Precipitation-Frequency Relations on the Pajarito Plateau and in the Eastern Jemez Mountains, New Mexico, and Examples of Extreme or Flood-Producing Storms

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PRECIPITATION-FREQUENCY RELATIONS ON THE PAJARITO PLATEAU AND IN THE EASTERN JEMEZ MOUNTAINS, NEW MEXICO, AND EXAMPLES OF EXTREME OR FLOOD-PRODUCING STORMS

ABSTRACT

An analysis of annual maximum precipitation amounts for durations of 15 min to 24 hr was used to revise precipitation-frequency relations on the Pajarito Plateau and in the eastern Jemez Mountains, New Mexico, using a longer period of record and more stations than were available in previous studies. This analysis indicates that annual maximum precipitation amounts for durations of 2 hr to 24 hr and return periods of 2 yr to 100 yr increase gradually from east to west across the study area. No sharp increase in precipitation occurs where the topography steepens in the eastern Jemez Mountains, and precipitation-distance regressions provide better predictive tools than precipitation-elevation regressions. Little or no east-to-west increase was found for 15-min and 30-min precipitation amounts, suggesting that the annual probability of exceeding specific 15-min or 30-min rainfall amounts is similar across the study area regardless of elevation or proximity to the range crest. The contrast in precipitation-frequency relations between durations of < 1 hr and > 1 hr is explainable by an increasing probability of multiple rainfall cells occurring in a 2-hr to 24-hr period to the west. The precipitation-frequency relations developed in this study are generally similar to published relations based on data from a larger region, although they differ from some previous local studies. Specifically, the results of this study indicate that precipitation amounts for a range of durations and return periods have been underestimated in the eastern part of the study area and overestimated in the western part in some previous studies, in turn affecting modeled estimates of runoff, erosion, and sediment transport. Recorded precipitation amounts in the study area that exceed estimated 50-yr events for durations ranging from 15 min to 24 hr have occurred in convective storms during the months of June through September, and convective storms have also been responsible for the largest recorded floods. Maximum 15-min to 1-hr precipitation amounts occurred in relatively short storms that lasted 1-2 hr, and maximum amounts for durations of 2-24 hr occurred in longer storms or during periods that included multiple discrete rainfall peaks. The maximum 15 min to 1 hr rainfall amounts recorded in the study area occurred on July 2, 2001, in an area that had experienced high burn severity in the Cerro Grande fire; the 30-min intensity at one gage had an estimated return period of about 90 yr, and the unusually high intensity nature of rainfall within this storm contributed to the magnitude of downstream flooding and associated damage.

INTRODUCTION

The eastern Jemez Mountains of northern New Mexico includes the headwaters of streams that flow through the Los Alamos National Laboratory (LANL) and the city of Los Alamos, both located on the Pajarito Plateau. The characteristics of extreme precipitation events in these areas have a strong influence on runoff and erosion, and estimates of rainfall characteristics can be applied to a variety of problems. For example, estimates of rainfall amounts for different return periods in the eastern Jemez Mountains (the Sierra de los Valles) and the Pajarito Plateau have been used to model potential flood discharges (Lane et al., 1985; McLin, 1992; BAER, 2000; McLin et al., 2001a, 2001b; URS, 2001; Wright Water Engineers, 2003), sediment transport

(Lane et al., 1985; Canfield et al., 2001; Wilson et al., 2001a; Lane, 2002; Malmon, 2002; Malmon et al., 2003), and hillslope erosion (Wilson et al., 2001b). Knowledge of long-term rainfall characteristics can also be applied to estimating the return periods of specific historic precipitation events and hence understanding which events are common and which are unusual. Understanding rainfall characteristics in the eastern Jemez Mountains increased in importance after the Cerro Grande fire of May, 2000. This fire burned 174 km^2 (43,000 acres) in the Sierra de los Valles and the Pajarito Plateau, resulting in significant, landscape-scale changes in hydrologic conditions (BAER, 2000) and increased flooding in the burn area and along downstream drainages (Shaull et al., 2003).

One widely used measure of precipitation is the largest amount that is expected to be equaled or exceeded at a site, on average, in a given number of years for a given duration. For example, 2-yr 1-hr precipitation refers to the 1-hr precipitation amount that is predicted to be equaled or exceeded, on average, once in a 2-yr period at a specific location, and 100-yr 1-hr precipitation refers to the amount that is expected to be equaled or exceeded once in 100 yr. This is analogous to the 100-yr flood, which is the peak discharge that is expected to be equaled or exceeded, on average, once every 100 yr at a point on a stream or river, and which is used in delineating 100-yr floodplains. These return periods can also be expressed as probabilities of occurrence, with a 2-yr event having a 50% probability of being equaled or exceeded in any given year, and a 100-yr event having a 1% probability. Similarly, a 2-yr event has a 75% probability of occurring in a 2-yr period, and a 100-yr event has a 63% probability of occurring in a 100-yr period. Estimates of maximum rainfall amounts for different durations and return periods are commonly used in predictions of flood size and other applications, and hence are an important underlying component of such predictive modeling.

The primary data used to estimate the size of relatively infrequent precipitation events are annual maximum precipitation amounts recorded at meteorological stations, which are compiled for the period of record and constitute the annual maximum series for each station. These data can be used to develop equations for estimating maximum precipitation amounts as a function of return period. Because of the large annual variability in precipitation, including the occurrence of wet and dry climate cycles, the reliability of such estimates improves with increasing length of record, particularly for infrequent events (relatively long return period events). As a result, it can be valuable to update estimates of rainfall frequency relationships at a station as longer periods of record become available.

Because of spatial variations in precipitation, data from meteorological stations with relatively long periods of record are often used to estimate precipitation amounts at locations without data or with short periods of record by developing regional relations between precipitation and one or more variables. Commonly used variables that have been found to be correlated with precipitation amounts in different areas include elevation (either the elevation at a station or an average elevation over some effective area) and distance from topographic barriers or moisture sources (e.g., Miller et al., 1973). It can also be valuable to revise regional relations as the length of record and/or the number of meteorological stations increases.

Estimates of spatial variations in extreme precipitation amounts across the Pajarito Plateau and the eastern Jemez Mountains have been previously made based either on regional rainfall relations (National Oceanic and Atmospheric Administration [NOAA] Atlas 2: Miller et al., 1973) or on an extrapolation from gages on the Pajarito Plateau at LANL (McLin, 1992, and McLin et al., 2001a), using data from Bowen (1990) and an assumed linear relation between precipitation and elevation. During finalization of this report, additional updated estimates were released by the National Weather Service (NOAA Atlas 14: NOAA, 2003). As illustrated in Figure 1, the NOAA estimates are significantly different from the locally-derived estimates, particularly in the Sierra de los Valles. The regional rainfall patterns presented in each NOAA Atlas predict a gradual increase in extreme short-duration precipitation amounts from east to west in this area, and suggest that an approximately linear precipitation-distance relation exists locally (distance as measured along the general topographic gradient from the crest of the mountains to the Rio Grande). In contrast, the use of a linear precipitation-elevation relation predicts much higher precipitation amounts in the higher elevation areas to the west where the topography is steeper. Smaller differences between these estimates are also seen in the lower

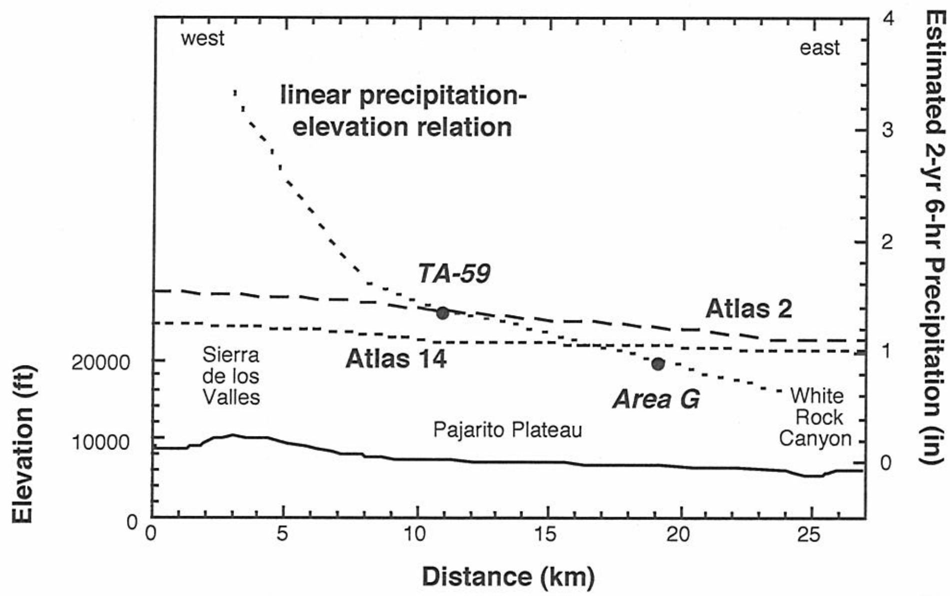

Figure 1. Topographic profile across Pajarito Plateau and eastern Jemez Mountains (lower solid line), and estimated east-to-west variations in 2-yr 6-hr precipitation (upper dashed lines) from McLin et al. (2001a, linear precipitation-elevation relation, based on analyses presented in Bowen, 1990), NOAA Atlas 2 (Miller et al., 1973, obtained from http://hydrology.nws.noaa.gov//oh/hdsc/noaaatlas2.htm), and NOAA Atlas 14 (NOAA, 2003, obtained from http://hdsc.nws.noaa.gov/hdsc/pfds/sa/nm_pfds. html). Estimated values at LANL stations at TA-59 and Area G from Bowen (1990). Estimated values from NOAA Atlas 2 are based on partial-duration series statistics, whereas those from NOAA Atlas 14 are based on annual series statistics. Profile passes through White Rock and the gages at TA-6 and Pajarito Mountain, and close to the TA-54 and Pajarito Canyon gages. No vertical exaggeration.

elevation areas to the east. These differences suggest that considerable uncertainty may exist in estimates of rainfall characteristics across the Pajarito Plateau and the Sierra de los Valles, and that additional evaluation of local precipitation data would be useful to reduce these uncertainties.

Since the original summary of climatological data presented in Bowen (1990), a considerable amount of data has been obtained from LANL and surrounding areas that allows revised estimates to be made of extreme precipitation events in this area. These data include significant increases in the length of record, particularly for short-duration precipitation, as well as an increase in the number and spatial distribution of stations. For example, the original analysis of Bowen (1990) included a 9 yr record of precipitation data collected at 15-min intervals at two stations on the Pajarito Plateau, whereas now up to 23 yr of 15-min data are available on the plateau. In addition, short-duration precipitation data are now available from the eastern Jemez Mountains as well as the plateau, allowing direct comparison of the relation of precipitation in the mountains to that on the plateau. Figure 2 shows the distribution of rain gages utilized in this study.

In this report we use the enlarged set of precipitation data from the Pajarito Plateau and the eastern Jemez Mountains to 1) document the seasonal distribution of maximum annual precipitation events for different durations, 2) compare the potential utility of precipitation-distance versus precipitation-elevation relations in describing spatial variations in maximum annual precipitation, 3) revise precipitation-frequency relations in this area, and 4) examine the characteristics and estimated return periods of select historic storms. The revised precipitation-frequency relations provide an improved basis for modeling runoff and erosion on the Pajarito Plateau and in the eastern Jemez Mountains and for understanding the return periods of specific historic precipitation events, and have direct applicability to flood hazard assessments and other studies.

STUDY AREA

The study area consists of the generally east-west trending mesas and canyons of the Pajarito Plateau in the vicinity of LANL and the generally steeper topography of the Sierra de los Valles to the west (Figure 2). It is bounded on the east by White Rock Canyon of the Rio Grande and on the west by the watershed divide with the Valles caldera, an east-west distance of about 20 km. Elevations range from 10,441 feet (3182 m) at the summit of Pajarito Mountain to about 6300 feet (1920 m) at the eastern edge of the plateau. Most of the data examined in this study were obtained in the area extending from the north part of Los Alamos south to Frijoles Canyon, a north-south distance of about 10-12 km. Several short precipitation records were also examined in the area extending about 10 km farther north to Santa Clara Canyon.

Mean annual precipitation (including both rain and the water equivalent of snow) increases from east to west across the study area, ranging from about 12" (30 cm) on the east edge of the Pajarito Plateau to about 27" (69 cm) at the crest of the Sierra de los Valles (Rogers, 1994; Figure 3a). Total rainfall in the "summer monsoon" also increases from east to west, and mean annual precipitation in the months of July to September ranges from about 6" (15 cm) on the east to about 11" (28 cm) on the west (Figure 3b). The months of July and August have the highest

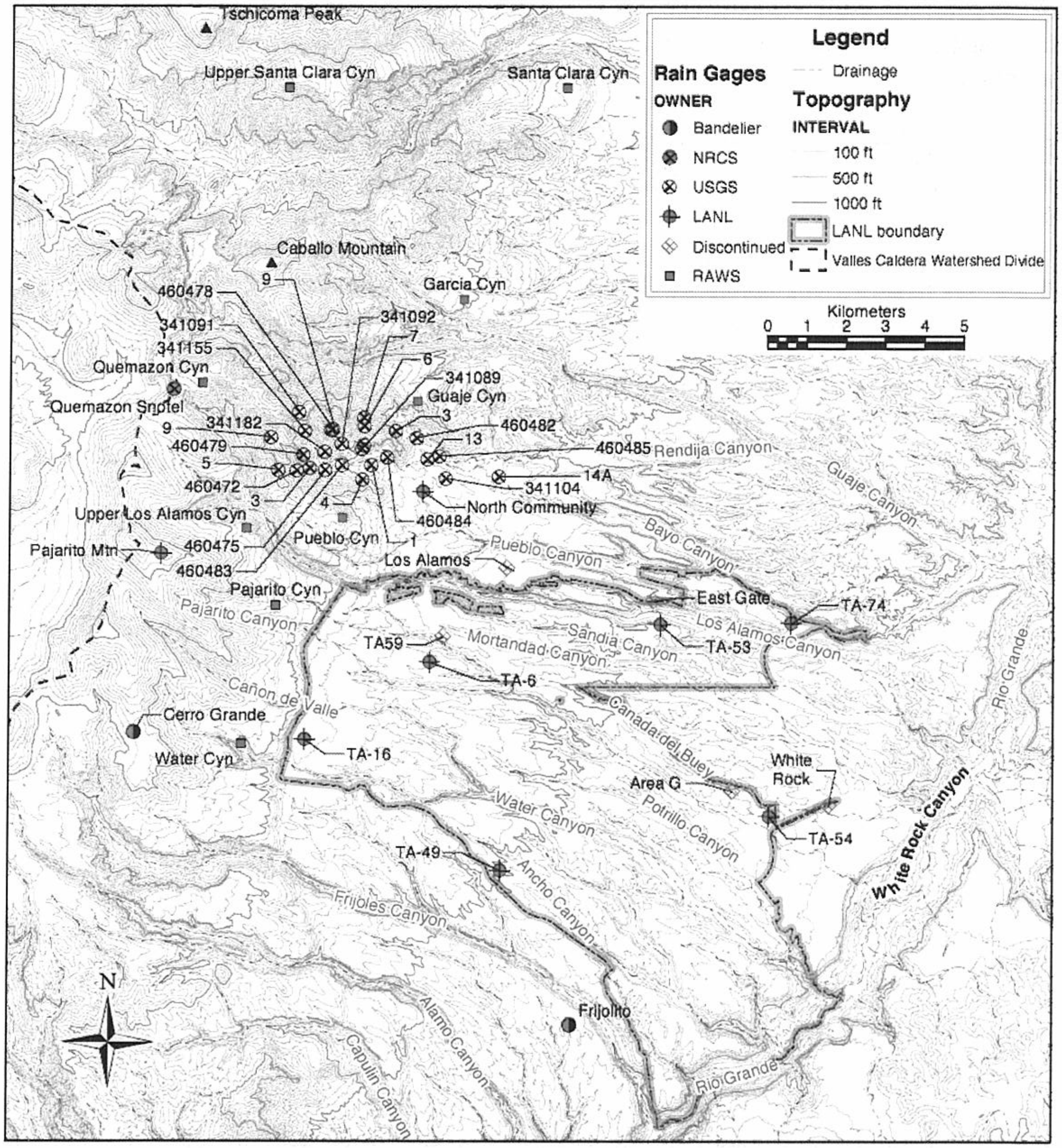

Figure 2. Map of the eastern Jemez Mountains and the Pajarito Plateau showing the location of rain gages used in this study.

average monthly precipitation and the highest average number of thunderstorm days (Bowen, 1990, 1996; Figure 4). The average number of days with rainfall from June through October increases from east to west across the Pajarito Plateau, although the average depth, duration, and intensity of rainfall in storms during these months is similar across the study area (Malmon, 2002; Figure 5). Convective rainfall in the study area typically starts earlier in the day to the west

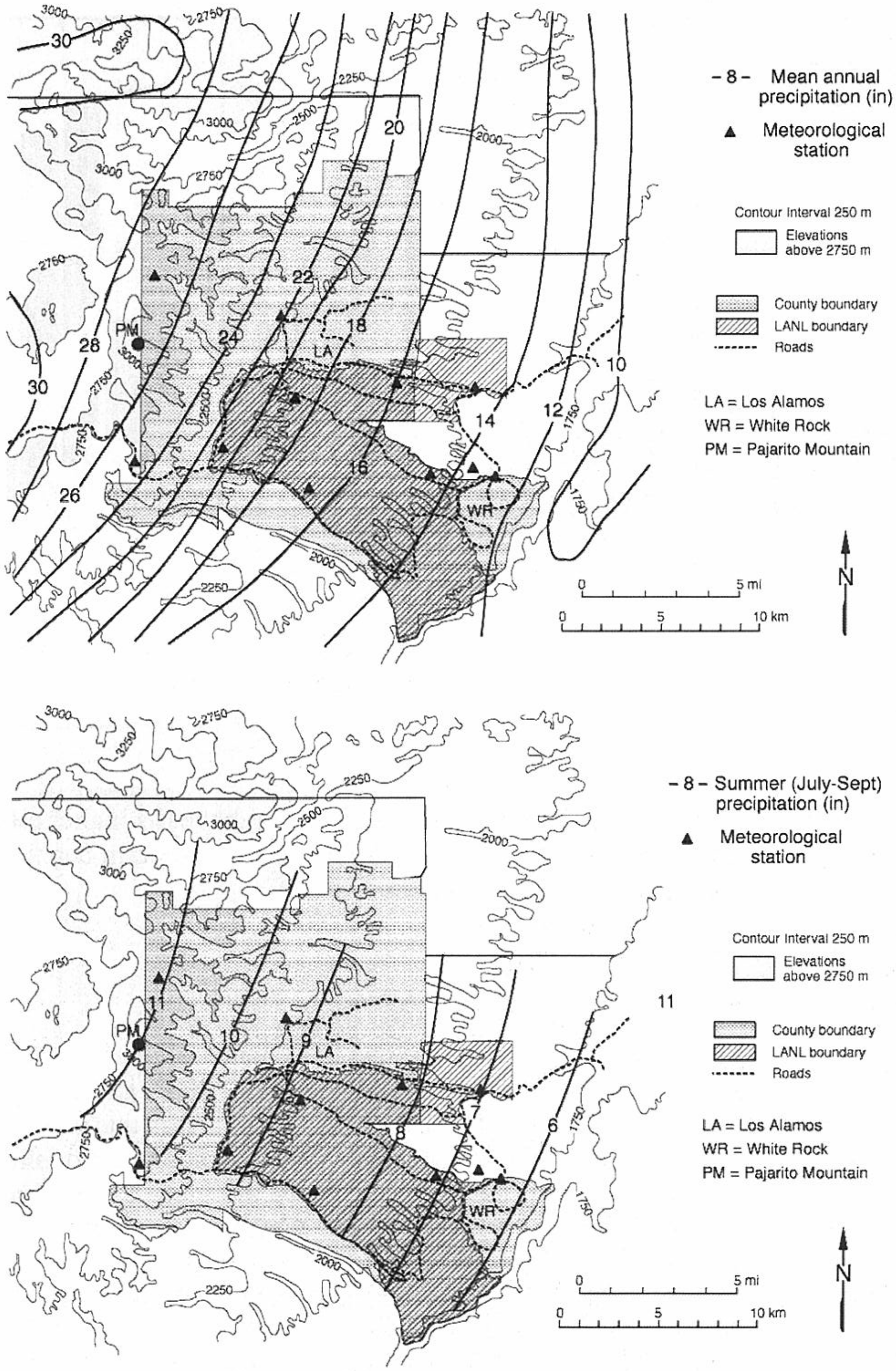

Figure 3. Maps showing east to west variations in (a) mean annual precipitation, and (b) July to September mean precipitation (the "summer monsoon") across the Pajarito Plateau and the Sierra de los Valles. From Rogers (1994), as modified from Bowen (1990) and Williams (1986).

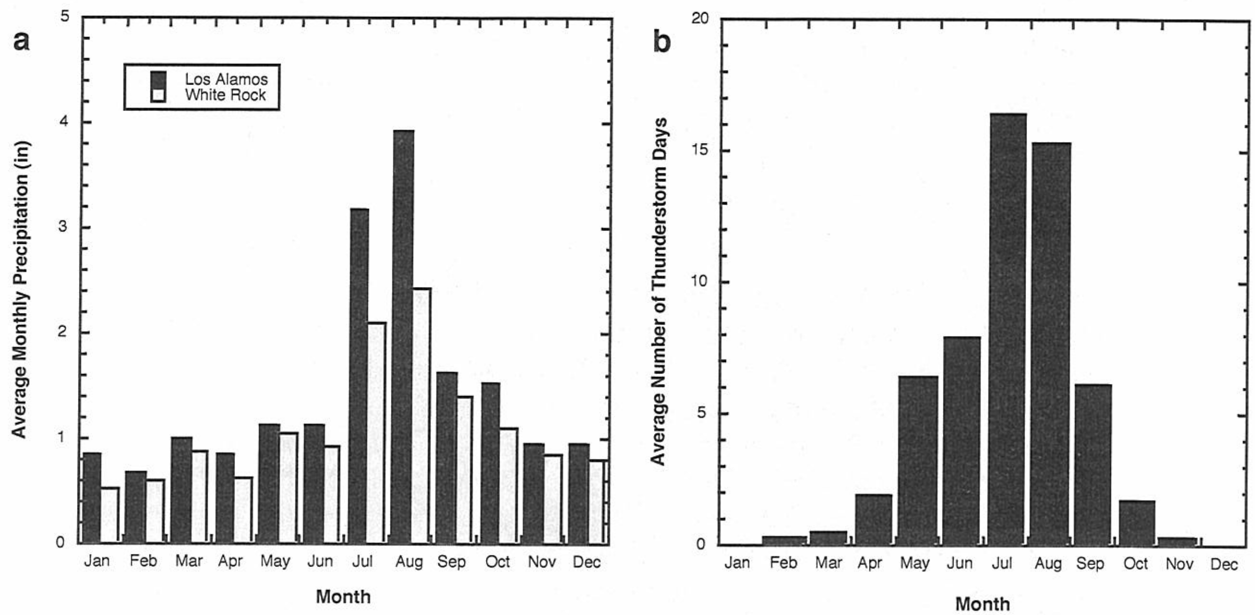

Figure 4. Monthly distribution of (a) average precipitation and (b) average number of thunderstorm days in study area (from Bowen, 1990, 1996).

than to the east, suggesting the initial accumulation of moisture above the higher elevation areas to the west and subsequent movement to the east, although the time that rain begins can vary significantly at a station (Bowen, 1990, 1996; Malmon, 2002).

METHODS

Annual maximum precipitation amounts were compiled from meteorological stations for durations of 15 min to 24 hr and for daily totals through the end of 2002, and these data constitute the annual series for each station. These data include both rain and snow events (using the water equivalent of snow), although the annual series for all durations are dominated by rain. The stations are listed in Table 1 and their locations are shown in Figure 2. Data from LANL stations (Baars et al., 1998) were obtained from the LANL Weather Machine (http://weather.lanl.gov) or from LANL group RRES-MAQ. Data from the Quemezon snowpack telemetry (SNOTEL) site were obtained from the Natural Resources Conservation Service (NRCS) web site (http://www.wcc.nrcs.usda.gov/ snotel). Data from the Cerro Grande and Frijolito stations were obtained from Bandelier National Monument (BNM). Data from Remote Area Weather Stations (RAWS) installed after the Cerro Grande fire were obtained from the Desert Research Institute (DRI) web site (http://www. losalamos.dri.edu). The annual series data from these stations are presented in Appendix A. If two or more days share the same maximum amount for a given station, the first is shown in Appendix A. Additional data are available from a network of U.S. Geological Survey (USGS) gages established in the Rendija Canyon area after the fire (e.g., Cannon et al., 2001; Moody and Martin, 2001; Moody et al., 2002), that record characteristics of some infrequent precipitation events in the eastern Jemez Mountains.

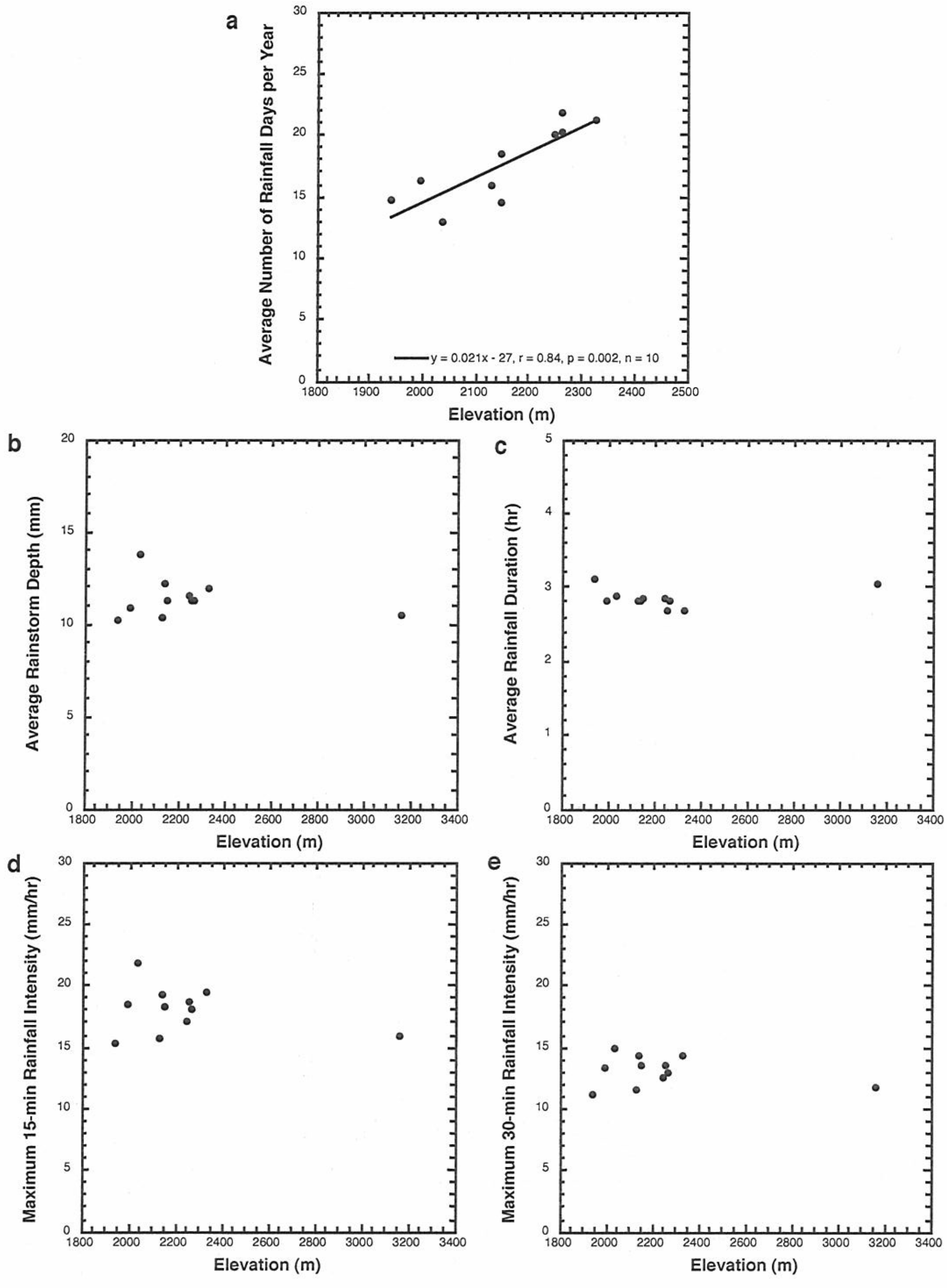

Figure 5. (a) Average number of rainfall days from June through October which exceed 0.2" (5 mm) vs. elevation; data from 10 LANL gages on the Pajarito Plateau. (b) Average rainstorm depth, (c) average rainfall duration, (d) average maximum 15-min rainfall intensity, and (e) average maximum 30-min rainfall intensity vs. elevation, at 11 LANL gages; a storm is defined here as a period with rainfall greater than 5 mm (0.2") separated by at least 1.5 hr with no rain. From Malmon (2002).

Table 1
Precipitation Stations on the Pajarito Plateau and in the Eastern Jemez Mountains

Station	Approximate Distance From Range Crest (km) [2]	Elevation (ft)	Source of Data	Measurement Interval	Period of Record
Quemezon SNOTEL	0.2	9500	NRCS	daily	6/4/80 to present
Pajarito Mountain	0.5	10360	LANL	15 min	8/1/97 to present
Quemezon Canyon RAWS	0.6	9770	DRI	1 hr	6/10/00 to present
Cerro Grande	2.1	9170	BNM	1 hr	5/2/96 to 12/31/01 [3]
Upper Santa Clara Canyon RAWS	2.6	10640	DRI	1 hr	6/10/00 to present
Upper Los Alamos Canyon RAWS	2.7	8800	DRI	1 hr	6/6/00 to present
Pajarito Canyon RAWS	3.6	8333	DRI	1 hr	6/5/00 to present
Water Canyon RAWS	4.7	8143	DRI	1 hr	6/3/00 to present
Garcia Canyon RAWS	5.0	8155	DRI	1 hr	6/1/00 to present
Guaje Canyon RAWS	5.2	8310	DRI	1 hr	6/4/00 to present
Pueblo Canyon RAWS	5.4	8400	DRI	1 hr	6/2/00 to present
TA-16 (S-Site)	5.9	7635	LANL	daily	1/1/77 to 12/31/95
TA-16 (S-Site)	5.9	7635	LANL	15 min	1/1/96 to present
North Community	6.9	7420	LANL	daily	1/1/86 to 12/31/95
North Community	6.9	7420	LANL	15 min	1/1/96 to present
TA-6	7.9	7424	LANL	15 min	2/1/90 to present
TA-59	7.9	7380	LANL	15 min	9/5/79 to 1/4/91
Los Alamos [1]	8.5	7360	LANL	daily	11/1/10 to 9/4/79
Santa Clara Canyon RAWS	8.8	7940	DRI	1 hr	6/5/00 to present
TA-49 (Bandelier)	12.0	7045	LANL	15 min	6/24/87 to present
TA-53 (LANSCE)	13.4	6990	LANL	15 min	2/8/92 to present
East Gate	13.7	7020	LANL	15 min	8/20/81 to 2/16/92
Frijolito	15.5	6540	BNM	15 min + daily [4]	7/26/93 to present
Area G (TA-54)	15.8	6690	LANL	15 min	1/1/87 to 12/31/91
TA-74 (White Rock Y)	16.8	6370	LANL	daily	7/24/81 to 12/31/95
TA-74 (White Rock Y)	16.8	6370	LANL	15 min	1/1/96 to present
TA-54 (White Rock)	17.4	6548	LANL	15 min	1/29/92 to present
White Rock	18.8	6380	LANL	daily	9/1/64 to 1/28/92

[1] Location moved several times between 7150 and 7410 feet elevation, but was largely between 7320 and 7400 feet (Bowen, 1990)

[2] Minimum distance from station to Valles caldera watershed divide, Caballo Mountain, or Tschicoma Peak

[3] Also has record from 6/20/94 to 6/21/95

[4] Recorded in 1-min intervals, but only daily totals and daily peak 15-min intervals summarized

Years at a station were not used when the record was missing a significant amount of time during the rainy season. For most stations, records that began by the beginning of May and extended through October were considered sufficiently complete because precipitation during these months dominate the annual series at all stations. Although the RAWS network was not installed until early June 2000, the record from these stations is considered essentially complete for 2000 because of the absence of major precipitation before June.

Several stations in the network have been discontinued and replaced by new stations at nearby locations, and data from such stations have been combined to produce longer records, as was done by Bowen (1990, 1996). The TA-6 station is now considered to be the official station for Los Alamos, replacing a station at TA-59 which in turn replaced stations in the Los Alamos town site (Fig. 2); together, these contain a 23-yr record with 15-min data and daily rainfall data extending to 1911. For daily precipitation, years for the Los Alamos station before 1922 were excluded because 4 of the 11 years from 1911 to 1921 were missing significant periods of record; after 1921, only 1 year (1945) was similarly missing significant amounts of data. The Area G station at TA-54, considered by Bowen (1990, 1996) to be representative of White Rock, was replaced by a station farther east in TA-54 in 1992 (Fig. 1). Daily rainfall was recorded at White Rock beginning in 1964, and together the White Rock station and the newer TA-54 station provide a 38-yr record of daily rainfall on the eastern Pajarito Plateau. Five years of data from the Area G station are combined with data from the newer TA-54 station to provide a 16-yr record of 15-min precipitation data on this part of the plateau. The East Gate station was discontinued in 1992 and replaced by a station at TA-53 a short distance to the south (Fig. 1), and together these stations provide a 21-yr record of 15-min rainfall.

The Gumbel or Fisher-Tippett type 1 extreme-value distribution (Gumbel, 1958) was used to estimate relations between precipitation amount and return period in this data set. This particular mathematical distribution is commonly used for evaluating extreme precipitation amounts (e.g., Hershfield, 1960; Gray, 1970; Miller et al., 1973; Dunne and Leopold, 1979; Wilks, 1995; Haan, 2002). The Gumbel is a double exponential distribution of the form

$$P = (1 - \exp(-\exp(-f(y)))) \qquad (1)$$

where P is the probability of equaling or exceeding a given value of precipitation, y, in a given year, and f (y) indicates a value that is a function of y. The average number of years within which that amount of precipitation will be equaled or exceeded, called the return period or the recurrence interval, is the inverse of the exceedance probability, P^{-1}.

Relations between precipitation amount and return period for subsets of data (e.g., all annual maximum 15-min values from a station) were calculated analytically, removing possible biases imparted by subjectively fitting curves to the data by hand. Data within each subset were ranked from high to low, and an exceedance probability was calculated for each value:

$$P = \text{rank} / (n + 1) \qquad (2)$$

where n is the number of years of record. Rearranging equation 1, the exceedance probabilities were transformed to obtain the independent variable x within the extreme value distribution:

$$x = -\ln(-\ln(1 - P)) \quad (3)$$

Linear regressions were fit to the values of x and y in the subsets of data, obtaining intercepts (a) and slopes (b):

$$y = a + bx \quad (4)$$

An example of a plot using the x-axis transformation of equation 3 and precipitation data from a station on the Pajarito Plateau, along with the resulting linear regression equation, is shown in Figure 6, and additional plots are included in Appendix B. These equations allow estimates of precipitation amounts for any return period to be calculated from a data set at a station, and allow evaluation of possible differences between stations. These equations also allow estimation of the return period for a given precipitation amount at a station.

