ESHID-601236

LA-UR-15-29420

Approved for public release;
distribution is unlimited.

December 2015

Analysis of Precipitation (Rain and Snow) Levels and Straight-line Wind Speeds in Support of the 10-year Natural Phenomena Hazards Review for Los Alamos National Laboratory

Los Alamos
NATIONAL LABORATORY
EST.1943

Prepared by: Elizabeth Kelly (CCS-6) and Jean Dewart (ENV-CP), Los Alamos National Laboratory, and Regina Deola, Sandia National Laboratory

Prepared for: U.S. Department of Energy, National Nuclear Security Administration, Los Alamos Field Office

An Affirmative Action/Equal Opportunity Employer

Contents

Figures

Tables

ACRONYMS

CW	collocated worker
DOE	Department of Energy
EF	Enhanced Fujita (tornados)
GEV	generalized extreme value
IQR	inter quartile range
LANL	Los Alamos National Laboratory
MOI	maximally exposed offsite individual
NDC	Natural Phenomena Hazards Design Category
NOAA	National Oceanographic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
PDC	Precipitation Design Category
PENS	Precipitation Emergency Notification System
PMP	probable maximum precipitation
PMWP	probable maximum winter precipitation
PPHA	Probabilistic Precipitation Hazard Assessment
PWHA	Probabilistic Wind Hazard Assessment
QQ	quantile-quantile (plots)
RL	return level (plots)
SDC	Seismic Design Category
TA	Technical Area
WDC	Wind Design Category
WMO	World Meteorological Organization

This page intentionally left blank.

ABSTRACT

This report provides site-specific return level analyses for rain, snow, and straight-line wind extreme events. These analyses are in support of the 10-year review plan for the assessment of meteorological natural phenomena hazards at Los Alamos National Laboratory (LANL). These analyses follow guidance from Department of Energy, DOE Standard, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities (DOE-STD-1020-2012), Nuclear Regulatory Commission Standard Review Plan (NUREG-0800, 2007) and ANSI/ ANS-2.3-2011, Estimating Tornado, Hurricane, and Extreme Straight-Line Wind Characteristics at Nuclear Facility Sites. LANL precipitation and snow level data have been collected since 1910, although not all years are complete. In this report the results from the more recent data (1990–2014) are compared to those of past analyses and a 2004 National Oceanographic and Atmospheric Administration report. Given the many differences in the data sets used in these different analyses, the lack of statistically significant differences in return level estimates increases confidence in the data and in the modeling and analysis approach.

1.0 INTRODUCTION

The purpose of this report is to provide site-specific return level analyses for rain, snow, and straight-line wind extreme events. These analyses are in support of the 10-year review plan for the assessment of meteorological natural phenomena hazards at Los Alamos National Laboratory (LANL or the Laboratory). The primary requirements document for this assessment is the Department of Energy (DOE) Standard, DOE-STD-1020-2012, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities (DOE 2012).

The methods for developing the Probabilistic Precipitation Hazard Assessment (PPHA) and the assessment for snow loading are specified in DOE-STD-1020 (DOE 2012) and in the draft Natural Phenomena Hazards Analysis and Design Handbook (DOE 2015). Detailed methods for the site-specific Probabilistic Wind Hazard Assessment (PWHA) for extreme straight-line wind speeds are specified in ANSI/ANS-2.3-2011, Estimating Tornado, Hurricane, and Extreme Straight-Line Wind Characteristics at Nuclear Facility Sites. The PWHA for tornados will be addressed in a future report. See Appendix A for the proposed approach. Hurricane winds are not a probable hazard to LANL because of LANL’s inland location (ANSI/ANS-2.3-2011). Hurricane winds have never occurred in Los Alamos.

2.0 BACKGROUND

2.1 PPHA and PWHA Return Periods

In DOE-STD-1020-2012, DOE AU-32 developed a system of Natural Phenomena Hazards Design Categories (NDCs), which includes five Wind Design Categories (WDCs) and five

Precipitation Design Categories (PDCs), derived from the five Seismic Design Category (SDC) classification system as specified in ANSI/ANS-2.26-2004 (R2010). This system identifies the robustness of design features required to prevent hazards to the public, worker, and environment from potential releases of radiological and toxic chemical substances. The NDC is established by the potential health impact to the maximally exposed offsite individual (MOI) and the collocated worker (CW) for unmitigated releases. For higher design categories, more stringent design controls are required to withstand extreme wind and extreme precipitation events. Higher design categories (i.e., NDC-3, -4, and -5) require a design to withstand more extreme meteorological events that are less frequent and that have higher return periods. LANL currently operates two nuclear facilities that are categorized as WDC-3 and PDC-3 (NDC-3 for wind and precipitation).

In this report, the extreme wind and extreme precipitation return periods for WDC-3 and -4 and PDC-3 and -4 have been analyzed, even though at this time LANL has only NDC-3 facilities. LANL has no plans to build an NDC-5 facility.

The mean return period for extreme straight-line winds for WDC-3 and -4 is specified for the purposes of ensuring robust structural design and protection from wind-borne missiles (DOE 2012). The mean return periods are:

WDC-3: 2,500-year return period

WDC-4: 6,250-year return period

The mean return period for extreme precipitation for PDC-3 and -4 is specified for the purposes of ensuring structural design and protection of dry-site flooding conditions. A dry site is defined as a site that does not have any flood hazards, with the exception of extreme precipitation. Other flood hazards are addressed in Section 5 of DOE-STD-1020-2012. The mean return periods for dry-site flooding are:

	Structural Loads	Flooding
PDC-3	2,500 years	10,000 years
PDC-4	6,250 years	25,000 years

The precipitation return levels determined in this report can be used in hydrological models to study flooding risks.

For winter precipitation structural loads, the return periods for both PDC-3 and -4 facilities is the weight of the 100-year snowpack plus the weight of the 48-hour probable maximum winter precipitation (PMWP) for the month corresponding to the selected snowpack (NUREG-0800, 2007).

2.2 LANL Site Description

LANL is located in Los Alamos County in north-central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (Figure 2.1). The 36-square-mile Laboratory is situated on the Pajarito Plateau, which consists of a series of fingerlike mesas separated by east-to-west oriented canyons cut by streams. Mesa tops range in elevation from approximately 7,800 feet on the eastern flanks of the Jemez Mountains to about 6,200 feet at the edge of the Rio Grande in White Rock Canyon. Most of the Laboratory facilities are located on the mesa tops.

Figure 2.1 Map of northern New Mexico with Los Alamos County and LANL.

Figure 2.2 shows the locations of Technical Area (TA) 55-4 and TA-16-205, the current set of LANL facilities characterized as WDC-3 and PDC-3. Long-term LANL facility plans are to locate future high-hazard nuclear facilities along Pajarito Road in the vicinity of TA-55 (DOE 2008).

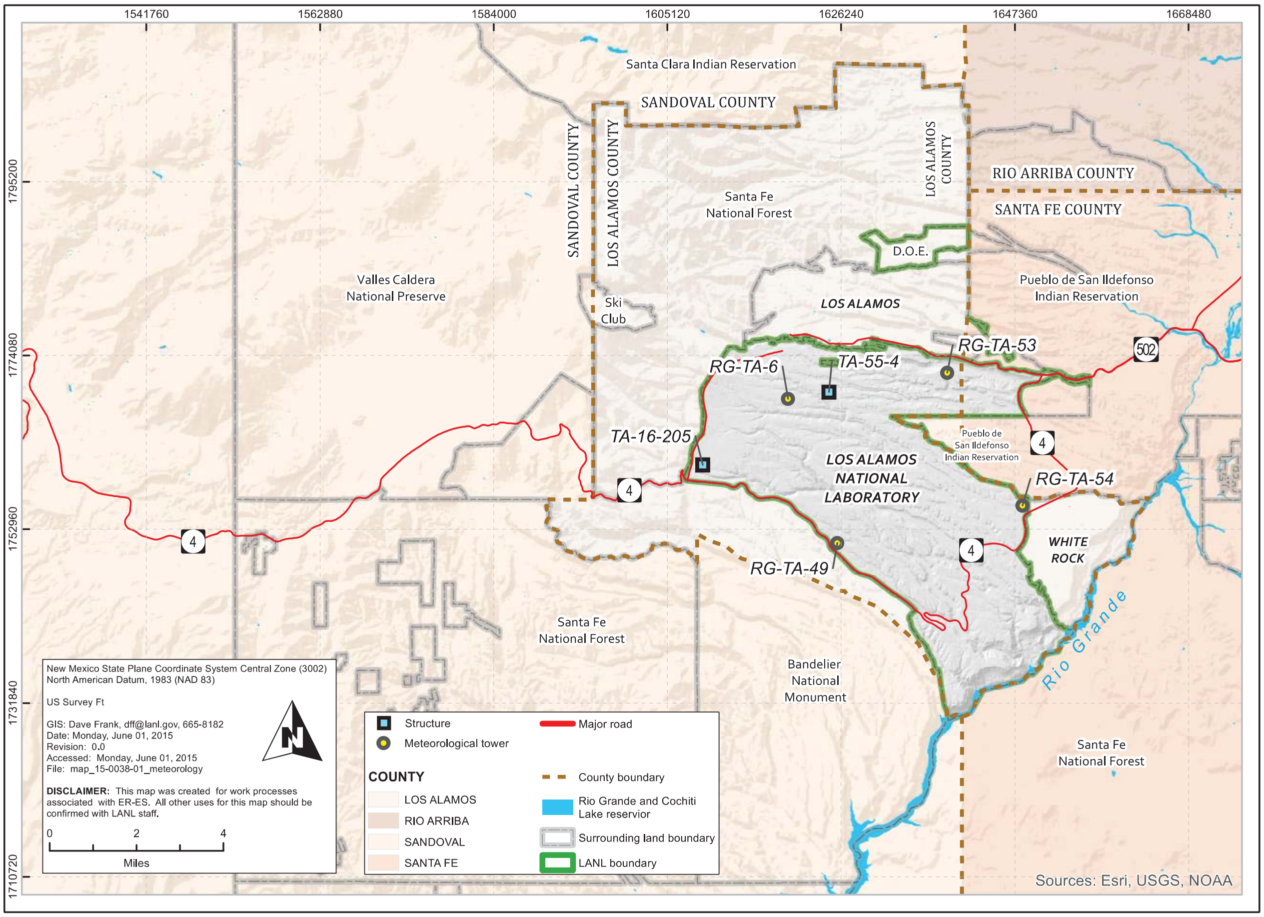

Figure 2.2 Map of Los Alamos County with TAs characterized as WDC-3 and PDC-3 identified.

2.3 LANL Site Climatology

Los Alamos has a temperate, semiarid mountain climate (LANL 2014a). Large differences in locally observed temperature and precipitation exist because of the 1,000-foot elevation change across the Laboratory site and the complex topography. Four distinct seasons occur in Los Alamos County. Winters are generally mild with occasional snowstorms. Spring is the windiest season. Summer is the rainy season with occasional afternoon thunderstorms. Fall is typically dry, cool, and calm.

Daily temperatures are highly variable with a range of 23°F. On average, winter temperatures range from 30°F to 50°F during the daytime and from 15°F to 25°F during the nighttime. The Sangre de Cristo Mountains to the east of the Rio Grande valley act as a barrier to wintertime arctic air masses that descend into the central United States, making the occurrence of local subzero temperatures rare. On average, summer temperatures range from 70°F to 88°F during the daytime and from 50°F to 59°F during the nighttime.

From 1981 to 2010, the average annual precipitation, which includes both rain and the water equivalent of frozen precipitation, was 18.97 inches. The average annual snowfall amount was 58.7 inches. The months of July and August account for 34 percent of the annual precipitation and encompass the bulk of the rainy season, which typically begins in early July and ends in early September. Afternoon thunderstorms form as moist air from the Pacific Ocean and the Gulf of Mexico is convectively and/or orographically lifted by the Jemez Mountains. The thunderstorms yield short, heavy downpours with an abundance of lightning. Local lightning density, among the highest in the United States, is estimated at 15 strikes per square mile per year. Lightning is most commonly observed between May and September, which accounts for about 97 percent of the local lightning activity.

