for the 24-hour duration analysis for the Semiarid study area is complete. It contains 1182 daily stations, 449 hourly stations, 145 SNOpack TELemetry (SNOTEL) stations, and 108 daily stations from Mexico. A procedure for mapping various return frequencies by combining the analytic skill of experienced meteorologists and the computational and graphic facility of the computer system has been determined. It is described in this report. A complete storm list is included, with 13 general or 'all-season' storms and 10 winter storms. Some storm analysis examples are included.

DATA

The complete dataset - daily, hourly, SNOTEL, and Mexican daily stations - for the Semiarid study is shown in the map in Figure 1. For reference, Figure 2 shows the regions and states. A partial duration series is used for all data analyses. Return frequencies are computed using L-moment statistics (Hosking and Wallis, 1991) and a Log-normal (LNO) probability distribution. However, certain adjustments must be made to the daily and SNOTEL return frequency values to make the different datasets compatible so that they can be combined in a single dataset.

- The daily return frequencies are converted to 24-hour data using the conversion factors shown in Table 1 (page 4). (Also shown are the conversions from 2-day data to 48-hour data.) The conversion is necessary because of varying observation times for daily data, and the fact that the maximum 24-hour amounts seldom fall within a single daily observation period. The conversion factors are described more fully in the Ninth Quarterly Report (Oct-Dec 1992).

- The hourly return frequencies do not need adjustment for the 24-hour duration. However, they must be adjusted for 1-hour and 2-hour durations for the same reasons given in the first item.

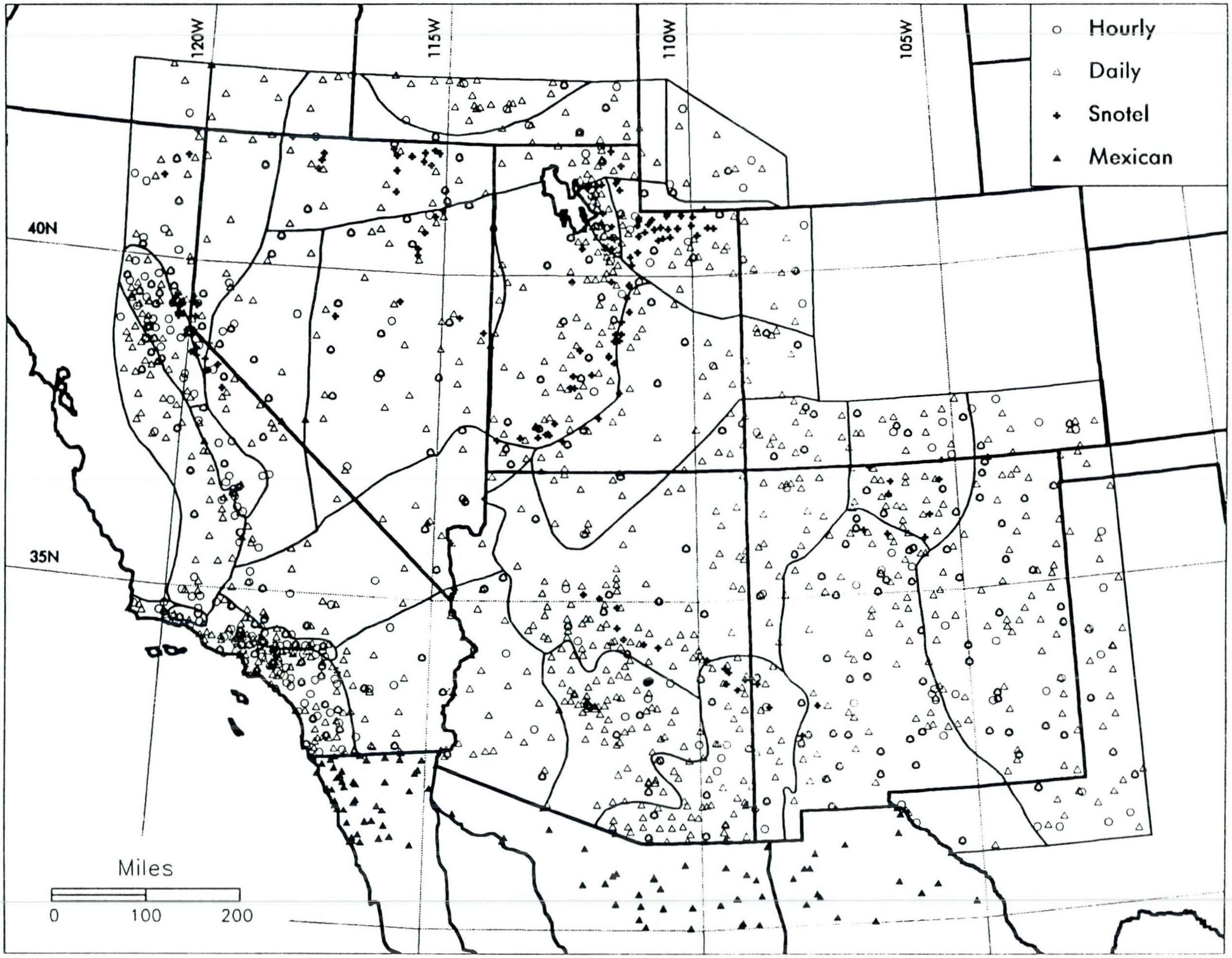

Figure 1. Location of hourly, daily, SNOTEL and Mexican daily stations used in the Semiarid study.

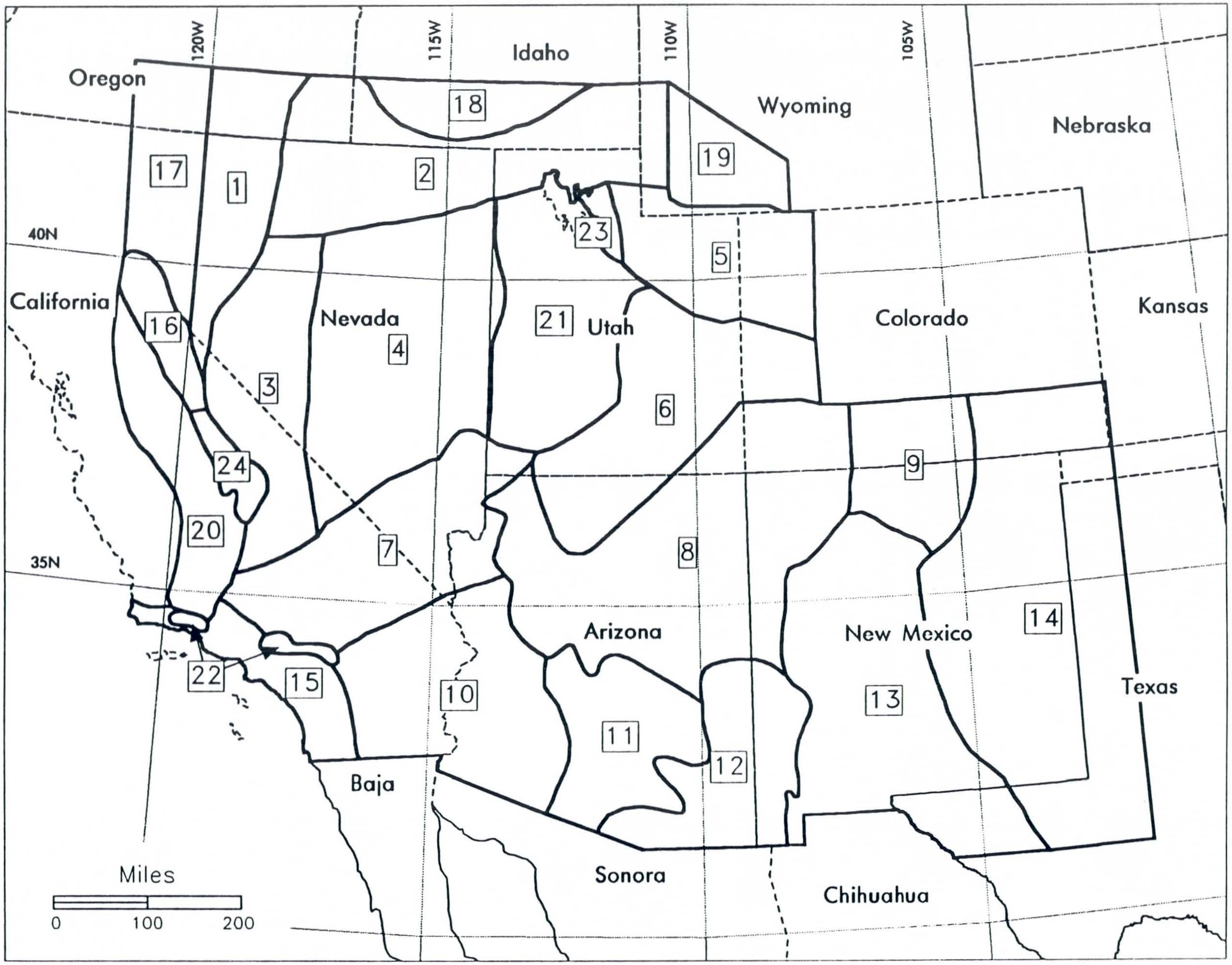

Figure 2. Climatic regions developed for the Semiarid study.

- The SNOTEL stations are sited at high altitudes (6000-11,000 feet) and add considerable information to the analyses, as NCDC coverage is very limited at high elevations. Unfortunately, SNOTEL records are rather short (from 5 to 14 years). Therefore, we have developed ratios of short records to long records, using nearby daily and hourly stations, to adjust the SNOTEL return-frequency dataset for its limited sample period. As SNOTEL data are daily observations, they are also converted to 24 hours with the factors in Table 1.

- The Mexican data are all daily observations, and are adjusted to 24-hour return frequencies using Table 1. The Mexican stations also have short records (from 5 to 15 years), but further adjustments have not been made at this time. These digital data were made available through the cooperation of Mr. Jorge Sanchez-Sesma, Instituto Mexicano de Technologia del Agua, Mexico City, Mexico.

Table 1.

Conversion Factors

Return Period	1-day to 24-hr	2-day to 48-hr
2-year	1.15	1.02
5-year	1.13	1.02
10-year	1.12	1.02
25-year	1.10	1.00
50-year	1.08	1.00
100-year	1.06	1.00
500-year	1.04	1.00

Period of Record

The years of record by state for all the stations are shown in Tables 2a-d: 2a, Daily; 2b, Hourly; 2c, SNOTEL; 2d: Mexican. The daily stations have the longest records with over 20 percent having records of more than 60 years, and nearly 3 percent with more than 90 years. Ninety-nine percent of daily stations have 20 or more years of data. The longest records (98 years) are at Santa Fe, New Mexico, and Clifton and Parker, Arizona. Several stations have been in operation through a longer period of time, but some years of data are missing. Eighty-eight percent of hourly stations have more than 20 years ofrecord, and nearly 50 percent have more than 40 years. For the SNOTEL and Mexican data the maximum records available are 15 years. In both cases, slightly more than 80 percent of the stations have from 10 to 15 years of record.

Table 2a.

Semiarid Precipitation Stations - Daily

Years of record by state.

#Yrs	AZ	CA	NM	NV	UT	ID	CO	TX	WY	OR	OK	Total	%total
19	3	1	2	5								11	100.0
20	5	4	1	4								14	99.1
21	7	10	3	1	2	1						24	97.9
22	7	7	1	2	2							19	95.9
23	3	7	2	2	3	1	3	1				22	94.2
24	5	12		2	3		2			1		25	92.4
25	9	9	2	5	2			1				28	90.3
26	6	8	3	6	3		2		1			29	87.9
27	6	3			2		1	1	2			15	85.4
28	4	6	6	2	3	1	1	1				24	84.2
29	6	6	2		4	1	1					20	82.1
30	5	4	3		2	2	1	1				18	80.5
31	9	5	5	2	2	3	2		1			29	78.9
32	8	5	2	1	3			1		1		21	76.5
33	5	6	5	1	3		2	1				23	74.7
34	6	6	2	2	8					1		25	72.8
35	7	3	2		8		1					21	70.6
36	5	4	1	3	2		1			1		17	68.9
37	4	4	6	3	5	1	1	2	1	1		28	67.4
38	5	4	8	2			2	1				22	65.1
39	2	3	1		2		1					9	63.2
40	10	7	1	5	7		2					32	62.4
41	7	8	3	1	2			1	1	1		24	59.7
42	2	4	8	3	5		4					26	57.7
43	10	12	12	1	10		2					47	55.5
44	2	46	5	1		1	7	1	1		1	65	51.5
45	5	65	6		1	7	14	3	1	2	2	106	46.0
46	3		10		2	1		2				18	37.1
47	1	1	3	2	3	1						11	35.5
48	2		4	2				1				9	34.6
49	7	2	6	1	3		1					20	33.8
50	5	1	4	3	2	1		1				17	32.1
51	3		6	1	4							14	30.7
52	7	1			2	1		1				12	29.5
53	4		4	1						1		10	28.5
54	2	2	5	1		1		1				12	27.7
55	4	1	1	1	1			2				10	26.6
56	3		5	1	5							14	25.8
57	6		7	1	1	1						16	24.6
58	3	1	3		1		1					9	23.3
59		1	1		1	1						4	22.5

Table 2a. (continued)

#Yrs	AZ	CA	NM	NV	UT	ID	CO	TX	WY	OR	OK	Total	%total
60	5	1	1	2				1				10	22.2
61		1	3		4	1		1		1		11	21.3
62	2	6	2	2	4	4		1				21	20.4
63			4	2	4		2					12	18.6
64			4		1							5	17.6
65	3	9	2		2							16	17.2
66		3	7	1	1		1					13	15.8
67	2		7		1			2				12	14.7
68	1		3	1	1							6	13.7
69			2		1	1		1				5	13.2
70	4		1		2				1			8	12.8
71	2		3		3			1				9	12.1
72	2		4	2	3							11	11.3
73	1		1		1							3	10.4
74	1		3	1								5	10.2
75			5		1							6	9.7
76	3		1	2								6	9.2
77	2			2	5				1			10	8.7
78	3				1							4	7.9
79	3			2	1	1						7	7.5
80	3		1									4	6.9
81	1		1		2							4	6.6
82	4		1		1							6	6.3
83	1			1	1							3	5.8
84	2				3							5	5.5
85	1				1		1					3	5.1
86	4		1	1	1							7	4.8
87			1	2			2					5	4.2
88			2		2							4	3.8
89				1	2		1					4	3.5
90	2				1							3	3.1
91	2			2	1		1		1			7	2.9
92	2				5							7	2.3
93	2		1		6		1					10	1.7
94	1								1			2	0.8
95	2											2	0.7
96	1											1	0.5
97	2											2	0.4
98	2		1									3	0.3
Sum	269	289	213	92	171	32	61	30	12	10	3	1182	

Table 2b.

Semiarid Precipitation Stations - Hourly

Years of record by state.

#Yrs	AZ	CA	NM	NV	UT	ID	CO	TX	WY	OR	Total	%total
15	1			1	1						3	100.0
16		2	1	1			1				5	99.3
17		5	2	1	1						9	98.2
18	2	5	1	1	1		1		1		12	96.2
19	4	4	1	1	3						13	93.5
20	1	4	4	1	1		1				12	90.6
21	2	5	5	2	3	1	1				19	88.0
22	1	3	4	3	2						13	83.7
23		3	3								6	80.8
24	1	8	5	2			2				18	79.5
25	2	4	3	2	2	1		1	1		16	75.5
26	1	3	2				1				7	71.9
27	1	4	1	2		1	1	1	1		12	70.4
28		3	1	1							5	67.7
29	1	3	2	1	1						8	66.6
30		6									6	64.8
31		1				1			1		3	63.5
32		3	2			1					6	62.8
33		5	2					1			8	61.5
34		3	1	2	1		1				8	59.7
35		3	1		1						5	57.9
36		7			2						9	56.8
37		3	1	1	1			1			7	54.8
38	2	3		1		1	1	1			9	53.2
39	1	1	1				1				4	51.2
40	1	4	1	3	1	1			1		12	50.3
41		8	1	1	1						11	47.7
42		7			3		2	1	1		14	45.2
43	1	16	1		2		1	1	1		23	42.1
44	4	8	2	3	1					2	20	37.0
45	16	48	33	11	16	2	11	1			138	32.5
46											0	1.8
47											0	1.8
48											0	1.8
49								4			4	1.8
50								3			3	0.9
51								1			1	0.2
Sum	42	182	81	41	44	9	25	16	7	2	449	

Table 2c.
Semiarid Precipitation Stations - SNOTEL

Years of record by state.

#Years	AZ	CA	NM	NV	UT	Total	%total
6					1	1	100.0
7		1			6	7	99.3
8	2	1			1	4	94.5
9	2			3		5	91.7
10	10	1				11	88.3
11		2	1	3	8	14	80.7
12		10	7	13	13	43	71.0
13		2	5	2	12	21	41.4
14		8		6	25	39	26.9
Sum	14	25	13	27	66	145	

Table 2d.
Semiarid Precipitation Stations - Mexico

Years of record by state.

#Years	Baja	Sonora	Chihuahua	Total	%total
5	3	2		5	100.0
6		2	1	3	95.4
7	3	1	2	6	92.6
8	4	1		5	87.0
9		2		2	82.4
10	7	1		8	80.6
11	2	1	2	5	73.1
12			1	1	68.5
13	2	2	3	7	67.6
14	4	6	3	13	61.1
15	23	21	9	53	49.1
Sum	48	39	21	108	

Other Durations

Using the daily data, partial duration series for 2, 4, 7, 10, 20, 30, 45, and 60 days are being developed. The 2-day and 10-day partial duration series are nearly complete. Frequency analyses for all these durations will be prepared using L-moment software and the Log-normal (LNO) probability distribution.

Partial duration series of hourly data have been used to prepare all-season, summer, and winter return-frequency values for various durations: 1, 2, 3, 6, 12, 24, and 48 hours. In addition, the hourly data have been used to develop ratios to daily data to extend the daily dataset to shorter durations, and to develop conversion factors from daily to 24-hour data.

N-Minute Data

Format problems have continued to plague the access of n-minute data. Although we now have about 20 to 30 stations with varying record lengths from the 1940s through 1992 (and a few stations that begin in the 1890s), these digital data are in at least three different formats. Therefore, software must be written to collate these data into a single database. However, it is anticipated that once the format problems are resolved, the data will need little or no quality control. The n-minute data are needed for calculating return frequencies of less than one-hour durations. The n-minute dataset includes durations of 5, 10, 15, 30, 45, 60, 120, and 180 minutes. There is also a dataset of 15-minute data only. These 15-minute data are also being processed for short-duration analysis.

Other Data

The data from 12 recording raingages from the U.S. Geological Survey (USGS) dense network for the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) have been sent to us by telnet. These data are 5-minute recorder data from 12 to 15 gages in the Albuquerque metropolitan area. These are invaluable for evaluation on small scales, both temporally and spatially.

ANALYSIS

Frequency Analysis

All frequency calculations are based on L-moment regional analysis of the stations within each region, thus taking advantage of the physical similarities or near-homogeneity within each region to strengthen the statistics.

Mapping procedure.
The procedure for producing maps of various return frequencies from the 2-year analysis using GRASS Geographic Information System software on RISC-6000 workstations, has been developed and tested. This system is capable of taking a field of isolines, (or vectors in 'GRASS-speak'), and returning a raster field, in which individual grid squares covering the entire study area are each given a discrete value. (A raster is a single grid square with a single value). Calculations can be made based on any mathematical relation between two such raster fields in the same geographical location. GRASS can also take a given raster field and make a new map of isolines.

The procedure begins with a computer-plotted map of the 2-year, 24-hour return frequencies for all station data in the Semiarid study area. Actually, it begins with the complete quality-controlled dataset described above, of return frequencies that have been calculated from partial-duration series, using L-moment software, a Log-normal probability distribution, and near-homogeneous regions (as shown in Figure 2). A hand-drawn isohyetal analysis is prepared using the plotted precipitation data and an underlying smoothed elevation map. These isohyets are digitized back into the computer using the GRASS software. Calculations are then made to convert the vectors into a raster field. To prepare a 100-year return frequency map, ratios are determined between the 2-year and the 100-year return frequencies, based on the L-moment output for each region. Ratios are interpolated at regional boundaries. Calculations, using these ratios, are made on each grid square of the 2-year 24-hour raster map and, thus, generate a 100-year raster map. The resulting raster field is then changed back into a vector field and printed for the 100-year duration. Maps of other durations and return frequencies will be prepared similarly.

A few notes on why the 2-year return frequency is used as the standard. There are two basic reasons and they both have to do with statistical stability. One reason is that the 2-year value is at or near the median value of the data. The median is a stable statistic and little affected by outliers in the data. The second reason is related to sample size. Two-year return frequencies can be determined with more certainty from our dataset of 40-60 years of record than the higher return frequencies.

STORM ANALYSIS

Data for the storms listed in Tables 3a and 3b have been accessed and are being analyzed. Local storms and storms used for other studies may be added to the list. The 'original' storm 1019 (September 28 - October 3, 1983) has been divided into FOUR storms:

- 1019 - Arizona and western New Mexico, 9/26-10/2/83;
- 1020 - northern Utah, 9/24/-9/30/83;
- 1020 - Nevada, 9/26-10/2/83;
- 1022 - northern Utah, 9/30-10/2/83.

(Note: The Storm Numbers are reference numbers that have been given to storms analyzed in this office and are for filing and tracking purposes only. They are rather like accession numbers for a collection and have no intrinsic meaning other than the order to which they were added to our list. The Hydrometeorological Branch numbering system begins with '1000' to differentiate from storms analyzed by other agencies, e.g., the Corps of Engineers).

The division of the September-October, 1983, intense rainfall period into 4 storms was based on the nature of the precipitation, which is temporally sporadic or in "bursts," and the spatial distribution. Storm locations for 1019, 1020, 1021, and 1022 are shown in Figure 3. Storms 1020 and 1022 are co-located, but were separated for analysis, as there was a dry day between intense precipitation events. This extreme rainfall period for the fall of 1983 is well-remembered in Arizona. In checking the likelihood of 2 inches/hour at one station near Phoenix, a phone call to the NWS Forecast Office got the answer, "that was a terrible storm. I certainly remember! I was working at the station for 24 hours a day!, etc., etc." These events were definitely associated with hurricanes and tropical storms. The synoptic maps show at least three named tropical storms which preceded and/or coincided with the extreme rainfall. Probably Hurricane Manuel was most important in 'setting up' the high moisture content over the Southwest. This storm was almost stationary off the Baja coast (at about 20N,120W) from September 16-20. This was followed by Tropical Storm Narda, which tracked westward; and then Tropical Storm Octave, which tracked into northern Baja and southern California at the end of September. Smith (1986) describes the effects of Manuel and Octave on the rainfall in the Southwest. Also, this storm had an effect on the Colorado River Basin and is cited in Morrison-Knudson's (1990) engineering report on design storms for the Bureau of Reclamation.

For Storm 1019, the center is at or near Nogales, Arizona and (Nogales, Sonora) with a 5-day total of over 9 inches of rain. Heavy rain also occurred in northern Mexico. Fortunately, we have 1984 Mexican data for Sonora and can extend the analysis into the northern Mexico part of the storm. The data for Storm 1019 have been mapped and mass curves prepared. An example of the timing of the daily stations to the hourly stations is shown in Figure 4 (Casa Grande). The mass curves, digitized NOAA Atlas 2

Table 3a.
Semiarid General Storms

Storm #	Dates	Location
1019	9/27-10/3/83	AZ,NM
1020	9/26-9/29/83	UT,ID
1021	9/27-10/3/83	NV
1022	10/1-10/2/83	UT,ID
1023	8/27-8/30/51	AZ,NM,UT,TX
1024	3/21-3/24/54	AZ,NM
1025	10/6-10/7/54	AZ,NM
1026	5/18-5/19/55	NM,CO
1027	10/29-10/30/59	AZ,NM,NV,CA
1028	8/5-8/8/60	NM,TX
1029	9/4-9/6/70	AZ,NM,CO
1030	10/19/72	AZ,NM,TX
1031	9/12/75	NM,TX

Table 3b.
Semiarid Winter Storms

Storm #	Dates	Location
1032	12/23/48	AZ,NM,CO
1033	12/30-12/31/51	AZ,NV,UT
1034	12/25/59	AZ,NV,UT
1035	12/10/65	AZ,NM,NV
1036	12/6/66	AZ,NV,UT,CO
1037	12/15-12/16/67	AZ,NV,UT,CA
1038	12/19-12/20/67	AZ,NM,UT
1039	12/17-12/20/78	AZ,NM,NV,UT
1040	12/4-12/5/92	AZ,NM,NV,CA
1041	12/28-12/29/92	AZ,NV,CA

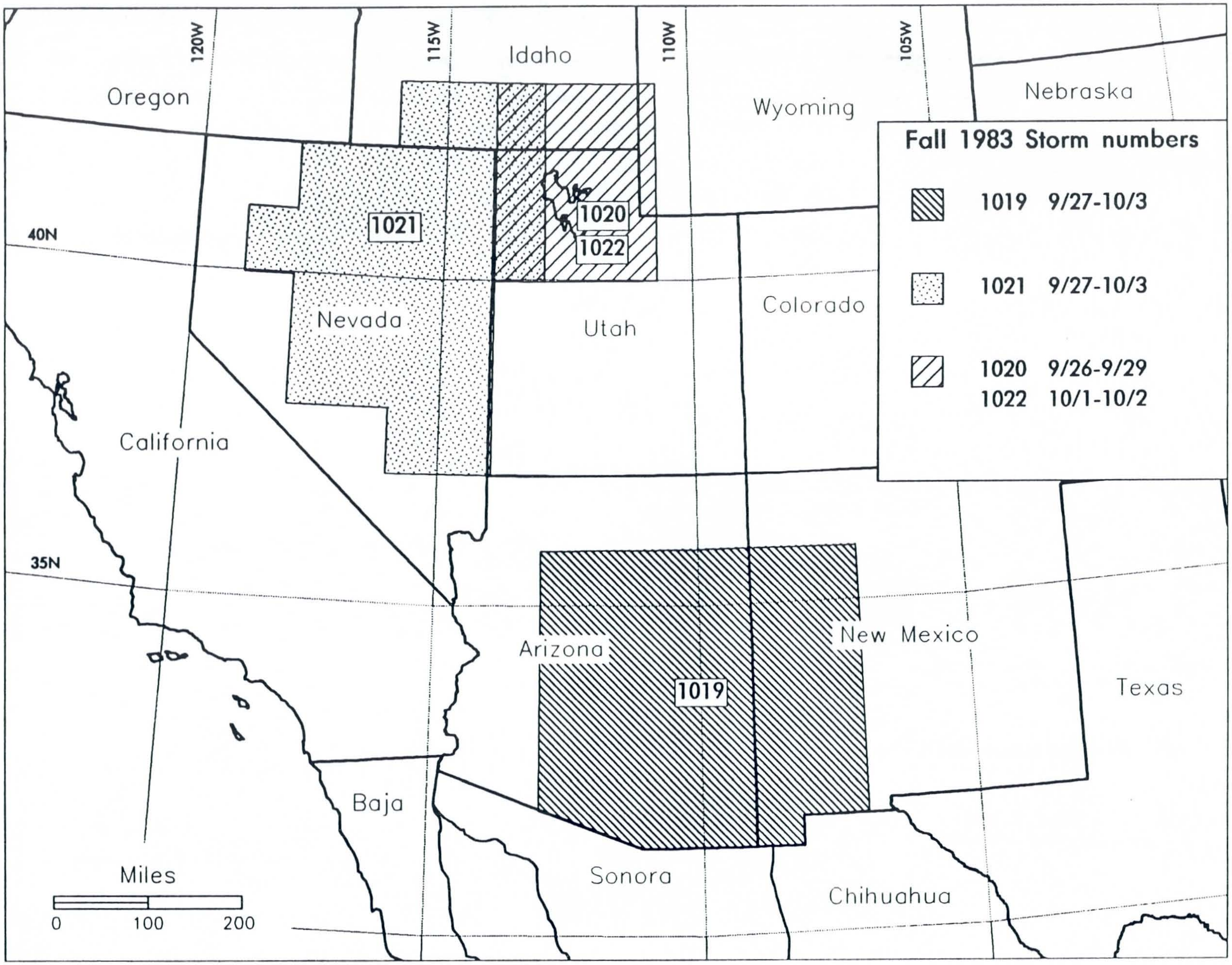

Figure 3. Fall 1983 storm dates and locations. Storm numbers for reference (see text for details).

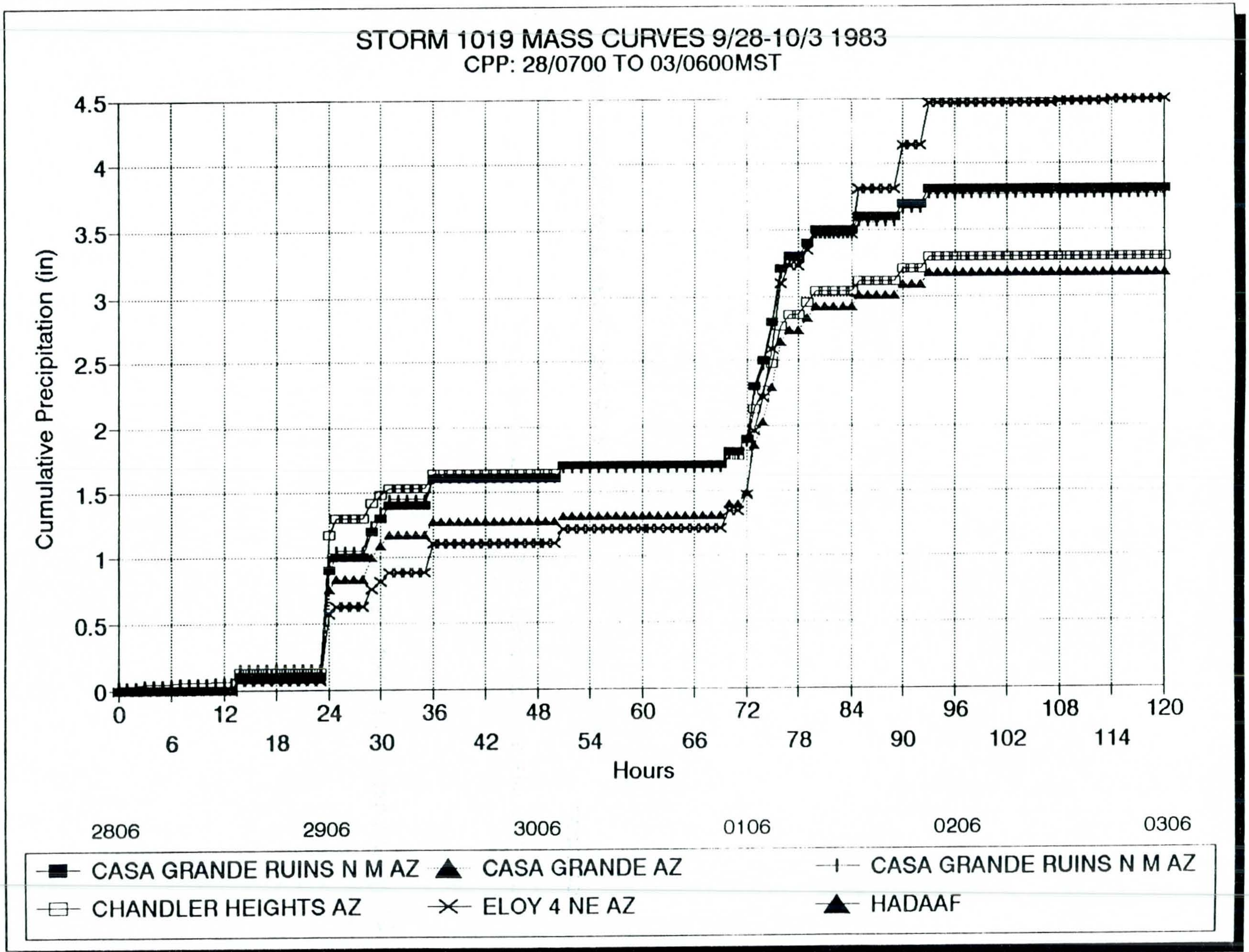

Figure 4. Example of mass curves used to time daily stations to hourly stations in storm analysis.

(Miller et al, 1973) data, and storm station data will be combined using several iterative steps of computer and hand-drawn analyses to produce an isohyetal map and depth-area-duration (DAD) curves for Storm 1019. All the storms will be processed in a similar manner and the final maps for each storm will be generated using GRASS software on the RISC-6000 workstation.

SUMMARY AND OUTLOOK

The dataset for the 24-hour duration analysis for the Semiarid study area is complete. It contains 1182 daily stations, 449 hourly stations, 145 SNOpack TELemetry (SNOTEL) stations, and 108 daily stations from Mexico. Durations up to 60 days, and those of less than one day are nearly complete.

Computer programs (L-moment and other software for data preparation, testing, analysis, computer mapping, etc.) have been developed, modified, and tested, and are operational. Ratios for shorter durations and multi-day partial duration series are nearly complete. Digital elevation data are ready on the computing system at a resolution of three arc-sec (about 90 meters). As a result, return frequency analyses are nearly ready for production for varying durations from 1 hour to 1 day to 60 days.

A procedure for mapping various return frequencies by combining the analytic skill of experienced meteorologists and the computational and graphic facility of the computer system has been developed and tested. The 24-hour, 2-year and 100-year maps are in production.

Storm analysis is in progress on 23 southwestern storms. Similar to the techniques we are using for frequency analysis, it combines human skill and computer resources to develop isohyetal maps and depth-area-duration curves. Thirteen general or 'all-season' storms and ten winter storms are in various stages of analysis.

N-minute data have been assembled. This took much longer than originally anticipated due to varying formats and difficulty in determining the correct formats. These data are being put into a single dataset with a format that we can input into the L-moment program.

Relationships between SNOTEL (higher elevation data) and data with longer records from NCDC have been determined and are being used to adjust the SNOTEL data. This provides return-frequency information at higher elevations; such data have not been previously available in southwestern United States.

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Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973: Precipitation-frequency atlas of the western United States, NOAA Atlas 2, National Weather Service, Silver Spring, Md.

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

August 22, 1994 W/OH11/LFT

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Eleventh Quarterly Report - Semiarid Precipitation Frequency Project, April 1 - June 30, 1994

Enclosed is a copy of the Eleventh Quarterly Progress Report for the Semiarid Precipitation Frequency Project for the southwestern United States. The report includes an update of the periods of record for the final datasets (daily, hourly, SNOTEL, and Mexican), and a description of the n-minute data. Also, included is a detailed example of the storm analysis process, using a September - October, 1983 storm in northern Utah.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

Recd 8/26/94

SEMIARID PRECIPITATION FREQUENCY STUDY

Eleventh Quarterly Progress Report
for the period from
April 1 through June 30, 1994

Lesley F. Tarleton, Julie M. Olson, Edwin H. Chin,
Susan M. Gillette, John L. Vogel, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
August 1994

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SEMIARID PRECIPITATION FREQUENCY STUDY

Eleventh Quarterly Progress Report
for the period from
April 1 through June 30, 1994

OVERVIEW

This Eleventh Quarterly Report summarizes the work for the Semiarid Precipitation Frequency Project for the period April 1 through June 30, 1994. Included in this report are: frequency map analysis, n-minute data quality control and analysis, and storm analysis with a specific example of a storm isohyetal map and a set of depth-area-duration (DAD) curves.

DATA

The complete Semiarid Project area, including border regions, is shown in Figure 1. The map shows 24 near-homogeneous climatic regions, with their associated precipitation seasons. Also indicated are the primary precipitation seasons: Cool (winter and spring) and Warm (summer). In general, cool season precipitation is of the general storm or long-duration variety; whereas, warm season precipitation is usually intense, short-duration convective rainfall. The Semiarid dataset - daily, hourly, SNOTEL, and Mexican daily stations - is shown in the map in Figure 2. It contains 1177 daily stations (1182 daily stations were reported in the Semiarid Tenth Quarterly Report (QR10)), 449 hourly stations, 147 SNOpack TELemetry (SNOTEL) stations, and 108 daily stations from Mexico. Figure 3 shows the areas of similar precipitation regimes for SNOTEL data. As SNOTEL data records have only about 12-14 years, the SNOTEL data were compared to nearby lower elevation stations with longer records for incorporation into the study. Figure 4 shows the n-minute stations and the groups used for analysis. The grouping is the same as the seasonal clusters of regions of Cool (winter), Cool (spring), and Warm (summer), with the exception that the Warm precipitation season is divided into an eastern and western section along the Continental Divide in Colorado and New Mexico. For seasonal analysis of the n-minute data, the seasons essentially coincide with those of the individual regions, and are also shown in Figure 4.

Period of Record

Tables 1a-d show the years of record for all stations. Table 1a (daily stations) has been revised from the Tenth Quarterly Report. The number of stations and years-of-record for

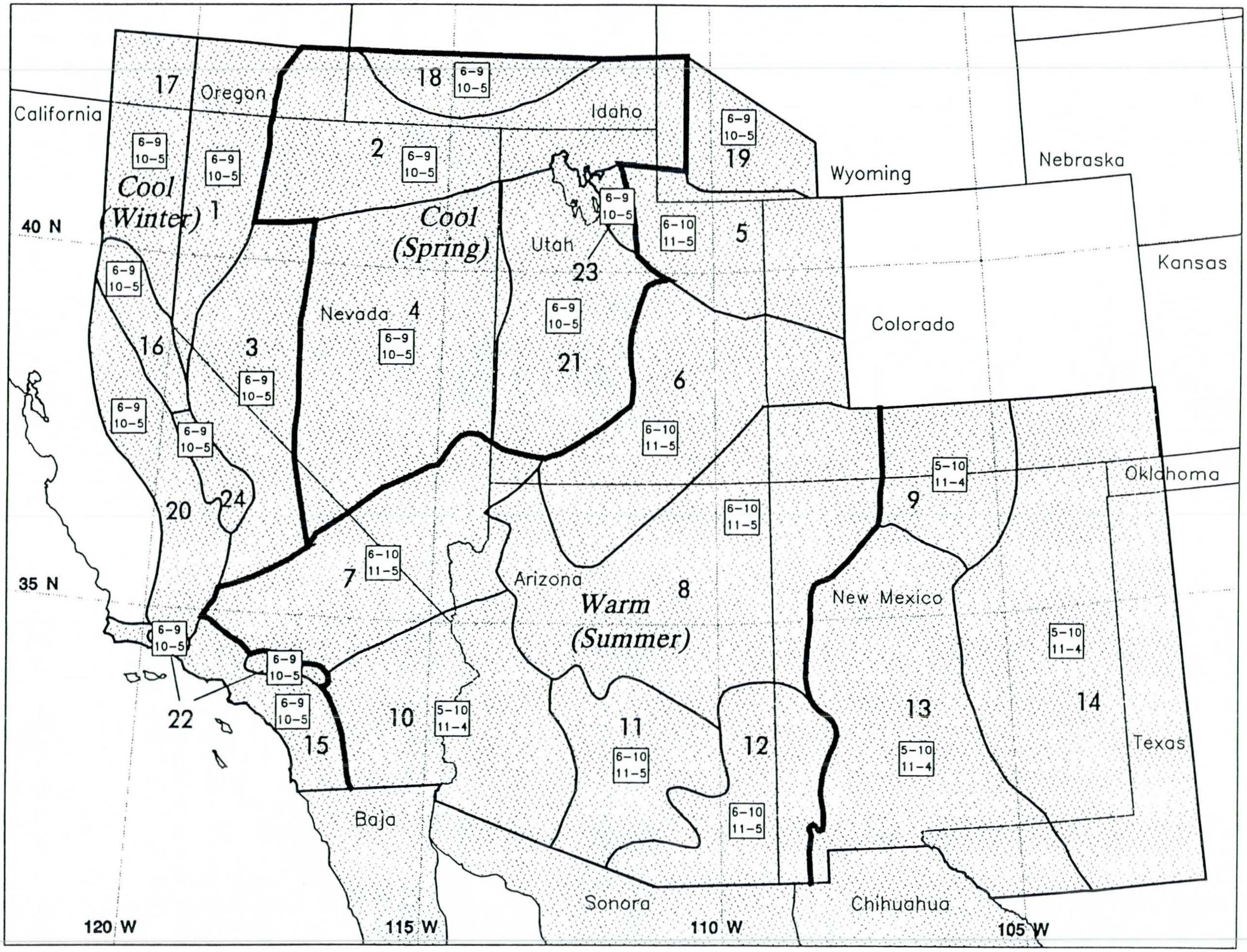


Figure 1. *Semiarid study climatic regions.*

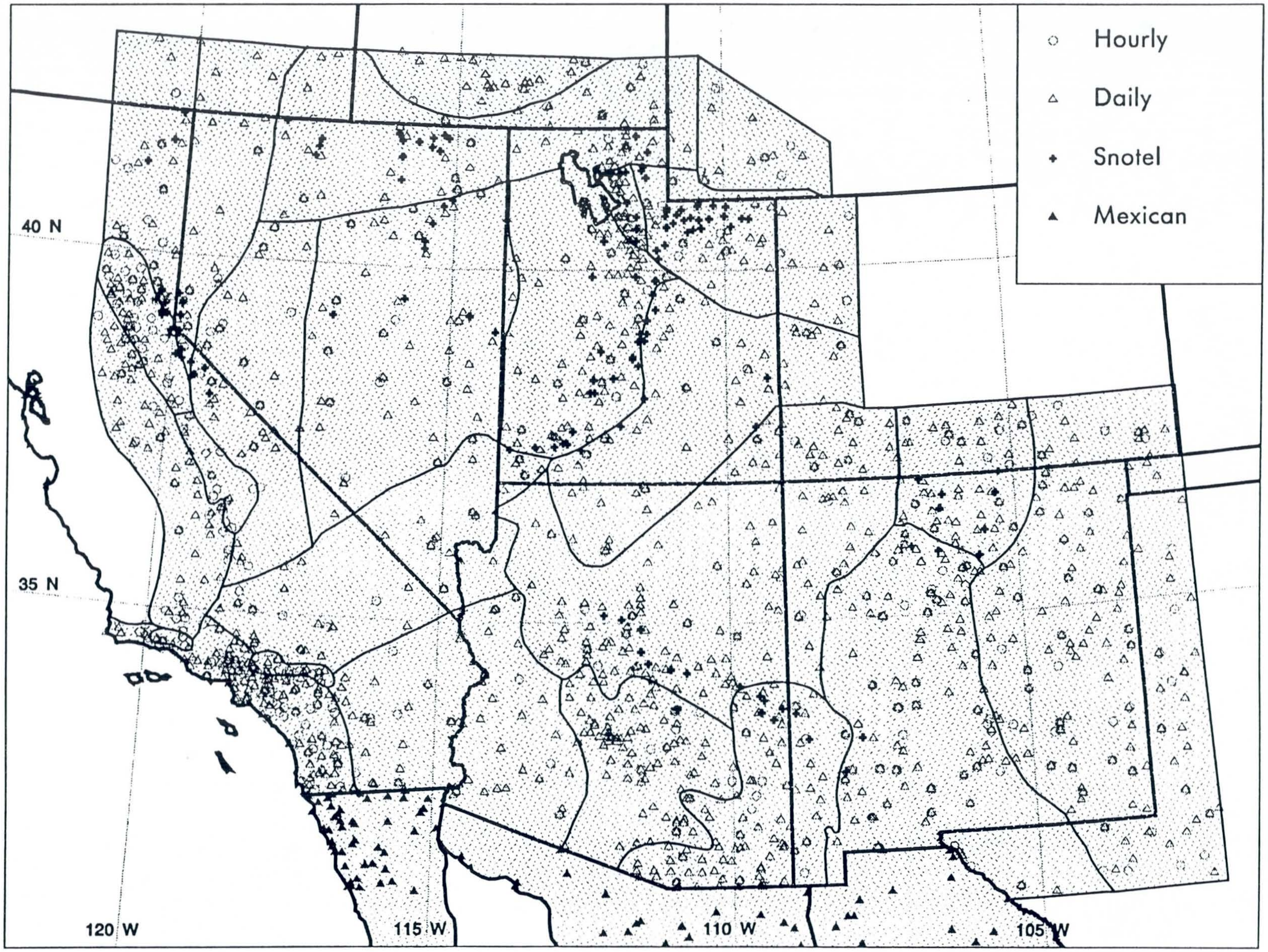


Figure 2. *Semiarid study station locations.*

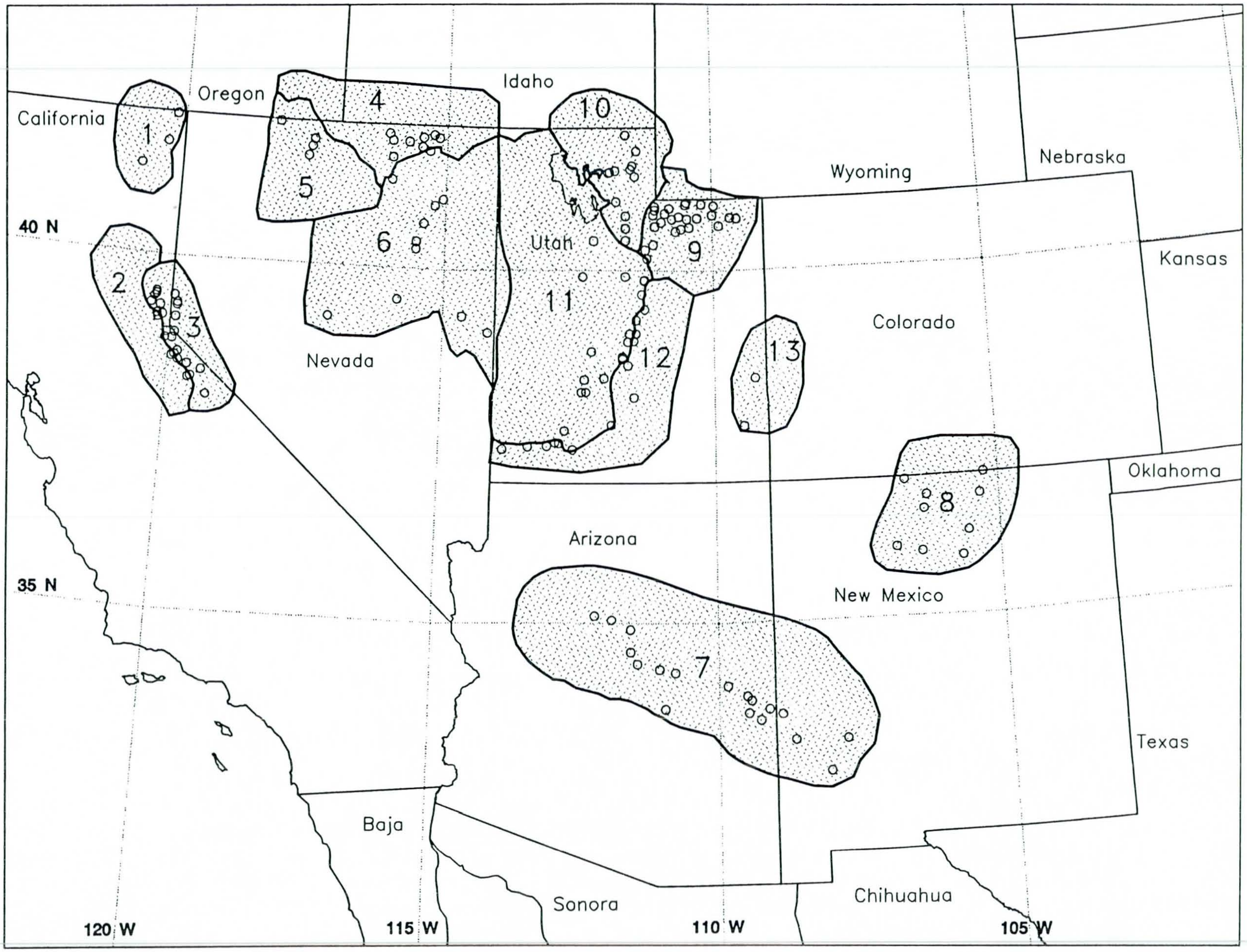


Figure 3. *SNOTEL areas developed for the Semiarid study.*

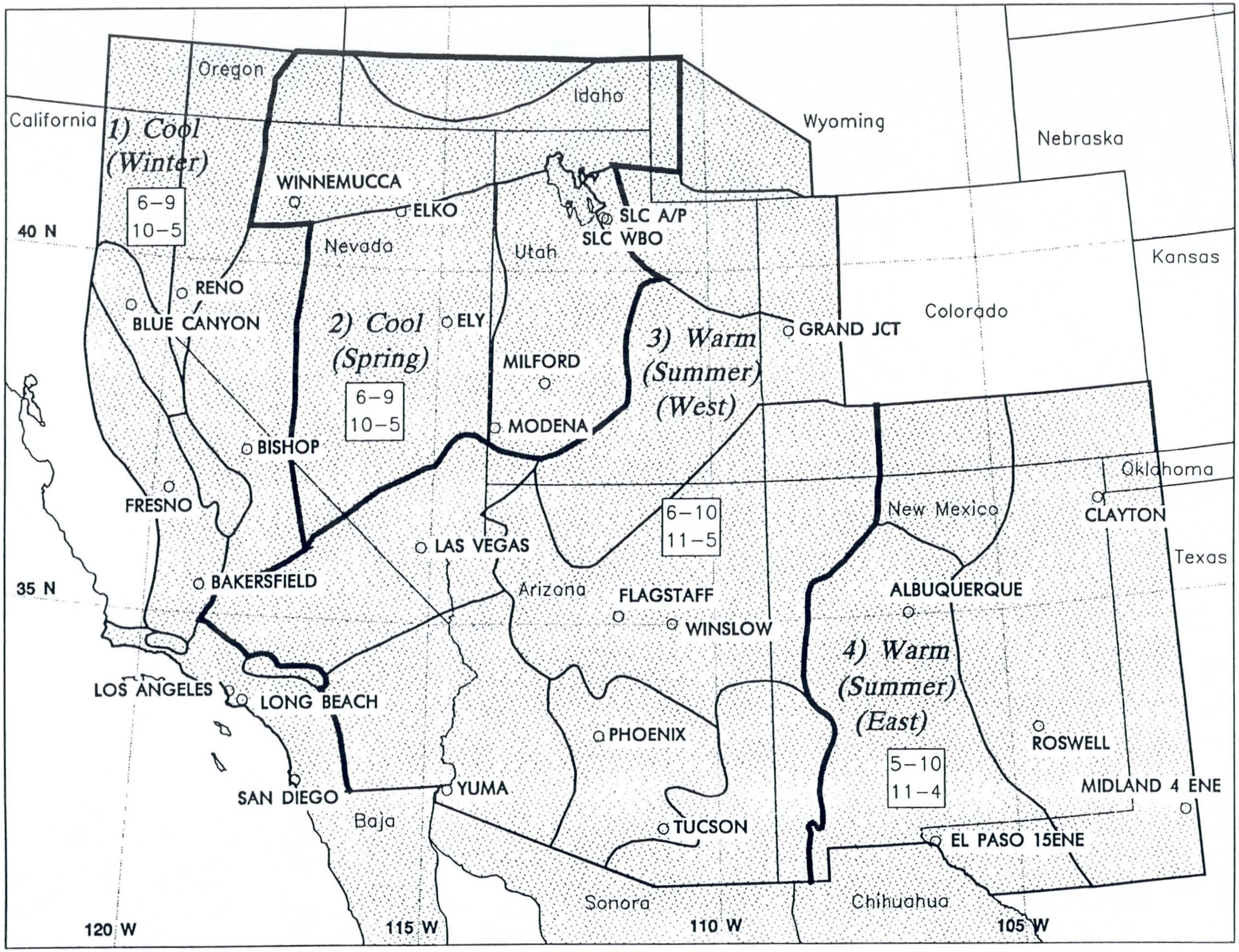


Figure 4. *N-Minute stations in the Semiarid study area.*

Table 1a.

Semiarid Precipitation Stations - Daily

Years of record by state.

#Yrs	AZ	CA	NM	NV	UT	ID	CO	TX	WY	OR	OK	Total	%total
19	3	1		5								9	100.0
20	4	4	1	4								13	99.2
21	9	10	6	1	2	1						29	98.1
22	6	7	6	3	1							23	95.7
23	4	7	5	2	2	1	3	1				25	93.7
24	6	12	3	2	5		2			1		31	91.6
25	5	9	2	5	4			1				26	89.0
26	4	8	3	7	3		2		1			28	86.7
27	8	3	5	2	5		1	1	2			27	84.4
28	11	6	3	3	3	1	1	1				29	82.1
29	12	6	8		4	1	1					32	79.6
30	6	4	2		4	2	1	1				20	76.9
31	2	5	4	2	2	3	2		1			21	75.2
32	6	5	5	1	4			1		1		23	73.4
33	9	6	2	1	4		2	1				25	71.5
34	5	6	4	2	3					1		21	69.3
35	4	3		1	4		1					13	67.5
36	6	4	9	4	5		1			1		30	66.4
37	4	4	1	2	9	1	1	2	1	1		26	63.9
38	4	4	4	3	5		2	1				23	61.7
39	4	3	3	2	5		1					18	59.7
40	9	7	9	4	1		2					32	58.2
41	2	7	2	1	2			1	1	1		17	55.5
42	4	4	1	5	7		4					25	54.0
43	5	12	2	4	7		2					32	51.9
44	7	46	5	7	5	1	7	1	1		1	81	49.2
45	23	65	102	4	35	7	14	3	1	2	2	258	42.3
46	3					1		2				6	20.4
47	1	1	1	1		1						5	19.9
48	1							1				2	19.5
49	3	2	1		1		1					8	19.3
50	4	1	1		1	1		1				9	18.6
51	2											2	17.8
52	2	1			1	1		1				6	17.7
53	3			1						1		5	17.2
54	3	2		1	1	1		1				9	16.7
55	3	1						2				6	16.0
56	2											2	15.5
57	5					1						6	15.3
58	3	1					1					5	14.8
59		1			1	1						3	14.4

Table 1a. (continued)

#Yrs	AZ	CA	NM	NV	UT	ID	CO	TX	WY	OR	OK	Total	%total
60	5	1			1			1				8	14.1
61		1		1		1		1		1		5	13.4
62		6	2	3		4		1				16	13.0
63				1	2		2					5	11.6
64	1			1	3							5	11.2
65	2	9		4	25							40	10.8
66		3					1					4	7.4
67	1		1					2				4	7.1
68	2		1									3	6.7
69						1		1				2	6.5
70	2								1			3	6.3
71	2							1				3	6.0
72	2			1	1							4	5.8
73	1											1	5.4
74	1		1									2	5.4
75	1											1	5.2
76												0	5.1
77	1								1			2	5.1
78	4											4	4.9
79	5					1						6	4.6
80			1		1							2	4.1
81	2											2	3.9
82	4											4	3.7
83	1		1									2	3.4
84	5											5	3.2
85	1						1					2	2.8
86	1				1							2	2.6
87			1				2					3	2.5
88	1		1									2	2.2
89			1				1					2	2.0
90	3				1							4	1.9
91	2						1		1			4	1.5
92												0	1.2
93							1					1	1.2
94	1								1			2	1.1
95	2											2	0.9
96	2		1									3	0.8
97	1											1	0.5
98	2											2	0.4
99	1											1	0.3
100	1											1	0.2
106			1									1	0.1
Sum	267	288	212	91	171	32	61	30	12	10	3	1177	

Table 1b.

Semiarid Precipitation Stations - Hourly

Years of record by state.

#Yrs	AZ	CA	NM	NV	UT	ID	CO	TX	WY	OR	Total	%total
15	1			1	1						3	100.0
16		2	1	1			1				5	99.3
17		5	2	1	1						9	98.2
18	2	5	1	1	1		1		1		12	96.2
19	4	4	1	1	3						13	93.5
20	1	4	4	1	1		1				12	90.6
21	2	5	5	2	3	1	1				19	88.0
22	1	3	4	3	2						13	83.7
23		3	3								6	80.8
24	1	8	5	2			2				18	79.5
25	2	4	3	2	2	1		1	1		16	75.5
26	1	3	2				1				7	71.9
27	1	4	1	2		1	1	1	1		12	70.4
28		3	1	1							5	67.7
29	1	3	2	1	1						8	66.6
30		6									6	64.8
31		1				1			1		3	63.5
32		3	2			1					6	62.8
33		5	2					1			8	61.5
34		3	1	2	1		1				8	59.7
35		3	1		1						5	57.9
36		7			2						9	56.8
37		3	1	1	1			1			7	54.8
38	2	3		1		1	1	1			9	53.2
39	1	1	1				1				4	51.2
40	1	4	1	3	1	1			1		12	50.3
41		8	1	1	1						11	47.7
42		7			3		2	1	1		14	45.2
43	1	16	1		2		1	1	1		23	42.1
44	4	8	2	3	1					2	20	37.0
45	16	48	33	11	16	2	11	1			138	32.5
46											0	1.8
47											0	1.8
48											0	1.8
49								4			4	1.8
50								3			3	0.9
51								1			1	0.2
Sum	42	182	81	41	44	9	25	16	7	2	449	

Table 1c.
Semiarid Precipitation Stations - SNOTEL
Years of record by state.