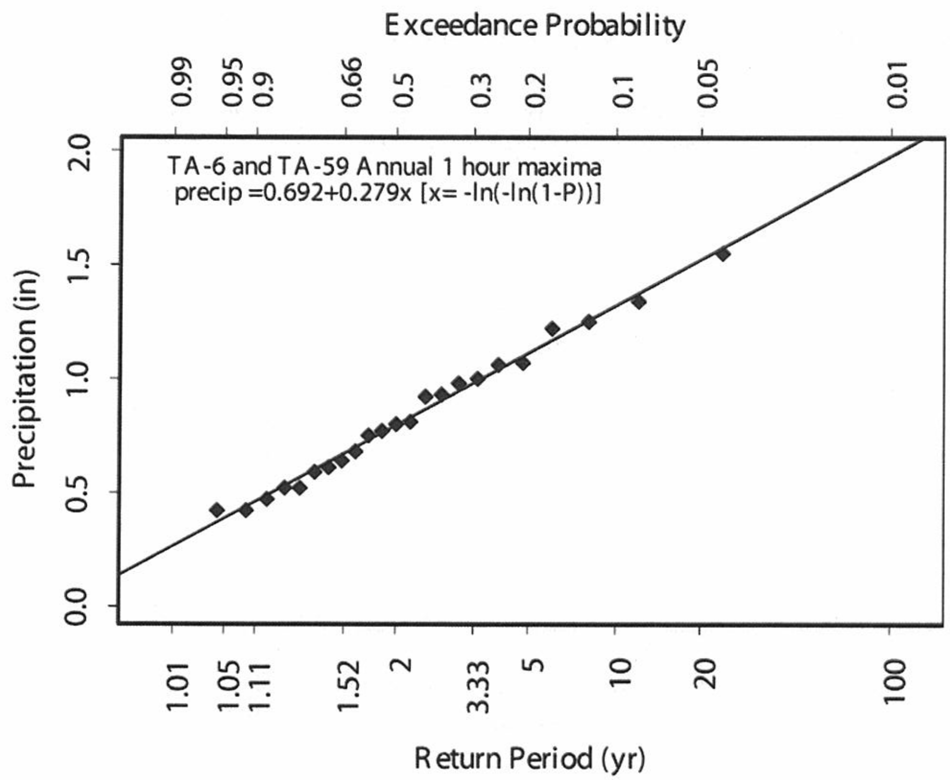

Figure 6. An example of a Gumbel extreme value precipitation plot, with annual maximum precipitation amounts plotted on the y axis and return period or exceedance probability plotted on the x axis. Data from the combined record of annual 1-hr precipitation maximums from TA-59 and TA-6 stations, 1980-2002.

The data set is influenced by record lengths that differ between stations, which potentially affects the comparison of records from different stations and the reliability of estimates at a station. For example, data from stations with relatively long records indicate that annual maximum precipitation amounts in the period 1996 to 2002 were generally below average. Thus data from stations with short periods of record could provide lower estimates of precipitation amounts for specific durations and return periods than estimates derived from longer records. Better estimates of the characteristics of infrequent events can also be obtained from stations with longer periods of record. To examine possible spatial trends in precipitation-frequency relations among stations, consistent periods of record were used (e.g., 1998-2002) in combination with estimates of frequent (2-yr return period) events. Estimates of the characteristics of infrequent events (e.g., 100-yr events) only used data from stations with ≥ 15 yr of record, and included an evaluation of possible systematic variations in rainfall characteristics as a function of elevation or distance from the range crest.

Annual series data are also affected by differences in the measurement interval at different stations and by the fact that the true maximum precipitation amount for any duration typically straddles fixed measurement intervals. For example, data from the Cerro Grande and RAWS gages are available in 1-hr intervals, compared with 15-min intervals for the LANL stations, and use of 1-hr measurement intervals can lead to lower values for maximum annual 1-hr precipitation than if the measurement interval was shorter. Similarly, part of the available record only includes daily rainfall totals, which are typically less than 24-hr rainfall totals that can include parts of two calendar days. This affect can be corrected for by using probability theory to calculate conversion factors, F, to adjust statistically derived precipitation-frequency values from an annual series to values that are independent of the measurement interval (Weiss, 1964). The equation for this conversion that is presented in Weiss (1964) reduces to

$$F = N / (N - 0.125) \qquad (5)$$

where N is the ratio of the precipitation interval of interest to the measurement interval (e.g., N = 1 for 1-hr totals derived from 1-hr data, and N = 4 for 1-hr totals derived from 15-min data). Conversion factors for durations considered in this study for measurement intervals of 15 min, 1 hr, and daily are presented in Table 2.

Table 2
Conversion Factors for Adjusting Fixed-Interval Precipitation Values to True Precipitation

Measurement Interval	Precipitation Interval							
	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr
15 min	1.1429	1.0667	1.0323	1.0159	1.0105	1.0052	1.0026	1.0013
1 hr	-	-	1.1429	1.0667	1.0435	1.0213	1.0105	1.0052
Daily	-	-	-	-	-	-	-	1.1429

Statistics derived from annual series data are often converted to partial-duration statistics for use in examining precipitation-frequency relations for frequent (< 10 yr return period) events. The difference between these series is that the annual series only includes the largest event in each calendar year, whereas the partial-duration series includes the largest events in a period of time, and two or more can occur in one calendar year. For the annual series, the return period is the average interval within which a given precipitation amount is predicted to be equaled or exceeded once as an annual maximum (the inverse of the annual probability of exceedance). For the partial-duration series, the return period is the average time between events that equal or exceed that amount. A 2-yr return period event from a partial-duration series is equal to a 2.54-yr event in the annual series, and a 1-yr event in a partial-duration series is equal to a 1.58-yr event in an annual series (Table 3; Langbein, 1949). Precipitation amounts for a given return period derived from annual series data can be converted to amounts in a partial-duration series using the conversion factors in Table 4 (derived from Miller et al., 1973, p. 3), and partial-duration relations are calculated in this study to allow estimation of the return periods of low-magnitude historic precipitation events. For return periods of > 10 yr, the differences between estimates from the annual and partial-duration series are negligible (Dunne and Leopold, 1978).

Table 3

Corresponding Return Periods For Annual and Partial-Duration Series

Return Period From Annual Series (yr)	Return Period From Partial-Duration Series (yr)
1.16	0.5
1.58	1
2	1.45
2.54	2
5.52	5
10.5	10
50.5	50
100.5	100

Table 4

Conversion of Annual Series Statistics to Partial-Duration Series Statistics

Return Period (yr)	Conversion Factor
2	1.136
5	1.042
10	1.010

SEASONALITY OF ANNUAL MAXIMUM PRECIPITATION AMOUNTS

Seasonal variations in storm characteristics influence the occurrence of extreme precipitation events on the Pajarito Plateau and in the eastern Jemez Mountains. In the record from LANL stations with 15-min measurement intervals, August has the most frequent occurrence of annual maximums for all durations, reflecting the dominance of the summer monsoon season on the occurrence of extreme precipitation events, and March has the fewest number of occurrences (Table 5, Figure 7). The monsoon months of June through August include 80-83% of the annual maximum precipitation amounts for durations of 15 min to 2 hr, and the months of May through September include 96-99% of the occurrences for these durations. While still important for longer durations, these months become progressively less frequent in the data set as the duration increases. For durations of 24 hr, June through August include 51% of the record of annual maximum precipitation amounts, and May through September include 72%. October storms are infrequent in the annual series record for short durations (1-5% for durations of 2 hr or less), but become progressively more common for longer durations, including 12-13% of the record for durations of 12 and 24 hr. Late fall, winter, and early spring storms are only part of the annual series for relatively long durations. November through April are not present in the annual series record at durations of less than 6 hr, but constitute 6% of the 6-hr record and 17% of the 24-hr record.

Table 5
Occurrence of Annual Maximum Series Values By Month (percent)

Month	Interval								
	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
1	0	0	0	0	0	1.0	2.0	3.9	6.9
2	0	0	0	0	0	0	2.9	2.9	2.9
3	0	0	0	0	0	0	0	1.0	1.0
4	0	0	0	0	0	1.0	1.0	2.0	2.0
5	7.8	5.9	5.9	3.9	4.9	7.8	10.8	8.8	6.9
6	20.6	18.6	20.6	23.5	19.6	16.7	12.7	11.8	11.8
7	27.5	28.4	25.5	25.5	23.5	20.6	15.7	14.7	10.8
8	32.4	33.3	37.3	31.4	33.3	29.4	26.5	24.5	26.5
9	10.8	11.8	8.8	11.8	12.7	11.8	11.8	11.8	13.7
10	1.0	2.0	2.0	3.9	5.9	7.8	12.7	11.8	11.8
11	0	0	0	0	0	2.9	2.9	3.9	3.9
12	0	0	0	0	0	1.0	1.0	2.9	2.0

A comparison of the monthly distribution of annual maximum precipitation events in the annual series (Table 5, Figure 7) with records of average monthly precipitation and average number of thunderstorm days per month (Figure 4; Bowen, 1990, 1996) provides a few observations of note. The occurrence of the greatest number of annual maximum events in August is consistent with August having, on average, the highest total precipitation. However, on average, a larger number of thunderstorms occur in July (Figure 4), suggesting that thunderstorms in August

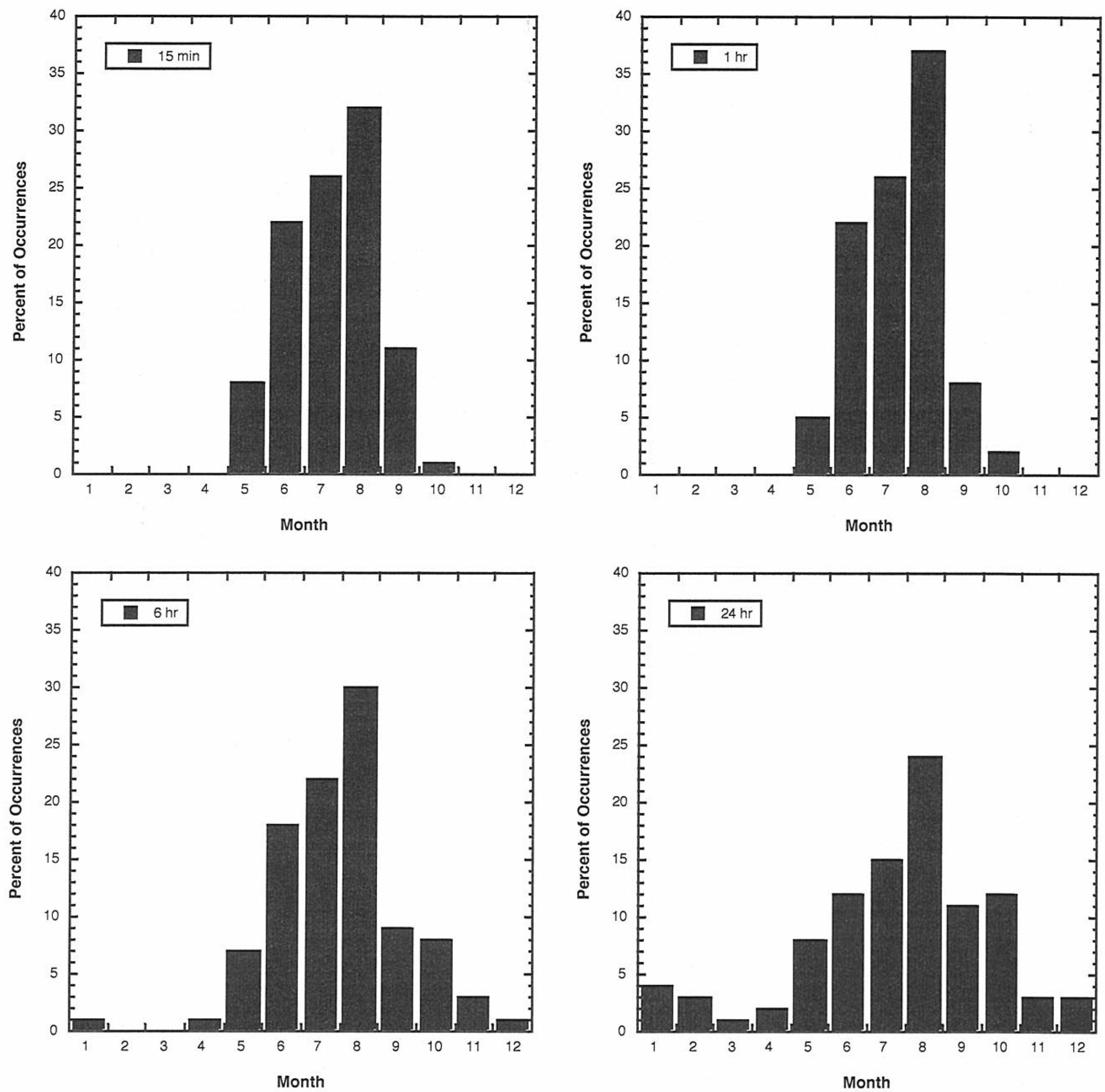

Figure 7. Distribution of annual maximum precipitation value for different durations, by month, from LANL gages with 15-min measurement intervals (n = 102).

typically contain more rain than those in July. The occurrence of the preponderance of thunderstorms in May through September (Figure 4) is also consistent with the importance of these months in the annual maximum series for durations of 15 min to 2 hr, due to the occurrence of the highest intensity rains in thunderstorms. However, June is over represented in the annual series with respect to average monthly precipitation or number of thunderstorm days. This suggests that thunderstorms occurring in June also tend to be relatively intense, although the reason for this is not certain.

EVALUATION OF TOPOGRAPHIC OR GEOGRAPHIC VARIATIONS IN PRECIPITATION

Possible systematic variations in annual maximum precipitation amounts as a function of elevation or distance from the crest of the Sierra de los Valles were evaluated by first comparing estimated 2-yr return period amounts calculated from the records at different stations on the Pajarito Plateau and in the eastern Jemez Mountains. The 2-yr event was used because geographic or topographic variations in annual maximum precipitation are expected to exist for both such relatively frequent events as well as infrequent events (e.g., 100-yr return period event; Miller et al., 1973; McLin, 1992), and because uncertainties in estimating precipitation-frequency relations increase for durations that are longer than the period of measurement, making such comparisons less reliable. One objective of these comparisons is to evaluate if there is a sharp increase in precipitation amounts moving from east to west where the steeper topography of the eastern Jemez Mountains is reached, as predicted from a precipitation-elevation model (Figure 1).

These comparisons employ different periods of record depending on the duration of interest. Longer records are more reliable than shorter records in estimating precipitation-frequency relations, but high elevation stations in the eastern Jemez Mountains generally do not have long records, limiting the geographic extent of valid comparisons. The following periods of record are used in this section: 2000-2002 (3 yr), which includes data from the extensive network of nine RAWS gages; 1998-2002 (5 yr), which includes the full length of record of the Pajarito Mountain gage, the only gage in the Sierra de los Valles with 15-min data; 1996-2001 (6 yr), which includes the period of continuous record of the Cerro Grande gage in the Sierra de los Valles with 1-hr data; and 1988-2002 (15 yr), which includes four LANL records with 15-min data on the Pajarito Plateau and eight records with daily precipitation data spanning the full east-west extent of the area of interest (either records from single gages or combined records from paired gages).

Figures 8 to 12 show calculated 2-yr precipitation amounts for a series of durations and periods of record plotted against either distance from the range crest or elevation. For durations of 1 hr or less, available data indicate little variation in precipitation with proximity to the range crest or elevation (Figures 8 and 9). The best correlations between precipitation and distance or elevation for these short durations are in the 1-hr data for the period 2000-2002 (Figure 9), although this period is least reliable because of the short period of record. Also, for the period 2000-2002 these data seem to fall into two general groups in the precipitation-distance plots, either greater than or less than about 10 km, with no systematic differences within these groups (best displayed for 2-hr and 6-hr precipitation, Figures 10 and 11). For 2000-2002, the stations in the eastern Jemez Mountains, < 5.5 km from the range crest, appear to be part of the same population as western Pajarito Plateau stations, 5.5-10 km from the crest.

For durations of 2 hr or more, inverse relations of estimated 2-yr precipitation and distance from the range crest and positive relations of precipitation and elevation exist for all durations and all periods of record examined (Figures 10 to 12), although few of these correlations are statistically significant ($p < 0.05$). For a given duration and period of record, correlations are commonly better (higher r values and lower p values) for the distance plots than the elevation plots.

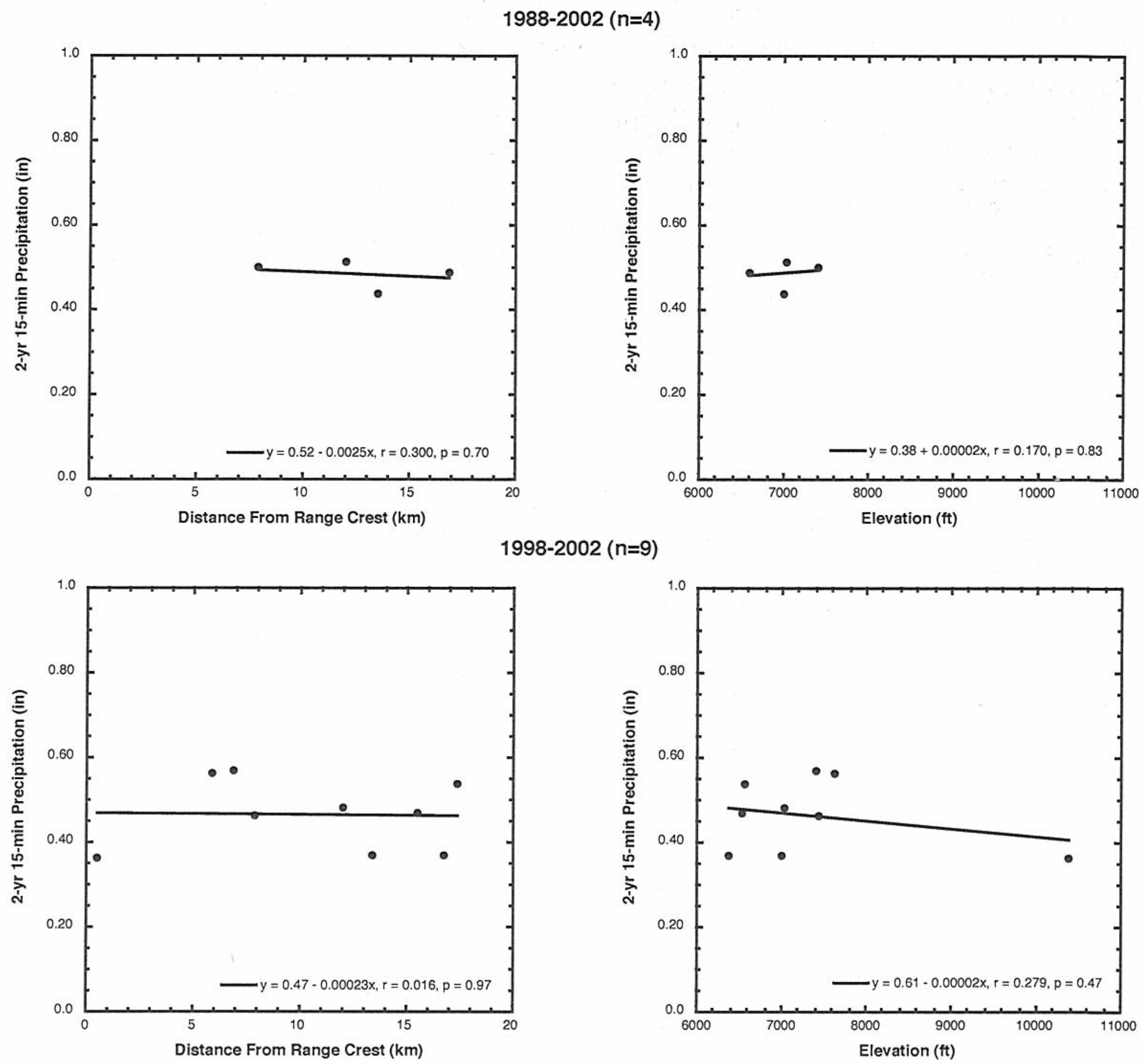

Figure 8. Estimated 2-yr 15-min precipitation amounts using data from 1988-2002 and 1998-2002, as a function of distance from the range crest and elevation.

A check on the reasonableness of precipitation-distance or precipitation-elevation regressions was made by combining regression curves for all durations on single plots, extrapolating to the boundaries of the study area (Figure 13). If the regressions are valid for the full east-west extent of the study area, there should be internal consistency, with no intersections of regression lines for different durations (e.g., at all locations, the predicted 2-hr precipitation amount for a given return period should be greater than the predicted 1-hr precipitation amount).

In these plots, estimated precipitation amounts were used from the stations with the longest periods of record ($\geq$ 15 yr) to minimize variability related to short periods of record. Data from the eight records with 15-80 yr of daily precipitation data were used to calculate linear regressions for 24-hr durations for 2-yr and 100-yr precipitation as a function of distance and

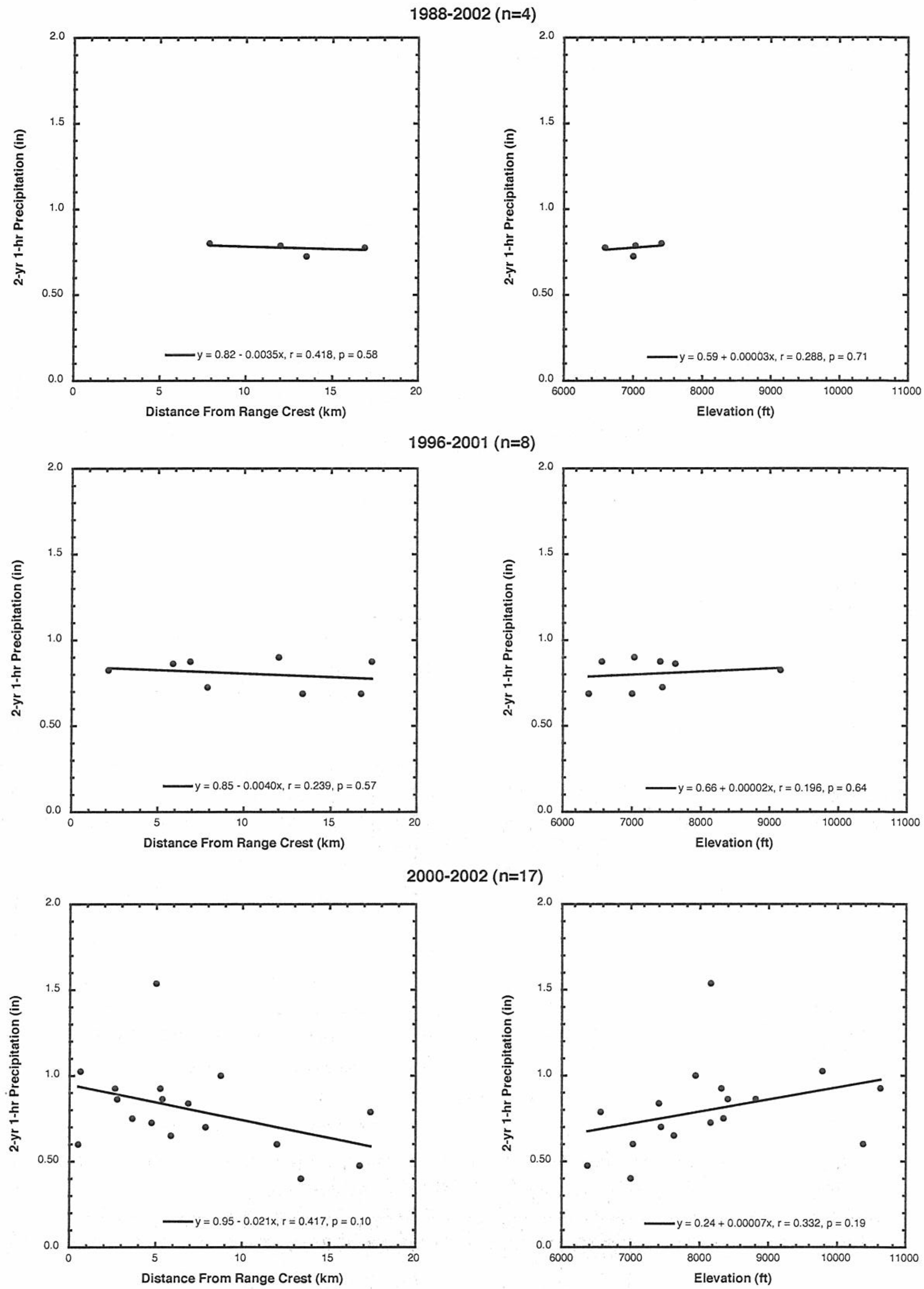

Figure 9. Estimated 2-yr 1-hr precipitation amounts using data from 1988-2002, 1996-2001, and 2000-2002, as a function of distance from the range crest and elevation.

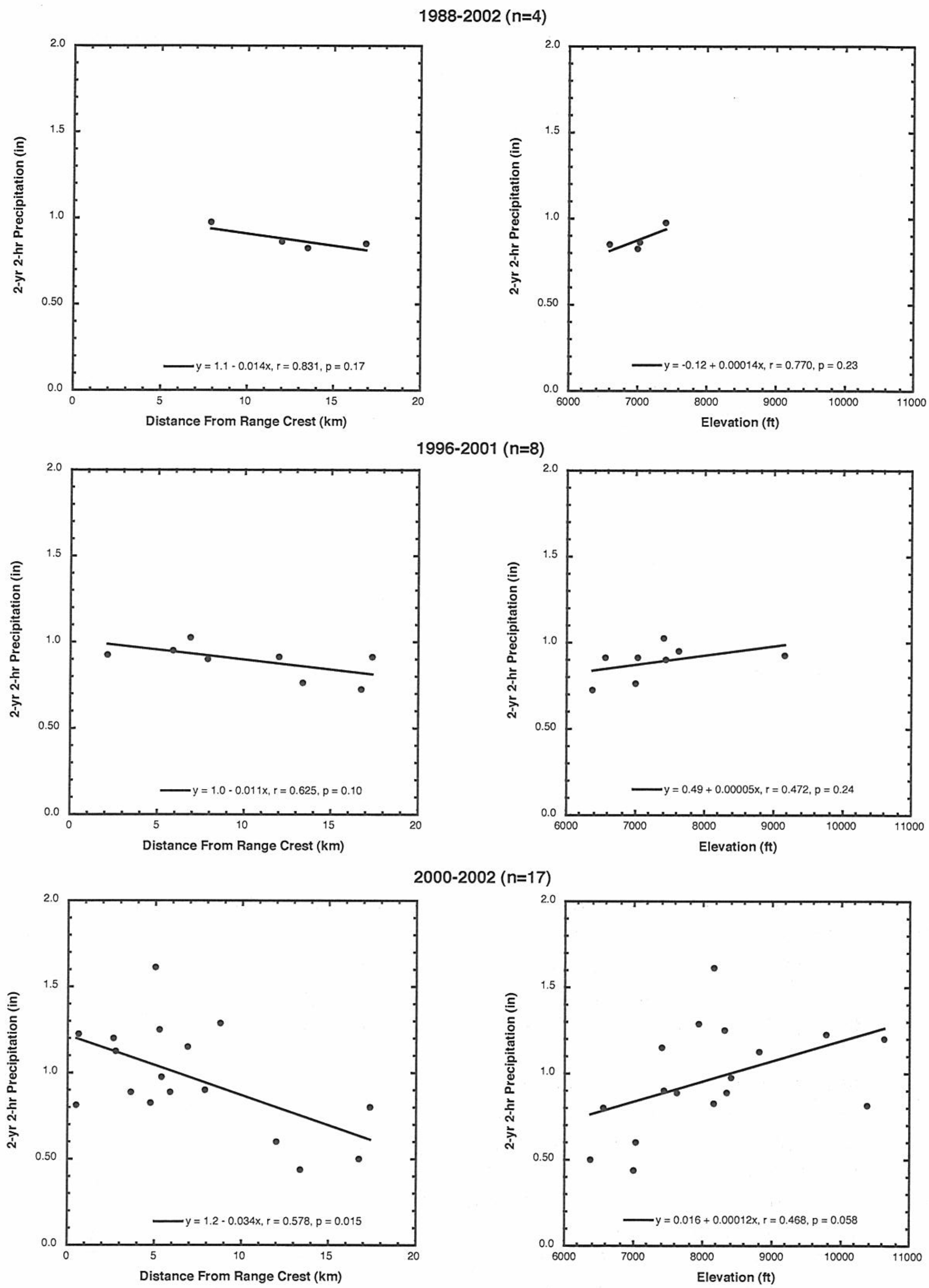

Figure 10. Estimated 2-yr 2-hr precipitation amounts using data from 1988-2002, 1996-2001, and 2000-2002, as a function of distance from the range crest and elevation.

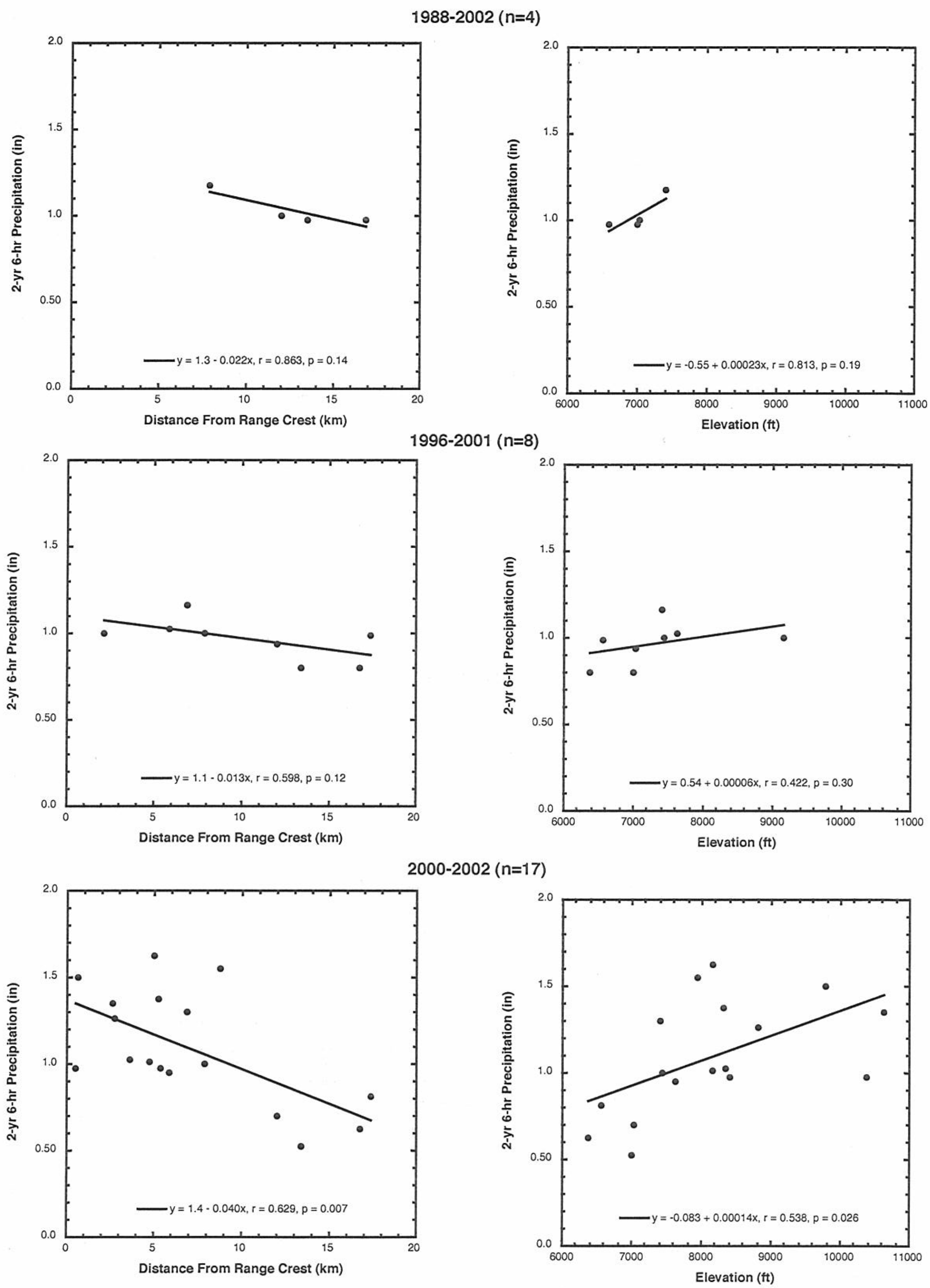

Figure 11. Estimated 2-yr 6-hr precipitation amounts using data from 1988-2002, 1996-2001, and 2000-2002, as a function of distance from the range crest and elevation.

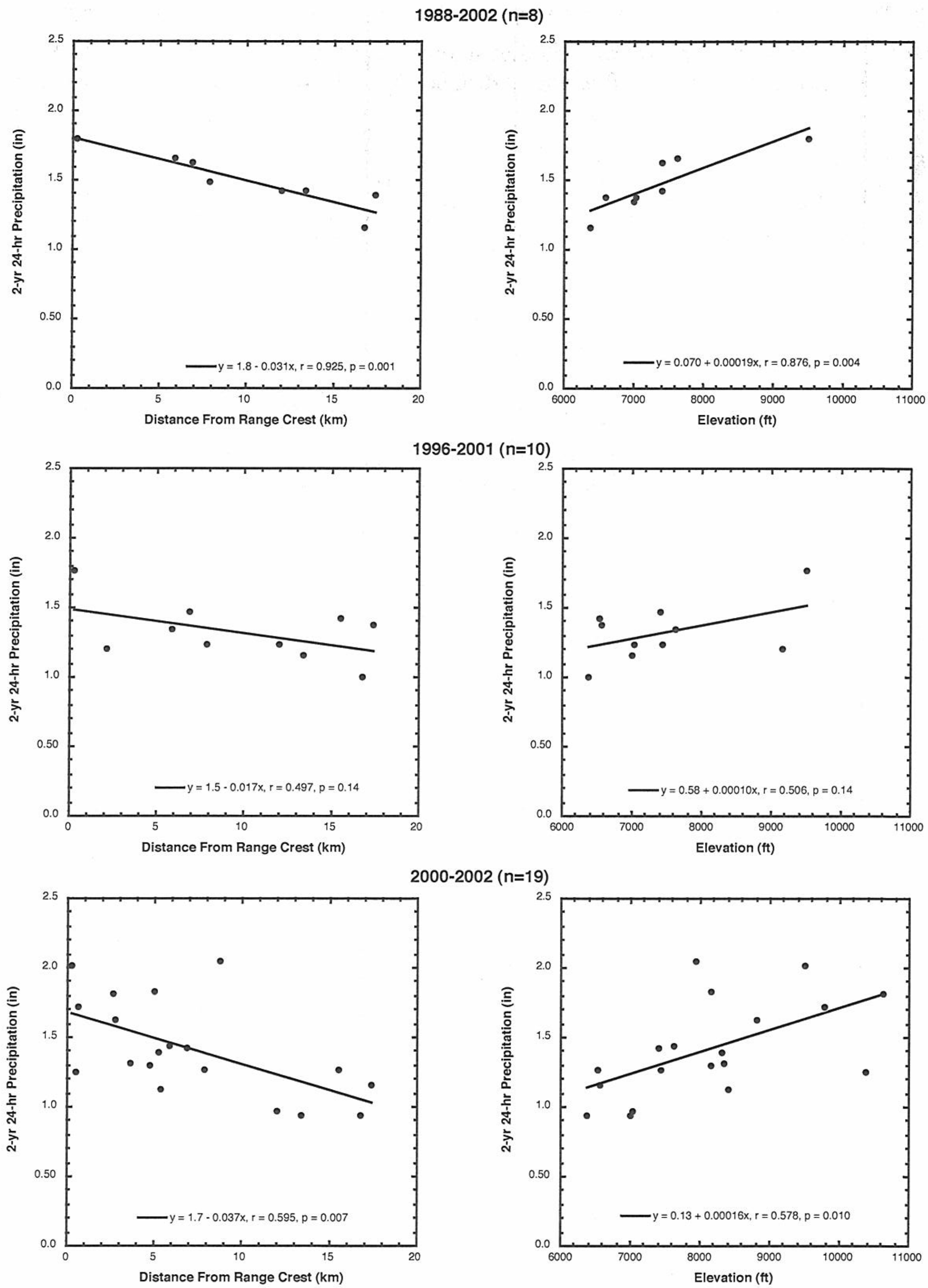

Figure 12. Estimated 2-yr 24-hr precipitation amounts using data from 1988-2002, 1996-2001, and 2000-2002, as a function of distance from the range crest and elevation.