The complex topography of the Pajarito Plateau influences local wind patterns. Often a distinct diurnal cycle of winds occurs. Daytime winds measured in the Los Alamos area are predominately from the south, consistent with the typical upslope flow (i.e., anabatic winds) of heated daytime air moving up the Rio Grande valley. Nighttime winds (i.e., sunset to sunrise) on the Pajarito Plateau are lighter and more variable than daytime winds and are typically from the west, resulting from a combination of prevailing winds from the west and downslope flow (i.e., katabatic winds) of cooled mountain air. Winds atop Pajarito Mountain (LANL 2008) are more representative of upper-level flows and primarily range from the north to the west, mainly because of the prevailing mid-latitude westerly winds.

3.0 LANL On-Site Meteorology Program and Data Collection

Surface temperature and precipitation measurements have been taken at various locations in the town of Los Alamos and at the Laboratory since 1910 as part of the National Weather Service, and its predecessors, cooperative weather observation program. These data include 24-hour precipitation amounts but do not include measurements of wind speed. This station is designated as the Los Alamos location in the National Weather Service records and has been located in eight different locations of very similar altitude over the course of 105 years. The Los Alamos station was moved to be collocated with the TA-6 meteorology tower in 1990 (Dewart and Boggs 2014).

The Laboratory began digital recording of 15-minute average data from the meteorology towers during the early 1980s (Dewart and Boggs 2014). At this time, the LANL weather datasets expanded to include wind speed and direction. The current location of meteorology towers at LANL was established between 1987 and 1992. The more than 20 years of wind and precipitation data meets the temporal representativeness objectives of DOE-STD-1020-2012 (DOE 2012) for using on-site data for the analysis of extreme winds and extreme precipitation.

Twenty-four hour snowfall has been measured since 1910, with a number of gaps in the data record. Snow on the ground has also been recorded; however, digital recording of these data only began in 1997.

3.1 Selection of Meteorology Tower for Return Period Analysis

The Laboratory operates five meteorology towers; four are located on mesa tops, as shown in Figure 2.2, and one (i.e., TA-5 MDCN) is located in a canyon, not shown in the figure. The TA-6 tower is the tower located in greatest proximity to the current LANL PDC-3 and WDC-3 facilities and collects meteorological data at a very similar altitude, as shown in Table 3.1. Because of this proximity and similar altitude, the TA-6 tower, also known as Los Alamos tower for 24-hour precipitation data, satisfies spatial representativeness criteria and thus was selected for this analysis.

Table 3.1. Locations of LANL Facilities with Respect to the TA-6 Meteorology Tower

Location	TA-6 met tower	TA-55-4	TA-16-205
Altitude (m) above MSL	2265	2225	2320
Distance from TA-6 meteorology tower (km)	—	1.5	4.0

3.1.1 Spatial Representativeness of TA-6 Wind Speed Data

TA-6 data appropriate for TA-55-4. The TA-6 tower is in close proximity to TA-55, both in terms of distance and altitude (Figure 2.2) (ANSI R2010). In addition, both locations are on the mesa top and in very similar forest cover. Therefore, the wind data are representative of this facility.

TA-6 data appropriate for TA-16-205. The TA-16-205 facility is about 4 kilometers southwest of the TA-6 meteorology tower, closer to where the Jemez Mountains rise up from the Pajarito Plateau. Average surface wind speeds decrease going westward across the Laboratory (LANL 2014a). This is due to the sheltering effect of the mountains and due to the greater surface roughness produced by the denser forests on the western side of LANL (McKown et. al. 2003). The TA-6 wind speeds will be somewhat higher than those expected at the TA-16-205 location. Therefore, wind data from the TA-6 tower will provide a conservative assessment of the wind speeds at TA-16-205.

3.1.2 Spatial Representativeness of TA-6 Rainfall and Snowfall Data

TA-6 data appropriate for TA-55-4. The TA-6 tower is located at a very similar altitude to TA-55 (Table 3.1) and is in close proximity with similar topography to TA-55 (Figure 2.2); therefore, the TA-6 tower precipitation and snowfall data are representative of the TA-55 location.

TA-6 data appropriate for TA-16-205. TA-16-205 is located approximately 4 kilometers southwest of the TA-6 tower (Figure 2.2) and at a slightly lower altitude (Table 3.1). Although the TA-6 tower is in close proximity to TA-16-205, average precipitation increases somewhat from east to west across the Laboratory (Bowen 1990). Thus it is possible for return period precipitation values at the TA-16-205 location to be higher than the values calculated with TA-6 data.

Twenty-four hour precipitation data were compiled from 1974 to 1991 for the TA-16 station (Bowen 1996). From the 1974 through 1991 data, the TA-16 location recorded annual precipitation about 10 percent higher than at TA-6. For the total summer monsoon (July–Sept), the variability is smaller between the two sites. Bowen (1996) concluded that the greatest variability is due to winter precipitation, most probably due to enhanced orographic lifting at the TA-16 location because it is closer to steepening topography west of the LANL boundary as compared to the TA-6 tower site (Figure 3.1).

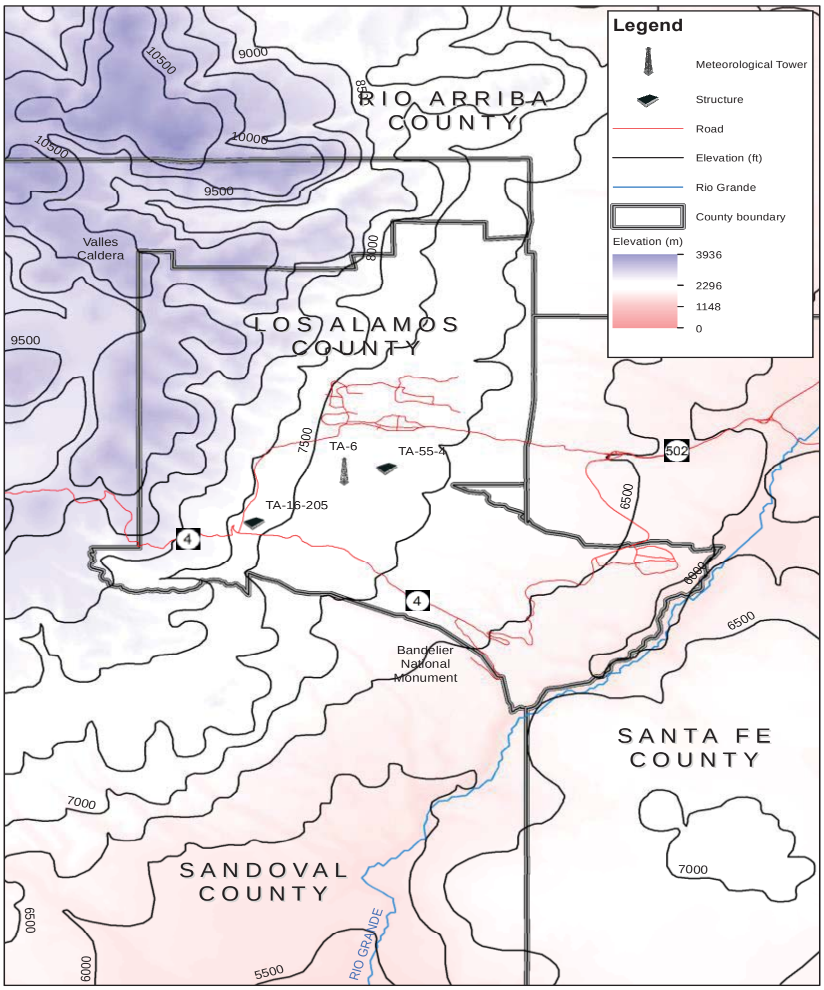

Figure 3.1 Contour map of LANL with towers.

Reneau et al. (2003) analyzed rainfall data for 15 minutes to 24 hours from a set of rain gage stations in the mountains above LANL. These gages provided data for various periods of record, primarily from 10 to 15 years. They demonstrated that for these time periods and return intervals of 2 to 100 years, rainfall totals increase gradually from east to west. There was not a sharp increase in precipitation as the topography steepens to the west of LANL. The best correlation between stations for return period rainfall was by distance from the mountain front of the Jemez, as opposed to station elevation. For the differences in elevation for 15-minute to 24-hour rainfall totals, the difference between an elevation at TA-16-205 and the TA-6 tower is less than 10 percent. For the very short duration rainfalls of 15 minutes to 30 minutes, the return period rainfalls are similar, with no increase the closer the precipitation is measured to the mountain front.

Some rainfall data are available for TA-16, but snowfall data are not available. Rainfall was digitally measured at TA-16 at a location 0.5 kilometers north of TA-16-205 from 1977 through 2005. The elevation of the TA-16 rain gage was 10 meters higher than at TA-16-205. This rain gage was located on the top of a one-story building, so it does not meet siting requirements for this analysis (DOE 2012). However, it does give some perspective on the differences between TA-6 and TA-16 precipitation. Digitally-recorded 15-minute precipitation measurements are available for 1996 through 2005. Appendix B contains a comparison of these TA-16 and TA-6 data. These data differ somewhat, sometimes TA-16 is higher and other times TA-6 is higher. This can be the result of thunderstorms that are more of a mesoscale phenomenon. For a given thunderstorm event, there can be variability between measurement sites more than for a rainfall with frontal origins. Despite these localized differences in the data, the predicted return levels and uncertainties are not significantly different. In fact, the TA-6 levels are slightly higher. Therefore the TA-6 return period rainfall results are used for the TA-16-205 facility site, which bounds the PPHA.

3.2 Wind and Precipitation Measurement Techniques Meet DOE-STD-1020

LANL follows ANSI/ANS-3.11-2005 (R2010) guidelines for the measurement and quality assurance of wind speed and precipitation and meets instrument and system accuracy objectives (LANL 2014b). LANL wind speeds are measured at 12 meters (Dewart and Boggs 2014). DOE-STD-1020 (DOE 2012) requires the use of wind speeds measured at 10 meters or corrected to 10 meters using logarithmic wind height conversion methods. The peak wind speeds measured at 12 meters will be approximately 3 percent faster than winds measured at 10 meters (Irwin 1979) based on the logarithmic wind speed profiles, assuming D stability class.

$$\text{Wind speed (10 meters)} = \text{wind speed (12 meters)} * (10/12)^{0.143}$$

LANL wind speed measurements have not been extrapolated down to 10 meters, which provides a more conservative (i.e., faster) estimate of return period wind speeds than is required by DOE-STD-1020.

LANL wind speeds are instantaneously measured every 3 seconds (Dewart and Boggs 2014) and the daily peak gust is selected from these 10,512 measurements recorded each day. This meets the DOE-STD-1020 requirement for measuring peak gusts (DOE 2012).

LANL precipitation measurements have been recorded using a tipping bucket rain gage since the mid-1980s. The rain gages provide a measurement for each 15-minute period. The gages are heated and snow is melted and measured as melted precipitation. These gages meet the accuracy requirements of EPA-454/R-99-005 (EPA 2000) and ANSI/ANS-3.11-2005 (R2010).

LANL 1990 through 2014 tipping bucket rainfall data analyzed in this study most probably underestimate heavy rainfall events for less than 1 hour (Molini et al. 2005). LANL is considering adding a weighing bucket rain gage to the TA-6 monitoring station to provide on-site data for comparison to the tipping bucket rain gage values.

Snowfall has been measured with a ruler to the nearest one tenth of an inch on a snow board, or equivalent, located adjacent to the rain gage site for most of the Los Alamos data record. Digital recording of snowfall, adjacent to the TA-6 tower, began in January 1998 using an ultrasonic snow depth sensor.

4.0 EXTREME RAINFALL EVENT ANALYSES

4.1 Rainfall Data

LANL has consistently collected rainfall (i.e., precipitation) data at various sites for 15-minute intervals since 1990. As discussed above, TA-6 has been determined to be the most representative site for the 10-year PPHA for TA-554-4 and TA-16-205. The 15-minute data monitored at TA-6 are used to construct hourly, 2-hour, 3-hour, 6-hour, 12-hour, and 24-hour data sets. Some of these 15-minute data have missing values. The missing values are addressed by either: 1) using data from a nearby spatially representative site (i.e., TA-59) or 2) making a data substitution. A substitution of zero is made, if all of the values surrounding the missing data are zero, following data substitution principles of ANSI/ANS-3.11-2005 (R2010). If data surrounding the missing value are not zero, then the average of the non-zero values is used.

In addition to 24-hour data constructed from the 15-minute data, 24-hour data exists independently for 1910 to 2014. Some of these data (1910–2005) were analyzed in a previous report (Lawrence 2006). An important quality assurance check for this analysis is that the maximums for the two different 24-hour data sets are almost identical for the years where they overlap (see Appendix C).[1] Appendix C also compares the data from 1910 to 1990 to the more recent data. This comparison shows that precipitation levels have generally decreased since 1990.