#Years	AZ	CA	NM	NV	UT	Total	%total
6					1	1	100.0
7		1			7	8	99.3
8	2	1			1	4	93.9
9	2			3		5	91.2
10	10	1				11	87.8
11		2	1	3	9	15	80.3
12		10	7	13	13	43	70.1
13		2	5	2	12	21	40.8
14		8		6	25	39	26.5
Sum	14	25	13	27	68	147	

Table 1d.
Semiarid Precipitation Stations - Mexico
Years of record by state.

#Years	Baja	Sonora	Chihuahua	Total	%total
5	3	2		5	100.0
6		2	1	3	95.4
7	3	1	2	6	92.6
8	4	1		5	87.0
9		2		2	82.4
10	7	1		8	80.6
11	2	1	2	5	73.1
12			1	1	68.5
13	2	2	3	7	67.6
14	4	6	3	13	61.1
15	23	21	9	53	49.1
Sum	48	39	21	108	

the daily data were incorrect in QR10, due to differences in record-years between annual maximum and partial duration series for daily stations and some variations in tabulating years of record and determining missing data. The earlier report contained all stations with 19 or more years of data, but many stations (or years) had only annual maximum values. The revised list has shorter records for many stations. Thus, for instance, the total number of stations with 45 years of data was changed from 106 to 258, so that although 42 percent of the stations have 45 or more years of data, only 20 percent have 46 or more years. The corrected tables are shown by state in Tables 1a-d: 1a, Daily; 1b, Hourly; 1c, SNOTEL; 1d, Mexican.

The daily stations have the longest records with over 15 percent having records of more than 55 years, and about 2 percent with more than 90 years. Ninety-nine percent of daily stations have 20 or more years of data. The longest records are at Santa Fe, New Mexico (106 years), Clifton, Arizona (100 years), and Buckeye, Arizona (99 years). Several stations have been in operation through a longer period of time, but some years of data are missing. Eighty-eight percent of hourly stations have more than 20 years of record, and nearly 50 percent have more than 40 years. For the SNOTEL and Mexican data the maximum record-length is 14 and 15 years, respectively. In both cases, about 80 percent of the records have 10-14 years of record. The SNOTEL and Mexican data are composed of daily observations. Even though these stations do not have at least 19 years of record, they provide information and guidance in the analysis procedure in regions where no other data are available.

N-Minute Data and Analysis

The 27 stations with n-minute data shown in Figure 4 have been collated from four sources, resulting in an annual maximum dataset with records of 14 to nearly 100 years. Eight of these stations have more than 80 years of data. Table 2a lists the n-minute stations, including station numbers (National Climatic Data Center (NCDC) and Weather Bureau, Army, Navy (WBAN)), years of record, and number of years with annual and monthly maximum data. Furthermore, to give an idea of the varying sources, the years of record are shown with regard to 'Dataset 1, 2, and/or 3'. Dataset 1 is an "in-house" dataset of annual maximums that had been used in a previous study. Datasets 2 and 3 are digital data that were sent from NCDC, except years 1982 and 1983. These two years (which we called Dataset 4) and half of 1985 and 1993 were hand-entered into Dataset 3 from Local Climatic Data (LCD) Bulletins, (12 months x 23 stations x 3 years x 12 durations = 9936 entries). Note also that there are no data for 1980 and 1981. In those two years, no short duration maximums were extracted from the station records, and therefore, are not available digitally or in hard-copy. Although Dataset 2 has only one

Table 2a.

	Station	State	NCDC Number	WBAN Number	SET 1	SET 2	SET 3	# of years Monthly max.	# of years Annual max.
1	FLAGSTAFF	AZ	02-3010	3103	51-78	73-79	82-93	19	40
2	PHOENIX	AZ	02-6481	23183	06-78	73-79	82-93	19	85
3	TUCSON	AZ	02-8820	23160	43-78	73-79	82-93	19	48
4	WINSLOW	AZ	02-9439	23194	51-78	73-79	82-93	19	40
5	YUMA	AZ	02-9660	23195		73-79	82-93	19	19
6	BAKERSFIELD	CA	04-0442	23155	39-78	73-79	82-93	19	52
7	BISHOP	CA	04-0822	23157	54-78	73-79	82-93	19	37
8	BLUE CANYON	CA	04-0897	23225	45-78	73-79	82-85	11	38
9	FRESNO	CA	04-3257	93193	04-78	73-79	82-85	11	79
10	LONG BEACH	CA	04-5085	23129		77-79	82-93	15	15
11	LOS ANGELES	CA	04-5114	23174	01-74	73-79	82-84,86-93	18	85
12	SAN DIEGO	CA	04-7740	23188	97-78	73-79	82-90	16	91
13	GRAND JCT	CO	05-3488	23066	99-78	73-79	82-93	19	92
14	ELKO	NV	26-2573	24121		73-79		7	7
15	ELY	NV	26-2631	23154		73-79	82-93	19	19
16	LAS VEGAS	NV	26-4436	23169		73-79	82-93	19	19
17	RENO	NV	26-6779	23185	06-78	73-79	82-93	19	85
18	WINNEMUCCA	NV	26-9171	24128	06-78	73-79	82-93	19	85
19	ALBUQUERQUE	NM	29-0234	23050	31-78	73-79	82-93	19	60
20	CLAYTON	NM	29-1887	23051		73-79	82-92	18	18
21	ROSWELL	NM	29-7610	23009	05-78	73-79		7	74
22	EL PASO 15ENE	TX	41-2797	23044	06-78	73-79	82-93	19	85
23	MIDLAND 4 ENE	TX	41-5890	23023	55-78	73-79	82-93	19	36
24	MILFORD	UT	42-5654	23176		73-79	82-88	14	14
25	MODENA	UT	42-5752	23177	04-44			0	41
26	SLC A/P	UT	42-7598	24127	36-78	73-79	82-93	19	55
27	SLC WBO	UT	42-7603	24175	96-51			0	56

more year than Dataset 1, it has monthly maximums, not just annual maximums. In Table 2b the completely collated datasets are shown, with the only distinction being whether stations have monthly as well as annual maximum data. The advantage of having monthly maximums is that a partial duration series can be prepared, and seasonal analysis of the data is possible. Dataset 1 has durations: 5, 10, 15, 30, 60, and 120 minutes; and datasets 2 and 3 have durations: 5, 10, 15, 20, 30, 45, 60, 80, 100, 120, 150, and 180 minutes.

L-moment analysis of n-minute data.

As with the longer durations, L-moment statistics are used for quality-control and return frequency estimates (Hosking and Wallis 1991). A part of the L-moment analysis is to determine the homogeneity of the areas, and to make any necessary adjustments to improve their homogeneity. L-moment definitions and tests for Discordancy (D), Heterogeneity (H), and Goodness-of-fit were given in QR9 and QR10 but are repeated here for reference in the Appendix.

Discordancy, Heterogeneity, and Goodness-of-Fit tests were evaluated for partial duration series for six durations: 5, 15, 30, 60, 120, and 180 minutes, for 25 stations with monthly maximums, and for each of the four areas shown in Figure 4. The areas proved to be mostly homogeneous, with no discordancies in the four areas. The Warm (summer)-West group has several scores above the threshold (≥ 2) for the coefficient-of-variation (L-CV) heterogeneity test, but that region is one of the most variable in the study area, and therefore, this is not considered significant. The other three groups do not exceed the threshold for any of the heterogeneity tests. In regard to the best-fit probability distribution, GPA is best, but LNO and Pearson-III are also acceptable.

Albuquerque Data

The U.S. Geological Survey (USGS) and Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) have sent us data from 12 recording raingages over the internet. These data are 5-minute recorder data in the Albuquerque metropolitan area recorded by USGS. Considerable effort by USGS, in particular, Robert Gold and Jack Veenhuis, and support from AMAFCA, through the efforts of Cliff Anderson, have made the reduction of these data possible for our use. This network, with records from 1976 through 1992 for most stations, is invaluable for evaluation on small scales, both temporally and spatially. This is particularly important for storm analysis.

Table 2b.

	Station	NCDC Number	State	Years of Annual max.*	# of years Annual max.	Years of Partial Dur.*	# of years Monthly max.
1	FLAGSTAFF	02-3010	AZ	1951-1993	40	1973-1993	19
2	PHOENIX	02-6481	AZ	1906-1993	85	1973-1993	19
3	TUCSON	02-8820	AZ	1943-1993	48	1973-1993	19
4	WINSLOW	02-9439	AZ	1951-1993	40	1973-1993	19
5	YUMA	02-9660	AZ	1973-1993	19	1973-1993	19
6	BAKERSFIELD	04-0442	CA	1939-1993	52	1973-1993	19
7	BISHOP	04-0822	CA	1954-1993	37	1973-1993	19
8	BLUE CANYON	04-0897	CA	1945-1985	38	1973-1985	11
9	FRESNO	04-3257	CA	1904-1985	79	1973-1985	11
10	LONG BEACH	04-5085	CA	1977-1993	15	1977-1993	15
11	LOS ANGELES	04-5114	CA	1901-1993	85	1973-1993	18
12	SAN DIEGO	04-7740	CA	1897-1990	91	1973-1990	16
13	GRAND JCT	05-3488	CO	1899-1993	92	1973-1993	19
14	ELKO	26-2573	NV	1973-1979	7	1973-1979	7
15	ELY	26-2631	NV	1973-1993	19	1973-1993	19
16	LAS VEGAS	26-4436	NV	1973-1993	19	1973-1993	19
17	RENO	26-6779	NV	1906-1993	85	1973-1993	19
18	WINNEMUCCA	26-9171	NV	1906-1993	85	1973-1993	19
19	ALBUQUERQUE	29-0234	NM	1931-1993	60	1973-1993	19
20	CLAYTON	29-1887	NM	1973-1992	18	1973-1992	18
21	ROSWELL	29-7610	NM	1905-1979	74	1973-1979	7
22	EL PASO 15ENE	41-2797	TX	1906-1993	85	1973-1993	19
23	MIDLAND 4 ENE	41-5890	TX	1955-1993	36	1973-1993	19
24	MILFORD	42-5654	UT	1973-1988	14	1973-1988	14
25	MODENA	42-5752	UT	1904-1944	41		
26	SLC A/P	42-7598	UT	1936-1993	55	1973-1993	19
27	SLC WBO	42-7603	UT	1896-1951	56		

* Data for 1980 and 1981 are unavailable.

ANALYSIS

Hourly and Daily Frequency Analysis

All 24-hour data have been processed from a total of 1881 daily and hourly stations (Table 1 and Figure 2), using L-moment statistical software and the Generalized Pareto (GPA) probability distribution with a partial duration series. In an earlier report (QR10) we indicated that the Log-Normal (LNO) distribution appeared optimal; however, further testing on 1-day and 2-day daily series indicated that GPA has a consistently better fit to partial duration series and is physically reasonable. Therefore, all analyses are being done on partial duration series and fitted to a GPA probability distribution.

Frequency maps are in production, using a combination of computer-plotted, computer-drawn, and hand-analysis. The 24-hour, 2-year and 100-year return frequency maps are being analyzed first; and then the intervening maps will be computer-generated. Partial duration series of 2-day (48-hour), 4-day, 7-day, and 10-day data are ready for analysis. Longer duration datasets (20, 30, 45, and 60 days) are being compiled.

Dataset and Analysis Summary

All frequency calculations are based on L-moment regional analysis of the stations within each region, thus taking advantage of the physical similarities or near-homogeneity within regions to strengthen the statistics. Data characteristics include:

- Partial duration series
- 24 near-homogeneous regions (Daily, Hourly)
- 13 higher-elevation areas (SNOTEL)
- 3 Mexican states (Mexican Daily)
- Generalized Pareto probability distribution
- Daily data - Converted from 1-day to 24-hour, 2-day to 48-hour
- Hourly data - Converted from 1-hour to 60-minute

Durations: 1, 2, 3, 6, 12, 24, and 48 hours; 1 day (24 hours), 2 days (48 hours), 4, 7, 10, 20, 30, 45, and 60 days.

Return Frequencies: 1, 2, 5, 10, 25, 50, 100, 200, 500, and 1000 years.

Map Scale: 1:1,000,000 for analysis, (1:2,000,000 for publication).

Elevation Map: 1:1,000,000 computer-generated, with elevations from minus 100 feet to over 14,000 feet. Contours: -100, 1, 100, 200, 400, 600, 800, 1000, 1500, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 12000. (Although there are elevations above 14,000 ft, there are no 14,000-ft contours on the smoothed maps.)

Procedure: Computer plot and hand-analysis of 2-year 24-hour map at 1:1,000,000 with an elevation map, (generated with Geographical Information Systems (GIS) Geographical Resources Analysis Support System (GRASS) software) for an underlay. This 2-year 24-hour analysis will be the standard map from which the primary isohyetal patterns will be determined. Then, a computer plot will be used to develop the 100-year 24-hour patterns and will be verified from a hand-analysis of the data for this return period. Digitize 2-year 24-hour isohyetal maps into GRASS. (A detailed discussion of the mapping procedure was given in QR10).

The 2-year return frequency is used as the standard for two basic reasons, both related to statistical stability. One is that the 2-year value is at or near the median value of the data. The median is a stable statistic and little affected by outliers. The second reason is related to sample size. Two-year return frequencies can be determined with more certainty from our dataset of 40-60 years of record than the higher return frequencies.

STORM ANALYSIS

Storm analysis involves several steps: a synoptic weather analysis, mass curves, an isopercental analysis, an isohyetal analysis, and finally a set of depth-area-duration (DAD) curves. Although this is a sequential process, each of the steps results in useful information that can stand on its own. Storm 1020, which occurred in northern Utah from September 26-29, 1983, is used as an example below to illustrate the process.

Synoptic Analysis

One of the most important objectives of a storm analysis is to attempt to understand how the precipitation was formed. Storm 1020 (and the other three storms in this period) were definitely associated with hurricanes and tropical storms. The synoptic maps show at least three named tropical storms which preceded and/or coincided with the extreme rainfall. Probably Hurricane Manuel was most important in 'setting up' the high moisture content over the Southwest. This storm was almost stationary off the Baja coast (at about 20N,120W) from September 16-20. This was followed by Tropical Storm Narda, which tracked westward; and then Tropical Storm Octave, which tracked into northern Baja and southern California at the end of September. Smith (1986) describes the effects of Manuel and Octave on the rainfall in the Southwest. Other synoptic factors that are considered include the location of the jet stream, temperatures, and moisture distribution, among others.

Mass Curves

After gathering the data for Storm 1020, mass curves were prepared and analyzed. The mass curve program allows for daily data to be divided into hourly amounts. Each daily station is assigned to an hourly station based on location and topography. Precipitation at the daily station follows the same pattern as precipitation at the assigned hourly station. A set of mass curves for Storm 1020 is shown in Figure 5. In this figure, three daily stations are timed to the hourly data at Bountiful-Val Verda, Utah. The program also gives a precipitation total for the Critical Precipitation Period (CPP) of each storm. Storm 1020 has a CPP from 9/26 at 0700 to 9/29 at 2400.

Isopercental Analysis

Using the GRASS GIS system the total amount of precipitation in the CPP for each station in Storm 1020 was divided by the NOAA Atlas 2 (Miller et al. 1973), 100-year, 24-hour amount. This process creates a percental map. The precipitation totals are divided by the NOAA Atlas 2 amounts to adjust effects topography has on area precipitation amounts. The percental map was then hand-analyzed. After digitizing the isopercentals into GRASS, an interpolation routine was performed, creating a raster file.

Isohyetal Analysis

The resulting isopercental file was then multiplied by the NOAA Atlas 2, 100-year, 24-hour raster file, resulting in a raster file of precipitation. Using this file another GRASS routine was performed creating the isohyetal map shown in Figure 6. The isohyetal map was studied to make sure there were no errors or inconsistencies. Concurrent with this step, polygons were drawn around each station used in the study. The area inside each polygon follows the same pattern of precipitation as the daily or hourly station in each polygon. Once satisfied with the isohyets and polygons, the depth-area-duration program was run.

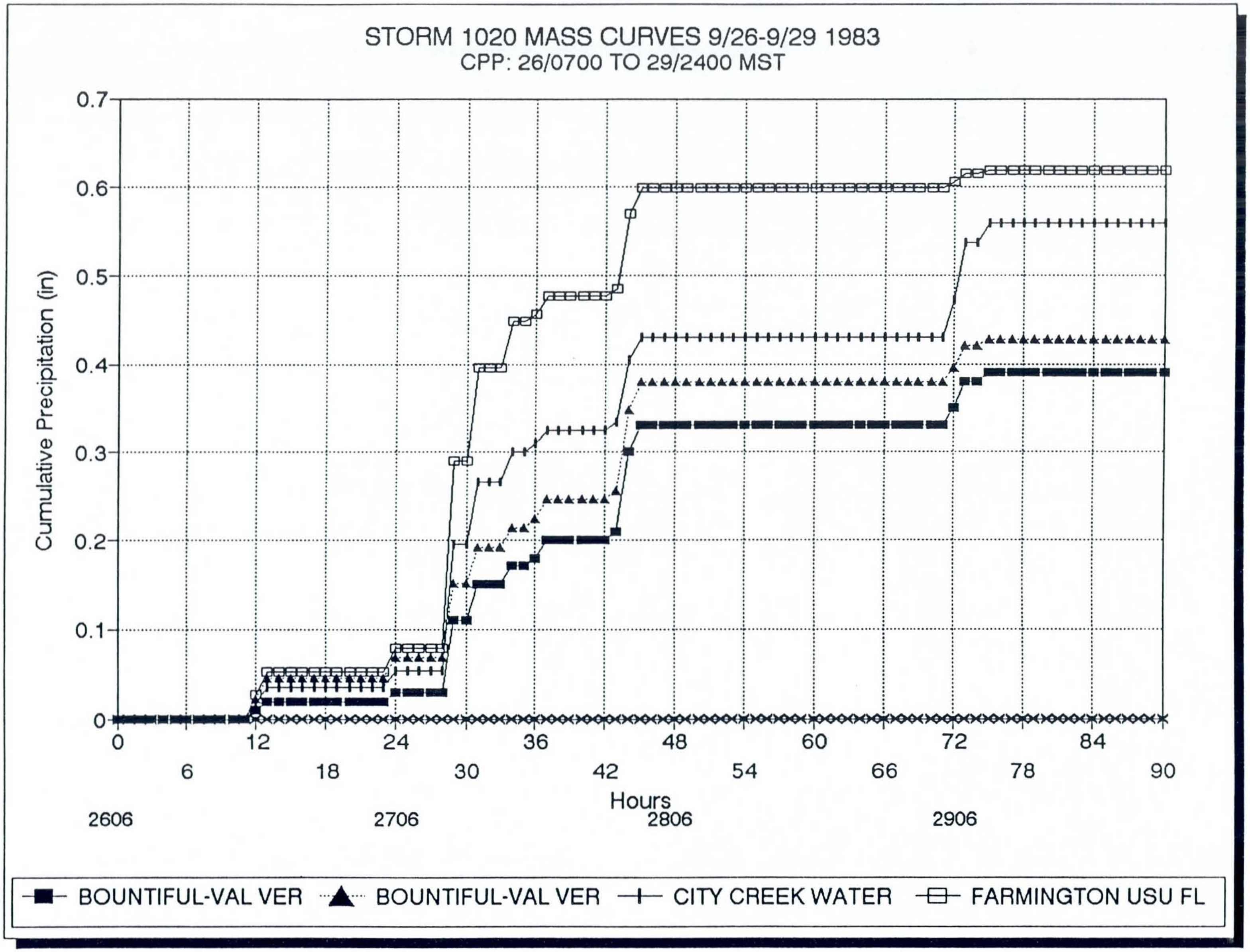


Figure 5. *Storm 1020 mass curve.*

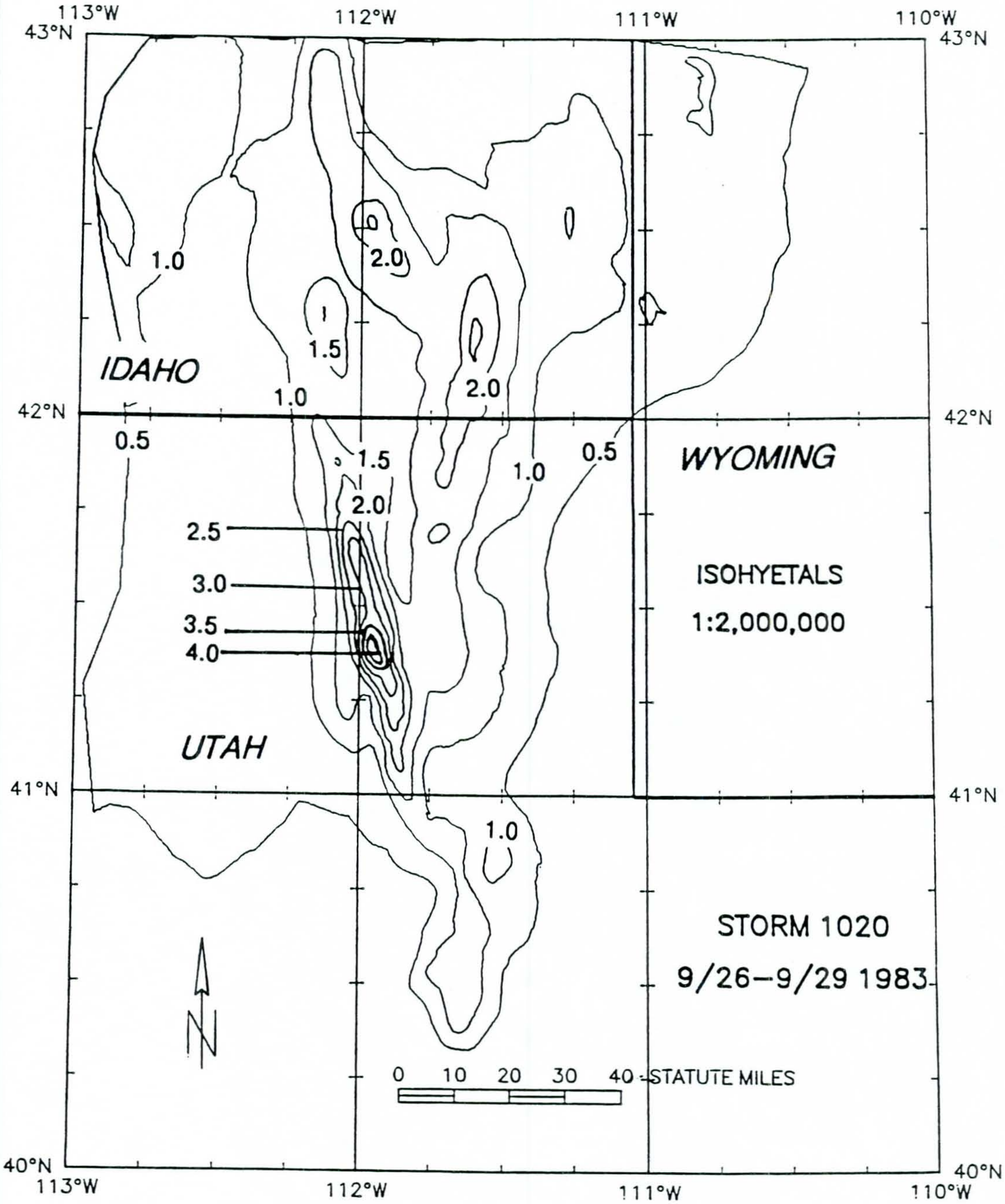


Figure 6. *Storm 1020 isohyetal map.*

Depth-Area-Duration

The depth-area-duration (DAD) program is run for several durations, usually the 1-, 3-, 6-, and 12-hour periods and every subsequent 12-hour period thereafter. The resulting values were plotted and a line drawn connecting the extreme values. Consistency has to be maintained when drawing the outer line, as the points have to come from the same center and starting hours of precipitation have to be within a few hours of each other. Storm 1020 had one primary center. If a storm has multiple centers worth considering, the depth-area-duration program is run separately for each center. After the outer line was drawn for each duration, different area-depths were entered into a pertinent data sheet for Storm 1020. These values were then normalized by the 24-hour, 10-square-mile value and the resulting percentages were plotted. Normalizing these values allows for comparison among storms with similar characteristics. Figure 7 shows the normalized DAD curves for Storm 1020. Note that for areas of 500 square miles and less, the 6-hour and 12-hour lines coincide; that is, for that size area, no more rain accumulated between 6 and 12 hours. For durations greater than 24 hours only the 60- and 90-hour lines are drawn.

Other Storms

Data for the storms listed in Tables 3a and 3b have been accessed and are being analyzed. Local storms and storms used for other studies may be added to the list. In addition to these storms, additional temporal and spatial information will be assembled from the Corps of Engineers Storm Catalog and the Bureau of Reclamation storm studies. The storms on the list in Table 3 are separated into general storms and winter storms. Further stratification will be based on the most prevalent type of precipitation, involvement of tropical storms and hurricanes, location within the semiarid area, return frequencies, and other factors. The storm numbers are reference numbers that have been given to storms analyzed in this office and are for filing and tracking purposes only. They are rather like accession numbers for a collection and have no intrinsic meaning other than the order to which they were added to our list. The Hydrometeorological Branch numbering system begins with '1000' to differentiate from storms analyzed by other agencies, e.g., the Corps of Engineers.

The first storms for analysis occurred in September and October in 1983. This intense rainfall period was divided into four storms based on the nature of the precipitation, which is temporally sporadic or in "bursts," and on the spatial distribution. Storm locations for these 1983 storms (1019, 1020, 1021, and 1022) are shown in Figure 8. Storms 1020 and 1022 are co-located, but were separated for analysis, as there is a dry day between

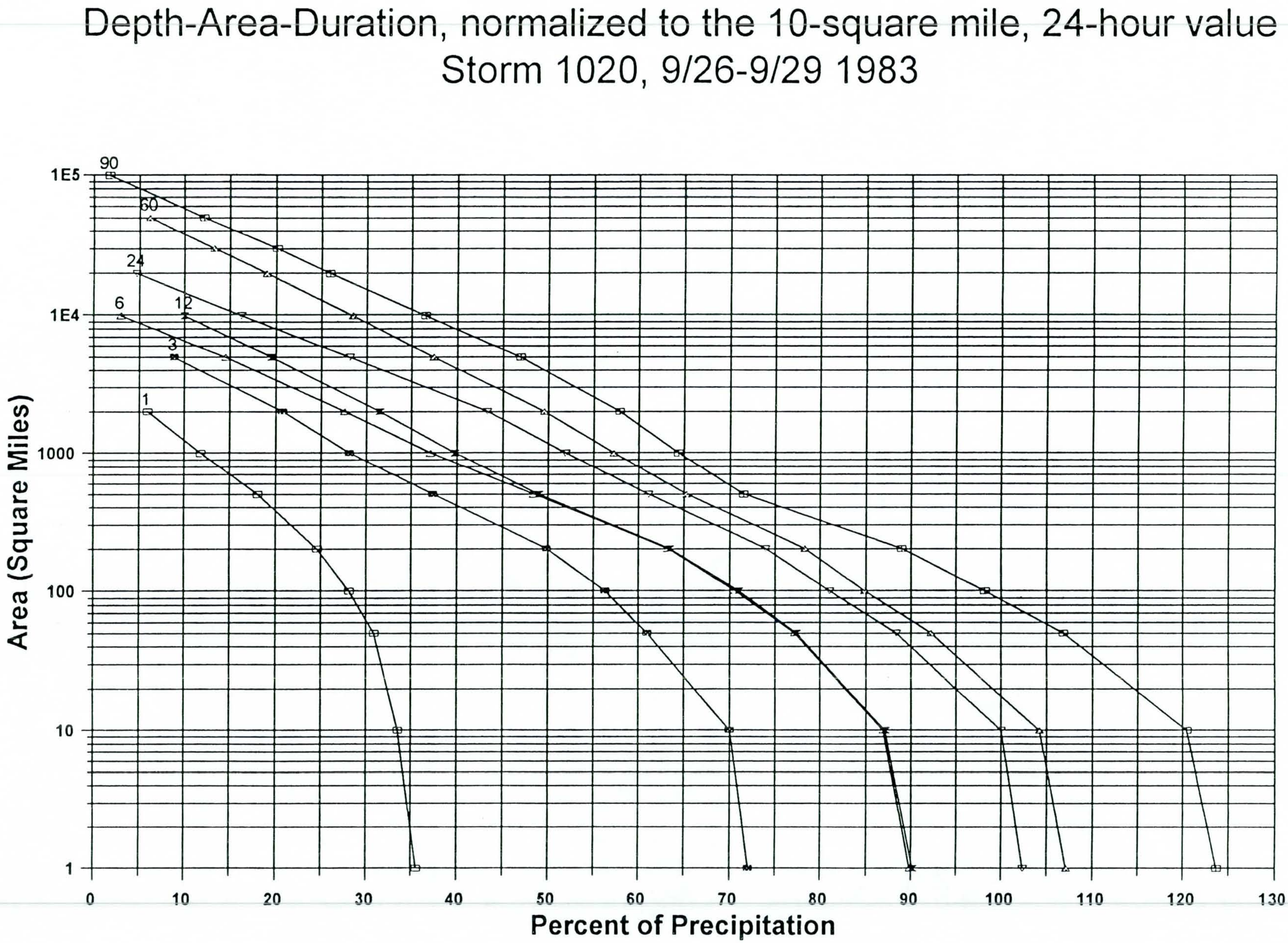


Figure 7. *Normalized depth-area-duration curves for storm 1020.*

Table 3a.
Semiarid General Storms

Storm #	Dates	Location
1019	9/27-10/3/83	AZ,NM,MX
1020	9/26-9/29/83	UT,ID
1021	9/27-10/3/83	NV,UT,ID
1022	10/1-10/2/83	UT,ID
1023	8/27-8/30/51	AZ,NM,UT,TX
1024	3/22-3/23/54	AZ,NM,UT,TX
1025	10/6-10/7/54	AZ,NM,UT,TX,CO
1026	5/18-5/19/55	NM,CO
1027	10/29-10/30/59	AZ,NM,NV,CA
1028	8/5-8/8/60	NM,TX
1029	9/4-9/6/70	AZ,NM,CO
1030	10/19/72	AZ,NM,TX
1031	9/12/75	NM,TX

Table 3b.
Semiarid Winter Storms

Storm #	Dates	Location
1032	12/23/48	AZ,NM,CO
1033	12/30-12/31/51	AZ,NV,UT
1034	12/25/59	AZ,NV,UT
1035	12/10/65	AZ,NM,NV
1036	12/6/66	AZ,NV,UT,CO
1037	12/15-12/16/67	AZ,NV,UT,CA
1038	12/19-12/20/67	AZ,NM,UT
1039	12/17-12/20/78	AZ,NM,NV,UT
1040	12/4-12/5/92	AZ,NM,NV,CA,MX
1041	12/28-12/29/92	AZ,NV,CA,MX

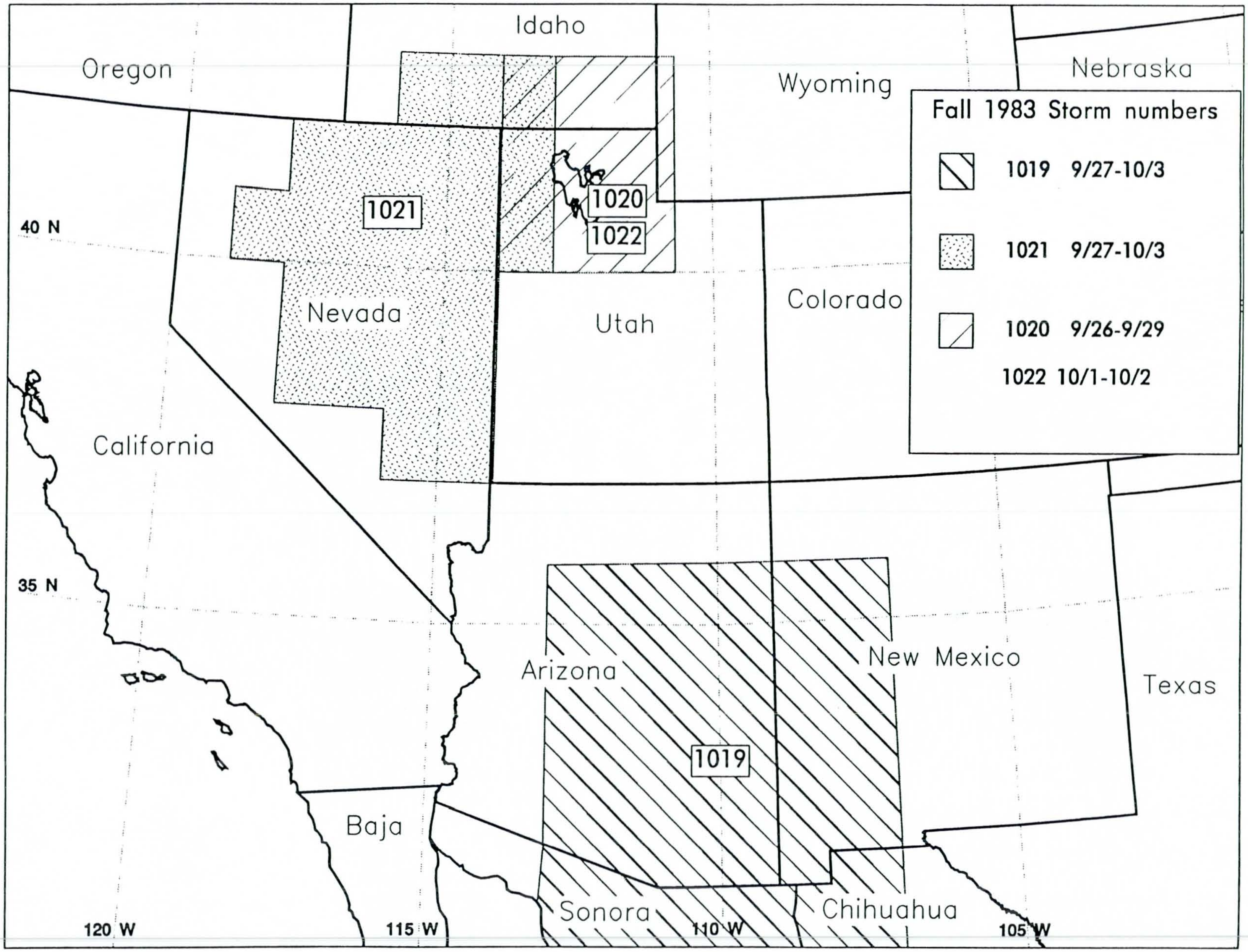


Figure 8. *Fall 1983 storm dates and locations.*

intense precipitation events. These events resulted, at least in part, from the moisture inflow from at least three named tropical storms. The analysis for Storm 1020 is complete. Storm 1019 is nearly complete. Storm 1019 is far more complex, with a wider area and multiple centers. Analysis has begun on two of the winter storms, the December 1992 storms, 1040 and 1041.

SUMMARY AND OUTLOOK

The hourly and daily dataset is complete and partial duration series of durations from one day (24 hours) to ten days are complete. Durations up to sixty days are in preparation. The n-minute dataset has been quality-controlled and return frequencies calculated for durations from 5 minutes to 180 minutes.

Return frequency maps are being analyzed, starting with the 24-hour, 2-year and 100-year frequencies.

Storm analysis is proceeding with Storm 1020 completed, and other storms in different stages of analysis.

REFERENCES

Hosking, J.R.M. and Wallis, J.R., 1991: Some statistics useful in regional frequency analysis, Research Report, RC 17096, IBM Res. Div., Yorktown Heights, N.Y., 23 pp.

Local Climatological Data, (1982,1983): [Data Bulletin], National Climatic Data Center, NOAA, Asheville, NC.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973: Precipitation-frequency atlas of the western United States, NOAA Atlas 2, National Weather Service, Silver Spring, Md.

Smith, W., 1986: The effects of eastern north Pacific tropical cyclones on the southwestern United States, NOAA Tech.Mem., NWS WR-197, DOC/NOAA/NWS, Salt Lake City, UT, 229 pp.

APPENDIX

Discordancy

Initially, the discordancy measure is used for data checking and quality control. However, in evaluating regions, it is used to determine if a site has been assigned to the appropriate region. It is based on L-moments (L-coefficient-of-variation (L-CV), L-skewness (L-SK), and L-kurtosis (L-KT)), which represent a point in 3-dimensional space, for each site. Then, discordancy (D) is a function of the distance from the cluster of points for the sites in the region being tested. The cluster center is in fact the unweighted mean of the three moments for the sites within the region being tested. Sites with a discordancy value of 3 or greater are considered discordant, and should be examined to see if they possibly belong in another region or have a data problem. The threshold value of 3 is not a rigorous test, but a reasonable level to be expected within a homogeneous region.

Heterogeneity

Actually, the heterogeneity test consists of three parts, one (H-1) based on L-CV, the second (H-2) based on L-CV and L-SK, and the third (H-3) based on L-SK and L-KT. As in the discordancy test, there is also a threshold value; Hosking and Wallis (1991) recommend a threshold of 1. However, they used wind data in establishing this threshold, and later conversations with Wallis (personal communication 1993) indicate that a threshold of 2 is reasonable, especially for precipitation data. Therefore, for each H-test, a value greater than 2 indicates heterogeneity (H>2), rather than homogeneity (H<2). In general, H-1, based on L-coefficient of variation (L-CV) is most stringent. As precipitation data are highly variable in any case, the heterogeneity results were considered giving less weight to the L-CV criterion.

Goodness-of-fit

This test measures the "distance" of L-moment statistical parameters of a dataset from various theoretical probability distributions. The threshold for goodness-of-fit tests is 1.64 (absolute value), and 'best-fit' values are those less than or equal to the threshold. For partial duration, Generalized Log-Normal (LNO), Pearson Log-III (PIII), and Generalized Pareto (GPA) are acceptable distributions for most durations.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

October 17, 1994 W/OH11/LFT

MEMORANDUM FOR: Semiarid Precipitation Frequency Study Participants

FROM: W/OH11 - Lesley F. Tarleton

SUBJECT: Notice for Semiarid Precipitation Frequency Study Meeting, Tempe, Arizona

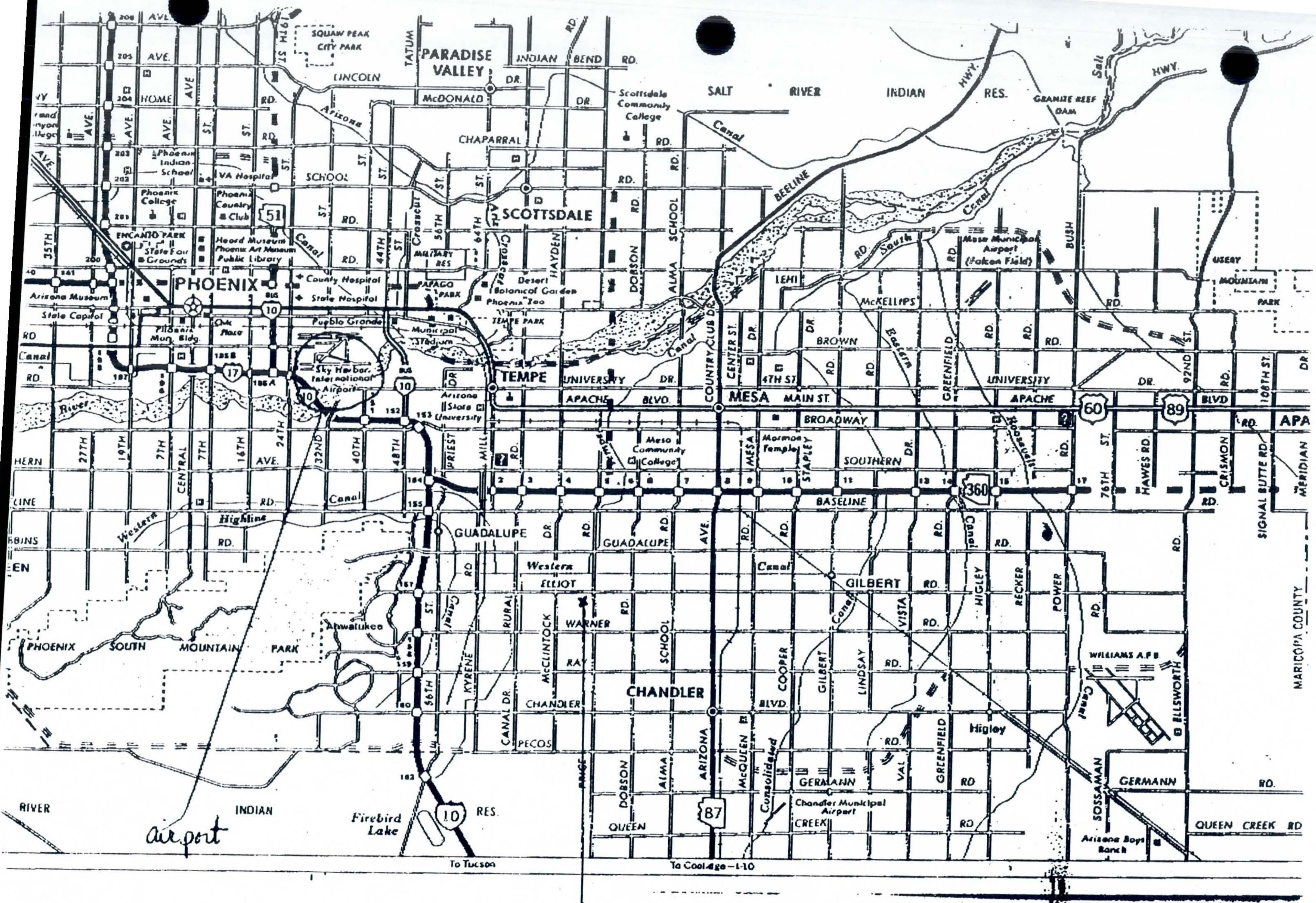
The Semiannual Status/Progress Report Meeting on the Semiarid Precipitation Frequency Study for the Southwest will be hosted by the Arizona Department of Transportation on 7 November 1994. Lesley Tarleton, of the National Weather Service (NWS), Hydrometeorological Branch, will present results of the study to date.

Date: Monday 7 November 1994
Time: 9:00 a.m. - 12:30 p.m.
Location:
Arizona Department of Transportation
7755 South Research Drive, Suite 106
Tempe, Arizona 85284
(602) 831-2620
(Maps of area enclosed)

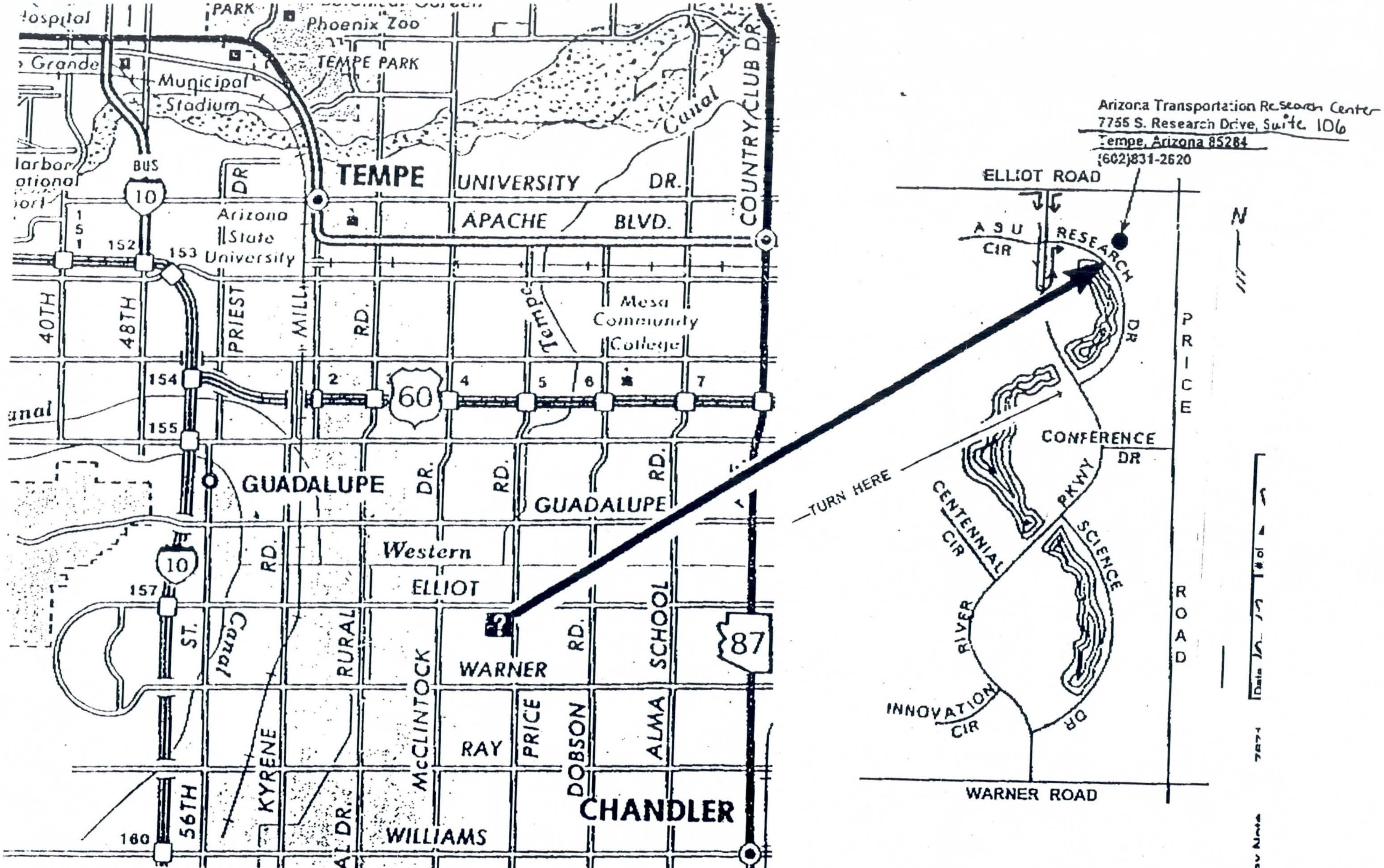
If you plan to attend or have any questions please contact:

Larry Scofield, Manager
Transportation-Research, ADOT
(602) 831-2620

Also, please don't hesitate to call me if you need further information, (301) 713-1669.



Arizona Transportation Research Center
ASU Research Park
Tempe Az



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TEMPE
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COUNTRY CLUB DR.
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Canal
PRIEST DR.
MILL
RD.
40TH
48TH
Tempe
Mesa Community College
60
10
GUADALUPE
Western
ELLIOT
WARNER
RAY
WILLIAMS
CHANDLER
KYRENE
RURAL
McCLINTOCK
PRICE
DOBSON
ALMA
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TURN HERE
ELLIOT ROAD
ASU CIR
RESEARCH DR
PRICE ROAD
CONFERENCE DR
CENTENNIAL CIR
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RIVER
INNOVATION CIR
WARNER ROAD
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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

October 28, 1994 W/OH11/LFT

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Twelfth Quarterly Report - Semiarid Precipitation Frequency Project, July 1 - September 30, 1994

Enclosed is a copy of the Twelfth Quarterly Progress Report for the Semiarid Precipitation Frequency Project for the southwestern United States. The report includes some comparisons with NOAA Atlas 2 and results from the analysis of n-minute data.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMIARID PRECIPITATION FREQUENCY STUDY

Twelfth Quarterly Progress Report
for the period from
July 1 through September 30, 1994

Lesley F. Tarleton, Julie M. Olson, Edwin H. Chin,
Susan M. Gillette, John L. Vogel, Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
October 1994

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SEMIARID PRECIPITATION FREQUENCY STUDY

Twelfth Quarterly Progress Report
for the period from
July 1 through September 30, 1994

OVERVIEW

This Twelfth Quarterly Report summarizes the work for the Semiarid Precipitation Frequency Project for the period July 1 through September 30, 1994. Included in this report are: some final details about the data; the mapping that is underway on the GRASS/GIS system; some discussion of results in two areas within the study area, Imperial County, California (Salton Sea area), and Washoe County, Nevada (Reno); n-minute ratios for the entire study area; and a brief statement on the status of the storm analysis. For reference the map of the complete Semiarid Project area, including border regions, is repeated from earlier quarterly reports in Figure 1. The map shows 24 near-homogeneous climatic regions, with their associated precipitation seasons.

DATA

Comparisons with NOAA Atlas 2

The Semiarid study area contains data from 1177 daily stations, 449 hourly stations, 147 SNOpack TELemetry (SNOTEL) stations, and 108 daily stations from Mexico. For durations of less than one hour, 27 additional stations with n-minute data have been analyzed. Table 1 shows a comparison between the number of stations in this update and the number used for NOAA Atlas 2 (Miller et al., 1973). A direct comparison can be made between the four core states (Arizona, Nevada, New Mexico, and Utah) for daily stations with more than 19 years, and hourly stations with more than 15 years of data. Although NOAA Atlas 2 used stations with 10 or more years of data, these stations with shorter records cannot be compared with the update. The Semiarid Project has 357 more daily stations and 87 more hourly stations in the four states of Arizona, Nevada, New Mexico, and Utah. Furthermore, the study has 147 SNOTEL and 108 Mexican daily stations, none of which were available to the NOAA Atlas 2 study. Thus, the Semiarid Project has at least 612 additional daily stations and 87 additional hourly stations for a total of 699 additional stations. Although we have additional stations in California and the border states, they are not included in the comparison as we do not have a breakdown of the NOAA Atlas 2 stations, except by whole states.

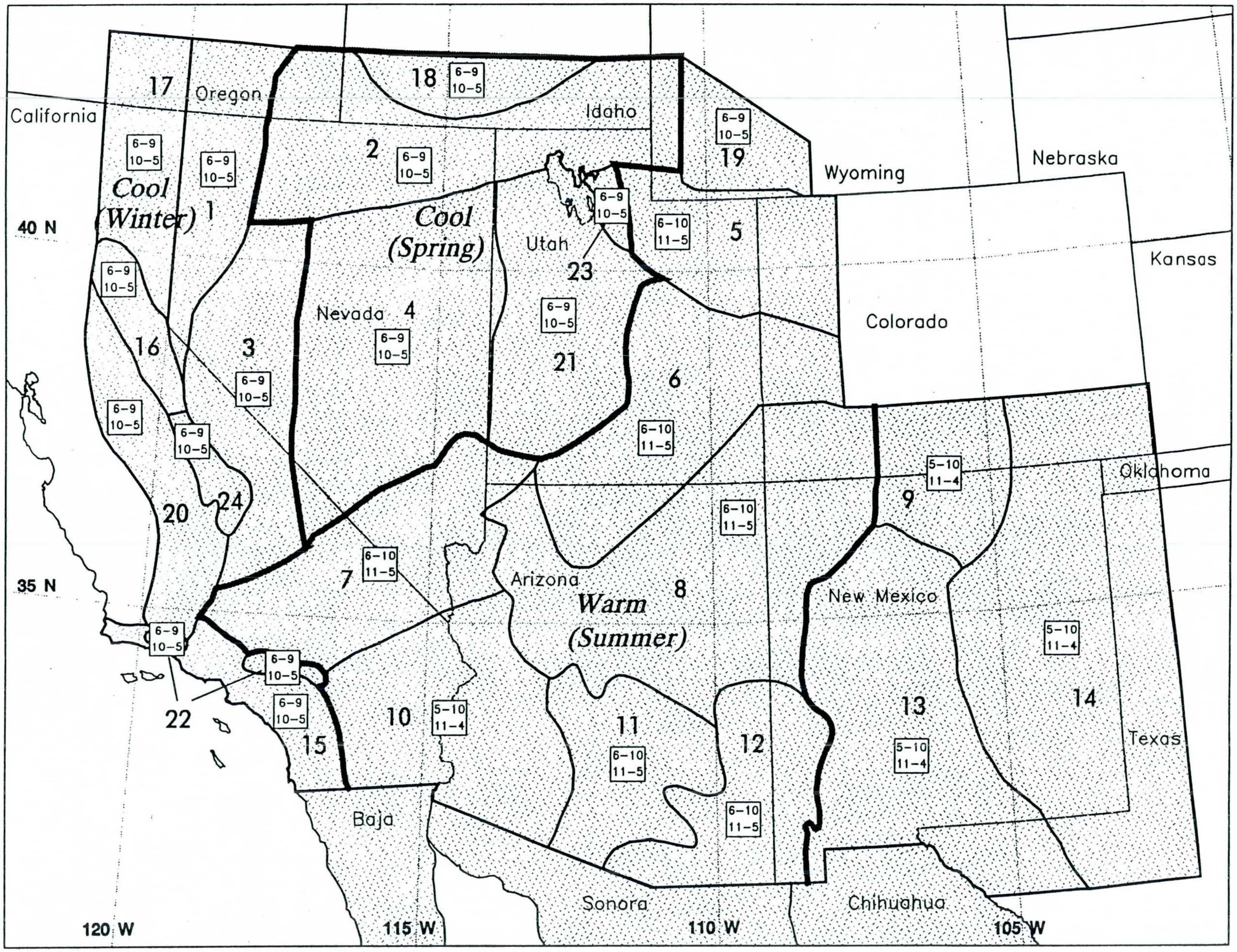

Figure 1. *Semiarid study climatic regions.*

Table 1.

DAILY STATIONS WITH AT LEAST 19 YEARS OF DATA

Core States	Semiarid	NOAA Atlas 2	**Increase**
Arizona	267	125	**142**
Nevada	91	34	**57**
New Mexico	212	143	**69**
Utah	171	82	**89**
Total	741	384	357

Other Stations	
California	288
Border states	148
SNOTEL	147
Mexico	108
Total Other	691
TOTAL DAILY	1432

HOURLY STATIONS WITH AT LEAST 15 YEARS OF DATA

Core States	Semiarid	NOAA Atlas 2	**Increase**
Arizona	42	32	**10**
Nevada	41	27	**14**
New Mexico	81	42	**39**
Utah	44	20	**24**
Total	208	121	**87**

Other Stations	
California	182
Border states	59
Total Other	241
TOTAL HOURLY	449

	TOTALS
DAILY	1432
HOURLY	449
TOTAL STATIONS	**1881**

Data Trends

A trend analysis has begun to insure that there are no secular trends on the precipitation data for the Semiarid region. Huff and Angel (1992) reported a climatic trend in precipitation data in the Midwest. They compared two periods, 1907-1946, and 1947-1986, and found that precipitation was 10 percent higher in the more recent period for the upper Midwest. Friedman tests have been run on about 50 daily stations with 80 years of record. Stations with 60 years of record are also being analyzed. Thus far, these non-parametric tests show no significant climatic trends in the Semiarid data sets.

Real-Data-Check

The daily data for 1-day and 4-day durations have been subjected to a real-data-check (RDC), which compares theoretical distributions with observed values, (Lin and Vogel 1993). The RDC results for hourly data were reported in the Ninth Quarterly Report (Tarleton et al. 1994). Format problems with the daily data had slowed the analysis of the daily data, so that a real-data-check was delayed. A real-data-check compares the exceedances of the data with the expected, theoretical value. For example, at the 2-year return frequency, fifty percent of the values are expected to be above and fifty percent below the computed (i.e., theoretical) frequency value. The other thresholds are: .20 (20 percent) for 5-year, .10 for 10-year, .04 for 25-year, .02 for 50-year, and .01 for 100-year return frequencies. That is for 100-year estimates, 1 percent of the data is expected to be higher than the 100-year frequency value. All the data were within a few percentage points of the threshold values. Therefore, based on RDC comparisons for the hourly and daily data, and the L-moment Goodness-of-fit procedures (Hosking and Wallis 1991), the Generalized Pareto (GPA) distribution has been confirmed as the best probability distribution for precipitation frequency analysis for the Southwest.

N-MINUTE DATA ANALYSIS

The regionalization of the n-minute data is the same as the seasonal clusters of regions shown in Figure 1. Figure 2 shows the four n-minute regions: 1) Cool (winter), 2) Cool (spring), and 3) Warm (summer) - West, and 4) Warm (summer) - East. The boundary between the two Warm (summer) precipitation regimes is the Continental Divide in Colorado and New Mexico. For seasonal analysis of the n-minute data, the seasons essentially coincide with those of the individual regions, and are also shown in Figure 2.

The 27 stations with n-minute data, also shown in Figure 2, were collated from both digital and hard-copy sources, resulting in a dataset with records of 14 to nearly 100 years. Eight of these stations have more than 80 years of data. The n-minute data were quality-controlled, regionalized, and tested for discordancy, heterogeneity, and goodness-of-fit with L-moment statistical software. The best-fit probability distribution proved to be the Generalized Pareto (GPA), same as the hourly and daily data. The return frequencies were computed using partial duration series for six durations: 5, 15, 30, 60, 120, and 180 minutes, for 25 stations with monthly maximums. Examples of n-minute return frequencies **(DRAFT)** are shown in the maps in Figures 3a (2-yr, 5-min), 3b (100-yr, 5-min), 3c (2-yr, 30-min) and 3d (100-yr, 30-min). In general, the highest values are in the southeast, in Arizona and New Mexico, and the lowest in the northwestern part of the study area.