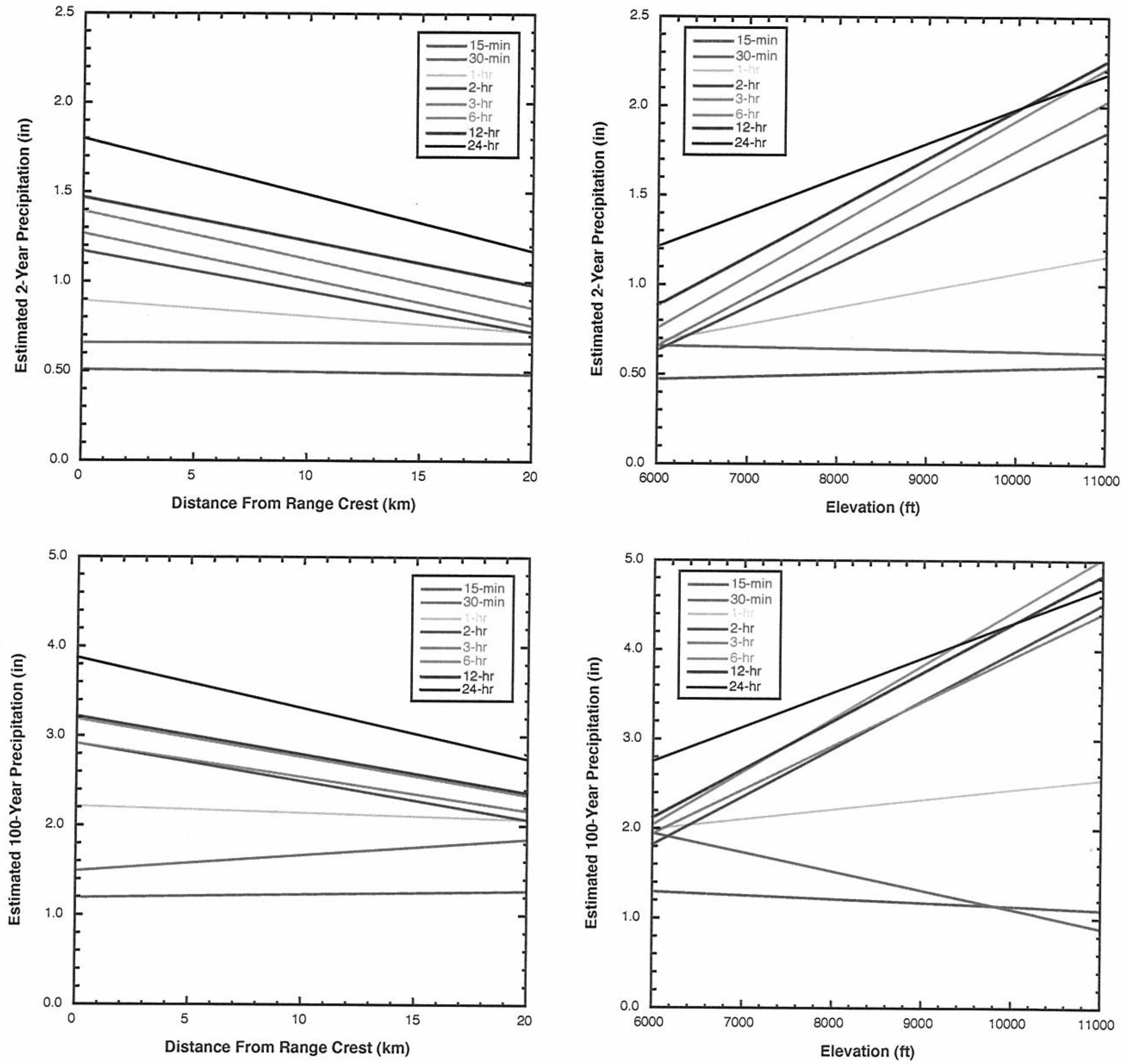

Figure 13. Precipitation-frequency relations derived from stations with ≥ 15 yr records.

elevation (Tables 6 and 7). Data from the four records with 15-23 yr of 15-min measurement interval data were used to calculate regressions for durations of 15 min to 12 hr. These regressions are plotted in Figure 13, and show that relations are internally consistent for the distance regressions (no intersections of regressions for different durations), but not for the elevation regressions. For this reason, precipitation-distance regressions are considered to provide a reasonable description of east-west variations across the study area, and are used in subsequent sections. In contrast, precipitation-elevation regressions are not considered reliable and are not used further.

Table 6
Estimated 2-Year Annual Maximum Precipitation For Stations with ≥15 Years of Record [1]

Station	Approximate Distance From Range Crest (km) [2]	Elevation (ft) [2]	Period of Record (yr) [2]	15 min (in)	30 min (in)	1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
Quemezon SNOTEL	0.2	9500	22	-	-	-	-	-	-	-	1.856	1.624
TA-16	5.9	7635	24	-	-	-	-	-	-	-	1.507	1.319
North Community	7.2	7420	17	-	-	-	-	-	-	-	1.627	1.423
TA-6, TA-59, Los Alamos	7.9/8.3	7400/7370	23/80	0.502	0.655	0.842	1.031	1.100	1.232	1.313	1.552	1.358
TA-49	12.0	7045	15	0.507	0.685	0.792	0.856	0.924	1.002	1.119	1.369	1.197
TA-53, East Gate	13.5	7000	21	0.458	0.607	0.747	0.840	0.874	1.002	1.147	1.319	1.139
TA-74	16.6	6370	22	-	-	-	-	-	-	-	1.222	1.069
TA-54, Area G, White Rock	16.9/18.4	6590/6430	16/38	0.489	0.665	0.764	0.827	0.874	0.986	1.083	1.325	1.159

Precipitation-Distance Regressions	parameter	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
	intercept (in)	0.519	0.658	0.906	1.178	1.271	1.400	1.478	1.801	1.576
	slope	-0.0024	-0.0004	-0.0095	-0.0230	-0.0261	-0.0274	-0.0248	-0.0320	-0.0282
	r	0.406	0.043	0.854	0.894	0.905	0.866	0.911	0.934	0.932
	n	4	4	4	4	4	4	4	8	8
	p	0.59	0.96	0.15	0.11	0.10	0.13	0.089	0.0007	0.0009

Precipitation-Elevation Regressions	parameter	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
	intercept (in)	0.360	0.715	0.109	-0.829	-0.980	-0.996	-0.761	0.037	0.024
	slope	0.00002	-0.00001	0.00010	0.00025	0.00027	0.00029	0.00027	0.00020	0.00017
	r	0.275	0.088	0.768	0.848	0.846	0.824	0.897	0.929	0.924
	n	4	4	4	4	4	4	4	8	8
	p	0.72	0.91	0.23	0.15	0.15	0.18	0.10	0.0009	0.0010

[1] values corrected for measurement interval

[2] two values are shown where different for 24-hr and daily intervals than for shorter durations; weighted averages used for distance and elevation for combined records

Table 7

Estimated 100-Year Annual Maximum Precipitation For Stations with ≥15 Years of Record [1]

Station	Approximate Distance From Range Crest (km) [2]	Elevation (ft) [2]	Period of Record (yr) [2]	15 min (in)	30 min (in)	1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
Quemezon SNOTEL	0.2	9500	22	-	-	-	-	-	-	-	4.140	3.622
TA-16	5.9	7635	24	-	-	-	-	-	-	-	3.395	2.971
North Community	7.2	7420	17	-	-	-	-	-	-	-	3.311	2.897
TA-6, TA-59, Los Alamos	7.9/8.3	7400/7370	23/80	1.139	1.522	2.032	2.531	2.576	2.824	2.843	3.176	2.779
TA-49	12.0	7045	15	1.430	2.004	2.348	2.380	2.383	2.520	2.600	3.314	2.594
TA-53, East Gate	13.5	7000	21	1.271	1.684	2.123	2.508	2.648	2.955	2.834	3.084	2.781
TA-74	16.6	6370	22	-	-	-	-	-	-	-	2.912	2.548
TA-54, Area G, White Rock	16.9/18.4	6590/6430	16/38	1.196	1.730	1.967	2.095	2.164	2.329	2.394	2.939	2.572

Precipitation-Distance Regressions	**parameter**	**15 min**	**30 min**	**1 hr**	**2 hr**	**3 hr**	**6 hr**	**12 hr**	**24 hr**	**daily**
	intercept (in)	1.198	1.502	2.233	2.926	2.926	3.213	3.214	3.880	3.378
	slope	0.0048	0.0185	-0.0091	-0.0435	-0.0384	-0.0442	-0.0434	-0.0581	-0.0519
	r	0.143	0.345	0.205	0.811	0.661	0.579	0.755	0.901	0.892
	n	4	4	4	4	4	4	4	8	8
	p	0.74	0.96	0.43	0.21	0.39	0.52	0.34	0.0023	0.0029

Precipitation-Elevation Regressions	**parameter**	**15 min**	**30 min**	**1 hr**	**2 hr**	**3 hr**	**6 hr**	**12 hr**	**24 hr**	**daily**
	intercept (in)	1.567	3.247	1.306	-1.383	-1.059	-1.491	-1.145	0.431	0.280
	slope	-0.00004	-0.00022	0.00012	0.00054	0.00050	0.00059	0.00054	0.00039	0.00035
	r	0.115	0.357	0.231	0.889	0.764	0.689	0.841	0.981	0.979
	n	4	4	4	4	4	4	4	8	8
	p	0.70	0.92	0.39	0.20	0.39	0.51	0.34	0.00002	0.00002

[1] values corrected for measurement interval

[2] two values are shown where different for 24-hr and daily intervals than for shorter durations; weighted averages used for distance and elevation for combined records

PRECIPITATION-FREQUENCY RELATIONS

Spatial variations in precipitation-frequency relations across the study area were estimated based on data from the stations with the longest periods of record (≥ 15 yr, Tables 6 and 7) and linear regressions between precipitation and distance from the crest of the Sierra de los Valles, interpolating to obtain values for return periods between 2 and 100 yr. This follows the general process used previously in establishing regional precipitation-frequency relations for New Mexico (Miller et al., 1973). Gumbel extreme value precipitation plots with these data are provided in Appendix B.

The precipitation-distance regressions in Tables 6 and 7 are only statistically significant ($p < 0.05$) for 24-hr and daily intervals, which suggests the possibility that no east-west variations in 15-min to 12-hr precipitation exist across the study area. However, the fact that the slopes of the 2-hr to 12-hr regressions in the distance plots are similar to that for the-24-hr regressions (Figure 13) provides evidence that they indicate a true east-west trend of increasing precipitation for different durations and return periods. Therefore, despite the absence of statistically significant relations, these regressions are assumed to provide the best estimate of east-west variations in precipitation across the study area.

The estimated 2-yr return period regressions in Table 6 are more reliable than the 100-yr regressions in Table 7 because the 2-yr regressions are for a time period that is much shorter than the period of record, whereas the 100-yr regressions require extrapolation beyond the period of record. The fact that r values are higher and p values are lower for the 2-yr regressions than the 100-yr regressions is consistent with this. Because of the greater reliability of the 2-yr return period regressions, they were used to provide a check on the 100-yr regressions. Specifically, the 2-yr regressions plotted in Figure 13 were first used to determine the general patterns of east-west variations in maximum precipitation as a function of duration. Then, it was judged whether the patterns displayed by the 100-yr regressions were consistent with the 2-yr regressions. If inconsistent, this was used as a basis for potentially modifying the equations describing 100-yr precipitation.

As shown in the precipitation-distance plots of Figure 13, the east-west patterns displayed by the estimated 2-yr precipitation amounts fall into two general groups, one for durations of 15 min to 1 hr and a second for durations of 2 hr to 24 hr. In the first group, slopes are low or nearly flat, indicating either slight increases or no increases in 2-yr precipitation amounts in the higher elevation western part of the study area relative to the lower elevation eastern part. In the second group, steeper increases in precipitation occur from east to west, with progressive increases in precipitation with increasing duration for all locations. An additional observation is that the estimated 1-hr and 2-hr 2-yr precipitation amounts are virtually identical at the eastern edge of the study area, and progressively diverge to the west.

The east-west patterns displayed by the estimated 100-yr precipitation amounts in Figure 13 fall into the same general groups as 2-yr precipitation (durations of ≤ 1 hr and ≥ 2 hr), and also indicate that estimated 1-hr and 2-hr precipitation are very similar to the east and diverge to the west. However, within the two groups there are some differences between 2-yr and 100-yr estimates. In the first group, the 100-yr regressions indicate positive slopes for durations of 15 min and 30 min, with predicted precipitation increasing from west to east, in contrast to the nearly flat or low negative slopes for the 2-yr regressions. In the second group, the 100-yr regressions indicate less difference between 2-hr and 3-hr precipitation to the west and between 6-hr and 12-hr precipitation across the study area than present in the 2-yr regressions (Figure 13).

The predicted decreases in 100-yr 15-min and 30-min precipitation from east to west are not considered reliable due to inconsistencies with 2-yr precipitation and uncertainties inherent in extrapolating beyond the period of record. Because of this, the regressions are modified by setting their slopes to zero, which is consistent with the low slopes of the 15-min and 30-min 2-yr regressions. Their intercepts are set to the average of the estimated 100-yr values at the four stations (1.259" and 1.735" for 15-min and 30-min durations, respectively).

The predicted similarities of 100-yr 2-hr and 3-hr precipitation to the west and in 100-yr 6-hr and 12-hr precipitation across the study area may also not be reliable. However, there is not considered to be sufficient basis for choosing how to adjust the 100-yr regressions to make them more consistent with the 2-yr regressions (i.e., whether to adjust slopes and/or intercepts for certain regressions). Therefore, the 100-yr 2-hr to 12-hr regressions are not modified.

Table 8 summarizes the parameters of the precipitation-distance equations that are discussed above, which are derived from precipitation-frequency relations using data corrected for the measurement interval. Table 8 also presents equivalent parameters for equations that have been modified to be consistent with statistics generated from 15-min or 1-hr measurement interval data. The original equations, those derived from data corrected for the measurement interval, are most appropriate for estimating rainfall amounts for various durations and return periods for use in hydrologic modeling or for estimating the return periods of rainfall amounts measured with data from gages with basically continuous measurements (e.g., tipping bucket gages). The latter equations are intended for use in estimating return periods of rainfall amounts obtained from 15-min or 1-hr measurement intervals, although such estimates are inherently less certain, particularly for short duration rainfall.

Tables 9, 10, and 11 show precipitation-frequency estimates derived from the equations in Table 8 for a series of return periods and distances from the range crest, for uses where maximum annual precipitation amounts are most appropriate. Tables 12, 13, and 14 show precipitation-frequency estimates that are based on the same equations but that are corrected to equivalent values in partial-duration series, using the correction factors in Table 4. Partial-duration series estimates are most useful for precipitation events with return periods of 10 years or less. For return periods of greater than 10 years, annual series and partial-duration series statistics provide virtually identical estimates.

COMPARISON WITH OTHER STUDIES

Estimates of maximum annual precipitation amounts in this area for durations of 24 hr or less and different return periods have been made in several previous studies (Miller et al., 1973; Bowen, 1990; McLin, 1992; McLin et al., 2001a), and an update of Miller et al. (1973; NOAA Atlas 2) was recently released (NOAA Atlas 14; NOAA, 2003). The relationship of 15-min and 30-min precipitation amounts to 1-hr amounts has also been examined by Arkell and Richards

Table 8
Precipitation-Distance Parameters For Estimating Maximum Annual Precipitation

Return Interval (yr)	Parameter	Precipitation Interval								
		15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
		Regressions Derived From Values Corrected For Measurement Interval								
2	intercept (in)	0.519	0.658	0.906	1.178	1.271	1.400	1.478	1.801	1.576
2	slope	-0.0024	-0.0004	-0.0095	-0.0230	-0.0261	-0.0274	-0.0248	-0.0320	-0.0282
100	intercept (in)	1.259	1.735	2.233	2.926	2.926	3.213	3.214	3.880	3.378
100	slope	0.0000	0.0000	-0.0091	-0.0435	-0.0384	-0.0442	-0.0434	-0.0581	-0.0519
		Regressions For Use With Data Collected in 15-Minute Measurement Intervals								
2	intercept (in)	0.454	0.617	0.878	1.159	1.258	1.393	1.474	1.798	1.576
2	slope	-0.0021	-0.0004	-0.0092	-0.0226	-0.0258	-0.0272	-0.0247	-0.0320	-0.0282
100	intercept (in)	1.102	1.627	2.163	2.880	2.895	3.196	3.205	3.875	3.378
100	slope	0.0000	0.0000	-0.0089	-0.0428	-0.0380	-0.0440	-0.0433	-0.0580	-0.0519
		Regressions For Use With Data Collected in 1-Hour Measurement Intervals								
2	intercept (in)	-	-	0.793	1.104	1.218	1.371	1.462	1.791	1.576
2	slope	-	-	-0.0084	-0.0215	-0.0250	-0.0268	-0.0246	-0.0319	-0.0282
100	intercept (in)	-	-	1.953	2.743	2.804	3.146	3.180	3.860	3.378
100	slope	-	-	-0.0080	-0.0408	-0.0368	-0.0433	-0.0430	-0.0578	-0.0519

Table 9
Precipitation-Frequency Estimates For Maximum Annual Precipitation, Corrected For Measurement Interval

Distance From Range Crest (km)	Return Period (yr)	Exceedance Probability	Precipitation								
			15 min (in)	30 min (in)	1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
0	2	0.5	0.52	0.66	0.91	1.18	1.27	1.40	1.48	1.80	1.58
0	5	0.2	0.72	0.95	1.26	1.65	1.71	1.89	1.94	2.36	2.06
0	10	0.1	0.85	1.14	1.50	1.96	2.01	2.21	2.25	2.73	2.38
0	25	0.04	1.01	1.38	1.79	2.35	2.38	2.61	2.64	3.19	2.78
0	50	0.02	1.14	1.56	2.01	2.64	2.65	2.91	2.93	3.54	3.08
0	100	0.01	1.26	1.74	2.23	2.93	2.93	3.21	3.21	3.88	3.38
5	2	0.5	0.51	0.66	0.86	1.06	1.14	1.26	1.35	1.64	1.43
5	5	0.2	0.71	0.94	1.21	1.50	1.57	1.73	1.79	2.16	1.89
5	10	0.1	0.84	1.14	1.45	1.80	1.85	2.03	2.08	2.51	2.18
5	25	0.04	1.01	1.38	1.75	2.16	2.21	2.42	2.45	2.94	2.56
5	50	0.02	1.13	1.56	1.97	2.44	2.47	2.71	2.73	3.27	2.84
5	100	0.01	1.26	1.74	2.19	2.71	2.73	2.99	3.00	3.59	3.12
10	2	0.5	0.49	0.65	0.81	0.95	1.01	1.13	1.23	1.48	1.29
10	5	0.2	0.70	0.94	1.17	1.36	1.42	1.57	1.64	1.97	1.71
10	10	0.1	0.83	1.14	1.40	1.63	1.69	1.86	1.92	2.29	1.99
10	25	0.04	1.01	1.38	1.70	1.98	2.03	2.23	2.27	2.70	2.34
10	50	0.02	1.13	1.56	1.92	2.24	2.29	2.50	2.52	3.00	2.60
10	100	0.01	1.26	1.74	2.14	2.49	2.54	2.77	2.78	3.30	2.86
15	2	0.5	0.48	0.65	0.76	0.83	0.88	0.99	1.11	1.32	1.15
15	5	0.2	0.69	0.94	1.12	1.22	1.27	1.41	1.50	1.77	1.54
15	10	0.1	0.83	1.13	1.36	1.47	1.53	1.68	1.75	2.07	1.80
15	25	0.04	1.00	1.38	1.65	1.80	1.86	2.03	2.08	2.45	2.12
15	50	0.02	1.13	1.56	1.88	2.04	2.11	2.29	2.32	2.73	2.36
15	100	0.01	1.26	1.74	2.10	2.27	2.35	2.55	2.56	3.01	2.60
20	2	0.5	0.47	0.65	0.72	0.72	0.75	0.85	0.98	1.16	1.01
20	5	0.2	0.68	0.94	1.07	1.08	1.13	1.25	1.35	1.58	1.37
20	10	0.1	0.82	1.13	1.31	1.31	1.38	1.51	1.59	1.85	1.60
20	25	0.04	1.00	1.38	1.61	1.61	1.69	1.84	1.89	2.20	1.90
20	50	0.02	1.13	1.56	1.83	1.83	1.93	2.09	2.12	2.46	2.12
20	100	0.01	1.26	1.74	2.05	2.06	2.16	2.33	2.35	2.72	2.34

Table 10
Precipitation-Frequency Estimates For Maximum Annual Precipitation, Modified For 15-Minute Measurement Interval

Distance From Range Crest (km)	Return Period (yr)	Exceedance Probability	Precipitation								
			15 min (in)	30 min (in)	1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
0	2	0.5	0.45	0.62	0.88	1.16	1.26	1.39	1.47	1.80	1.58
0	5	0.2	0.63	0.89	1.22	1.62	1.70	1.88	1.94	2.35	2.06
0	10	0.1	0.74	1.07	1.45	1.93	1.99	2.20	2.24	2.72	2.38
0	25	0.04	0.89	1.29	1.74	2.31	2.35	2.60	2.63	3.19	2.78
0	50	0.02	0.99	1.46	1.95	2.60	2.63	2.90	2.92	3.53	3.08
0	100	0.01	1.10	1.63	2.16	2.88	2.90	3.20	3.21	3.88	3.38
5	2	0.5	0.44	0.61	0.83	1.05	1.13	1.26	1.35	1.64	1.43
5	5	0.2	0.62	0.89	1.18	1.48	1.55	1.72	1.79	2.16	1.89
5	10	0.1	0.74	1.07	1.40	1.77	1.83	2.02	2.08	2.50	2.18
5	25	0.04	0.88	1.29	1.69	2.13	2.18	2.41	2.45	2.94	2.56
5	50	0.02	0.99	1.46	1.91	2.40	2.45	2.69	2.72	3.26	2.84
5	100	0.01	1.10	1.63	2.12	2.67	2.71	2.98	2.99	3.59	3.12
10	2	0.5	0.43	0.61	0.79	0.93	1.00	1.12	1.23	1.48	1.29
10	5	0.2	0.61	0.88	1.13	1.34	1.41	1.56	1.64	1.96	1.71
10	10	0.1	0.73	1.06	1.36	1.61	1.67	1.85	1.91	2.29	1.99
10	25	0.04	0.88	1.29	1.65	1.95	2.01	2.21	2.26	2.69	2.34
10	50	0.02	0.99	1.46	1.86	2.20	2.27	2.49	2.52	3.00	2.60
10	100	0.01	1.10	1.63	2.07	2.45	2.52	2.76	2.77	3.29	2.86
15	2	0.5	0.42	0.61	0.74	0.82	0.87	0.98	1.10	1.32	1.15
15	5	0.2	0.60	0.88	1.08	1.20	1.26	1.40	1.49	1.77	1.54
15	10	0.1	0.72	1.06	1.31	1.45	1.52	1.67	1.75	2.07	1.80
15	25	0.04	0.88	1.29	1.60	1.77	1.84	2.02	2.07	2.45	2.12
15	50	0.02	0.99	1.46	1.82	2.00	2.09	2.28	2.32	2.73	2.36
15	100	0.01	1.10	1.63	2.03	2.24	2.33	2.54	2.56	3.00	2.60
20	2	0.5	0.41	0.61	0.69	0.71	0.74	0.85	0.98	1.16	1.01
20	5	0.2	0.60	0.88	1.04	1.06	1.11	1.24	1.34	1.58	1.37
20	10	0.1	0.72	1.06	1.27	1.29	1.36	1.50	1.58	1.85	1.60
20	25	0.04	0.87	1.29	1.56	1.59	1.67	1.83	1.89	2.20	1.90
20	50	0.02	0.99	1.46	1.77	1.81	1.91	2.07	2.12	2.46	2.12
20	100	0.01	1.10	1.63	1.99	2.02	2.14	2.32	2.34	2.71	2.34

Table 11
Precipitation-Frequency Estimates For Maximum Annual Precipitation, Modified For 1-Hour Measurement Interval

Distance From Range Crest (km)	Return Period (yr)	Exceedance Probability	Precipitation						
			1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
0	2	0.5	0.79	1.10	1.22	1.37	1.46	1.79	1.58
0	5	0.2	1.10	1.54	1.64	1.85	1.92	2.35	2.06
0	10	0.1	1.31	1.83	1.92	2.16	2.23	2.71	2.38
0	25	0.04	1.57	2.20	2.28	2.56	2.61	3.18	2.78
0	50	0.02	1.76	2.47	2.54	2.85	2.90	3.52	3.08
0	100	0.01	1.95	2.74	2.80	3.15	3.18	3.86	3.38
5	2	0.5	0.75	1.00	1.09	1.24	1.34	1.63	1.43
5	5	0.2	1.06	1.41	1.50	1.69	1.77	2.15	1.89
5	10	0.1	1.27	1.68	1.77	1.99	2.06	2.49	2.18
5	25	0.04	1.53	2.03	2.11	2.37	2.43	2.93	2.56
5	50	0.02	1.72	2.28	2.37	2.65	2.70	3.25	2.84
5	100	0.01	1.91	2.54	2.62	2.93	2.97	3.57	3.12
10	2	0.5	0.71	0.89	0.97	1.10	1.22	1.47	1.29
10	5	0.2	1.02	1.28	1.36	1.53	1.63	1.96	1.71
10	10	0.1	1.23	1.53	1.62	1.82	1.90	2.28	1.99
10	25	0.04	1.49	1.86	1.95	2.18	2.24	2.68	2.34
10	50	0.02	1.68	2.10	2.19	2.45	2.50	2.98	2.60
10	100	0.01	1.87	2.34	2.44	2.71	2.75	3.28	2.86
15	2	0.5	0.67	0.78	0.84	0.97	1.09	1.31	1.15
15	5	0.2	0.98	1.14	1.22	1.38	1.48	1.76	1.54
15	10	0.1	1.19	1.38	1.47	1.65	1.74	2.06	1.80
15	25	0.04	1.45	1.68	1.79	1.99	2.06	2.44	2.12
15	50	0.02	1.64	1.91	2.02	2.24	2.30	2.72	2.36
15	100	0.01	1.83	2.13	2.25	2.50	2.54	2.99	2.60
20	2	0.5	0.63	0.67	0.72	0.83	0.97	1.15	1.01
20	5	0.2	0.94	1.01	1.08	1.22	1.33	1.57	1.37
20	10	0.1	1.15	1.23	1.32	1.48	1.57	1.84	1.60
20	25	0.04	1.41	1.51	1.62	1.80	1.87	2.19	1.90
20	50	0.02	1.60	1.72	1.85	2.04	2.10	2.45	2.12
20	100	0.01	1.79	1.93	2.07	2.28	2.32	2.70	2.34

Table 12
Precipitation-Frequency Estimates Using Partial-Duration Series Statistics, Corrected For Measurement Interval

Distance From Range Crest (km)	Return Period (yr)	Exceedance Probability	Precipitation								
			15 min (in)	30 min (in)	1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
0	0.5	0.8621	0.34	0.39	0.58	0.74	0.86	0.95	1.05	1.28	1.13
0	1	0.6329	0.45	0.56	0.79	1.03	1.13	1.24	1.33	1.62	1.42
0	2	0.3937	0.58	0.74	1.01	1.31	1.40	1.54	1.61	1.96	1.71
0	5	0.1812	0.74	0.97	1.30	1.69	1.76	1.93	1.99	2.41	2.11
0	10	0.0952	0.86	1.15	1.51	1.98	2.03	2.23	2.27	2.75	2.40
5	0.5	0.8621	0.32	0.39	0.53	0.65	0.75	0.83	0.95	1.16	1.02
5	1	0.6329	0.44	0.56	0.74	0.92	1.00	1.11	1.21	1.47	1.29
5	2	0.3937	0.56	0.74	0.96	1.19	1.26	1.40	1.48	1.79	1.56
5	5	0.1812	0.73	0.97	1.25	1.55	1.61	1.77	1.84	2.21	1.93
5	10	0.0952	0.85	1.15	1.47	1.81	1.87	2.05	2.10	2.53	2.20
10	0.5	0.8621	0.31	0.39	0.48	0.57	0.63	0.72	0.84	1.03	0.91
10	1	0.6329	0.43	0.56	0.69	0.81	0.88	0.98	1.09	1.32	1.16
10	2	0.3937	0.55	0.74	0.91	1.07	1.13	1.25	1.35	1.62	1.41
10	5	0.1812	0.72	0.97	1.20	1.40	1.46	1.61	1.68	2.01	1.75
10	10	0.0952	0.84	1.15	1.42	1.65	1.71	1.88	1.94	2.31	2.01
15	0.5	0.8621	0.29	0.38	0.43	0.48	0.52	0.60	0.74	0.90	0.79
15	1	0.6329	0.42	0.56	0.65	0.71	0.75	0.85	0.98	1.17	1.03
15	2	0.3937	0.54	0.74	0.87	0.94	0.99	1.11	1.22	1.45	1.26
15	5	0.1812	0.71	0.97	1.15	1.26	1.31	1.45	1.53	1.82	1.58
15	10	0.0952	0.84	1.15	1.37	1.49	1.55	1.70	1.77	2.09	1.81
20	0.5	0.8621	0.28	0.38	0.38	0.39	0.40	0.49	0.64	0.77	0.68
20	1	0.6329	0.40	0.56	0.60	0.60	0.63	0.72	0.86	1.02	0.90
20	2	0.3937	0.53	0.73	0.82	0.82	0.86	0.97	1.09	1.28	1.11
20	5	0.1812	0.70	0.97	1.11	1.11	1.16	1.29	1.38	1.62	1.40
20	10	0.0952	0.83	1.15	1.33	1.33	1.39	1.53	1.60	1.87	1.62

Table 13

Precipitation-Frequency Estimates Using Partial-Duration Series Statistics, Modified For 15-Minute Measurement Interval

Distance From Range Crest (km)	Return Period (yr)	Exceedance Probability	Precipitation								
			15 min (in)	30 min (in)	1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
0	0.5	0.8621	0.29	0.37	0.56	0.73	0.85	0.95	1.04	1.28	1.13
0	1	0.6329	0.40	0.53	0.77	1.01	1.11	1.24	1.32	1.62	1.42
0	2	0.3937	0.50	0.69	0.98	1.29	1.38	1.53	1.61	1.96	1.71
0	5	0.1812	0.64	0.91	1.26	1.66	1.74	1.92	1.98	2.41	2.11
0	10	0.0952	0.75	1.08	1.47	1.95	2.01	2.22	2.27	2.75	2.40
5	0.5	0.8621	0.28	0.36	0.51	0.64	0.74	0.83	0.94	1.16	1.02
5	1	0.6329	0.39	0.53	0.72	0.91	0.99	1.11	1.21	1.47	1.29
5	2	0.3937	0.49	0.69	0.93	1.17	1.25	1.39	1.48	1.79	1.56
5	5	0.1812	0.64	0.91	1.21	1.52	1.59	1.76	1.83	2.21	1.93
5	10	0.0952	0.74	1.08	1.42	1.79	1.85	2.04	2.10	2.53	2.20
10	0.5	0.8621	0.27	0.36	0.47	0.56	0.62	0.71	0.84	1.03	0.91
10	1	0.6329	0.37	0.52	0.67	0.80	0.87	0.98	1.09	1.32	1.16
10	2	0.3937	0.48	0.69	0.88	1.05	1.12	1.25	1.35	1.62	1.41
10	5	0.1812	0.63	0.91	1.16	1.38	1.44	1.60	1.68	2.01	1.75
10	10	0.0952	0.74	1.08	1.37	1.63	1.69	1.87	1.93	2.31	2.01
15	0.5	0.8621	0.25	0.36	0.42	0.47	0.51	0.60	0.74	0.90	0.79
15	1	0.6329	0.36	0.52	0.63	0.70	0.74	0.85	0.98	1.17	1.03
15	2	0.3937	0.47	0.69	0.84	0.93	0.98	1.10	1.21	1.45	1.26
15	5	0.1812	0.62	0.91	1.12	1.24	1.30	1.44	1.53	1.81	1.58
15	10	0.0952	0.73	1.08	1.33	1.47	1.54	1.69	1.77	2.09	1.81
20	0.5	0.8621	0.24	0.36	0.37	0.38	0.40	0.48	0.64	0.77	0.68
20	1	0.6329	0.35	0.52	0.58	0.59	0.62	0.72	0.86	1.02	0.90
20	2	0.3937	0.47	0.69	0.79	0.81	0.85	0.96	1.08	1.28	1.11
20	5	0.1812	0.61	0.91	1.07	1.09	1.15	1.28	1.38	1.62	1.40
20	10	0.0952	0.73	1.07	1.28	1.31	1.38	1.52	1.60	1.87	1.62

Table 14
Precipitation-Frequency Estimates Using Partial-Duration Series Statistics, Modified For 1-Hour Measurement Interval

Distance From Range Crest (km)	Return Period (yr)	Exceedance Probability	Precipitation						
			1 hr (in)	2 hr (in)	3 hr (in)	6 hr (in)	12 hr (in)	24 hr (in)	daily (in)
0	0.5	0.8621	0.50	0.70	0.82	0.93	1.04	1.28	1.13
0	1	0.6329	0.69	0.96	1.08	1.22	1.31	1.61	1.42
0	2	0.3937	0.88	1.23	1.34	1.51	1.59	1.95	1.71
0	5	0.1812	1.13	1.59	1.68	1.89	1.97	2.40	2.11
0	10	0.0952	1.32	1.85	1.94	2.18	2.25	2.74	2.40
5	0.5	0.8621	0.46	0.61	0.71	0.82	0.94	1.15	1.02
5	1	0.6329	0.65	0.86	0.96	1.09	1.20	1.46	1.29
5	2	0.3937	0.84	1.12	1.21	1.37	1.46	1.78	1.56
5	5	0.1812	1.09	1.45	1.54	1.73	1.82	2.20	1.93
5	10	0.0952	1.28	1.70	1.79	2.01	2.08	2.52	2.20
10	0.5	0.8621	0.42	0.53	0.60	0.70	0.84	1.02	0.91
10	1	0.6329	0.61	0.76	0.84	0.96	1.08	1.32	1.16
10	2	0.3937	0.80	1.00	1.08	1.23	1.33	1.61	1.41
10	5	0.1812	1.05	1.31	1.40	1.58	1.67	2.00	1.75
10	10	0.0952	1.24	1.55	1.64	1.84	1.92	2.30	2.01
15	0.5	0.8621	0.38	0.45	0.49	0.59	0.74	0.90	0.79
15	1	0.6329	0.57	0.66	0.72	0.84	0.97	1.17	1.03
15	2	0.3937	0.76	0.88	0.95	1.09	1.20	1.44	1.26
15	5	0.1812	1.01	1.18	1.26	1.42	1.52	1.81	1.58
15	10	0.0952	1.20	1.40	1.49	1.67	1.75	2.08	1.81
20	0.5	0.8621	0.34	0.36	0.38	0.48	0.64	0.77	0.68
20	1	0.6329	0.52	0.56	0.60	0.71	0.85	1.02	0.90
20	2	0.3937	0.72	0.77	0.82	0.95	1.08	1.27	1.11
20	5	0.1812	0.97	1.04	1.11	1.26	1.37	1.61	1.40
20	10	0.0952	1.16	1.25	1.34	1.50	1.59	1.86	1.62

(1986) for a larger region that includes the study area. In this section we compare precipitation-frequency estimates from these studies with estimates developed in the previous section, using the equations in Table 8. These comparisons are made to evaluate how the estimates developed in this study from local precipitation data relate to those made in the broader region, and how these locally derived estimates relate to previous estimates that were based on a more limited data set from the Pajarito Plateau.