4.2 Precipitation Amounts for Specified Return Periods

Return periods and associated uncertainties are calculated for 15-minute, 1-hour, 2-hour, 3-hour, 5-hour, 12-hour, and 24-hour yearly maximum rainfalls for four return periods. The return periods, 2,500, 6,250, 10,000, and 25,000 years, are based on DOE Structure System and Component requirements for PDC-3 and -4 (DOE 2012).

A standard approach for return level analysis for precipitation data is to use a generalized extreme value (GEV) distribution to fit maxima. For example, National Oceanographic and Atmospheric Administration (NOAA) uses GEV distributions to model precipitation maxima, as described in NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, Volume 6 (Perica et al. 2014) and Volume 1 (Bonnin et al. 2011). Additionally, there is asymptotic theory that justifies the use of the GEV for maxima (Coles 2001). The GEV distribution is a three-parameter distribution with location, scale, and shape parameters (Coles 2001). The shape parameter controls the behavior of the tails of the distribution. If the shape parameter is zero, the upper tail is somewhat large; if it is

[1] The data sets differ in only 5 years. All but one of the differences (1990) are in the hundredths of inches. In 1990, the Lawrence value is 0.16 inches greater than the TA-6 value. This is the year that the Los Alamos station was moved to be at TA-6.

positive the upper tail is very large. If the shape parameter is negative there is a large lower tail, but no upper tail (see https://en.wikipedia.org/wiki/Generalized_extreme_value_distribution).

In this analysis, each yearly maximum data set was first fit to the full, three parameter, GEV distribution using the R-package "extRemes" (Gilleland and Katz 2011). In all cases the shape parameter was not statistically significantly different from zero. In some cases it was very slightly positive and in other cases very slightly negative. A comparison of the full GEV model to the two parameter model (i.e., zero shape parameter) using the R-package "evd: Extreme Value Distributions" (Stephenson 2002) showed that there was no significant difference between models. Slight variations from positive to negative shape parameters can cause inconsistencies in predictions (e.g., 2-hour return levels greater than 3-hour or 6-hour return levels). Therefore, the distribution selected to determine return levels and uncertainties is the GEV with a shape parameter equal to zero. This distribution is called a Fisher-Tippett or Gumbel distribution and is recommended in wind-speed extreme event analyses in ANSI/ANS-2.3-2011.

Table 4.1 contains the precipitation return levels with 95 percent uncertainty limits for the specified return periods for the 15-minute, 1-hour, 2-hour, and 3-hour data. Table 4.2 contains the same information for the 6-hour, 12-hour, 24-hour, and 48-hour data.

Table 4.1. Return levels with 95% uncertainty limits for the specified return periods and for four precipitation data sets.

Precipitation Data Event Duration	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
15-minute	2,500	1.33	1.03	1.60
	6,250	1.43	1.10	1.74
	10,000	1.48	1.14	1.80
	25,000	1.59	1.22	1.94
1-hour	2,500	2.78	2.10	3.42
	6,250	3.02	2.26	3.72
	10,000	3.14	2.35	3.89
	25,000	3.38	2.52	4.20
2-hour	2,500	2.96	2.28	3.65
	6,250	3.22	2.46	3.98
	10,000	3.35	2.54	4.15
	25,000	3.60	2.72	4.48
3-hour	2,500	3.54	2.67	4.35
	6,250	3.85	2.88	4.74
	10,000	4.01	2.99	4.94
	25,000	4.32	3.21	5.34

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

The 24-hour data values are very close to the 12-hour data values as shown in Appendix D; the return period results are virtually the same. In fact, there are no statistically significant differences between the expected return periods for the four event times.

Appendix D contains plots of yearly maximum precipitation level for each data set, as well as diagnostic plots to evaluate the fit of the data to the GEV distribution and plots of return levels versus return periods with 95 percent uncertainty bounds.

Table 4.2. Return levels with 95% uncertainty limits for the specified return periods and for three precipitation data sets.

Precipitation Data Event Times	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
6-hour	2,500	3.81	2.88	4.68
	6,250	4.14	3.11	5.11
	10,000	4.31	3.23	5.32
	25,000	4.64	3.47	5.75
12-hour	2,500	3.97	3.01	4.90
	6,250	4.31	3.25	5.34
	10,000	4.48	3.36	5.56
	25,000	4.82	3.60	6.00
24-hour	2,500	4.27	3.69	4.86
	6,250	4.63	3.98	5.29
	10,000	4.81	4.13	5.5
	25,000	5.17	4.42	5.93
48-hour	2,500	5.58	4.24	6.91
	6,250	6.05	4.57	7.53
	10,000	6.30	4.73	7.85
	25,000	6.77	5.05	8.47

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

5.0 EXTREME SNOWFALL EVENT ANALYSIS

5.1 Overview

Requirements and guidance for extreme snowfall analysis for design requirements are given in DOE-STD-1020, Section 7, Criteria and Guidelines for Precipitation Design (DOE 2012) and in the Nuclear Regulatory Commission (NRC) Standard Review Plan (NUREG-0800 2007). DOE-STD-1020 suggests the use of NUREG-0800 guidance to determine the structural loads for PDC-3, -4, and -5 facilities. NUREG-0800 states that the extreme winter precipitation loads should be based on the weight of the 100-year snowpack at ground level, plus the weight of the 48-hour PMWP for the month corresponding to the selected snowpack. The combination of these data is not available for LANL.

To determine what guidance to use for calculating extreme winter precipitation loads when the snowpack data and PMWP are not available, the authors contacted the Office of Nuclear Facility Safety Programs, AU-32, since they are responsible for and currently revising the DOE-STD-1020-2012. They recommended following the NRC guidance, *Final Interim Staff Guidance on Assessment of Normal and Extreme Winter Precipitation Loads on the Roofs of Seismic Category 1 Structures* (see http://pbadupws.nrc.gov/docs/ML0914/ML091490542.pdf and http://adams.nrc.gov/wba/view). AU-32 indicated that this guidance is applicable to PDC-3 and -4 facilities. This NRC guidance specifies that the three winter precipitation events to be used for designing roof loads are:

- Extreme Frozen Winter Precipitation Event,
- Normal Winter Precipitation Event, and
- Extreme Liquid Winter Precipitation Event.

The Extreme Frozen Winter Precipitation Event is defined as the highest ground-level weight between (1) the 100-year return period snowfall event and (2) the historical maximum snowfall event in the site region. These statistics are available for Los Alamos and the analytical results are provided in Section 5.4.1.

The Normal Winter Precipitation Event is defined as the highest ground-level weight among (1) the 100-year return period snowpack, (2) the historical maximum snowpack, (3) the 100-year return period snowfall event, or (4) the historical maximum snowfall event, all in the site region. Snowpack data are not available for Los Alamos. Because snowpack data are not available, only (3) and (4) can be evaluated. Thus, the Extreme Frozen Winter Precipitation Event is the same as the Normal Winter Precipitation Event based on the available data for Los Alamos (Section 5.4.1).

The Extreme Liquid Winter Precipitation Event is defined as the theoretically greatest depth of precipitation for a 48-hour period that is physically possible over a 10-square-mile area during the winter months (i.e., PMWP). At this time, NOAA’s Hydrometeorological Design Studies Center has not calculated PMWP values for the Los Alamos region. The World Meteorological Organization (WMO; 2009) provides guidance on calculating probable maximum precipitation (PMP) values. The PMP is estimated according to the maximum 48-hour storm of the observed data in the specific location. This is the local method and is applicable when there are several years of observed data. Following the WMO guidance, maximum 48-hour winter precipitation (i.e., melted snow plus precipitation) is used to estimate the PMWP. This maximum is based on 68 years of complete winter data for Los Alamos (Section 5.4.2).

The data analyzed for the normal/extreme winter frozen and extreme winter liquid precipitation events are discussed in the following section.

5.2 Snowfall Data

The data used in this analysis are located on the LANL Weather machine (http://www.weather.lanl.gov). For this analysis, the 24-hour snowfall data (for those years with complete data) from 1910 to 2014 are used. There are 68 full years with complete data. Figure 5.1 shows the maximum yearly 1-day, 2-day, 3-day, and 5-day snowfall events versus year of occurrence. The 1987 maximum snowfall appears to be an outlier for the 2-day, 3-day, and 5-day data per the analysis that follows.

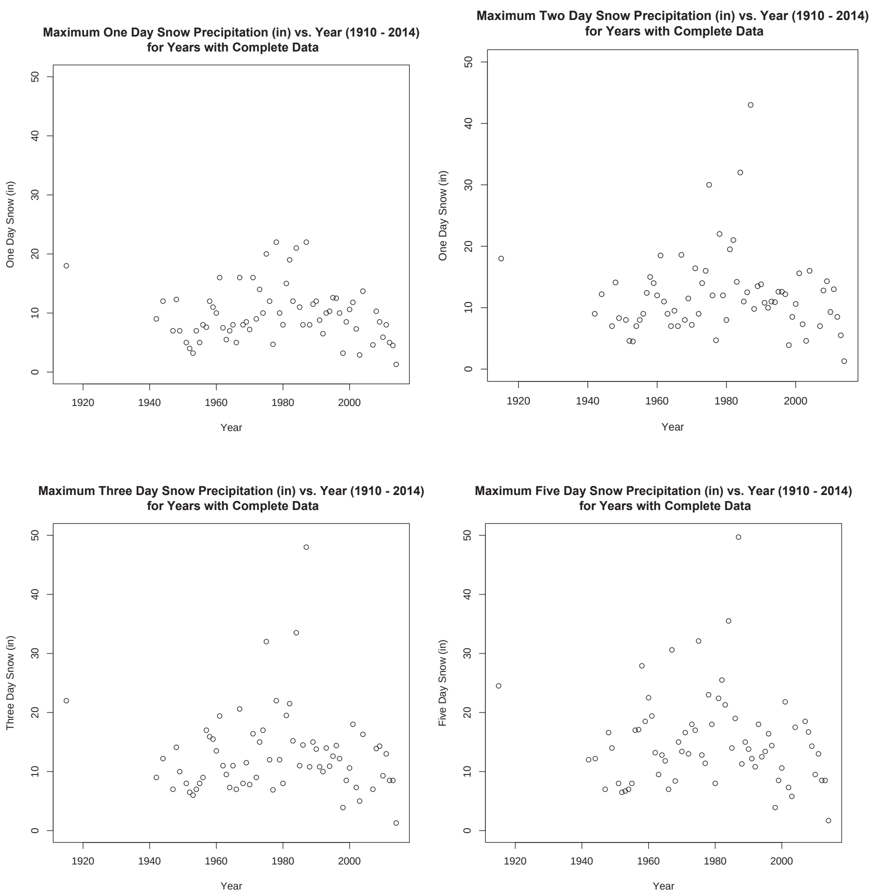

Figure 5.1 Yearly snowfall maxima versus year for 1-day, 2-day, 3-day, and 5-day events.

The greatest snowstorm on record for Los Alamos occurred from January 15 through 17, 1987. The snowfall was produced by an overrunning situation from a stationary upper-level low pressure system located in Arizona that produced moist southerly upslope winds over the Jemez Mountains. High pressure from a continental polar air mass to the east of Los Alamos kept the average surface temperatures well below freezing (i.e., between 15°F and 25°F) during the entire period of the snowstorm. The combination of abundant moisture, orographic lifting, and cold temperatures produced 48 inches of fine light snow for the 3-day storm. On the first day 22 inches fell, 21 inches fell on the second day, and 5 inches fell on the third day. A 40-inch snow cover was recorded on the ground on January 15 and January 16. Importantly, the snow/water ratio of the snowfall to melted precipitation was 34 to 1 for the entire storm, indicating light snow as opposed to a more dense wet and heavy snow. This type of snowfall has a smaller effect on roof loading.

The ratio of snowfall to precipitation for all 24-hour observations of snow and precipitation for the available record was calculated. For all observations, the average snow/water ratio is 15.8, and for all snowstorms where the 24-hour total was greater or equal to 10 inches, the snow/water ratio is 15.5. The January 1987, snowfall to precipitation ratio of 34 to 1 is a reflection of the very cold temperatures that occurred during the storm, which resulted in a low moisture budget. Although the January 1987 snowfall is a large outlier in comparison to all other 3-day and 5-day snowfall events, the storm did not produce large roof loading concerns due to the very large snow/water ratio.