To determine seasonality of short-duration precipitation, the extremes were also tabulated by the month of occurrence. Two seasonal histograms are shown in Figures 4a (Phoenix, Arizona) and 4b (Winnemucca, Nevada). Phoenix is more typical of most of the southwest with the convective storms of late summer contributing most of the high-intensity rainfall. In Winnemucca, Nevada, Figure 4b, the influence of late spring precipitation is apparent with the most intense precipitation occurring in May and June. However, July and August are nearly as high, indicating the convective storms are also important in this part of the study area. The maps in Figure 3 show that the intensities in Phoenix in south central Arizona are much higher than in Winnemucca in northwestern Nevada. This corroborates that the more intense storms are convective, rather than general.

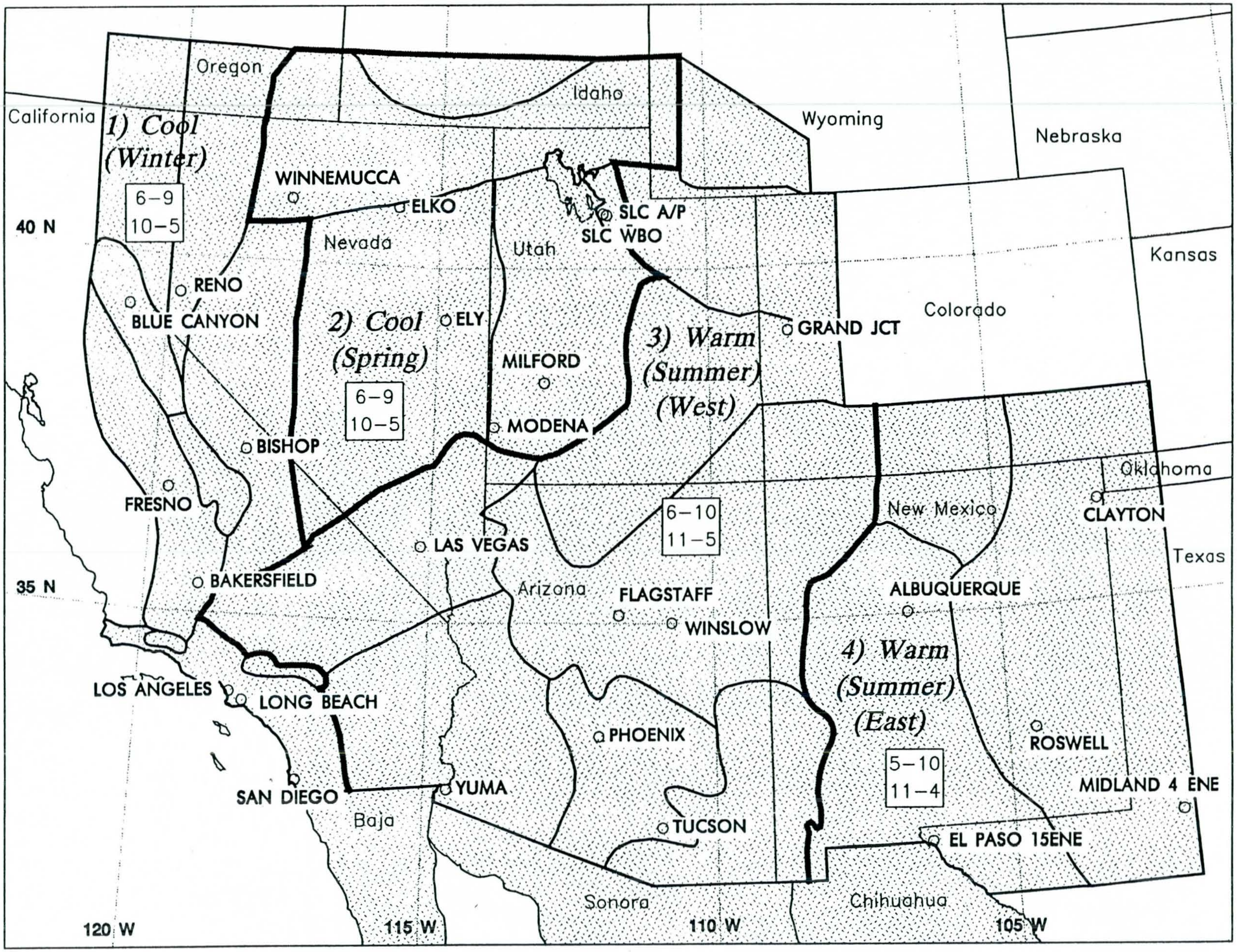

Figure 2. *N-minute stations in the Semiarid study area.*

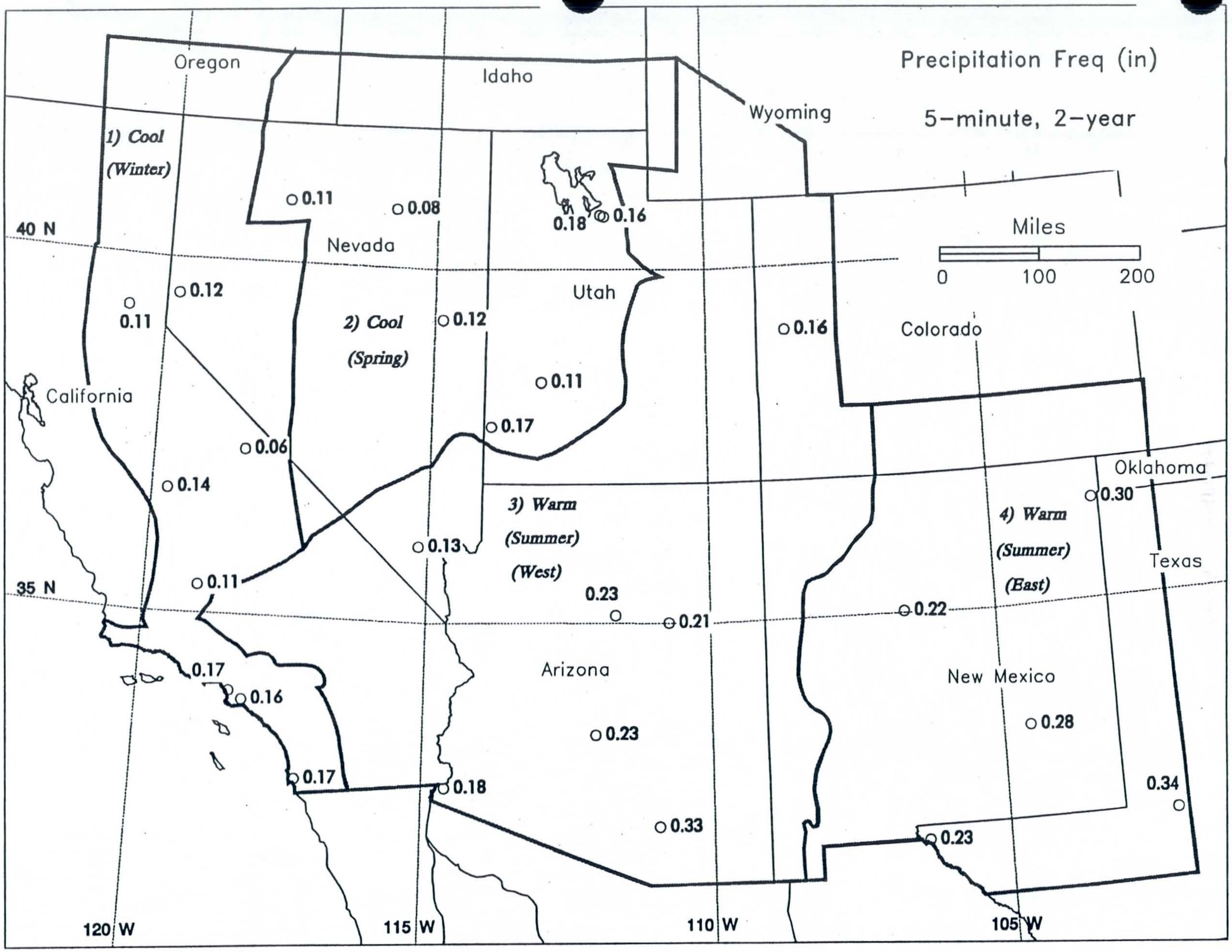

Figure 3a. *2-year, 5-minute precipitation frequencies for N-minute stations.*

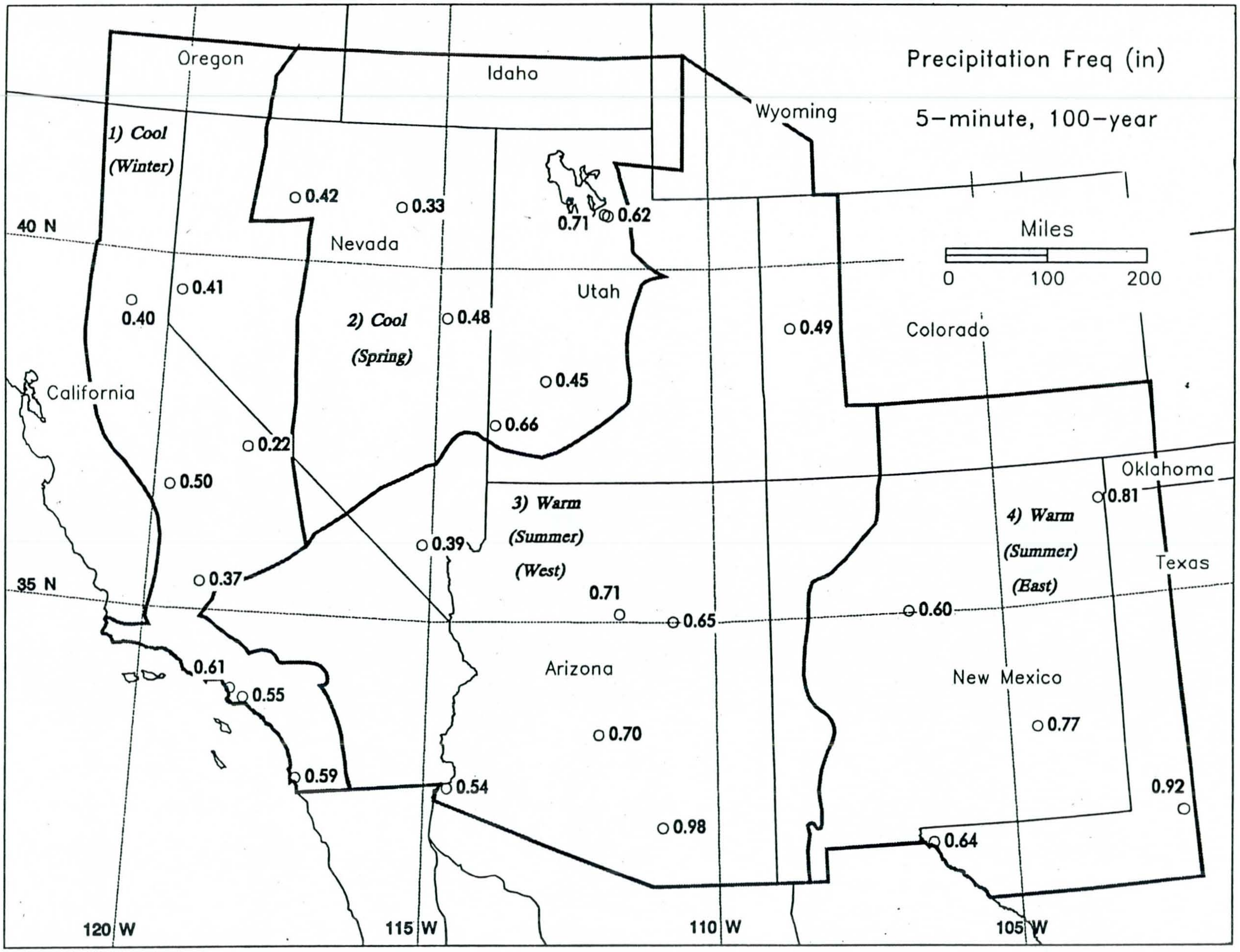

Figure 3b. *100-year, 5-minute precipitation frequencies for N-minute stations.*

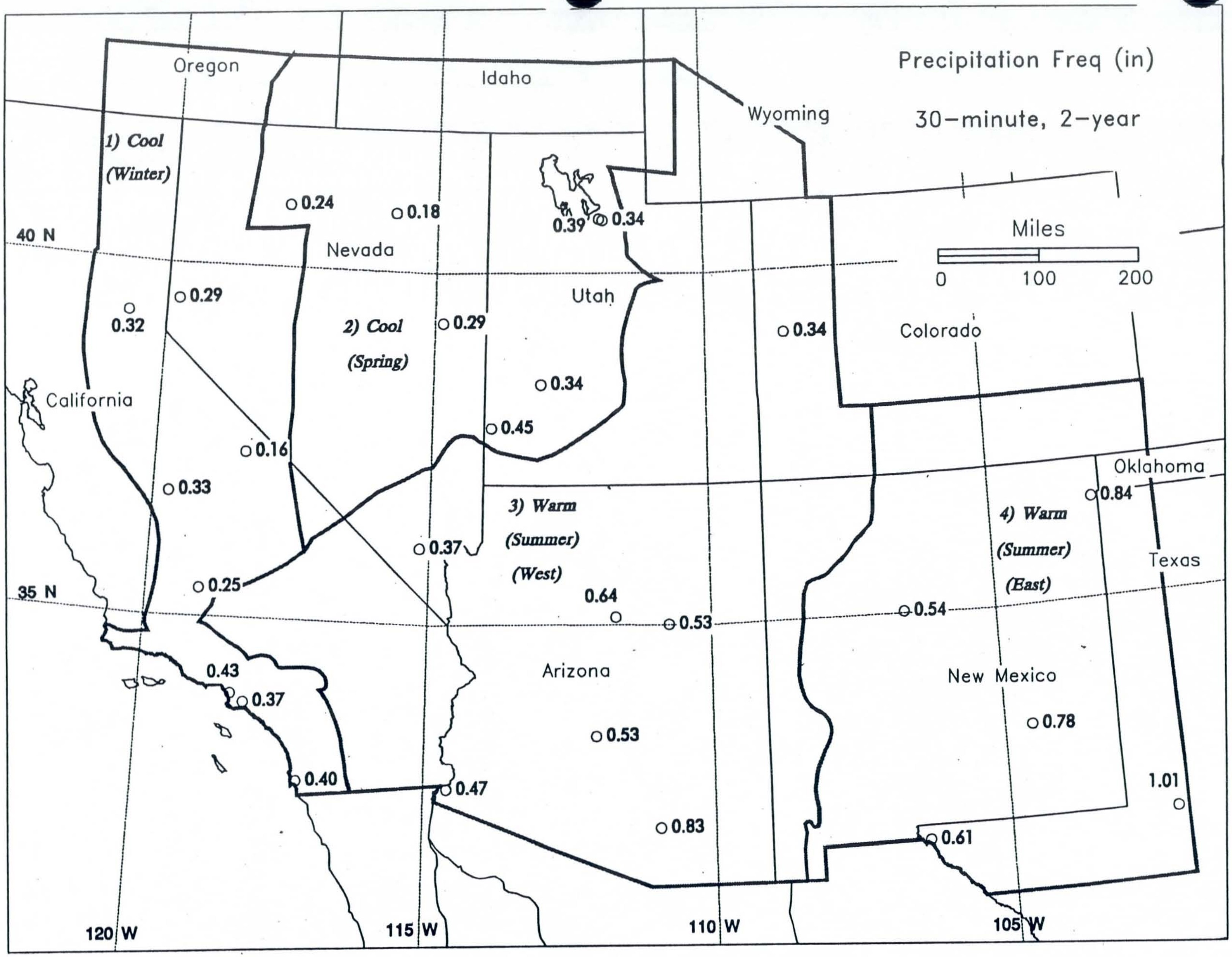

Figure 3c. *2-year, 30-minute precipitation frequencies for N-minute stations.*

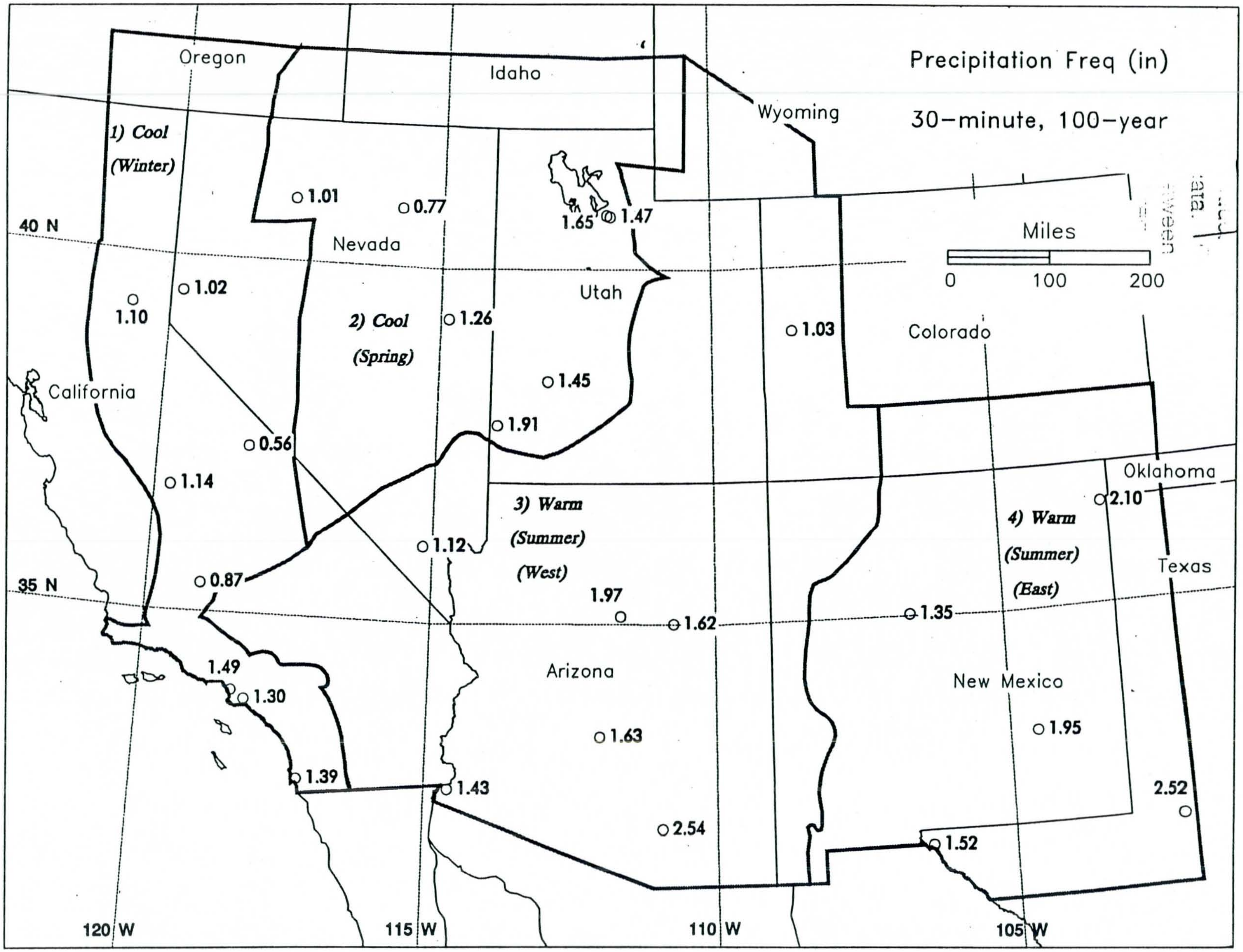

Figure 3d. *100-year, 30-minute precipitation frequencies for N-minute stations.*

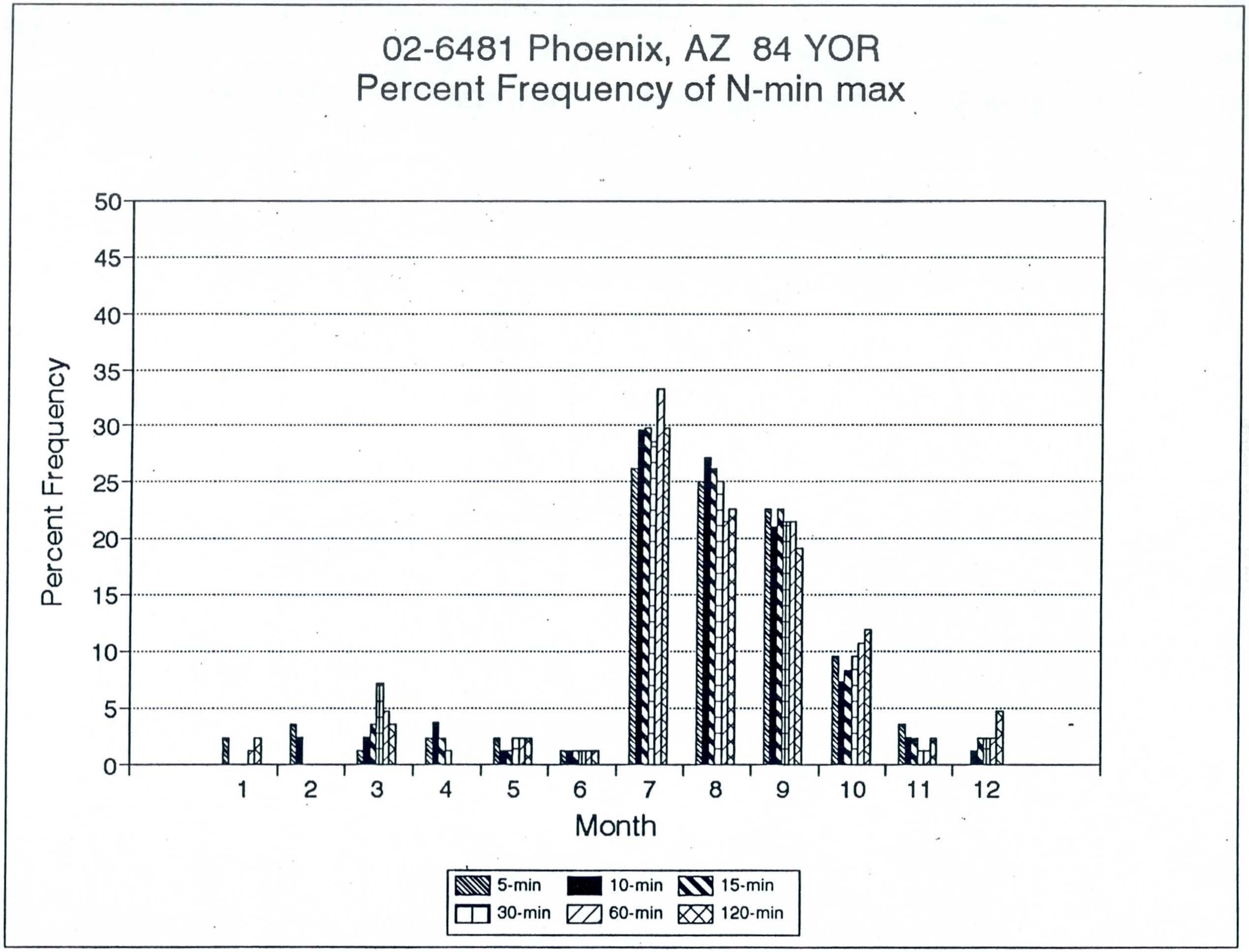

Figure 4a. *Seasonal histogram for Phoenix, Arizona.*

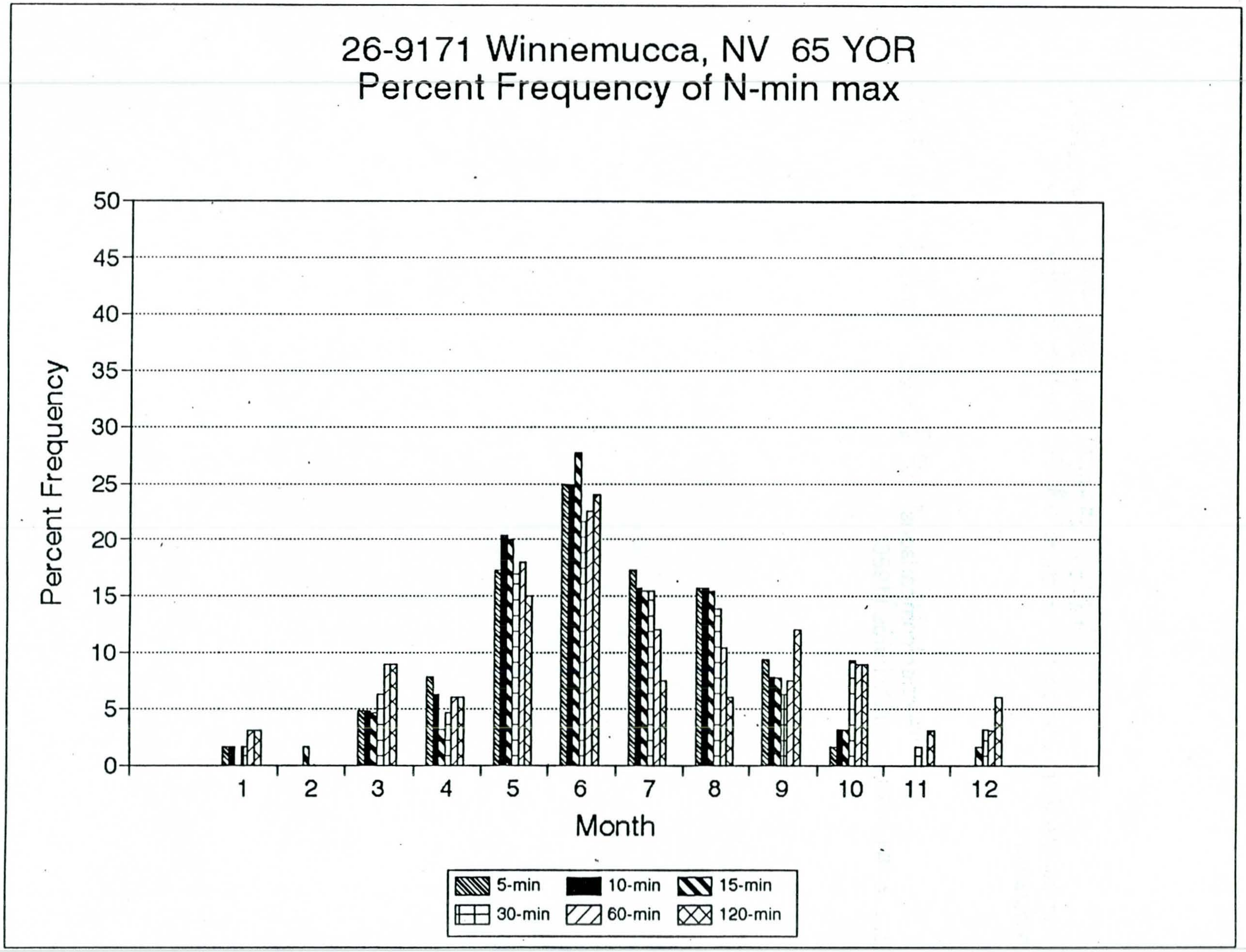

Figure 4b. *Seasonal histogram for Winnemucca, Nevada.*

The final product of the intensive analysis of the n-minute data is the ratios to the 60-minute data. The ratios were computed for each region separately, but the largest difference between any two regions was 0.03. Therefore, the ratios for the entire area were considered to be essentially homogeneous across the whole Semiarid region. Furthermore, the ratios were found to be the essentially the same, regardless of return frequency. This confirms the findings in Hershfield et al. 1961 Technical Paper 40 and adapted in NOAA Atlas 2. Table 2 shows the n-minute ratios (n-min/60-min) computed for the Semiarid study and those reported in NOAA Atlas 2 for 5, 10, 15, and 30 minutes. Also shown in Table 2 are the ratios used by Huff and Angel (1992). The Semiarid ratios are .03 higher than the NOAA Atlas 2 values except at 5 minutes, where the ratio is .04 higher. The Huff and Angel values are the same as NOAA Atlas 2, except at 5-minutes, where their ratio is lower than both the Semiarid and the NOAA Atlas 2 values. Further comparisons will be made with other short duration studies, such as Arkell and Richards (1986).

Table 2.

Comparison of Semiarid n-minute ratios
to NOAA Atlas 2 ratios

	5-min	10-min	15-min	30-min
Semiarid Ratios	0.33	0.49	0.60	0.82
NOAA Atlas 2	0.29	0.45	0.57	0.79
Huff and Angel 1992	0.26	0.45	0.57	0.79
Difference	0.04 (.07)	0.03	0.03	0.03

MAPPING

Isohyetal Maps

Isohyetal maps and/or ratios are used to represent return frequencies from 2-year to 100-year (also 200, 500, and 1000 year estimates) for durations from 5 minutes to 60 days. The index map for 2-year/24-hour return frequency has been plotted, hand-analyzed, and is being digitized into the GIS/GRASS computing system. An initial raster map has been generated and a vector (isohyetal) map generated from the raster map. The first draft of the 100-year/24-hour map for Utah and southern Arizona has been computer-generated from the 2-year index map, by multiplying the 2-year raster map by the Regional Growth Factors (RGFs), derived from the L-moment regional analysis. The other return frequencies will be computer-generated in the same way. However, this process will take additional consideration as the RGFs vary among the different regions; and how to best resolve any finite discontinuities between regions is still undecided. Possibly a spline-fitting technique may be developed for interpolation between regions. A linear interpolation between regions was successful on a study in Hayes County, Texas; but the area had only two regions, not 24, and the topography was not nearly as complex.

Ratios

To determine return frequencies for durations less than 24 hours, ratios to 24 hours are used, and for durations less than 60 minutes, ratios to 60 minutes are used. These computations are complete, although not in final form. Ratios are used for these shorter durations, because of the limited number of stations available, which precludes adequate spatial coverage for mapping. The n-minute ratios are shown in the section on n-minute data analysis.

REGIONAL STUDIES

Two detailed studies were done to compare NOAA Atlas 2 with the current study. These were done for Washoe County, Nevada and Imperial County, California.

Washoe County, Nevada

The results show little change from NOAA Atlas 2 in Washoe County (Reno area), but the greatest differences are in the mountains to the west of Reno. The Semiarid Project values are higher in the mountains. This is due in large part to the high values of the SNOTEL data in high elevations, where essentially no data were available for NOAA Atlas 2.

Imperial County, California

Imperial County contains most of the Salton Sea and about a third of the county is below sea level. In the interest of water resources, the question was asked how do the surrounding mountains fare in regard to rainfall, as nearly the only rainfall occurs in the higher elevations in the county. The Salton Sea area is 'rain-shadowed' on three sides, and only opens to the southeast on a relatively narrow swath to the Gulf of California, thus it is no surprise that it is very dry. The map in Figure 5 shows station names and numbers and elevations for Imperial County and surroundings. Six of the stations are below sea level, four of them 100 feet or more below sea level. All the stations that are above sea level are within the valley. The Chocolate Mountains rise to about two or three thousand feet along the northeast side of the valley, although to the east of Gold Rock Ranch (490 feet), a relatively isolated peak rises to only 1500 feet. The mountain barrier that blocks the Pacific moisture from the west ranges from over 10,000 feet in the northern part of the range to about 5500 feet west of Crawford Ranch. Preliminary precipitation return frequency values, 2-year/24-hour and 100-year/24-hour, were mapped and are shown in Figures 6a and 6b. Although higher elevations generally have higher precipitation values, there is no direct linear relationship, i.e., Ocotillo (410 feet) has a 2-year/24-hour value of 1.60 inches, but Coyote Wells (250 feet) and Brawley (-30 feet) have essentially the same value, 1.07 and 1.06, respectively. In Figures 7a and 7b, the differences between the Semiarid study and NOAA Atlas 2 for 2-year/24-hour and 100-year/24-hour are given. In the 100-year return period, there are a few small increases, but most of the values decreased by several tenths of an inch. Only one decrease is more than 1 inch, at Ocotillo Wells which shows a decrease of 1.28 inches.

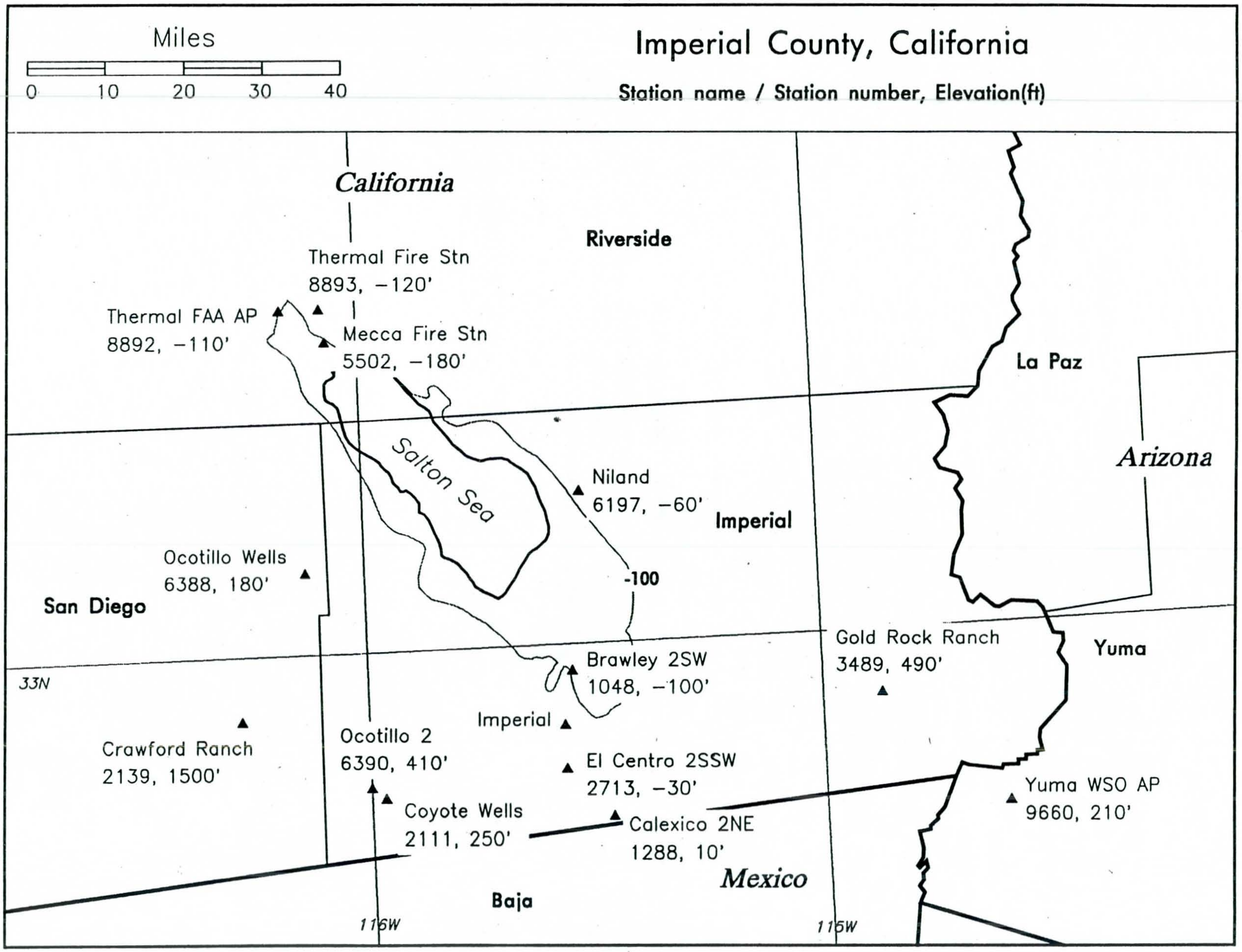

Figure 5. *Stations in the Imperial County study area.*

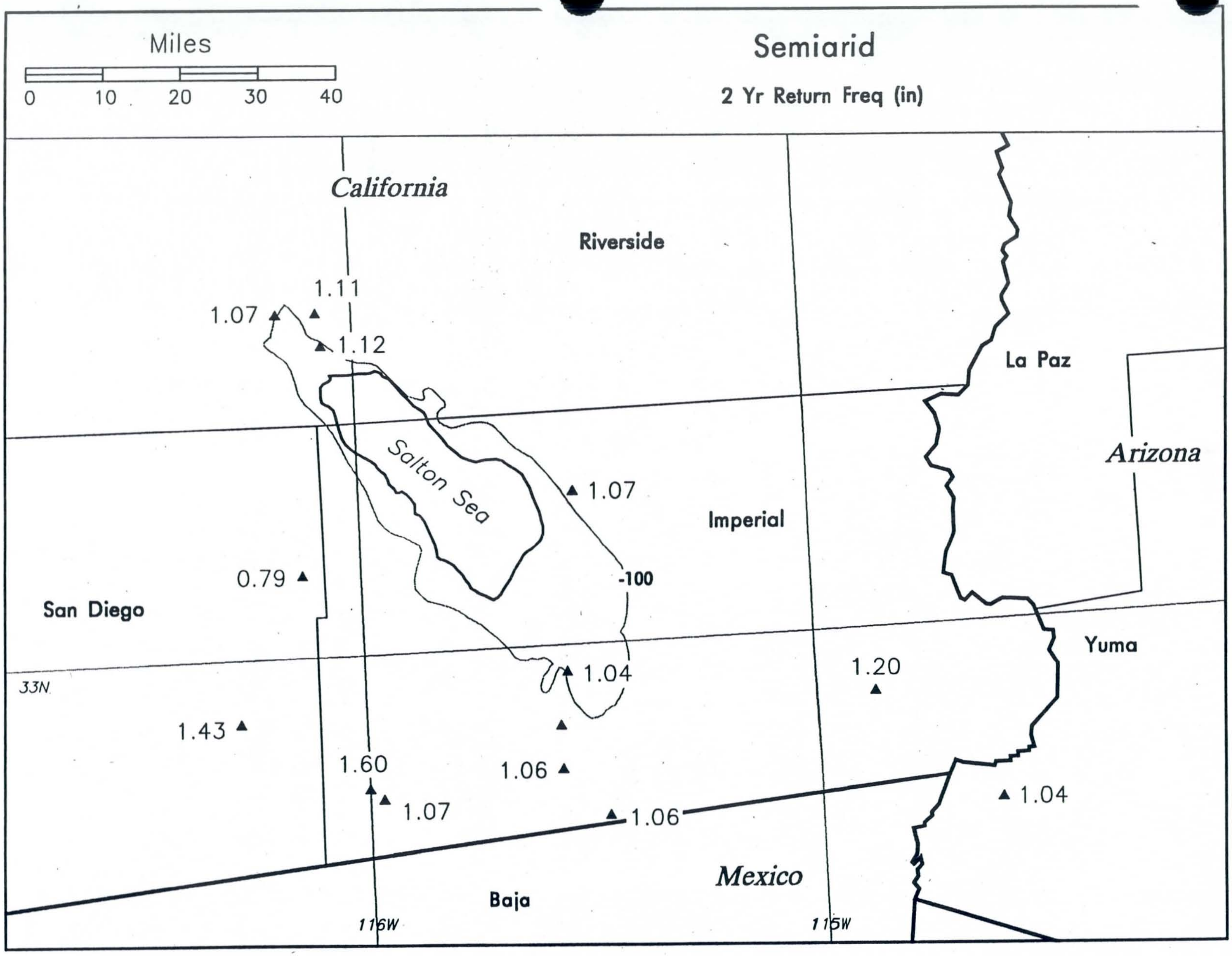

Figure 6a. *2-year, 24-hour precipitation frequencies for Imperial County.*

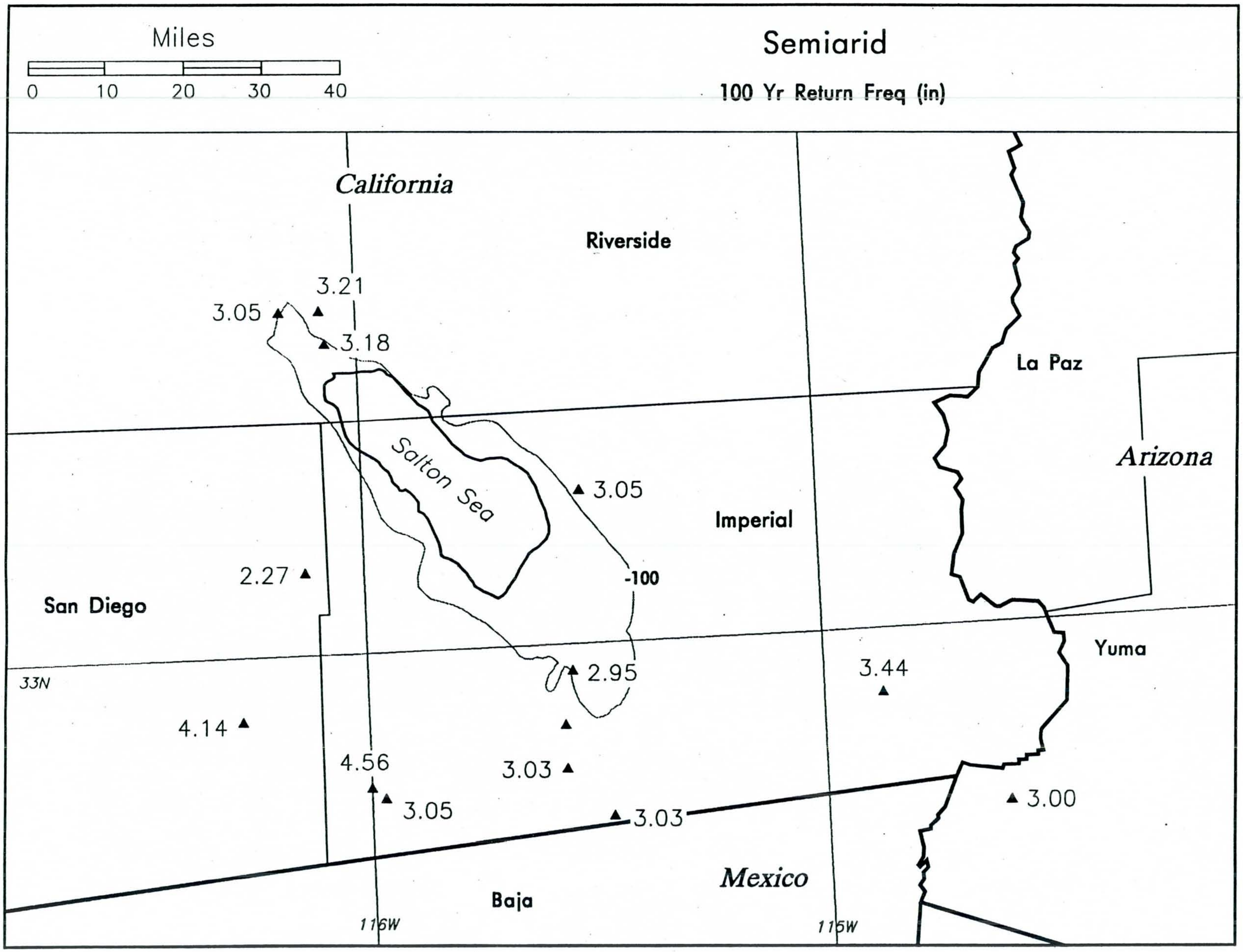

Figure 6b. *100-year, 24-hour precipitation frequencies for Imperial County.*

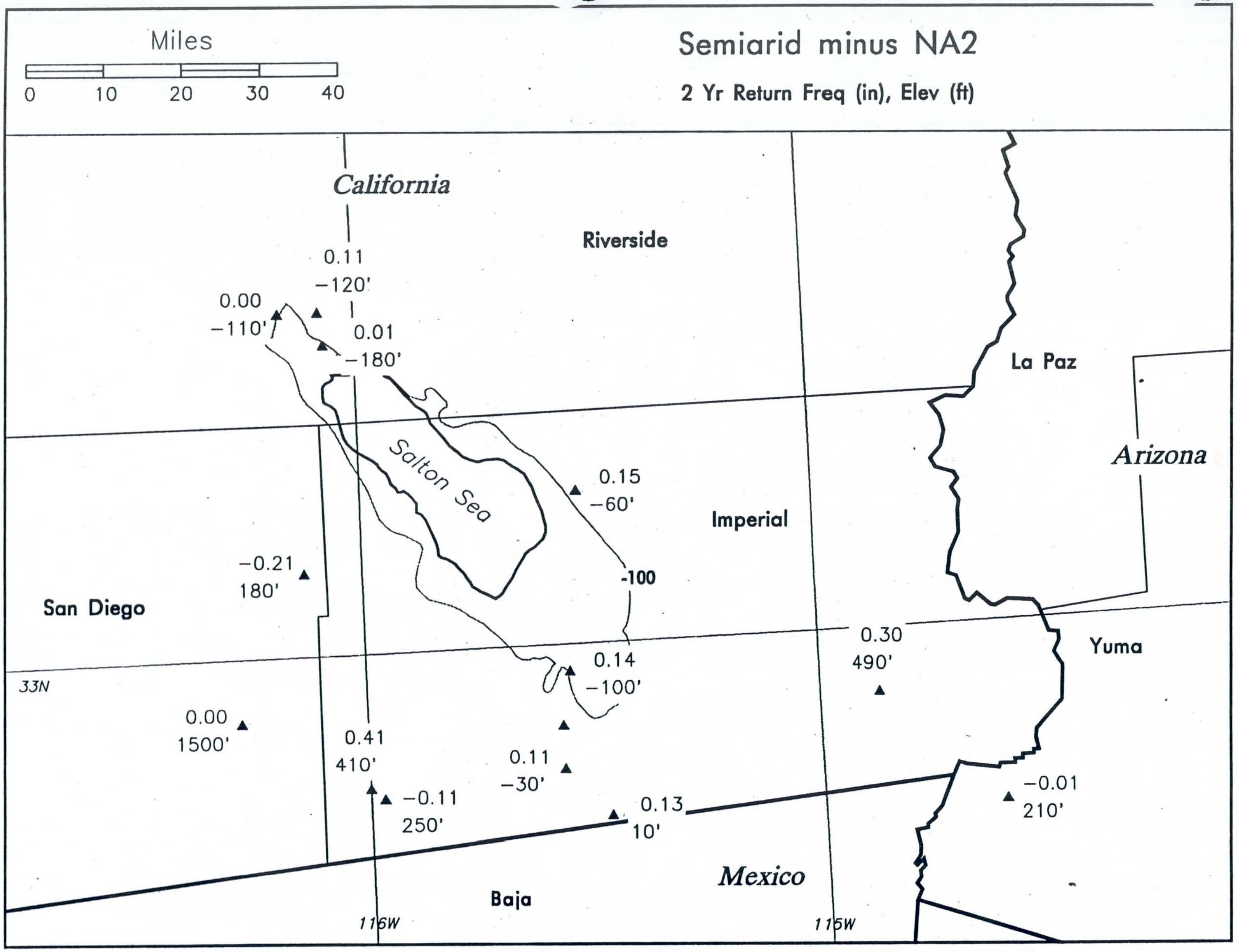

Figure 7a. *Difference of Semiarid study and NOAA Atlas 2 precipitation frequencies for 2-yr, 24-hr (inches).*

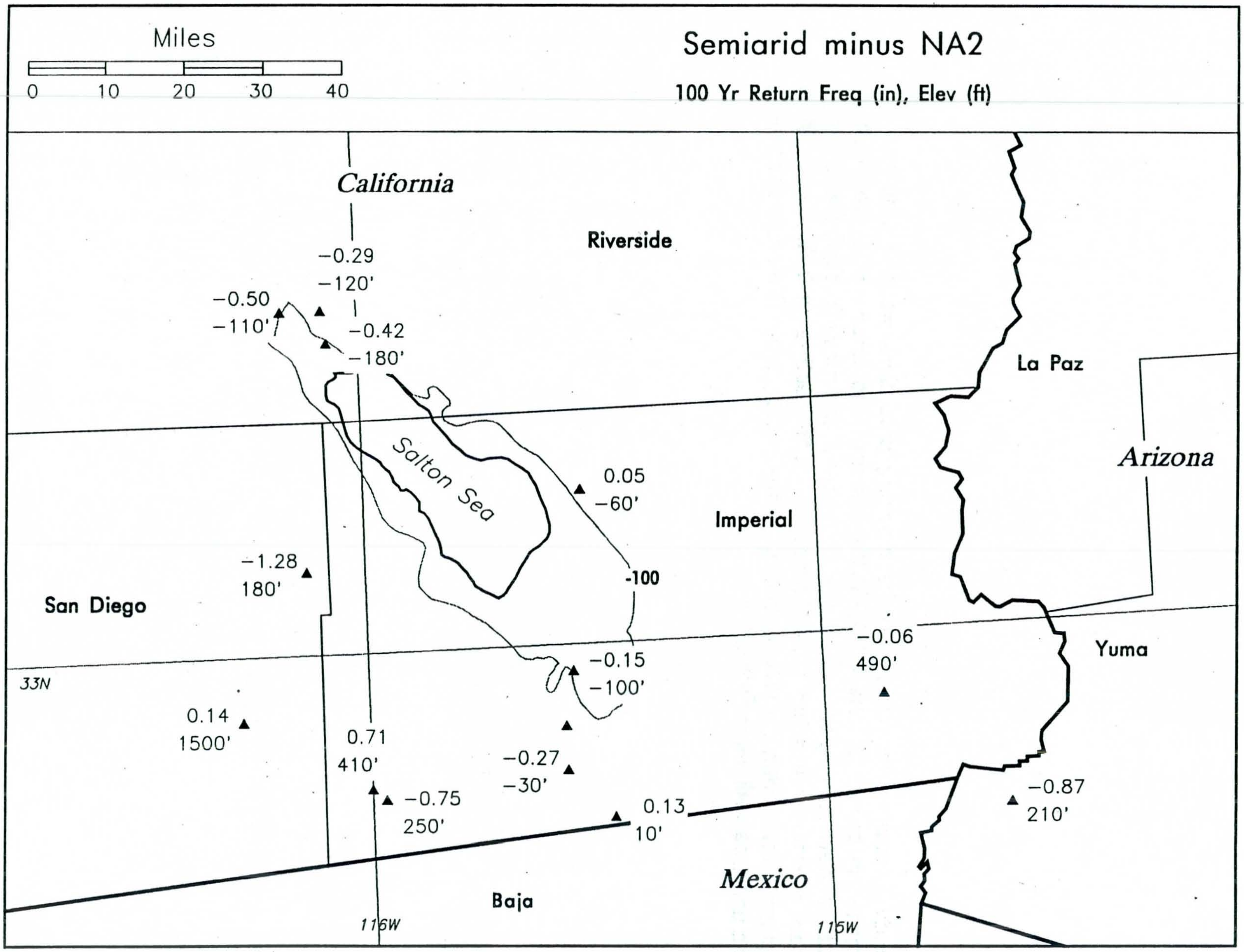

Figure 7b. *Difference of Semiarid study and NOAA Atlas 2 precip. frequencies for 100-yr, 24-hr (inches).*

STORM ANALYSIS

The analysis of the four storms (1019, 1020, 1021, 1022) of Fall 1983 (9/27-10/3) has been completed and depth-area-duration (DAD) curves prepared. Two December 1992 storms (1040, 1041) are being analyzed. The mass curves for 1040 have been completed. Additional DAD curves are available from other storm studies for Semiarid storms 1023 (August 1951), 1029 (September 1970), and 1030 (October 1972). The other Semiarid storms continue to be processed.

SUMMARY

The study is coming together, with the mapping procedure working well and map preparation underway on the GRASS/GIS system. As soon as a procedure for interpolation between regions is in place, the project can move into production mode. The short duration ratios have been prepared. The depth-area-duration curves for seven storms have been completed, and more are in progress. The final report will be in metric units, as well as in English units.

REFERENCES

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

March 8, 1995 W/OH5/LFT

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH5 - John Vogel and Lesley Tarleton

SUBJECT: Thirteenth Quarterly Report - Semiarid Precipitation Frequency Project, October 1 - December 31, 1994

Enclosed is a copy of the Thirteenth Quarterly Progress Report for the Semiarid Precipitation Frequency Project for the southwestern United States. The report includes mapping procedures, some comparisons with NOAA Atlas 2, and results from the analysis of n-minute data and long-duration data.

As a mistake was made in determining the multiplicative factors for computing the 100-year maps from the 2-year maps, some mapping results reported at the Semiannual meeting at the Arizona Department of Transportation (ADOT) in Tempe 7 November 1994 were incorrect. This quarterly report was, therefore, delayed so that we could correct the error and report the proper results for the 100-year maps.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMIARID PRECIPITATION FREQUENCY STUDY

Thirteenth Quarterly Progress Report
for the period from
October 1 through December 31, 1994

Lesley F. Tarleton, Julie M. Olson, Edwin H. Chin,
Susan M. Gillette, John L. Vogel, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
January/February 1995

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SEMIARID PRECIPITATION FREQUENCY STUDY

Thirteenth Quarterly Progress Report for the period from October 1 through December 31, 1994

OVERVIEW

This Thirteenth Quarterly Report summarizes the work for the Semiarid Precipitation Frequency Project for the period September 1 through December 31, 1994. Included in this report are: mapping, n-minute data summary, and long duration results. For reference the map of the complete Semiarid Project area, including border regions, is repeated from earlier quarterly reports in Figure 1. The map shows 24 near-homogeneous climatic regions, with their associated precipitation seasons. As a mistake was made in determining the multiplicative factors for computing the 100-year maps from the 2-year maps, the results reported at the Semiannual meeting at the Arizona Department of Transportation (ADOT) in Tempe 7 November 1994 were incorrect. This quarterly report was, therefore, delayed so that we could correct the error and report the proper results for 100-year maps.

MAPPING AND ANALYSIS

The dataset for the Semiarid precipitation return frequency analysis for all durations from 5 minutes through 60 days is summarized in Table 1. All data are prepared from partial duration series, using L-moment statistics. Return frequencies include 2 to 1000 years. Return frequencies for greater than 100 years (200, 500, and 1000 years) are being prepared as a result of user requests for the higher value return frequencies. If we were to map all these durations and return frequencies for annual, summer and winter precipitation seasons, it would result in 486 maps. This seems a bit much. Thus, a combination of maps, tables, and graphs will be used to present the required return frequencies in as accessible way as possible. In the following paragraphs, the analysis and presentation of results for various durations and return frequencies will be discussed in the following groups - 1) 1-day (24-hour), 2) 1-hour (60-minute) to 24-hour, 3) 5-minute to 60-minute, and 4) 2-day to 60-day.

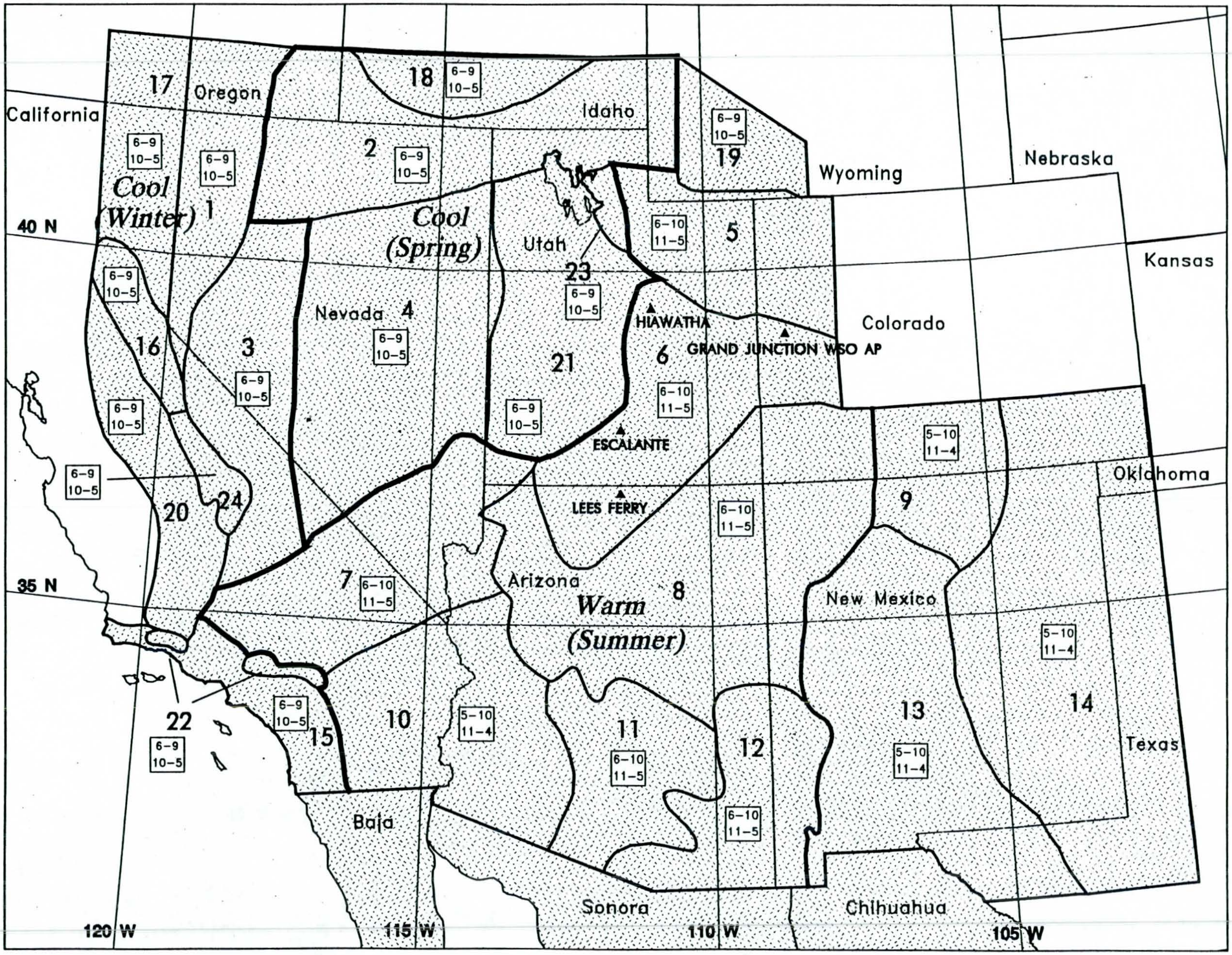

Figure 1. *Semiarid study climatic regions.*

TABLE 1.