Table 15 compares the estimates of Bowen (1990, p. 156) and this study for durations of 15 min to 12 hr and daily precipitation for 2-yr and 100-yr return periods. Estimates in this study are either higher or lower than the earlier estimates of Bowen (1990), depending on the location, duration, and return period. The estimates in this study differ the most for the estimated 100-yr 15-min precipitation at TA-59 (31% less) and the estimated 100-yr 3-hr precipitation at Area G (25% more). In general, values estimated in this study are higher than Bowen (1990) for the eastern Pajarito Plateau (Area G) and lower for the western plateau (TA-59).

Table 15

Comparison With Estimated Precipitation From Bowen

Station	Approximate Distance From Range Crest (km)	Study	Return Period (yr)	Precipitation					
				15 min (in)	30 min (in)	1 hr (in)	3 hr (in)	12 hr (in)	daily (in)
TA-59	7.9	Bowen (1990)	2	0.59	0.84	1.03	1.24	1.47	1.45
TA-59	7.9	this study	2	0.50	0.65	0.83	1.06	1.28	1.35
TA-59	7.9	Bowen (1990)	100	1.82	2.00	2.25	2.52	2.74	3.06
TA-59	7.9	this study	100	1.26	1.74	2.16	2.62	2.87	2.97
Area G	15.8	Bowen (1990)	2	0.49	0.62	0.69	0.81	1.06	1.18
Area G	15.8	this study	2	0.48	0.65	0.76	0.86	1.09	1.13
Area G	15.8	Bowen (1990)	100	1.46	1.62	1.75	1.86	2.11	2.52
Area G	15.8	this study	100	1.26	1.74	2.09	2.32	2.53	2.56

Table 16 and Figure 14 compare estimates from NOAA Atlas 14 (NOAA, 2003), Miller et al. (1973, NOAA Atlas 2), and this study for 2-yr and 100-yr precipitation at the east and west sides of the study area. The NOAA Atlas 2 values utilize a conversion of 2-yr relations from annual maximum series data to partial duration statistics (Miller et al., 1973, p. 3), which increases all values by a factor of 1.136, and we have made this same conversion to estimates from this study and from NOAA Atlas 14 to allow valid comparisons. (The NOAA Atlas 14 values utilize annual series relations, and are therefore directly comparable to the values in this study.) No similar conversions are made for 100-yr return period amounts.

Table 16
Comparison With Estimated Precipitation From NOAA

Location	Approximate Distance From Range Crest (km)	Study	Return Period (yr)	Series	Precipitation			
					15 min (in)	1 hr (in)	6 hr (in)	24 hr (in)
Pajarito Mountain	0	NOAA Atlas 14	2	annual	0.51	0.85	1.24	1.75
Pajarito Mountain	0	this study	2	annual	0.52	0.91	1.40	1.80
Pajarito Mountain	0	Miller et al. (1973)	2	partial duration	-	-	1.52	2.07
Pajarito Mountain	0	NOAA Atlas 14	2	partial duration	-	-	1.41	1.99
Pajarito Mountain	0	this study	2	partial duration	-	-	1.59	2.05
Pajarito Mountain	0	Miller et al. (1973)	100	annual	-	-	3.22	4.23
Pajarito Mountain	0	NOAA Atlas 14	100	annual	1.38	2.29	3.06	4.10
Pajarito Mountain	0	this study	100	annual	1.26	2.23	3.21	3.88
White Rock, east side	20	NOAA Atlas 14	2	annual	0.42	0.71	1.02	1.38
White Rock, east side	20	this study	2	annual	0.47	0.72	0.85	1.16
White Rock, east side	20	Miller et al. (1973)	2	partial duration	-	-	1.14	1.49
White Rock, east side	20	NOAA Atlas 14	2	partial duration	-	-	1.16	1.57
White Rock, east side	20	this study	2	partial duration	-	-	0.97	1.32
White Rock, east side	20	Miller et al. (1973)	100	annual	-	-	2.55	3.29
White Rock, east side	20	NOAA Atlas 14	100	annual	1.19	1.98	2.57	3.23
White Rock, east side	20	this study	100	annual	1.26	2.05	2.33	2.72

As shown in Figure 14, the NOAA Atlas 14 values are either essentially identical to the Atlas 2 values or somewhat lower, and the predicted relations from this study show generally similar trends and values to the NOAA estimates. The NOAA studies indicate that linear relations between precipitation and distance provide reasonable approximations across the study area, although they do predict some relatively low-magnitude changes in the east-west precipitation gradient that are presumably related to topographic variations (Figure 14); changes of this magnitude can not be resolved with available data from the study area. The east-west gradients from the NOAA studies are generally similar to those obtained in this study, with the gradients in this study being somewhat steeper for longer duration (larger predicted change from east to west for 6 hr and 24 hr precipitation from this study than from NOAA). The biggest differences between NOAA Atlas 14 and the analysis presented in this report are in the predicted 2-yr and 100-yr 6-hr and 24-hr precipitation amounts for the east side of the study area, which are 9-16% lower in this study (Table 16). The estimates in this study are also locally higher than NOAA Atlas 14, up to 13% higher for the 2-yr 6-hr precipitation at Pajarito Mountain and 12% higher for the 2-yr 15-min precipitation at White Rock. Elsewhere, the differences between this study and NOAA Atlas 14 are less than 10%.

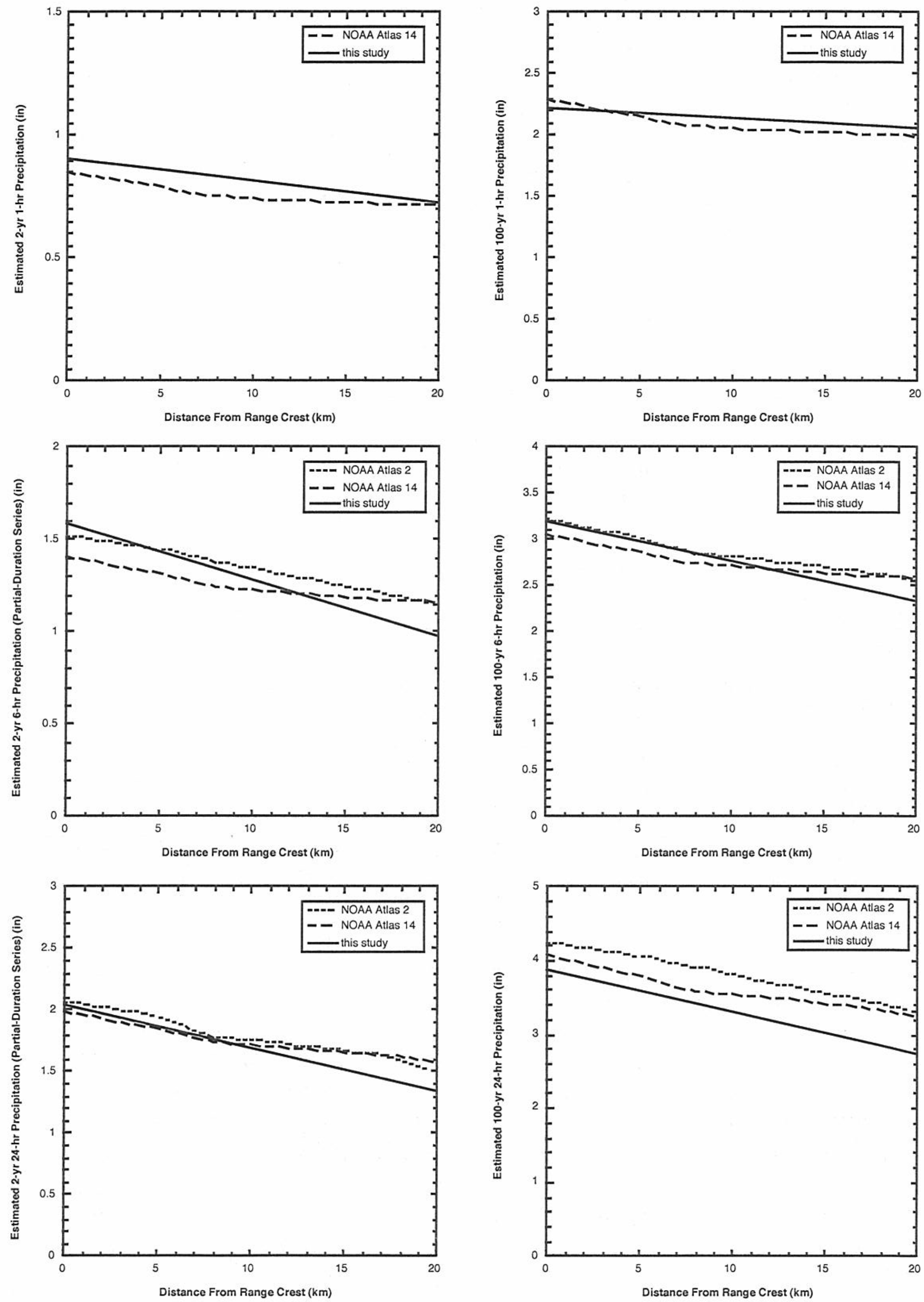

Figure 14. Comparison of precipitation-distance regressions derived in this study with those from Miller et al. (1973; NOAA Atlas 2) and NOAA Atlas 14 (NOAA, 2003).

Table 17 compares the estimates of McLin (1992, p. 12) and McLin et al. (2001a, p. 24) and this study for 2-yr and 100-yr 6-hr precipitation for a series of sub-watersheds spanning the east-west extent of the study area. Values estimated in this study are consistently higher for the lower elevation eastern areas and lower for the higher elevation western areas. The differences are greatest for estimated 2-yr precipitation, with the estimates of McLin et al. (2001a) being close to twice that in this study to the west, and one fourth to the east. These differences derive from the assumption of a linear precipitation-elevation relation, and the smaller east-to-west differences in this study than those previously presented by Bowen (1990).

Table 17

Comparison With Estimated 6-Hour Precipitation From McLin et al.

Sub-basin	Approximate Elevation of Basin Centroid (ft)	Approximate Distance From Range Crest (km)	Return Period (yr)	McLin (1992) 6-hr (in)	McLin et al. (2001a) 6-hr (in)	this study 6-hr (in)
Upper Los Alamos Canyon	9200	2.0	2	2.26	2.53	1.35
Upper Pueblo Canyon	8400	5.2	2	1.84	2.01	1.26
Middle Pueblo Canyon	7300	8.6	2	1.27	1.29	1.16
Lower Pueblo Canyon	6480	15.3	2	0.84	0.75	0.98
Lower Los Alamos Canyon	5600	20.9	2	0.38	0.18	0.83
Upper Los Alamos Canyon	9200	2.0	100	4.23	4.38	3.12
Upper Pueblo Canyon	8400	5.2	100	3.54	3.60	2.98
Middle Pueblo Canyon	7300	8.6	100	2.60	2.53	2.83
Lower Pueblo Canyon	6480	15.3	100	1.61	1.74	2.54
Lower Los Alamos Canyon	5600	20.9	100	1.18	0.88	2.29

An additional parameter of interest is the relation of short duration rainfall amounts to that occurring over longer durations, as intense short-duration rain is particularly important in the generation of runoff in convective storms in this area. Table 18 and Figure 15 compare estimated 15-min and 30-min precipitation amounts as a ratio of 1-hr amounts for 2-yr and 100-yr return periods as derived by Arkell and Richards (1986), NOAA (2003), and in this study. The ratios in Arkell and Richards (1986) are averages for the Rocky Mountains-South region, which extends from west-central New Mexico north to west-central Wyoming, and their analyses tend to be dominated by data from lower elevation stations. They consider the range of their ratios to be about 3500-7000 feet elevation in the south part of this region, and they do not consider them to be necessarily applicable to higher elevations The ratios from NOAA Atlas 14 are virtually identical across the study area.

Table 18
Comparison of Ratio of Estimated 15-Minute and 30-Minute Precipitation to 1-Hour Precipitation

Area	Elevation (ft)	Reference	Return Period (yr)	Ratio of 15-min to 1-hr	Ratio of 30-min to 1-hr
Rocky Mountains-South (average)	3500-7000	Arkell and Richards (1986)	2	0.65	0.83
Los Alamos area	6000-10,500	NOAA Atlas 14	2	0.60	0.80
Eastern Edge of Pajarito Plateau (20 km)	6000-6500	this study	2	0.66	0.91
West-central Pajarito Plateau (10 km)	7150-7350	this study	2	0.61	0.81
Crest of Sierra de los Valles (0 km)	9500-10,500	this study	2	0.57	0.73
Rocky Mountains-South (average)	3500-7000	Arkell and Richards (1986)	100	0.62	0.81
Los Alamos area	6000-10,500	NOAA Atlas 14	100	0.60	0.81
Eastern Edge of Pajarito Plateau (20 km)	6000-6500	this study	100	0.61	0.85
West-central Pajarito Plateau (10 km)	7150-7350	this study	100	0.59	0.81
Crest of Sierra de los Valles (0 km)	9500-10,500	this study	100	0.56	0.78

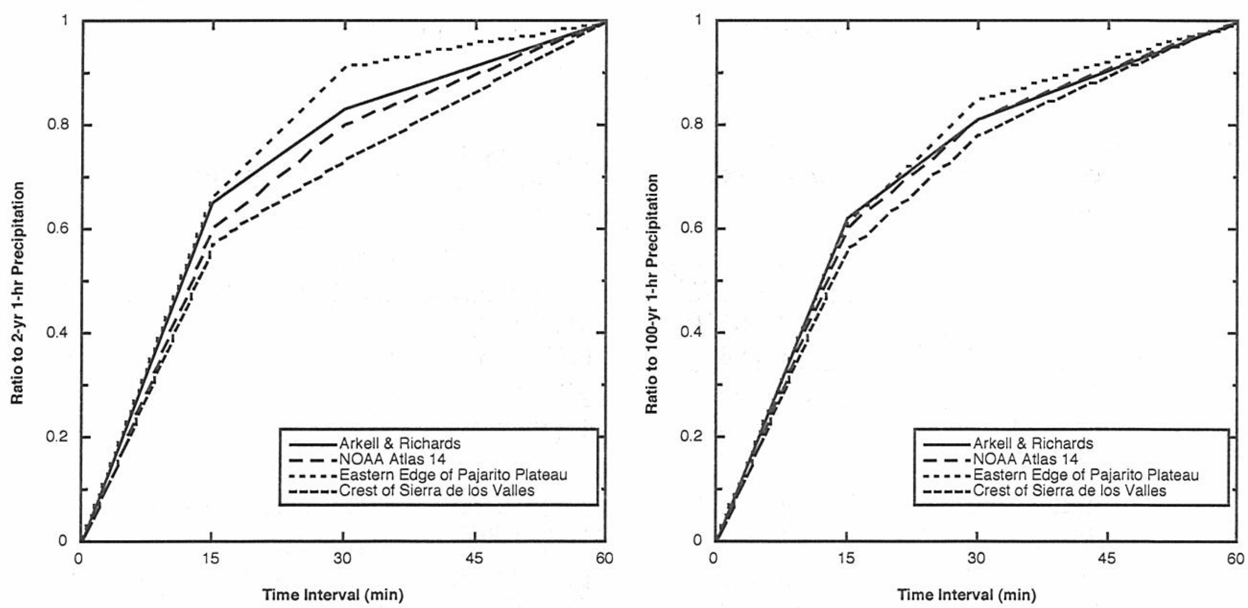

Figure 15. Plots of the ratios of 15-min and 30-min precipitation amounts to 1-hr precipitation amounts for the Rocky Mountains-South region (Arkell and Richards, 1986), from NOAA Atlas 14 (NOAA, 2003), and for the eastern Pajarito Plateau and the Sierra de los Valles (this study).

As shown in Table 18 and Figure 15, the average relations presented by Arkell and Richards (1986) and NOAA Atlas 14 (NOAA, 2003) fall within the range of those derived from this study, showing the same general pattern of the rainfall that occurs in a 15-min period being over 50% of that in a 1-hr period. Both Arkell and Richards (1986) and this study also indicate that the ratios of 15-min and 30-min to 1-hr precipitation are generally lower in 100-yr events than 2-yr events, although the NOAA Atlas 14 indicates these ratios are virtually identical for 2-yr and 100-yr events. It is also notable that the different estimates in Table 18 and Figure 15 are all very similar for 100-yr events, despite the uncertainties which might be expected in estimates of such infrequent events.

Table 19 compares 15-min rainfall as a percentage of 6-hr rainfall for 2-yr and 100-yr return periods as used in the design storm of McLin (1992) and McLin et al (2001a), and as derived from NOAA Atlas 14 (NOAA 2003) and this study. Although the assumed design storm has no east-to-west variations in the ratio of 15 min to 6 hr precipitation, and estimates in NOAA Atlas 14 also indicate little variation, the data in this study indicate that this ratio decreases from east to west across the study area. For the 2-yr 6-hr design storm, comparison with the analyses in this study indicates that the importance of 15-min rainfall is underestimated on the eastern Pajarito Plateau and overestimated in the eastern Jemez Mountains. For the 100-yr 6-hr design storm, the importance of 15-min rainfall is overestimated for all locations, with the overestimate being greatest in the eastern Jemez Mountains. The design storm assumes that 67% of the 100-yr 6-hr rainfall occurs in a 15-min period, whereas the precipitation-frequency relations developed in this study indicate that the ratio of 100-yr 15-min to 100-yr 6-hr precipitation varies from about 0.54 on the eastern plateau to 0.39 at the range crest.

Table 19

Comparison of Ratio of Estimated 15-Minute to 6-Hour Precipitation

Distance From Range Crest (km)	Return Period (yr)	Ratio of 15-min to 6-hr Precipitation (McLin, 1992; McLin et al., 2001a)	Ratio of 15-min to 6-hr Precipitation (NOAA Atlas 14)	Ratio of 15-min to 6-hr Precipitation (this study)
0	2	0.45	0.41	0.37
0	100	0.67	0.34	0.39
10	2	0.45	0.41	0.44
10	100	0.67	0.35	0.45
20	2	0.45	0.42	0.55
20	100	0.67	0.37	0.54

SELECTED PRECIPITATION EVENTS

This section discusses select storms recorded in the local rain gage network that produced relatively high precipitation, that are associated with notable floods, or both, with the goal of providing insight into some specific characteristics of extreme or flood-producing storms in this area. Included are all storms where recorded precipitation amounts equal or exceed estimated 50-yr return period values for one or more durations at a station, and storms that occurred after the Cerro Grande fire that produced significant floods in one or more canyons. Return periods for these storms for a series of durations are estimated using a three-step process. First, 2-yr and 100-yr return period amounts are calculated for each duration that are specific to the measurement interval and location of a station relative to the range crest, using the equations in Table 8. Second, a linear regression is fit to these values using transformed probabilities (equation 3) for the independent variable (x value). Third, the x value corresponding to the measured precipitation amount is obtained from this equation, and the x value is un-transformed to obtain the exceedance probability, which is the inverse of the return period. Calculated return periods for storms discussed in this section are presented in Table 20.

Several caveats are appropriate to consider here. The estimated return periods presented in this section apply to precipitation at a station, and not necessarily to a larger scale. For example, if the size of extreme storm cells is smaller than the size of a watershed, then multiple storms in a 50-yr period would probably occur that equal or exceed 50-yr rainfall intensities somewhere in the watershed. Return periods for rainfall at these larger spatial scales have not yet been addressed in this area. Similarly, the peak intensity in a storm may not be recorded at a station because the locus of highest rainfall intensity may be small in area compared with the spacing of stations. Also, the estimated return periods apply to specific durations, and the 50-yr 1-hr precipitation amount may occur in a different storm than 50-yr 6-hr or 50-yr 24-hr amounts.

October 5, 1911

The highest daily precipitation amount reported in the study area is 3.48" on October 5, 1911, in Los Alamos. The duration and short-term intensities in this storm are unknown, although October storms are typically relatively long duration, low intensity storms. This is a much higher precipitation amount than the next highest daily rainfall in the Los Alamos record (2.51" on June 10, 1913) and has an estimated return period of about 400 yr. In comparison, the return period for 24-hr amounts could be as short as about 100-150 yr if the daily precipitation was equal to the maximum 24-hr precipitation in this storm. This is the first full year of record in Los Alamos, and the reliability of measurements from this period are unknown. Rain gages were manually read at this time, and daily rainfall totals could be affected by differences in the time of measurement between different days.

April 30 (?), 1981

The second highest daily precipitation amount reported in the study area is 3.3" on April 30, 1981, at the Quemezon SNOTEL station. The estimated return period for this much daily rainfall is about 70-80 yr, but the return period could be as low as 30 yr for a 24-hr period if the daily

Table 20
Estimated Return Periods For Selected Historic Storms Using Annual Maximum Series

Month	Day	Year	Station	Parameter	Precipitation Interval								
					15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
10	5	1911	Los Alamos	precipitation (in)	-	-	-	-	-	-	-	-	3.48
10	5	1911	Los Alamos	estimated return period (yr)	-	-	-	-	-	-	-	-	419
4	30	1981	Quemezon SNOTEL	precipitation (in)	-	-	-	-	-	-	-	-	3.3
4	30	1981	Quemezon SNOTEL	estimated return period (yr)	-	-	-	-	-	-	-	-	86
8	10	1985	East Gate	precipitation (in)	0.67	1.14	1.51	2.15	2.36	2.72	2.72	2.75	2.72
8	10	1985	East Gate	estimated return period (yr)	7	14	18	66	96	140	136	45	116
6	29	1995	Frijolito	precipitation (in)	0.81	0.95	1.04	1.18	1.20	1.26	1.32	1.34	1.32
6	29	1995	Frijolito	estimated return period (yr)	8	5	4	5	4	4	3	2	3
6	29	1996	TA-49	precipitation (in)	1.05	1.41	1.58	1.59	1.59	1.59	1.61	1.64	1.64
6	29	1996	TA-49	estimated return period (yr)	72	41	21	11	9	6	5	3	5
6	17	1999	TA-54	precipitation (in)	0.72	1.44	1.83	1.94	1.94	2.07	2.10	2.28	2.11
6	17	1999	TA-54	estimated return period (yr)	10	46	56	55	42	37	35	22	33
6	28	2000	Cerro Grande	precipitation (in)	-	-	0.68	0.95	0.99	0.99	0.99	0.99	0.99
6	28	2000	Cerro Grande	estimated return period (yr)	-	-	1.6	1.7	1.5	1.3	1.2	1.0	1.1
6	28	2000	Water Canyon	precipitation (in)	-	-	0.78	0.79	0.79	0.79	0.79	1.23	0.79
6	28	2000	Water Canyon	estimated return period (yr)	-	-	2	1.4	1.2	1.1	1.1	1.2	1.0
7	2	2001	Rendija USGS Gage 4	precipitation (in)	1.21	1.70	1.83	1.94	1.94	1.94	1.98	1.98	1.98
7	2	2001	Rendija USGS Gage 4	estimated return period (yr)	75	88	33	15	13	8	8	4	6

Table 20 (continued)

Month	Day	Year	Station	Parameter	Precipitation Interval								
					15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
7	2	2001	North Community	precipitation (in)	0.42	0.78	1.06	1.20	1.23	1.23	1.23	1.23	1.23
7	2	2001	North Community	estimated return period (yr)	1.8	3	4	3	3	2	1.8	1.3	1.6
6	21	2002	North Community	precipitation (in)	0.63	0.74	0.81	1.58	1.67	1.81	1.82	1.89	1.67
6	21	2002	North Community	estimated return period (yr)	5	3	2	7	8	7	6	3	4
6	21	2002	Rendija USGS Gage 460483	precipitation (in)	0.88	1.07	1.12	1.58	1.66	2.03	2.04	2.12	1.50
6	21	2002	Rendija USGS Gage 460483	estimated return period (yr)	13	8	4	6	6	10	9	4	2
6	21	2002	Pueblo Canyon	precipitation (in)	-	-	0.80	1.30	1.37	1.39	1.39	1.45	1.38
6	21	2002	Pueblo Canyon	estimated return period (yr)	-	-	2	4	4	3	2	1.6	1.9
9	10	2002	Santa Clara Canyon	precipitation (in)	-	-	1.47	2.41	2.65	2.73	3.09	3.22	3.20
9	10	2002	Santa Clara Canyon	estimated return period (yr)	-	-	19	55	85	48	106	36	90
8	23	2003	Guaje Canyon	precipitation (in)	-	-	1.67	1.69	1.69	1.69	1.69	1.69	1.69
8	23	2003	Guaje Canyon	estimated return period (yr)	-	-	42	10	8	5	4	2	3
8	23	2003	North Community	precipitation (in)	0.71	1.33	1.59	1.81	1.81	1.81	1.81	1.81	1.81
8	23	2003	North Community	estimated return period (yr)	9	29	19	13	11	7	6	3	5
8	23	2003	Pueblo Canyon	precipitation (in)	-	-	0.95	1.37	1.37	1.37	1.37	1.37	1.37
8	23	2003	Pueblo Canyon	estimated return period (yr)	-	-	4	5	4	3	2	1.4	1.8

precipitation was equal to the maximum 24-hr precipitation. The short-term intensities in this storm are unknown. Examination of records from the Pajarito Plateau indicate that the date may be recorded incorrectly. No rain was reported at TA-59 on this date, although 1.00" of low-intensity rain was recorded between 5:30 PM and midnight on May 1, presumed to be the same storm.

August 10, 1985

The second highest precipitation amounts recorded in the study area for durations of 2-hr to 12-hr occurred on August 10, 1985, at East Gate. This storm is most notable for the 6-hr rainfall total, 2.72", which has an estimated return period of about 140 yr at this location. Rainfall occurred over a 5-hr period from 4:45 PM to 9:45 PM, with two discrete peaks in the first 2 hr of the storm followed by several hr of lower intensity rain (Figure 16). Maximum 15-min to 1-hr intensities in this storm had estimated return periods of 7-18 yr. This storm also had the annual maximum amounts for all durations at TA-59, including the second highest 15-min and 30-min amounts in the combined 23-yr record at TA-6 and TA-59 (estimated return periods of 14-25 yr). At TA-59, however, the 6-hr precipitation (1.76") was less unusual, with an estimated return period of about 7 yr.

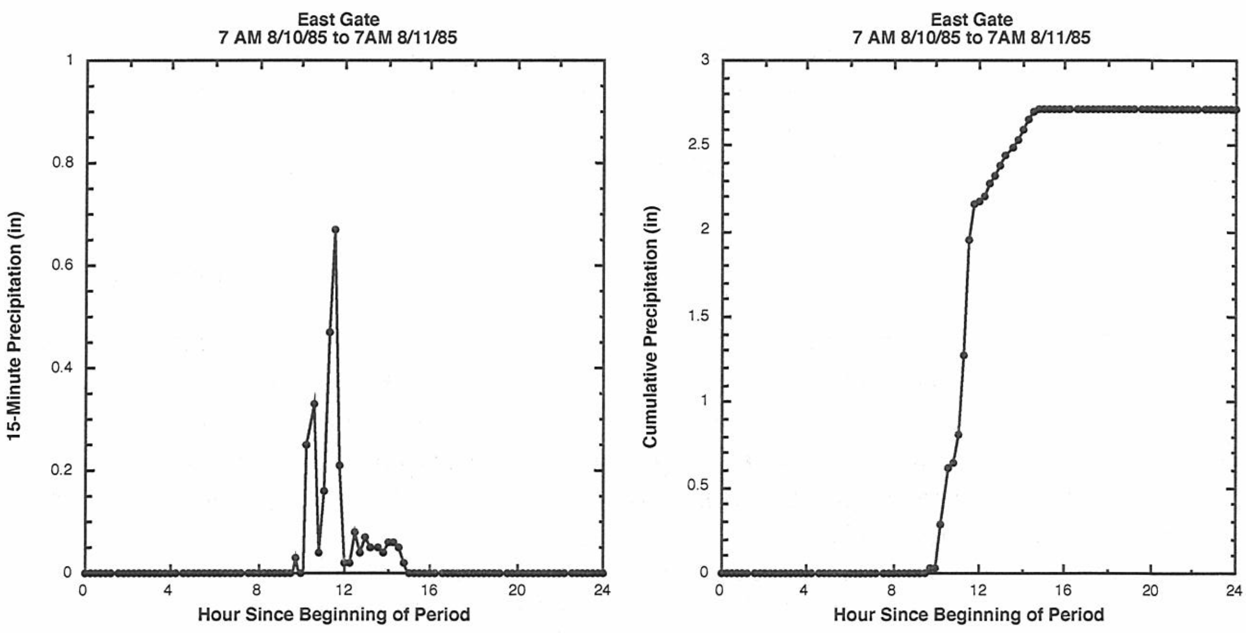

Figure 16. Plots of 15-min precipitation and cumulative precipitation for East Gate station, August 10-11, 1985.

June 29, 1995

The flood with the highest discharge from a non-fire affected area in the LANL stream gage network was recorded in Ancho Canyon on June 29, 1995 (520 cubic feet per second [cfs]; Shaull et al., 2003). The closest rain gage was the Frijolito station in Bandelier National Monument, which recorded 0.81" in a true 15-min period, equivalent to a 9-yr return period event. This was also the maximum 15-min rainfall in the 9-yr station record. Rainfall amounts for longer durations were less unusual. This storm started abruptly about 2 PM, and 61% of the daily rainfall total at the Frijolito station fell in the first 15 min, with rainfall tapering off quickly after the peak (Figure 17). The maximum 1-hr rainfall amount was only 0.32" at the next closest station, TA-49, near the head of the Ancho watershed, indicating that the main rainfall cell had a limited east-west extent.

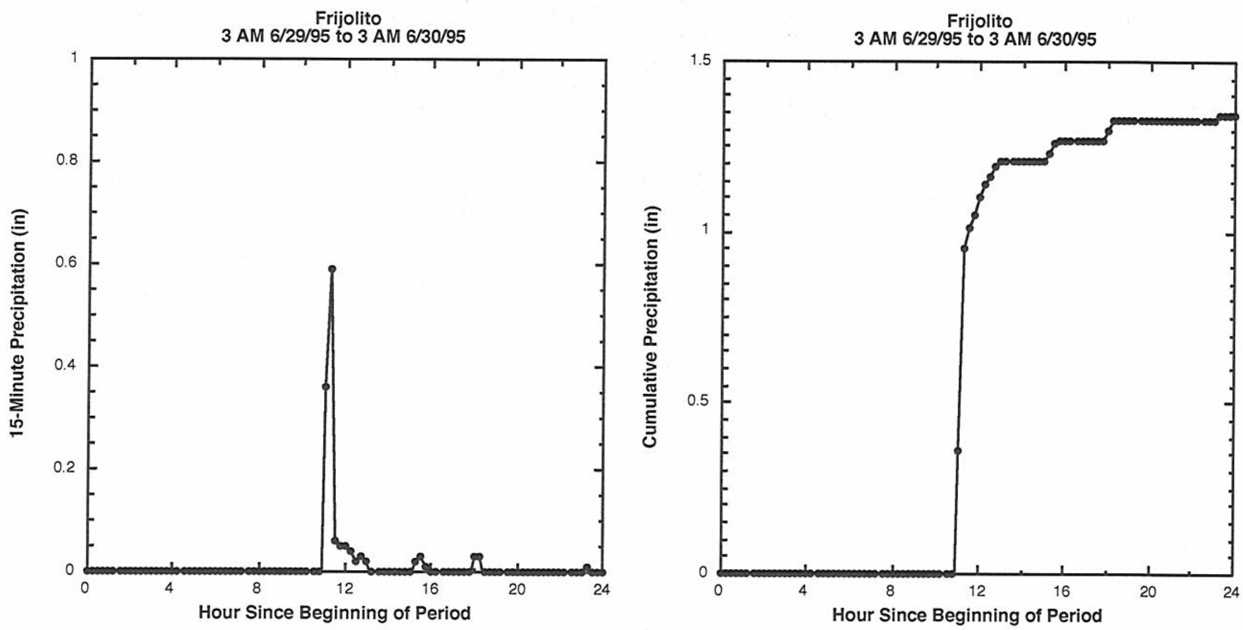

Figure 17. Plots of 15-min precipitation and cumulative precipitation for Frijolito station, June 29-30, 1995. Data collected in 1-min measurement intervals, and binned into 15-min intervals for plots.

June 29, 1996

The highest 15-min precipitation amount reported in the LANL network is 1.05" on June 29, 1996, at TA-49. The estimated return period for the 15-min total is about 70 yr, and for the 30-min total (1.41") is about 40 yr. The storm lasted about 1 hr at TA-49, between 5:15 and 6:15

PM, with 66% of the 1-hr total falling in a 15-min measurement interval and 89% in 30 min (Figure 18). Annual maximums for durations of 1 hr or less were also recorded on this day at TA-6 and TA-54, although precipitation amounts at these stations were less unusual (< 3 yr return periods). Ancho Canyon had its peak annual flood that day, although this flood was only about one-fifth the size of the June 29, 1995 flood (111 cfs; Shaull et al., 2003), suggesting that the storm had a smaller geographic extent and/or a lower average intensity.