5.3 Snowfall Levels for Specified Return Periods

As with the rainfall data, the 1-day, 2-day, 3-day, and 5-day yearly maximum data sets were first fit to the full, three parameter, GEV distribution using the R-package "extRemes" (Gilleland and Katz 2011). In all cases the shape parameter was not statistically significantly different from zero. A comparison of the full GEV model to the two-parameter model (i.e., zero shape parameter) using the R-package "evd: Extreme Value Distributions" (Stephenson 2002), showed that there was no significant difference between the models. As previously noted, slight variations in the shape parameter, especially from positive to negative, can result in inconsistencies in predictions. Therefore, the distribution used to determine return levels and uncertainties is the GEV with a shape parameter equal to zero (Gumbel distribution).

Figures 5.2, 5.3, and 5.4 show the quantile-quantile (QQ) plots and return level (RL) plots with 95 percent uncertainty limits for the three data sets. The QQ plots compare the GEV model quantiles to the quantiles derived from the data (i.e., empirical quantiles). If there is a good fit of the model to the data, the circles lie on the straight line x = y. The QQ plot provides a diagnostic for how good the model fit is to data and helps to identify observations that look different than the rest of the data (i.e., potential outliers). Note that the January 1987 snow event does not appear to be an outlier for the 1-day events; however, for the 2-day, 3-day, and 4-day event, it definitely appears to be an outlier.

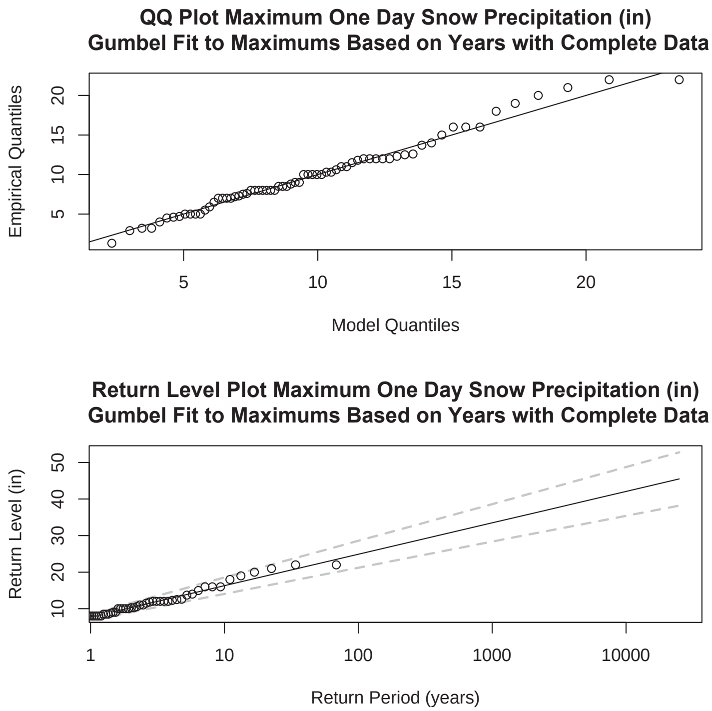

Figure 5.2 **QQ and RL plots (with 95% uncertainties) for Gumbel distribution fits to 1-day maximums for complete years.**

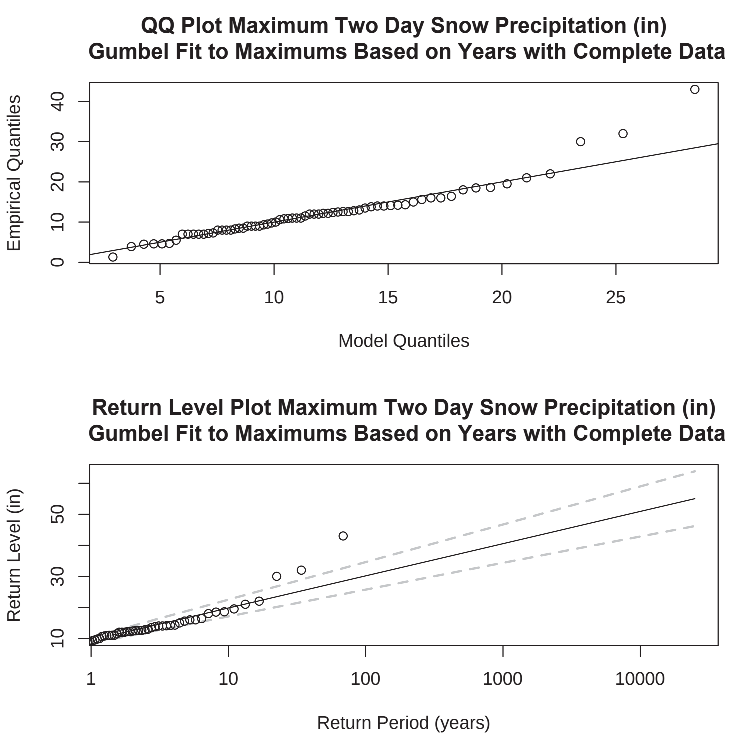

Figure 5.3 **QQ and RL plots (with 95% uncertainties) for Gumbel distribution fits to 2-day maximums for complete years.**

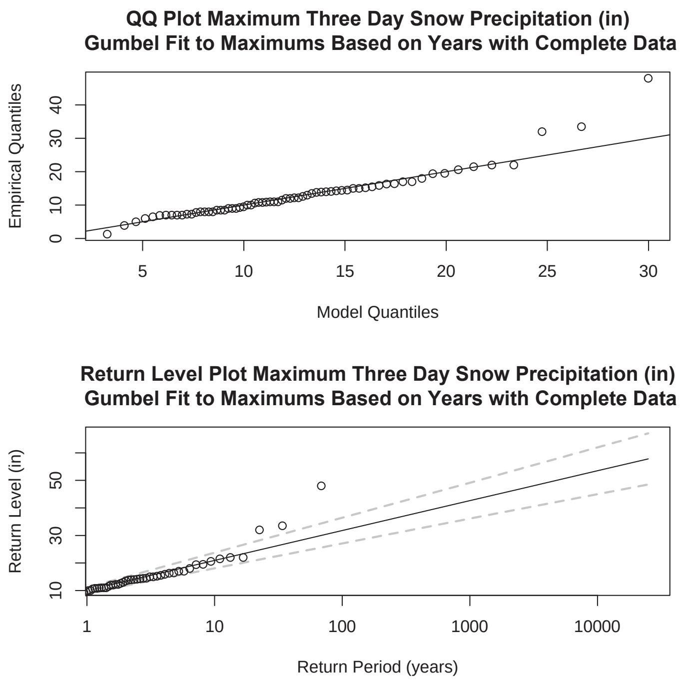

Figure 5.4 QQ and RL plots (with 95% uncertainties) for Gumbel distribution fits to 4-day maximums for complete years.

Table 5.1 contains the predicted return levels with 95 percent uncertainty limits for the specified return periods for 1-day, 3-day, and 5-day extreme snowfall events.

Table 5.1. Return levels with 95% uncertainty limits for the specified return periods for the extreme snowfall data sets.

Snowfall Period	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
1-day	100	24.9	21.3	28.4
	2,500	36.9	31.2	42.6
	6,250	40.3	34.0	46.6
	10,000	42.1	35.4	48.7
	25,000	45.5	38.2	52.7
2-day	**100**	**30.1**	**25.8**	**34.4**
	2,500	44.7	37.6	51.6
	6,250	48.8	40.9	56.4
	10,000	50.9	42.6	58.9
	25,000	55.0	45.9	63.8
3-day	100	31.7	27.0	36.3
	2,500	46.9	39.2	54.3

Snowfall Period	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
	6,250	51.3	42.7	59.4
	10,000	53.5	44.5	62.0
	25,000	57.8	47.9	67.0
5-day	100	38.2	32.5	43.4
	2,500	56.7	47.4	65.2
	6,250	61.9	51.6	71.3
	10,000	64.6	53.8	74.5
	25,000	69.9	58.0	80.7

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

To evaluate the impact of the January 1987 event on the return level predictions and associated uncertainties for the 2-day, 3-day, and 5-day events, the analysis was repeated without the January 1987 event. Figure 5.5 shows the QQ plots and RL plots with 95 percent uncertainty limits for the 2-day event with the outlier omitted. These plots show that, while the fit is improved, the return levels and uncertainties are not significantly changed; they are shifted slightly lower. The same plots for the 3-day and 5-day events are comparable.

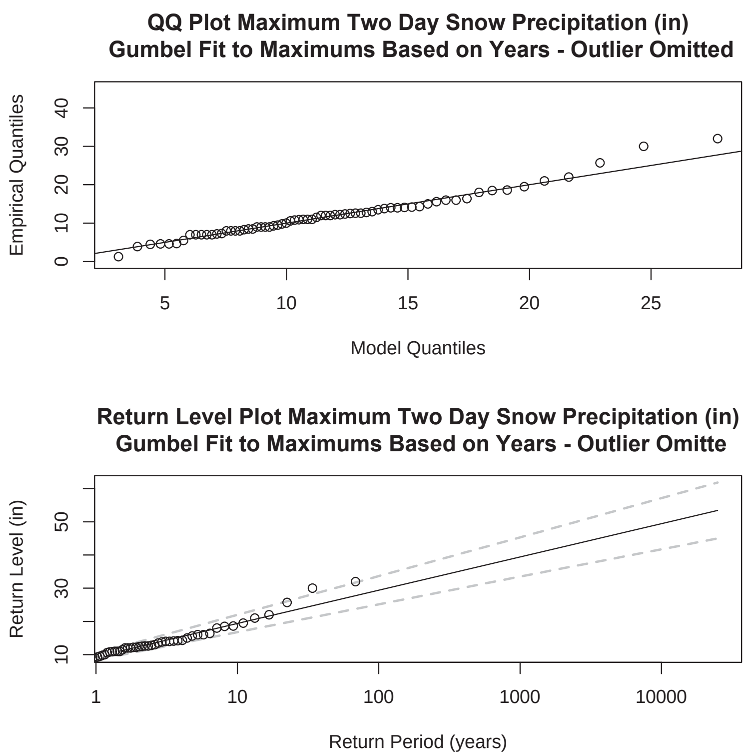

Figure 5.5 QQ and RL plots (with 95% uncertainties) for Gumbel distribution fits to 2-day maximums with January 1987 outlier removed.

Table 5.2, which contains the return levels and associated uncertainties when the January 1987 event is omitted, confirms these results. The return levels and uncertainties are from 1.4 to 4 percent higher. The differences for the upper confidence limits for the 3-day return levels are the greatest. Since the shifts are small and return levels are well within uncertainty bounds, which have considerable overlap, the impact of the January 1987 outlier is not considered important for this analysis. In addition, the shift is in the conservative direction, e.g., the values with the outlier included are larger.

Table 5.2. Return Levels with 95% Uncertainty Limits for the Specified Return Periods for the Extreme Snowfall Data Sets with the January, 1987 Event Removed

Snowfall Period	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
2-day	100	29.4	25.2	33.6
	2,500	43.4	36.6	50.4
	6,250	47.4	39.8	55.1
	10,000	49.4	41.5	57.6
	25,000	53.4	44.7	62.3
3-day	100	30.7	26.3	35.0
	2,500	45.2	38.1	52.2
	6,250	49.4	41.5	57.1
	10,000	51.5	43.2	59.6
	25,000	55.6	46.5	64.4
5-day	100	37.4	32.0	42.7
	2,500	55.6	46.6	63.9
	6,250	60.7	50.8	70.0
	10,000	63.4	53.0	73.1
	25,000	68.5	57.2	79.2

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

5.4 Normal Winter, Extreme Frozen, and Extreme Liquid Winter Precipitation Events

Estimates for the normal winter, extreme frozen, and liquid winter precipitation events to be used in calculating structural requirements for roofs of PDC-3 and -4 facilities are provided below. These values are based on available data from Los Alamos and meet applicable NRC guidance.

5.4.1 Normal Winter/Extreme Frozen Winter Precipitation Events

Based on the available snowfall data for Los Alamos, the Normal Frozen Winter Precipitation Event is the same as the Extreme Winter Precipitation Event. The historical 2-day snowfall totals were compared with the 100-year return period 2-day snowfall. The historical maximum 2-day snowfall at Los Alamos is 43 inches, which was recorded on January 15 to 16, 1987. The predicted 100-year return period 2-day snowfall of 30.1 inches (see bolded value in Table 5.1) is less than the historical maximum 2-day snowfall. Thus, the historical maximum snowfall event at Los Alamos of 43 inches for a 2-day snowfall is considered to be both the normal winter and extreme frozen winter precipitation event.