Dataset and Analysis Summary
Data

- 24 near-homogeneous regions (Daily, Hourly)
- 13 higher-elevation areas (SNOTEL)
- 3 Mexican states (Mexican Daily)
- Daily data - Converted from 1-day to 24-hour; 2-day to 48-hour
- Hourly data - converted from 1-hour to 60-min; from 2-hour to 120-min
- 4 N-minute areas
- Return frequencies from L-moment statistical analysis
- Partial duration series
- Generalized Pareto probability distribution

Durations

- Daily/24-hour: 1 day (24 hours), 2 days (48 hours), 4, 7, 10, 20, 30, 45, and 60 days.
- Hourly/60-minute: 1, 2, 3, 6, 12, 24, and 48 hours.
- N-minute data: 5, 10, 15, 30, 60, and 120 minutes;
  (limited number of records for 20, 45, 80, 100, 150, and 180 minutes).

Return Frequencies

- 2, 5, 10, 25, 50, 100, 200, 500, and 1000 years.

Scale

- 1:1,000,000 for analysis (1:2,000,000 for publication)

Elevation Map

- 1:1,000,000 computer-generated, with elevations from 100 feet below sea level to over 14,000 feet; contours: -100, 1, 100, 200, 400, 600, 800, 1000, 1500, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 12000. (Although there are elevations above 14,000 ft, there are no 14,000-ft contours on the smoothed maps.)

1-Day (24-hour) Maps

The 24-hour maps are pivotal. The 24-hour information is most directly observed, has the most stations, and the longest periods of record. Shorter and longer durations are related to the 24-hour directly and indirectly. The 24-hour data include both daily and hourly reporting stations, with daily observations adjusted to the 24-hour period of maximum precipitation. The 2-year return period approximates the median value and is the most stable statistically. Furthermore, the periods of record (approximately 15 to nearly 100 years) permit the best estimates at short return periods. Therefore, the 2-year, 24-hour map is used as an Index Map. The 2-year, 24-hr map has been plotted, hand-analyzed, and digitized into GRASS and changed into rasters for computation of other return frequencies. Regional growth factors (RGF) are used to compute the various return frequencies from the 2-year, 24-hour Index Map.

Regional Growth Factors

Regional growth factors (RGF) are derived from L-moment analysis of the extreme precipitation data, using a partial duration series and the Generalized Pareto distribution in each near-homogeneous region. The choice of distribution was made as a result of curve-fitting tests within the L-moment software and real data comparisons with theoretical distributions. This process has been discussed in the Ninth and Tenth Quarterlies (Tarleton et al 1994a, 1994b). For reference, a description of L-moment quality-control and curve-fitting procedures is included here in the Appendix. The RGFs are used to determine the return frequency values for each station by multiplying the station mean (mean of the partial duration series for that station for that duration) by the regional growth factor for the region and return frequency of interest. Table 2a gives the RGFs (adjusted from daily to 24 hours) for return frequencies from 2 years to 1000 years for the 24 regions. The adjustment factors are noted in the first line of data in the table. An example illustrates how the values in Table 2a are determined:

> The RGFs for the daily data partial duration series are determined from L-moment statistical routines, and for region 1 (2-year) is **0.90**. The conversion factor from daily to 24-hour data for a 2-year return frequency is **1.15**. Thus, the adjusted RGF (2-year) for region 1 is **0.90 * 1.15 = 1.04**.

Table 2a.

Adjusted Regional Growth Factors from 1-day to 24-hour values (conversion factors given in 1st row)
1-Day, PD Series, GPA distribution.

Return frequency: 1d to 24h:	2-y 1.15	5-y 1.13	10-y 1.12	25-y 1.1	50-y 1.08	100-y 1.06	200-y 1.05	500-y 1.04	1000-y 1.02
Region 1	1.04	1.33	1.56	1.86	2.09	2.31	2.56	2.90	3.13
Region 2	1.05	1.30	1.50	1.76	1.97	2.17	2.41	2.74	2.97
Region 3	1.02	1.34	1.60	1.96	2.23	2.52	2.84	3.31	3.64
Region 4	1.05	1.32	1.54	1.81	2.01	2.20	2.41	2.70	2.88
Region 5	1.05	1.30	1.51	1.79	2.00	2.22	2.46	2.81	3.06
Region 6	1.05	1.31	1.52	1.79	1.99	2.19	2.41	2.71	2.92
Region 7	1.03	1.35	1.59	1.91	2.14	2.36	2.61	2.95	3.17
Region 8	1.04	1.31	1.53	1.81	2.03	2.25	2.49	2.84	3.08
Region 9	1.05	1.30	1.50	1.76	1.96	2.16	2.39	2.72	2.94
Region 10	0.99	1.38	1.69	2.13	2.47	2.83	3.23	3.82	4.25
Region 11	1.04	1.32	1.54	1.81	2.01	2.21	2.43	2.73	2.93
Region 12	1.05	1.31	1.51	1.76	1.93	2.09	2.27	2.51	2.66
Region 13	1.05	1.32	1.52	1.77	1.95	2.12	2.30	2.54	2.69
Region 14	1.03	1.34	1.59	1.92	2.17	2.43	2.72	3.13	3.42
Region 15	1.04	1.36	1.60	1.89	2.09	2.29	2.49	2.77	2.93
Region 16	1.05	1.32	1.54	1.82	2.01	2.20	2.41	2.70	2.88
Region 17	1.03	1.32	1.55	1.87	2.12	2.37	2.65	3.06	3.35
Region 18	1.05	1.30	1.50	1.77	1.97	2.18	2.42	2.76	2.99
Region 19	1.03	1.34	1.58	1.89	2.12	2.35	2.60	2.94	3.17
Region 20	1.05	1.30	1.51	1.79	2.00	2.21	2.45	2.79	3.02
Region 21	1.06	1.30	1.49	1.73	1.91	2.09	2.28	2.55	2.72
Region 22	1.02	1.37	1.64	2.00	2.26	2.52	2.81	3.20	3.46
Region 23	1.07	1.29	1.45	1.66	1.81	1.95	2.10	2.31	2.44
Region 24	1.01	1.33	1.60	1.98	2.27	2.59	2.94	3.47	3.86
mean	1.04	1.32	1.55	1.84	2.06	2.28	2.53	2.87	3.11
sd	0.02	0.02	0.05	0.10	0.14	0.19	0.24	0.32	0.39
max	1.07	1.38	1.69	2.13	2.47	2.83	3.23	3.82	4.25
min	0.99	1.29	1.45	1.66	1.81	1.95	2.1	2.31	2.44
range	0.08	0.09	0.24	0.47	0.66	0.88	1.13	1.51	1.81

Table 2b.

Final Regional Growth Factors (24-hour) for 2-year to higher frequencies
Each frequency's RGF is divided by the 2yr RGF.
These RGFs include the conversion from 1-day to 24-hour.

Return frequency:	2-y	5-y	10-y	25-y	50-y	100-y	200-y	500-y	1000-y
1-d to 24h:	1.15	1.13	1.12	1.1	1.08	1.06	1.05	1.04	1.02
Region 1	1.00	1.28	1.50	1.79	2.01	2.22	2.46	2.79	3.01
Region 2	1.00	1.24	1.43	1.68	1.88	2.07	2.30	2.61	2.83
Region 3	1.00	1.31	1.57	1.92	2.19	2.47	2.78	3.25	3.57
Region 4	1.00	1.26	1.47	1.72	1.91	2.10	2.30	2.57	2.74
Region 5	1.00	1.24	1.44	1.70	1.90	2.11	2.34	2.68	2.91
Region 6	1.00	1.25	1.45	1.70	1.90	2.09	2.30	2.58	2.78
Region 7	1.00	1.31	1.54	1.85	2.08	2.29	2.53	2.86	3.08
Region 8	1.00	1.26	1.47	1.74	1.95	2.16	2.39	2.73	2.96
Region 9	1.00	1.24	1.43	1.68	1.87	2.06	2.28	2.59	2.80
Region 10	1.00	1.39	1.71	2.15	2.49	2.86	3.26	3.86	4.29
Region 11	1.00	1.27	1.48	1.74	1.93	2.13	2.34	2.63	2.82
Region 12	1.00	1.25	1.44	1.68	1.84	1.99	2.16	2.39	2.53
Region 13	1.00	1.26	1.45	1.69	1.86	2.02	2.19	2.42	2.56
Region 14	1.00	1.30	1.54	1.86	2.11	2.36	2.64	3.04	3.32
Region 15	1.00	1.31	1.54	1.82	2.01	2.20	2.39	2.66	2.82
Region 16	1.00	1.26	1.47	1.73	1.91	2.10	2.30	2.57	2.74
Region 17	1.00	1.28	1.50	1.82	2.06	2.30	2.57	2.97	3.25
Region 18	1.00	1.24	1.43	1.69	1.88	2.08	2.30	2.63	2.85
Region 19	1.00	1.30	1.53	1.83	2.06	2.28	2.52	2.85	3.08
Region 20	1.00	1.24	1.44	1.70	1.90	2.10	2.33	2.66	2.88
Region 21	1.00	1.23	1.41	1.63	1.80	1.97	2.15	2.41	2.57
Region 22	1.00	1.34	1.61	1.96	2.22	2.47	2.75	3.14	3.39
Region 23	1.00	1.21	1.36	1.55	1.69	1.82	1.96	2.16	2.28
Region 24	1.00	1.32	1.58	1.96	2.25	2.56	2.91	3.44	3.82
mean	1.00	1.27	1.49	1.78	1.99	2.20	2.44	2.77	3.00
sd	0.00	0.04	0.08	0.13	0.17	0.22	0.27	0.36	0.43
max	1.00	1.39	1.71	2.15	2.49	2.86	3.26	3.86	4.29
min	1.00	1.21	1.36	1.55	1.69	1.82	1.96	2.16	2.28
range	0.00	0.19	0.35	0.60	0.80	1.04	1.30	1.70	2.01

Most adjusted RGFs are a little greater than 1.00 for the 2-year return frequency and average 2.20 for the 100-year return frequency. Region 10 (the desert area of southeastern California and southwestern Arizona) is the most varied, with a 2-year adjusted RGF of 0.99 and a 100-year value of 2.83. This appears to reflect the desert extreme precipitation with its 'all or nothing' character.

To generate the 100-year (or other return frequencies), the 2-year Index Map is multiplied by the appropriate RGF. However, the 2-year values are **not** the mean values, thus we must divide the RGFs in Table 2 by the 2-year RGFs to determine the correct factor. The factors used to convert the 2-year, 24-hour map to other return frequencies are given in Table 2b. To carry through the example for region 1 from Table 2a:

> The adjusted RGFs are: 2-year, **1.04**; 100-year, **2.31**. Therefore, the 100-year value divided by the 2-year value is **2.31 ÷ 1.04 = 2.22**. The value **2.22** is shown in Table 2b for region 1 for the 100-year return frequency factor. Naturally, the 2-year values are all 1.00.

The first maps generated have been the 100-year, 24-hour maps. As the RGFs vary among the different regions some finite discontinuities may occur at the borders between regions. Experiments with different filters has led to the use of centered averages on the raster field. The RGF raster field is smoothed four times, using grids of 25 X 25, 23 X 23, 17 X 17, and 3 X 3, respectively. The smoothed RGFs are then used to multiply the 2-year raster map to produce a 100-year raster map. This map is smoothed one more time with a 3 X 3 grid to minimize ragged edges on the GRASS vectors or contours (isohyets). With minor exceptions, this procedure appears to take care of transitions at borders between regions. For any residual problems, some additional smoothing can be done by hand and patched into the vector map.

The differences between NOAA Atlas 2 (Miller et al 1973) 100-year/24-hour maps and the current Semiarid Project have been computed using GRASS. The percentages by area of change for Arizona, Nevada, New Mexico, and Utah are shown in Figure 2 and Table 3.

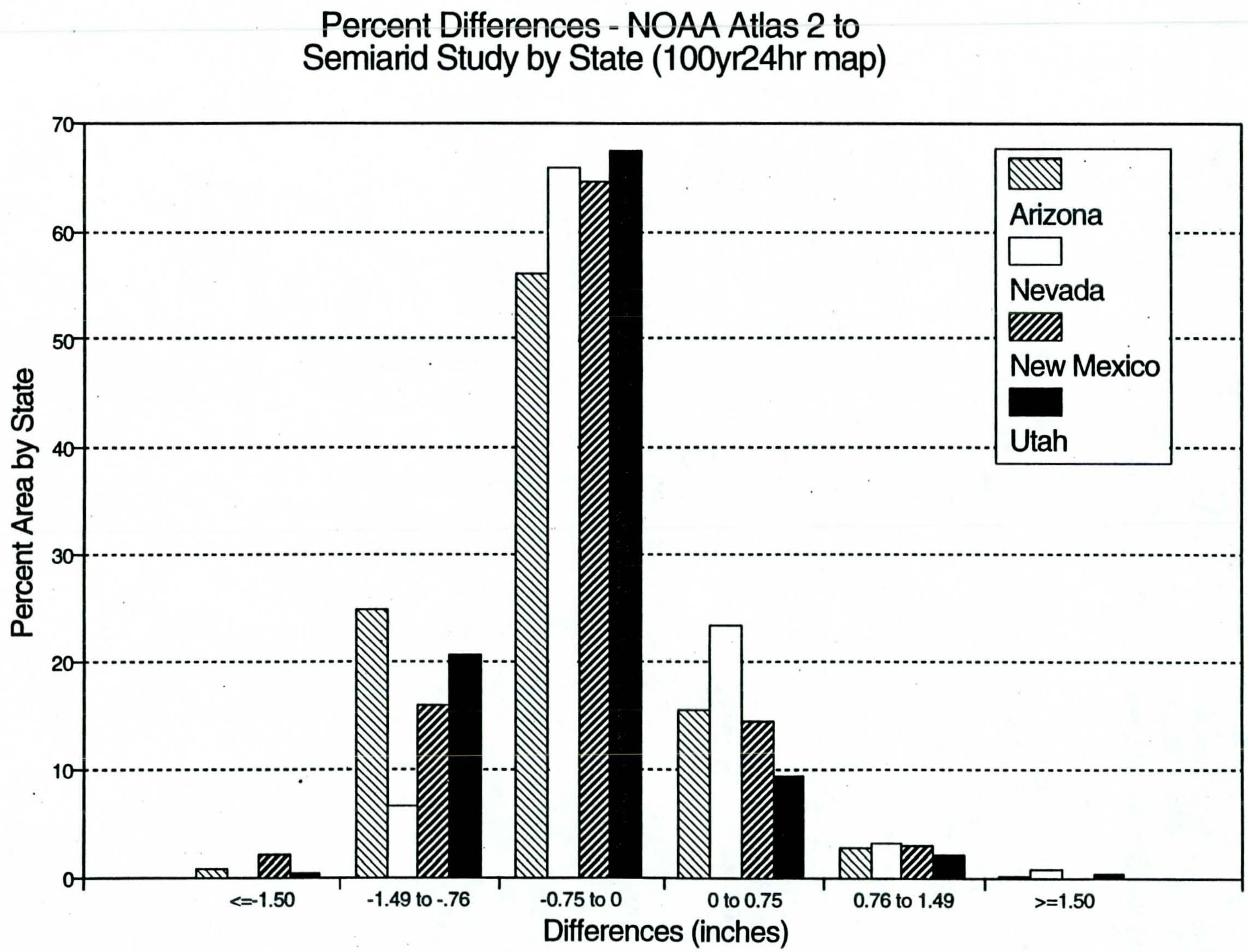

Figure 2. *Percent differences of NOAA Atlas 2 to Semiarid Study, by state.*

Table 3.

Percent area differences from NOAA Atlas 2 to Semiarid Study
by State
100-year 24-hour computer-generated map

DIFFERENCE (inches)	<=-1.50	-1.49 to -0.75	-0.74 to -0.01	0.00 to 0.75	0.76 to 1.49	>=1.50
Arizona	0.7	24.9	56.0	15.5	2.7	0.1
Nevada	0.0	6.6	65.9	23.4	3.2	0.9
New Mexico	2.2	15.9	64.6	14.4	2.9	0.0
Utah	0.3	20.5	67.3	9.2	2.2	0.5

			Range:
Arizona	81.6% < 0	18.3% > 0	-2.33 to 2.11
Nevada	72.5% < 0	27.5% > 0	-1.46 to 3.29
New Mexico	82.7% < 0	17.3% > 0	-2.69 to 1.49
Utah	88.1% < 0	11.9% > 0	-1.93 to 3.37

The Semiarid (SA) values are lower than NOAA Atlas 2 values over about 80 percent of the area in Arizona, New Mexico and Utah, and over 70 percent of the area in Nevada. Most SA values are between 0 and 0.75 inches less than NOAA Atlas 2. About 20 percent of the area of Arizona and Utah has even lower values, that is from .76 to 1.49 inches lower than NOAA Atlas 2. The SA areas that are higher than NOAA Atlas 2 are generally those in higher elevations where SNOTEL data are now available, such as the Wasatch Range and the Uinta Mountains in Utah and some areas of Nevada. For reference, the SNOTEL station areas are shown in Figure 3. Although in general, SNOTEL values are higher than NOAA Atlas 2 estimates, Arizona provides an exception, where the precipitation observed at SNOTEL stations is not notably higher than NOAA Atlas 2. Another area where SA values are higher is the region 10 part of southwestern Arizona. Region 10 has the highest RGFs, which may have some effect, but other areas within region 10 have values that are lower than NOAA Atlas 2. Another difference between SA and NOAA Atlas 2 is that the 'dry areas are drier and the wet areas wetter' in several areas of the Southwest study area. The changes reflect information from longer datasets, observations in areas where there were none for NOAA Atlas 2, more objective curve-fitting techniques, and regionalized analysis, among others.

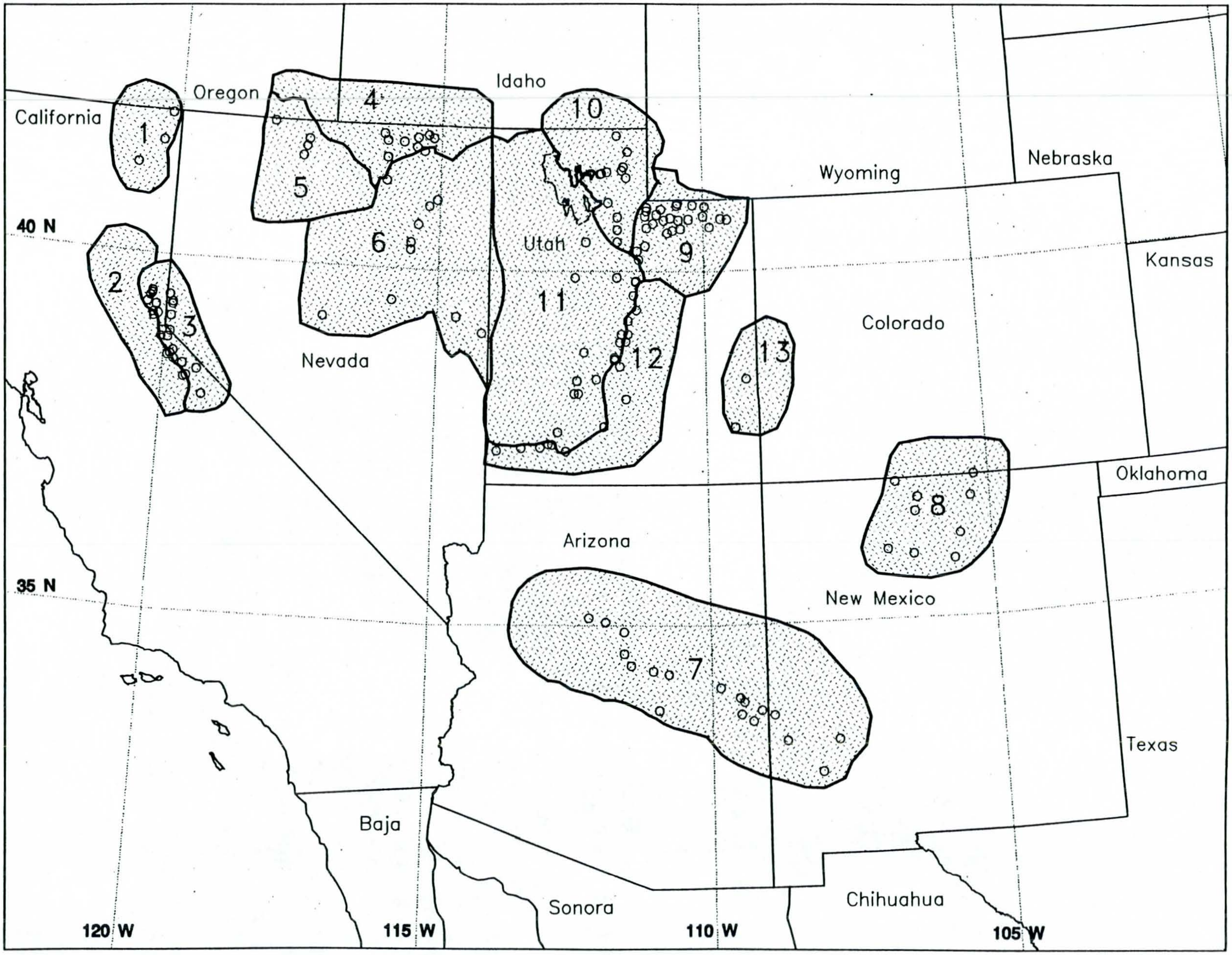

Figure 3. *SNOTEL areas developed for the Semiarid study.*

1-hour (60 minutes) Maps

Two-year 1-hour/24-hour ratio maps have been prepared for all-season and warm and cold seasons. The ratio maps will be digitized, and 2-year, 1-hour maps computer-generated from 1-hour/24-hour ratios and the 24-hour map using GRASS. This should be a relatively quick process as the 2-year, 24-hour maps are already computerized and the ratios, although they vary over the southwestern states, are fairly straightforward in their pattern. This will provide the most requested maps - the 1-hour - and the 24-hour maps. (The other 1-hour return frequencies can also be computer-generated from the 2-year map using regional growth factors). Furthermore, the 1-hour (60-minute) map will then become the basis for the n-minute return frequencies, which have already been determined, and were discussed in the Twelfth Quarterly (Tarleton et al 1994c). The 2-, 3-, 6-, and 12-hour return frequencies can be determined from the appropriate ratios to 24 hours, and presented in graph or tabular form.

Before the ratios were calculated, the hourly data were converted to 60 minutes. Both the 1-hour and 2-hour datasets were adjusted to 60 minutes and 120 minutes in a manner similar to the adjustment of daily data to a 24-hour time period (Seventh Quarterly, Tarleton et al 1993). The relationships were determined using 22 co-located hourly and n-minute stations. As there were a limited number of coincident years and insufficient n-minute data to prepare a partial duration series, the comparisons were done using annual maximum series for both hourly and n-minute data. The results for the 2-year return frequency regressions are shown in Figures 4a and 4b. Ratios of 60 minutes to 1 hour were also computed, and the final factors were based on an evaluation of the ratios and the regressions. The adjustment factors for 1 hour and 2 hours are shown in Table 4. These values are consistent with those in NOAA Atlas 2 and Technical Paper 40 (Herschfield 1961). In these publications, the value of 1.13 was used to convert 1 hour to 60 minutes for all return frequencies.

Table 4.

Conversion Factors: 1 Hour to 60 minutes, 2 Hours to 120 Minutes

Return Frequency	1hr/60min	2hr/120min
2 year	1.11	1.01
5 year	1.11	1.01
10 year	1.10	1.01
25 year	1.10	1.01
50 year	1.10	1.01
100 year	1.10	1.01

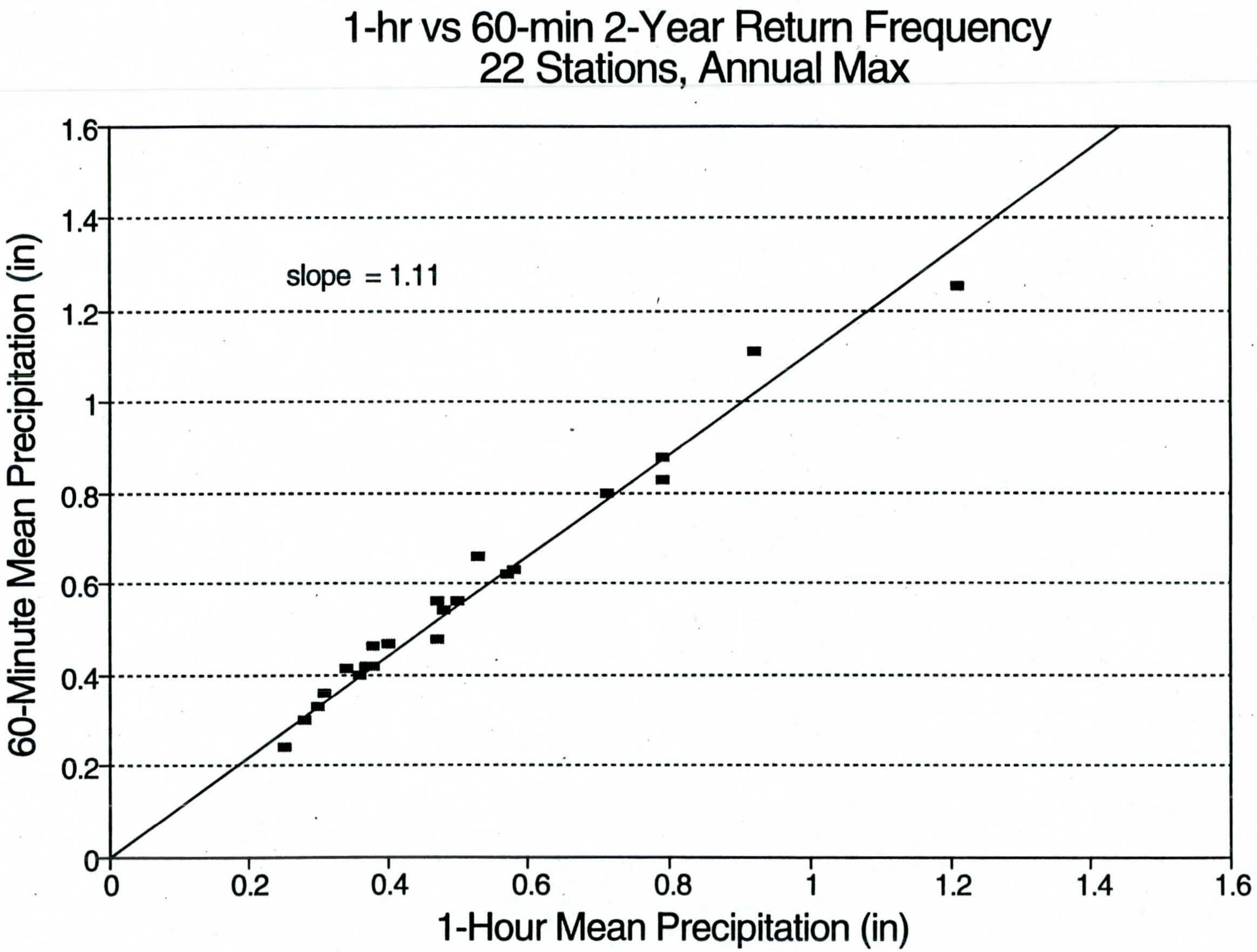

Figure 4a. *N-minute ratios of 1-hour to 60-minutes.*

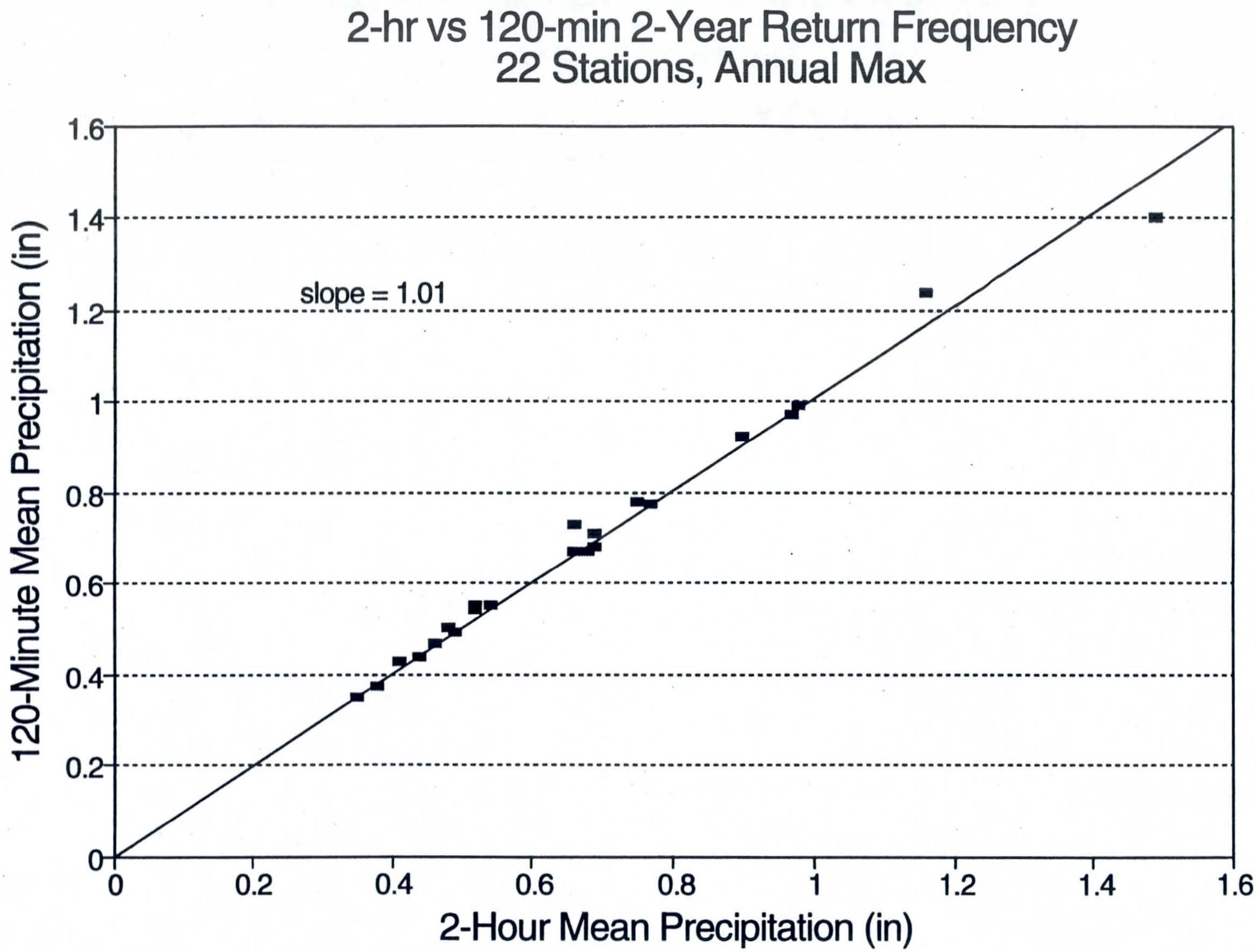

Figure 4b. *N-minute ratios of 2-hour to 120-minutes.*

N-Minute Data and Analysis

N-minute Data

The combination of one hand-entered and three digital datasets have resulted in 27 n-minute stations in the Semiarid study area. Most of these records contain only an annual maximum for each duration. However, a subset of these records have maxima recorded for each month in the period of record. The stations and periods of record for the annual and partial duration series are shown in Figure 5.

Annual Maximum series. The period of record in the annual maximum dataset ranges from 7 to 91 years; 11 stations have more then 50 years of record. The annual maximum dataset has durations: 5, 10, 15, 30, 60, and 120 minutes.

Partial Duration Series. Twenty-five stations have sufficient monthly maximum data to prepare a partial duration series. Unfortunately, the period of record in this partial duration series is limited, with only 7 to 19 years of data. Sixteen (of 25) stations have 19 years of record. The years of record available in each dataset at each station is shown in Figure 5. In addition to the durations recorded in the annual maximum data set, the partial duration set includes durations of 20, 45, 80, 100, 150, and 180 minutes. The partial duration series are used to adjust the annual maximum series results to partial duration, and also to assess seasonality of short duration precipitation events.

Results

The final product of the intensive analysis of the n-minute data is the ratios to the 60-minute data. The ratios were computed for each n-minute region separately, but the largest difference between any two regions was 0.03. Therefore, the ratios for the entire area were considered to be homogeneous across the whole Semiarid region. Furthermore, the ratios were found to be essentially the same, regardless of return frequency. This confirms the findings in Technical Paper 40 and adapted in NOAA Atlas 2. Table 5 shows the n-minute ratios (n-min/60-min) computed for the Semiarid study and those reported in NOAA Atlas 2 for 5, 10, 15, and 30 minutes. Also shown in Table 5 are the ratios used by Huff and Angel (1992). The Semiarid ratios are .04 higher than the NOAA Atlas 2 at 5 and 10 minutes and .03 higher at 15 and 30 minutes. The Huff and Angel values are the same as NOAA Atlas 2, except at 5 minutes, where their ratio is lower than both the Semiarid and the NOAA Atlas 2 values. However, the Huff and Angel values are for a distinctly different climate in the northern part of the Midwest. For a nearly comparable area, Arkell and Richards (1986) found values that are slightly higher than SA. They did not include California in their study.

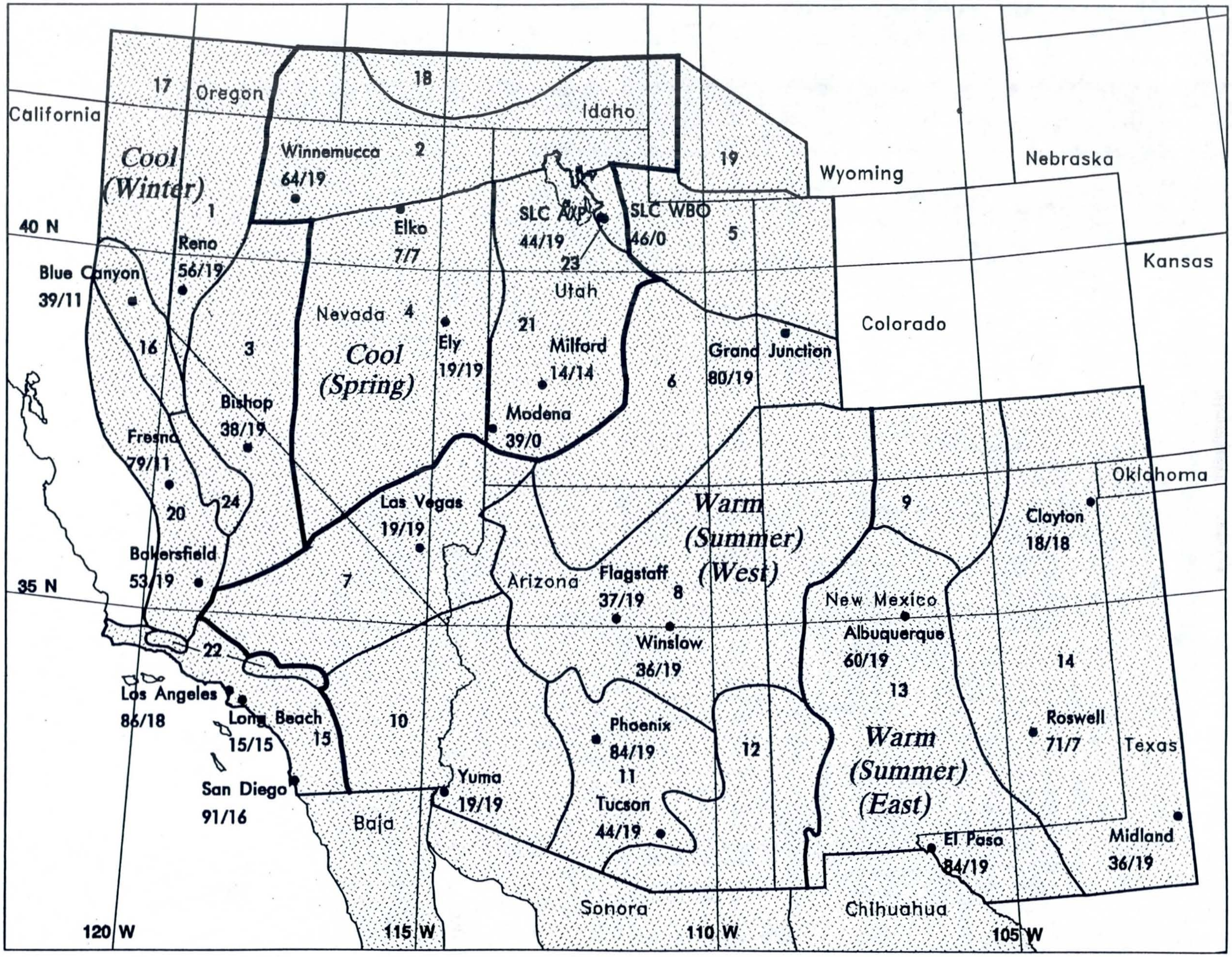

Figure 5. *N-minute stations in the Semiarid study area with years of record: annual maximum/partial duration.*

Table 5.

Comparison of Semiarid n-minute ratios
to NOAA Atlas 2 ratios

	5-min	10-min	15-min	30-min
Semiarid Ratios	**0.33**	**0.49**	**0.60**	**0.82**
NOAA Atlas 2	0.29	0.45	0.57	0.79
Huff and Angel 1992	0.26	0.45	0.57	0.79
Arkell and Richards 1986	0.34	0.52	0.62	0.82

Longer Durations - 2 to 60 Days

The daily data have been assembled into annual maximum and partial duration datasets for durations: 2, 4, 7, 10, 20, 30, 45, and 60 days. The datasets were checked for discordancies, homogeneity, and goodness-of-fit, using L-moment software. As with the shorter durations, the results indicated that annual maximum series best fit a Generalized Extreme-Value (GEV) distribution and partial duration series best fit the Generalized Pareto (GPA) distribution. Thus, a partial duration series and GPA distribution is used for daily data at all durations. An example of the heterogeneity and goodness-of-fit tests for 10-day events is given in Table 6. For reference, a brief description of L-moment discordancy, heterogeneity, and goodness-of-fit tests is given in the Appendix. In Table 6 the first three lines are various tests of heterogeneity, based on: (H1), L-coefficient of variation (L-CV); (H2), L-skewness (L-SK) and L-CV; and (H3), L-kurtosis (L-K) and L-SK, respectively. The threshold value for precipitation data is 2, i.e., a value greater than 2 indicates heterogeneity (H>2), rather than homogeneity (H<2). In general, (H), based on L-coefficient of variation (L-CV) is most stringent. However, as precipitation data are highly variable in any case, less weight is given to L-CV criteria in evaluating heterogeneity results. Although about one-half the regions do not meet the L-CV criterion for homogeneity, all regions except 3 and 13 meet both the other two criteria.

Table 6.

PARTIAL DURATION 10-DAY PRECIPITATION SERIES
HOMOGENEITY and GOODNESS-OF-FIT TESTS

	REGN 1	REGN 2	REGN 3	REGN 4	REGN 5	REGN 6	REGN 7	REGN 8	REGN 9	REGN 10	REGN 11	REGN 12
HETEROGENEITY MEASURE H												
H 1	3.20	2.28	6.10	4.77	0.61	1.57	6.97	2.80	2.44	5.44	-1.67	1.45
H 2	0.10	1.13	2.51	1.94	-0.40	0.33	0.81	-0.33	0.54	0.69	-2.34	-0.60
H 3	-1.12	1.12	1.72	1.24	-0.80	0.01	-0.75	-1.02	0.49	-1.02	-2.38	-0.48
GOODNESS-OF-FIT MEASURE Z												
GLO	3.22	9.38	4.32	7.56	5.82	7.41	7.06	11.63	6.83	5.51	8.46	10.09
GEV	2.42	6.84	3.01	5.71	4.13	5.44	5.01	8.20	4.99	3.98	6.31	7.18
LNO	0.98	4.53	1.32	3.62	2.19	3.05	3.19	4.54	3.10	1.51	2.99	4.06
PIII	-1.49	0.58	-1.57	0.04	-1.12	-1.02	0.06	-1.69	-0.14	-2.70	-2.67	-1.27
GPA	-0.30	-0.26	-1.00	0.23	-0.89	-0.48	-0.69	-1.79	-0.31	-1.04	-0.65	-1.31

	REGN 13	REGN 14	REGN 15	REGN 16	REGN 17	REGN 18	REGN 19	REGN 20	REGN 21	REGN 22	REGN 23	REGN 24
HETEROGENEITY MEASURE H												
H 1	11.52	5.74	4.92	-0.09	0.12	0.32	-0.35	2.12	1.97	-2.09	6.86	-0.38
H 2	2.61	2.05	-0.65	-1.71	-2.18	1.12	-1.82	-0.90	-1.52	-2.46	1.29	-1.76
H 3	2.55	1.00	-2.38	-1.82	-2.04	0.73	-1.78	-0.38	-1.54	-2.65	0.74	-1.73
GOODNESS-OF-FIT MEASURE Z												
GLO	9.82	10.07	16.10	6.47	2.21	5.06	2.76	9.40	6.80	3.04	5.21	2.64
GEV	6.92	7.13	12.41	5.16	1.52	3.86	2.07	7.35	4.63	2.22	3.79	2.26
LNO	3.97	3.35	8.89	3.26	-0.06	2.14	1.12	5.05	2.11	0.88	2.18	1.25
PIII	-1.07	-3.09	2.88	0.01	-2.77	-0.79	-0.50	1.13	-2.19	-1.42	-0.56	-0.45
GPA	-1.42	-1.88	1.95	1.01	-1.05	0.06	-0.09	1.32	-1.81	-0.48	-0.41	0.76

Also shown in Table 6 are the goodness-of-fit measures for 10-day events. The threshold is 1.64 (absolute value), and 'best-fit' values are those less than or equal to the threshold. All but four of the regions have values below the threshold for the Generalized Pareto (GPA) distribution, and similar scores for the Pearson Log III (PIII) distribution. The remaining four regions have no scores below the threshold, but the GPA is still the best-fit in three regions (14, 15, and 21) and second in the fourth (8). The Generalized Logistic (GLO) and Generalized Extreme Value (GEV) fit none of the regions. The Log-normal (LNO) fits in seven regions. Thus, as in other durations, the GPA is the best distribution for partial duration series of extreme precipitation data.

The 2-year, 10-day values have been computed and plotted and are being analyzed. This will be the Index Map for the longer durations. Graphs of four stations in region 6 (Figures 6a-6d) show systematic variations across duration and return frequency. The stations, with periods of from 68 to 93 years, are: Figure 6a, 5-3488 Grand Junction, Colorado; 6b, 4-4849 Lee's Ferry, Arizona; 6c,42-2592 Escalante, Utah; and 6d, 42-3896 Hiawatha, Utah. The stations are shown in the map in Figure 1. Using similar graphs and/or tables, interpolation can be used between known return frequency values to derive intermediate values. Note, however, that the curves are not straight lines, and in particular, the deviation from 'linearity' (on a log scale) increases with increasing duration.

SUMMARY

The mapping procedure is working well and map preparation of various frequencies and durations is underway on the GRASS/GIS system. The return frequency analyses are all essentially complete, but how to present all the information in the most useful and efficient manner is still under discussion. Storm analysis is continuing and is about 25 percent complete. A storm in Arizona and New Mexico on July 22-24, 1992 has been added to the storm list.

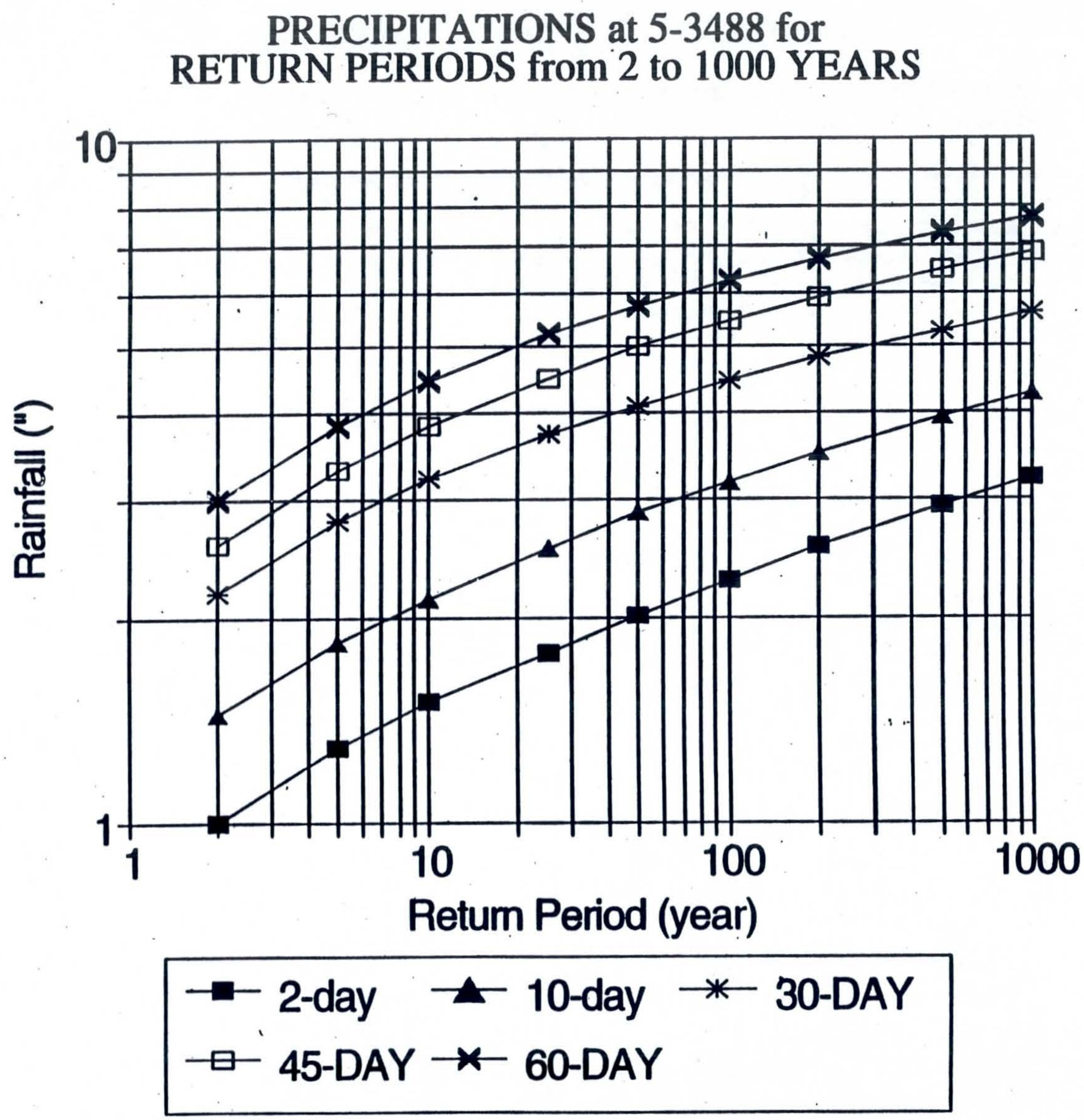

Figure 6a. *Return Periods from 2 to 1000 years for various durations at Grand Junction, CO.*

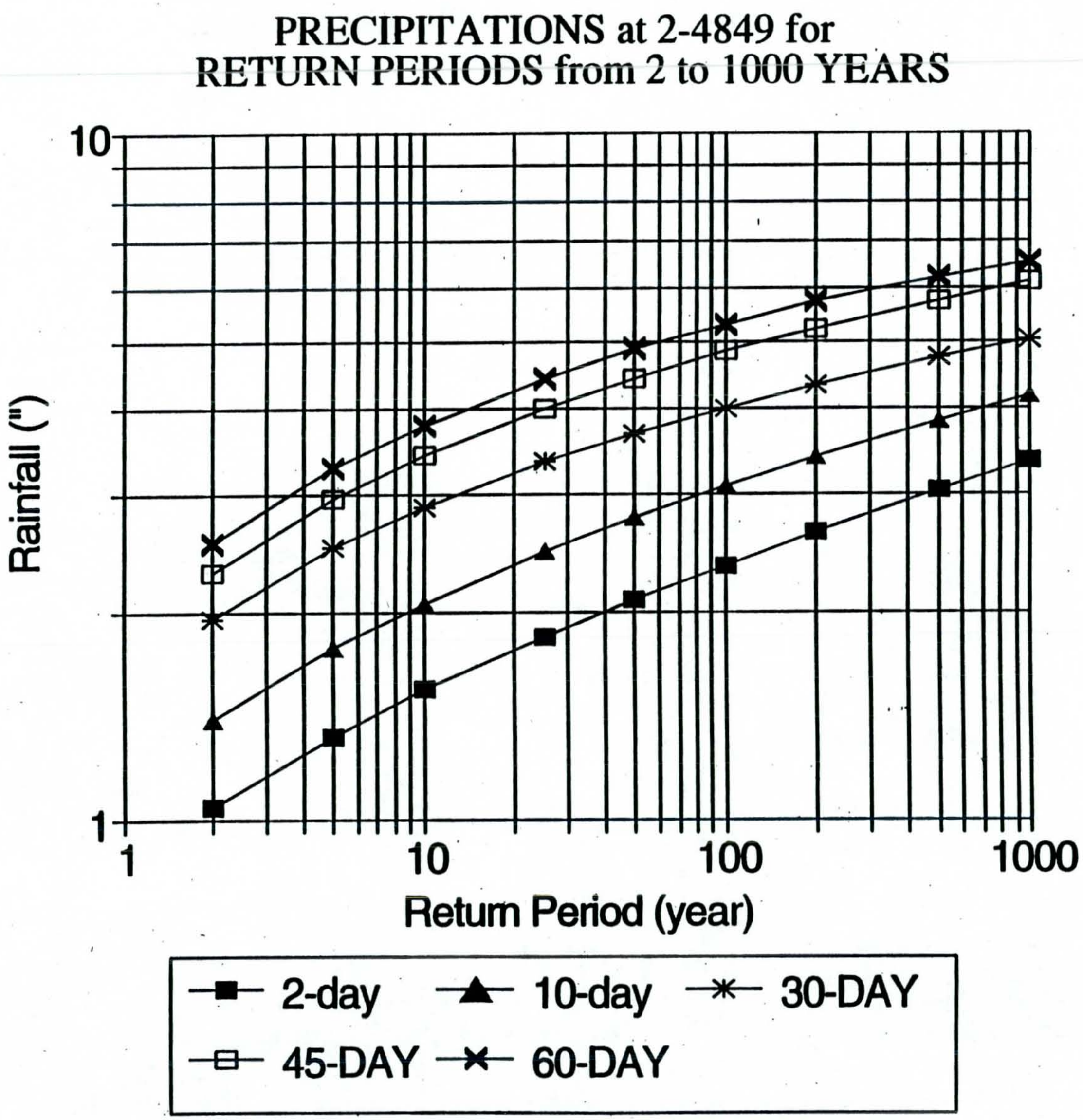

Figure 6b. *Return Periods from 2 to 1000 years for various durations at Lee's Ferry, AZ.*

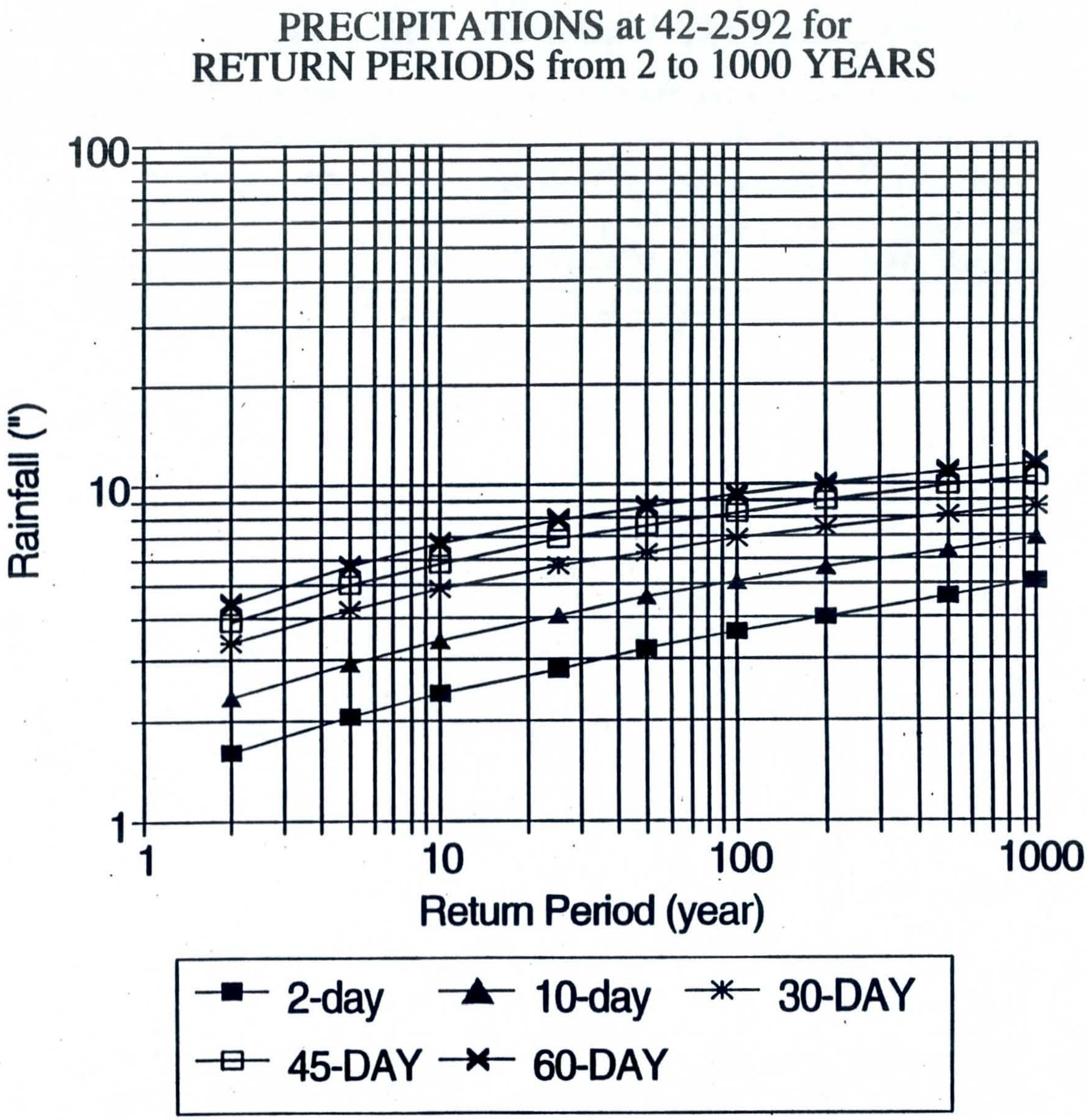

Figure 6c. *Return Periods from 2 to 1000 years for various durations at Escalante, UT.*

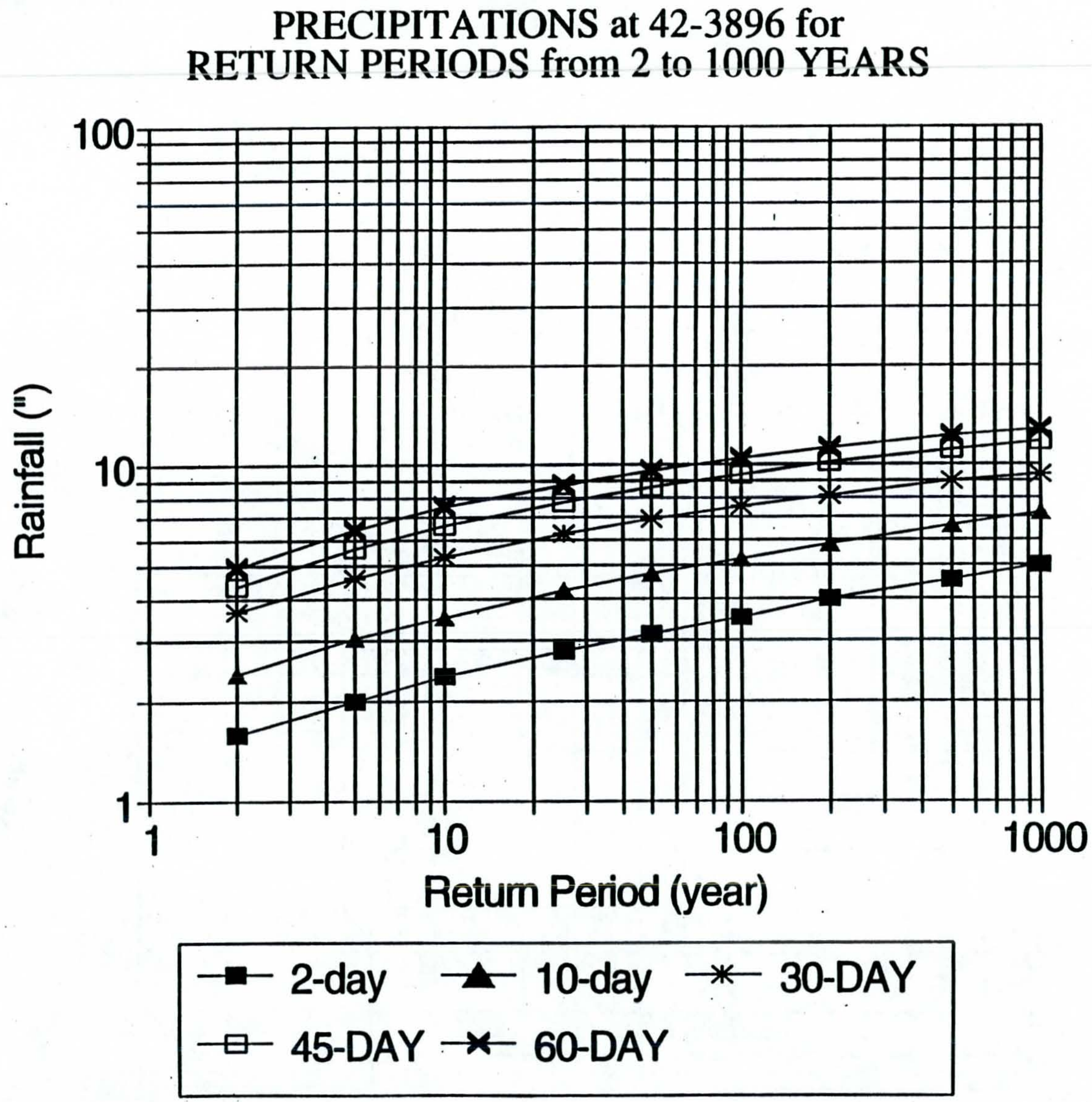

Figure 6d. *Return Periods from 2 to 1000 years for various durations at Hiawatha, UT.*

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APPENDIX

Discordancy

Initially, the discordancy measure is used for data checking and quality control. However, in evaluating regions, it is used to determine if a site has been assigned to the appropriate region. It is based on L-moments (L-coefficient-of-variation (L-CV), L-skewness (L-SK), and L-kurtosis (L-KT)), which represent a point in 3-dimensional space, for each site. Then, discordancy (D) is a function of the distance from the cluster of points for the sites in the region being tested. The cluster center is in fact the unweighted mean of the three moments for the sites within the region being tested. Sites with a discordancy value of 3 or greater are considered discordant, and should be examined to see if they possibly belong in another region or have a data problem. The threshold value of 3 is not a rigorous test, but a reasonable level to be expected within a homogeneous region.