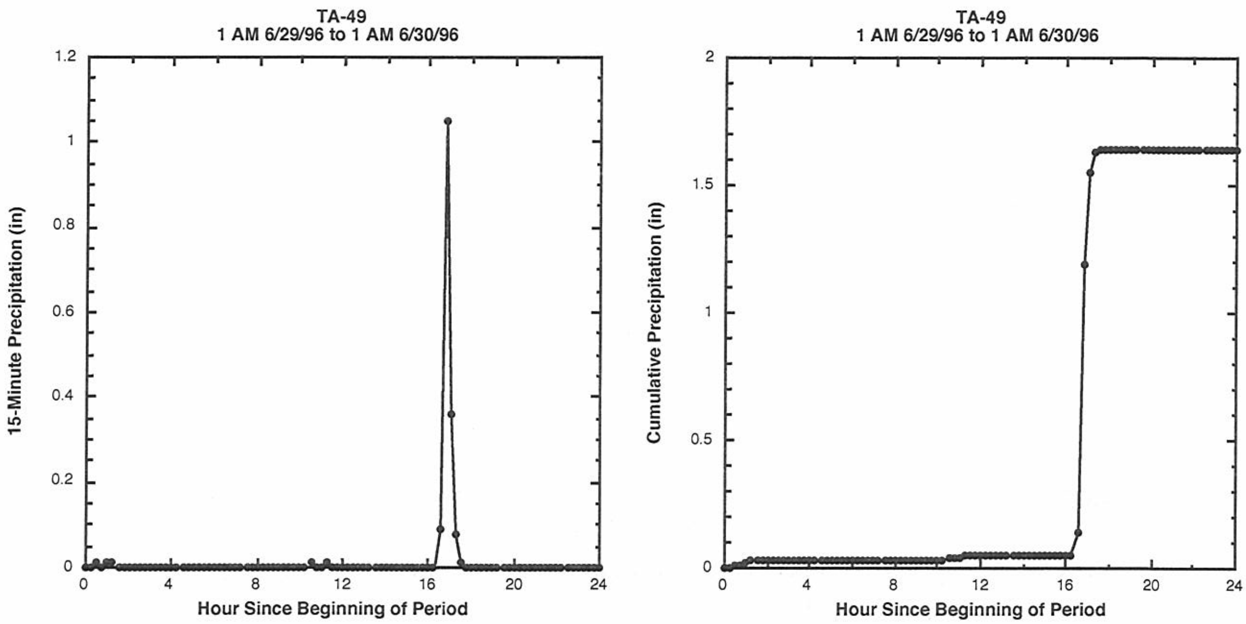

Figure 18. Plots of 15-min precipitation and cumulative precipitation for TA-49 station, June 28-29, 1996.

June 17, 1999

The highest 30-min and 1-hr precipitation amounts recorded in the LANL network are 1.44" and 1.83", respectively, on June 17, 1999, at TA-54. The 1-hr and 2-hr rainfall totals have estimated return periods of about 55 yr, and the 30-min total of about 45 yr. The highest daily precipitation in the combined 38-yr record for TA-54 and White Rock, 2.11", also occurred that day, and had an estimated return period of about 30 yr. The storm lasted just over 1 hr, between 1:30 and 2:45 PM, and included two consecutive 15-min measurement intervals with 0.72" of rain (Figure 19). The largest flood in Cañada del Buey at State Road 4 in the 9-yr period of record occurred in this storm (210 cfs; Shaull et al., 2003). Field observations of runoff indicated that the main rainfall cell extended about 2 km west of the TA-54 station (Drakos et al., 2000, p. 33), and that intense rain extended at least as far south as Indio Canyon. The only other station that had an annual maximum amount that day was TA-74 for a duration of 24 hr, although the total of 1.11" was less than half that recorded at TA-54 (2.28").

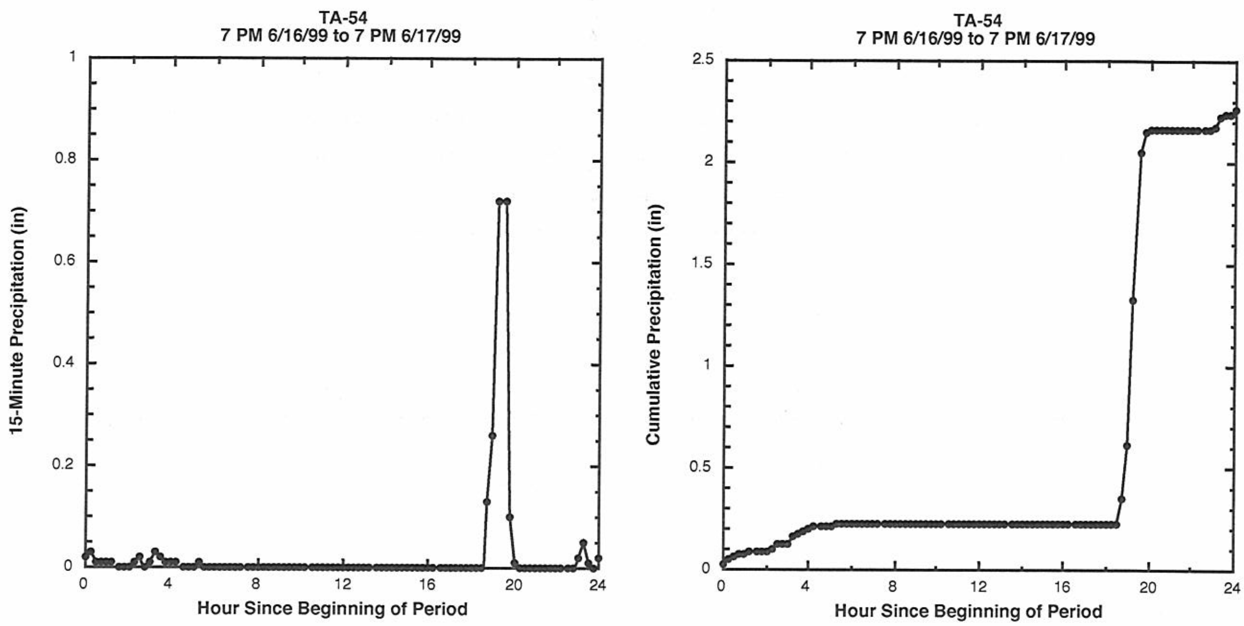

Figure 19. Plots of 15-min precipitation and cumulative precipitation for TA-54 station, June 16-17, 1999.

June 28, 2000

The largest floods in the period of record for Cañon de Valle, Pajarito Canyon, and Water Canyon occurred on June 28, 2000 (780, 1020, and 840 cfs; Shaull et al., 2003), following the first large thunderstorm after the Cerro Grande fire. Annual maximum precipitation amounts for durations of 1 to 12 hr occurred at the Cerro Grande, Pajarito Canyon, and Water Canyon stations, and for shorter durations at TA-16 and TA-49. A precipitation isopach map for this storm is presented in Koch et al. (2001, p. 51). The highest storm total (0.99") was recorded at the Cerro Grande station, which has a return period of < 2 yr at this station using the annual maximum series, and about 1 yr using the partial-duration series. The highest 1-hr total (0.78") was recorded at the Water Canyon station, and has an estimated return period of about 2 yr using the annual maximum series, and about 1-2 yr using the partial-duration series. The storm lasted less than 3 hr, with the peak 1-hr intensity occurring at the beginning of the storm (Figure 20).

July 2, 2001

The highest precipitation amounts recorded in the study area for durations of 15 min to 1 hr occurred on July 2, 2001, at a USGS station on the divide between the Pueblo Canyon and Rendija Canyon watersheds at the head of School Canyon (gage 4; S. Cannon, unpublished data). The 30-min value, 1.70", is approximately equal to the estimated 90-yr return period amount (note that this is a tipping bucket gage, and the measurement amount is for a true 30-min interval; also note that these data are provisional, pending internal quality checks by the USGS). The 15-min and 1-hr amounts (1.21" and 1.83") are equal to approximately 75-yr and 35-yr return period events, respectively. At this station rain started at about 5:15 PM and continued

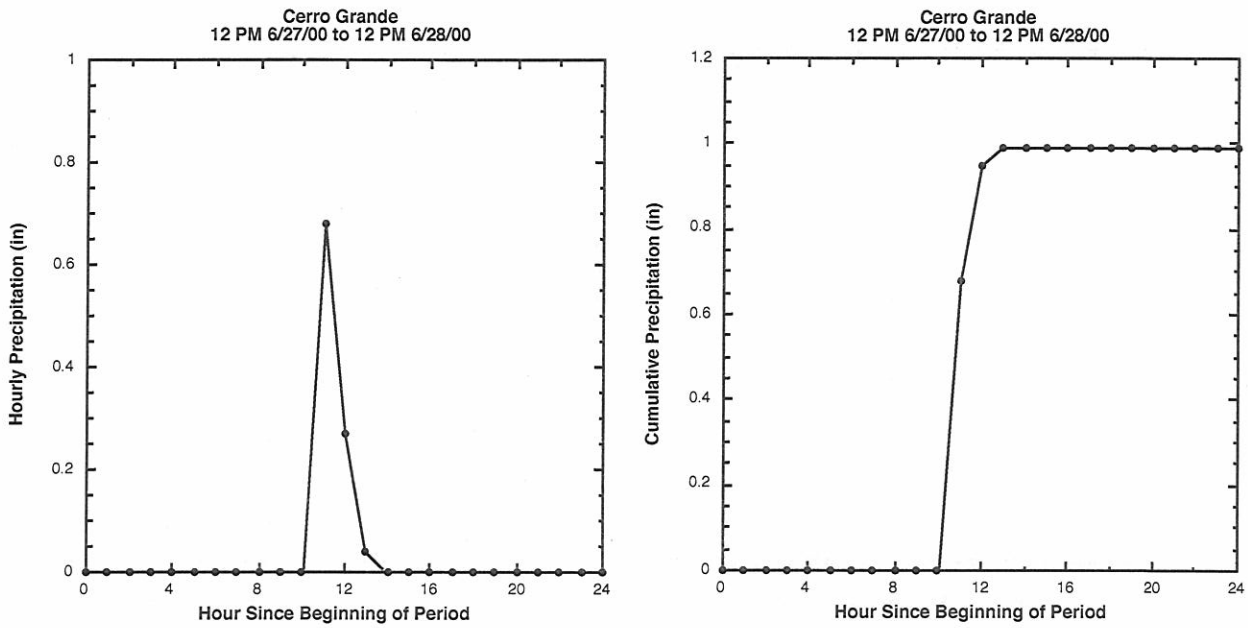

Figure 20. Plots of 1-hr precipitation and cumulative precipitation for Cerro Grande station, June 27-28, 2000.

until 7:10 PM, with the peak intensities occurring between 5:45 and 6:15 PM (Figure 21). This storm produced the largest flood on record in Pueblo Canyon (1440 cfs; Shaull et al., 2003), which caused significant damage to North Road and to a sewer line farther downstream, and caused flooding in North Community along School Canyon (Los Alamos Monitor, 2001). Rainfall was extremely variable in this storm, even over relatively short distances, as indicated by the network of USGS gages. Only this one of 20 USGS gages in the upper Rendija Canyon watershed had a 30-min amount exceeding estimated 50-yr intensities, and the next highest amounts (1.48" at gage 460483, and 1.43" at gage 460475; J. Moody, unpublished provisional data) have estimated return periods of 30-40 yr. These three gages are within 1 km of each other on or near the south edge of the Rendija watershed, and provide a minimum east-west extent for the area of highest intensities. This storm produced annual maximum values for all durations for the North Community and Pueblo Canyon gages, and the 1-hr values in this storm (1.06" and 0.70") have estimated return periods of 4 yr and 2 yr, respectively. Note that the Pueblo Canyon RAWS record for this storm is probably not reliable. U.S. Forest Service personnel visited the gage later in July and found that it had been vandalized (tilted; note that the gage was subsequently fixed). Field observations that runoff and erosion from this storm were significantly higher than from a storm in 2000 that had higher precipitation amounts recorded at the Pueblo Canyon gage (July 9, 2000) indicate that rainfall was under recorded on July 2, 2001, at the Pueblo Canyon gage. A precipitation isopach map for this storm that does not include the USGS gages and that includes the suspect Pueblo Canyon RAWS value is shown in Koch et al. (2002, p. 73).

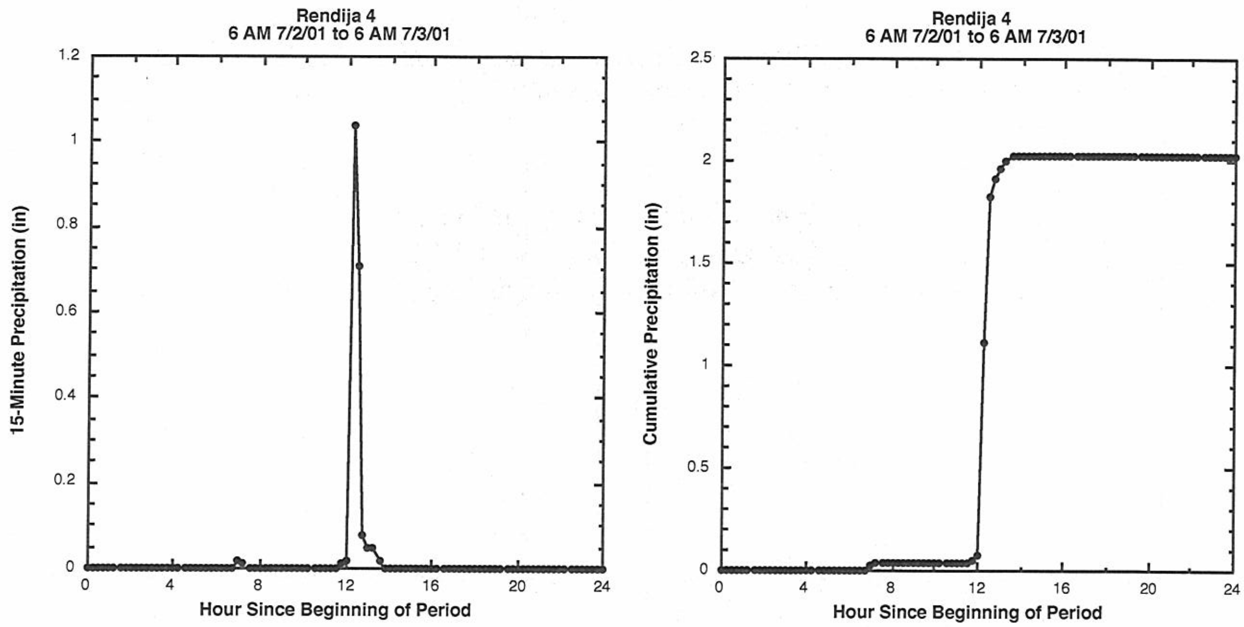

Figure 21. Plots of 15-min precipitation and cumulative precipitation for Rendija gage 4, July 2-3, 2001. Data collected from tipping bucket gage, and binned into 15-min intervals for plots.

August 11, 2001

The largest flood reported after the Cerro Grande fire occurred on August 11, 2001, in Rendija Canyon (2120 cfs; Shaull et al., 2003). The maximum 30-min intensity in the 20 USGS gages in upper Rendija Canyon was 1.06" (gage 460484; J. Moody, unpublished provisional data), equivalent to an estimated 8-yr return period event. Rainfall was not unusual at any station in the LANL or RAWS networks in or near the watershed, with the maximum reported storm total being 0.71" at the Pueblo Canyon gage, representing a return period of less than 2 yr for all durations. The extreme nature of this flood may have been due more to the specifics of how the rainfall cell was moving than to the intensity during the storm. An examination of the timing of the rainfall peak at each of the USGS gages indicates that the storm was moving from west to east, which should have helped amplify the flood peak (J. Moody, personal communication). In addition, storms that occurred in the prior week may have helped enhance runoff on August 11 by increasing antecedent moisture in the watershed and thereby reducing infiltration during the storm. A precipitation isopach map for this storm that does not include the USGS gages is shown in Koch et al. (2002, p. 85).

June 21-22, 2002

Many LANL stream gages had peak annual discharges on June 21-22, 2002 (DP Canyon; Los Alamos Canyon; Mortandad Canyon; Pajarito Canyon; Pueblo Canyon; Water Canyon; Shaull et al., 2003). The highest discharge was reported from Pueblo Canyon (583 cfs), constituting the third largest flood in that canyon since the Cerro Grande fire. This storm was widespread, and many stations in the eastern Jemez Mountains and on the western Pajarito Plateau had annual maximum values for various durations during this storm, and all western stations had 24-hr totals > 1.3". In the LANL and RAWS networks, the North Community gage had the highest 2-hr to 24-hr and daily rainfall amounts in this storm (1.58-1.89"). The 15-min and 2-hr to 12-hr amounts at North Community were the highest in the 7-yr record at this station (prior to 2003), and the 2-hr to 6-hr totals had estimated return periods of 8-9 yr. Recorded precipitation amounts were somewhat higher at some of the USGS stations in Rendija Canyon, with estimated return periods for 15-min periods of up to 13 yr and for 6-hr periods of up to 10 yr (gage 460483; J. Moody, unpublished provisional data). In contrast, 1-hr to 6-hr precipitation amounts at the Pueblo Canyon and Upper Los Alamos Canyon RAWS had estimated return periods of 2-5 yr. At the North Community gage, the storm began at about 9:15 PM, with the highest 15-min and 30-min intensities occurring within the first half hour (Figure 22). A second period of relatively high-intensity rain began at about 10:45 PM, also lasting for about a half hour, followed by about 2 hr with lower intensity rainfall. The same general timing and rainfall distribution was recorded at the USGS gages, with the highest intensity peak occurring at the beginning of the storm, followed by multiple smaller peaks over the next several hr.

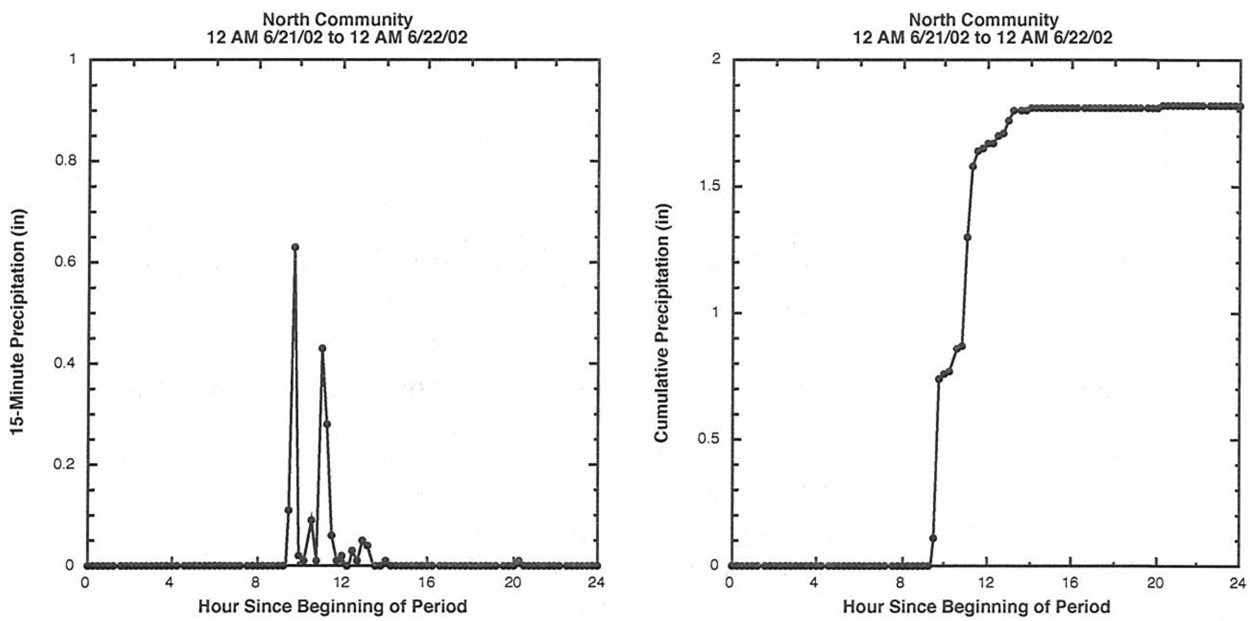

Figure 22. Plots of 15-min precipitation and cumulative precipitation for North Community station, June 21-22, 2002.

September 10, 2002

The highest precipitation amounts recorded in the study area for durations of 2 to 24 hr occurred on September 10, 2002, at the Santa Clara Canyon RAWS gage. This storm also represents the third highest daily precipitation reported in the study area, 3.20". It was most unusual for the 12-hr rainfall total, 3.09", which has an estimated return period of about 100 yr at this location. This storm also produced 2-hr, 3-hr, and daily totals that exceeded estimated 50-yr events. The storm started abruptly at this location sometime after 1 AM, and 75% of the daily rainfall occurred in a 2-hr period between 1 and 3 AM (Figure 23). Lower intensity rain continued until 4 PM. This was a widespread storm, and annual maximums for various durations were also recorded at the Frijolito, Garcia Canyon, Quemezon Canyon, TA-16, TA-49, TA-53, TA-54, TA-74, Upper Los Alamos Canyon, and Water Canyon gages.

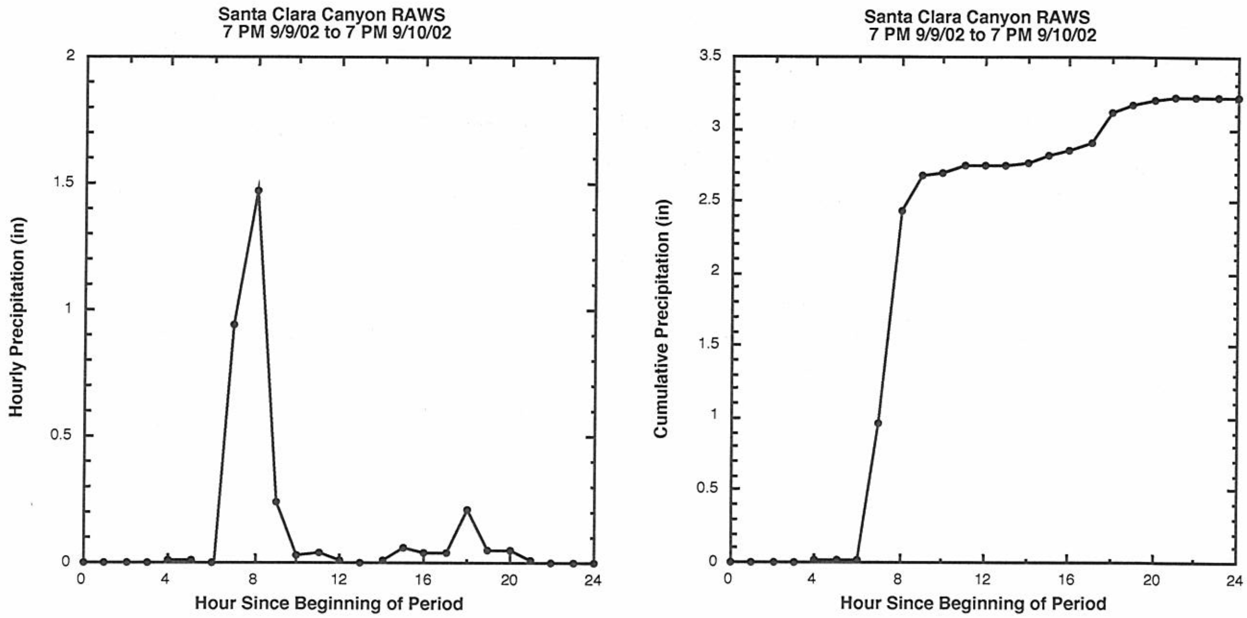

Figure 23. Plots of 1-hr precipitation and cumulative precipitation for Santa Clara Canyon station, September 9-10, 2002.

August 23, 2003

During finalization of this report, a storm occurred on August 23, 2003, that produced a flood in Pueblo Canyon comparable in magnitude to that occurring on July 2, 2001, and a smaller flood in Rendija Canyon (relative magnitudes are based on field observations of high water lines; discharge estimates are not yet available). This storm was widespread, and many stations in the eastern Jemez Mountains and on the western Pajarito Plateau recorded over 1" of rain. The 1-hr precipitation total at the Guaje Canyon RAWS, on the northern watershed divide of Rendija Canyon, was the highest recorded at any RAWS gage since the Cerro Grande fire (1.67"). This 1-hr total has an estimated return period of about 40 yr at that location using 1-hr measurement interval relations; the return period at the Guaje Canyon RAWS could be as short as 20 yr if the actual maximum 1-hr precipitation amount was equal to the measured amount. The North

Community gage experienced the highest rainfall amounts in its 8-yr period of record for durations of 15 min to 3 hr, and tied for the highest 6-hr total. At this gage, the storm began at about 1:45 PM and lasted about 1.5 hr (Figure 24). Most notable at the North Community gage was the 30-min total, 1.33", which has an estimated return period of about 30 yr. The 1-hr total has an estimated return period of about 20 yr at this station. Lower return periods of 4-5 yr are estimated for 1-hr to 2-hr precipitation at the Pueblo Canyon RAWS, and of 3-4 yr at the Upper Los Alamos Canyon RAWS.

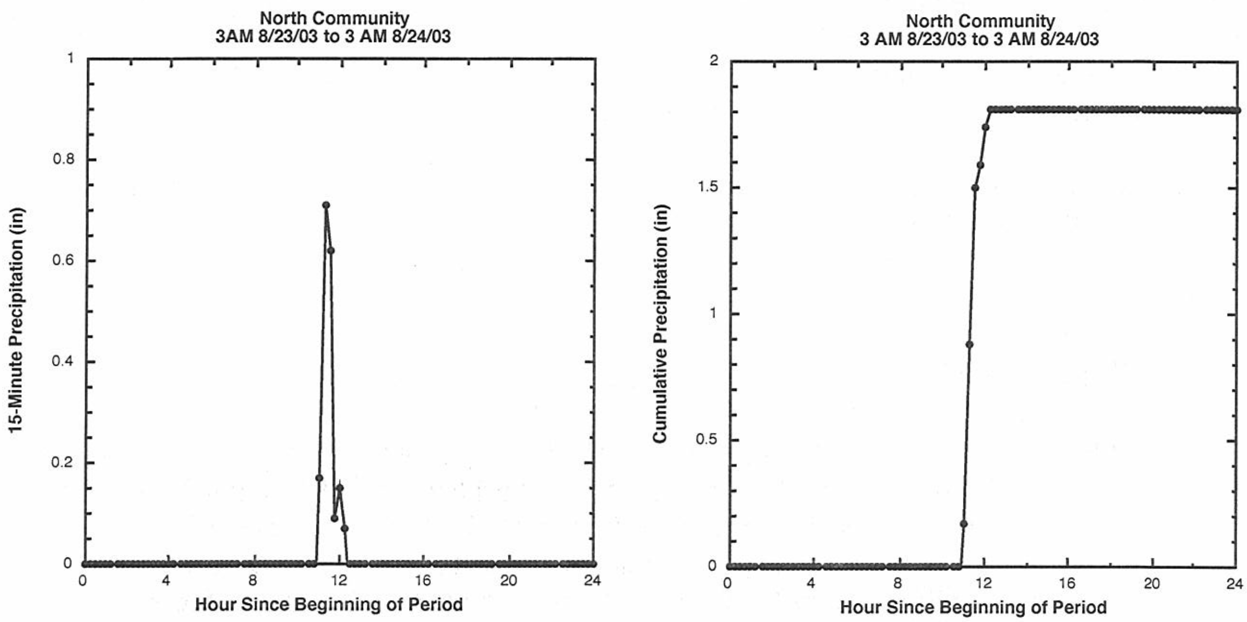

Figure 24. Plots of 15-min precipitation and cumulative precipitation for North Community station, August 23-24, 2003.

DISCUSSION AND CONCLUSION

The examination of precipitation data presented in this report indicates that the annual maximum precipitation amount for durations of 2-24 hr and return periods of 2-100 yr increases gradually from east to west across the Pajarito Plateau and the eastern Jemez Mountains. This trend is generally consistent with spatial patterns presented in a previous study by NOAA (Miller et al., 1973) and a recent update by NOAA (2003; NOAA Atlas 14), although the east-to-west gradient derived from the current study is generally somewhat steeper. Positive correlations of precipitation and elevation are also present in these data, but precipitation-distance regressions provide better predictive tools than precipitation-elevation regressions, in part because of internal inconsistencies in the latter. In addition, available data do not indicate a sharp increase in 2-24 hr precipitation amounts as the topography becomes steeper in the Sierra de los Valles, as would be expected if a linear precipitation-elevation relation existed.

No evidence was found for significant, systematic increases in precipitation amounts for durations of 15-30 min from east to west, and some regressions instead suggest inverse relations. The east-to-west change in 1-hr precipitation amounts is also small. This contrasts with earlier conclusions by Bowen (1990, 1996), based on a shorter period of record at two stations, and with estimates in NOAA Atlas 14 (NOAA, 2003) that short-duration precipitation also increases from east to west. The data examined in this study suggest that the annual probability of 15-30 min rainfall of a given amount in the study area is similar regardless of elevation or distance from the mountains, but that the probability of multiple storm cells occurring in a given 2-24 hr period increases from east to west. This interpretation is consistent with the conclusion of Malmon (2002) that the intensity and duration of summer storms do not vary from east to west across the study area, but that the frequency of storms increases towards the west.

The observations discussed above, combined with the tendency for rainfall to begin earlier to the west than to the east (Bowen, 1990, 1996; Malmon, 2002), suggests the following conceptual model for short-duration precipitation amounts in the study area. Moist air masses derived from the Gulf of Mexico and the Gulf of California to the south are orographically lifted as they reach the Jemez Mountains, causing storms to typically begin over the mountains and to be most frequent there. These moist air masses then drift away from the mountains over the Pajarito Plateau, retaining their general characteristics that control short duration ($\leq$ 1 hr) rainfall intensity while becoming progressively less frequent away from the mountains. The result is a similarity of maximum 15-min to 1-hr precipitation amounts for different return periods, but a gradual decrease in amounts for longer durations, from west to east.

Previous estimates of precipitation-frequency relations by Bowen (1990) indicated a steeper increase in precipitation amounts from east to west for a variety of durations and return periods than is shown by this study. Use of these precipitation-frequency relations proposed by Bowen (1990), and an assumed linear precipitation-elevation relation (McLin, 1992; McLin et al., 2001a), resulted in predictions of precipitation amounts for all return periods that are significantly higher to the west and lower to the east than indicated in either this study, Miller et al. (1973), or NOAA (2003). The analyses in this study indicate that extrapolation of Bowen's relations to the eastern Jemez Mountains has resulted in overestimates of precipitation amounts for extreme events in the area affected by the Cerro Grande fire, particularly for short durations (e.g., 15 min). These overestimates of precipitation amounts have been incorporated into modeled estimates of flood discharge, erosion, and sediment transport after the fire (e.g., McLin et al., 2001a, 2001b; URS, 2001; Wilson et al., 2001a, 2001b; Lane, 2002; Wright Water Engineers, 2003), and lower modeled estimates would result from use of the values derived either in this study or by NOAA.

Recorded precipitation amounts in the study area that exceed estimated 50-yr events for durations ranging from 15 min to 24 hr have occurred in convective storms during the months of June through September. Maximum 15-min, 30-min, and 1-hr amounts occurred in relatively short storms that lasted 1-2 hr (6/29/96, 6/17/99, 7/2/01). Maximum amounts for durations of 2-24 hr occurred in longer storms or during periods that included multiple discrete rainfall peaks

(8/10/85, 9/10/02). In relation to its share of total rainfall or its frequency of thunderstorm days, June seems to be particularly well represented in the annual maximum series and in the occurrence of extreme events in the record, suggesting that June storms may be more intense, on average, than those in other months, although the reason for this is not certain.

Storms that have generated significant floods in the historic record are typically short, less than 2 hr in duration at a station. During these storms, rainfall at a site can start abruptly, with over 50% of the peak 1-hr rainfall amount falling within a 15-min interval at or near the beginning of the storm, and with rainfall subsequently tapering off. Based on the precipitation-frequency relations, the peak 30-min rainfall amount is estimated to average 73-91% of the peak 1-hr rainfall, further illustrating the importance of short-duration precipitation amounts in these convective storms. The use of 30-min rainfall intensities to evaluate peak flood discharge and sediment flux in convective storms in this area by Cannon et al. (2001), Moody and Martin (2001), and Moody et al. (2002) is consistent with these storm characteristics, although unfortunately many stations (e.g., RAWS) do not report data in < 1 hr intervals.

In some convective storms, multiple rainfall peaks occur within a 2-hr period (e.g., 8/10/85, 6/21/02). These conditions should enhance runoff volume and possibly peak discharge by wetting both hillslopes and channels early in the storm, reducing infiltration losses on the slopes and allowing faster propagation of flood bores down channels.

The largest floods in the study area have been generated in convective storms, and available data indicate that these storms possess considerable spatial variability in short-duration precipitation amounts. Examples of spatial variations in storms are shown in isopach maps in Koch et al. (2001, 2002) and Moody and Martin (2001). Because the spacing of rain gages can be greater than the size of storm cells, floods can be generated from intense rainfall that is poorly recorded at meteorological stations. For example, the largest flood recorded in the study area that was not fire-related (Ancho Canyon, 6/29/95; Shaull et al., 2003) occurred on a day that had minimal rainfall at a station near the head of the watershed (TA-49). Similarly, the largest flood reported after the Cerro Grande fire (Rendija Canyon, 8/11/01) was not associated with annual maximum values for any of the gages in or near the watershed, although west-to-east movement of this storm may have acted to enhance flood peaks (J. Moody, pers. com.). Other storms appear to affect more of a watershed (e.g., 6/21/02), which should enhance flood discharge. A fairly dense network of stations is likely required to adequately define rainfall conditions in flood-producing storms, such as the network set up in upper Rendija Canyon after the Cerro Grande fire by the USGS (Cannon et al., 2001; Moody and Martin, 2001; Moody et al., 2002). The spatial variability in rainfall amounts in convective storms and the utility of dense rain gage networks have also been addressed in other studies (e.g., Osborn et al., 1979). NEXRAD weather radar data can also be useful in identifying the spatial variability in rainfall in a storm.