However, as noted in Section 5.1, the January 1987 snowstorm was a very cold storm; the light fluffy snow observed in consistently cold temperatures produced the great snow depths. For additional insight into the question of roof loading for the maximum 2-day snowfall, Table 5.3 provides the total precipitation, as melted snow, for the 10 largest 2-day snowfalls.

Table 5.3. Precipitation content for the 10 highest 2-day snowfalls

Month	Ending day of 2-day snowfall	Year	High Temp (°C)	Low Temp (°C)	Total 2-day snowfall (inches)	Total 2-day precipitation (inches)	Ratio of 2-day snow/2-day precipitation
January*	16	1987	-7.8	-11.7	43	1.25	34.4
December	14	1984	-1.7	-5.6	32	1.79	17.9
April	**12**	**1975**	**-0.6**	**-2.2**	**30**	**2.93**	**10.2**
January	17	1987	-5.6	-13.3	26	0.73	35.6
February	19	1987	-2.2	-7.8	26	1.27	20.2
December	15	1984	-1.1	-7.2	22.5	1.16	19.4
December	6	1978	-3.9	-12.2	22	1.60	13.8
January	15	1987	-0.0	-7.8	22	0.68	32.4
February	4	1982	-7.8	-11.7	21	0.68	30.9
February	20	1987	-2.2	-12.2	21	1.01	20.8

* The January 15–17, 1987, storm is presented in this table as three 2-day events: January 15–16, January 16–17, and January 17–18.

As Table 5-3 indicates, the January 1987 storm had very small water content, in comparison to other 2-day snowfalls. The greatest water content found in the 10 largest 2-day snowfall events occurred in the 30-inch snowfall in April 1975. This event is very similar to the predicted 100-year, 2-day snowfall event. For maximizing roof loading from the maximum 2-day snowfall event, the 30-inch snowfall of April 1975 is most appropriate.

5.5.2 Extreme Liquid Winter Precipitation Events

The WMO (2009) provides guidance on calculating PMP values. The PMP is estimated according to the maximum 48-hour storm of the observed data in the specific location. This is the local method and is applicable when there are several years of observed data. Extrapolating this technique to wintertime precipitation, Los Alamos 48-hour precipitation totals were ranked for the winter months of November through April (Table 5.4). The largest 2-day precipitation (i.e., rain plus melted snow) event during the winter months was 3.05 inches and occurred from January 26 through 27, 1916. Therefore, it is proposed that 3.05 inches is the extreme liquid winter precipitation event for Los Alamos.

Table 5.4. Highest[1] Los Alamos 2-Day Precipitation Events

Month	Day	Year	Max Temp (°C)	Min Temp (°C)	Total Snowfall (inches)	Total Precipitation (inches)
January	27	1916	N/A[2]	N/A	16	3.05
April	12	1975	-0.6	-2.2	30	2.93
December	1	2007	11.1	2.1	7	2.46
January	28	1916	N/A	N/A	11	2.45
March	30	1916	N/A	N/A	18	2.25
December	19	1918	6.7	-8.3	2.2	2.21
November	26	1978	4.4	-5.0	0	2.11
November	23	1931	-0.6	-12.8	20	2.09
November	12	1978	5.6	-1.7	trace	2.01
January	19	1916	N/A	N/A	2.5	1.95

1 High 2-day rainfall totals can be produced by a single day of high rainfall. For example, the March 29–30, 1916, 2-day precipitation event occurred on March 30. And so, the March 30–31, 1916, 2-day precipitation total is also 2.25 inches. The March 30–31, 1916, event is not included in this table since it is a duplicate to the March 29–30, 1916, event. December 19–20, 1918, is also not included since it is a duplicate to the December 18–19, 1918, event.

2 N/A = not available.

6.0 STRAIGHT-LINE WIND SPEED

6.1 Wind Speed Data

LANL has annual maximum 3-second gust wind speed data, which was collected from 1990 through 2014 at TA-6 (LANL 2014b). As previously indicated in Section 2, wind gusts are measured at 12 meters. As previously discussed, these data are appropriate for site-specific analyses for the WDC-3 and -4 facilities at TA-55 and TA-16.

6.2 Wind Speed Return Levels for Specified Return Periods

The methods for determining the site-specific return levels are specified by ANSI/ANS-2.3-2011 and Chapter 4 of DOE-STD-1020-2012. This guidance recommends using the Fisher-Tippett Type I statistical extreme value distribution to fit the yearly maximum 3-second gust data collected at 10 meters. Since the LANL data are collected at 12 meters, use of data at this height results in conservative estimates of return levels as compared to logarithmically converting it to a 10-meter level.

As in the case of the precipitation (i.e., rain and snow) data, the full GEV was evaluated first, and in all cases the shape parameter was not significantly different from zero. Thus, as recommended by the ANSI/ANS-2.3-2011 guidance, the Fisher-Tippett or Gumbel distribution was used to determine return levels and associated uncertainties.

Table 6.1 shows the results for specified return periods of 2,500 for WDC-3 and 6,250 years for WDC-4.

Table 6.1. Return Levels for Specified Return Periods and 95% Confidence Bounds

Return Period (years)	Return Level (mph)	95% LCL[1]	95% UCL[2]
2,500	78	71	85
6,250	81	73	89

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

Figure 6.1 presents plots of yearly maximum 24-hour wind speed levels versus year of occurrence, as well as QQ plots to evaluate the fit of the GEV to the data and plots of return levels versus return periods with 95 percent uncertainty bounds. These plots demonstrate that the GEV provides a good fit to the data.

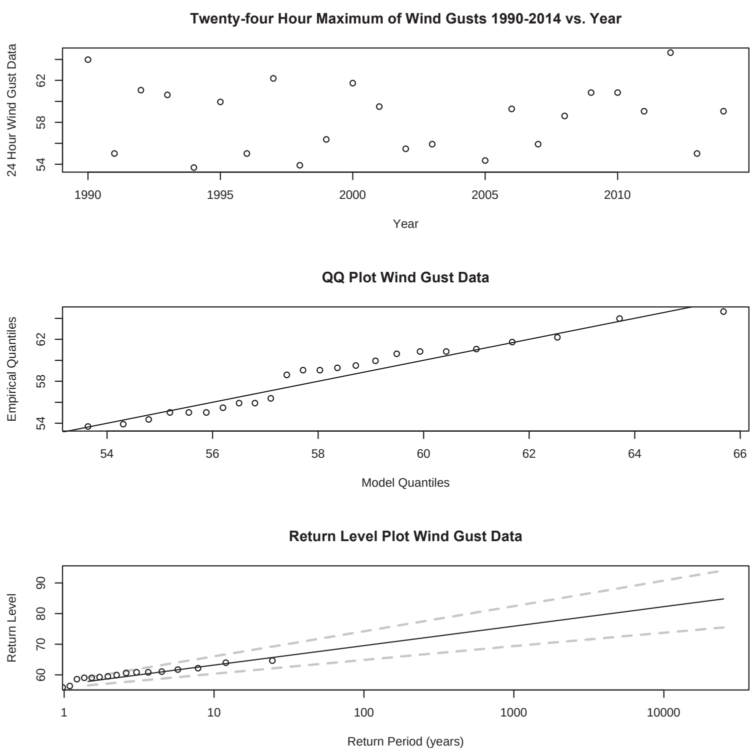

Figure 6.1 Plots of yearly maximum 24-hour wind speed levels versus year and QQ plots to evaluate the fit of the GEV to the data and plots of return levels versus return periods with 95% uncertainty bounds.

7.0 SUMMARY

7.1 PPHA

7.1.1 Rainfall

Return period rainfall values calculated with TA-6 data from 1990 through 2014 are somewhat lower than values previously published in Lawrence (2006) and the 2004 NOAA report that was revised in 2011 (Bonnin et al. 2011). The primary reason for the lower values calculated in this study using current LANL data is the long-term drought that New Mexico has experienced since 1998.

Available 24-hour rainfall measurements from TA-16 are evaluated in Appendix B. The data are consistent with the TA-6 return period values.

7.1.2 Comparison of the Return Period Rainfall Values with NOAA (2004) and Lawrence (2006)

The analysis performed for return period rainfall from the 2004 NOAA Atlas 14 revision (Bonnin et al. 2011), the Lawrence (2006) report, and the current calculations is compared. A comparison of the data used in the current study and the Lawrence (2006) is presented in Appendix C. The values of 24-hour rainfall used in the two data sets are essentially identical for the time periods when the time series are overlapping (1990–2005). The primary difference between the two data sets is the decreasing rainfall measured from 1990 onward, which is only partially included in Lawrence (2006).

The NOAA method for calculating return periods combines regional data from surrounding areas to determine appropriate distributions and parameter estimates. It allows projections to locations and time scales for which no measurements were taken. (In particular the NOAA data for Los Alamos consists of only 24-hour data.) The assumptions behind the integration of the various data sets require spatial and temporal homogeneity on various scales. Additionally, the estimates and predictions are based on a more liberal use of the incomplete years. Therefore, the NOAA return period calculations are not directly comparable to the data used in Lawrence (2006) or the current study. Despite these many differences, the results between the analyses of the different data sets are consistent when uncertainties are considered.

7.1.3 Comparison of 24-hour Rainfall for Three Data Sets

Each of the analyses includes a calculation for the 24-hour return period rainfall. Figure E-1 compares the values for the three studies. The NOAA (Bonnin et al. 2011) calculations are 15 to 19 percent higher than Lawrence (2006). The Lawrence values are from 1 to 31 percent higher than the current study. However, when 95 percent uncertainties are considered, the estimated return levels do not differ significantly.

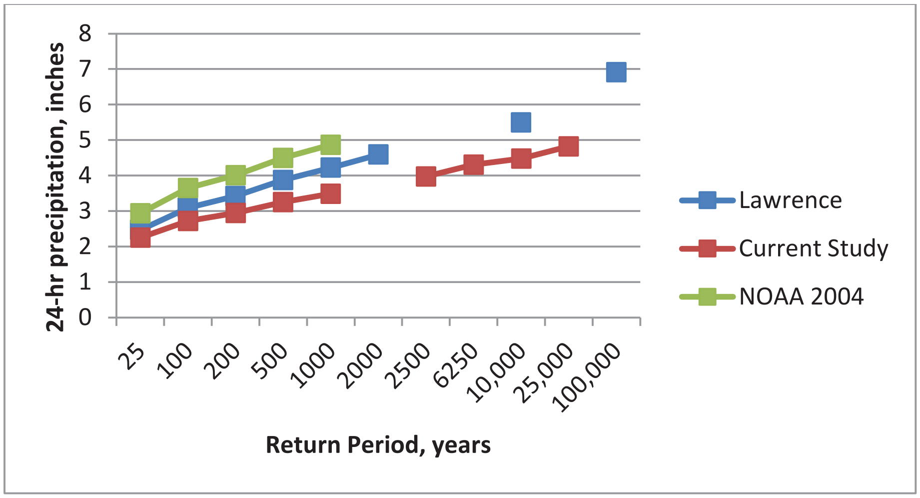

Figure 7.1 24-hr precipitation versus return periods.

7.1.4 Comparison of Site-specific LANL Data Estimates to NOAA Estimates

The strength of the current study is its use of actual measurements. NOAA (Bonnin et al. 2011) calculates the return levels based on combined regional data and for time periods less than 24 hours uses the ratio of short-term precipitation to 24-hour.

Results of return period levels from NOAA Atlas 14 (2004 version) were compared to the current calculations for a 1,000-year return period (the longest return period for the NOAA Atlas 14. The NOAA Atlas 14 1,000-yr expected return levels are all higher than the current study's 1,000-yr expected return levels (Tables 7.1 and 7.2).