Heterogeneity

Actually, the heterogeneity test consists of three parts, one (H1) based on L-CV, the second (H2) based on L-CV and L-SK, and the third (H3) based on L-SK and L-KT. As in the discordancy test, there is also a threshold value; Hosking and Wallis (1991) recommend a threshold of 1. However, they used wind data in establishing this threshold, and later conversations with Wallis (personal communication 1993) indicate that a threshold of 2 is reasonable, especially for precipitation data. Therefore, for each H-test, a value greater than 2 indicates heterogeneity (H>2), rather than homogeneity (H<2). In general, H-1, based on L-coefficient of variation (L-CV) is most stringent. As precipitation data are highly variable in any case, the heterogeneity results were considered giving less weight to the L-CV criterion.

Goodness-of-fit

This test measures the "distance" of L-moment statistical parameters of a dataset from various theoretical probability distributions. The threshold for goodness-of-fit tests is 1.64 (absolute value), and 'best-fit' values are those less than or equal to the threshold. For partial duration, Generalized Log-Normal, Pearson Log-III, and Generalized Pareto are acceptable distributions for most durations.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

May 24, 1995 W/OH11/LFT

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton

SUBJECT: Fourteenth Quarterly Report - Semiarid Precipitation Frequency Project, January 1 - March 31, 1995

Enclosed is a copy of the Fourteenth Quarterly Progress Report for the Semiarid Precipitation Frequency Project for the southwestern United States. The report focuses on mapping procedures and includes DRAFT maps for Washoe County, Nevada and Albuquerque, New Mexico vicinity.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMIARID PRECIPITATION FREQUENCY STUDY

Fourteenth Quarterly Progress Report
for the period from
January 1 through March 31, 1995

Lesley F. Tarleton, Julie M. Olson, Edwin H. Chin,
Susan M. Gillette, John L. Vogel, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
April/May 1995

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SEMIARID PRECIPITATION FREQUENCY STUDY

Fourteenth Quarterly Progress Report
for the period from
January 1 through March 31, 1995

OVERVIEW

This fourteenth Quarterly Report focuses on the mapping process for the Semiarid Precipitation Frequency Project for the period January 1 through March 31, 1995. Included in this report are DRAFT maps of two areas in Nevada and New Mexico for 2- and 100-year return frequencies for 1- and 24-hour durations. For reference the map of the complete Semiarid Project area, with the areas of detail outlined, is shown in Figure 1.

MAPPING AND ANALYSIS

Datasets

The datasets for the Semiarid precipitation return frequency analysis for all durations from 5 minutes through 60 days have been prepared from a partial duration series, using L-moment statistics. Return frequencies include 2 to 1000 years. Return frequencies for greater than 100 years (200, 500, and 1000 years) are being prepared as a result of user requests for the higher value return frequencies. As noted in Twelfth and Thirteenth quarterly reports (Tarleton et al, 1994b, 1994c), the 2-year, 24-hour map is the primary *Index Map*, and is used to compute other return frequencies and other durations. The 2-year, 24-hour map (*Index Map*) was hand-analyzed from critically quality-controlled data and return-frequency values computed using L-moment statistical software over near-homogeneous regions.

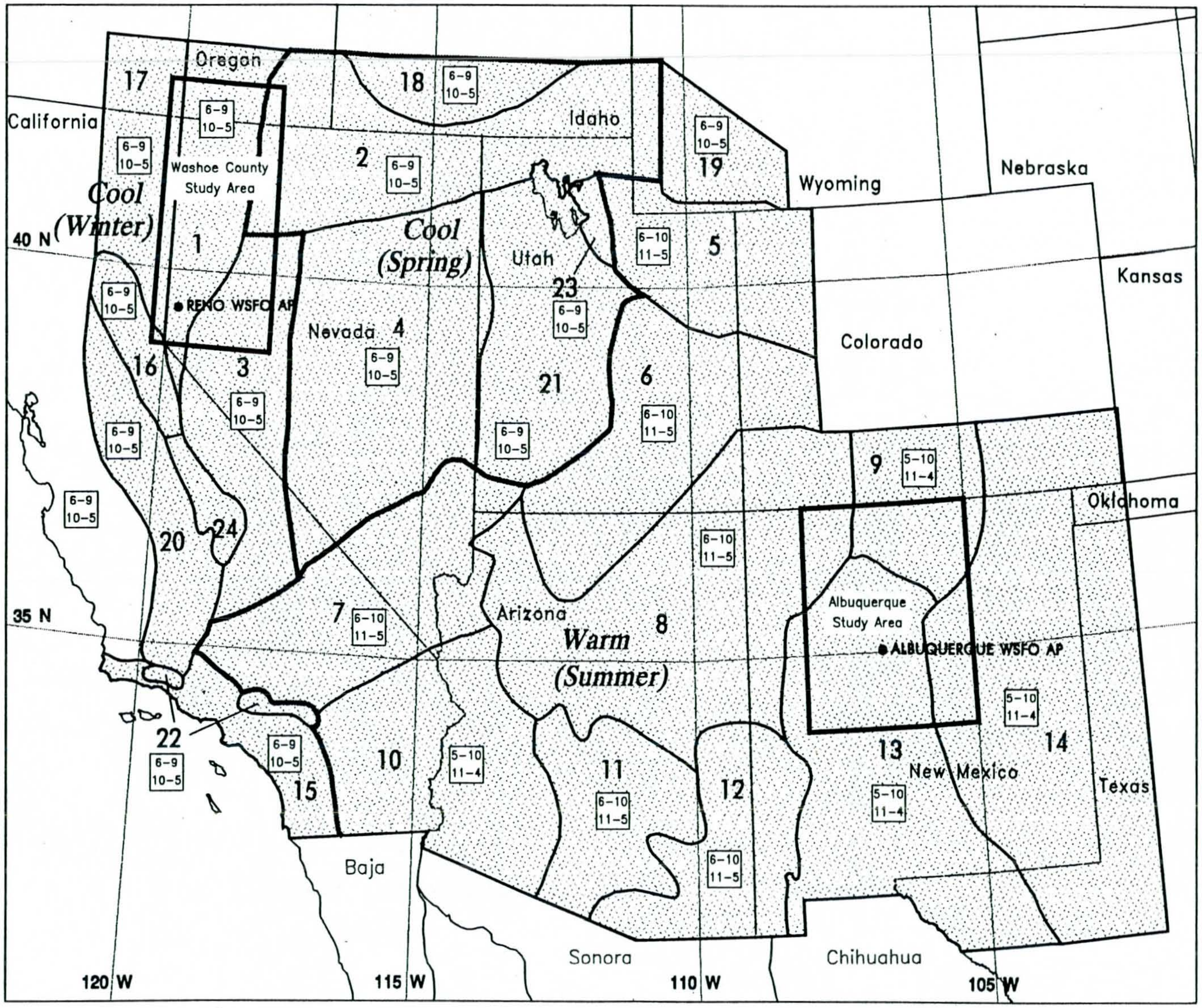

Figure 1. *Semiarid study climatic regions. The Washoe County and Albuquerque study areas are outlined.*

Process

The essence of the combined hand-analysis and computer mapping technique is to create an *Index Map*, determine its relation to other durations and/or return frequencies, and use the computer to do the arithmetic to generate other maps of interest. The system we are following is to use the 2-year, 24-hour map as the *Index Map*. This *Index Map* is multiplied by the appropriate regional growth factors (RGFs) for the 24-hour return frequency of interest. To produce maps of less than 24-hour duration, the *Index Map* is multiplied by ratios of hourly values to 24-hour values. Then, to get higher return frequencies, for example, a 100-year, 1-hour map, the 2-year, 1-hour map is multiplied by 100-year, 1-hour RGFs. Actually, this is not quite true, the respective RGFs must be divided by the 2-year RGF to be properly related to the 2-year map. The 24-hour RGFs and examples of how they are applied are given in the Thirteenth Quarterly (Tarleton et al, 1994c). A diagram of the process is given in the flow chart below.

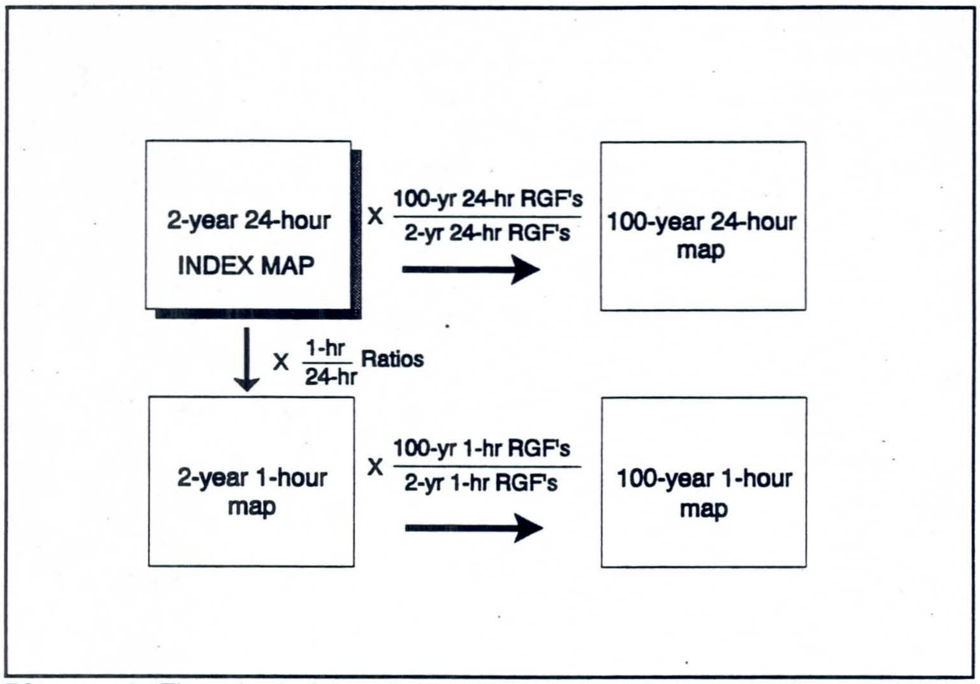

Diagram 1. *Flow chart of mapping procedure.*

Conversion Factors

Although simply stated, various obstacles present themselves in carrying out this process. One of these is to put the data in the 'same' duration, meaning that daily data must be converted to 24-hour values, hourly data converted to 60-minute values. The factor 1.13 was used to convert daily to 24 hours and to convert hourly to 60 minutes for all return frequencies in <u>NOAA Atlas 2</u> (Miller et al 1973) and <u>Technical</u>

Paper 40 (TP40) (Herschfield 1961). The Semiarid (SA) studies found comparable values for 2-year return frequencies, but lower values at higher return frequencies. The conversion factors are shown in Tables 1 and 2. In the Thirteenth Quarterly (Tarleton et al 1994c, p11) different values were shown for the 1-hour to 60-minute conversion. However, as a result of a review of the 60-minute data and an evaluation of the first drafts of 1-hour maps, we revised these figures to be more in accord with 1-day to 24-hour conversions; that is, they decrease with increased return frequencies.

Table 1.

Daily Conversion Factors

Return Period	1-day to 24-hr	2-day to 48-hr
2-year	1.15	1.02
5-year	1.13	1.02
10-year	1.12	1.02
25-year	1.10	1.00
50-year	1.08	1.00
100-year	1.06	1.00
500-year	1.04	1.00
1000-year	1.02	1.00

Table 2.

Hourly Conversion Factors

Return Period	1-hr to 60-min	2-hr to 120-min
2-year	1.11	1.01
5-year	1.10	1.01
10-year	1.08	1.01
25-year	1.06	1.01
50-year	1.04	1.01
100-year	1.02	1.01
200-year	1.01	1.00
500-year	1.00	1.00
1000-year	1.00	1.00

Regional Growth Factors

Regional growth factors (RGF) for the Semiarid study are derived from L-moment analysis of the extreme precipitation data, using a partial duration series and the Generalized Pareto (GPA) distribution in each near-homogeneous region.

The GPA distribution was chosen as a result of curve-fitting tests within the L-moment software and real data comparisons with theoretical distributions. This process has been discussed in the Ninth and Tenth Quarterlies (Tarleton et al 1993, 1994a). The RGFs are used to determine the return frequency values for each station by multiplying the station mean (mean of the partial duration series for that station for that duration) by the regional growth factor for the region and return frequency of interest. A detailed example of the map multiplication process is given in the Thirteenth Quarterly (Tarleton et al 1994c). Although every L-moment analysis uses a partial duration series and GPA distribution, the RGFs for each region/duration are determined uniquely.

2-Year, 1-Day (24-hour) *Index Map*. The 2-year, 24-hour maps are pivotal. The 24-hour information is most directly observed, has the most stations, and the longest periods of record. The 24-hour data include both daily and hourly reporting stations, with daily observations adjusted to the 24-hour period of maximum precipitation. The 2-year return period approximates the median value and is the most stable statistically. Furthermore, the periods of record (approximately 15 to nearly 100 years) permit the best estimates at short return periods. Therefore, the 2-year, 24-hour map is used as the *Index Map*. The 2-year, 24-hour map has been plotted, hand-analyzed, and digitized into GRASS and changed into rasters for computation of other return frequencies. Regional growth factors (RGFs) are used to compute the various return frequencies from the 2-year, 24-hour *Index Map*.

100-year, 24-hour Maps. The first computer-generated maps were the 100-year, 24-hour maps. As the RGFs vary among the different regions, some finite discontinuities occur at the borders between regions. Experiments with different filters has led to the use of centered averages on the raster field. The RGF raster field is smoothed four times, using grids of 25 X 25, 23 X 23, 17 X 17, and 3 X 3, respectively. The smoothed RGFs are then used to multiply the 2-year raster map to produce a 100-year raster map. This map is smoothed one more time with a 3 X 3 grid to minimize ragged edges on the GRASS vectors or contours (isohyets). With minor exceptions, this procedure appears to take care of transitions at borders between regions. For any residual problems, some additional smoothing can be done by hand and patched into the vector map.

2-year, 1-hour (60-minute) Maps. Two-year 1-hour(60-minute)/24-hour ratio maps have been prepared for all-season and warm and cool seasons. Before the ratios were calculated, the hourly data were converted to 60 minutes. (The terms 1-hour and 60-minute will be used interchangeably for the purpose of this discussion). The all-season 2-year, 1-hour/24-hour ratio map has been digitized, and a 2-year, 1-hour map has been computer-generated from mapped ratios and the *Index Map* (2-year, 24-hour) using GRASS. This provides the most requested maps: 1-hour and 24-hour maps. Furthermore, the 1-hour (60-minute) map will then become the basis for determining the n-minute return frequencies. Ratios to 60 minutes have already been determined and were discussed in the Twelfth Quarterly (Tarleton et al 1994b). The 2-, 3-, 6-, and 12-hour return frequencies can be determined from the appropriate ratios to 24 hours, and presented in graph or tabular form.

100-year, 1-hour Maps. The 100-year, 1-hour map is computer-generated by multiplying the 2-year, 1-hour map by the 100-year, 1-hour RGF (adjusted to the 2-year, 1-hour RGF). The hourly RGFs are computed from hourly data only; the daily (24-hour) RGFs are computed from daily data. The higher return frequency maps are the most derivative, or the "farthest" from the *Index Map*. For example:

♦ the 100-year, 1-hour map has been computed from the 2-year, 24-hour map by multiplication by a ratio map (which itself has been computed, plotted, hand-analyzed, digitized, rasterized, and interpolated); multiplied by smoothed regional RGFs; and lightly smoothed to eliminate raster edges.

Differences between NOAA Atlas 2 and Semiarid Project 100-year, 24-hour maps

Differences between NOAA Atlas 2 (Miller et al 1973) 100-year, 24-hour maps and the first draft Semiarid Project were computed using GRASS. Table 3 (repeated from the Thirteenth Quarterly) shows the differences by state (except California). The Semiarid (SA) values were found to be less than NOAA Atlas 2 values over about 80 percent of the area in Arizona, New Mexico and Utah, and over 70 percent of the area in Nevada. Most SA values are between 0 and 0.75 inches less than NOAA Atlas 2. About 20 percent of the area of Arizona and Utah has even lower values, that is from .76 to 1.49 inches lower than NOAA Atlas 2. The SA areas that are higher than NOAA Atlas 2 are generally those in higher elevations where SNOpack TELemetry (SNOTEL) data are now available, such as the Wasatch Range and the Uinta Mountains in Utah, central and southeastern New Mexico, and in the Sierra along the border of California and Nevada. Another area where SA values are higher is the region 10 part of southwestern Arizona. Region 10 has the highest RGFs, which may have some effect, but other areas within region 10 have values that are lower than NOAA Atlas 2. Another difference between SA and NOAA Atlas 2 is that the 'dry areas are drier and the wet areas wetter' in several areas of the Southwest study area. Although the changes reflect information from longer datasets, more objective curve-fitting techniques, regionalized analysis, and observations in areas where there were none for NOAA Atlas 2; these areas of major change are being carefully checked to be certain the there is sufficient information to justify changes.

Table 3.

Percent area differences from NOAA Atlas 2 to Semiarid Study
by State
100-year 24-hour computer-generated map

DIFFERENCE (inches)	<=-1.50	-1.49 to -0.75	-0.74 to -0.01	0.00 to 0.75	0.76 to 1.49	>=1.50
Arizona	0.7	24.9	56.0	15.5	2.7	0.1
Nevada	0.0	6.6	65.9	23.4	3.2	0.9
New Mexico	2.2	15.9	64.6	14.4	2.9	0.0
Utah	0.3	20.5	67.3	9.2	2.2	0.5

	Percentages		Range
Arizona	81.6% < 0	18.3% > 0	-2.33 to 2.11
Nevada	72.5% < 0	27.5% > 0	-1.46 to 3.29
New Mexico	82.7% < 0	17.3% > 0	-2.69 to 1.49
Utah	88.1% < 0	11.9% > 0	-1.93 to 3.37

Special Study Areas

For each of the two study areas, four DRAFT maps have been prepared and are shown in Figures 2 and 3 (Washoe County) and Figures 4 and 5 (Albuquerque area). The maps have been prepared as described above. The areas are highlighted in Figure 1, and Reno, Nevada, and Albuquerque, New Mexico, are shown for reference. Also shown in Figure 1 are regional boundaries and the warm and cool precipitation seasons. The maps are at the same scale as NOAA Atlas 2, 1:2,000,000. The maps were generated using GRASS software on a RISC/6000 workstation. The isopluvials are in inches. Because of limitations in GRASS, label locations are pre-set, and cannot be read in areas where there is a dense gradient. The station locations are shown: triangles = daily, squares = hourly, and diamonds = SNOTEL. In some places daily and hourly stations are coincident.

Washoe County, Nevada

Two-year, 24-hour Map. The 2-year, 24-hour DRAFT map for Washoe County and vicinity is shown in Figure 2a. The unlabelled isopluvial line in the center and south of 40N is a 0.75 inch. A digitizing label error (south of this map segment) may have contributed to the high values and steep gradient in the southwestern part of this map.

One hundred-year, 24-hour Map. The 100-year, 24-hour DRAFT map is shown in Figure 2b. As to be expected from the process, the pattern is very similar to the 2-year map, but with higher values and steeper gradients. Also, any errors or discrepancies in the 2-year map are carried over to the 100-year map, and most likely exaggerated in the higher return frequency map.

Two-year, 1-hour Map. The 2-year, 1-hour DRAFT map is shown in Figure 3a. The pattern is again similar to the 2-year 24-hour map with values equal to 30 to 40 percent of the 24-hour map.

One hundred-year, 1-hour Map. The 100-year, 1-hour DRAFT map is shown in Figure 3b. As most of the map segment is in region 1, with an RGF of about 3.25, the map pattern has not changed very much, and the values are a little more than 3 times higher.

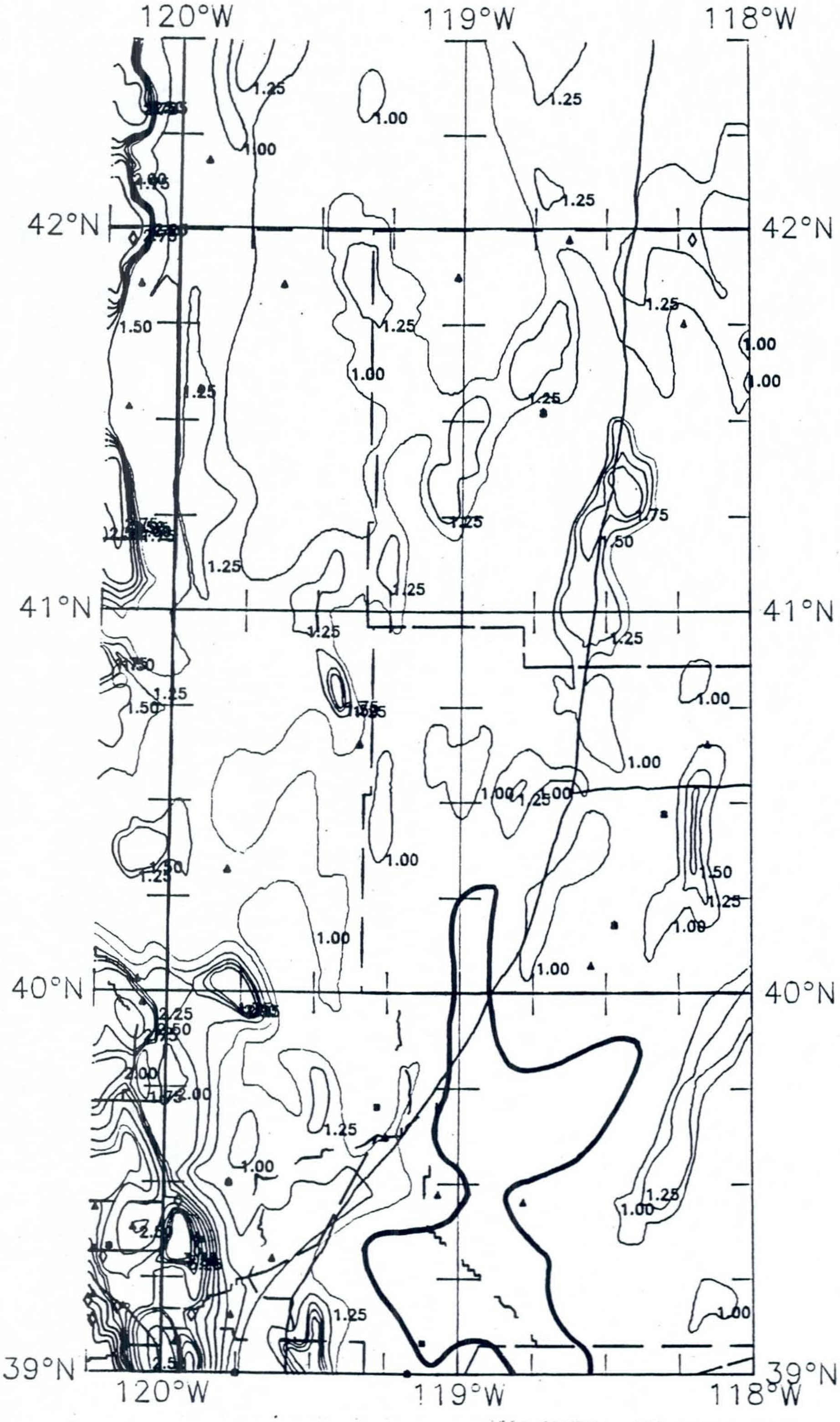

Figure 2a. *2-year 24-hour isopluvials for the Washoe County area. Scale = 1:2,000,000. DRAFT*

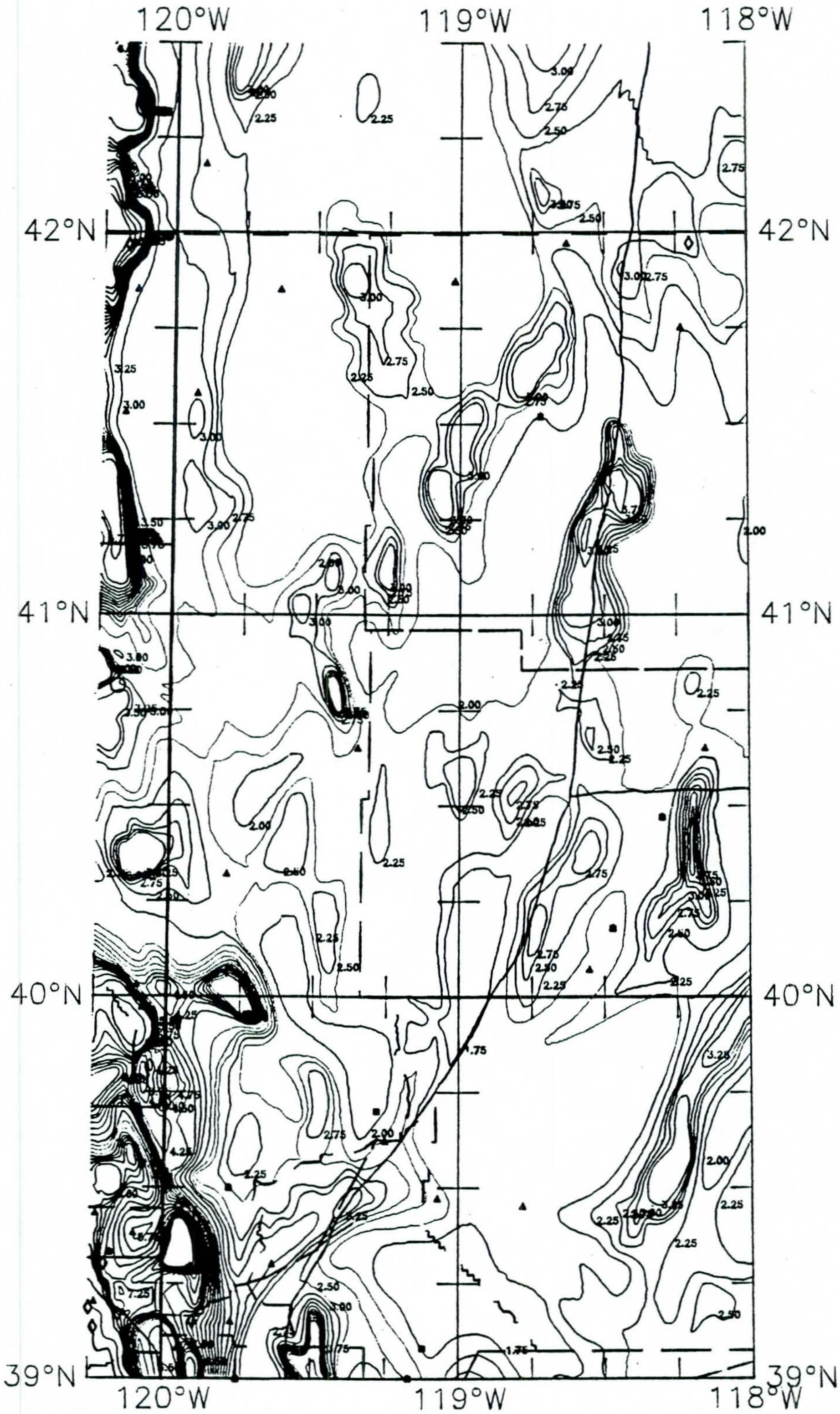

Figure 2b. *100-year 24-hour isopluvials for the Washoe County area. Scale = 1:2,000,000. DRAFT*

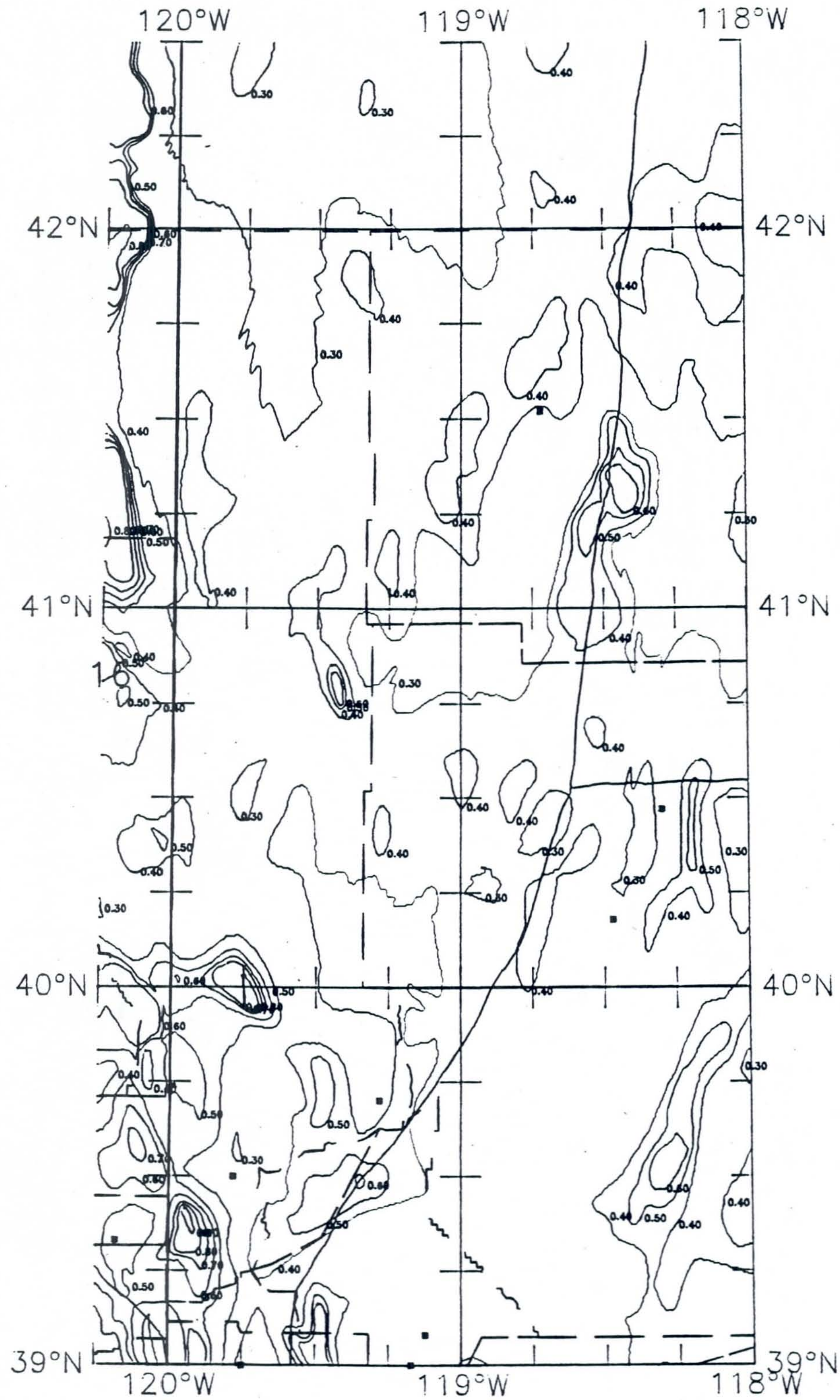

Figure 3a. *2-year 1-hour isopluvials for the Washoe County area. Scale = 1:2,000,000. DRAFT*

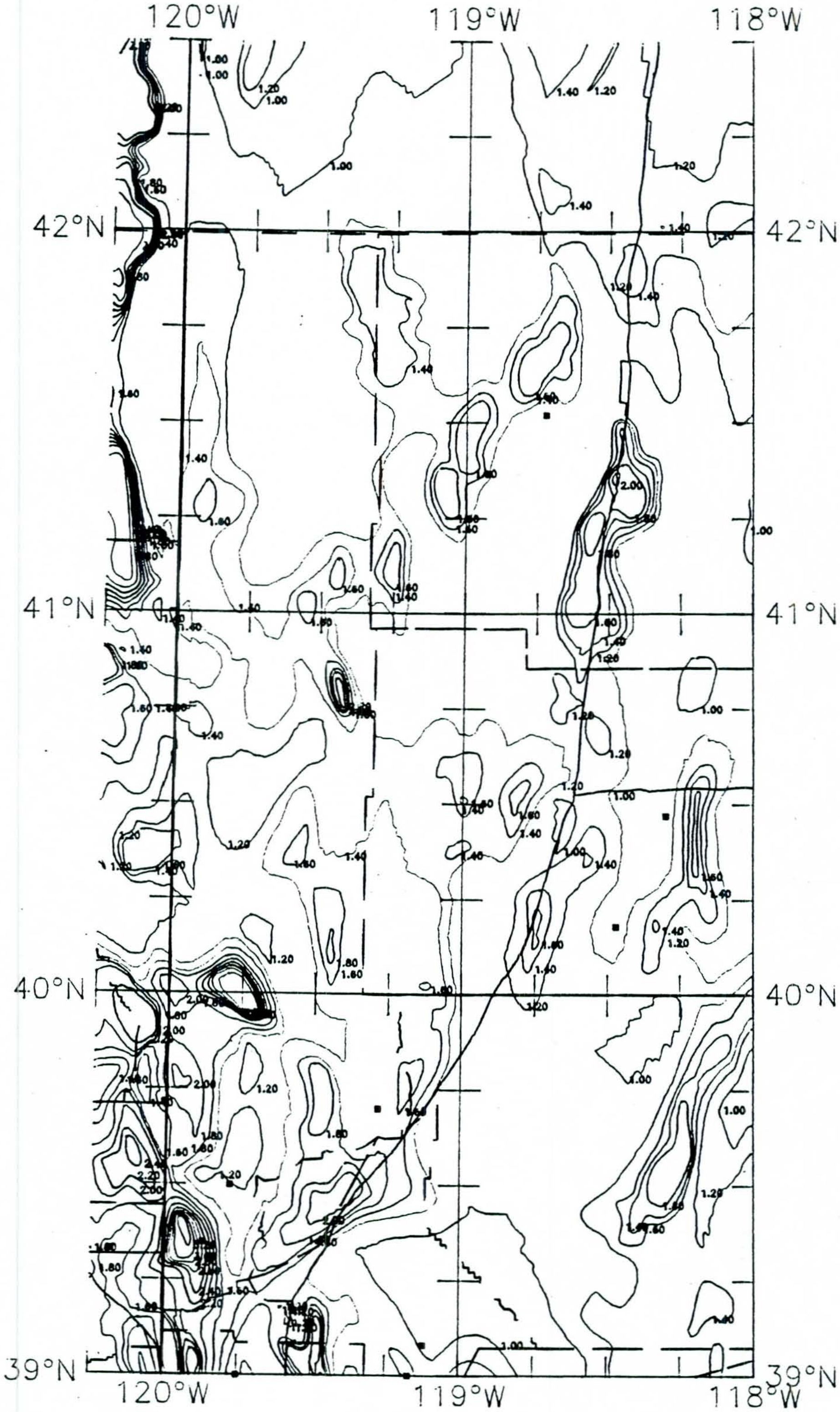

Figure 3b. *100-year 1-hour isopluvials for the Washoe County area. Scale = 1:2,000,000. DRAFT*

Albuquerque, New Mexico vicinity

Two-year, 24-hour Map. The 2-year, 24-hour DRAFT map for north-central New Mexico is shown in Figure 4a. Two areas show particular differences from NOAA Atlas 2: the San Luis Valley (just east of 106W and south of 37N) and the high center in the southeastern quad of the map segment, just south of 35N. The values in the San Luis Valley are lower and more extensive than NOAA Atlas 2. The other area is higher than NOAA Atlas 2 and has a more detailed pattern. Both these areas are being re-evaluated to be certain that the changes are reasonable.

One hundred-year, 24-hour Map. The 100-year, 24-hour DRAFT map is shown in Figure 4b. As to be expected from the process, the pattern is very similar to the 2-year map, but with higher values and steeper gradients. Also, any errors or discrepancies in the 2-year map are carried over to the 100-year map, and most likely exaggerated in the higher return frequency map.

Two-year, 1-hour Map. The 2-year, 1-hour DRAFT map is shown in Figure 5a. The pattern is again similar to the 2-year 24-hour map with values equal to 50 to 60 percent of the 24-hour map.

One hundred-year, 1-hour Map. The 100-year, 1-hour DRAFT map is shown in Figure 5b. The map pattern has not changed very much from the 2-year, 1-hour map, and the values are about 3 times higher.

Comparisons and Contrasts between Reno and Albuquerque

A comparison between the two special studies areas illustrates some regional differences in rainfall in the Southwest. Values read from the maps in Figures 2-5 are shown in Table 4.

Table 4.

	Reno, Nevada		Albuquerque, New Mexico	
	2yr	100yr	2yr	100yr
1 hour:	0.35	1.20	0.70	2.25
24 hour:	1.20	2.50	1.20	2.35

Note that at 1 hour, estimates at Albuquerque are about twice those of Reno, but at 24 hours they are nearly the same. Furthermore, in Reno the 2-year, 24-hour value is the same as the 100-year, 1-hour value. Some of these variations are due to differences in prevailing storm type - general or convective. From some preliminary seasonal estimates, the 24-hour, all-season values for Reno are very similar to a cool (general or winter-type storms) situation; 1-hour values for Reno appear representative of both seasons. Whereas, in Albuquerque the 1-hour and 24-hour Albuquerque values are both similar to warm (convective) season rainfall.

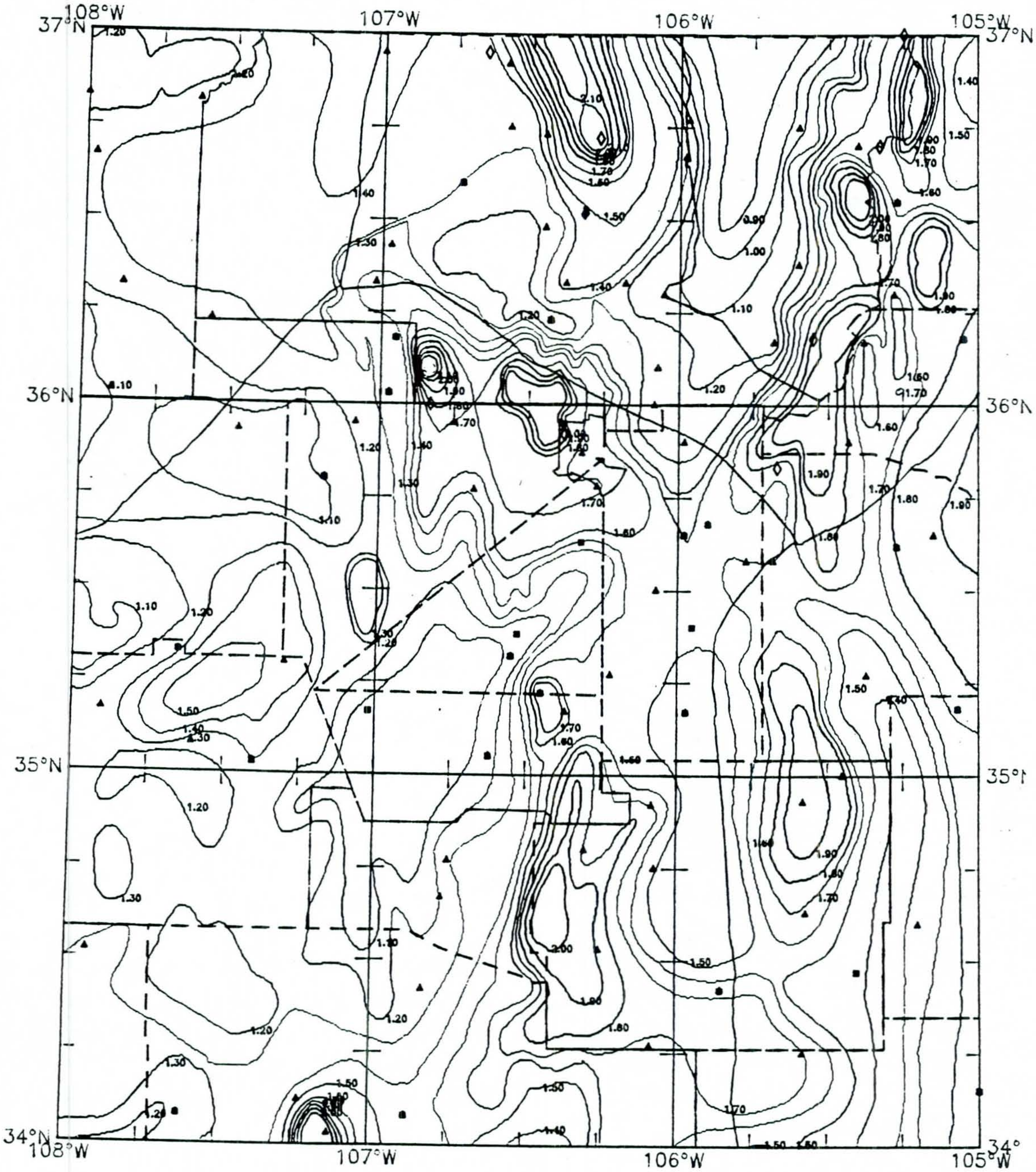

Figure 4a. *2-year 24-hour isopluvials for the Albuquerque area. Scale = 1:2,000,000. DRAFT*

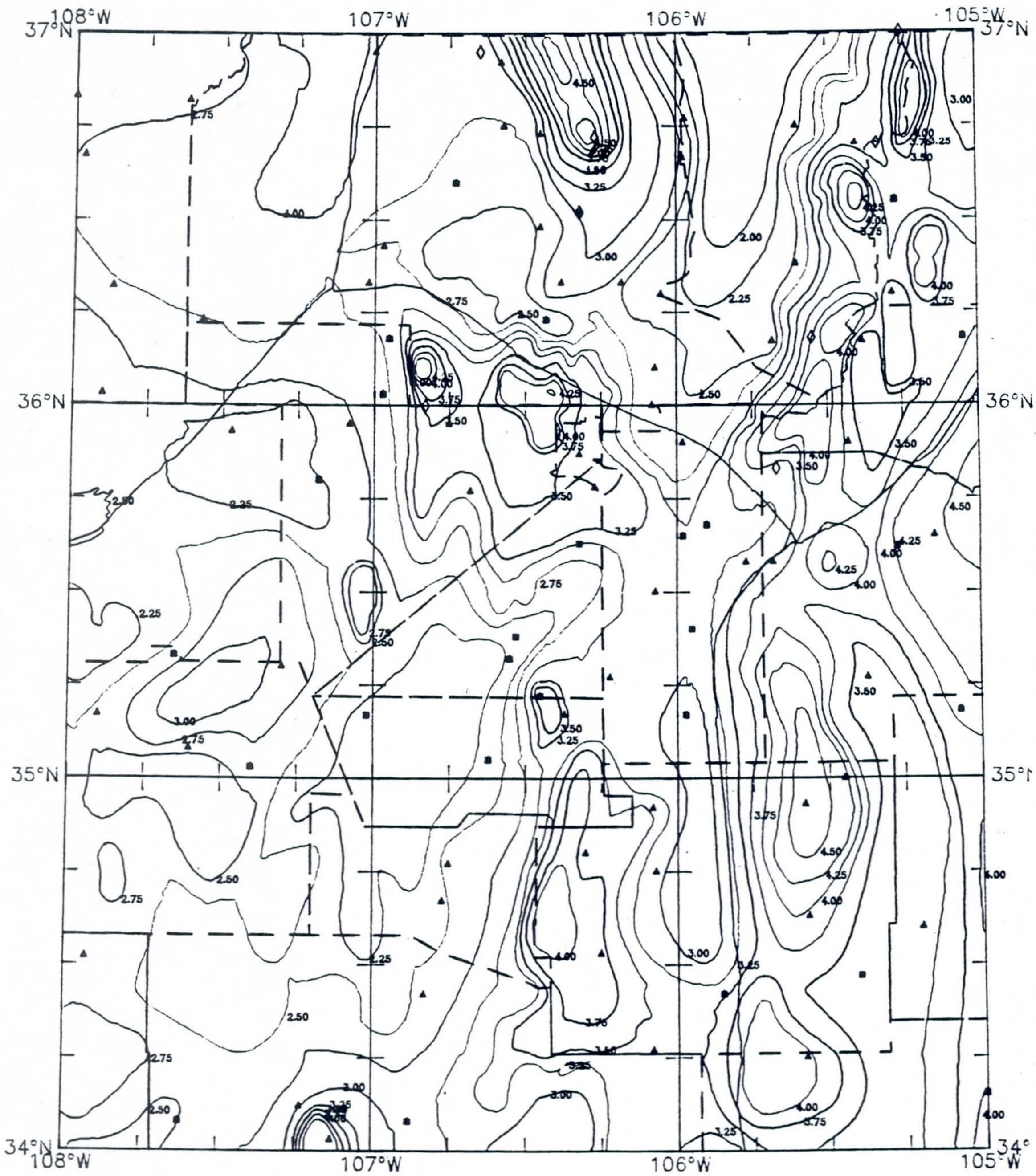

Figure 4b. *100-year 24-hour isopluvials for the Albuquerque area. Scale = 1:2,000,000. DRAFT*

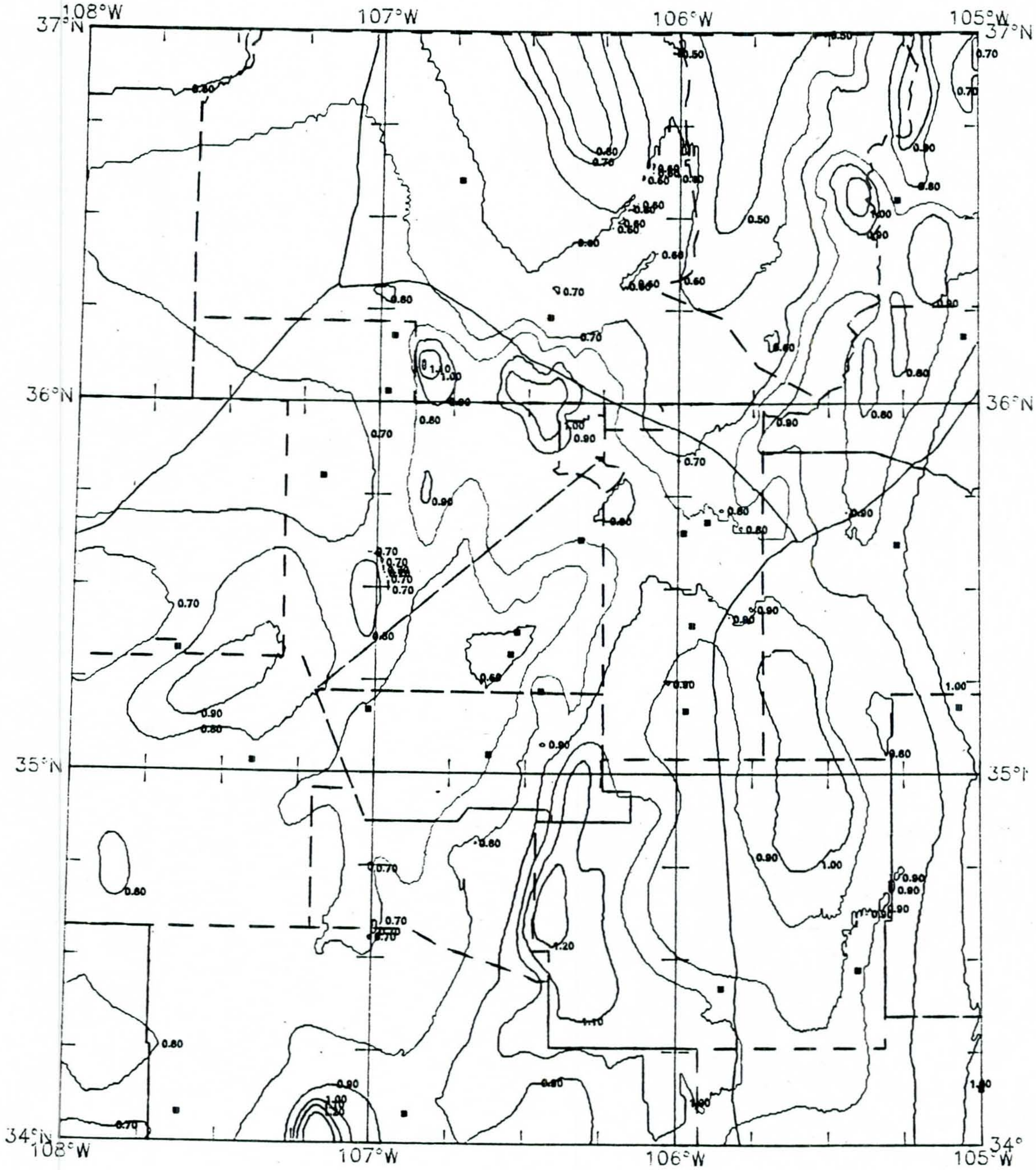

Figure 5a. *2-year 1-hour isopluvials for the Albuquerque area. Scale = 1:2,000,000. DRAFT*

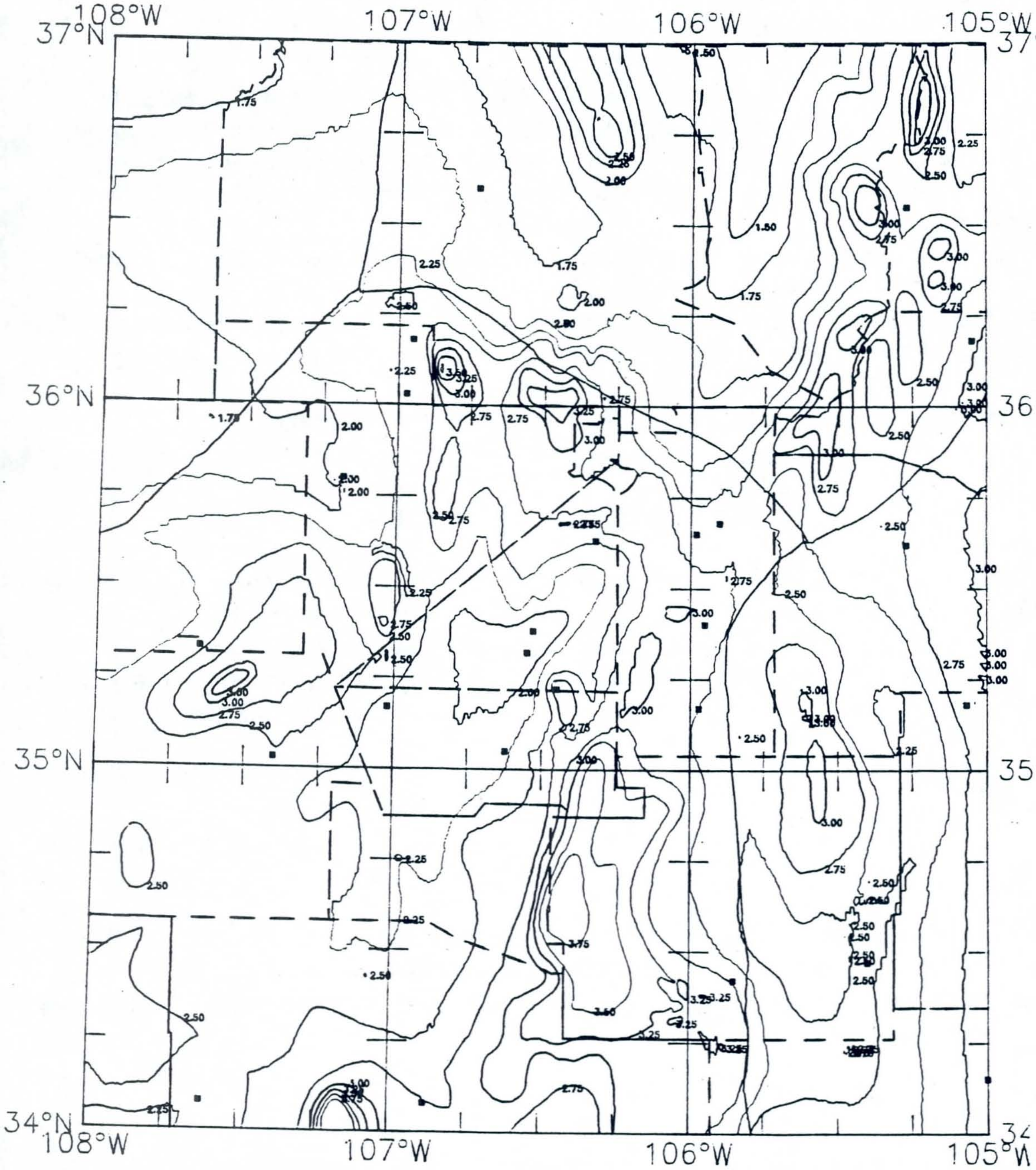

Figure 5b. *100-year 1-hour isopluvials for the Albuquerque area. Scale = 1:2,000,000. DRAFT*

Map Summary

It must be emphasized is that these are DRAFT maps and there is considerable evaluation that must be undertaken to assure that they are the most representative of the rainfall in the Southwest. Although, the overall changes from NOAA Atlas 2 at 100-year, 24-hour appear to be lower, there are several areas where the values are higher. As a result, both the high and low areas will be particularly scrutinized. However, that said, the 24-hour maps are, in general, reasonable. From an initial review of the 1-hour maps, it appears that in the two study areas, the estimates are higher than expected. Review and appraisal of the process should indicate where changes need to be made. Thus, the steps to be followed are:

- Make certain that the *Index Map* (2-year, 24-hour map) reflects the best representation of the rainfall possible with the available data and technology. This includes, but is not limited to, checking for computer software shortcomings, digitizing errors, and station data comparisons with computer-generated isolines.
- Use the *Index Map* to generate other return frequencies, and check against station data. Adjust if and where necessary.
- Use the *Index Map* with appropriate ratio maps to generate 1-hour maps and seasonal maps. Check against station data and adjust process and/or revise as necessary.
- Have maps reviewed in-house and by the review committee.