Comparison of annual maximum series data for the drought years of 2000-2002 with the longer period of record suggests that although the study area experienced below-normal precipitation, for some areas and durations the years 2000-2002 were not unusual in the context of 2-yr short-duration precipitation amounts. Figure 25 shows that the estimated 2-yr annual maximum precipitation amounts for durations of 1 hr and 2 hr calculated from the 2000-2002 data set are

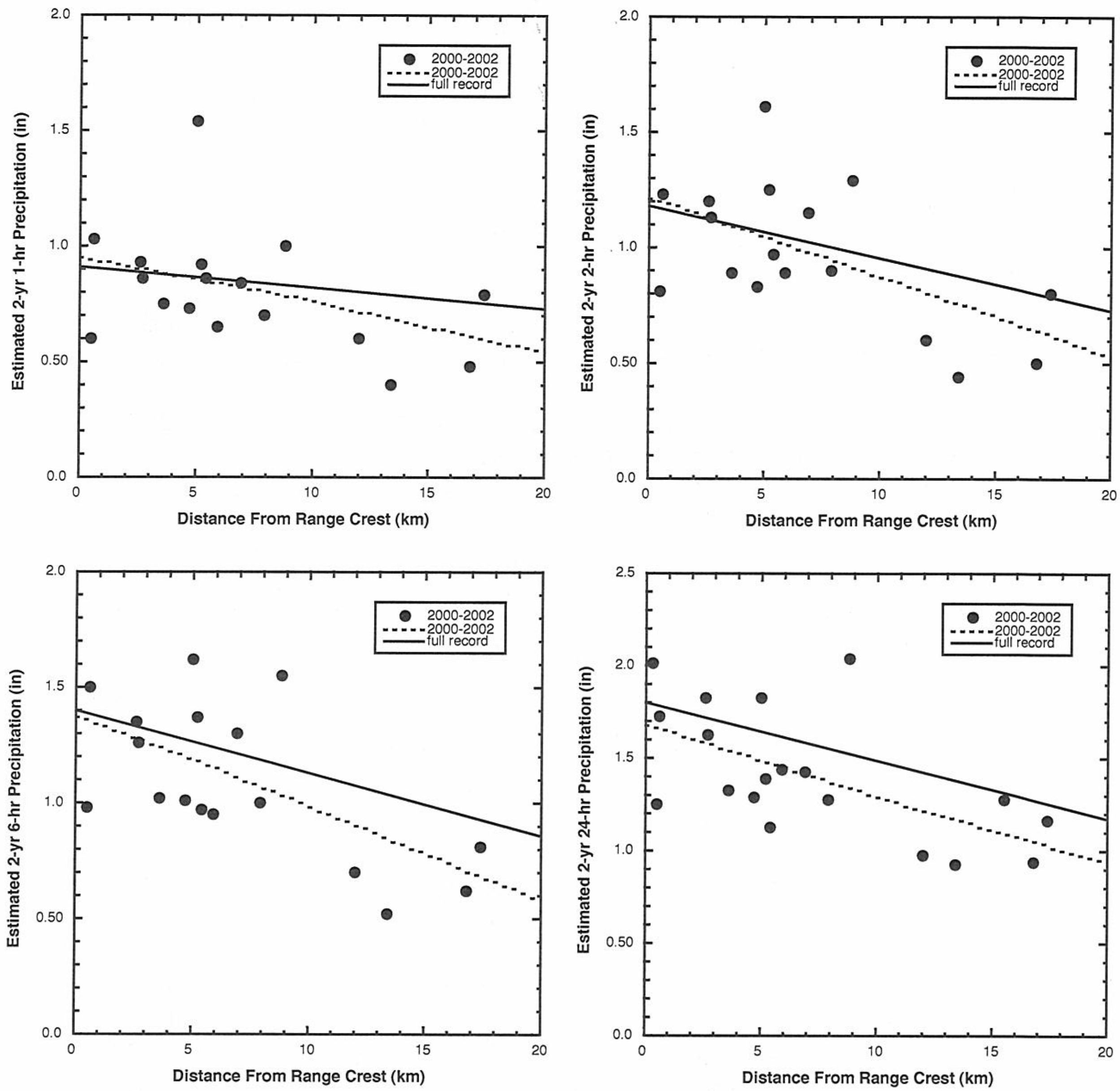

Figure 25. Estimated 2-yr precipitation amounts for 2000-2002 for durations of 1 hr, 2 hr, 6 hr, and 24 hr, showing precipitation-distance regressions based on the 2000-2002 data set and the full period of record from stations providing ≥ 15 yr of data.

scattered around the predicted long-term average for the eastern Jemez Mountains and western Pajarito Plateau stations, 0-10 km from the range crest. In contrast, estimates based on the 2000-2002 data set for longer durations for these areas tend to be below the long-term average, especially for 24-hr duration precipitation. For the same period, the eastern Pajarito Plateau tended to experience 2-yr precipitation amounts below the long-term average for all durations (Figure 25).

One watershed that has attracted particular attention after the Cerro Grande fire because of the severity of the burn and because of downstream flood impacts, Pueblo Canyon, has experienced three notable storms in the four years following the fire. The first, on July 2, 2001, included a storm cell with the highest precipitation amounts recorded in the study area for durations of 15 min to 1 hr, recorded at a USGS gage on the northern edge of the watershed in an area that experienced high burn severity. The 30-min rainfall amount at this gage is estimated to have a return period of about 90 yr. Although rain of this intensity may have only occurred in a small part of the upper watershed, this part of the basin is particularly steep and includes large areas of thin soil and bare rock, and is therefore especially susceptible to runoff.

The second storm occurred on June 21, 2002, and produced the highest rainfall amounts for durations of 15 min and 2-6 hr in the 7-yr record at the North Community gage from 1996 to 2002. The 15-min amount had an estimated return period of 5 yr, and the 2-6-hr amounts of 7-8 yr. Nearby USGS gages in the Rendija Canyon watershed recorded 15-min and 6-hr rainfall with estimated return periods of up to 13 yr and 10 yr, respectively. In contrast to the July 2, 2001 storm, the June 21 storm was both longer in duration and covered larger areas. As such, it should have been particularly effective at generating runoff. Field observations indicated that intense rain in the Los Alamos town site was in part responsible for the downstream flood, with the non-burned basin of Acid Canyon flooding as well as drainages below burned areas.

The third storm occurred on August 23, 2003. Similar to the June 21, 2002 storm, this one was widespread, producing high rainfall amounts at many stations, but it had higher short-term intensities at the North Community gage. At this gage, it produced the highest rainfall amounts for durations of 15 min to 3 hr in the 8-yr station record. The 30-min amount had an estimated return period of about 30 yr, and the 1-hr amount of about 20 yr. The 1-hr total at the nearby Guaje Canyon RAWS gage had an estimated return period of about 40 yr. The extent of flood damage that has occurred in Pueblo Canyon since the Cerro Grande fire was thus influenced by the occurrence of a series of notable storms, as well as by altered hydrologic conditions in the watershed.

Rainfall is a controlling factor for a variety of earth surface processes, and analysis of existing rainfall data can aid in an evaluation of these processes and associated natural hazards such as flooding. Having an improved definition of rainfall characteristics can lead to improvements both in predictive modeling and in understanding the return periods of specific historic precipitation events, allowing resultant floods and other effects to be placed in a better context.

ACKNOWLEDGMENTS

This study was begun as part of an effort to better understand flood hazards in Pueblo Canyon after the Cerro Grande fire under an affiliation with the Volunteer Task Force, which is an informal group of Los Alamos residents; Diane Albert, June Fabryka-Martin, Mat Johansen, Craig Martin, and other local residents provided encouragement during the early part of this study. Discussions with Steve McLin (RRES-WQH), Everett Springer and Cathy Wilson (EES-2), and Steve Geiger, Tim Simmons, and Karen Stearns (URS Corporation) also helped stimulate this work. Danny Katzman (EES-9) provided some support during the later part of this study through a LANL Environmental Restoration Project task to evaluate plutonium transport in

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APPENDIX A
ANNUAL MAXIMUM SERIES (in inches)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
Area G	8	8	1987		0.48							
Area G	8	13	1987	0.40								
Area G	8	23	1987					0.59		1.21	1.42	
Area G	8	25	1987			0.55	0.57		1.06			1.06
Area G	7	5	1988	0.44								
Area G	8	9	1988					0.83				
Area G	9	12	1988		0.63	0.72	0.73		1.32	1.47	1.89	1.65
Area G	5	9	1989			0.87	0.98	0.99	1.03	1.05		
Area G	8	1	1989	0.38	0.65						1.15	1.15
Area G	7	14	1990	0.45								
Area G	7	20	1990		0.52	0.58	0.59	0.59				
Area G	9	28	1990						0.75	0.75		
Area G	11	2	1990								1.04	1.03
Area G	5	21	1991								1.29	
Area G	7	18	1991	0.40	0.49					0.89		
Area G	8	2	1991			0.59						
Area G	9	6	1991				0.73	0.79	0.87			1.11
Cerro Grande	8	22	1996			1.03	1.07	1.08	1.08	1.58	1.74	1.63
Cerro Grande	8	1	1997			1.01	1.04	1.04	1.04	1.04	1.04	1.04
Cerro Grande	8	1	1998				0.70					
Cerro Grande	8	25	1998					0.88	0.92			0.93
Cerro Grande	9	30	1998			0.48						
Cerro Grande	10	1	1998							1.00	1.18	
Cerro Grande	4	30	1999							1.18	1.24	1.17
Cerro Grande	7	7	1999				0.84	1.01	1.08			
Cerro Grande	8	29	1999			0.56						
Cerro Grande	6	28	2000			0.68	0.95	0.99	0.99	0.99		
Cerro Grande	10	23	2000								1.22	1.18
Cerro Grande	7	13	2001				0.73	0.75				
Cerro Grande	7	26	2001			0.71			0.81	0.83	0.94	0.87
Cerro Grande			2002			missing	missing	missing	missing	missing	missing	missing
East Gate	6	20	1982	0.21	0.42	0.58	0.64	0.64				
East Gate	11	10	1982						0.67			
East Gate	12	9	1982							0.83	0.92	0.84
East Gate	5	28	1983	0.86	0.99	1.01						1.20
East Gate	8	2	1983				1.04	1.17	1.51	1.55	1.55	
East Gate	8	6	1984					0.54				
East Gate	8	20	1984			0.46	0.48			0.87		0.94
East Gate	8	26	1984	0.30	0.37							
East Gate	12	15	1984								0.96	
East Gate	12	27	1984						0.58			
East Gate	8	10	1985	0.67	1.14	1.51	2.15	2.36	2.72	2.72	2.75	2.72
East Gate	6	8	1986						0.82	0.88		0.88

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	Daily
East Gate	8	17	1986									
East Gate	9	14	1986	0.38	0.54	0.70	0.72	0.72			1.05	
East Gate	8	23	1987						0.85	1.02	1.04	
East Gate	9	8	1987	0.49	0.58	0.63	0.63	0.63				0.76
East Gate	4	16	1988							1.07		
East Gate	6	10	1988	0.39			0.68	0.68				
East Gate	6	30	1988		0.57	0.66						
East Gate	9	12	1988						0.95		1.55	1.26
East Gate	5	9	1989			0.68	0.99	1.13	1.22	1.23	1.24	1.23
East Gate	7	22	1989	0.34	0.47							
East Gate	8	21	1990	0.70	1.19	1.64	1.64	1.64	1.64	1.64	1.69	1.64
East Gate	7	22	1991	0.77	1.06	1.14	1.16	1.2	1.53	1.59	2.07	1.58
Frijolito	9	5	1994	0.20								
Frijolito	10	14	1994									1.40
Frijolito	6	29	1995	0.81								1.34
Frijolito	8	21	1996	0.41								
Frijolito	10	4	1996									1.27
Frijolito	6	7	1997									1.08
Frijolito	7	29	1997	0.46								
Frijolito	8	13	1998	0.56								
Frijolito	10	31	1998									1.39
Frijolito	6	16	1999	0.64								1.19
Frijolito	8	9	2000	0.34								
Frijolito	8	18	2000									1.65
Frijolito	7	2	2001	0.68								1.05
Frijolito	7	25	2002	0.23								
Frijolito	9	10	2002									0.73
Garcia Canyon	7	16	2000			1.32	1.59	1.69	1.70	1.73	1.73	1.73
Garcia Canyon	8	16	2001			1.56	1.75	1.87	1.88	1.88	2.04	2.04
Garcia Canyon	7	4	2002			1.20	1.25	1.25	1.25			
Garcia Canyon	9	10	2002							1.54	1.72	1.67
Guaje Canyon	7	16	2000			1.17	1.63	1.64	1.64	1.68	1.68	1.68
Guaje Canyon	7	2	2001			0.66	0.76	0.77	0.78	0.82	0.82	0.82
Guaje Canyon	6	21	2002			0.64	1.23	1.38	1.70	1.73	1.74	1.38
Los Alamos	10	5	1911									3.48
Los Alamos	6	24	1912									1.09
Los Alamos	6	10	1913									2.51
Los Alamos	9	20	1914									1.00
Los Alamos	7	26	1915									1.87
Los Alamos	1	27	1916									2.45
Los Alamos			1917									missing
Los Alamos			1918									missing
Los Alamos	5	24	1919									1.60
Los Alamos			1920									missing
Los Alamos			1921									missing

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
Los Alamos	4	26	1922									1.12
Los Alamos	8	19	1923									1.02
Los Alamos	7	10	1924									1.69
Los Alamos	8	10	1925									2.05
Los Alamos	7	5	1926									1.32
Los Alamos	6	12	1927									1.50
Los Alamos	8	15	1928									0.99
Los Alamos	9	22	1929									2.21
Los Alamos	7	14	1930									1.98
Los Alamos	11	22	1931									1.46
Los Alamos	7	26	1932									1.10
Los Alamos	8	24	1933									1.30
Los Alamos	7	25	1934									1.53
Los Alamos	8	20	1935									1.46
Los Alamos	8	30	1936									1.24
Los Alamos	8	16	1937									1.15
Los Alamos	10	8	1938									1.02
Los Alamos	10	8	1939									1.43
Los Alamos	8	22	1940									1.22
Los Alamos	9	29	1941									1.80
Los Alamos	4	17	1942									1.20
Los Alamos	8	18	1943									1.40
Los Alamos	10	17	1944									2.20
Los Alamos			1945									missing
Los Alamos	8	14	1946									1.43
Los Alamos	5	10	1947									1.10
Los Alamos	2	11	1948									0.81
Los Alamos	4	19	1949									0.97
Los Alamos	7	11	1950									1.23
Los Alamos	8	1	1951									2.26
Los Alamos	8	20	1952									1.92
Los Alamos	7	4	1953									1.13
Los Alamos	7	31	1954									1.54
Los Alamos	8	22	1955									1.76
Los Alamos	6	29	1956									0.79
Los Alamos	8	23	1957									2.23
Los Alamos	9	13	1958									1.66
Los Alamos	10	30	1959									1.38
Los Alamos	10	17	1960									1.05
Los Alamos	8	23	1961									1.35
Los Alamos	7	9	1962									1.08
Los Alamos	7	9	1963									1.76
Los Alamos	11	18	1964									0.87
Los Alamos	8	18	1965									1.72
Los Alamos	8	2	1966									1.29

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
Los Alamos	8	31	1967									1.88
Los Alamos	7	31	1968									2.47
Los Alamos	7	24	1969									1.57
Los Alamos	8	18	1970									1.02
Los Alamos	10	25	1971									1.33
Los Alamos	7	18	1972									0.91
Los Alamos	9	10	1973									1.86
Los Alamos	8	17	1974									1.23
Los Alamos	4	12	1975									2.00
Los Alamos	7	16	1976									1.24
Los Alamos	8	12	1977									1.12
Los Alamos	11	25	1978									1.77
Los Alamos	8	15	1979									1.28
North Community	6	3	1986									1.45
North Community	2	19	1987									1.15
North Community	9	12	1988									1.67
North Community	9	5	1989									1.54
North Community	11	2	1990									1.40
North Community	8	4	1991									2.40
North Community	7	23	1992									1.78
North Community	1	8	1993									1.14
North Community	10	14	1994									2.20
North Community	7	18	1995									1.21
North Community	6	26	1996	0.33	0.39	0.46	0.57		1.01	1.12		0.99
North Community	8	22	1996					0.65			1.23	
North Community	5	20	1997								1.45	
North Community	8	17	1997			0.83	1.26	1.28	1.31	1.32		1.29
North Community	8	22	1997	0.43	0.57							
North Community	7	3	1998	0.59	0.86	1.12	1.15	1.15	1.15	1.64	2.34	
North Community	10	31	1998									1.34
North Community	7	9	1999	0.54	0.91	1.24	1.39	1.45	1.45	1.45	1.58	1.50
North Community	6	2	2000				0.73	0.76				
North Community	8	5	2000		0.53	0.58						
North Community	9	8	2000	0.38								
North Community	10	23	2000							1.04	1.23	1.13
North Community	11	23	2000						0.93			
North Community	7	2	2001	0.42	0.78	1.06	1.20	1.23	1.23	1.23	1.23	1.23
North Community	6	21	2002	0.63			1.58	1.67	1.81	1.82	1.89	1.67
North Community	7	31	2002		0.79	0.85						
Pajarito Canyon	6	28	2000			0.61	0.69	0.69	0.69			
Pajarito Canyon	10	23	2000							1.25	1.59	1.55
Pajarito Canyon	8	9	2001			0.53	0.79	0.79	0.80	0.80	0.80	0.80
Pajarito Canyon	6	21	2002			0.88	1.08	1.51	1.63	1.64	1.66	1.51
Pajarito Mountain	7	26	1998	0.39	0.51						1.13	
Pajarito Mountain	8	25	1998			0.65	0.82	0.85	0.92	0.92		0.92

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
Pajarito Mountain	7	7	1999	0.37	0.48	0.53	0.62					
Pajarito Mountain	7	9	1999					0.72	0.76			
Pajarito Mountain	8	4	1999									1.23
Pajarito Mountain	8	5	1999							0.95	1.36	
Pajarito Mountain	6	2	2000				0.48	0.57	0.60			
Pajarito Mountain	7	12	2000	0.20	0.29	0.35						
Pajarito Mountain	11	23	2000							0.83	1.08	1.08
Pajarito Mountain	1	16	2001								1.32	1.27
Pajarito Mountain	7	13	2001		0.65	0.89	1.00	1.09	1.13	1.16		
Pajarito Mountain	7	26	2001	0.37								
Pajarito Mountain	6	21	2002	0.28	0.46	0.57	0.96	1.05	1.28	1.28	1.38	
Pajarito Mountain	9	11	2002									1.22
Pueblo Canyon	7	9	2000			0.77	0.81	0.81	0.81			
Pueblo Canyon	10	23	2000							0.92	1.27	1.15
Pueblo Canyon	7	2	2001			0.70	0.70	0.70	0.72	0.72	0.72	0.72
Pueblo Canyon	6	21	2002			0.80	1.30	1.37	1.39	1.39	1.45	1.38
Quemezon Canyon	7	16	2000			1.28	1.28	1.28	1.29	1.42		1.42
Quemezon Canyon	10	23	2000								1.52	
Quemezon Canyon	7	13	2001			1.01				1.77	1.79	1.78
Quemezon Canyon	9	13	2001				1.38	1.66	1.69			
Quemezon Canyon	6	21	2002						1.47			
Quemezon Canyon	9	10	2002			0.51	0.86	1.14		1.66	1.87	1.86
Quemezon SNOTEL	4	30	1981									3.3
Quemezon SNOTEL	8	24	1982									2.1
Quemezon SNOTEL	8	2	1983									1.6
Quemezon SNOTEL	12	14	1984									1.5
Quemezon SNOTEL	4	28	1985									1.7
Quemezon SNOTEL	6	25	1986									2.0
Quemezon SNOTEL	7	16	1987									1.6
Quemezon SNOTEL	4	16	1988									1.2
Quemezon SNOTEL	7	21	1989									1.4
Quemezon SNOTEL	9	28	1990									1.6
Quemezon SNOTEL	11	15	1991									1.9
Quemezon SNOTEL	8	24	1992									1.8
Quemezon SNOTEL	1	8	1993									1.4
Quemezon SNOTEL	10	14	1994									2.1
Quemezon SNOTEL	7	18	1995									1.5
Quemezon SNOTEL	8	22	1996									1.6
Quemezon SNOTEL	7	30	1997									1.0
Quemezon SNOTEL	7	27	1998									1.4
Quemezon SNOTEL	4	30	1999									1.2
Quemezon SNOTEL	10	23	2000									2.8
Quemezon SNOTEL	1	16	2001									1.7
Quemezon SNOTEL	6	22	2002									1.0
Santa Clara Canyon	9	8	2000			0.80	0.89	1.05	1.08			

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
Santa Clara Canyon	10	23	2000							1.35	1.56	1.43
Santa Clara Canyon	7	2	2001			0.47	0.55					
Santa Clara Canyon	7	13	2001					0.83	0.96	1.51	1.52	1.52
Santa Clara Canyon	9	10	2002			1.47	2.41	2.65	2.73	3.09	3.22	3.20
TA-6	7	22	1990	0.54	0.82	1.25	1.40	1.40	1.40	1.40	1.51	1.40
TA-6	7	22	1991	0.89	1.21	1.34	1.35	1.51	1.51	1.53	1.84	1.52
TA-6	9	15	1992	0.41	0.70	1.06	1.25	1.25	1.58	1.58	1.65	1.65
TA-6	1	8	1993									1.20
TA-6	7	14	1993		0.70	1.00	1.17	1.17	1.17	1.17		
TA-6	7	19	1993	0.45							1.48	
TA-6	6	21	1994	0.38	0.40							
TA-6	8	21	1994			0.42						
TA-6	10	14	1994				0.54	0.78	1.35	1.78	2.19	1.97
TA-6	4	22	1995									1.02
TA-6	5	29	1995							0.88	1.18	
TA-6	8	5	1995	0.42	0.47							
TA-6	9	7	1995			0.61	0.67	0.73	0.74			
TA-6	6	26	1996			0.77	0.91	1.00	1.36	1.51	1.54	1.36
TA-6	6	29	1996	0.33	0.62							
TA-6	8	17	1997			0.80	1.26	1.27	1.30	1.31	1.50	1.29
TA-6	9	3	1997	0.47	0.65							
TA-6	7	6	1998	0.30	0.49	0.92	1.02	1.07	1.07	1.18		
TA-6	10	31	1998								1.38	1.32
TA-6	4	2	1999								1.05	
TA-6	8	10	1999	0.47	0.49	0.52						
TA-6	9	14	1999				0.86	0.94	0.94	0.94		0.94
TA-6	8	19	2000	0.30								
TA-6	10	23	2000									1.00
TA-6	10	27	2000		0.37	0.52	0.59	0.59	0.63	0.96	1.17	
TA-6	8	16	2001	0.46	0.65	0.75	0.84	0.86	0.86	0.86	0.95	0.94
TA-6	6	21	2002	0.56	0.76	0.81	1.33	1.45	1.62	1.63	1.80	1.43
TA-16	8	5	1977									1.46
TA-16			1978									missing
TA-16	6	8	1979									0.99
TA-16	7	23	1980									0.69
TA-16	7	27	1981									1.75
TA-16	8	21	1982									1.12
TA-16	7	11	1983									0.87
TA-16	12	14	1984									0.96
TA-16	4	28	1985									1.60
TA-16	9	13	1986									1.08
TA-16	8	26	1987									1.28
TA-16	4	16	1988									1.39
TA-16	7	14	1989									1.97
TA-16	11	2	1990									1.47

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
TA-16	8	6	1991									1.91
TA-16	8	24	1992									1.42
TA-16	7	14	1993									1.28
TA-16	10	14	1994									2.50
TA-16	8	29	1995									1.52
TA-16	5	21	1996	0.74	1.09							
TA-16	6	26	1996			1.30	1.38	1.48	1.84	1.92	1.94	1.84
TA-16	9	3	1997	0.56	0.82							
TA-16	9	5	1997			0.91	0.96	0.99	0.99	0.99		0.99
TA-16	9	21	1997								1.26	
TA-16	7	1	1998			0.89	0.98	0.98	0.98			
TA-16	7	19	1998	0.59	0.71							
TA-16	10	31	1998							1.05	1.46	1.46
TA-16	4	2	1999								1.23	
TA-16	10	11	1999	0.68	1.06	1.06	1.06	1.06	1.06	1.06		1.06
TA-16	6	28	2000	0.26	0.41							
TA-16	7	9	2000			0.45	0.66	0.73	0.73			
TA-16	10	23	2000							0.97	1.22	1.14
TA-16	1	16	2001									0.94
TA-16	1	28	2001								1.10	
TA-16	8	3	2001			0.61	0.73	0.73	0.73	0.73		
TA-16	8	9	2001	0.32	0.43							
TA-16	6	21	2002	0.68	0.83	0.89	1.33	1.40	1.48			
TA-16	9	10	2002							1.80	2.10	1.95
TA-49	7	16	1988	0.42			0.86	0.96	0.96			
TA-49	8	23	1988		0.60	0.75						
TA-49	9	13	1988							1.14	1.66	1.19
TA-49	5	9	1989	0.44								
TA-49	7	14	1989		0.54	0.65	0.72	0.72	0.72		1.14	
TA-49	8	1	1989							0.79		1.01
TA-49	7	14	1990	0.44	0.61	0.61	0.61					
TA-49	9	16	1990					0.68	0.79	0.85		
TA-49	11	2	1990								1.15	1.14
TA-49	7	26	1991								1.97	
TA-49	8	2	1991	0.64	1.25	1.61	1.67	1.73	1.76	1.76		1.76
TA-49	5	20	1992	0.31								
TA-49	5	30	1992								0.85	
TA-49	8	11	1992		0.42	0.51	0.72	0.80	0.80	0.80		0.80
TA-49	1	9	1993									1.41
TA-49	8	26	1993				1.11	1.26	1.27	1.27	2.34	
TA-49	8	27	1993	0.55								
TA-49	9	6	1993		0.78	0.93						
TA-49	7	9	1994		0.29							
TA-49	8	1	1994			0.44						
TA-49	9	6	1994	0.20								

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
TA-49	10	14	1994				0.59	0.88	1.42	1.79	2.10	1.85
TA-49	5	29	1995						1.50	1.56	1.85	1.58
TA-49	9	7	1995	0.48	0.83	0.91	1.08	1.11				
TA-49	6	29	1996	1.05	1.41	1.58	1.59	1.59	1.59	1.61	1.64	1.64
TA-49	2	28	1997							1.18	1.67	1.35
TA-49	6	7	1997			0.65	0.78					
TA-49	9	10	1997	0.36	0.51			0.88	0.88			
TA-49	7	1	1998	0.65	0.83							
TA-49	7	6	1998			1.28	1.29	1.29	1.29	1.33	1.33	1.29
TA-49	4	24	1999						0.64			
TA-49	8	10	1999	0.44	0.51	0.57	0.57	0.57		0.72	0.87	0.87
TA-49	6	28	2000	0.30	0.53	0.55	0.55					
TA-49	8	19	2000						0.62		1.23	1.18
TA-49	10	23	2000					0.60		1.12		
TA-49	8	11	2001	0.56	0.85	0.87	0.87	0.87	0.87	0.87	0.87	0.87
TA-49	6	21	2002	0.23			0.41	0.53	0.62			
TA-49	9	1	2002		0.32	0.38						
TA-49	9	10	2002							0.72	0.84	0.74
TA-53	5	29	1992							1.05	1.29	1.07
TA-53	8	11	1992			0.52	0.70	0.78	0.78			
TA-53	8	26	1992	0.28	0.45							
TA-53	1	8	1993							1.16		1.19
TA-53	8	26	1993	0.44	0.59	0.75	0.99	1.10	1.11		1.58	
TA-53	8	21	1994	0.33	0.49	0.81	1.00	1.00				
TA-53	10	15	1994						1.39	1.66	1.89	1.63
TA-53	5	29	1995			0.58			1.10	1.15	1.43	1.17
TA-53	7	16	1995	0.36	0.46							
TA-53	9	7	1995				0.69	0.73				
TA-53	6	13	1996	0.31	0.44	0.51	0.55	0.57				
TA-53	10	4	1996						0.74	0.89	1.12	0.85
TA-53	2	28	1997							1.15	1.51	1.22
TA-53	8	22	1997	0.47	0.70	0.85	0.90	0.91	0.93			
TA-53	7	3	1998			1.17	1.49	1.49	1.49	1.50	1.52	1.49
TA-53	8	25	1998	0.52	0.62							
TA-53	8	6	1999	0.46	0.71	0.87	0.88	0.88	0.88	0.88	1.06	0.91
TA-53	6	2	2000			0.45	0.55					
TA-53	7	29	2000	0.26	0.29							
TA-53	10	23	2000					0.56	0.60	1.12	1.21	1.15
TA-53	1	25	2001						0.40			
TA-53	1	28	2001								0.70	0.63
TA-53	5	4	2001							0.57		
TA-53	6	27	2001	0.23	0.33	0.37	0.37	0.37				
TA-53	7	18	2002	0.20	0.33	0.35						
TA-53	9	10	2002				0.41	0.44	0.56	0.82	0.95	0.86
TA-54	5	25	1992	0.24	0.31	0.37						

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
TA-54	5	29	1992				0.52	0.70	0.83	1.02	1.21	0.86
TA-54	8	26	1993	0.37	0.66	0.86	1.11	1.20	1.21	1.22	1.47	1.21
TA-54	7	28	1994	0.63	0.76	0.76	0.76	0.76				
TA-54	10	15	1994						0.94			
TA-54	11	12	1994							1.25	1.83	1.21
TA-54	8	29	1995	0.58	0.68	0.72						
TA-54	9	7	1995				0.92	0.96	0.97	0.98	1.64	0.97
TA-54	6	29	1996	0.38	0.72	0.85						
TA-54	7	8	1996				0.91	1.15	1.32	1.35	1.51	1.18
TA-54	6	7	1997		0.54	0.66	0.76	0.78	0.80	0.93	1.16	1.07
TA-54	8	22	1997	0.43								
TA-54	7	28	1998	0.34	0.63	0.76	0.78	0.79	0.80			
TA-54	10	31	1998							0.96	1.31	1.30
TA-54	6	17	1999	0.72	1.44	1.83	1.94	1.94	2.07	2.10	2.26	2.11
TA-54	8	9	2000	0.35	0.60	0.73	0.74	0.74	0.74			
TA-54	8	19	2000								1.77	1.71
TA-54	10	23	2000							1.10		
TA-54	7	2	2001	0.26	0.38							
TA-54	8	4	2001			0.55	0.56	0.56	0.56	0.56	0.56	0.56
TA-54	8	28	2002	0.82	1.05	1.09	1.13	1.18	1.18	1.18		1.18
TA-54	9	10	2002								1.30	
TA-59	8	5	1980	0.27	0.38	0.42						
TA-59	8	8	1980				0.53	0.60	0.63	0.63	1.01	0.62
TA-59	3	11	1981								1.22	1.06
TA-59	5	1	1981						0.94	1.02		
TA-59	7	27	1981				0.66	0.66				
TA-59	8	31	1981	0.48	0.60	0.64						
TA-59	7	29	1982	0.29	0.46							
TA-59	8	24	1982			0.68	0.90	0.94	1.38	1.59	1.72	1.67
TA-59	7	23	1983			1.07	1.59	1.59	1.59	1.59	1.59	1.59
TA-59	9	11	1983	0.31	0.56							
TA-59	8	20	1984			0.59	0.71	0.71	0.71	0.97		
TA-59	9	21	1984	0.45	0.47							
TA-59	12	14	1984								1.12	1.09
TA-59	8	10	1985	0.88	1.15	1.22	1.33	1.52	1.76	1.76	2.06	1.76
TA-59	6	3	1986	0.37		0.93	1.23	1.32	1.58	1.58	1.58	1.58
TA-59	8	25	1986		0.61							
TA-59	6	7	1987	0.47	0.88	1.55	2.10	2.11	2.16	2.16	2.16	2.16
TA-59	6	10	1988	0.50	0.67	0.98	1.36	1.56	1.94	2.08	2.09	2.05
TA-59	5	9	1989	0.37	0.40			0.72	0.74	0.75		
TA-59	7	14	1989			0.47	0.47					
TA-59	8	1	1989								0.91	0.91
TA-59	7	22	1990	0.50	0.70	1.18	1.24	1.24	1.24	1.24	1.34	1.24
TA-74	7	11	1982									1.31
TA-74	7	27	1983									1.05

APPENDIX A (continued)

Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
TA-74	12	14	1984									0.90
TA-74	4	24	1985									2.24
TA-74	6	26	1986									1.22
TA-74	5	15	1987									0.99
TA-74	7	5	1988									1.25
TA-74	5	9	1989									2.03
TA-74	7	20	1990									1.31
TA-74	7	22	1991									1.11
TA-74	5	29	1992									0.79
TA-74	8	3	1993									1.18
TA-74	10	14	1994									1.20
TA-74	5	29	1995									0.73
TA-74	5	18	1996	0.81	1.06	1.06	1.06	1.06	1.06	1.06		1.06
TA-74	10	4	1996								1.22	
TA-74	2	28	1997							0.99	1.18	0.91
TA-74	8	2	1997		0.57	0.74	0.75	0.77	0.77			
TA-74	8	5	1997	0.47								
TA-74	8	13	1998		0.46	0.70	0.78	0.80				
TA-74	8	25	1998	0.25					0.82	0.83	0.83	0.82
TA-74	5	27	1999	0.64	0.74							
TA-74	6	17	1999								1.11	
TA-74	7	8	1999			0.78	0.94	0.94	0.97	1.01		0.99
TA-74	8	9	2000		0.41	0.52	0.57	0.57				
TA-74	8	19	2000								1.31	1.27
TA-74	8	23	2000	0.28								
TA-74	11	23	2000						0.93	1.12		
TA-74	1	27	2001							0.41	0.50	0.45
TA-74	6	7	2001	0.17	0.33	0.38	0.38	0.39	0.39			
TA-74	8	28	2002	0.35	0.48	0.52	0.55	0.59	0.59			
TA-74	9	10	2002							0.69	1.09	0.80
Upper Los Alamos Cyn	7	12	2000				0.81					
Upper Los Alamos Cyn	9	8	2000			0.65		0.83				
Upper Los Alamos Cyn	10	23	2000						0.92	1.54	1.91	1.84
Upper Los Alamos Cyn	7	13	2001			0.84						
Upper Los Alamos Cyn	8	9	2001				1.24	1.24	1.24	1.24	1.24	1.24
Upper Los Alamos Cyn	6	21	2002			0.80	1.19	1.57	1.63	1.63		1.66
Upper Los Alamos Cyn	9	10	2002								1.77	
Upper Santa Clara Cyn	8	28	2000			0.58	0.89	1.08	1.31	1.32	1.32	1.32
Upper Santa Clara Cyn	7	25	2001			0.64	0.96	0.96	1.05	1.11	1.22	1.11
Upper Santa Clara Cyn	6	22	2002			1.31	1.62	1.67	1.67	1.67	3.12	2.06
Water Canyon	6	28	2000			0.78	0.79	0.79	0.79			
Water Canyon	10	23	2000							1.09	1.53	1.41
Water Canyon	8	9	2001			0.42	0.72	0.72	0.72	0.72	0.72	0.72
Water Canyon	6	22	2002			0.75	0.83	1.46	1.55			
Water Canyon	9	10	2002							1.62	1.73	1.58

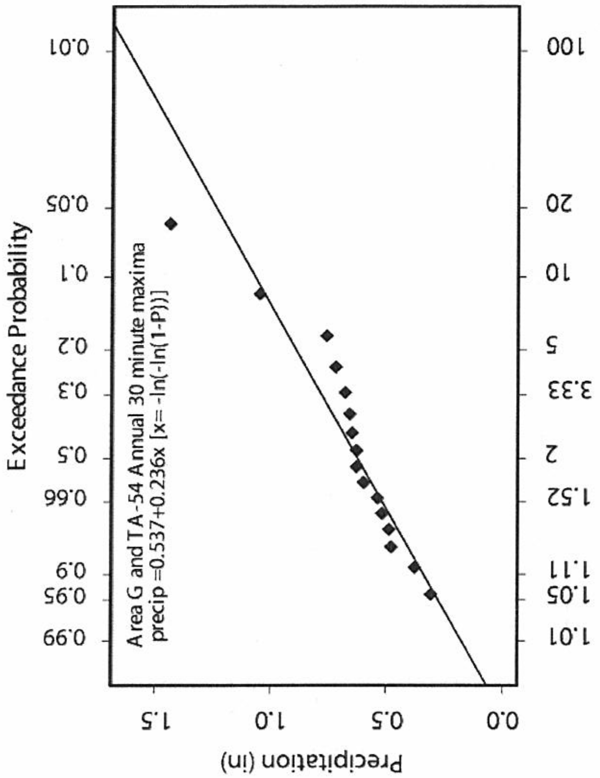
APPENDIX A (continued)