Table 7.1. Site-specific Return Levels for Los Alamos for 1,000-year Return Period (current data [1990–2014] and all data [1910–2014])

Precipitation Data	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
15 minutes	1,000	1.22	.95	1.50
1 hour	1,000	2.54	1.94	3.09
2 hours	1,000	2.71	2.10	3.34
3 hours	1,000	3.23	2.44	3.96
5 hours	1,000	3.48	2.65	4.33
12 hours	1,000	3.63	2.80	4.47
24 hours	1,000	3.48	2.71	4.21
24 hours Using all data (1910–2014)	1,000	3.92	3.39	4.44

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

Table 7.2 NOAA Atlas 14 (2004) Calculation of Return Levels for Los Alamos for 1,000-year Return Period

Precipitation Data	Return Period (years)	Return Level (inches)	90% LCL[1] (inches)	90% UCL[2] (inches)
15 minutes	1,000	1.83	1.52	2.13
1 hour	1,000	3.05	2.53	3.54
2 hours	1,000	3.62	2.94	4.26
3 hours	1,000	3.77	3.08	4.40
5 hours	1,000	3.95	3.28	4.56
12 hours	1,000	4.32	3.65	4.92
24 hours	1,000	4.87	4.40	5.26

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

These differences can be attributed to the different data sets used in the NOAA Atlas 14 and the current study. The NOAA Atlas 14 data represent precipitation data for Los Alamos from 1910 through 2000. The current study uses 1990 through 2014 data. Los Alamos has experienced drought conditions from the 1998 period through 2012. This is one reason for the current study prediction of lower return period rainfall. In addition, Los Alamos recorded lower than average precipitation for 16 of 25 years, between 1990 and 2014, the period of record for the current study.

Another reason that the LANL data has lower return period rainfall estimates for less than a 1-hour period is that the tipping bucket rain gages used by LANL are known to underestimate levels for short durations (e.g., 15 minutes) during heavy rainfall (Molini et al. 2005). The NOAA (Bonnin et al. 2011) short-term estimates are primarily calculated using different rain gages and do not have this bias. Once the rainfall time period lengthens to 1 hour or greater there is much less discrepancy between the current study and the NOAA study. As mentioned previously, another reason for differences is that the NOAA data are not site specific, but are extrapolated from combined regional data.

NOAA calculates the 90 percent confidence intervals. Except for the 15-minute and 24-hour data sets, these intervals intersect with the 95 percent intervals for the current data. Since the 90 percent intervals are shorter than 95 percent intervals, and since differences are all small between the 90 percent NOAA and 95 percent current data intervals, it is expected that 95 percent intervals will intersect. Given the many differences in these data sets, the lack of significant differences in return level estimates increases confidence in the data and the modeling and analysis approaches.

The Climate Change 2014 Synthesis Report (IPCC 2014) predicts long-term increases in heavy precipitation events for the United States. However, data for the most recent 50 years indicate that the current trend in the southwestern United States is not greater than the natural variations (IPCC 2014). If climate change impacts the LANL area, then the 10-year update of return period rainfall values will provide sufficient margin to facility design.

7.1.2 Snowfall

Following NUREG-0800 (2007) guidance for snow loading, the 100-year return period for snowfall has been calculated for the 68 years of available Los Alamos data. For consistency with previous analyses (Lawrence 2006), return period snowfall for 1-day, 3-day, and 5-day periods has been calculated using the 68 years of complete data, between 1910 and 2014, for Los Alamos. The results from the current analysis agree with those from the previous analysis (Lawrence 2006).

In addition, NUREG-0800 (2007) requires the evaluation of the 48-hour PMWP event. NRC Interim Staff Guidance has been followed concerning the evaluation of winter precipitation loads on roofs. The PMWP for the Los Alamos area was not previously calculated. Therefore, this value was estimated as the maximum 48-hour precipitation measured during the 68-year data record, following WMO (2009) guidance. This PMWP value of 3.05 inches, converted to roof weight, is greater than the roof weight of the 100-year return period snowfall, and thus provides the extreme winter precipitation event for roof loading.

7.2 PWHA

7.2.1 Straight-Line Wind Speeds

Return period straight-line wind speeds, calculated with LANL 1990 through 2014 TA-6 on-site data, are lower than the values previously published for engineering design criteria (Cuesta 2004). The previous recommendations were taken from DOE-STD-1020-2002 (DOE 2012) and were not calculated from onsite wind measurements (Cuesta 2004). The data used in the current calculations well represent the current locations of LANL WDC-3 facilities and the 25-year period of measurement meets the measurement requirements of DOE-STD-1020-2012 (DOE 2012).

7.2.2 Hurricane Wind Speeds

Since Los Alamos is far inland, hurricanes that strike the Texas coast and migrate inland will not have high wind speeds by the time they reach the northern New Mexico area. Accordingly, hurricane winds do not have to be considered at Los Alamos.

8.0 REFERENCES

ANSI/ANS-2.26-2004 (R2010). 2010. Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design.

ANSI/ANS-3.11-2005 (R2010). 2010. Determining Meteorological Information at Nuclear Facilities.

ANSI/ANS-2.3-2011 (2011). Estimating Tornado, Hurricane, and Extreme Straight-Line Wind Characteristics at Nuclear Facility Sites.

Bonnin, G. M., D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley (2011). Precipitation-Frequency Atlas of the United States. NOAA Atlas 14, Volume 1, Version 5, Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Maryland, 2004 revised 2006, revised 2011.

Bowen, B. (1990). Los Alamos Climatology. LA-11735-MS.

Bowen, B. (1996). Rainfall and Climate Variation over a Sloping New Mexico Plateau during the North American Monsoon. *Journal of Climate, Volume 9*, 3432–3442.

Coles, S. (2001). An Introduction to Statistical Modeling of Extreme Values. Great Britain. Springer-Verlag.

Cuesta, I. (2004). Design-Load Basis for LANL Structures, Systems, and Components. LA-14165.

Dewart, J. and M. Boggs. (2014). Meteorology Monitoring at Los Alamos. LA-UR-14-23378.

DOE (Department of Energy). (2008). Complex Transformation Supplemental Programmatic Environmental Impact Statement (SPEIS). DOE/EIS-0236-S4.

DOE (Department of Energy). (2012). Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities. DOE-STD-1020-2012.

DOE (Department of Energy). (2015). Natural Phenomena Hazards Analysis and Design Handbook for DOE Facilities. DOE-STD-1088-2000, August 2015.

EPA (Environmental Protection Agency). (2000). Meteorological Monitoring Guidance for Regulatory Modeling Applications. EPA-454/R-99-005.

Gilleland, E. and R.W. Katz. (2011). New software to analyze how extremes change over time. *EOS, Volume 92*, *Issue 2*, 13–14.

IPCC. (2014). Climate Change 2014: Synthesis Report Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Irwin, J. (1979). Scheme for estimating dispersion parameters as a function of release height. EPA Tech. Rep. 600:4-79-062.

LANL (Los Alamos National Laboratory). (2008). Environmental Surveillance at Los Alamos during 2007. LA-14369-ENV.

LANL (Los Alamos National Laboratory). (2014a). LANL 2013 Annual Site Environmental Report. LA-UR-14-27564.

LANL (Los Alamos National Laboratory). (2014b). Technical Project Plan for Meteorological Monitoring. ENV-PLAN-300, December 2014.

Lawrence, E. (2006). Site-Specific Extreme Rainfall and Snow Hazard Curves at Los Alamos National Laboratory, Los Alamos, New Mexico. LA-UR-06-6329.

McKown, B., S. Koch, R. Balice, and P. Neville. (2003). Land Cover Map for the Eastern Jemez Region. LA-14029, June 2003.

Molini, A., L.B. Lanza, and P. LaBarbera. (2002). The Impact of Tipping Bucket Raingauge Measurement Errors on Design Rainfall for Urban-scale Applications. *Hydrological Process* 19(2005), pp. 1073–1088.

NUREG-0800. (2007). United States NRC Standard Review Plan, March 2007.

Perica, S., S. Dietz, S. Heim, L. Hiner, K. Maitaria, D. Martin, S. Pavlovic, I. Roy, C. Trypaluk, D. Unruh, F. Yan, M. Yekta, and T. Zhao. (2014). Precipitation-Frequency Atlas of the United States. NOAA Atlas 14, Volume 6, Version 2.3, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Maryland, 2011, revised 2014.

Reneau, S., G. Kuyumjian, D. Malmon, and M. Tardiff. (2003). Precipitation-Frequency Relations on the Pajarito Plateau and in the Eastern Jemez Mountains, New Mexico, and Example of Extreme or Flood-Producing Storms. LA-UR-03-6484, September 2003.

Stephenson, A. G. (2002). evd: Extreme Value Distributions. R News, 2(2):31–32, June 2002. URL: http://CRAN.R-project.org/doc/Rnews/.

WMO (World Meteorological Organization). (2009). Manual on Estimation of Probably Maximum Precipitation. WMO-No.1045.

APPENDIX A PROPOSED TORNADO ANALYSIS

Los Alamos is located in Region III for the analysis of extreme and rare wind events (ANS/ANSI-2.3-2011). For WDC-3 facilities, the tornado wind requirement in Region III is ~100 miles per hour for a return period of 50,000 years (ANS/ANSI-2.3-2011). This value was generated using tornado statistics representing 1950 through 2003 (Ramsdell and Rishell 2007).

An additional 10 years of tornado data are now available from the National Climatic Data Center, Storm Data Publication/Database (http://www.ncdc.noaa.gov/data-access/quick-links#storm-d). During this time period, 20 tornados have been observed within about 80 miles of LANL. Each of these tornados has been evaluated as Enhanced Fujita (EF) 0 tornados (max wind speed <85 mph) with one exception. In September of 2014, an EF1 tornado was observed just west of Chama, New Mexico, approximately 75 miles north-northwest of LANL. Based on the observed damage by the National Weather Service, the maximum winds for this tornado are estimated to be 110 mph.

Although the Chama, New Mexico, tornado occurred in rolling terrain and not in terrain with steep topographic aspects similar to LANL, the location does fall into the same area as LANL in the Ramsdell and Rishell (2007) analysis. Because the Chama, New Mexico, tornado is estimated to have a larger wind speed than the ANS/ANSI-2.3-2011 recommendation for the LANL area, we are recommending that the Ramsdell and Rishell (2007) analysis be updated to include the 2004 through 2014 tornado data near LANL.

When the updated design basis tornado is determined, standard design missiles will be calculated following ANSI/ANS-2.3-2011.

References

ANSI/ANS-2.3-2011 (2011). Estimating Tornado, Hurricane, and Extreme Straight-Line Wind Characteristics at Nuclear Facility Sites.

Ramsell, J.V. and J.P. Rishel. (2007). Tornado Climatology of the Continuous United States. NUREG/CR-4461, Rev.2, PNNL-15112, Rev. 1.

APPENDIX B TA-16 RAINFALL ANALYSIS AND COMPARISON OF RETURN LEVELS TO TA-6 LEVELS

The 15-minute data for TA-16 are from 1996 to 2005. Because of missing data during the Cerro Grande fire (5,147 records), the 2000 data are not used in the analysis. Although 1996 has 229 records missing, these are in the month of May, not a time of maximum rainfall, so these data are included. The year 1998 has only 24 records missing, 2001 has only 131 missing records, and 2004 has only two records missing; so these data are used in the analysis. The other years, 1997, 1999, 2002, 2003, and 2005 are complete. This results in nine years of data for the 15-minute maximum rainfall analysis. Nine observations are unlikely to provide reliable results using the GEV approach.

The 24-hour data are for 1977 through 2005. The year 1978 is missing. Since 56 days of 2000 are missing because of the Cerro Grande fire (including August and much of September), these data are not used. Only one day of 2001 is missing so it is included in the analysis. This results in 27 years of data for the 24-hour maximum rainfall analysis. The 27 observations are a small data set for the GEV approach, but not unreasonable.

B.1 Analysis for TA-16 15-Minute Yearly Maximum Rainfall

The differences between the measurements at T-6 and TA-16 are shown in Table B.1.

Table B.1. Differences between the Measurements at T-6 and TA-16

Year	TA-6 Data - TA-16 Data
1996	-0.41
1997	-0.09
1998	-0.029
1999	0.21
2001	0.14
2002	-0.12
2003	0.09
2004	-0.02
2005	0.01

The measurements at TA-6 are much lower than those for TA-16 for the years 1996 and 2002. They are much higher for 1999 and 2001. They do not differ importantly for the other years. Figure B.1 contains plots of yearly maximum 15-minute rainfall versus year, as well as QQ plots to evaluate the fit of the GEV to the data and plots of return levels versus return periods with 95 percent uncertainty bounds. However, there is not enough data to determine reliable estimates.