Longer Durations - 2 to 60 Days

Return frequencies have been computed from the daily data for durations: 2, 4, 7, 10, 20, 30, 45, and 60 days. L-moment software was used with partial duration series and the Generalized Pareto (GPA) distribution. Return frequencies for the two "rainfall" seasons (warm and cool) for durations 2 to 7 days have also been prepared. Some additional software is being developed for seasonal analysis for durations from 7 days to 60 days.

SUMMARY

Twenty-four-hour and one-hour return frequency maps have been generated. In-house review is in progress and drafts will be sent to the outside review committee early in June. Graphs and tables for longer durations and seasonal return frequencies are being developed.

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Hershfield, D.M., 1961: Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years, Weather Bureau Technical Paper No. 40, U.S. Weather Bureau, Washington, D.C., 115 pp.

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

August 14, 1995 W/OH11/LTJ

MEMORANDUM FOR: Southwest Semiarid Precipitation Frequency Study Group

FROM: W/OH11 - John Vogel and Lesley Tarleton Julian

SUBJECT: Fifteenth Quarterly Report - Semiarid Precipitation Frequency Project, April 1 - June 31, 1995

Enclosed is a copy of the Fifteenth Quarterly Progress Report for the Semiarid Precipitation Frequency Project for the southwestern United States. The report focuses on mapping procedures and precipitation-frequency products. Comparisons between the Semiarid study and NOAA Atlas 2 for 100-year, 24-hour maps for the entire area are included.

If you have any questions, comments, or suggestions, please feel free to call either of us at (301) 713-1669.

SEMIARID PRECIPITATION FREQUENCY STUDY

Fifteenth Quarterly Progress Report
for the period from
April 1 through June 30, 1995

Lesley Tarleton Julian[1], Julie M. Daniel[2], Edwin H. Chin,
Susan M. Gillette, John L. Vogel, and Michael Yekta

Office of Hydrology
National Weather Service
Silver Spring, Maryland
July 1995

[1] name change: Lesley F. Tarleton to Lesley Tarleton Julian
[2] name change: Julie M. Olson to Julie M. Daniel

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SEMIARID PRECIPITATION FREQUENCY STUDY

Fifteenth Quarterly Progress Report
for the period from
April 1 through June 30, 1995

OVERVIEW

This Fifteenth Quarterly Report focuses on map production and review for the Semiarid Precipitation Frequency Project for the period April 1 through June 30, 1995. Raster and vector maps of return frequencies for the entire Semiarid Study area have been computed, using GRASS/GIS on a RISC6000 workstation. An *Index map* of the 2-year, 24-hour intensities; as well as, 100-year, 24-hour; 2-year, 1-hour; and 100-year, 1-hour return-frequency DRAFT maps have been plotted for each state. A set of 3 maps (omitting the 2-year, 1-hour) for each state were prepared for review. Selected state maps were prepared for approximately 20 reviewers for additional input and comment. As the maps must be made one at a time on a HP Draftmaster Pen Plotter, the production of over 100 maps took several weeks. They have been completed and were sent to individual reviewers.

In addition to the 24-hour and 1-hour maps, computation and production of other durations and return frequencies are presented here. Also in this report is a discussion of some differences between Semiarid Study results and NOAA Atlas 2 (Miller et al 1973). In general, the Semiarid results at 100 years, 24 hours are lower than NOAA Atlas 2 with about 80 percent of the total Semiarid study area lower than NOAA Atlas 2. Comparisons between states and distributions for each state are shown in tables and illustrated graphically. For reference, the map of the complete Semiarid Project area is shown in Figure 1.

MAPPING AND ANALYSIS

The datasets for the Semiarid precipitation return-frequency analysis for all durations from 5 minutes through 60 days were prepared from partial duration data series, using L-moment statistics. Return frequencies include 2 to 1000 years. The durations and return frequencies are listed below.

Durations:

5, 10, 15, and 30 minutes;
1 (60 minutes), 2, 3, 6, 12, 24 (1 day), and 48 (2 days) hours;
4, 7, 10, 20, 30, 45, and 60 days.

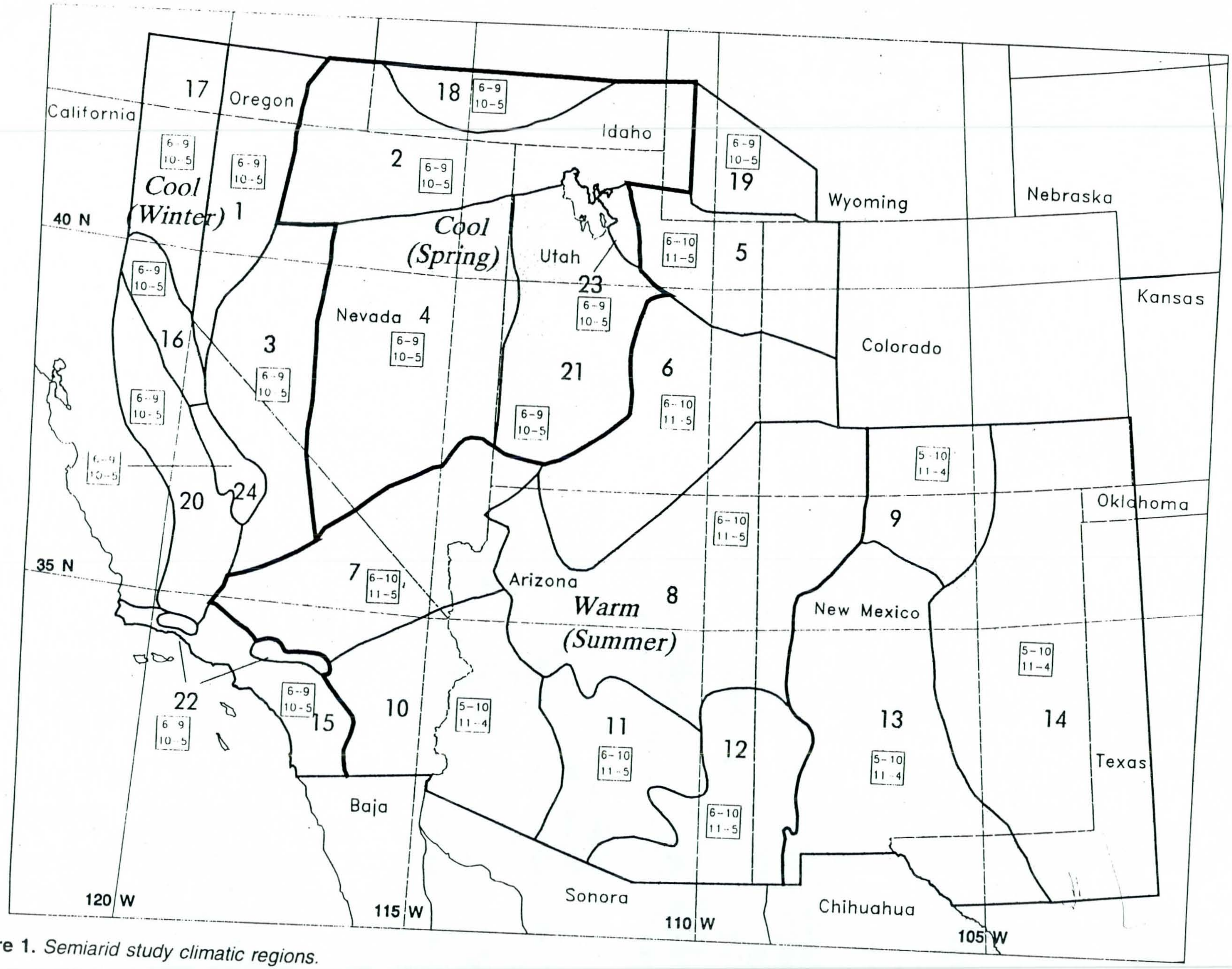

Figure 1. *Semiarid study climatic regions.*

Return frequencies:

2, 5, 10, 25, 50, 100, 200, 500, and 1000 years.

Mapping Process

The mapping and analysis process is a combined hand-analysis and computer mapping technique that creates an *Index Map*, determines its relation to other durations and/or return frequencies, and uses the computer to do the arithmetic to generate other maps of interest. The 2-year, 24-hour map (*Index Map*) was hand-analyzed from exactingly quality-controlled data, and return-frequency values computed using L-moment statistical software over near-homogeneous climatic regions. The *Index Map* is multiplied by the appropriate regional growth factors (RGFs) for the 24-hour return frequency of interest. Since the RGFs are defined relative to the mean value, the RGFs for return frequencies other than 2-year, 24-hour must be divided by the 2-year, 24-hour RFGs; and then this ratio is used as the multiplier to define the intensity for a particular return frequency. Furthermore, it is important to note that 1- and 2-day values are converted to 24 and 48 hours, and 1-hour and 2-hour values are converted to 60 and 120 minutes. The conversion factors are dependent on return frequency. For example, for 1-day values, the conversion factor decreases from 1.15 at 2 years to 1.06 at 100 years. The 1-hour conversion factors to 60 minutes are 1.13 and 1.02, for 2 and 100 years, respectively. To produce maps of less than 24-hour duration, the *Index Map* is spatially multiplied by ratios of hourly values to 24-hour values. An example of the process is given in the Thirteenth Quarterly (Tarleton et al 1994). The process is illustrated in the flow chart in Diagram 1.

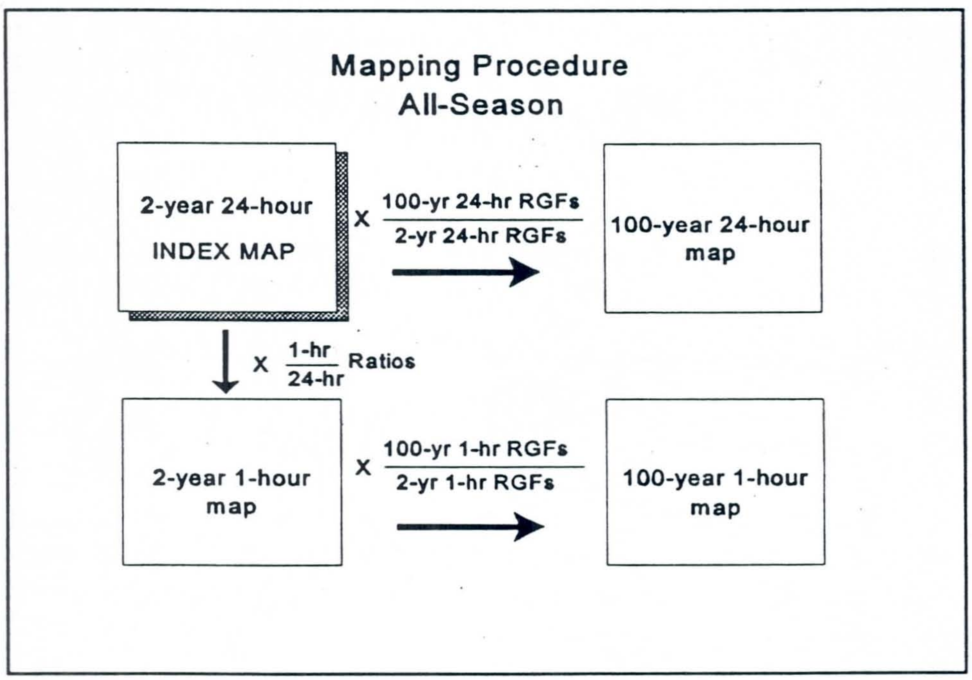

Diagram 1. *Flow chart of all-season mapping procedure.*

Products

Table 1 shows the various durations and return frequencies, sorted according to product. The total planned for each state is 66 isopluvial maps, 26 ratio maps, 5 tables, and 6 histograms.

All-season

Standard durations and return frequencies. The plan is to prepare all-season isopluvial maps for a range of the most used values: 1-hour, 6-hour, and 24-hour for the standard return frequencies from 2 to 100 years. For longer durations, 10-day and 60-day maps will also be prepared for standard return periods up to 100 years.

Intermediate durations. Intermediate durations will be represented by ratio maps to the respective *Index maps* of 6 and 24 hours, and of 10 and 60 days. Ratio maps of 2- and 3-hour to the 6-hour, and 12- to the 24-hour maps will be given. For durations of more than 1 day, ratio maps of 2-, 4-, and 7-day to the 10-day map; and 20-, 30-, and 45-day to the 60-day map will be presented. It may be necessary to prepare a set of 4-day maps if the ratios between 2 days and 10 days are not linear or another simple function.

Long return frequencies. For 200-, 500-, and 1000-year return frequencies, tables of regional growth factors (RGFs), to be used with 2-year or 100-year isopluvial maps, will be included. Table 2 shows 24-hour RGFs for return frequencies greater than 100 years for the 24 regions.

N-minute values. For durations less than 60 minutes, ratios to 60 minutes have been previously reported (Thirteenth Quarterly, Tarleton et al 1994), and will be used in the final report. Ratios to 60-minutes for all return frequencies are: *5-min: 0.33, 10-min: 0.49, 15-min: 0.60, 30-min: 0.82.*

Five-six events per year. Users have requested information about more frequent events. Information on precipitation intensities which are equalled or exceeded 5 or 6 times a year will also be provided.

Seasonal

Maps. Seasonal information will also be included in the final documents. The seasonal maps will be based on the ratio of the warm (cool) season to the all-season 2-year maps for 1-hour, 6-hour, and 24-hour durations. The process is illustrated in Diagrams 2 and 3. In addition, ratio maps of warm (cool) season to all-season values for 2-, and 4-day durations (2-year and 100-year) will be included.

Table 1.

Maps and Tables.

All-Season

Isopluvial Maps At Standard Freq*	Ratio Maps At 2-year & 100-year	Long Return Freq	Short Duration Ratios
1-hour	2-hr/6-hr	1-hour	5-minutes
6-hour	3-hr/6-hr	6-hour	10-minutes
24-hour	12-hr/24-hr	24-hour	15-minutes
10-day	2-day/10-day	10-day	30-minutes
60-day	4-day/10-day	60-day	
	7-day/10-day		
	20-day/60-day		
	30-day/60-day		
	45-day/60-day		
30 maps	*18 maps*	*5 tables* Each with 200, 500, 1000-year	*1 table*

Seasonal (Cool and Warm)

Isopluvial Maps At Standard Freq*	Ratio Maps Cool (Warm) to All-Season At 2-year &100-year	Histograms
1-hour	2-day	7-day
6-hour	4-day	10-day
24-hour		20-day
		30-day
		45-day
		60-day
18 maps per season	*4 maps per season*	

*Standard Return Frequencies: 2-year, 5-year, 10-year, 25-year, 50-year, 100-year

Table 2.

Long Duration 24-Hour Regional Growth Factors
(Related to 2-year 24-hour Index Map)

	200-year	500-year	1000-year
Region 1	2.46	2.79	3.01
Region 2	2.30	2.61	2.83
Region 3	2.78	3.25	3.57
Region 4	2.30	2.57	2.74
Region 5	2.34	2.68	2.91
Region 6	2.30	2.58	2.78
Region 7	2.53	2.86	3.08
Region 8	2.39	2.73	2.96
Region 9	2.28	2.59	2.80
Region 10	3.26	3.86	4.29
Region 11	2.34	2.63	2.82
Region 12	2.16	2.39	2.53
Region 13	2.19	2.42	2.56
Region 14	2.64	3.04	3.32
Region 15	2.39	2.66	2.82
Region 16	2.30	2.57	2.74
Region 17	2.57	2.97	3.25
Region 18	2.30	2.63	2.85
Region 19	2.52	2.85	3.08
Region 20	2.33	2.66	2.88
Region 21	2.15	2.41	2.57
Region 22	2.75	3.14	3.39
Region 23	1.96	2.16	2.28
Region 24	2.91	3.44	3.82

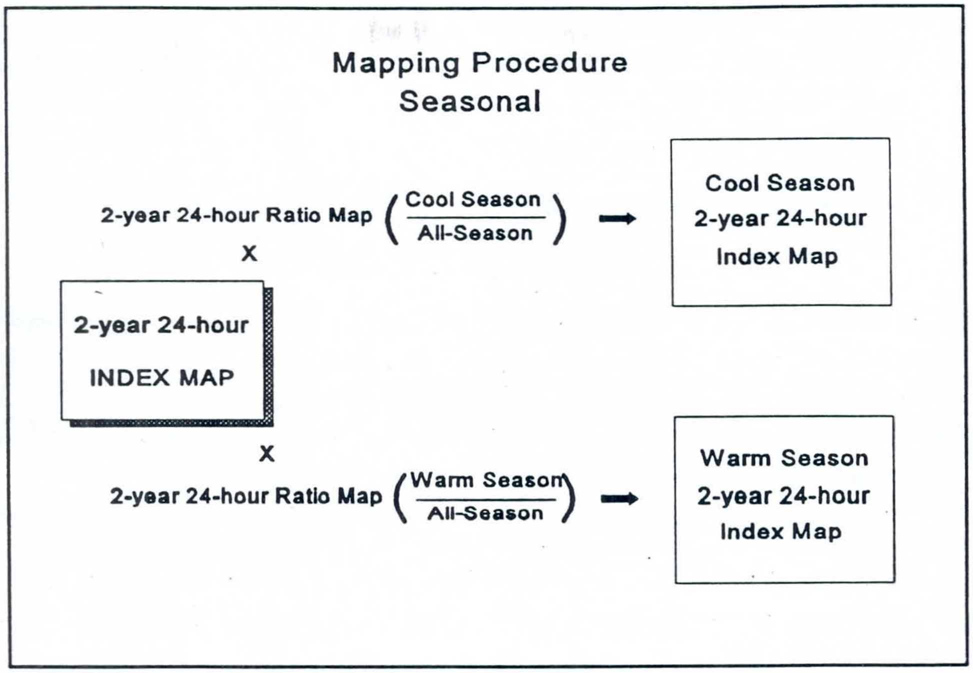

Diagram 2. *Flow chart of seasonal mapping procedure.*

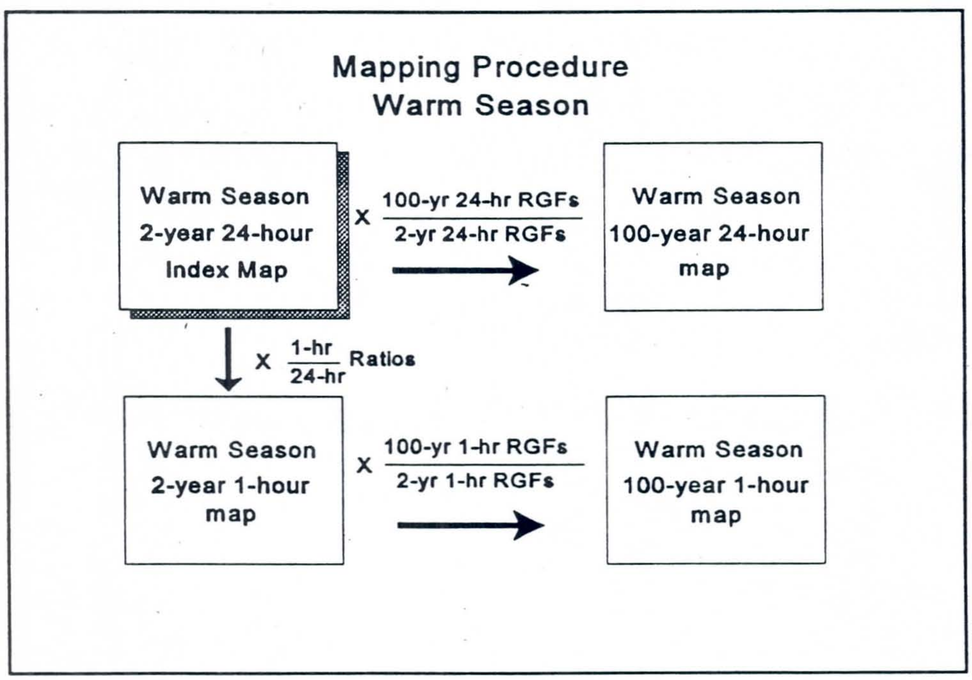

Diagram 3. *Flow chart of warm season mapping procedure.*

Histograms. For the longer durations, 7, 10, 20, 30, 45, and 60 days, histograms of the month of occurrence of the beginning day and maximum day for each duration will be prepared.

Differences between Semiarid Project and NOAA Atlas 2 100-year, 24-hour maps

Differences between the draft Semiarid Project 100-year, 24-hour maps and NOAA Atlas 2 (Miller et al 1973) were computed using GRASS. Tables 3a and 3b, updated from the Thirteenth Quarterly, show the differences by state, now including California. The Semiarid (SA) values were found to be less than NOAA Atlas 2 100-year, 24-hour values over about 80 percent of the area in Arizona, New Mexico, Utah, and California, and over 70 percent of the area in Nevada. Most SA values are between 0.00 and 0.75 inches less than NOAA Atlas 2. About 20 percent of the area of Arizona and Utah has even lower values, that is from 0.76 to 3.37 inches lower than NOAA Atlas 2. The percent differences from Table 3a have been graphed and are shown in Figures 2 to 4.

Table 3a.

Differences in inches of Semiarid minus NOAA Atlas 2 by percent of area by state.

	< -1.25	-1.25 to -0.76	-0.75 to -0.26	-0.25 to 0.25	0.26 to 0.75	0.76 to 1.25	> 1.25	
Arizona	3.9	21.9	39.8	25.2	6.4	2.5	0.3	100%
Nevada	0.2	6.7	40.0	39.8	9.3	2.4	1.6	100%
New Mexico	3.8	14.4	42.6	31.3	5.1	2.5	0.3	100%
Utah	2.1	18.7	55.8	16.7	3.9	1.9	0.9	100%
SE California	20.7	15.9	30.6	26.2	4.9	0.9	0.8	100%
Total Study Area	5.9	15.4	41.3	28.5	6.0	2.1	0.8	100%
Total (w/o CA)	2.5	15.3	43.8	29.0	6.3	2.4	0.7	100%

Table 3b.

Percent area differences between Semiarid Study and NOAA Atlas 2 by State 100-year 24-hour computer-generated map

	Percentages:		Range:
Arizona	81.7% < 0	18.3% > 0	-2.32 to 2.11
Nevada	73.8% < 0	26.2% > 0	-1.49 to 3.29
New Mexico	82.6% < 0	17.4% > 0	-2.69 to 1.49
Utah	88.1% < 0	11.9% > 0	-1.93 to 3.37
California	83.7% < 0	16.3% > 0	-10.33 to 5.83
Total Semiarid	81.6% < 0	18.4% > 0	-10.33 to 5.83
Total w/o CA	81.2% < 0	18.8% > 0	-2.69 to 3.29

Southeastern California has the greatest differences in values, both positive and negative, between SA and NOAA Atlas 2 at 100-year, 24-hour return frequencies. Furthermore, it has the largest area in the negative range, -1.25 to -10.33 inches. Interestingly though, overall, there is not much difference between Figure 2a, which includes California in its total and Figure 2b, which does not. Only at values less than -1.25 inches, is there a major difference. Nearly 6 percent of the total area is 1.25 inches lower when California is included (Figure 2a) against 2.5 percent of the area when California is excluded (Figure 2b). This is primarily due to lowered values in southwestern California, from the coast to the mountains, regions 15 and 22 on the map in Figure 1.

Differences between states show up more clearly in the histograms for the individual states at 100 years (Figures 3a-3e). Arizona, Figure 3a, has a similar distribution to the overall total between SA and NOAA Atlas 2, with the greatest area difference (39.8 percent) between -0.26 and -0.75 inches. Nevada, Figure 3b, has the largest percentage of the area with little change from NOAA Atlas 2 at 100 years, with about 40 percent of its area in the middle range, between -0.25 and +0.25 inches. It also has 40 percent of the area between -0.26 and -0.75 inches. One reason for the lack of change for Nevada, is that it is the driest state and there are large areas where there are only minor quantitative differences, even though the percentage differences are 10 to 20 percent. New Mexico (Figure 3c) has a distribution similar to Arizona, although it has 6 percent more area in the middle range, -0.25 to +0.25 inches, (31.3 compared to 25.2 percent). A majority of the area (55.8 percent) of Utah (Figure 3d) has a difference from NOAA Atlas 2 at 100 years between -0.26 and -0.75 inches. The graph (Figure 3e) for Southeastern California and Tables 3a and 3b show the heavy bias toward lowered values in this part of the Semiarid study area. It should be noted that these comparisons are not only for desert southeastern California, but for the part of

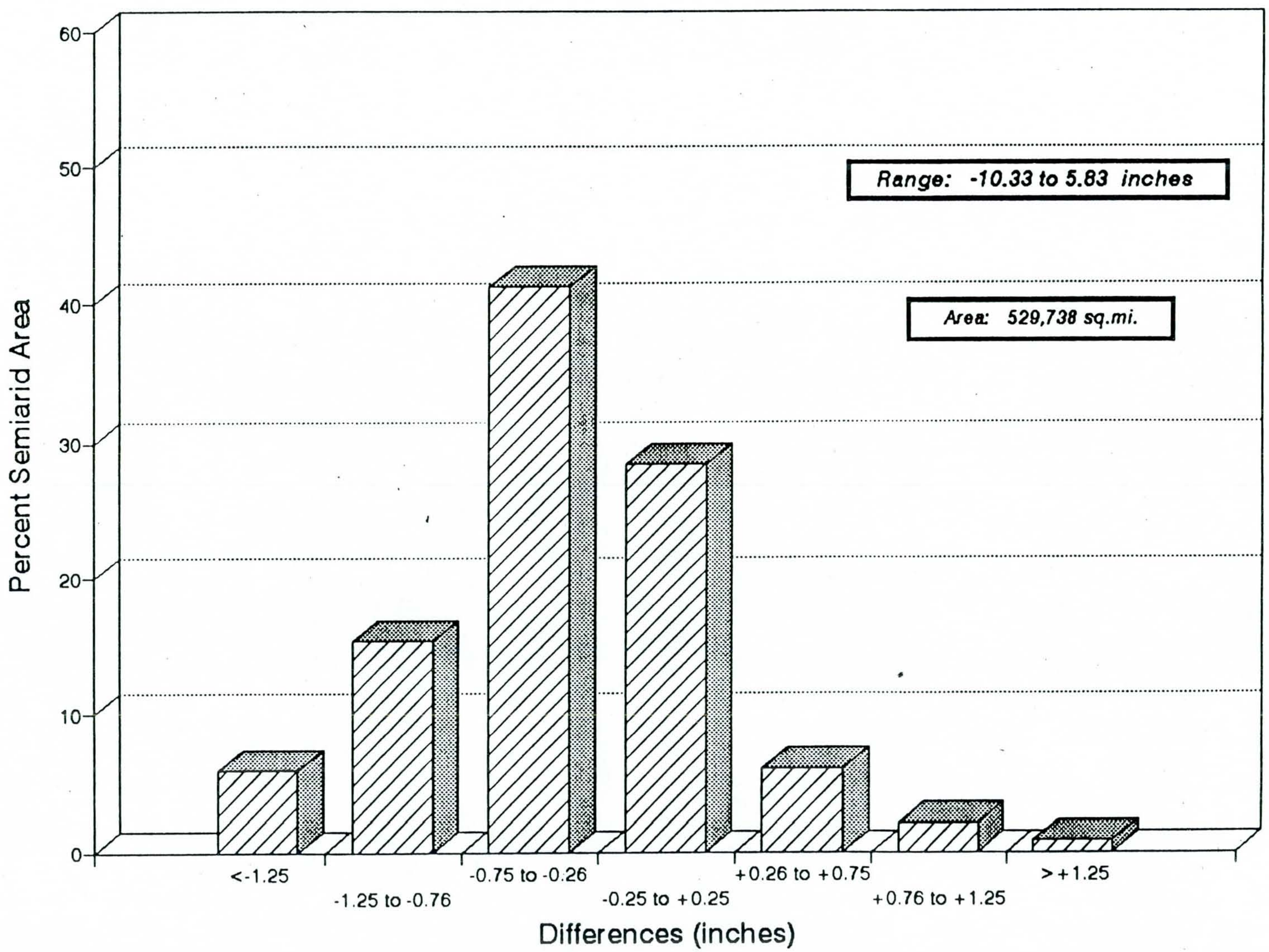

Figure 2a. *Differences of 100-yr, 24-hour values (Semiarid minus NOAA Atlas 2) by percent of the total study area.*

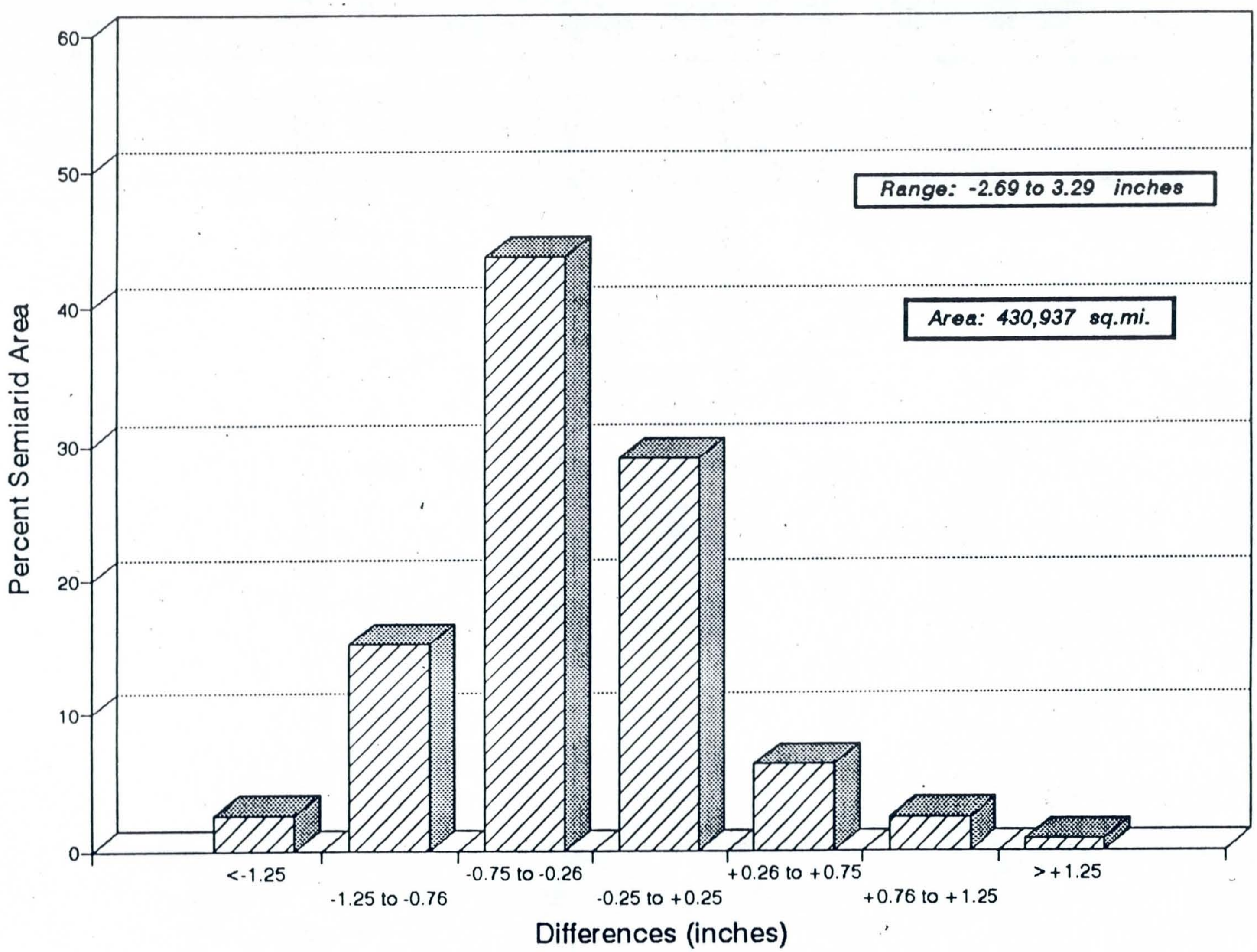

Figure 2b. *Differences of 100-yr, 24-hour values (Semiarid minus* *__NOAA Atlas 2__*) *by percent of the total study area, excluding California.*

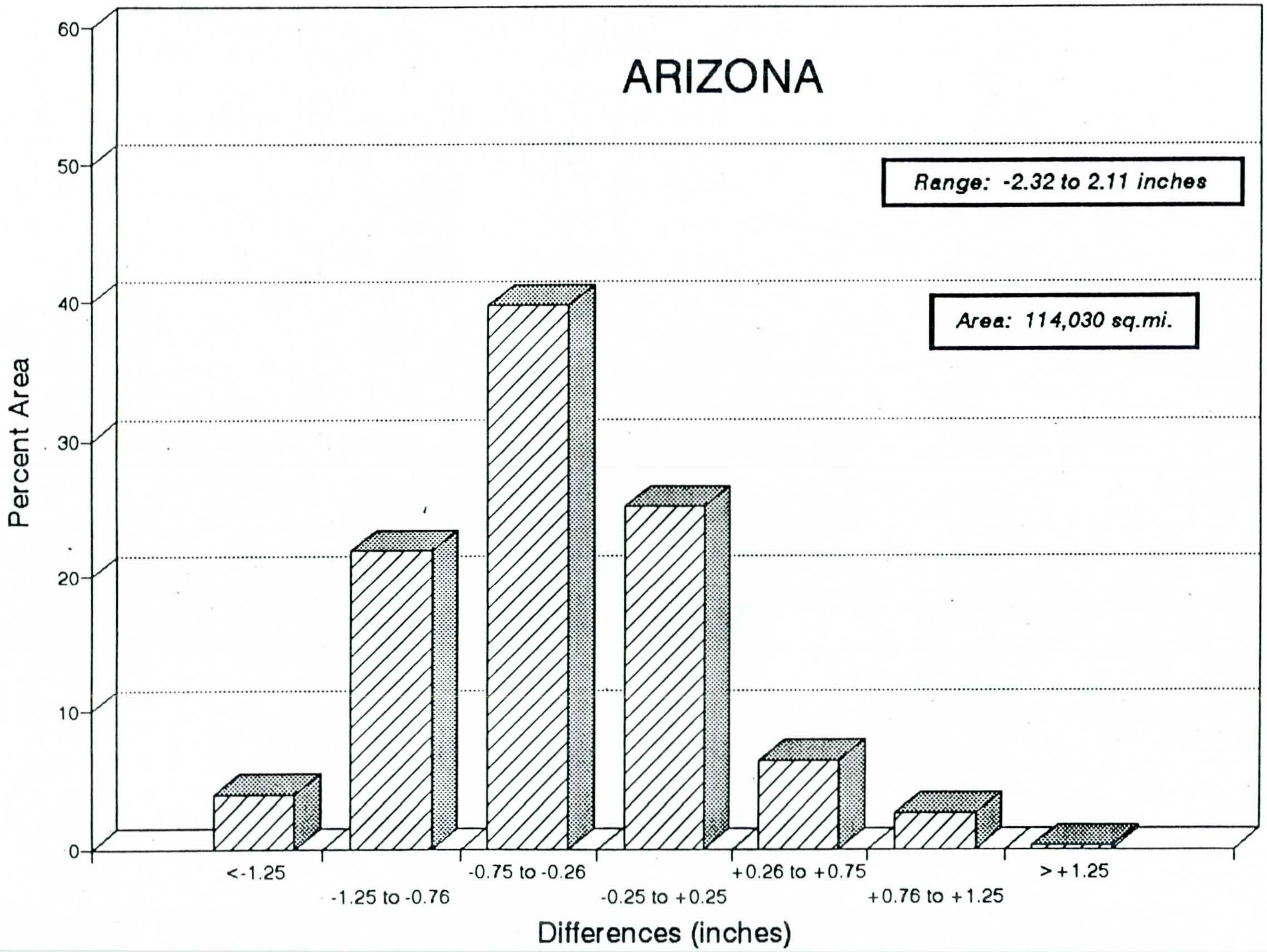

Figure 3a. *Differences of 100-yr, 24-hour values (Semiarid minus NOAA Atlas 2) by percent of area for Arizona.*

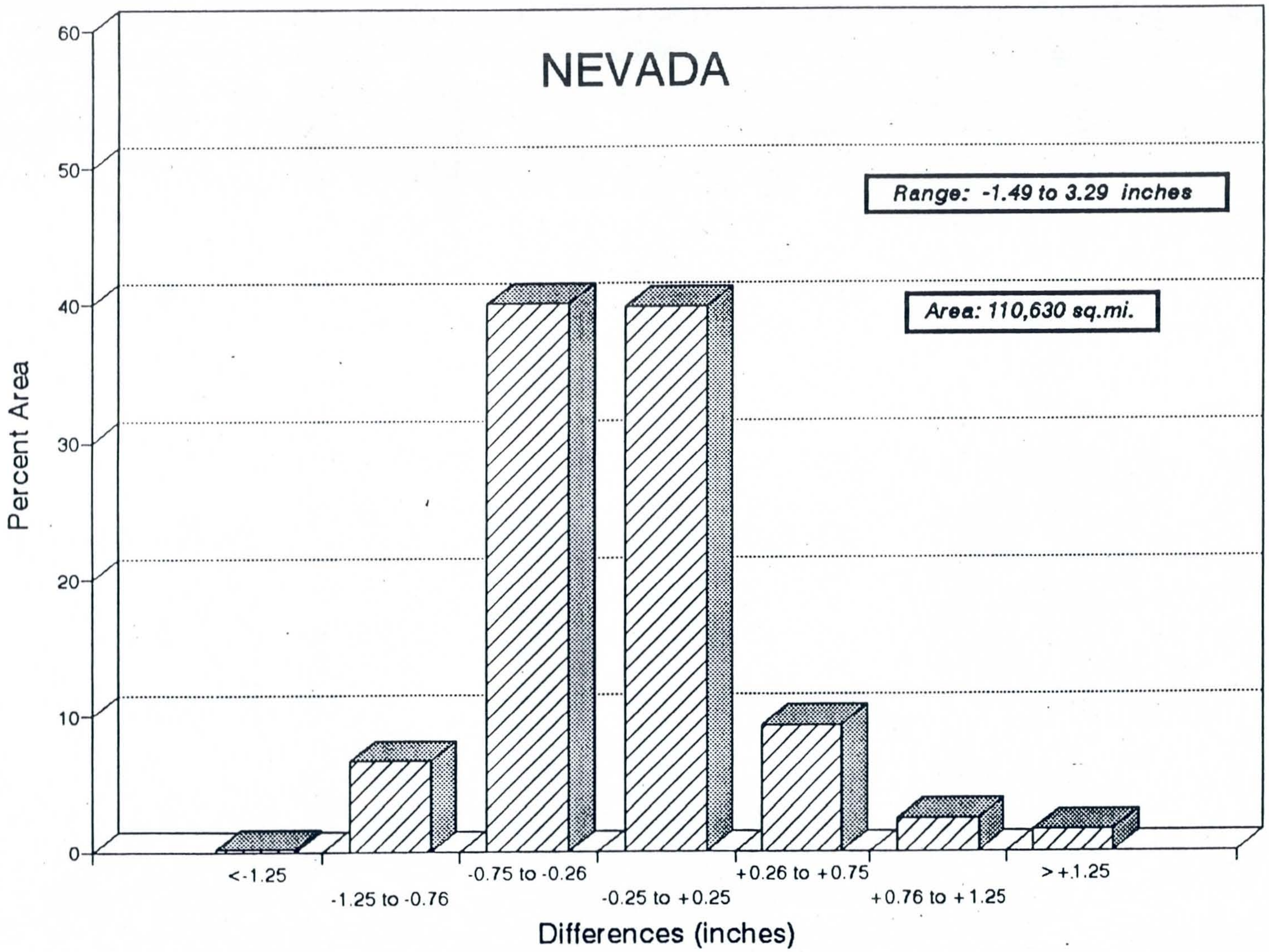

Figure 3b. *Differences of 100-yr, 24-hour values (Semiarid minus* *NOAA Atlas 2) by percent of area for Nevada.*

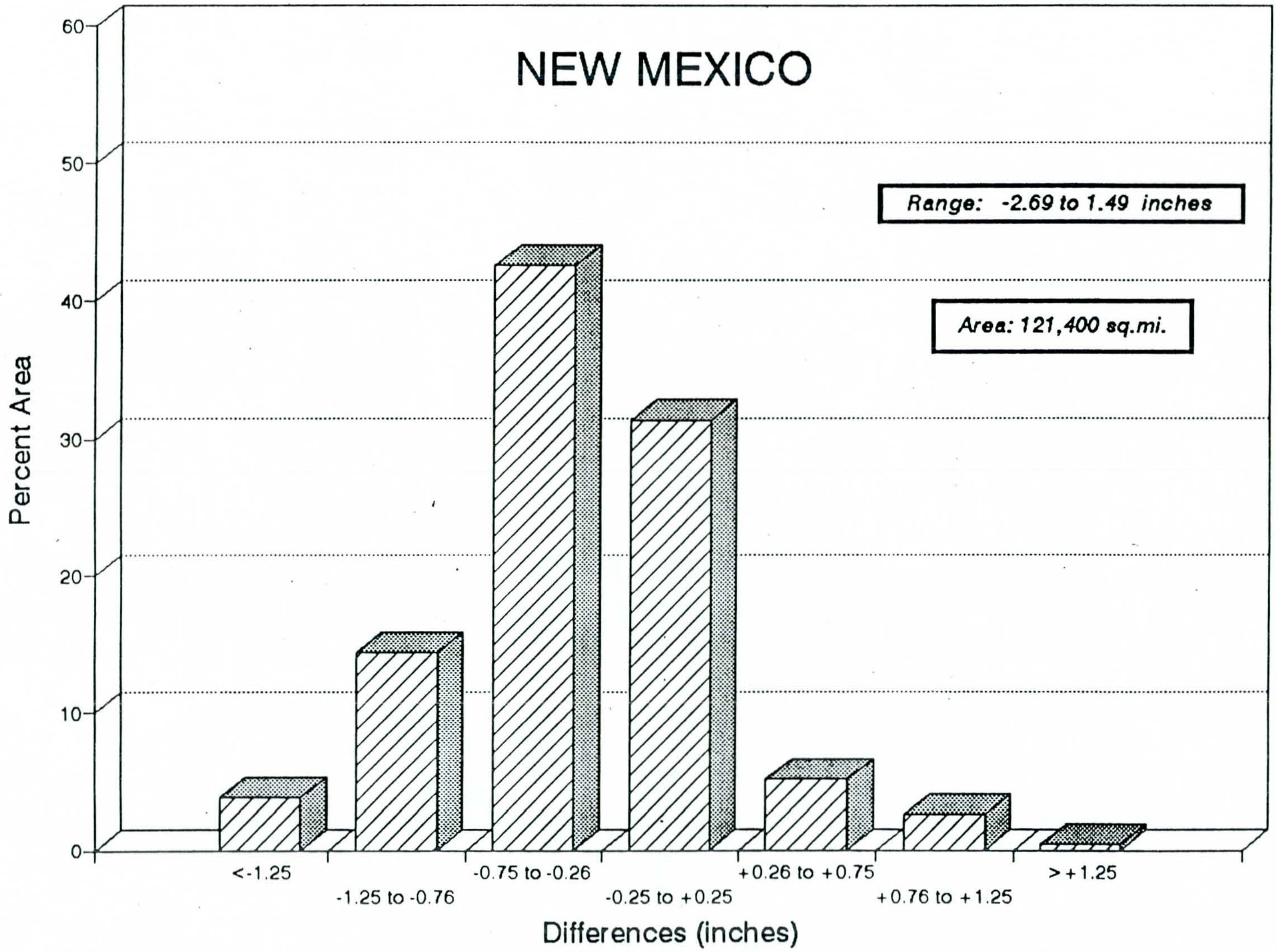

Figure 3c. *Differences of 100-yr, 24-hour values (Semiarid minus NOAA Atlas 2) by percent of area for New Mexico.*

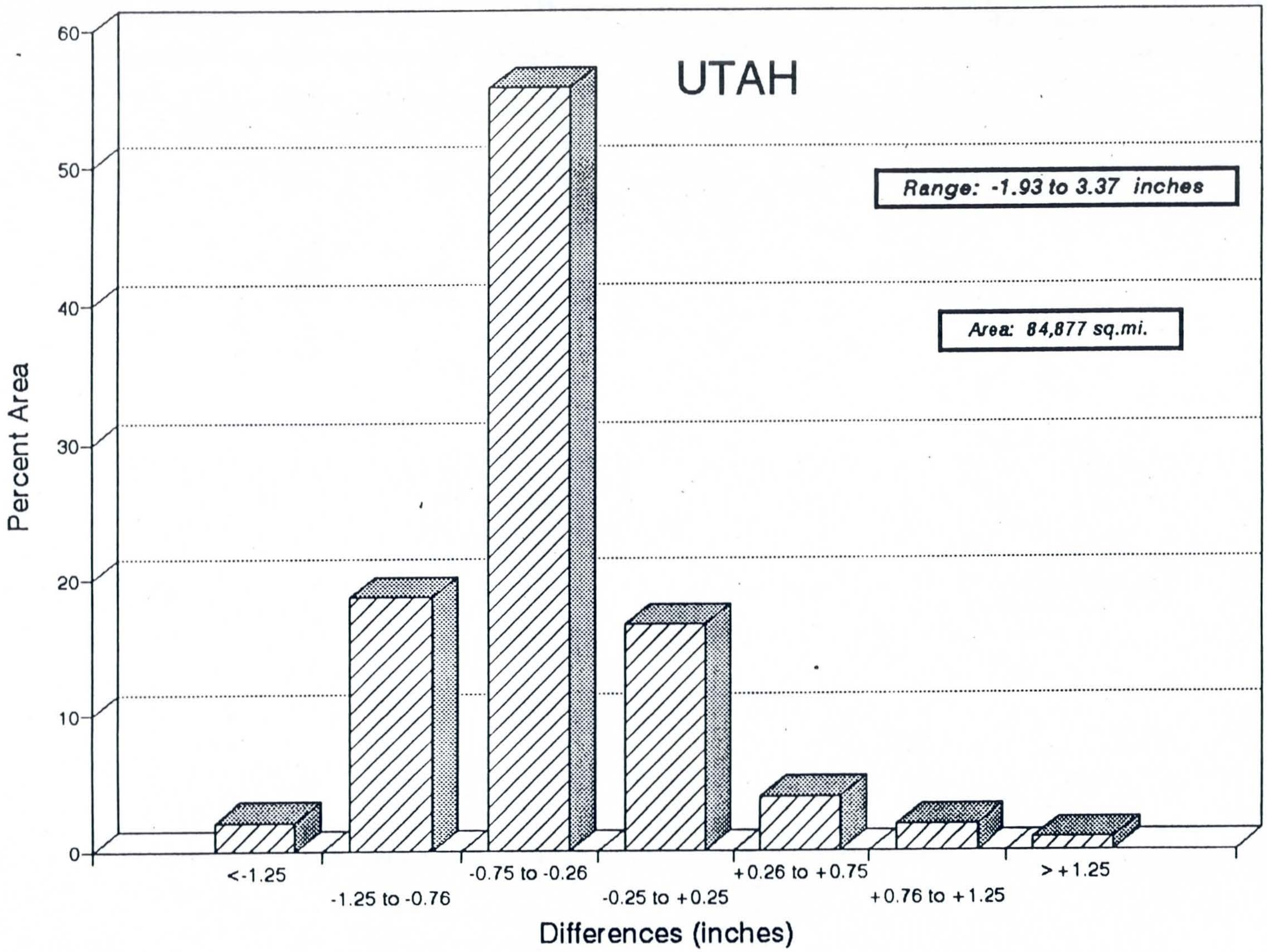

Figure 3d. *Differences of 100-yr, 24-hour values (Semiarid minus NOAA Atlas 2) by percent of area for Utah.*

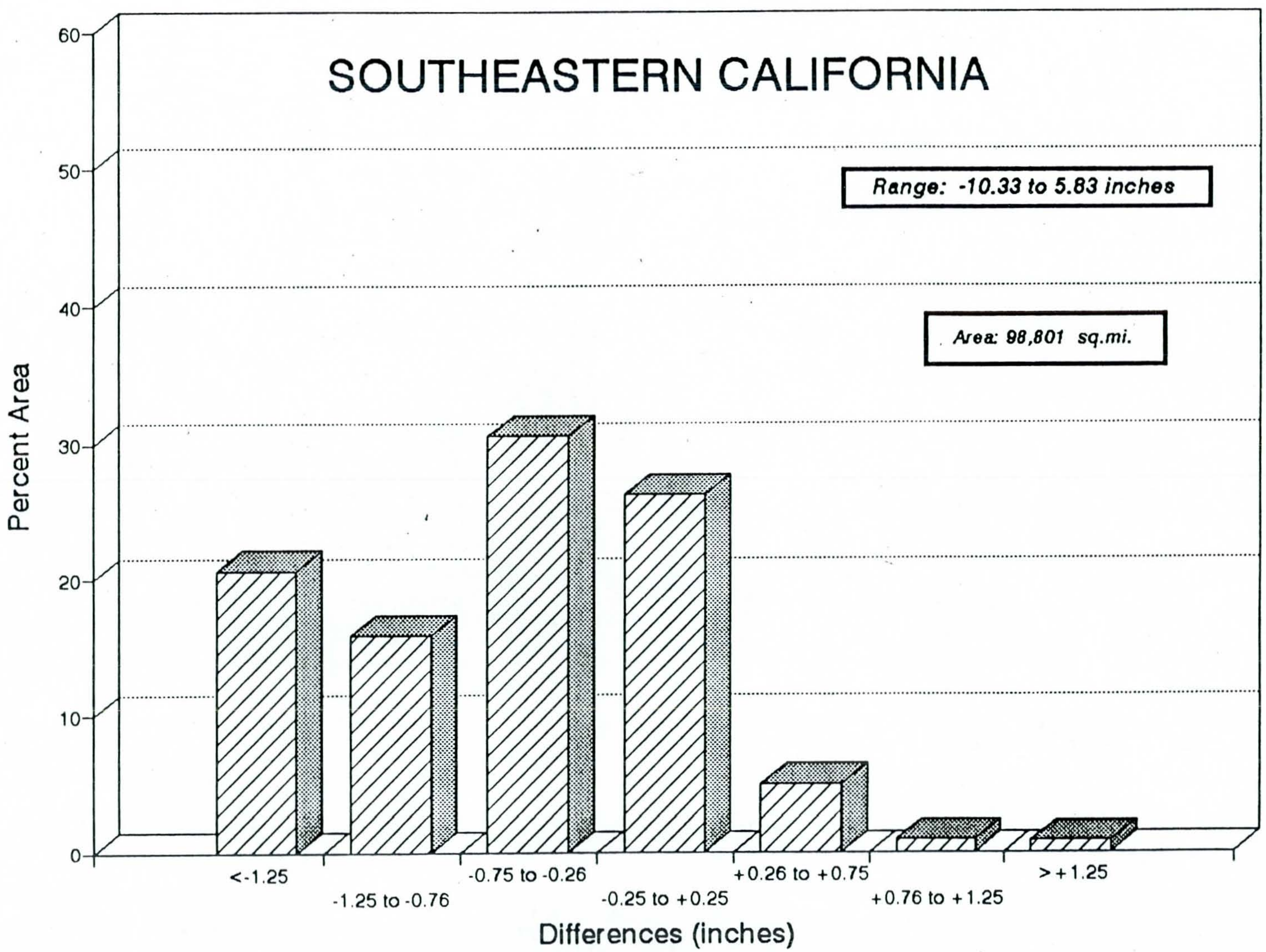

Figure 3e. *Differences of 100-yr, 24-hour values (Semiarid minus NOAA Atlas 2) by percent of area for Southeastern California.*

California that was analyzed (at least in part) for its border interest (Figure 1). Figure 4a (with California) and Figure 4b (without California) illustrate the differences between the states on single graphs.

Since maps were not included in this report, it is difficult to point out the various areas where the values have changed and where they have not changed. The difference maps that have been prepared, are color raster maps and do not lend themselves to mass copying. However, we can summarize as follows: In general, the Semiarid areas that have intensities greater than NOAA Atlas 2 (100-year, 24-hour) are: 1) the Sierra along the border of California and Nevada; 2) the Uinta Mountains and northern Wasatch Range in Utah; 3) the Sonoran desert (Region 10) in southwestern Arizona; and 4) central and southeastern New Mexico. Lower values than NOAA Atlas 2 (100-year, 24-hour) occur in: 1) most of California, except the southeastern desert and the San Joaquin Valley; 2) most of western and central Utah; northwestern and southeastern Arizona; and northeastern New Mexico. SNOw TELemetry (SNOTEL) data have provided increased data coverage at higher elevations. The SNOTEL data have indicated larger values in the Sierra along the California- Nevada border and the mountains in northern Utah, and lower values along the Wasatch Mountains in central Utah and along the southeastern Mogollon Rim in Arizona and into New Mexico. The larger Semiarid values in the Sonoran desert may be due to larger RGFs in that area. Region 10 (southwestern Arizona and southeastern California) has the highest RGFs of any region in the Semiarid study. However, other areas within region 10 have values that are lower than NOAA Atlas 2. Another difference between SA and NOAA Atlas 2 is that the "dry areas are drier and the wet areas wetter" in several areas of the Southwest study area. Altogether the changes reflect information from: 1) longer datasets, 2) more objective curve-fitting techniques, 3) regionalized analysis, and 4) observations in areas where there were none for NOAA Atlas 2. Nonetheless, it is essential that these areas of major change be carefully checked to be certain there is sufficient information to justify changes.

SUMMARY

The DRAFT maps, being reviewed in-house and by outside reviewers, will be carefully evaluated to assure that they are as representative as possible of the rainfall regimes in the Southwest. Although overall changes from NOAA Atlas 2 at 100 years, 24 hours appear to be lower, there are several areas where the values are higher. As a result, both the high and low areas will be particularly scrutinized. However, that said, the 24-hour maps are, in general, reasonable. Since the Fourteenth Quarterly (Tarleton et al 1995), a few digitizing errors were corrected and the various state maps integrated into a single raster map. This assures continuity at the borders, and physical consistency between the states.