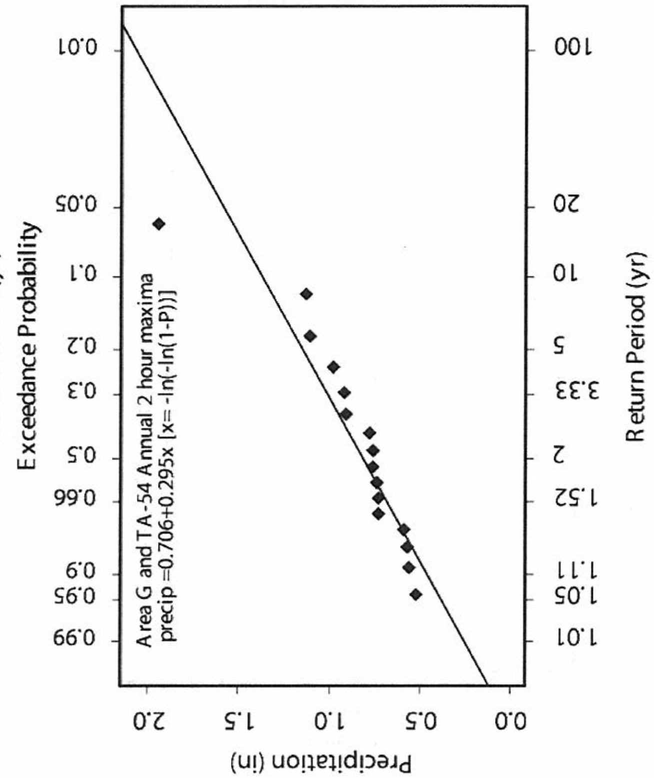
Station	month	day	year	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	daily
White Rock	12	11	1965									1.60
White Rock	8	2	1966									1.26
White Rock	8	10	1967									1.55
White Rock	7	31	1968									1.88
White Rock	4	11	1969									1.75
White Rock	7	6	1970									0.67
White Rock	1	3	1971									1.22
White Rock	5	30	1972									1.05
White Rock	9	10	1973									1.42
White Rock	3	10	1974									0.75
White Rock	7	17	1975									1.60
White Rock	8	1	1976									1.16
White Rock	11	7	1977									0.78
White Rock	11	11	1978									0.71
White Rock	8	15	1979									0.66
White Rock	5	15	1980									0.50
White Rock	9	4	1981									1.25
White Rock	8	21	1982									1.46
White Rock	8	2	1983									0.98
White Rock	8	6	1984									0.97
White Rock	6	26	1986									1.01
White Rock	8	22	1987									1.46
White Rock	9	12	1988									1.36
White Rock	10	31	1989									1.93
White Rock	7	20	1990									1.18
White Rock	7	25	1991									1.19

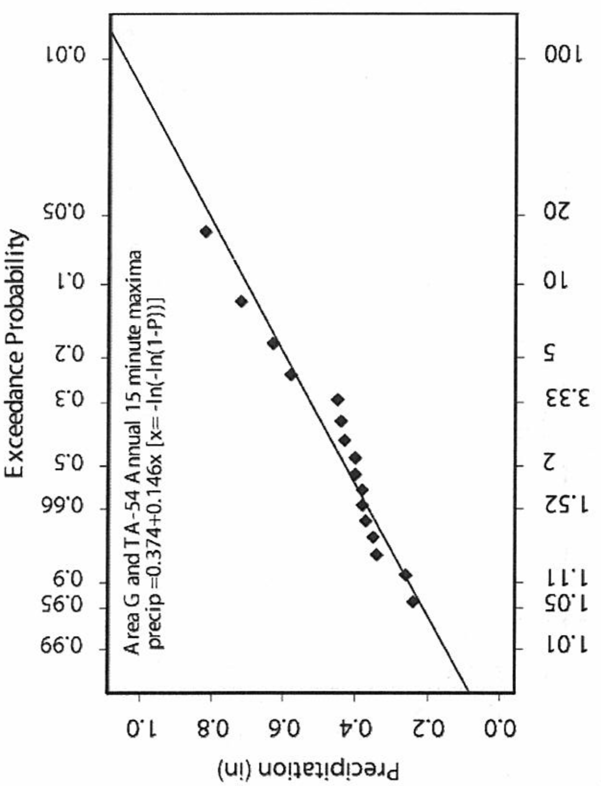
APPENDIX B

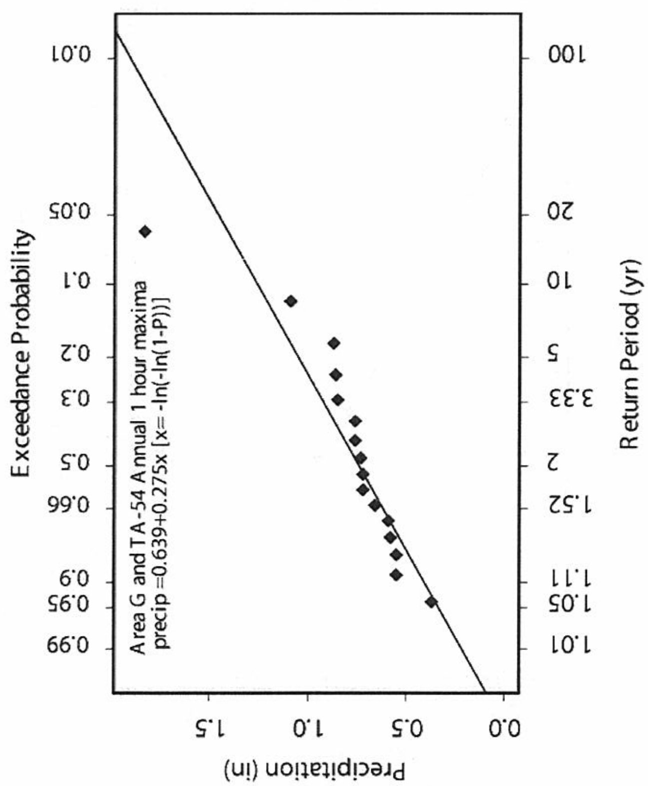
GUMBEL EXTREME VALUE PRECIPITATION PLOTS

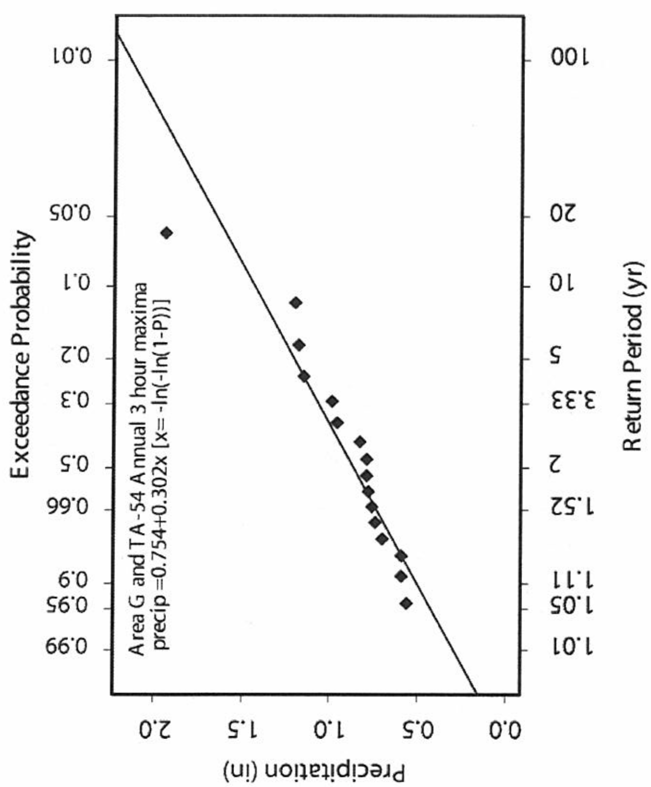
FOR RECORDS ≥ 15 YEARS IN LENGTH

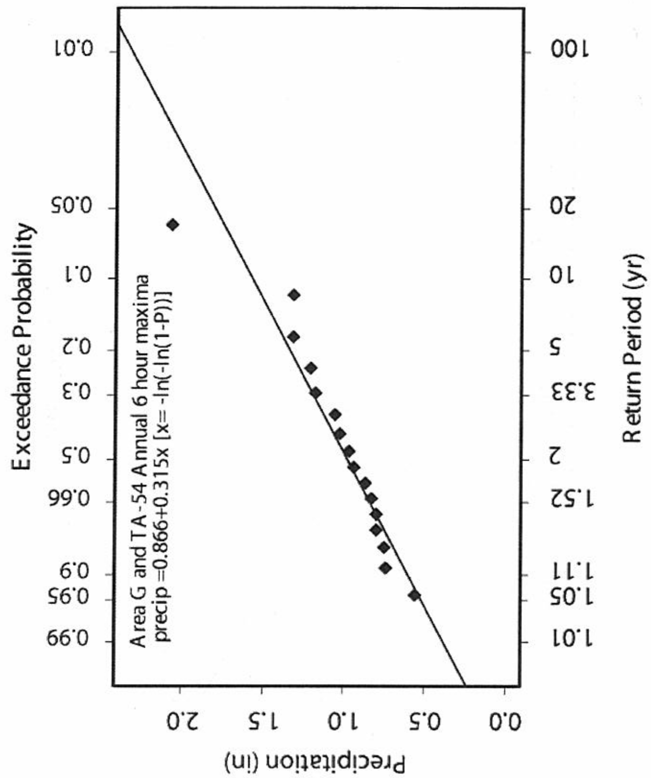

Area G and TA-54 Annual 30 minute maxima
precip =0.537+0.236x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

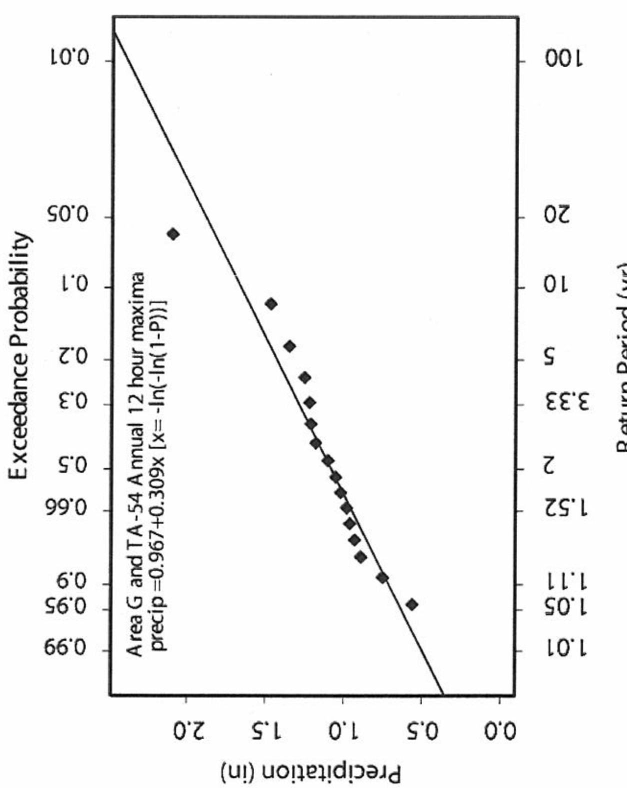

Area G and TA-54 Annual 2 hour maxima
precip =0.706+0.295x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

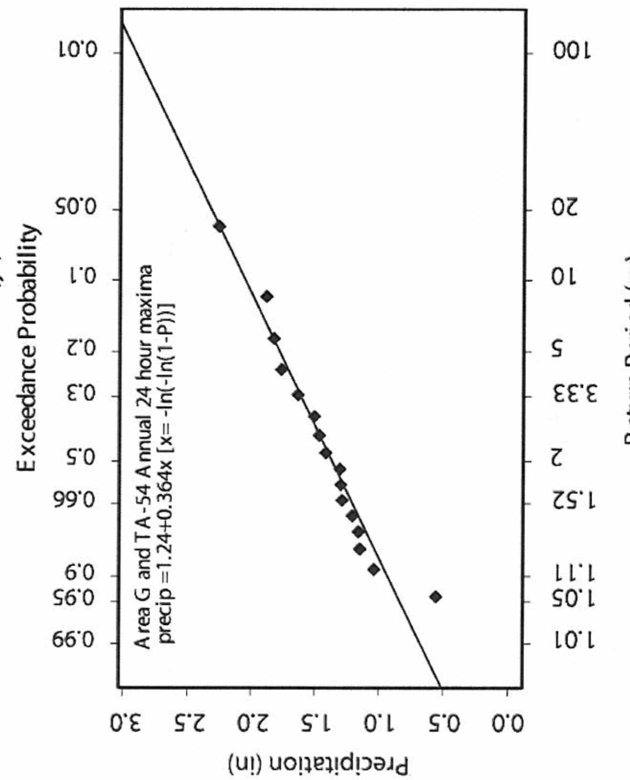

Area G and TA-54 Annual 15 minute maxima
precip =0.374+0.146x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

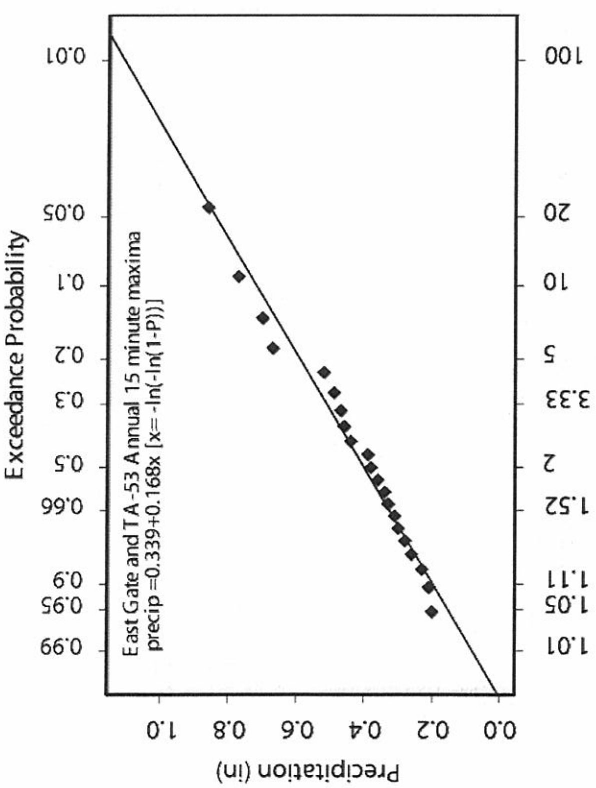

Area G and TA-54 Annual 1 hour maxima
precip =0.639+0.275x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

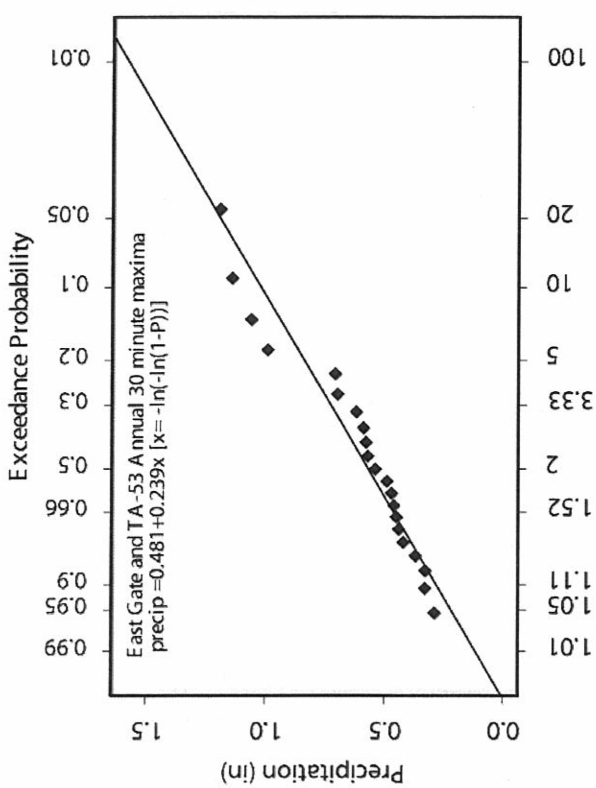

Area G and TA-54 Annual 3 hour maxima
precip =0.754+0.302x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

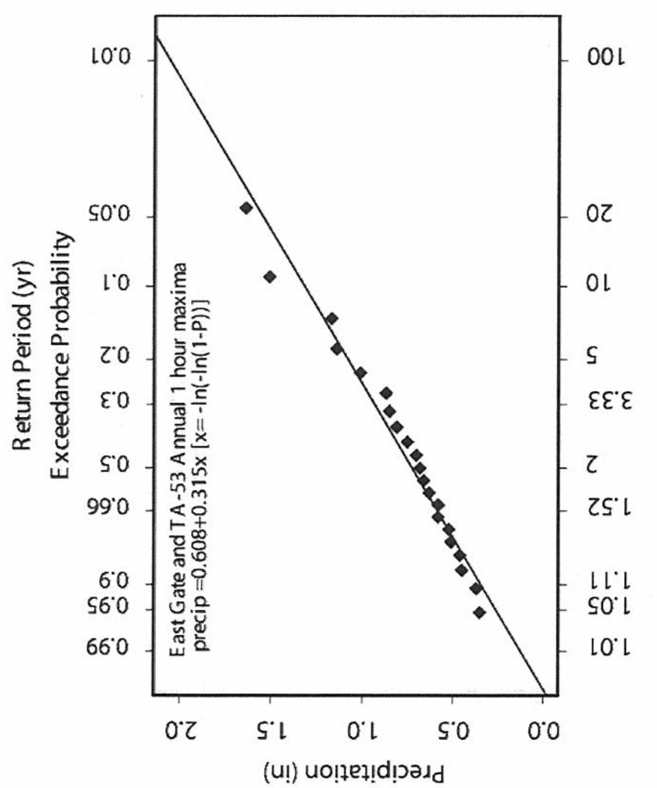

Area G and TA-54 Annual 6 hour maxima
precip =0.866+0.315x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

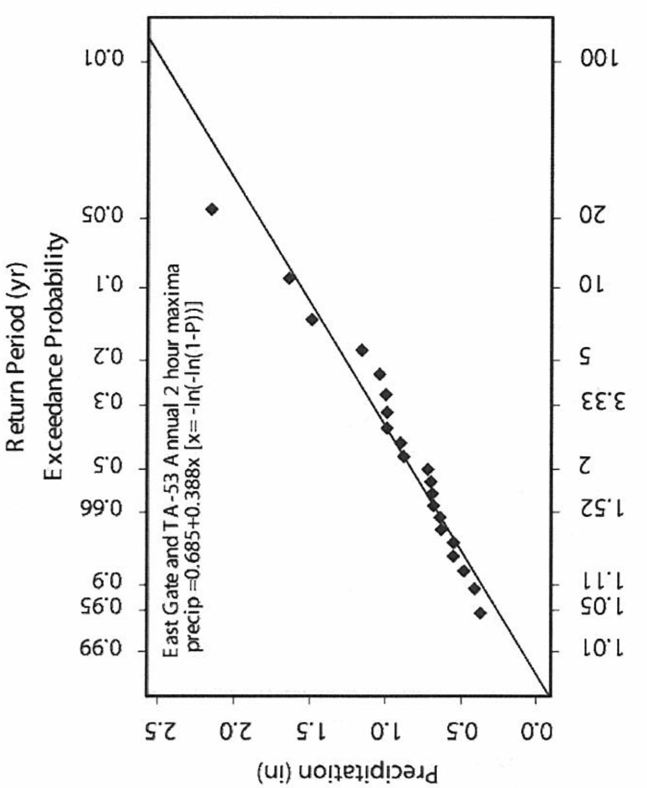

Area G and TA-54 Annual 12 hour maxima
precip =0.967+0.309x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

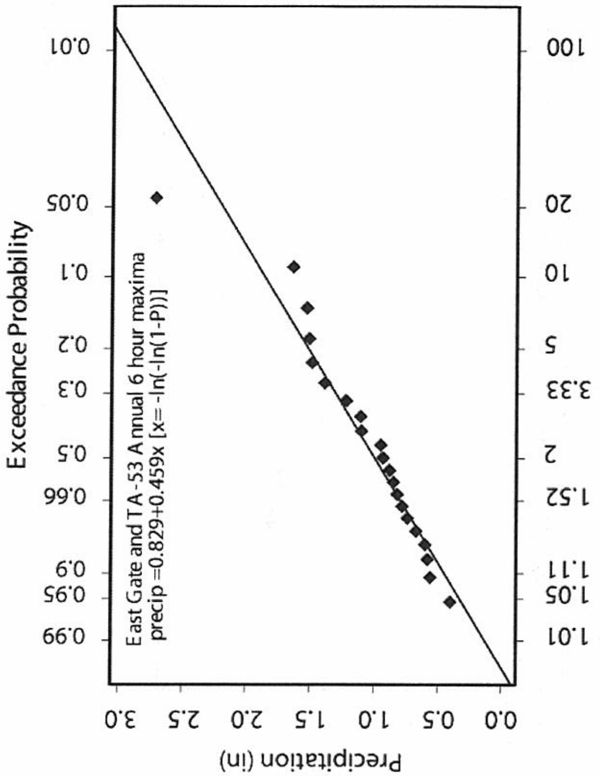

Area G and TA-54 Annual 24 hour maxima
precip =1.24+0.364x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

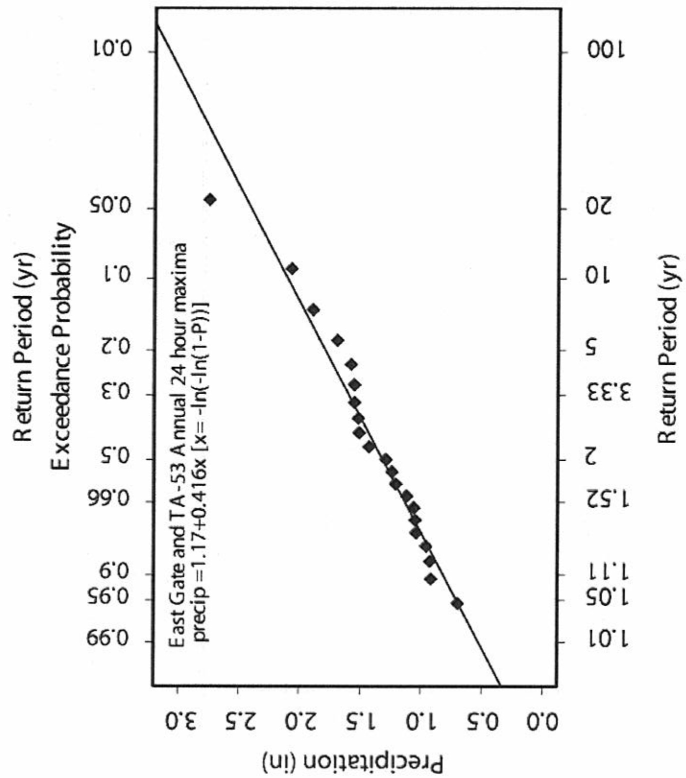

Exceedance Probability
East Gate and TA-53 Annual 15 minute maxima
precip =0.339+0.168x [x=-ln(-ln(1-P))]
Precipitation (in)
Return Period (yr)

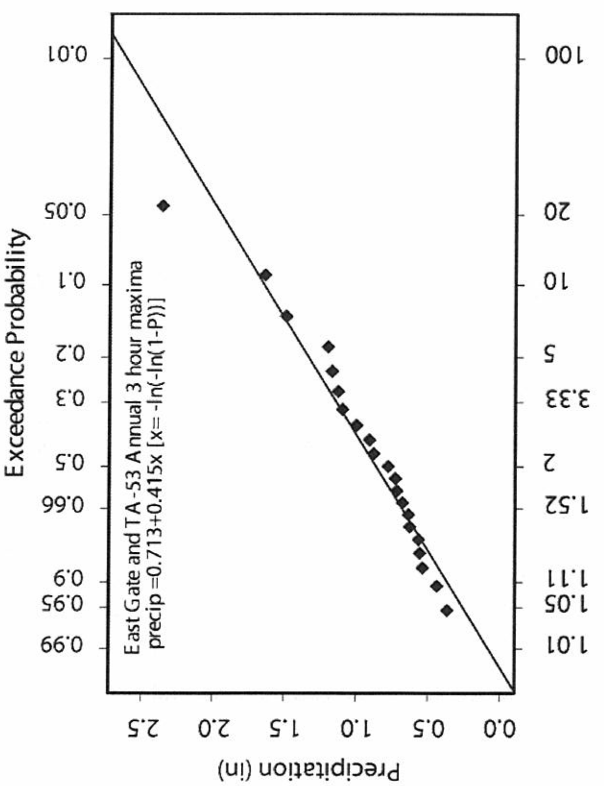

Exceedance Probability
East Gate and TA-53 Annual 30 minute maxima
precip =0.481+0.239x [x=-ln(-ln(1-P))]
Precipitation (in)
Return Period (yr)

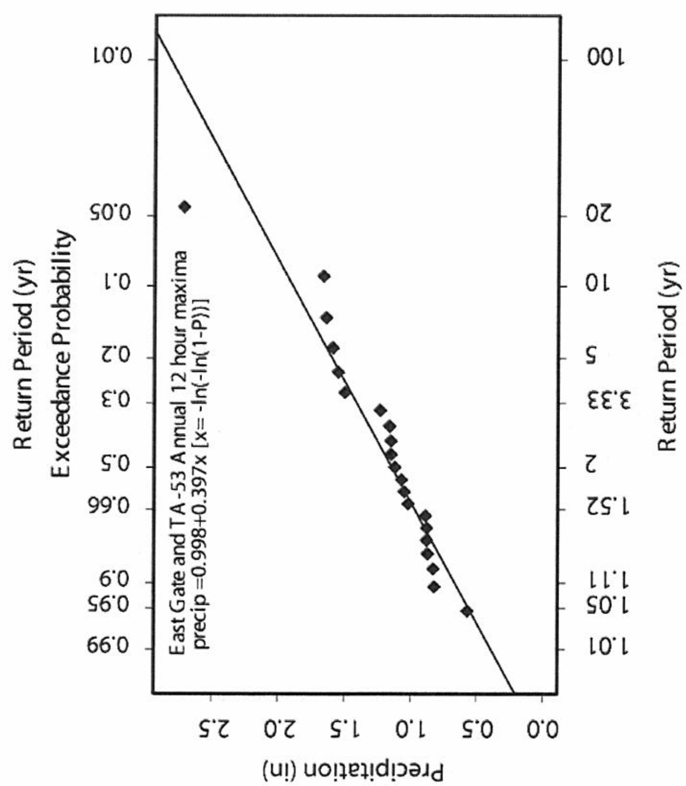

Exceedance Probability
East Gate and TA-53 Annual 1 hour maxima
precip =0.608+0.315x [x=-ln(-ln(1-P))]
Precipitation (in)
Return Period (yr)

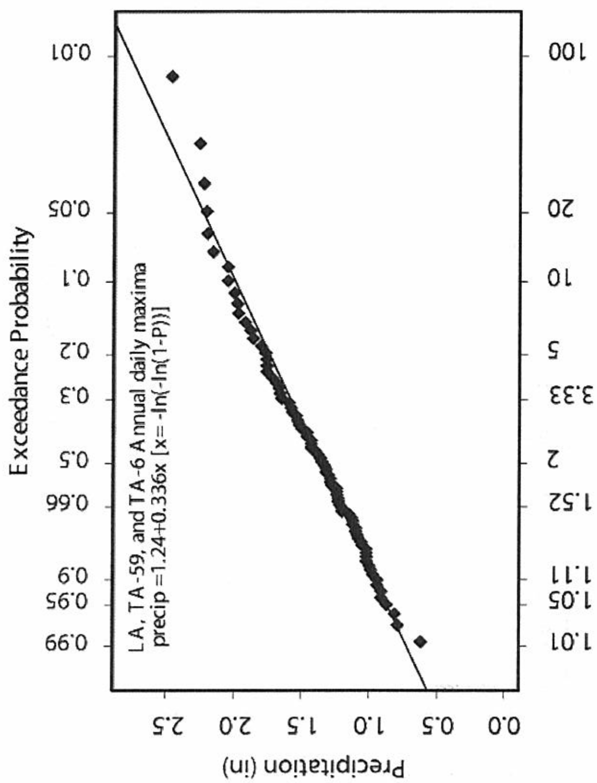

Exceedance Probability
East Gate and TA-53 Annual 2 hour maxima
precip =0.685+0.388x [x=-ln(-ln(1-P))]
Precipitation (in)
Return Period (yr)

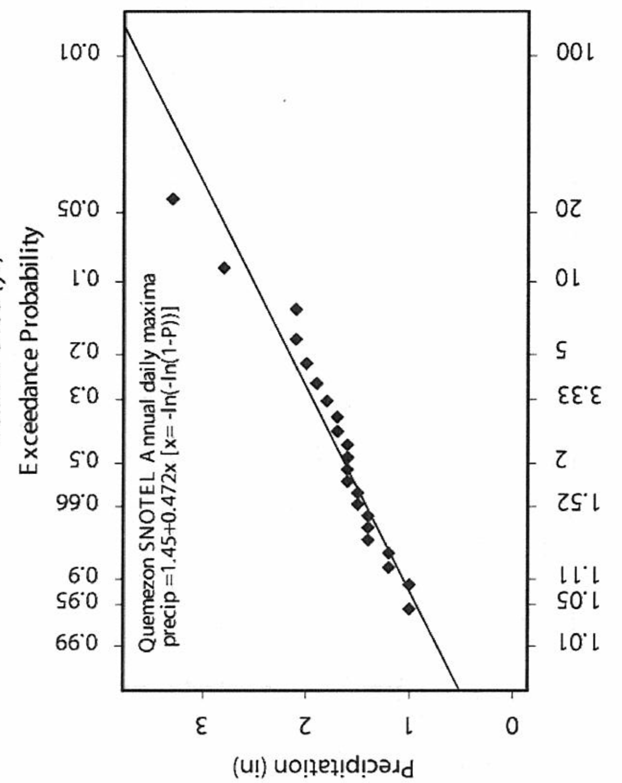

East Gate and TA-53 Annual 6 hour maxima
precip =0.829+0.459x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

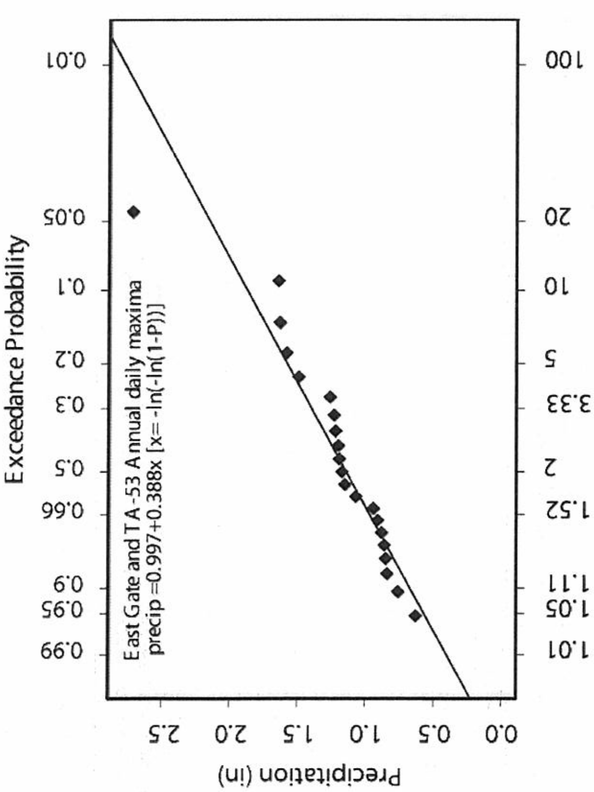

East Gate and TA-53 Annual 24 hour maxima
precip =1.17+0.416x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

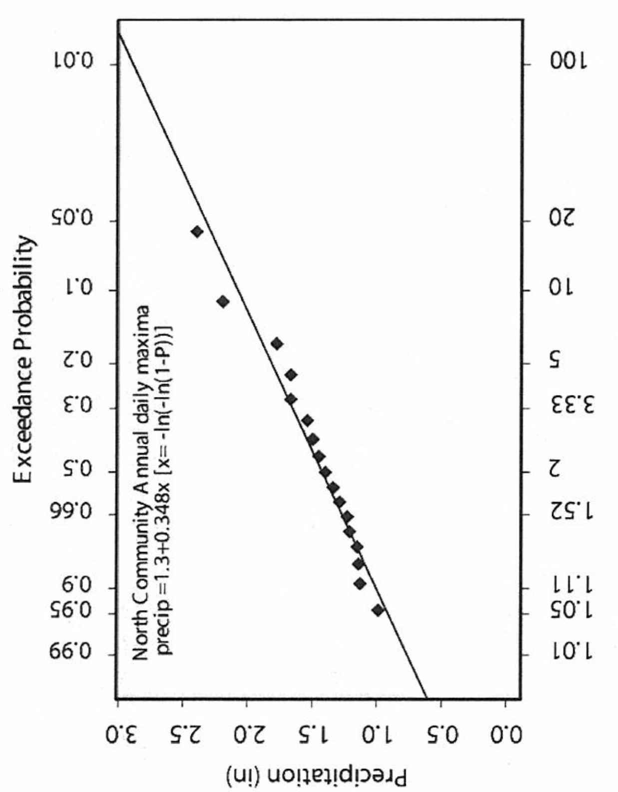

East Gate and TA-53 Annual 3 hour maxima
precip =0.713+0.415x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

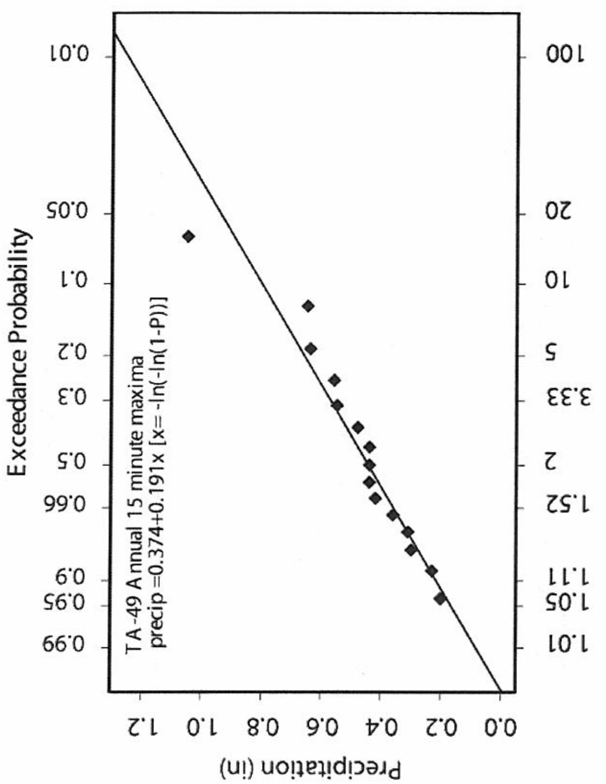

East Gate and TA-53 Annual 12 hour maxima
precip =0.998+0.397x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