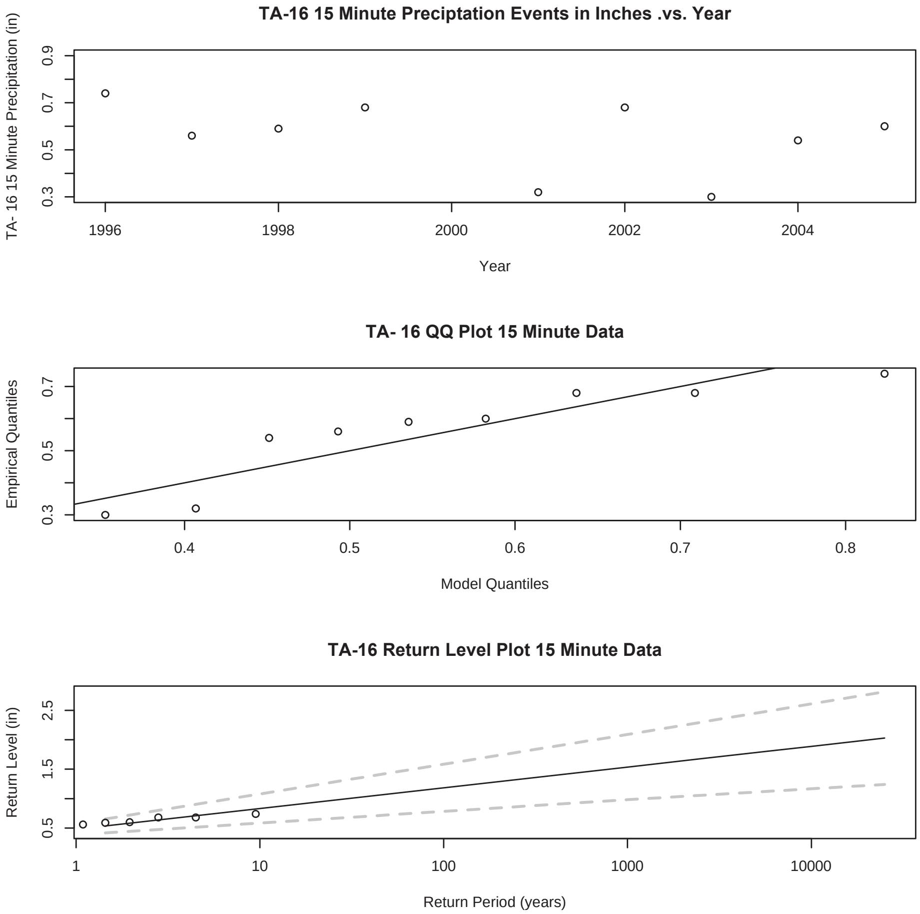

Figure B.1 Plots of yearly maximum 15-minute rainfall versus year and QQ plots to evaluate the fit of the GEV to the data and plots of return levels versus return periods with 95% uncertainty bounds.

The predicted return levels for TA-16 are given in Table B.2. They are higher than for the TA-6 data shown in Table B.3. The lower confidence levels are not different; however, the upper limits are much higher. The limited data with so much variability makes this a questionable data set for analysis of 15-minute annual maximum events.

Table B.2. Return Levels with 95% Uncertainty Limits for the Specified Return Periods and for TA-16 Yearly Maximum for 15-minute Rainfall Measurements

Precipitation Data	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
15 minutes	2,500	1.68	1.03	2.31
	6,250	1.82	1.10	2.51
	10,000	1.89	1.13	2.62
	25,000	2.03	1.20	2.83

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

Table B.3. Return Levels with 95% Uncertainty Limits for the Specified Return Periods and for TA-6 Yearly Maximum for 15-minute Rainfall Measurements

Precipitation Data	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
15 minutes	2,500	1.33	1.03	1.60
	6,250	1.43	1.10	1.74
	10,000	1.48	1.14	1.80
	25,000	1.59	1.22	1.94

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

B.2 Analysis for TA-16 24-Hour Yearly Maximum Rainfall

Table B.4 contains the differences for the TA-6 (Los Alamos) maximum 24-hour measurements and those for TA-16. They differ, but not consistently. Sometimes the TA-6 values are higher and other times the TA-16 values are higher. In this case the data are sufficient to do a GEV return level analysis. Figure B.2 contains plots of yearly maximum 24 rainfall versus year, as well as QQ plots to evaluate the fit of the GEV to the data and plots of return levels versus return periods with 95 percent uncertainty bounds.

As shown in Tables B.5 and B.6, despite differences in the data the predicted return levels and uncertainties are not significantly different for those based on the TA-6 data. In fact, the TA-6 levels are slightly higher. From these analyses, it can be concluded that the existing TA-16 24-hour data are consistent with the TA-6 data return period rainfall data.

Table B.4. Differences for the TA-6 (Los Alamos) Maximum 24-hour Measurements and Those for TA-16.

Year	TA-6 Data - TA-16 Data
1977	-0.3
1979	0.29
1980	-0.1
1981	-0.75
1982	0.42
1983	0.69
1984	0.13
1985	0.16
1986	0.5
1987	0.88
1988	0.66
1989	-1.06
1990	-0.23
1991	-0.39
1992	0.23
1993	-0.08
1994	-0.53
1995	-0.5
1996	-0.48
1997	0.3
1998	-0.14
1999	-0.12
2001	0
2002	-0.52
2003	0.13
2004	-0.26
2005	-0.22

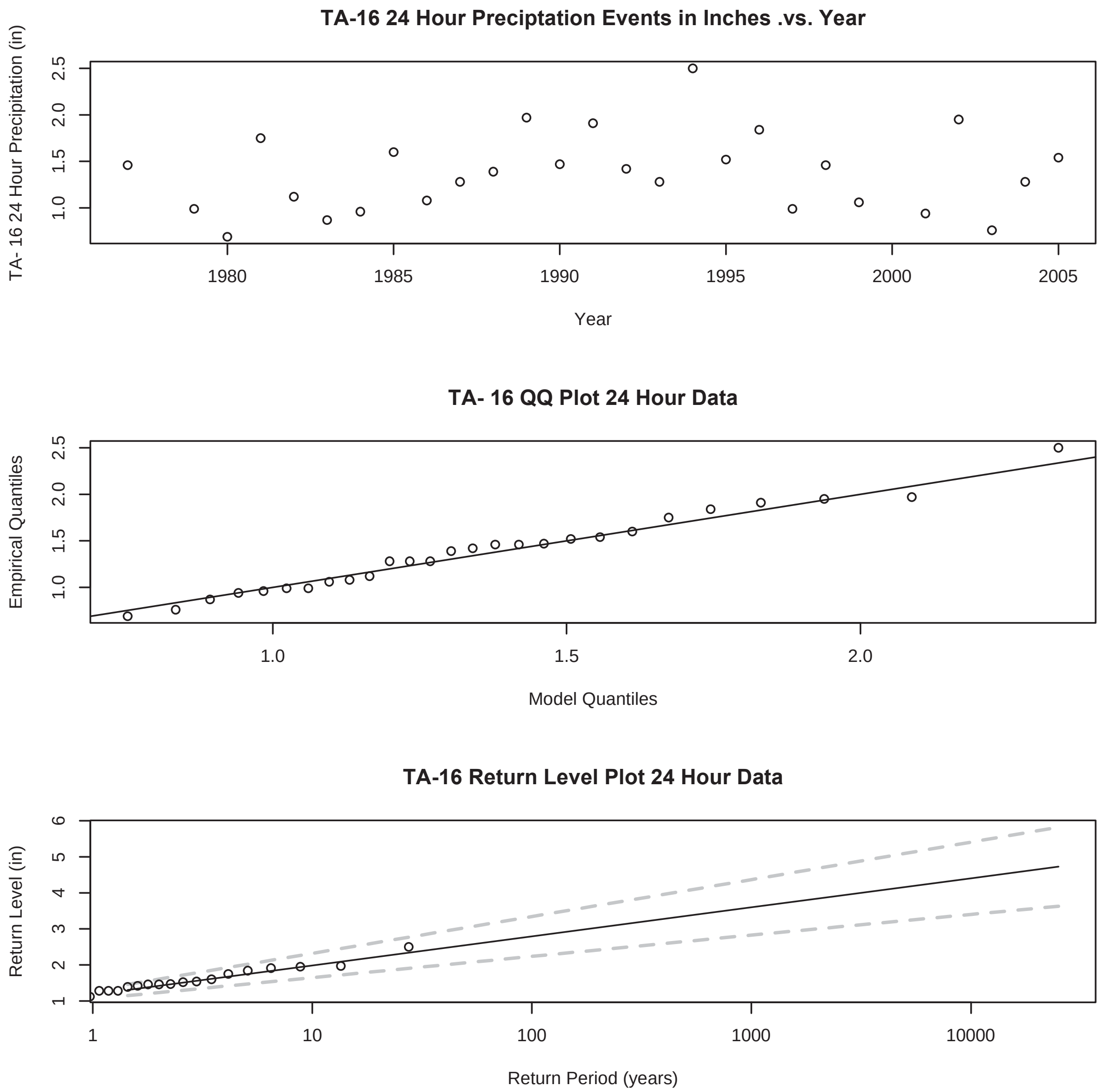

Figure B.2 **Plots of yearly maximum 24-hour rainfall versus year and QQ plots to evaluate the fit of the GEV to the data and plots of return levels versus return periods with 95% uncertainty bounds.**

Table B.5. Return Levels with 95% Uncertainty Limits for the Specified Return Periods for TA-16 Yearly Maximum for 24-hour Rainfall Measurements

Precipitation Data	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
24-hour	2,500	3.92	3.05	4.80
	6,250	4.24	3.27	5.22
	10,000	4.40	3.39	5.43
	25,000	4.73	3.61	5.84

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

Table B.6. Return Levels with 95% Uncertainty Limits for the Specified Return Periods for TA-6 Yearly Maximum for 24-hour Rainfall Measurements.

Precipitation Data	Return Period (years)	Return Level (inches)	95% LCL[1] (inches)	95% UCL[2] (inches)
24-hour	2,500	3.97	3.01	4.83
	6,250	4.31	3.23	5.26
	10,000	4.48	3.35	5.47
	25,000	4.82	3.59	5.90

[1] LCL = Lower confidence limit

[2] UCL = upper confidence limit

APPENDIX C COMPARISON OF 24-HOUR PRECIPITATION DATA BASED ON 15-MINUTE DATA (1990–2014) COLLECTED FROM TA-6 TO PREVIOUS 24-HOUR DATA (1910–2005) COLLECTED FROM THE LOS ALAMOS SITE

In 2006, an analysis of the daily precipitation from 1910 to 2005 was completed (Lawrence 2006). These data came from the Los Alamos Weather Machine (http://www.weather.lanl.gov). Prior to 1990 these data are from sites collectively known as the Los Alamos Site. After 1990, they are from the TA-6 site.

A GEV distribution was used to model the yearly maximum data. Only years with complete data were used, resulting in 64 observations. Although the shape parameter was not significantly different from zero, the three-parameter GEV was used allowing a non-zero shape parameter. Using the non-zero shape parameter resulted in higher return levels than the Fisher-Tippett or Gumbel and larger uncertainties (Lawrence 2006).[2]

Figure C.1 provides a comparison of boxplots of the Lawrence (2006) data [Lawrence (1910–2005)] with subsets of the Lawrence (2006) data, one prior to 1990 [Lawrence (1910–1989)] and one from 1990 to 2005 [Lawrence (1990–2005)]. Also shown in the figure is the boxplot for the data used in this analysis [TA-6 (1990–2014)]. The bottoms and tops of the boxes are the first and third quartiles, and the band inside the boxes is the median. The length of the boxes, the middle 50 percent, is called the inter quartile range (IQR). The lines coming out of the boxes (whiskers) extend to the lowest datum still within 1.5*IQR of the lower quartile and the highest datum still within 1.5*IQR of the upper quartile. Circles outside the whiskers are considered outliers (http://en.wikipedia.org/wiki/Box_plot).

Comparison of the boxplots shows that although the medians do not vary across data sets, the variability and the skewness of the data change. The pre-1990 Lawrence data are more variable and have higher values than the post-1989 Lawrence data and the TA-6 (1990–2014) data. Figure C.2 shows the maximums versus year for the Lawrence and the TA-6 data. These plots also show the greater variability for the Lawrence data and the general decrease in maximum precipitation events beginning around 1990.

The use of a non-zero shape parameter and the decrease in high precipitation events after 1990 result in higher estimates of return levels for 24-hour data in the Lawrence report (2006) as compared to those in this report. However, the 95 percent uncertainty intervals overlap.

[2] Note that the problem with allowing the shape parameter to be non-zero when it is not significantly different from zero can be seen in the snow analysis data from the Lawrence report. For some return periods the 3-day snowfall is greater than the 5-day snowfall.