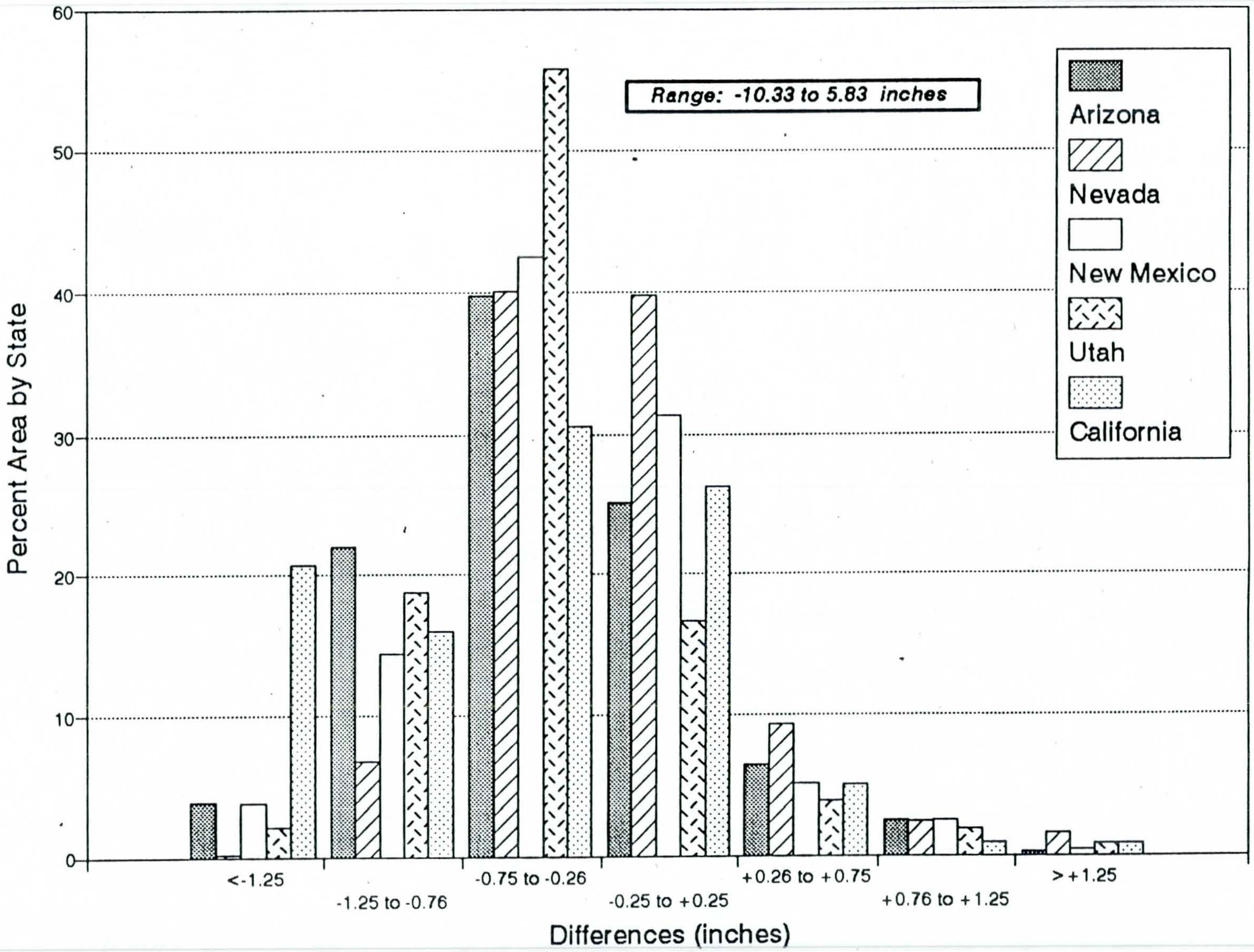

Figure 4a. *Differences of 100-yr, 24-hour values (Semiarid minus* *NOAA Atlas 2) by percent of area by state.*

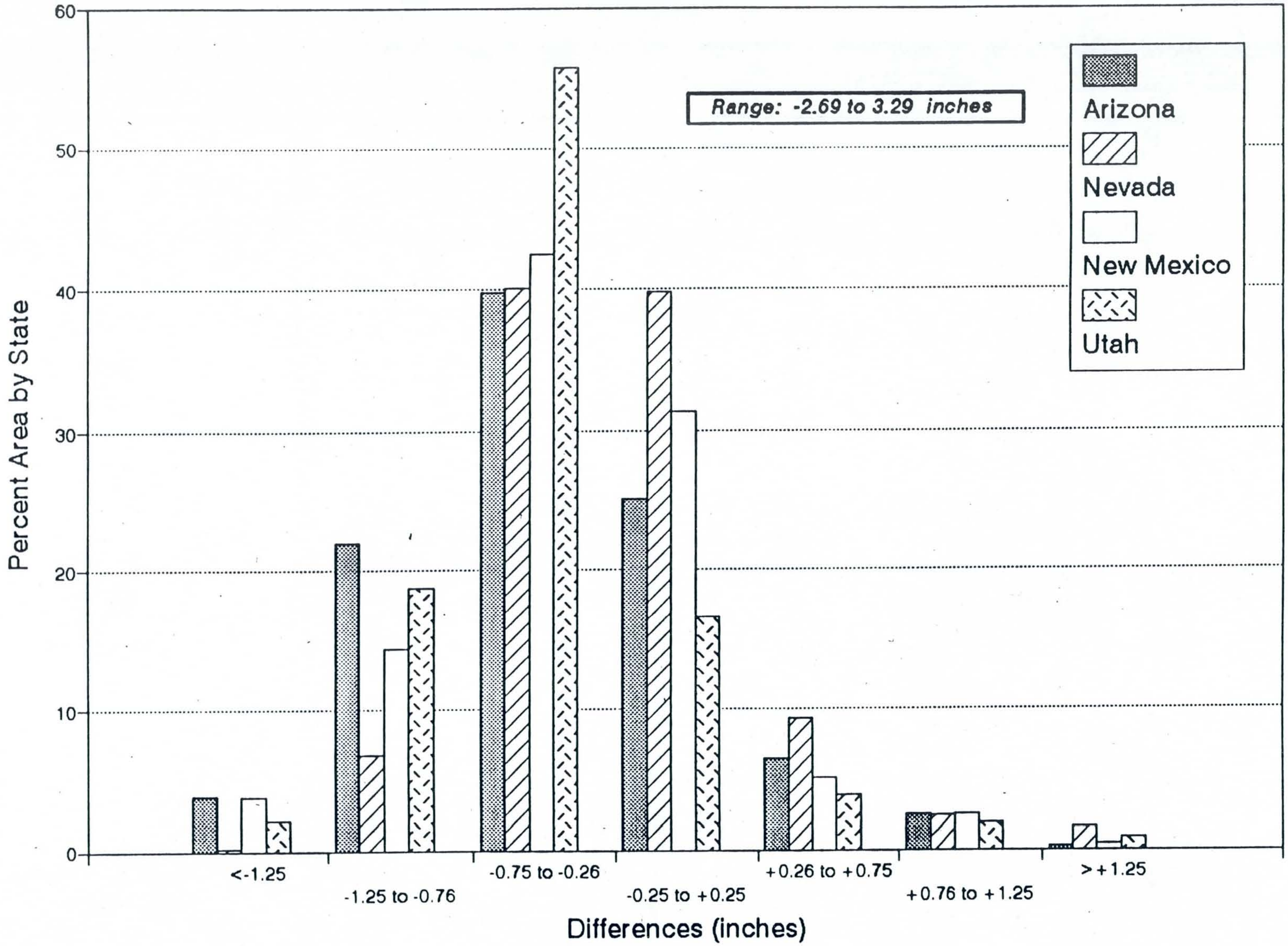

Figure 4b. *Differences of 100-yr, 24-hour values (Semiarid minus* *NOAA Atlas 2) by percent of area by state, excluding California.*

REFERENCES

Miller, J.F., R,H. Frederick, and R.J. Tracey, 1973: Precipitation-frequency atlas of the western United States, NOAA Atlas 2, National Weather Service, Silver Spring, Md.

Tarleton, L.F., J.M. Olson, E.H. Chin, S.M. Gillette, J.L. Vogel, and M. Yekta, 1994: Semiarid precipitation frequency study, Thirteenth Quarterly Report, 25 pp.

Tarleton, L.F., J.M. Olson, E.H. Chin, S.M. Gillette, J.L. Vogel, and M. Yekta, 1995: Semiarid precipitation frequency study, Fourteenth Quarterly Report, 19 pp.

SEMIARID PRECIPITATION FREQUENCY STUDY

Sixteenth Quarterly Progress Report
for the period from
July 1 through September 30, 1995

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November 1995

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SEMIARID PRECIPITATION FREQUENCY STUDY

Sixteenth Quarterly Progress Report
for the period from
July 1 through September 30, 1995

OVERVIEW

This Sixteenth Quarterly Report focuses on the draft map review and other work for the Semiarid Precipitation Frequency Project for the period July 1 through September 30, 1995. Included are dataset comparisons with NOAA Atlas 2 (Miller et al 1973), results of seasonal analyses, a secular trend evaluation, and local storm analysis in the Albuquerque, New Mexico area.

The DRAFT *Index Map* of 2-year, 24-hour return frequencies and 100-year, 24-hour; 2-year, 1-hour, and 100-year, 1-hour maps were prepared for each state. A set of 3 maps (omitting the 2-year, 1-hour) for each state was sent to approximately 20 reviewers for additional input and comment. As a result of internal and outside review, changes have been made in the analysis of the 100-year, 1-hour maps. The revised map preparation is discussed here. For reference, a map depicting the Semiarid Project area is shown in Figure 1.

MAPPING AND ANALYSIS

Original Process

Index Map

Mapping. The mapping and analysis process is: 1) a combined hand-analysis and computer mapping technique that develops an *Index Map*, 2) determines its relation to other durations and/or return frequencies, and 3) uses the computer to do the arithmetic to generate other maps of interest. The 2-year, 24-hour map (*Index Map*) was hand-analyzed from exactingly quality-controlled data, and return-frequency values computed using L-moment statistical software over near-homogeneous climatic regions. The *Index Map* is multiplied by the appropriate regional growth factors (RGFs) for the 24-hour return frequency of interest. Since the RGFs are defined relative to mean values (and not 2-year values), the RGFs for return frequencies other than 2-year, 24-hour must be divided by the 2-year, 24-hour RFGs; and then this ratio used as the multiplier to define the intensity for a particular return frequency.

Conversion to 24 hours and 60 minutes. Furthermore, it is important to note that 1- and 2-day values are converted to 24 and 48 hours, and 1-hour and 2-hour

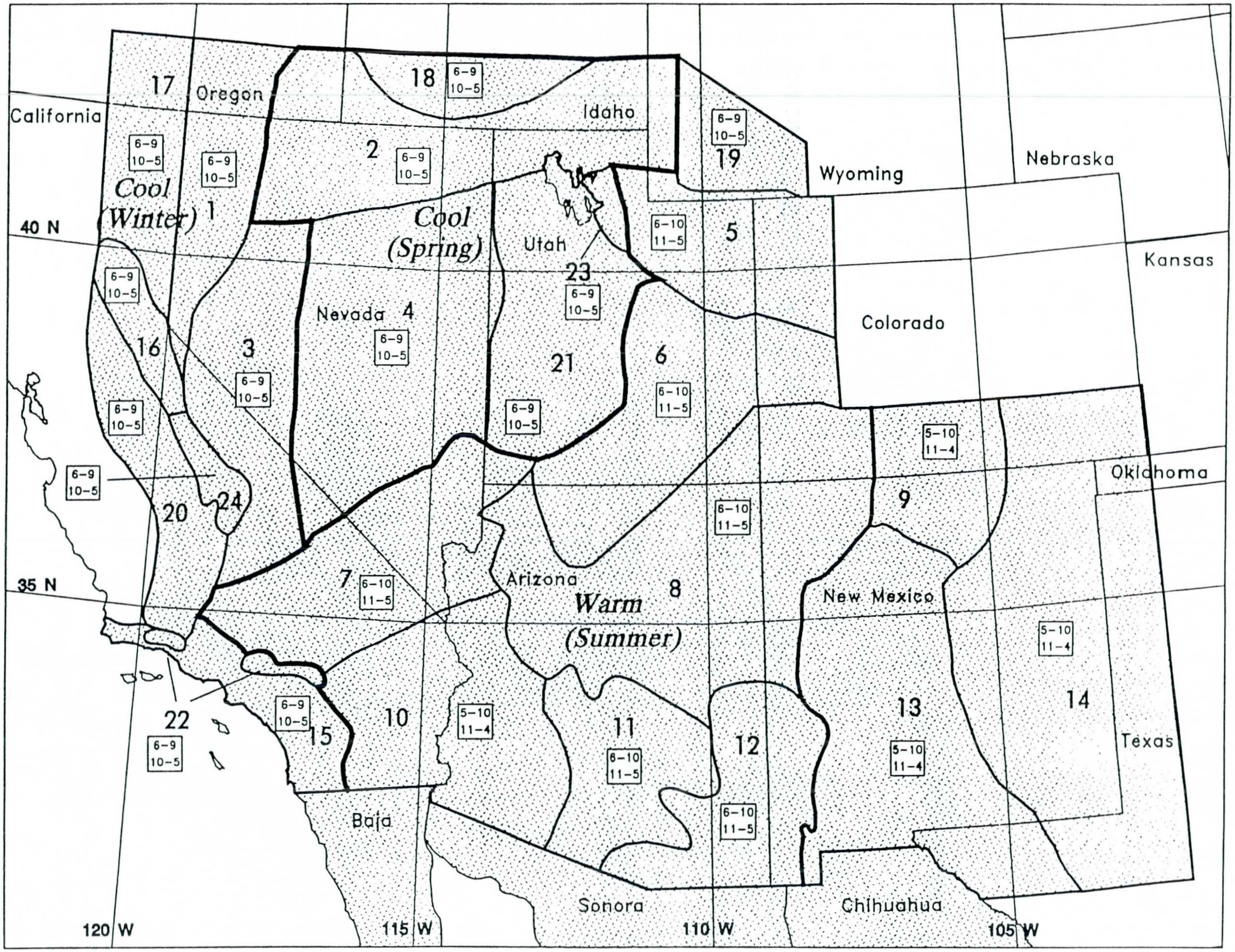

Figure 1. *Semiarid study climatic regions.*

values are converted to 60 and 120 minutes. The conversion factors are dependent on return frequency. For example, for 1-day values, the conversion factor decreases from 1.15 at 2 years to 1.06 at 100 years. The 1-hour conversion factors to 60 minutes are 1.11 and 1.02, for 2 and 100 years, respectively. A complete table of conversion factors is given in the Fourteenth Quarterly Report (Tarleton et al 1995).

Ratios of hourly to 24 hours

To produce maps for durations less than 24 hours the *Index Map* is spatially multiplied by ratios of hourly values to 24-hour values. The mapping procedures are discussed in the following section.

Revised Procedures

The generation of higher return frequency (e.g. 100-year) maps for 24 hours from the 2-year *Index Map* is working well. However, the 100-year, 1-hour maps did not match the station return frequencies as well as the 24-hour maps. Both inside and outside reviewers had concerns with the process, and several adjustments were made to improve the analysis. A major difficulty is that the two primary datasets from the National climatic Data Center (NCDC) - the hourly and daily - are not perfectly congruent. As the daily dataset is more stable (longer records, and many more stations), it was given a greater weight in the analysis of the *Index* (24-hour) maps; but at the shorter durations, the hourly stations are the only data available and have considerably less spatial and temporal coverage.

Regional growth factors

Initially, the 100-year, 1-hour maps were generated from the 2-year, 1-hour maps, using only the regional growth factors (RGFs) derived from the L-moment analysis of the 1-hour data. However, RGFs developed from hourly data differ from RGFs developed from daily data, and also vary differently among climatic regions. These spatial RGF differences reflect differences between short- and long-duration precipitation events, seasonal differences, as well as varying precipitation regimes. Another source of varying values may be due to more limited hourly data (about two-thirds fewer hourly stations and shorter records than daily data). The RGFs for all regions and return frequencies up to 100 years can be seen in Table 1: for 1 hour (Table 1a), 24 hours (Table 1b), and the ratios of 1-hour RGFs to 24-hour RGFs (Table 1c). All values have been normalized to the 2-year values, thus all the 2-year values in Table 1 are 1.00.

An illustration of RGF differences is shown in Figures 2a and 2b. The 1-hour and the 24-hour RGFs (adjusted to 2-year RGFs) are plotted against return frequency for Regions 7 (Figure 2a) and Region 12 (Figure 2b). In Region 7 the 100-year 1-hour RGF is greater than 3, while the 100-year, 24-hour RGF is about 2.3. In contrast, in

Table 1a.

1-hr Growth Factors, Adjusted to 60-min and Divided by 2-year

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Region 1	1.00	1.36	1.72	2.32	2.91	3.62
Region 2	1.00	1.37	1.71	2.19	2.58	3.03
Region 3	1.00	1.39	1.73	2.24	2.66	3.12
Region 4	1.00	1.40	1.75	2.26	2.67	3.12
Region 5	1.00	1.35	1.64	2.06	2.39	2.74
Region 6	1.00	1.37	1.70	2.15	2.53	2.94
Region 7	1.00	1.40	1.73	2.21	2.61	3.04
Region 8	1.00	1.36	1.64	2.01	2.27	2.54
Region 9	1.00	1.38	1.68	2.09	2.39	2.71
Region 10	1.00	1.49	1.90	2.49	2.96	3.45
Region 11	1.00	1.34	1.58	1.86	2.04	2.20
Region 12	1.00	1.33	1.57	1.84	2.02	2.17
Region 13	1.00	1.35	1.61	1.92	2.14	2.34
Region 14	1.00	1.35	1.61	1.96	2.23	2.47
Region 15	1.00	1.27	1.49	1.80	2.05	2.31
Region 16	1.00	1.24	1.45	1.79	2.08	2.42
Region 17	1.00	1.34	1.69	2.24	2.76	3.38
Region 18	1.00	1.40	1.75	2.25	2.66	3.09
Region 19	1.00	1.36	1.66	2.10	2.46	2.86
Region 20	1.00	1.26	1.50	1.85	2.15	2.48
Region 21	1.00	1.40	1.74	2.22	2.62	3.05
Region 22	1.00	1.27	1.49	1.75	1.95	2.14
Region 23	1.00	1.36	1.69	2.14	2.53	2.95
Region 24	1.00	1.27	1.51	1.89	2.20	2.57
mean	1.00	1.35	1.65	2.07	2.41	2.78
sd	0.00	0.06	0.10	0.19	0.29	0.41
max	1.00	1.49	1.90	2.49	2.96	3.62
min	1.00	1.24	1.45	1.75	1.95	2.14
range	0.00	0.25	0.45	0.73	1.01	1.48

Table 1b.
24-hr Growth Factors Divided by 2-year

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Region 1	1.00	1.28	1.50	1.79	2.01	2.22
Region 2	1.00	1.24	1.43	1.68	1.88	2.07
Region 3	1.00	1.31	1.57	1.92	2.19	2.47
Region 4	1.00	1.26	1.47	1.72	1.91	2.10
Region 5	1.00	1.24	1.44	1.70	1.90	2.11
Region 6	1.00	1.25	1.45	1.70	1.90	2.09
Region 7	1.00	1.31	1.54	1.85	2.08	2.29
Region 8	1.00	1.26	1.47	1.74	1.95	2.16
Region 9	1.00	1.24	1.43	1.68	1.87	2.06
Region 10	1.00	1.39	1.71	2.15	2.49	2.86
Region 11	1.00	1.27	1.48	1.74	1.93	2.13
Region 12	1.00	1.25	1.44	1.68	1.84	1.99
Region 13	1.00	1.26	1.45	1.69	1.86	2.02
Region 14	1.00	1.30	1.54	1.86	2.11	2.36
Region 15	1.00	1.31	1.54	1.82	2.01	2.20
Region 16	1.00	1.26	1.47	1.73	1.91	2.10
Region 17	1.00	1.28	1.50	1.82	2.06	2.30
Region 18	1.00	1.24	1.43	1.69	1.88	2.08
Region 19	1.00	1.30	1.53	1.83	2.06	2.28
Region 20	1.00	1.24	1.44	1.70	1.90	2.10
Region 21	1.00	1.23	1.41	1.63	1.80	1.97
Region 22	1.00	1.34	1.61	1.96	2.22	2.47
Region 23	1.00	1.21	1.36	1.55	1.69	1.82
Region 24	1.00	1.32	1.58	1.96	2.25	2.56
mean	1.00	1.27	1.49	1.78	1.99	2.20
sd	0.00	0.04	0.08	0.13	0.17	0.22
max	1.00	1.39	1.71	2.15	2.49	2.86
min	1.00	1.21	1.36	1.55	1.69	1.82
range	0.00	0.19	0.35	0.60	0.80	1.04

Table 1c.

Ratios of the 1-hr:24-hr Growth Factors

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Region 1	1.00	1.06	1.15	1.30	1.45	1.63
Region 2	1.00	1.11	1.19	1.31	1.37	1.46
Region 3	1.00	1.06	1.10	1.16	1.22	1.26
Region 4	1.00	1.11	1.19	1.31	1.39	1.49
Region 5	1.00	1.09	1.14	1.21	1.26	1.29
Region 6	1.00	1.10	1.17	1.26	1.33	1.41
Region 7	1.00	1.07	1.12	1.19	1.26	1.33
Region 8	1.00	1.08	1.11	1.15	1.16	1.17
Region 9	1.00	1.11	1.17	1.24	1.28	1.32
Region 10	1.00	1.07	1.11	1.16	1.19	1.21
Region 11	1.00	1.06	1.07	1.07	1.06	1.03
Region 12	1.00	1.07	1.09	1.10	1.10	1.09
Region 13	1.00	1.07	1.11	1.14	1.15	1.16
Region 14	1.00	1.04	1.05	1.05	1.06	1.05
Region 15	1.00	0.97	0.97	0.99	1.02	1.05
Region 16	1.00	0.98	0.99	1.03	1.09	1.15
Region 17	1.00	1.05	1.12	1.23	1.34	1.47
Region 18	1.00	1.13	1.23	1.33	1.42	1.49
Region 19	1.00	1.04	1.08	1.14	1.20	1.26
Region 20	1.00	1.02	1.04	1.08	1.13	1.18
Region 21	1.00	1.14	1.24	1.36	1.46	1.55
Region 22	1.00	0.95	0.92	0.89	0.88	0.87
Region 23	1.00	1.13	1.24	1.38	1.49	1.62
Region 24	1.00	0.97	0.96	0.96	0.98	1.00
mean	1.00	1.06	1.11	1.17	1.22	1.27
sd	0.00	0.05	0.09	0.13	0.16	0.20
max	1.00	1.14	1.24	1.38	1.49	1.63
min	1.00	0.95	0.92	0.89	0.88	0.87
range	0.00	0.19	0.32	0.49	0.62	0.76

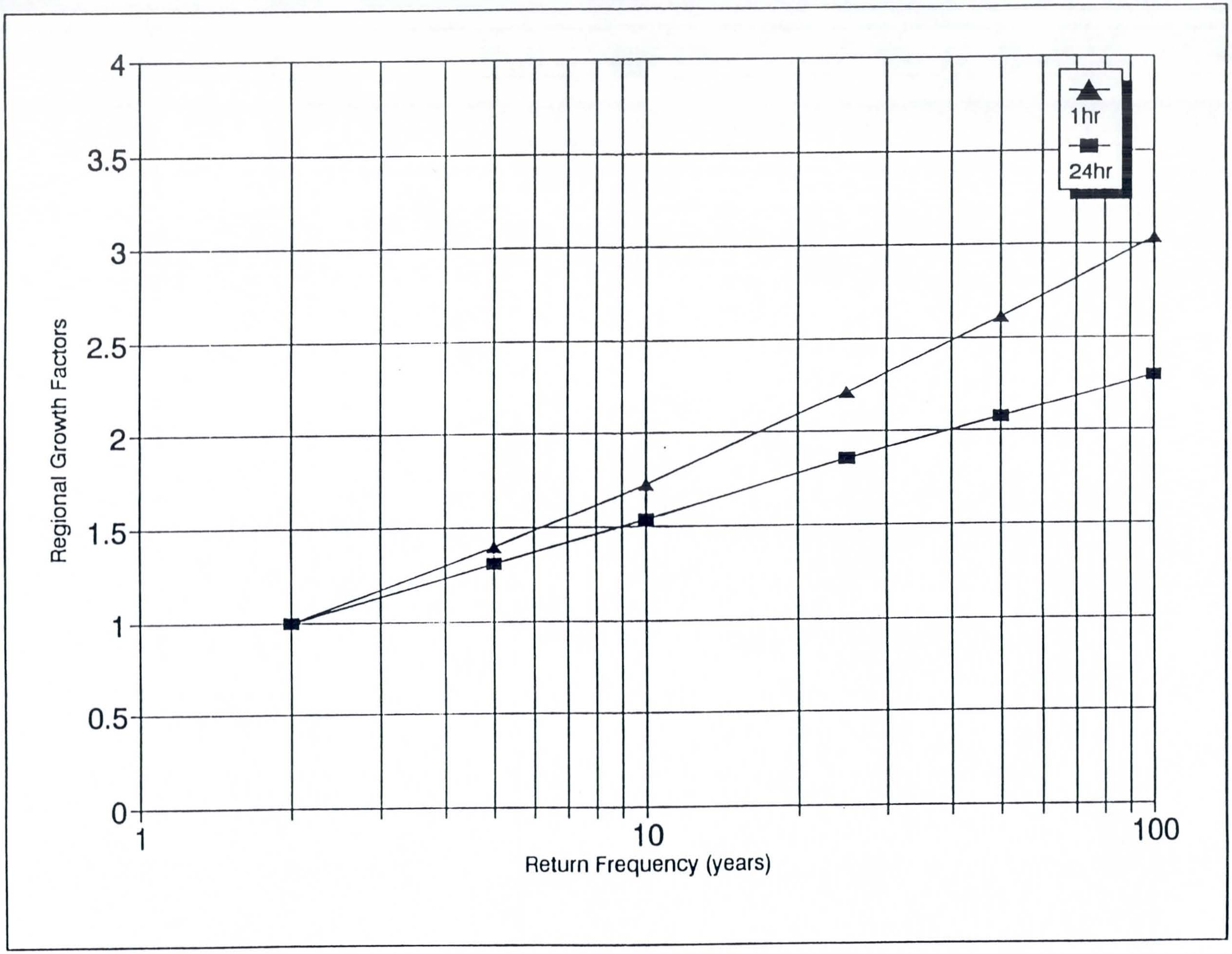

Figure 2a. *One-hour and 24-hour Regional Growth Factors for Region 7.*

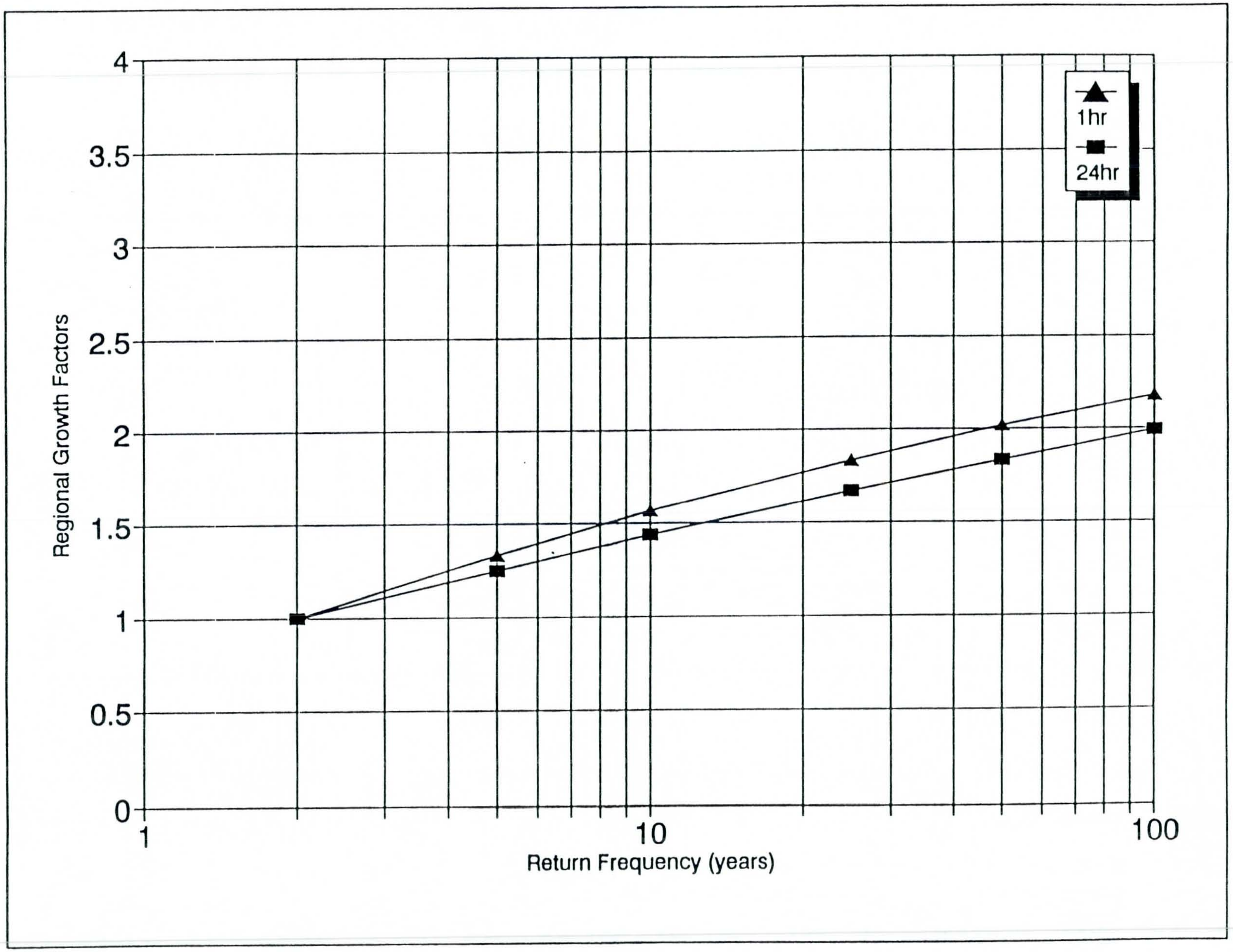

Figure 2b. *One-hour and 24-hour Regional Growth Factors for Region 12.*

Region 12 the 1-hour and 24-hour RGFs track very closely; and the 100-year, 1-hour RGF is only slightly higher than the 100-year, 24-hour value. Region 7 is an example of a much higher hourly RGF at 100 years. Region 12 is an example where the differences in slope and RGF values are small. In all regions except Regions 22 and 24, the hourly RGFs (100-year) are greater than the daily; and, in general, increase faster with increasing return period (see Table 1). Regions 11, 15, and 24 (figures not shown) have nearly equal RGFs for both hourly and daily data.

The effect of these RGFs upon the frequency curves can be illustrated in Figure 3. Effectively the RGFs increase the short duration intensities more rapidly relative to the 2-year intensity than the 24-hour values, indicating that individual plots of these curves converge as the event becomes rarer.

The RGF differences are related to the meteorology and seasonality of the various regions. Areas where intense summer convective storms cause the extreme values will have higher short duration extremes than areas with primarily general storm winter precipitation. The spatial differences are reflected in the all-season data, as various precipitation types prevail in different climatic areas. Thus, it is apparent that these spatial and temporal differences must be taken into account in the determination of the 100-year, 1-hour maps.

Determination of a 100-year, 1-hour map

Map input factors. Several different processes were tested to prepare the 100-year, 1-hour map. The factors that were considered and used implicitly and/or explicitly are:

- *Index Map* (2-year, 24-hour)
- 100-year, 24-hour map
- 1-hour regional growth factors (RGFs) (Table 1a)
- 24-hour regional growth factors (RGFs) (Table 1b)
- 2-year, (1:24-hour ratios)
- 100-year, (1:24-hour ratios) (Table 1c)

Process A. Algebraically the process is shown in Figure 4a where the *Index* Map is multiplied by 2-year (1:24-hour ratios) to produce the 2-year, 1-hour map; then that map is multiplied by the adjusted 100-year, 1-hour RGFs to determine the 100-year, 1-hour map. Process A uses the hourly RGFs explicitly; but does not use the relationship between the 100-year, 24-hour and 100-year, 1-hour values.

Process B. In this case (Figure 4b), the 2-year, 1-hour map is prepared in the same way as in process A. However, in addition to the multiplication by the 1-hour RGFs, the 2-year, 1-hour map is multiplied by the 100-year (1:24-hour ratios). This necessitated the drawing and digitizing of a 100-year, 1:24-hour ratio map to be

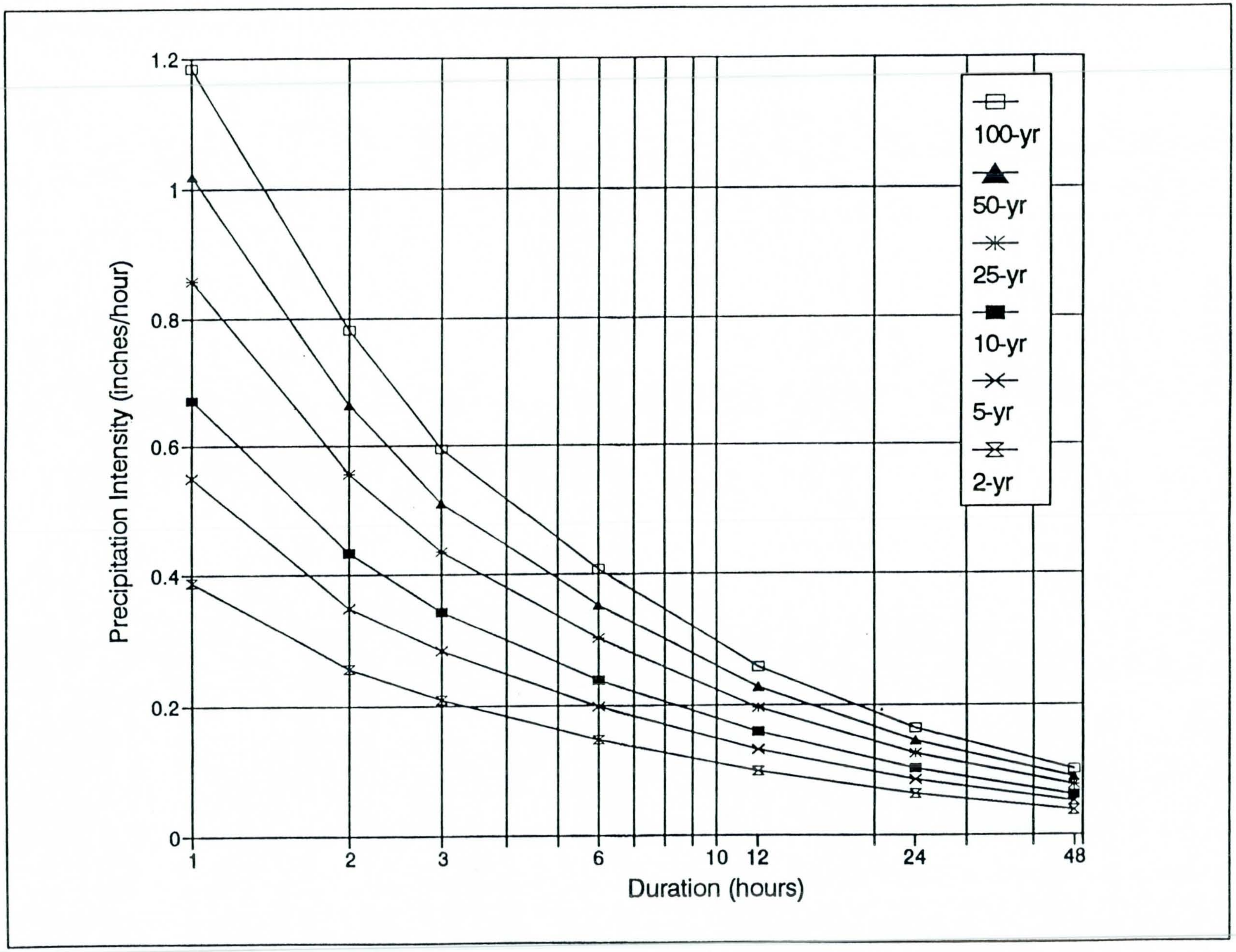

Figure 3. *Intensity Duration Frequency Curve for station 04-8832 in Region 7.*

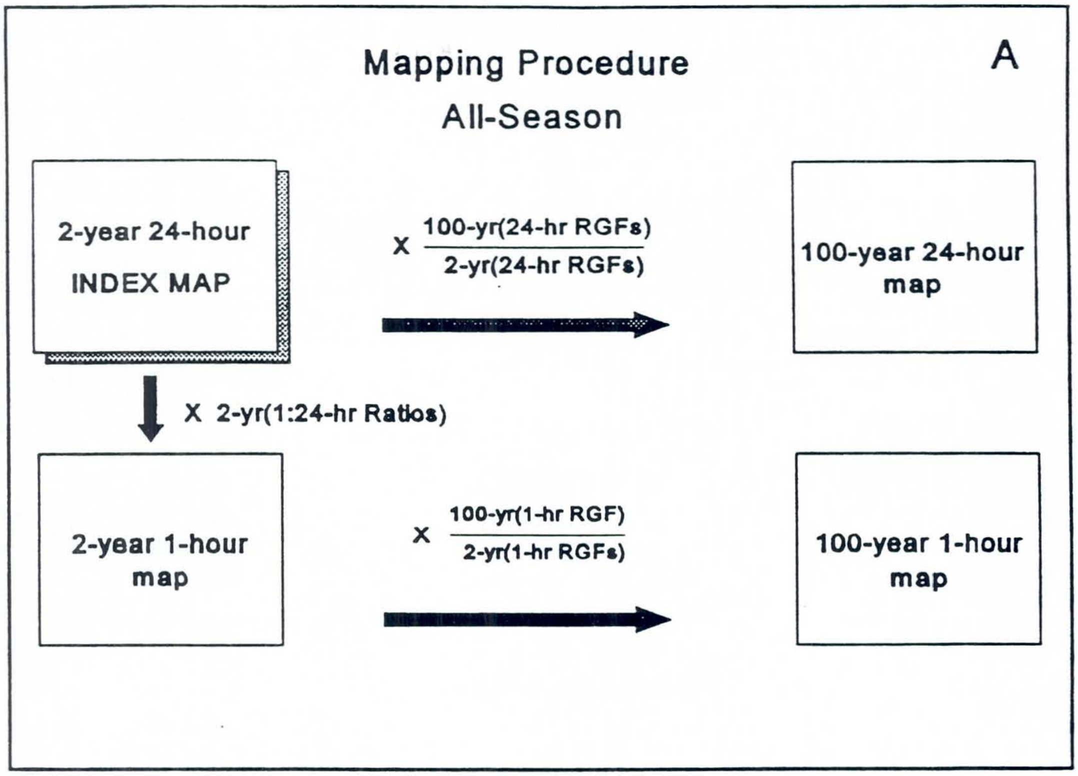

Figure 4a. *Flow chart of all-season mapping procedure, process a (see text).*

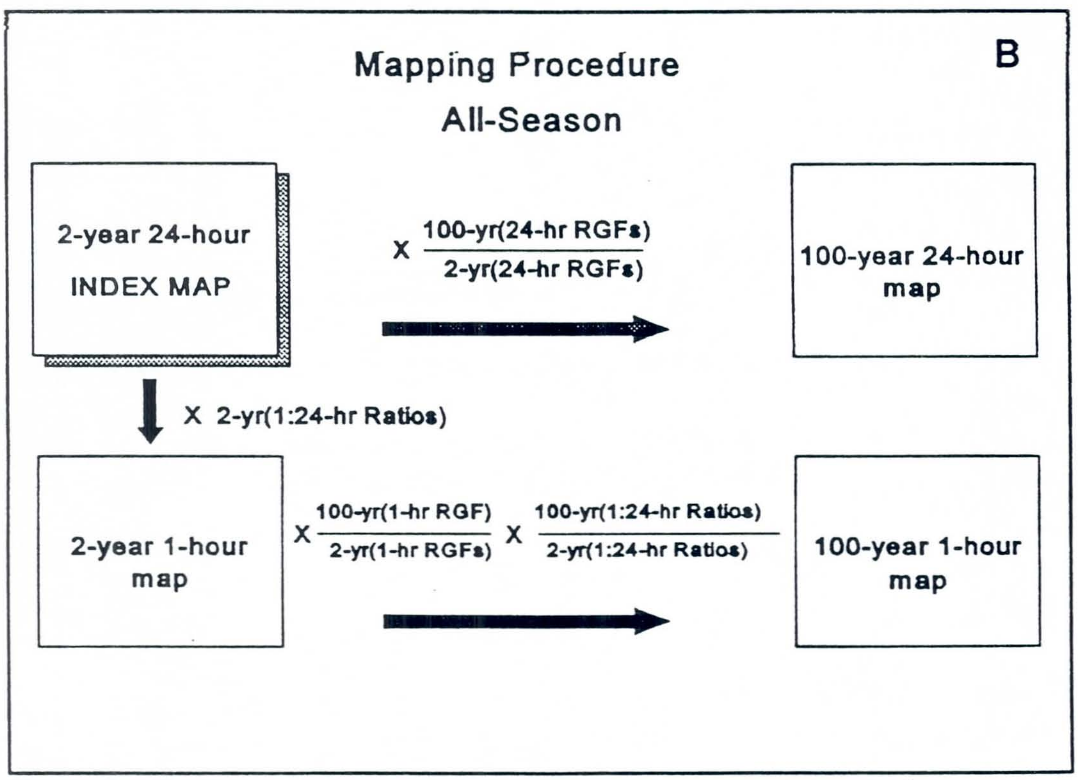

Figure 4b. *Flow chart of all-season mapping procedure, process b (see text).*

included in the analysis. Note that both these factors (RGFs and ratios) are adjusted to (divided by) the 2-year values of RGFs or ratios, respectively. In Process B, the 1-hour RGFS and the relationship of the 100-year, 1-hour to the 100-year, 24-hour are included explicitly in the computations.

Process C. In process C (Figure 4c) the 100-year, 1-hour map is computed directly from the 100-year, 24-hour map, using only the 100-year, 1:24-hour ratios. Thus, in this case the 1-hour RGFs are used implicitly from the ratio calculations, but not explicitly.

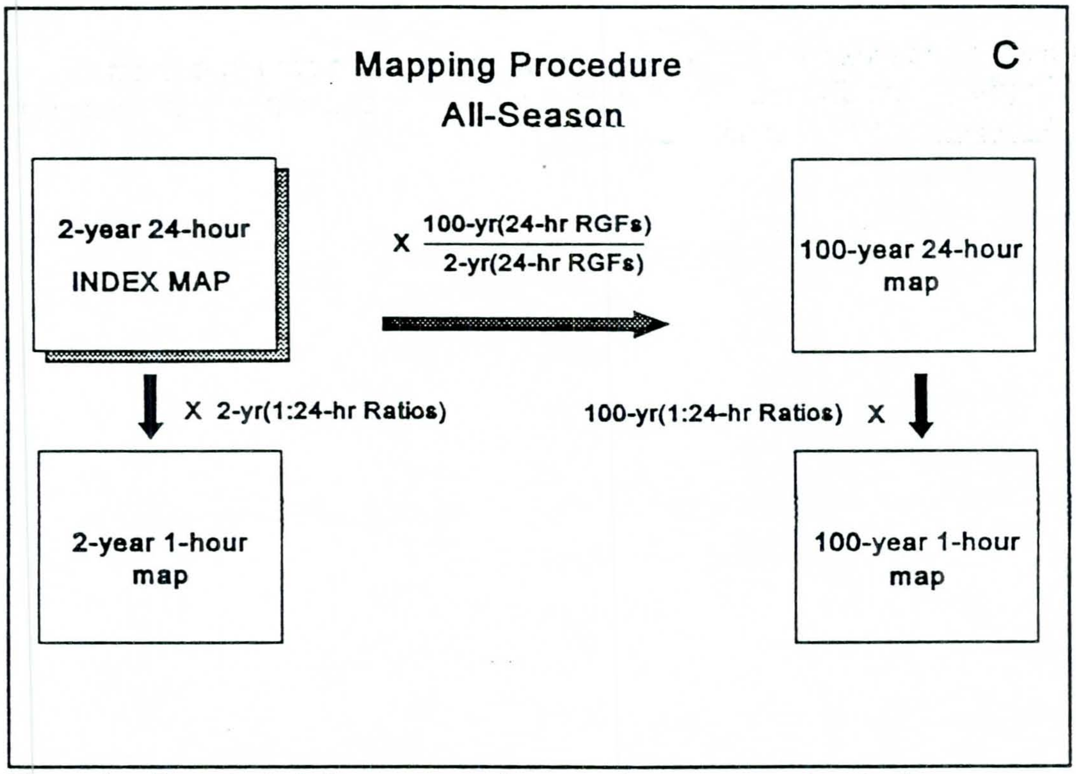

Figure 4c. *Flow chart of all-season mapping procedure, process c (see text).*

And so... Evaluation of the three processes is proceeding and includes, but is not limited to, spatial analysis, comparisons with station data, and comparisons with NOAA Atlas 2. As soon as the final determination is made on the analytic process for the 100-year, 1-hour map, production of other durations and return frequencies will proceed quickly.

Dataset Comparisons with NOAA Atlas 2

The Semiarid study used more stations and many more years of record than were available to NOAA Atlas 2 (Miller et al 1973). Many of the new stations provide information in critical areas, where no data were available to NOAA Atlas 2, including SNOw TELemetry (SNOTEL) stations at higher elevations and data from Mexico for continuity along the southern border of the study area. Table 2a shows an increase of 28 hourly, 178 daily, 122 SNOTEL, and 108 Mexican for a total of 436 additional stations for Mexico and the four states of Arizona, Nevada, New Mexico, and Utah. (As the Semiarid study includes only the southeastern part of California, it is not possible to make a direct comparison of California stations to NOAA Atlas 2). Table 2b shows the numbers of stations by state. Of the 436 additional stations, 230 are either SNOTEL or Mexican, leaving a net increase of National Climatic Data Center (NCDC) stations of 206 stations, spread out over four states.

However, if one looks at years-of-record, the differences are more dramatic. Figures 5a (daily) and 5b (hourly) show the number of stations and their record lengths for NOAA Atlas 2 and the Semiarid study. Many of the daily stations in Figure 5a are the same, but now have 30 more years of record. For NOAA Atlas 2, over 30 percent of the stations had less than 20 years, and nearly one-half (47.4 percent) had less than 25 years. Many of these same stations provided the Semiarid study with over 40 years of observations. The longest daily records in NOAA Atlas 2 were 65-69 years, whereas, in the Semiarid study the longest records were 105-109 years. Although the number of hourly stations (Figure 5b) increased by only 28, they show a similar increase in record length (from 20-24 years to 45-49 years).

SEASONAL ANALYSIS

Seasonal information will also be included in the final report. Seasonal maps will be based on the ratio of the cool (warm) season to the all-season maps for 1-hour, 6-hour, and 24-hour durations. In addition, ratio maps of cool (warm) season to all-season values for 2-, and 4-day durations (2-year and 100-year) will be included. The seasonality for longer duration (7- to 60-day) events will be shown graphically.

Two-year, 24-hour Seasonal Maps

Figure 6a is an all-season, 2-year, 24-hour map of the California/Arizona border region of the Semiarid study. The values are L-moment station values in inches. Seasonal 2-year, 24-hour ratio maps of the same area are shown in Figures 6b and 6c. Figure 6b is a plot of ratios of cool season to all-season; Figure 6c is warm season to all-season. At first glance one may wonder why the summer and winter ratios do not add up to 1.00; and the answer is that three separate datasets are derived from the initial data record. If, for example, a station has 45 years of data; then the partial duration series has the top 45 values for the all-season series, and the top 45 values for each season (cool or warm) alone. If one season predominates, then its values will be close to the all-season, and the ratios will be near 1.00 in one season and low in the other. If the seasons are similar in their distribution of extremes then the ratios will vary

Table 2a.

Comparison of NOAA Atlas 2 and Semiarid Study

Hourly	NOAA Atlas 2	Semiarid	Increase
Arizona	38	42	4
Nevada	38	41	3
New Mexico	71	81	10
Utah	33	44	11
Total	**180**	**208**	**28**

Daily	NOAA Atlas 2	Semiarid	Increase
Arizona	191	267	76
Nevada	49	91	42
New Mexico	210	212	2
Utah	113	171	58
Total	**563**	**741**	**178**

SNOTEL	
Arizona	14
Nevada	27
New Mexico	13
Utah	68
Total	**122**

Mexico	
Baja	48
Sonora	39
Chihuahua	21
Total	**108**

Table 2b.

Comparison Summary of NOAA Atlas 2 and Semiarid Study

	NOAA Atlas 2	Semiarid	Increase
Hourly	180	208	28
Daily	563	741	178
SNOTEL	0	122	122
Mexico	0	108	108
Total	**743**	**1179**	**436**

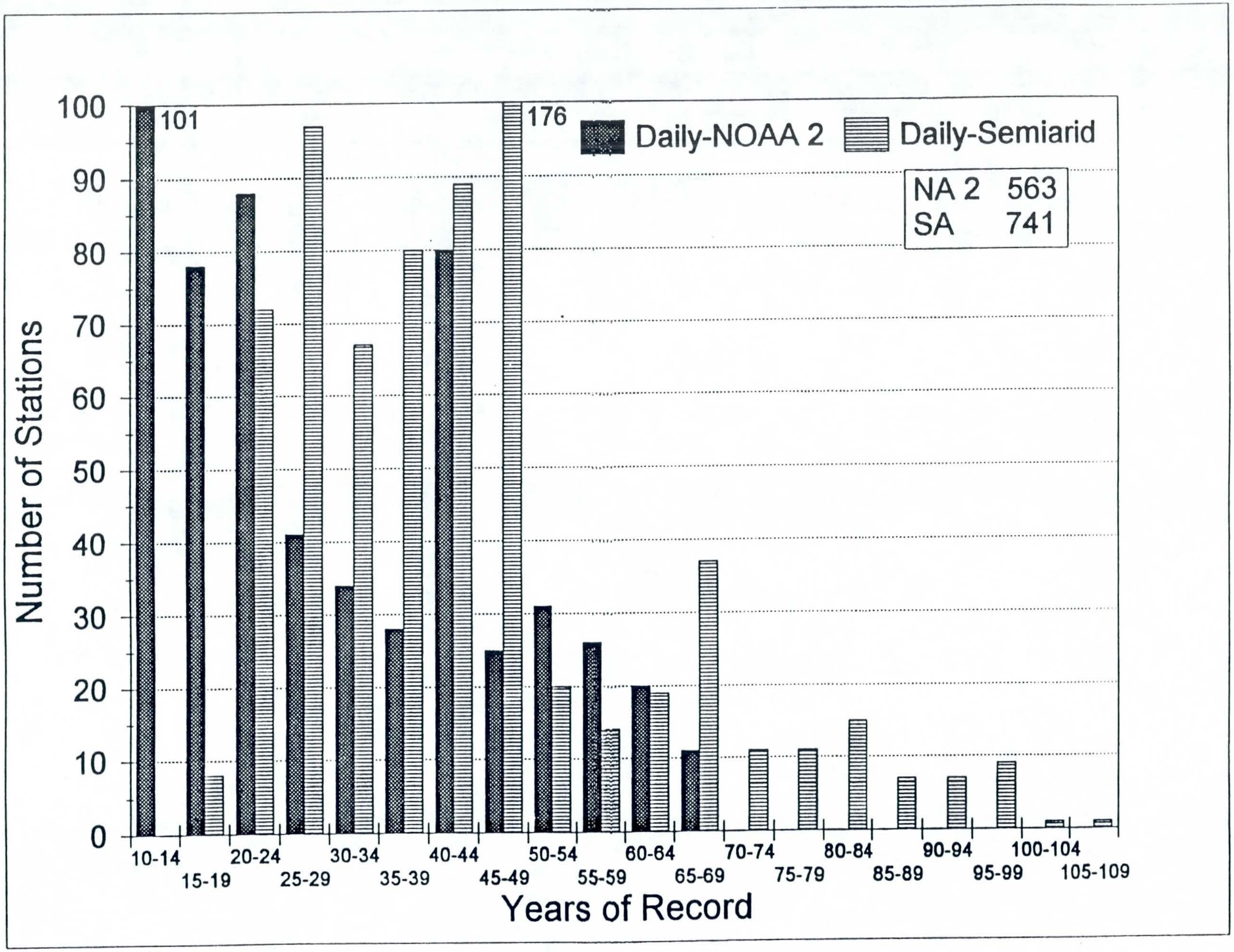

Figure 5a. *Comparison of NOAA Atlas 2 and Semiarid daily stations, by years of record.*

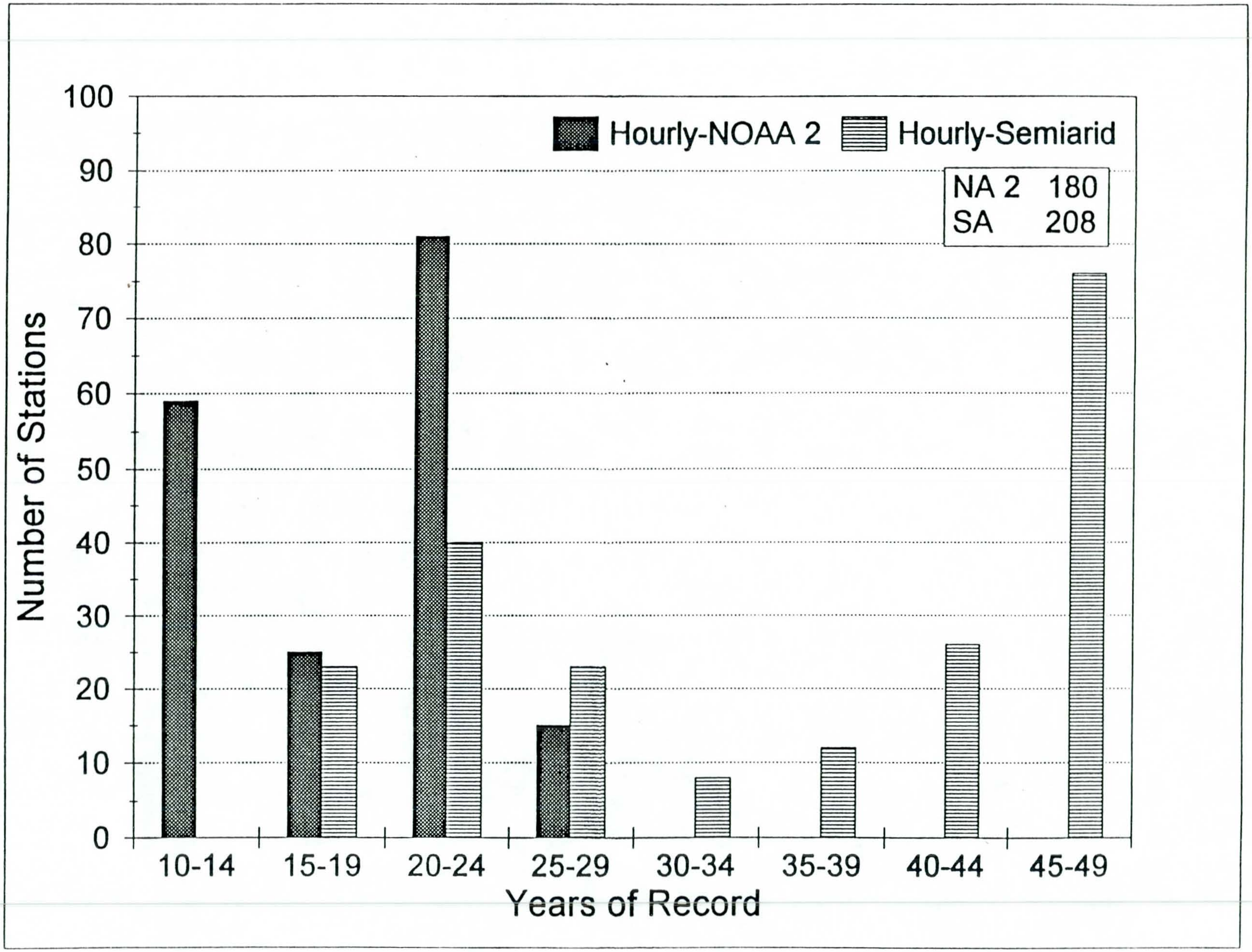

Figure 5b. *Comparison of NOAA Atlas 2 and Semiarid hourly stations, by years of record.*