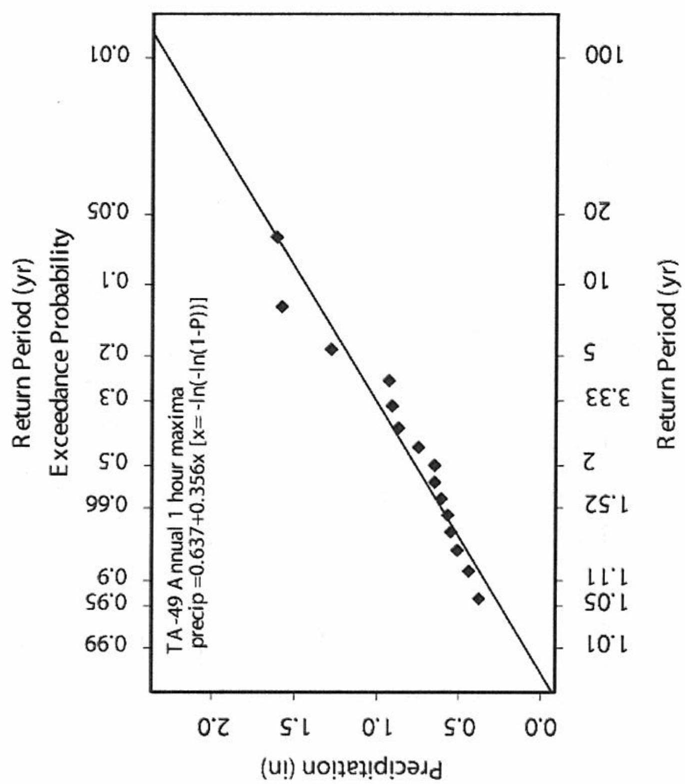

LA, TA-59, and TA-6 Annual daily maxima
precip =1.24+0.336x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

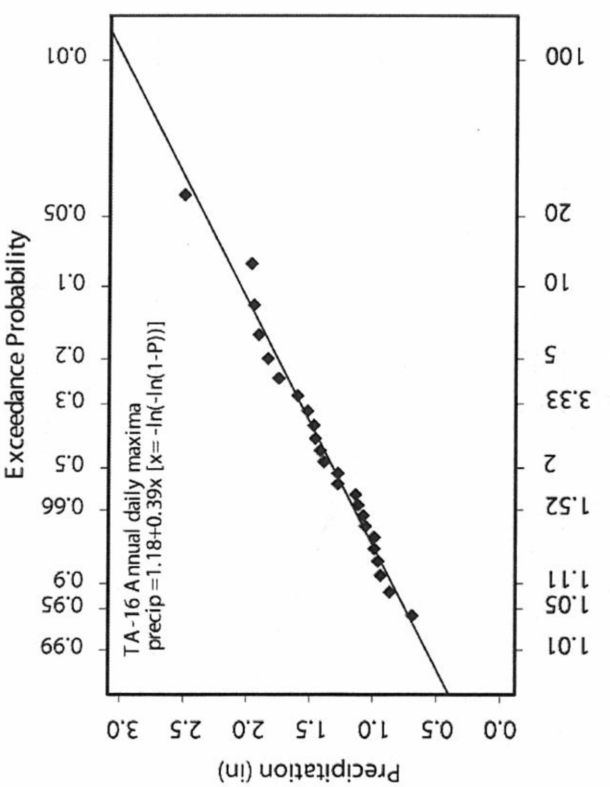

Quemezon SNOTEL Annual daily maxima
precip =1.45+0.472x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

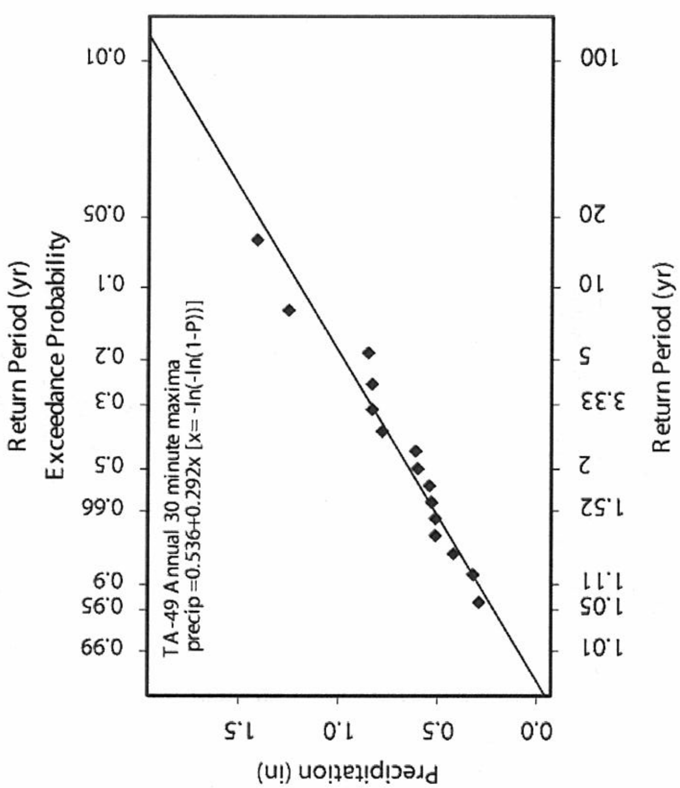

East Gate and TA-53 Annual daily maxima
precip =0.997+0.388x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

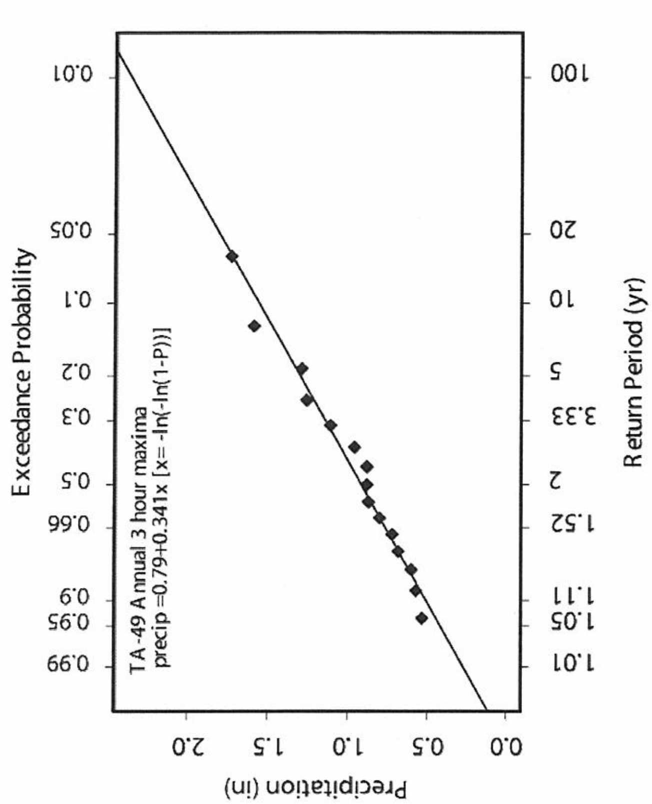

North Community Annual daily maxima
precip =1.3+0.348x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

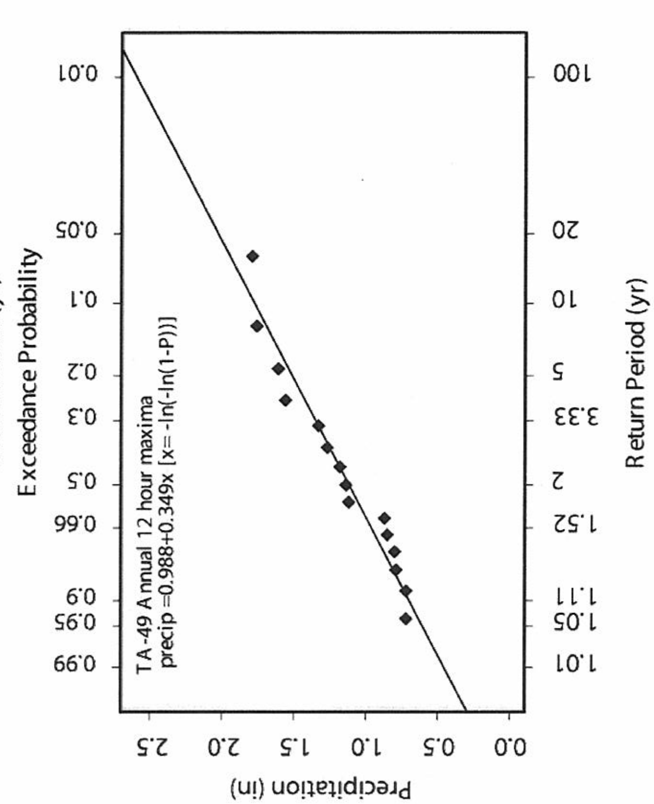

TA-49 Annual 15 minute maxima
precip =0.374+0.191x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

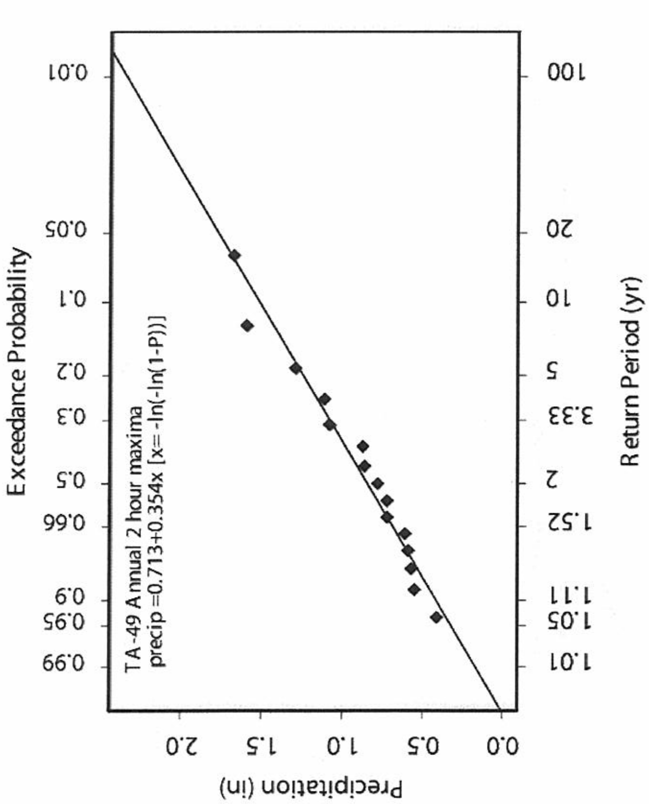

TA-49 Annual 1 hour maxima
precip =0.637+0.356x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

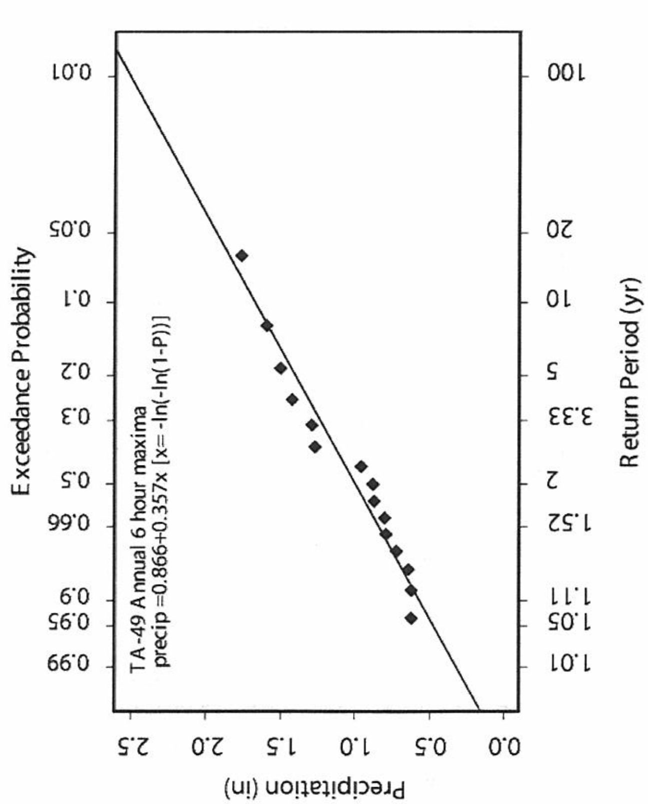

TA-16 Annual daily maxima
precip =1.18+0.39x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

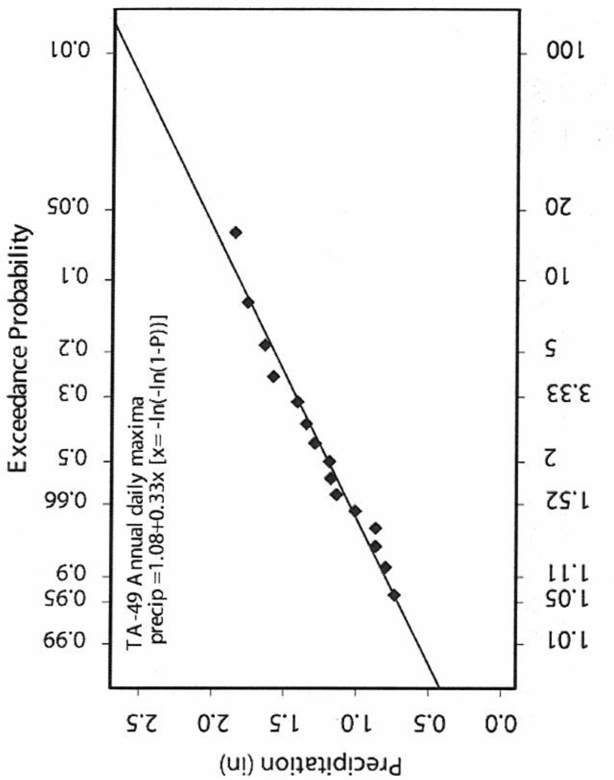

TA-49 Annual 30 minute maxima
precip =0.536+0.292x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

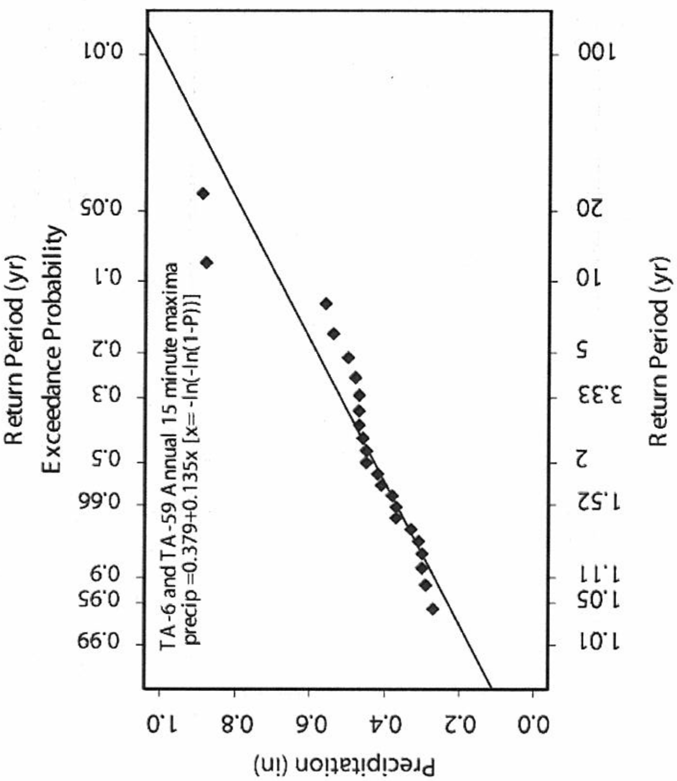

TA-49 Annual 3 hour maxima
precip =0.79+0.341x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

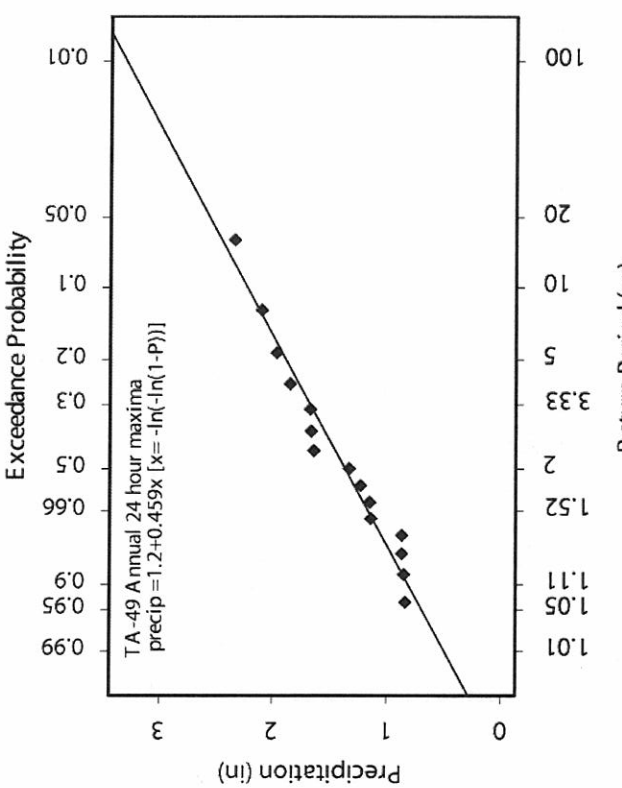

TA-49 Annual 12 hour maxima
precip =0.988+0.349x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

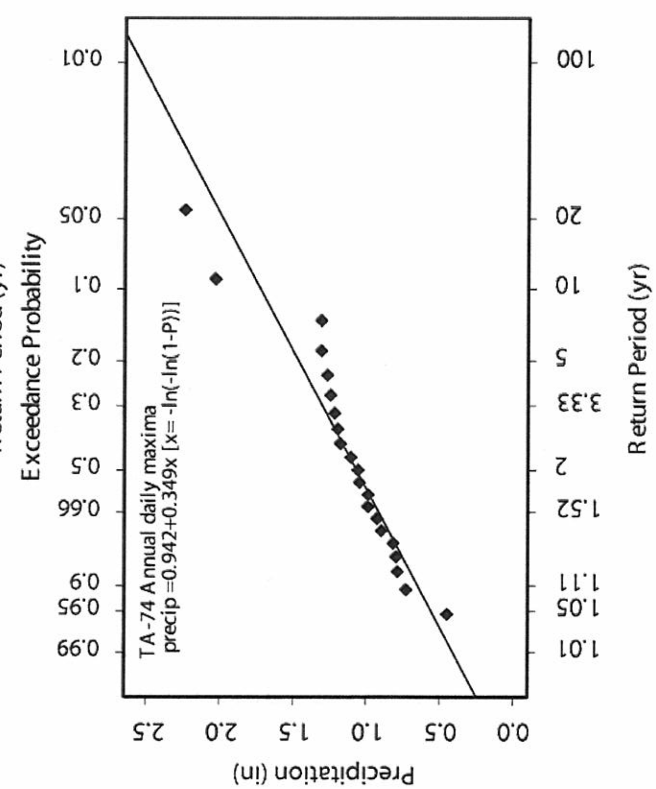

TA-49 Annual 2 hour maxima
precip =0.713+0.354x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

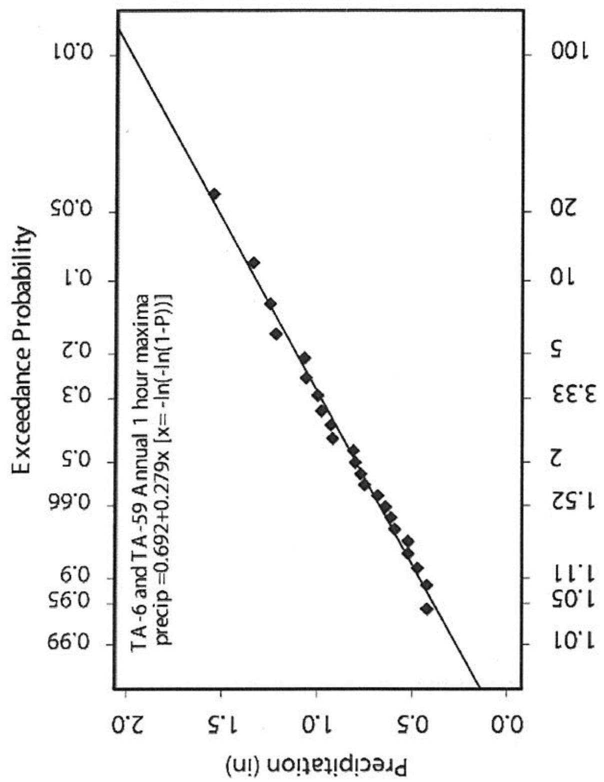

TA-49 Annual 6 hour maxima
precip =0.866+0.357x [x= -ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

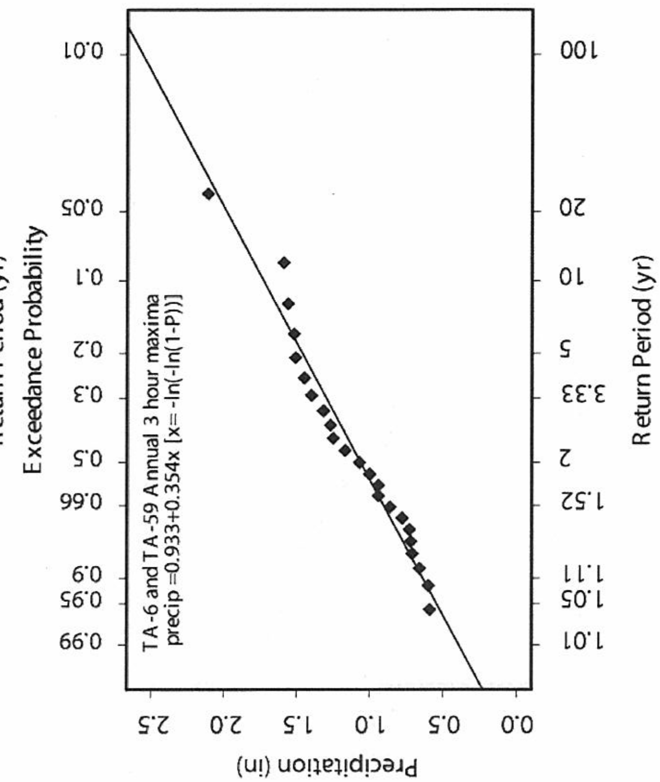

TA-49 Annual daily maxima
precip =1.08+0.33x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

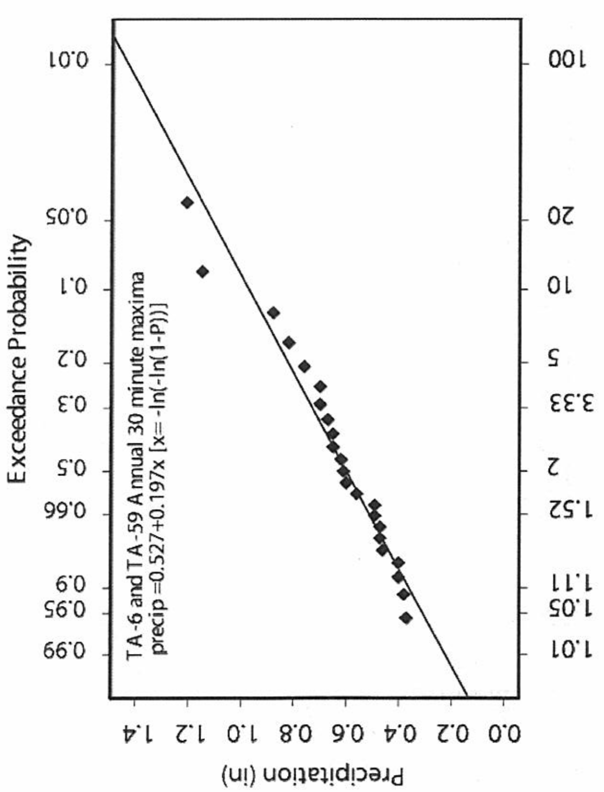

TA-6 and TA-59 Annual 15 minute maxima
precip =0.379+0.135x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

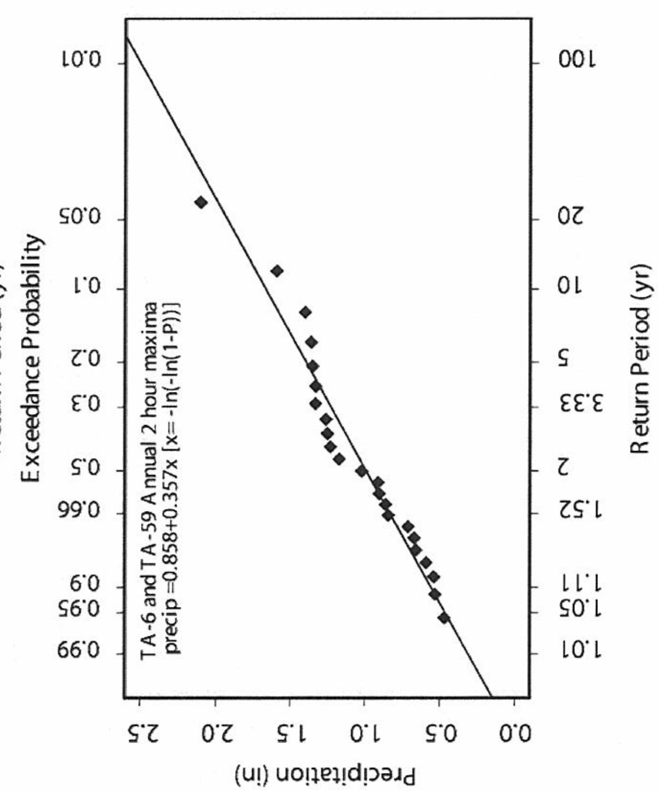

TA-49 Annual 24 hour maxima
precip =1.2+0.459x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

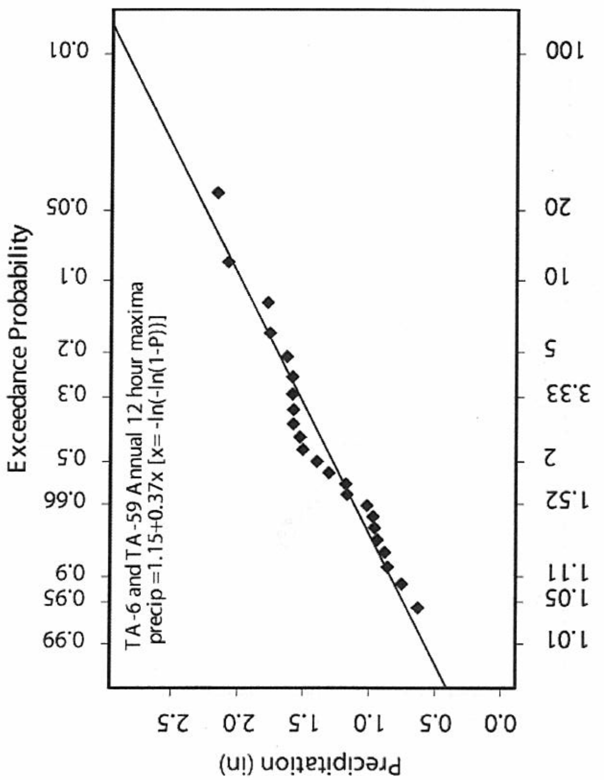

TA-74 Annual daily maxima
precip =0.942+0.349x [x=-ln(-ln(1-P))]
Exceedance Probability
Return Period (yr)
Precipitation (in)

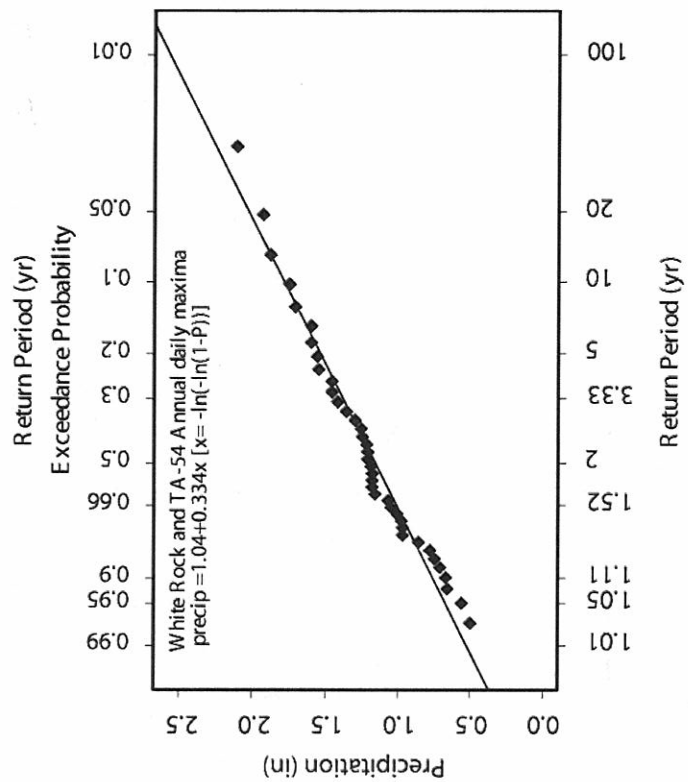

TA-6 and TA-59 Annual 1 hour maxima
precip =0.692+0.279x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99
0.95
0.9
0.66
0.5
0.3
0.2
0.1
0.05
0.01
Precipitation (in)
0.0
0.5
1.0
1.5
2.0
Return Period (yr)
1.01
1.05
1.11
1.52
2
3.33
5
10
20
100

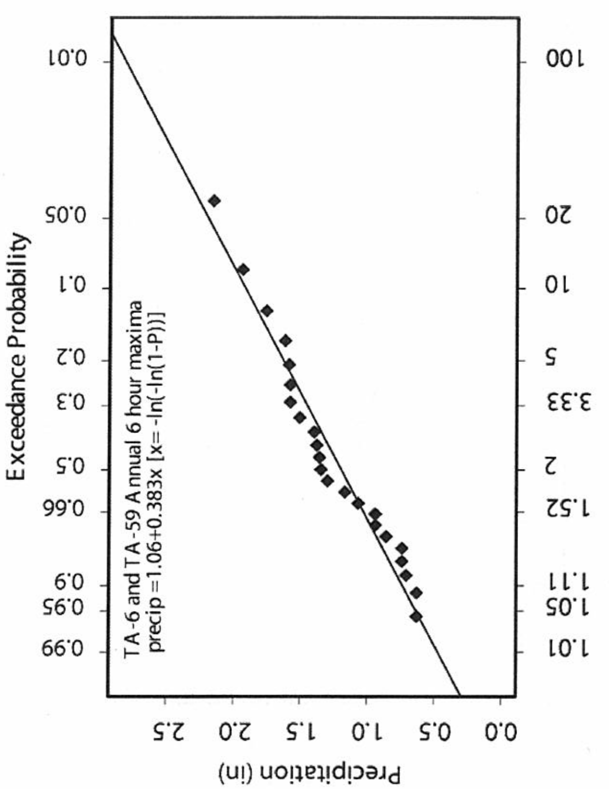

TA-6 and TA-59 Annual 3 hour maxima
precip =0.933+0.354x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99
0.95
0.9
0.66
0.5
0.3
0.2
0.1
0.05
0.01
Precipitation (in)
0.0
0.5
1.0
1.5
2.0
2.5
Return Period (yr)
1.01
1.05
1.11
1.52
2
3.33
5
10
20
100

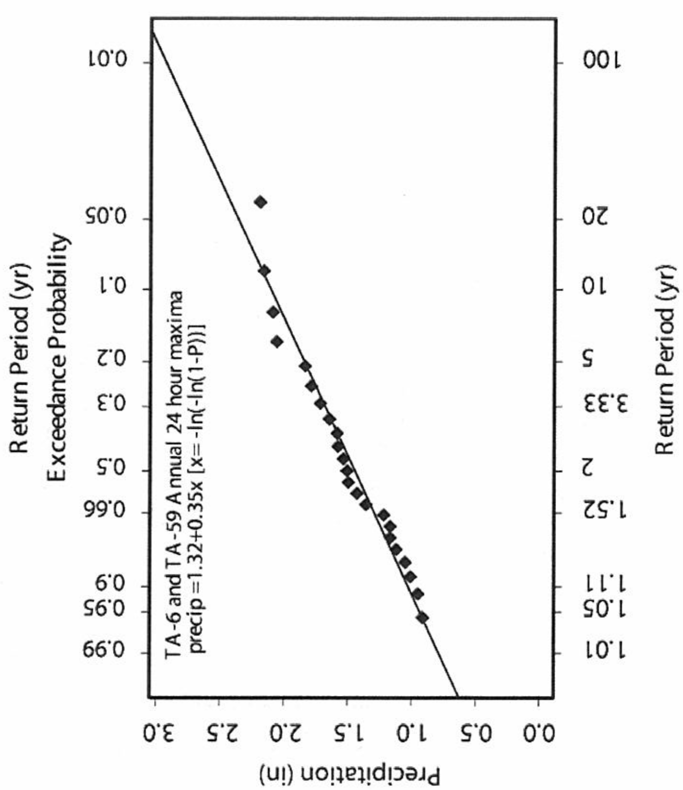

TA-6 and TA-59 Annual 30 minute maxima
precip =0.527+0.197x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99
0.95
0.9
0.66
0.5
0.3
0.2
0.1
0.05
0.01
Precipitation (in)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Return Period (yr)
1.01
1.05
1.11
1.52
2
3.33
5
10
20
100


TA-6 and TA-59 Annual 2 hour maxima
precip =0.858+0.357x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99
0.95
0.9
0.66
0.5
0.3
0.2
0.1
0.05
0.01
Precipitation (in)
0.0
0.5
1.0
1.5
2.0
2.5
Return Period (yr)
1.01
1.05
1.11
1.52
2
3.33
5
10
20
100


TA-6 and TA-59 Annual 12 hour maxima
precip =1.15+0.37x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99 0.95 0.9 0.66 0.5 0.3 0.2 0.1 0.05 0.01
Return Period (yr)
1.01 1.05 1.11 1.52 2 3.33 5 10 20 100
Precipitation (in)
0.0 0.5 1.0 1.5 2.0 2.5


White Rock and TA-54 Annual daily maxima
precip =1.04+0.334x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99 0.95 0.9 0.66 0.5 0.3 0.2 0.1 0.05 0.01
Return Period (yr)
1.01 1.05 1.11 1.52 2 3.33 5 10 20 100
Precipitation (in)
0.0 0.5 1.0 1.5 2.0 2.5


TA-6 and TA-59 Annual 6 hour maxima
precip =1.06+0.383x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99 0.95 0.9 0.66 0.5 0.3 0.2 0.1 0.05 0.01
Return Period (yr)
1.01 1.05 1.11 1.52 2 3.33 5 10 20 100
Precipitation (in)
0.0 0.5 1.0 1.5 2.0 2.5


TA-6 and TA-59 Annual 24 hour maxima
precip =1.32+0.35x [x= -ln(-ln(1-P))]
Exceedance Probability
0.99 0.95 0.9 0.66 0.5 0.3 0.2 0.1 0.05 0.01
Return Period (yr)
1.01 1.05 1.11 1.52 2 3.33 5 10 20 100
Precipitation (in)
0.0 0.5 1.0 1.5 2.0 2.5 3.0