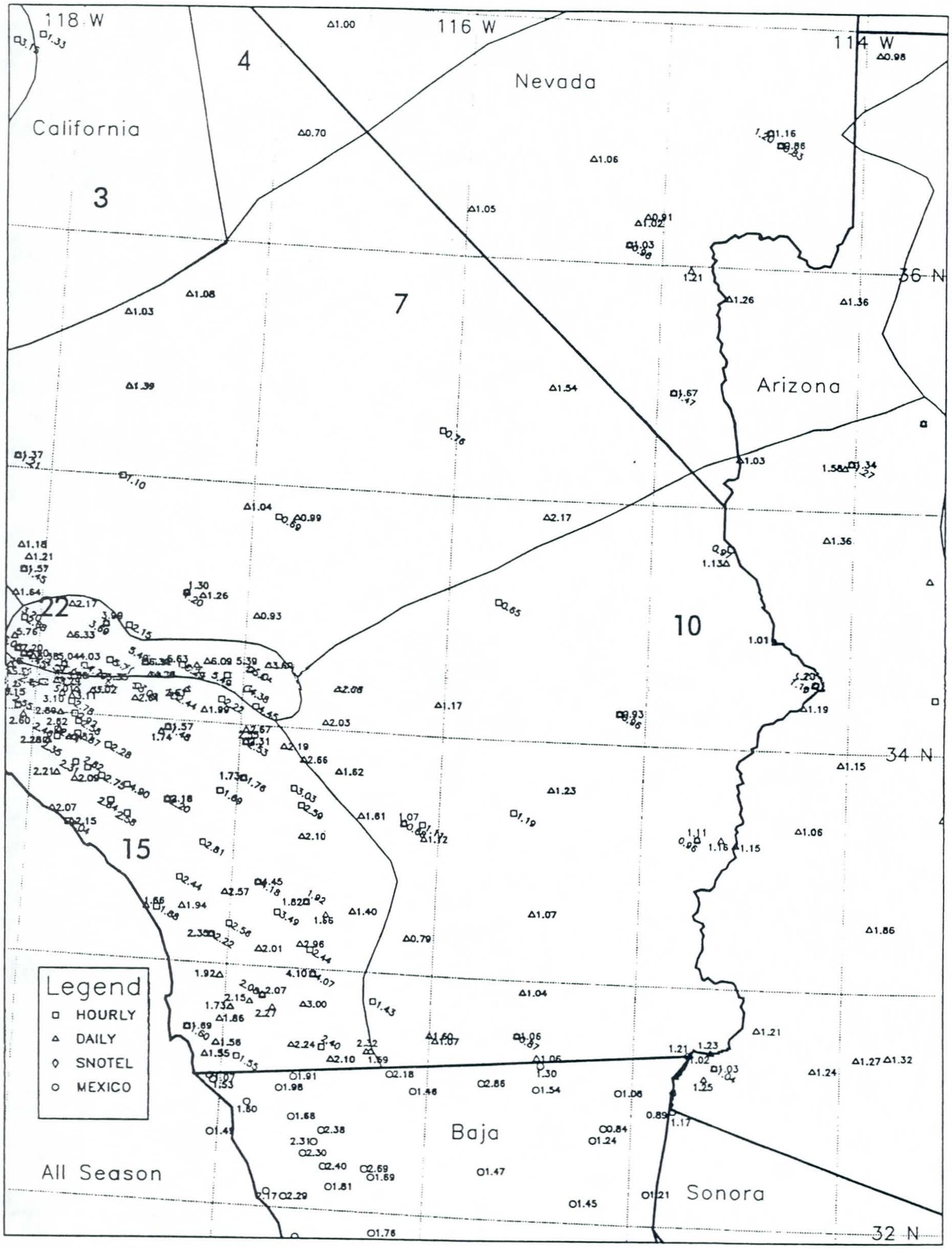

Figure 6a. *2-year, 24-hour all-season L-moment values. (inches)*

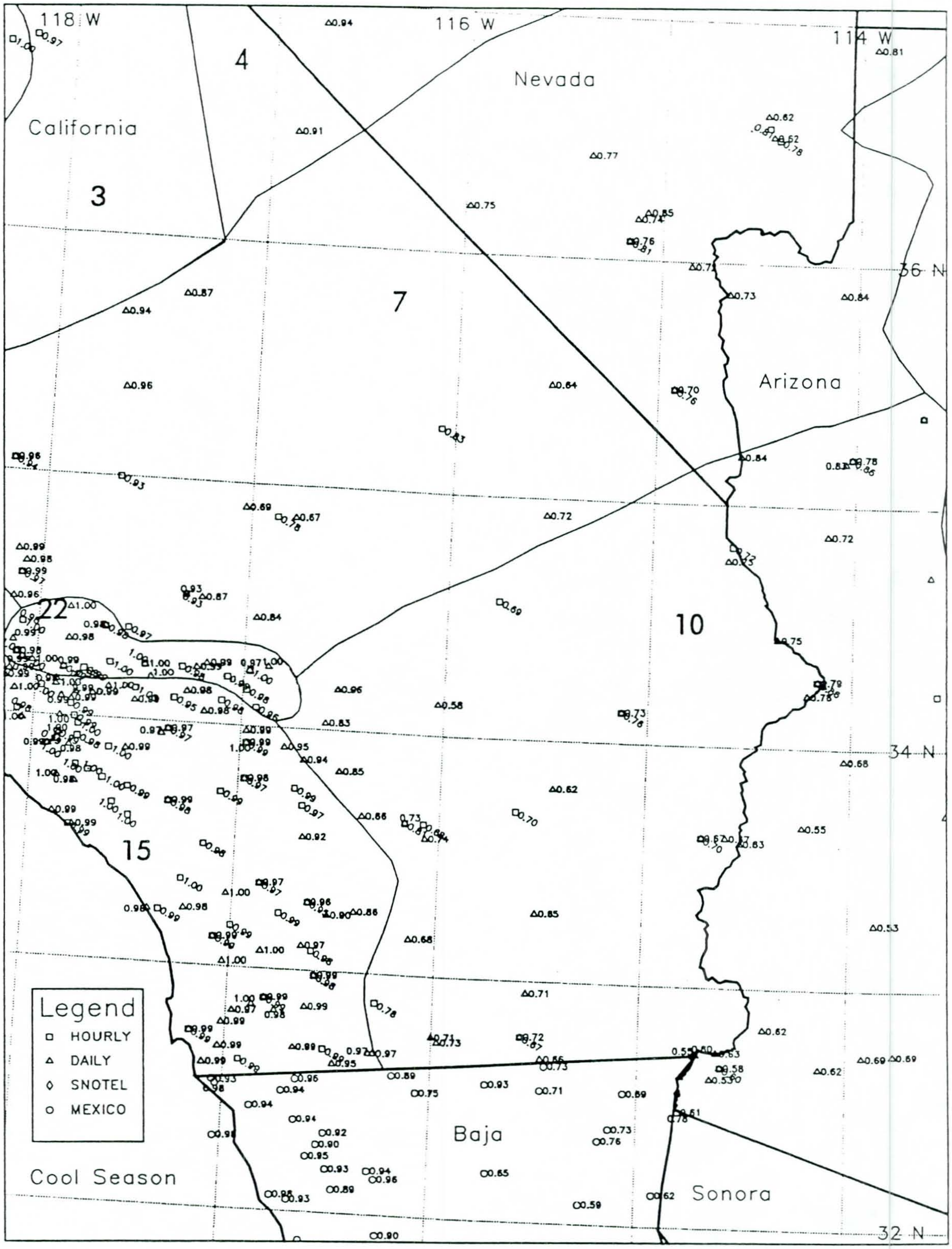

Figure 6b. *Ratios of 2-yr, 24-hr cool season to 2-yr, 24-hr all-season precipitation frequencies.*

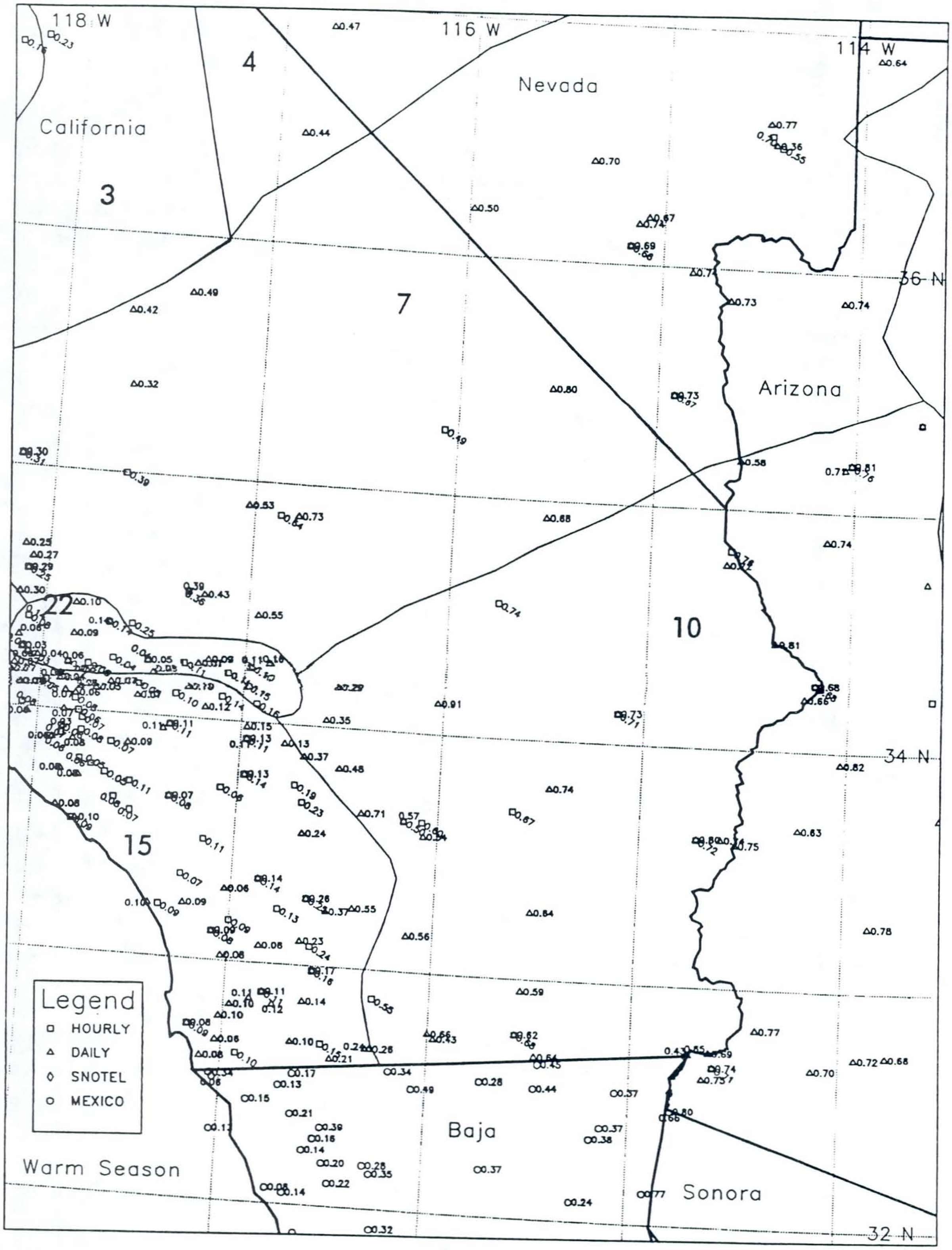

Figure 6c. *Ratios of 2-yr, 24-hr warm season to 2-yr, 24-hr all-season precipitation frequencies.*

around middling values. Region 15 in southern California is an excellent example of a climate where cool season precipitation predominates. The cool season ratios to all-season are from 0.98 to 1.00, and the warm season values are 0.06 to 0.14. In contrast, the desert sections east of the Sierra in southeastern California and western Arizona have similar ratios summer and winter, varying around 0.58 to 0.86, with summer slightly higher in some areas. As an example, there is a California station shown in Figure 6a, directly east of the Region Number **15**, with a 2-year 24-hour all-season value of 2.81 inches. For the same station, the cool season ratio is 0.98 (Figure 6b), and the warm season ratio is 0.11 (Figure 6c). Multiplying the all-season value of 2.81 inches, one can obtain:

2-year, 24-hour cool season = (2.81) x (0.98) = 2.75 inches
2-year, 24-hour warm season = (2.81) x (0.11) = 0.31 inches.

Seasonality for Long Duration Events

For 7-, 10-, 20-, 30-, 45-, and 60-day durations, seasonality graphs, rather than seasonal maps will be included in the final report. Graphs for each region have been prepared depicting the percent of records exceeding all-season return frequencies, by month. Each graph includes the six standard return frequencies, 2-, 5-, 10-, 25-, 50-, and 100-years. Figures 7-9 are examples of the graphs for 7- and 45-day durations for Regions 13, 21, and 22. To prepare the graphs, data at each station were examined and the number of events exceeding the all-season L-moment value for each of the standard return frequencies was found. The output for every station in each region was then combined and sorted by month. For example, Figure 7a shows an example of the output for the 7-day duration for Region 13; the percentages for each return frequency do not add up to 100 percent, rather they represent the percent of total events exceeding the return frequency. The x-axis in Figures 7-9a (7-day) and 7-9c (45-day) represents the month in which the long-duration event began; whereas, in Figures 7-9b (7-day) and 7-9d (45-day) the x-axis represents the month in which the largest 1-day precipitation of the event occurred. These are all 13-month graphs, so January is repeated for continuity. The user can readily see the trends or differences for each month relative to the surrounding months.

As an illustration, Table 3a shows the data used for Figure 7d (Region 13, 45-day duration, month of maximum day). In Region 13, for example, 18.28% of all the events exceed the 2-year return frequency and occur in July. Only 1.42% of all events exceed the 100-year return frequency; September is the month with the most events exceeding the 100-year return frequency with 0.47 percent.

Theoretically, 50% of the events should exceed the 2-year L-moment value, 20% should exceed the 5-year value, 10% should exceed the 10-year value, 4% should exceed the 25-year value, 2% should exceed the 50-year value, and 1% should exceed the 100-year value (Lin and Vogel, 1993). Table 3b shows the 45-day output, sorted by

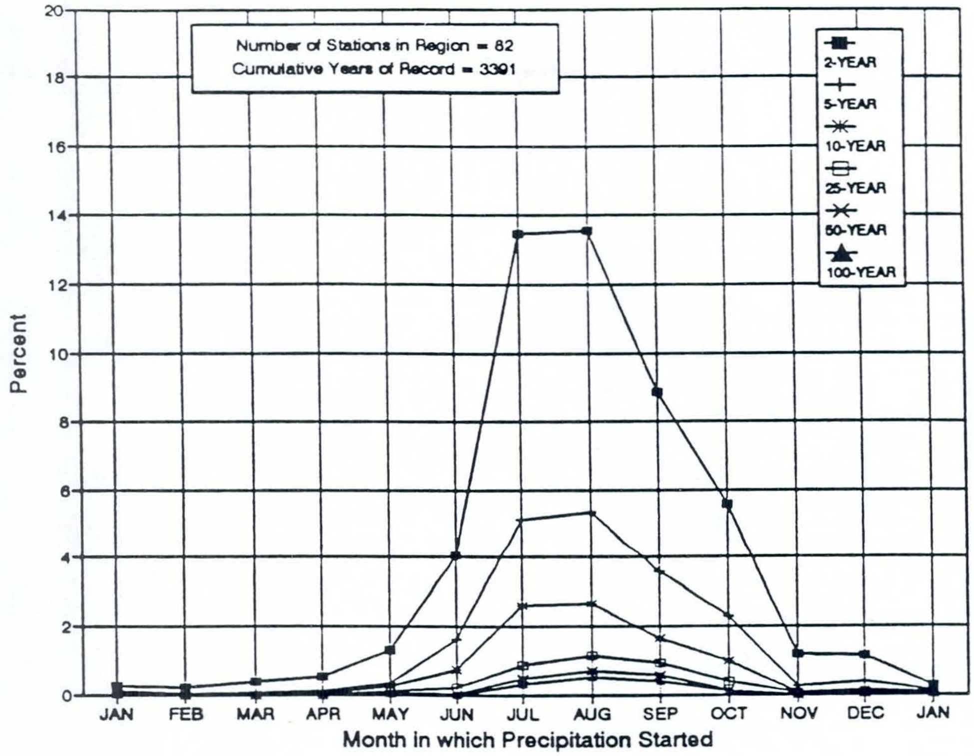

Figure 7a. *Region 13: percent of 7-day records exceeding return frequencies, by beginning month.*

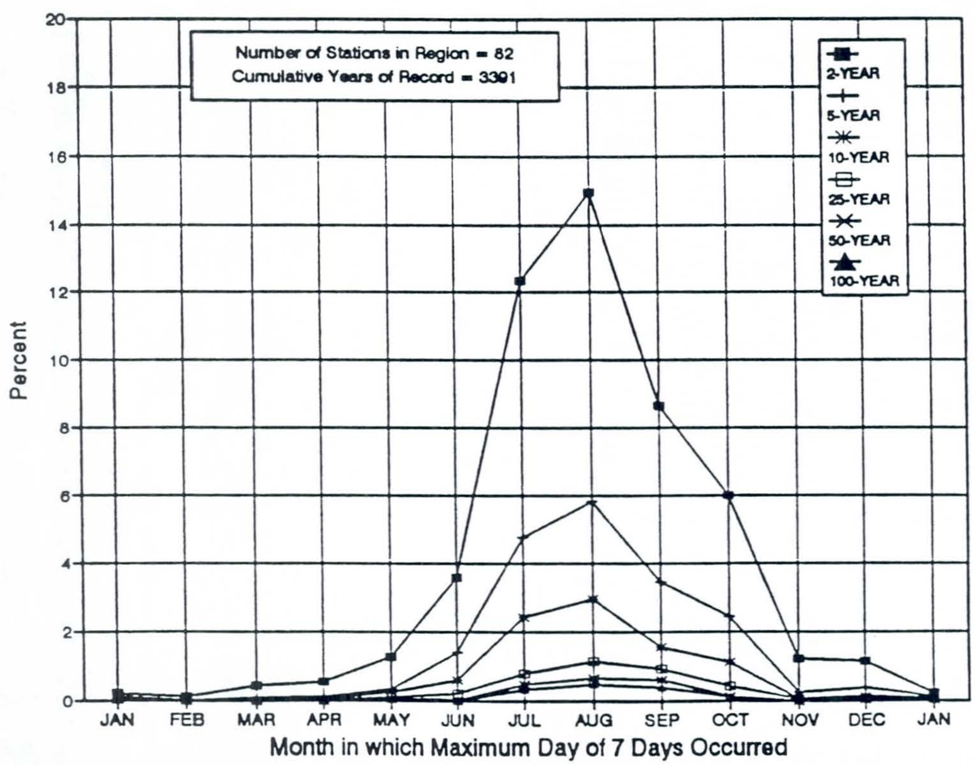

Figure 7b. *Region 13: percent of 7-day records exceeding return frequencies, by maximum month.*

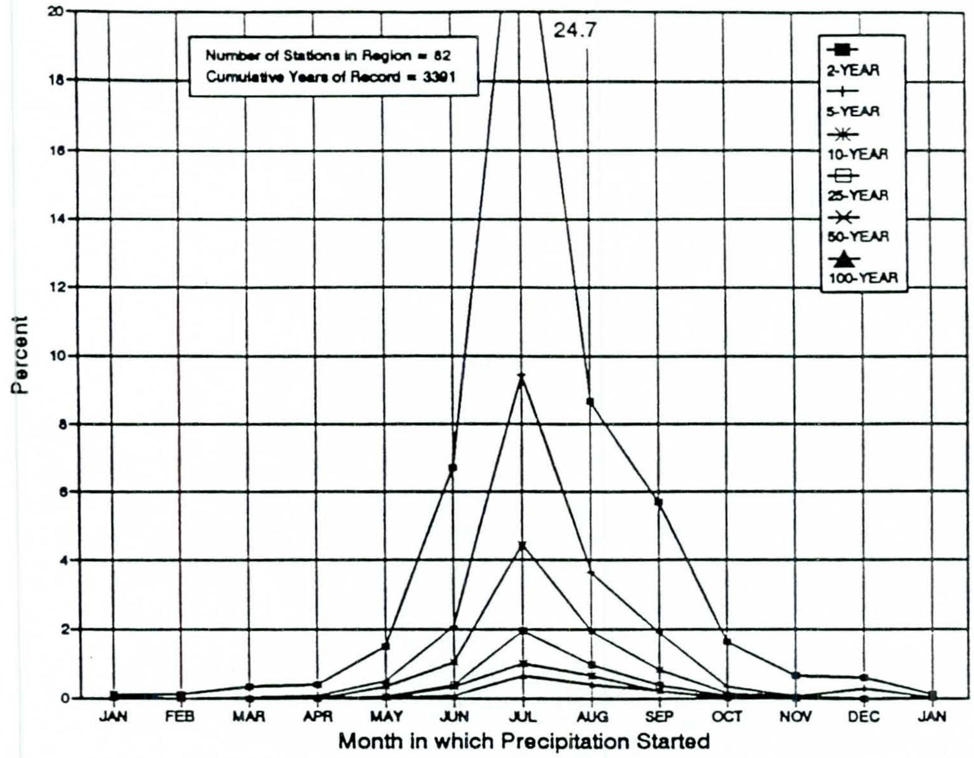

Figure 7c. *Region 13: percent of 45-day records exceeding return frequencies, by beginning month.*

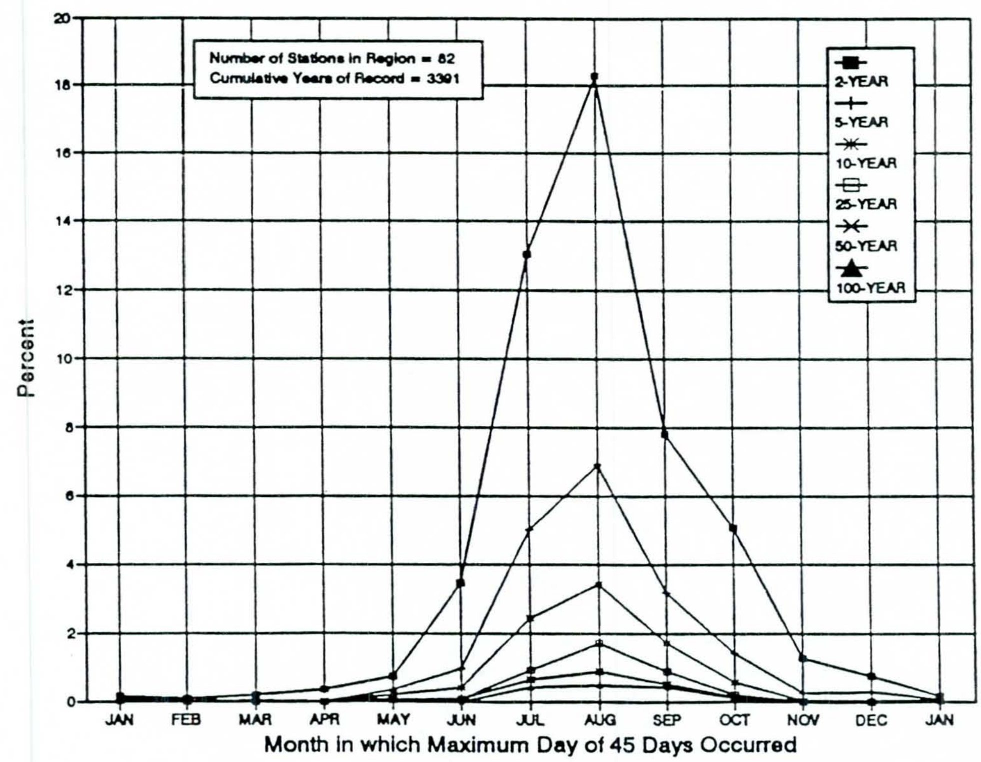

Figure 7d. *Region 13: percent of 45-day records exceeding return frequencies, by maximum month.*

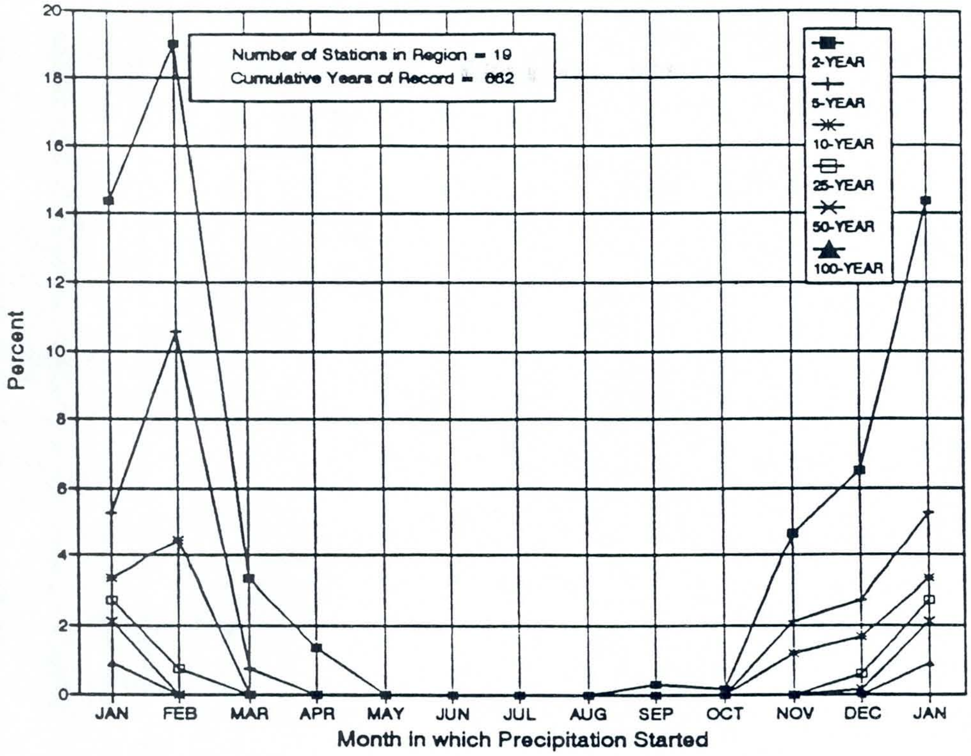

Figure 8a. *Region 22: percent of 7-day records exceeding return frequencies, by beginning month.*

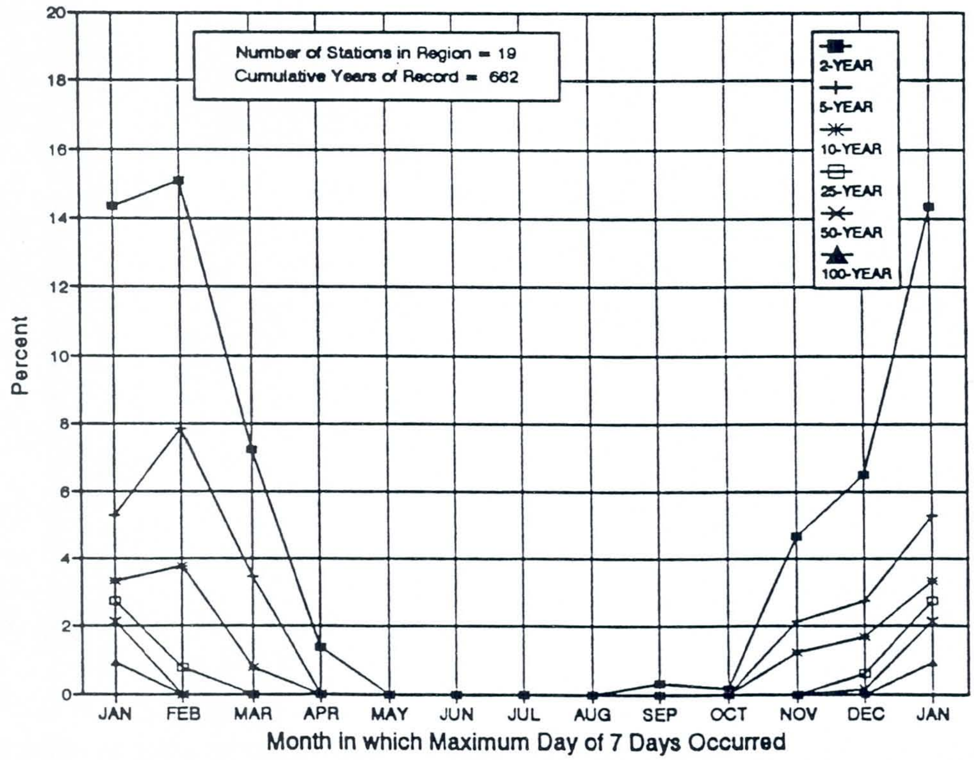

Figure 8b. *Region 22: percent of 7-day records exceeding return frequencies, by maximum month.*

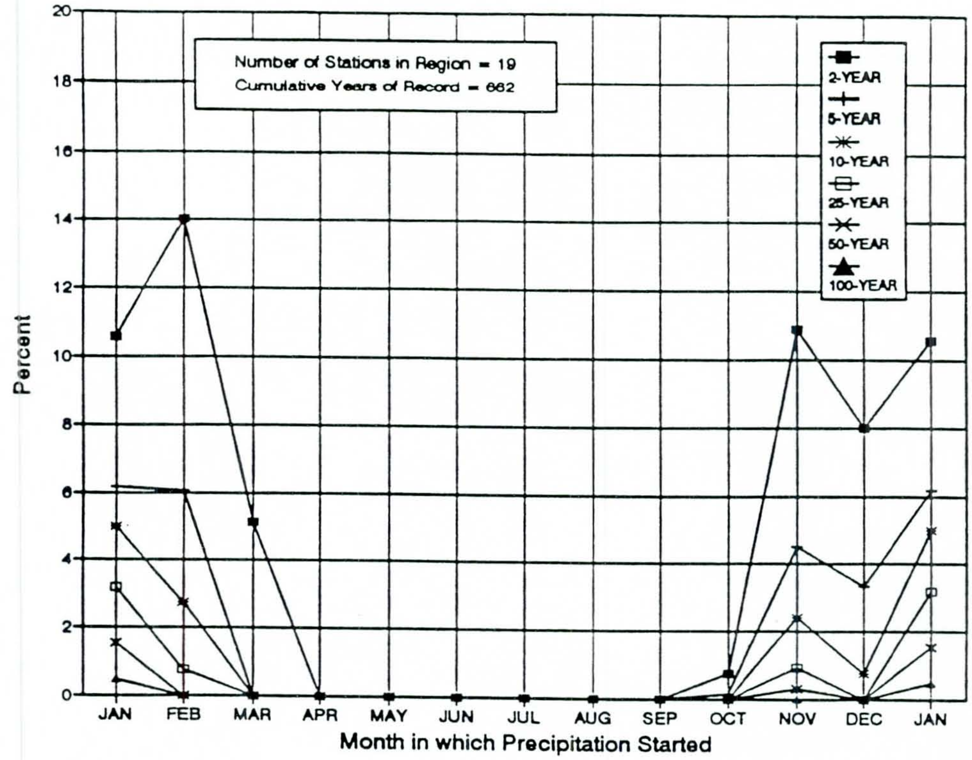

Figure 8c. *Region 22: percent of 45-day records exceeding return frequencies, by beginning month.*

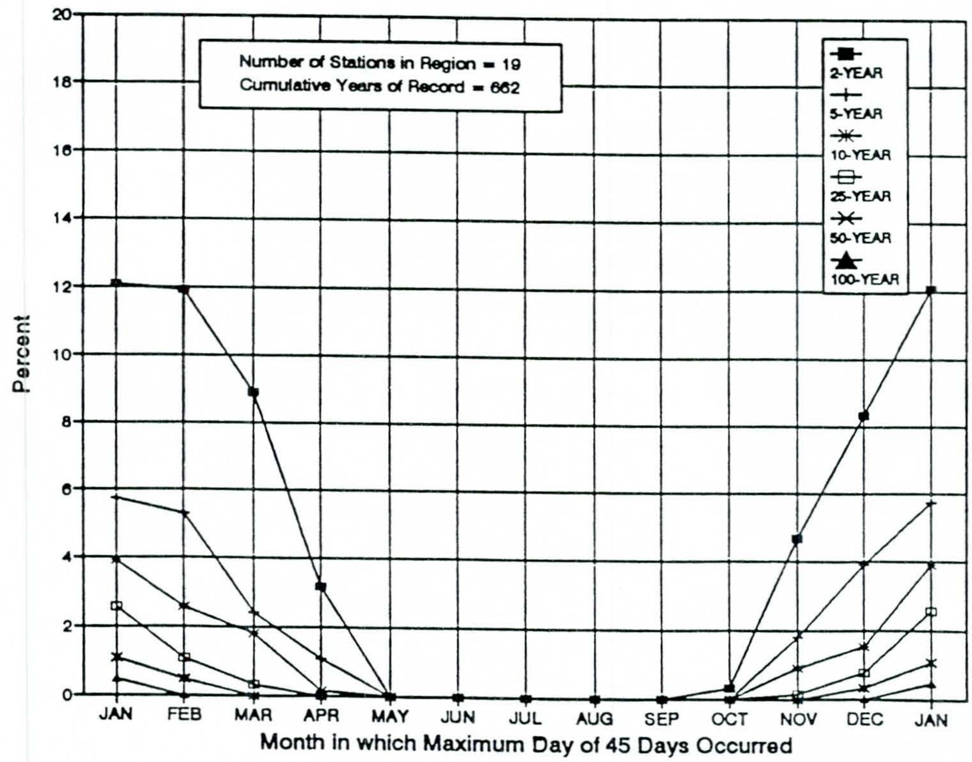

Figure 8d. *Region 22: percent of 45-day records exceeding return frequencies, by maximum month.*

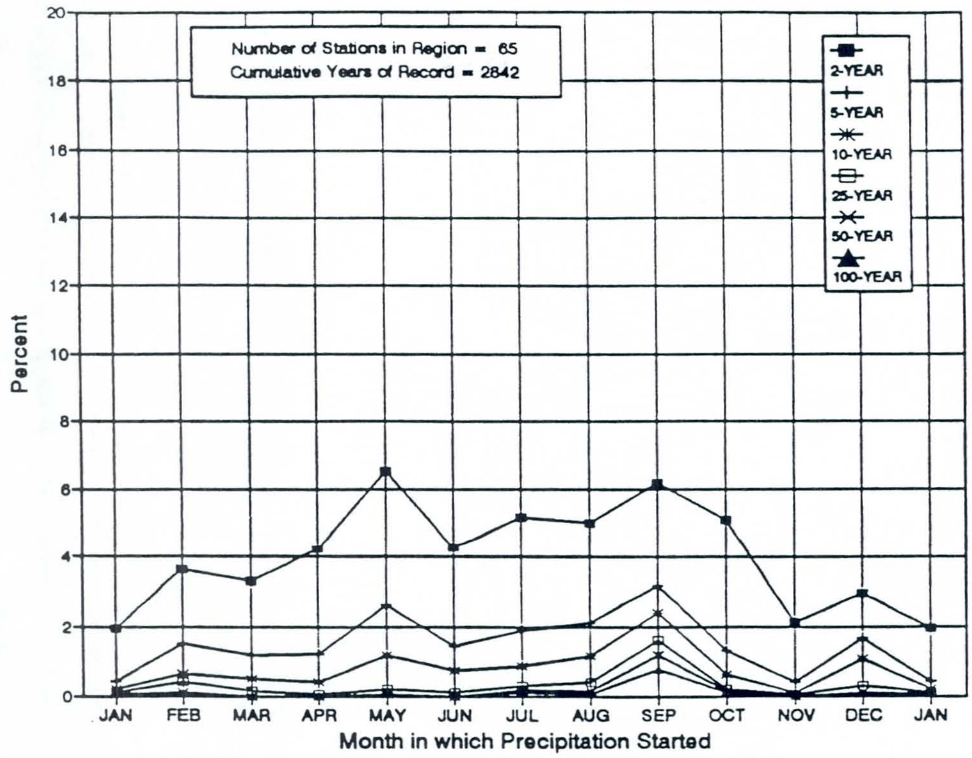

Figure 9a. *Region 21: percent of 7-day records exceeding return frequencies, by beginning month.*

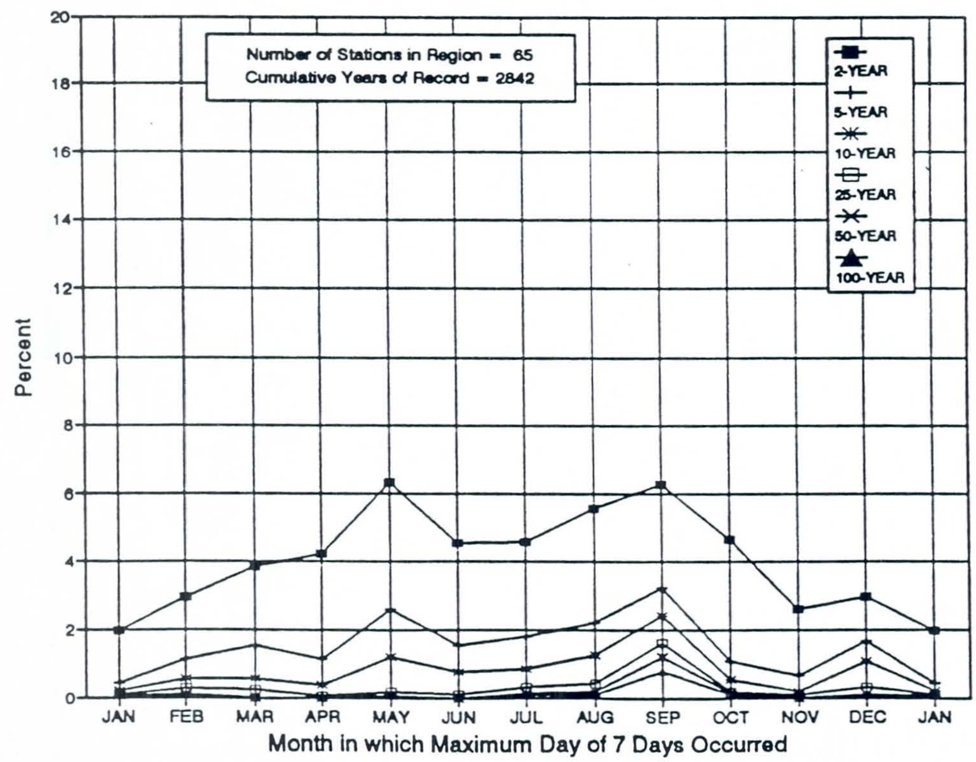

Figure 9b. *Region 21: percent of 7-day records exceeding return frequencies, by maximum month.*

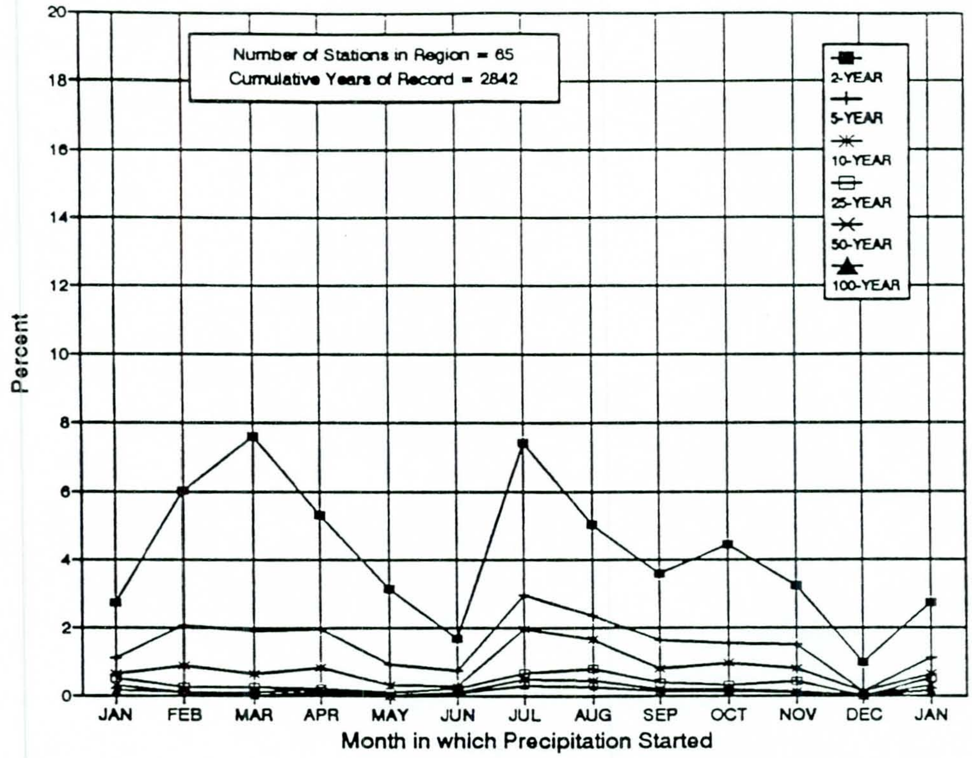

Figure 9c. *Region 21: percent of 45-day records exceeding return frequencies, by beginning month.*

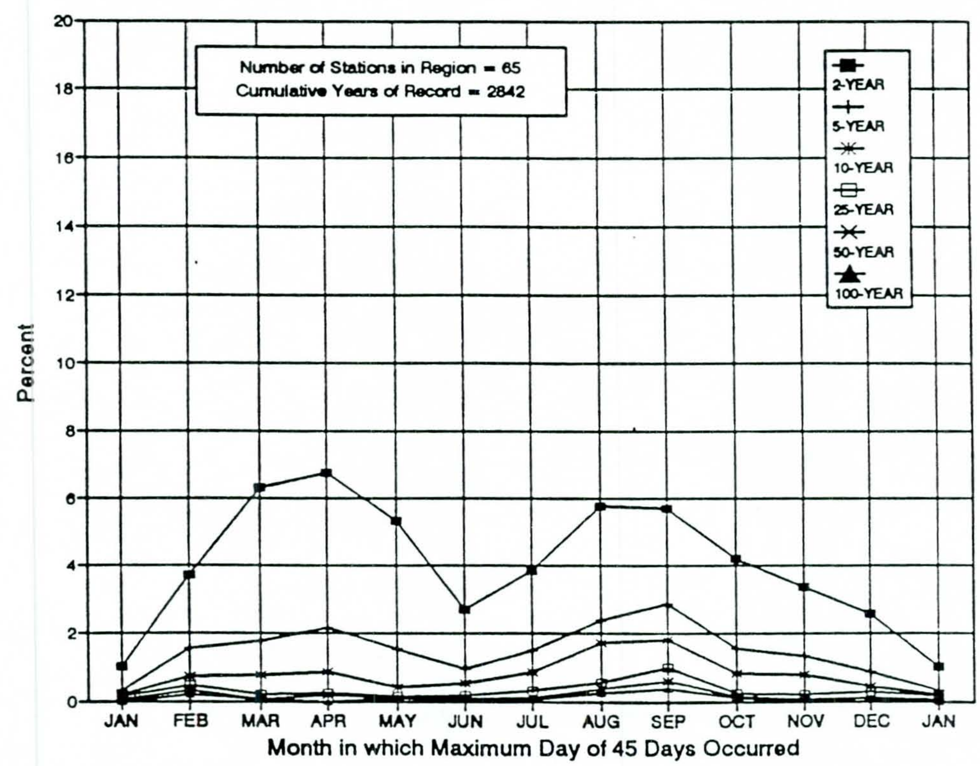

Figure 9d. *Region 21: percent of 45-day records exceeding return frequencies, by maximum month.*

Table 3a.

Region 13: Percent of 45-Day Records Exceeding Return Frequencies, by Max Month

MONTH	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
JAN	0.15	0.06	0.03	0.03	0.03	0.03
FEB	0.09	0.00	0.00	0.00	0.00	0.00
MAR	0.18	0.03	0.00	0.00	0.00	0.00
APR	0.32	0.00	0.00	0.00	0.00	0.00
MAY	0.71	0.32	0.18	0.06	0.03	0.03
JUN	3.45	0.97	0.38	0.09	0.09	0.00
JUL	13.06	5.01	2.42	0.91	0.62	0.38
AUG	18.28	6.90	3.42	1.71	0.88	0.47
SEP	7.81	3.16	1.71	0.88	0.50	0.41
OCT	5.07	1.42	0.56	0.18	0.12	0.09
NOV	1.27	0.24	0.03	0.00	0.00	0.00
DEC	0.74	0.27	0.03	0.03	0.00	0.00
JAN	0.15	0.06	0.03	0.03	0.03	0.03
TOTAL	51.14	18.37	8.76	3.89	2.27	1.42

Table 3b.

Percent of 45-Day Records Exceeding Return Frequencies, Maximum Month

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Region 1	51.17	19.17	9.66	3.59	2.34	1.52
Region 2	51.09	19.50	9.77	4.16	2.53	1.40
Region 3	50.63	19.98	9.41	3.30	1.55	1.07
Region 4	49.36	20.56	9.38	3.55	2.01	1.14
Region 5	50.07	19.06	8.43	4.07	2.14	1.10
Region 6	50.75	18.84	8.60	4.02	2.29	1.28
Region 7	49.96	19.73	9.07	3.46	1.66	0.86
Region 8	50.84	18.58	9.27	3.82	1.96	1.08
Region 9	50.65	19.54	9.87	3.73	1.96	0.98
Region 10	51.61	19.14	8.87	3.93	2.07	1.28
Region 11	49.16	20.43	9.90	3.86	2.00	0.62
Region 12	50.74	19.19	8.78	3.88	2.13	1.24
Region 13	51.14	18.37	8.76	3.89	2.27	1.42
Region 14	51.80	18.52	9.10	4.32	2.29	1.31
Region 15	50.04	20.57	11.93	3.79	1.04	0.28
Region 16	50.12	20.18	10.01	4.56	1.22	0.16
Region 17	49.89	20.89	10.34	4.11	1.79	0.95
Region 18	50.27	19.89	10.59	3.42	1.82	0.86
Region 19	48.97	21.24	10.62	3.24	1.18	0.59
Region 20	49.76	20.46	10.07	3.50	1.56	0.75
Region 21	51.27	18.68	9.78	3.98	2.04	1.13
Region 22	49.40	20.24	10.88	4.83	1.81	0.45
Region 23	50.37	19.89	9.74	4.02	2.22	1.48
Region 24	49.62	21.76	7.63	3.44	1.15	0.38
min	48.97	18.37	7.63	3.24	1.04	0.16
max	51.80	21.76	11.93	4.83	2.53	1.52
avg	50.36	19.77	9.60	3.85	1.88	0.97

maximum month, for all 24 regions. The all-season percentages for the 45-day duration shown in Table 3b are very close to the theoretical values in all of the regions. All the other durations (not shown) have percentages close to the theoretical values as well. This is another way of checking the final products.

Looking at the graphs, one can easily see when the wet and dry seasons occur. For example, Figures 7a-d show that most of the large precipitation events in Region 13 (central New Mexico) occur June through October, whether the duration of the event is 7 days or 45 days. For the 7-day duration, the months with the most events exceeding return frequencies are July and August, regardless if the data are sorted by the beginning month or maximum month. At the 45-day duration, however, the beginning month is much more likely to be July, while the maximum month is still spread over July and August. In contrast, Region 22 (southwest California mountains), Figures 8a-d, gets most of its significant precipitation from November through March, again without much variation between durations. Region 22 also has less variation than Region 13 between the beginning and maximum months. Region 22 is an example of an extreme summer minimum; no stations in the months of June, July, and August have ever recorded an event which exceeds the 2-year L-moment value.

Some of the regions do not have such pronounced wet and dry seasons. For example, Region 21 (western Utah), Figures 9a-d, has small precipitation maximums in the spring and the fall. In general, the events are spread over the entire year. The maximum and beginning months are almost identical in Region 21 at the 7-day duration, and even at 45-days there is little difference. As seen in all the graphs, the different return frequencies tend to track each other with precipitation maximums occurring in the same month whether it is the 2-year or 100-year return frequency.

A further study will examine how the precipitation occurs within the different durations. For example, what percentage of the precipitation tends to fall in the first few days, the middle, or in the last days of a 7-day duration event.

SECULAR TREND ANALYSIS

A trend analysis was performed on 25 long-term stations (those with at least 80 years of data) to determine if extreme precipitation events showed any increase or decrease over the data period in the Semiarid Southwest. The Friedman test was used to test for significant trends in the means and medians of annual maximum precipitation data over the 80-year period. The Friedman test is non-parametric and uses ranks as a means of detecting trends in data.

For the 25 stations scattered throughout the Semiarid region, means and medians of 24-hour maximum annual precipitation were computed for each of twenty-year periods: 1911-1930, 1931-1950, 1951-1970, and 1971-1990. The need for long-term stations (back to at least 1911) restricted the number of stations available for testing. However, because these stations were located throughout the study area, they provided a reasonable sample for statistical testing purposes. The Friedman test showed no secular trends in either the means or the medians.

A different set of 20-year periods, namely: 1921-1940, 1941-1960, and 1961-1980, was also analyzed to test "overlapping periods". Once again, the Friedman tests indicated no significant trends in either the mean or median 24-hour maximum annual precipitation.

There were 95 stations with continuous 24-hour maximum annual precipitation records going back to at least 1931. These stations were analyzed for trends using 10-year periods: 1931-1940, 1941-1950, 1951-1960, 1961-1970, 1971-1980, and 1981-1990. As expected, there were many more "10-year period" stations than "20-year period" stations. Due to computer software limitations, all "10-year" stations could not be tested collectively. However, the stations used were varied and the Friedman tests repeated for various subsets of the data.

With the exception of one region, the Friedman tests on the means and medians indicated no significant trends in the data for the period 1931-1990. Therefore, it can be assumed that the data are homoscedastic, and that there are no significant, temporal variations in the occurrence of extreme precipitation events in the southwestern United States.

LOCAL STORM ANALYSIS

Albuquerque, New Mexico

The Albuquerque Metropolitan Arroyo and Flood Control District (AMAFCA), in cooperation with the U.S. Geological Survey (USGS), has a network of precipitation and stream-gaging stations in the Albuquerque area. The stations are shown on a smoothed elevation map of the Albuquerque area in Figure 10. Table 4 lists the AMAFCA raingages, station numbers, locations, period-of-record, and elevations.

AMAFCA and USGS has provided digital 5-minute data from 1978-1992 for the 12 stations shown in Figure 10. Using these data and the hourly partial duration series for the Albuquerque Weather Service Forecast Office (WSFO), 29-0234, a list of local storms has been prepared (Table 5). The list includes those dates that are in the 3-hour, 6-hour, and/or 24-hour partial duration series for Albuquerque, and for which there are data from the AMAFCA network. Also given in Table 5 are the Albuquerque values for 3, 6, and 24 hours. The last column indicates the availability of n-minute data for the storm date. Seven storms have been partially analyzed, and the times are given in Table 5.

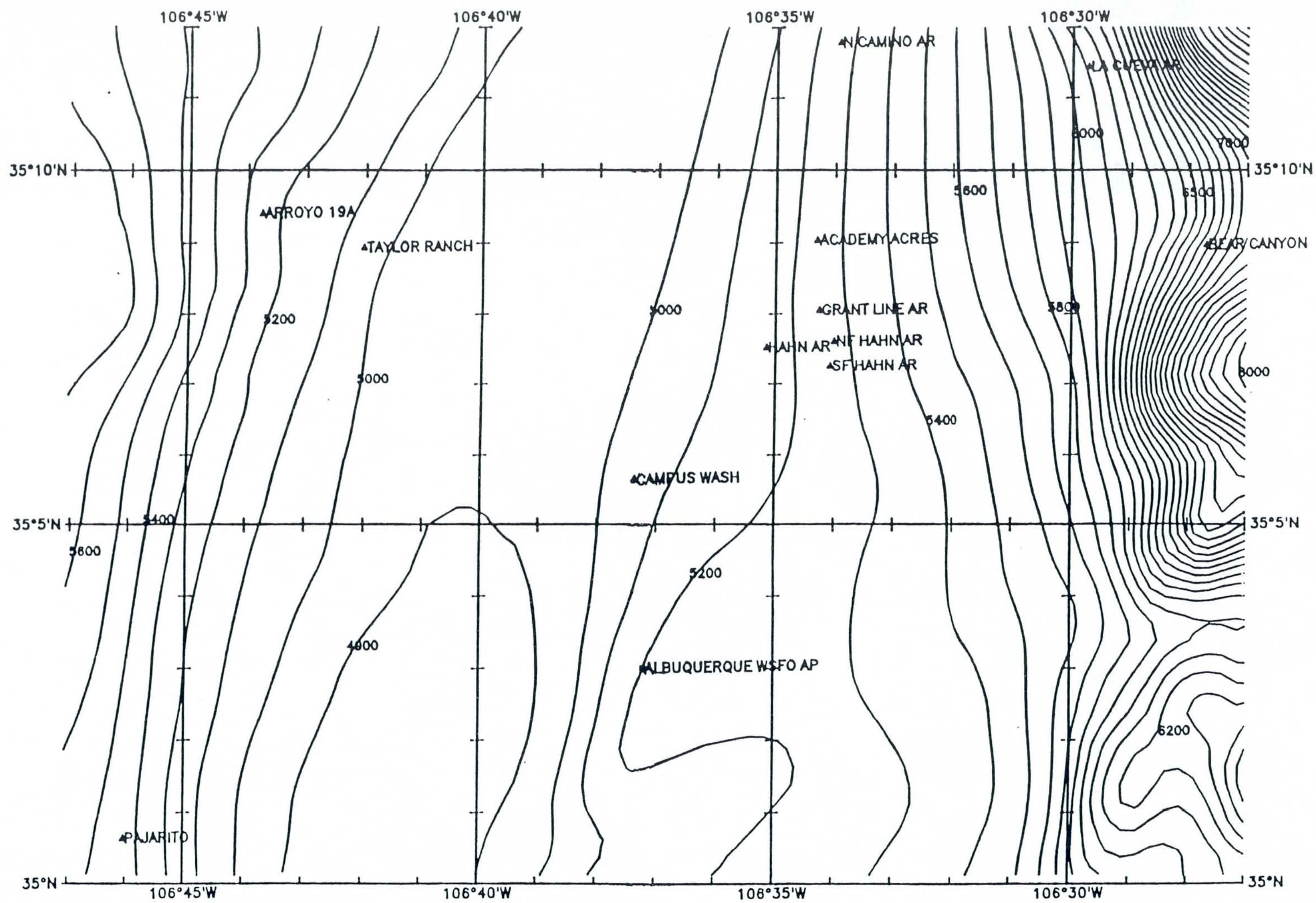

Figure 10. *AMAFCA station locations and topography of area in feet.*

Table 4.

AMAFCA Stations

ID	NAME	LAT	LON	POR	ELEV
700	CAMPUS WASH	35.09	106.62	7/82-9/92	5050
838	SF HAHN ARROYO	35.12	106.57	10/78-9/92	5298
839	NF HAHN ARROYO	35.13	106.57	6/79-9/92	5286
840	HAHN ARROYO	35.13	106.59	10/78-9/92	5190
860	GRANT LINE ARROYO	35.13	106.57	7/76-9/92	5302
880	ACADEMY ACRES	35.15	106.57	7/76-9/92	5306
890	LA CUEVA ARROYO	35.19	106.50	7/77-9/92	6100
914	N CAMINO ARROYO	35.20	106.57	6/79-9/92	5364
935	ARROYO 19A	35.16	106.73	6/77-9/92	5328
936	TAYLOR RANCH	35.15	106.70	8/78-9/92	5102
5330	PAJARITO	35.01	106.77	10/81-9/89	5325
4330	BEAR CANYON	35.15	106.46	7/84-8/92	6900

For an example, data for two local storms are given in Tables 6a and 6b. The tables include station numbers, beginning and ending times, storm totals, the most intense 5- and 30-minute and 3- and/or 6-hour totals, as appropriate. The last line in the tables contains the Albuquerque 3-, 6-, and 24-hour values for the storm. The two storms are quite different. In the 14 August 1980 storm (# 29101), most of the AMAFCA stations record far more rain (up to a storm total of 4.04 inches) than the Albuquerque WSFO. From the times shown in Table 5b, it is apparent that this is a 6-hour storm. A decaying hurricane/tropical storm (Allen) from the Gulf of Mexico provided much of the moisture and energy for this event. In contrast, in the 8 September 1980 storm (# 29102) the network gages recorded only small amounts of rain (0.10 to 0.38 inches). However, the Albuquerque WSFO recorded 0.44 inches, higher than any in the network; but it was only a fraction of the 24-hour-total amount of 1.06 inches, most of which was spread out over the following 18 hours (on 9 September 1980). The synoptic conditions associated with this event included an upper-level trough off southern California and widespread moisture over the Southwest from the Pacific and the Gulf of California.

Further local storm investigations will include, but are not limited to, mass curves, spatial analysis, and the synoptic meteorology of the storms.

Table 5.

Albuquerque, New Mexico (29-0234) Local Storms
Storm Number: NM=29 AMAFCA=100 series

AMAFCA/USGS Network for Albuquerque, New Mexico						
Storm	Date	Time Local	3 hr	6 hr	24 hr	nm
29100	6/29/78	0130-0830	0.68	0.90	0.93	X
29101	8/14/80	0300-0900	1.34	1.72	1.75	
29102	9/8/80	2045-2400	-	-	1.06	
29103	10/2/81	1400-2400	0.64	-	1.23	
29104	6/24/83	1400-2000	1.02	1.04	1.09	X
29105	8/7/84	2100-2400	0.91	0.97	0.97	X
29106	10/15/84	1215-1905	-	-	1.25	
29107	4/28/85		0.66	0.92	1.17	
29108	10/10/85		-	-	0.98	
29109	8/10/86		0.94	0.94	0.94	
29110	3/31/88		-	-	1.11	
29111	7/9/88		0.84	0.96	1.00	
29112	8/9/88		1.39	1.39	1.39	X
29113	4/25/90		-	-	0.89	
29114	7/14/90		1.00	1.01	1.15	
29115	5/21/91		0.66	0.82	1.02	
29116	7/24/91		1.03	1.03	1.23	X
29117	11/15/91		0.72	1.08	1.67	
29118	8/9/79		0.78	0.78	-	
29119	6/17/86		0.74	0.74	-	X
29120	8/24/87		0.72	0.74	-	X
29121	8/6/92		0.68	0.81	-	X
29122	8/17/81		0.64	-	-	X
29123	7/20/85		0.68	-	-	
29124	9/1/88		0.70	-	-	

Table 6a.

Albuquerque, New Mexico (29-0234) Local Storms, AMAFCA Network

Storm 29101 1980 8/14/80									
Stn	beg	end	dur	**storm total**	top 5m	top 30m	3 hr	6 hr	24 hr
700	-								
838	0335	0845	5h10	**2.05**	0.17	0.68		2.05	
839	0320	0835	5h15	**2.37**	0.17	0.90		2.37	
840	0355	0825	4h30	**1.84**	0.24	0.69		1.84	
860	0315	0855	5h40	**2.02**	0.17	0.74		2.02	
880	0105	0825	7h20	**2.25**	0.23	0.63		2.12	
890	0005	0845	8h40	**3.31**	0.20	0.76		3.25	
914	0150	0850	7h	**4.04**	0.30	0.95		4.01	
935	0410	0855	4h45	**0.20**	0.03	0.07		0.20	
936	0405	0905	5h	**0.50**	0.09	0.21		0.50	
5330	-								
4330	-								
0234	0200	0800	6h	**1.72**			1.34	1.72	1.75

Table 6b.

Albuquerque, New Mexico (29-0234) Local Storms, AMAFCA Network

Storm 29102				1980		9/8/80			
Stn	beg	end	dur	**storm total**	top 5m	top 30m	3 hr	6 hr	24 hr
700	-								
838	2045	2400	3h45	**0.19**	0.06	0.13	0.16	0.19	
839	2100	2200	1h	**0.10**	0.02	0.02	0.10		
840	2035	2240	2h5	**0.34**	0.07	0.22	0.34		
860	2100	2205	1h5	**0.14**	0.07	0.10	0.14		
880	2045	2200	1h15	**0.38**	0.10	0.19	0.38		
890	-								
914	-								
935	-								
936	-								
5330	-								
4330	-								
0234	2000	2400	4h	**0.44**			-	-	1.06

SUMMARY

Definition of the mapping process is nearing completion. As soon as the evaluation of the 100-year, 1-hour mapping has been satisfactorily completed, production of all return-frequency maps should proceed quickly. Seasonal analysis is complete for long-duration events and proceeding for the shorter duration events. A trend analysis has been done, and no secular trends were found in the data. Spatial analysis is being done in conjunction with local storm studies using the Albuquerque, New Mexico local raingage network.

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