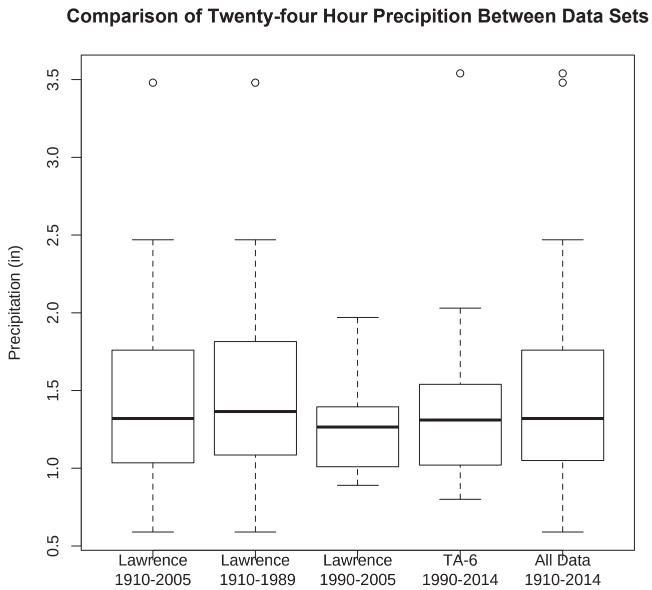

Figure C.1 Boxplots comparing various 24-hour precipitation data sets.

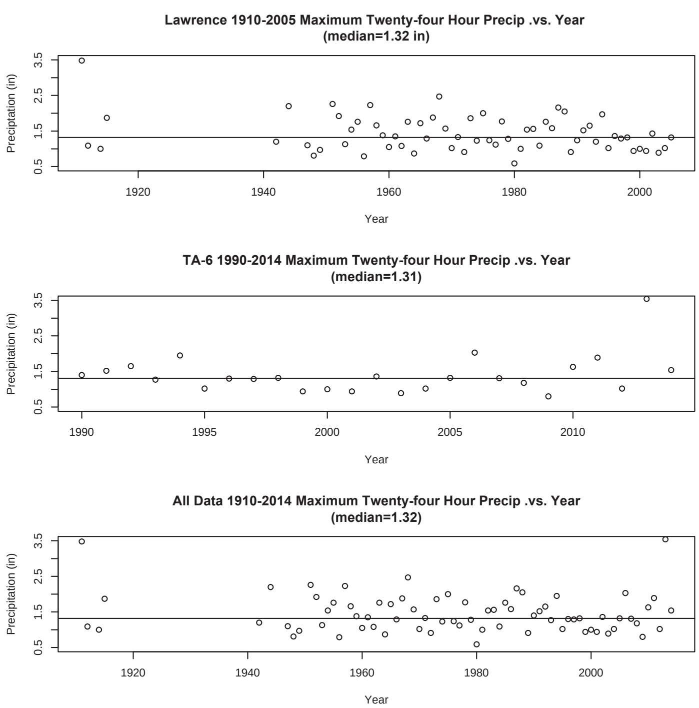

Figure C.2 Comparison of Lawrence (2006) (1910–2005), TA-6 (1990–2014) data, and all data (data 1910–2014).

Reference

Lawrence, E. (2006). Site-Specific Extreme Rainfall and Snow Hazard Curves at Los Alamos National Laboratory, Los Alamos, New Mexico. LA-UR-06-6329.

APPENDIX D YEARLY MAXIMUM PRECIPITATION ANALYSIS PLOTS

This appendix contains plots of maximum yearly precipitation levels versus year for each precipitation data set, QQ plots for each data set to evaluate the fit of the GEV to the data and plots of return levels versus return periods with 95 percent uncertainty bounds for each data set. The circles on the return level plot are based on the quantiles of the data. These plots are generated using the R-package “extRemes” (Gilleland and Katz 2011).

The plots in Figure D.1 show that the GEV provides a good fit to the 15-minute precipitation data.

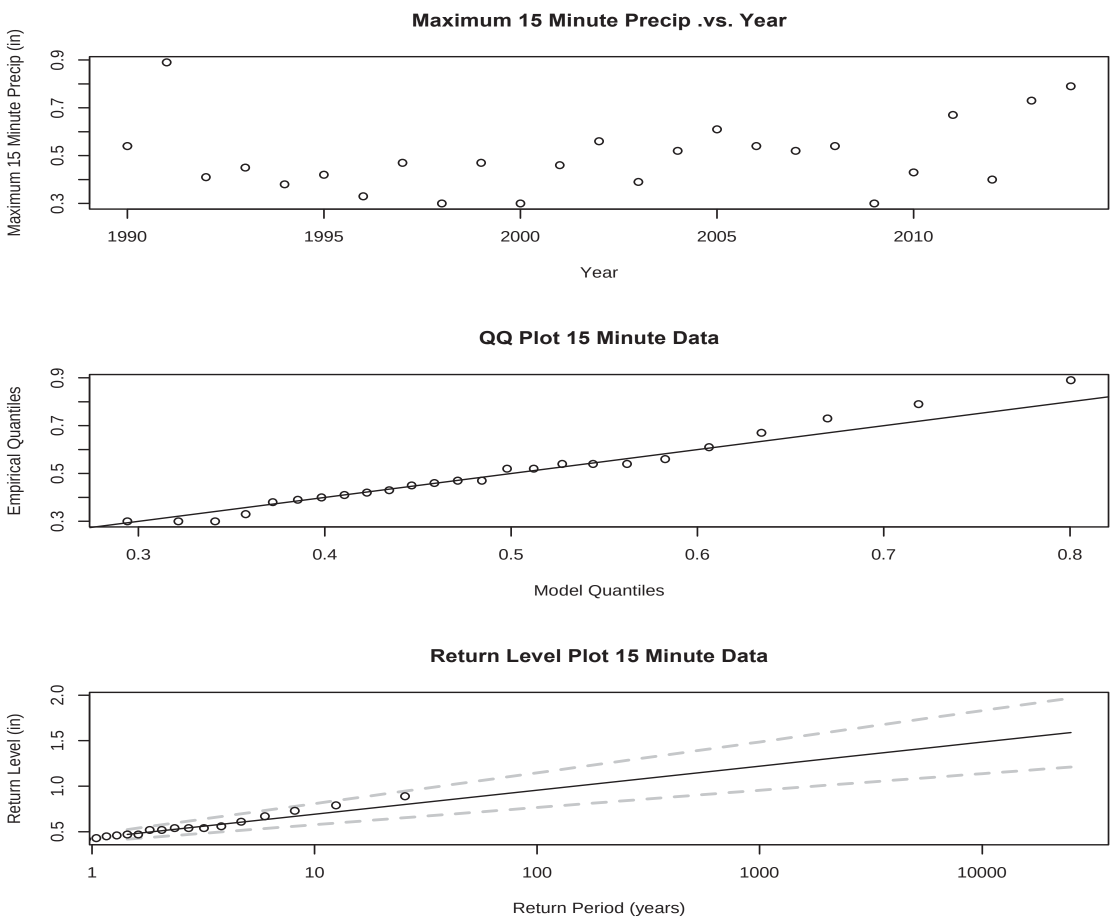

Figure D.1 Analysis plots for the 15-minute data.

The data in Figure D.2 show the high level of precipitation in 2013. The highest 1-hour rainfall during the September 2013 storm was 1.60 inches on September 13. This value is consistent with a 25-year return level for a 1-hour total calculated by NOAA in 2004 (Bonnin et al. 2011) using the longer 1910 through 2000 dataset and is within the uncertainty bounds for the 25-year return level based on the current data (from 1990 to 2014).

The high levels for this storm are explained by an upper-level low pressure system “parked” over the Great Basin from September 10 through 15, with a high-pressure system centered to the east of

New Mexico and Colorado (LANL 2014a). This combination of a stationary low pressure to our west and high pressure to our east produced a deep layer of southerly winds, brining subtropical moisture from Mexico into New Mexico. A total of 7 inches of rain fell at the TA-6 station during these 5 days; this is considered to be a once-in-1000-yr storm (Bonnin et al. 2011) for Los Alamos. Flooding occurred in most of the LANL canyons; however, flooding did not impact mesa-top facilities.

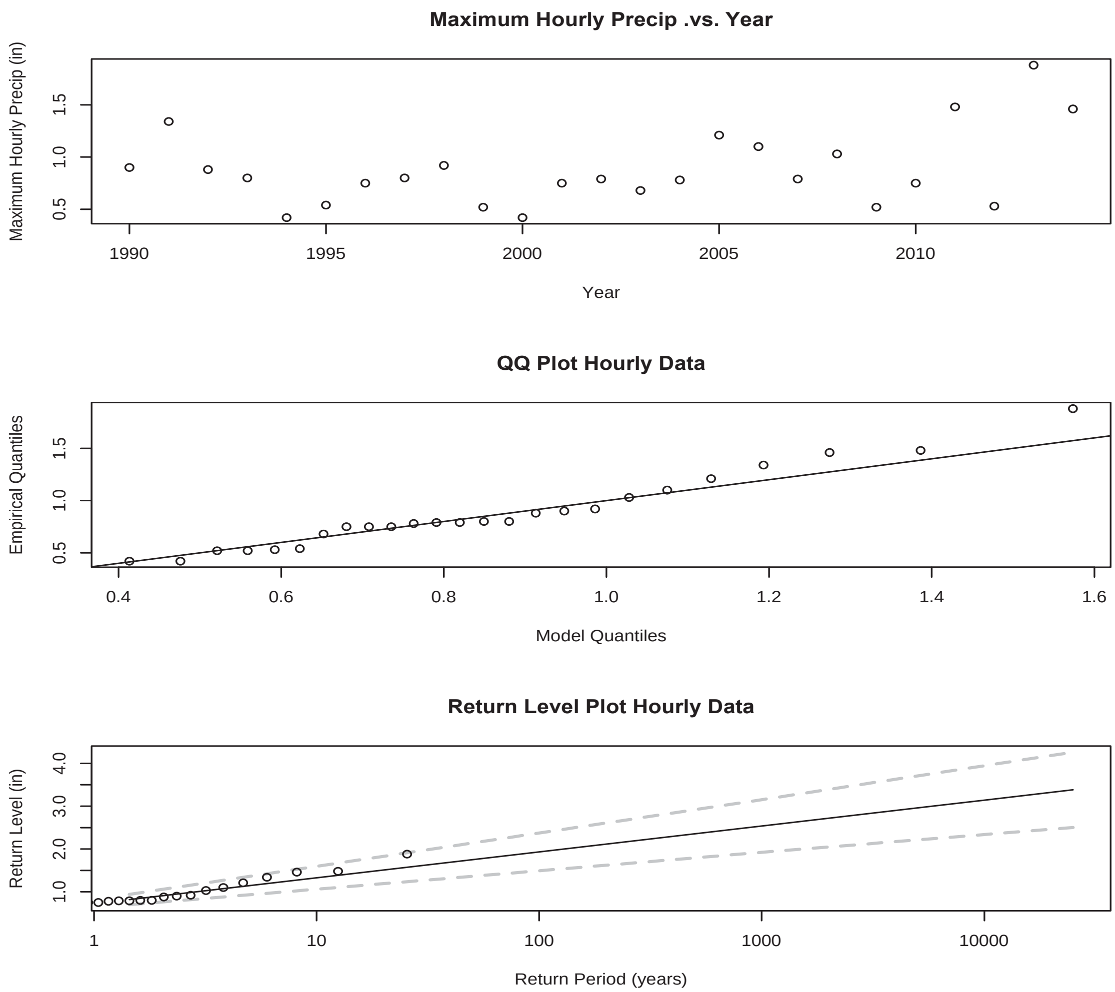

Figure D.2 Analysis plots for the hourly data.

In addition to the LANL network, the Laboratory operates two other sets of rain gages during the warm season (May through October). One set of rain gauges is located within and adjacent to the Laboratory boundary, to assist in determining when stormwater is flowing in LANL canyons. The second set of rain gauges, known as the Precipitation Emergency Notification System (PENS) is located in the mountains west of the Laboratory boundary, between 8,200 and 9,800 feet. The PENS was installed following the 2011 Las Conchas fire and provides automated notifications when heavy precipitation in the mountains could produce localized flooding in Laboratory canyons. Data from all three rain gauge networks for September 10 through 15 are presented in

Figure D.3. Rainfall totals in the mountains are much higher than across the Laboratory. Rainfall totals across the Laboratory, between 6,300 and 7,700 feet, did not vary greatly during the September precipitation event.

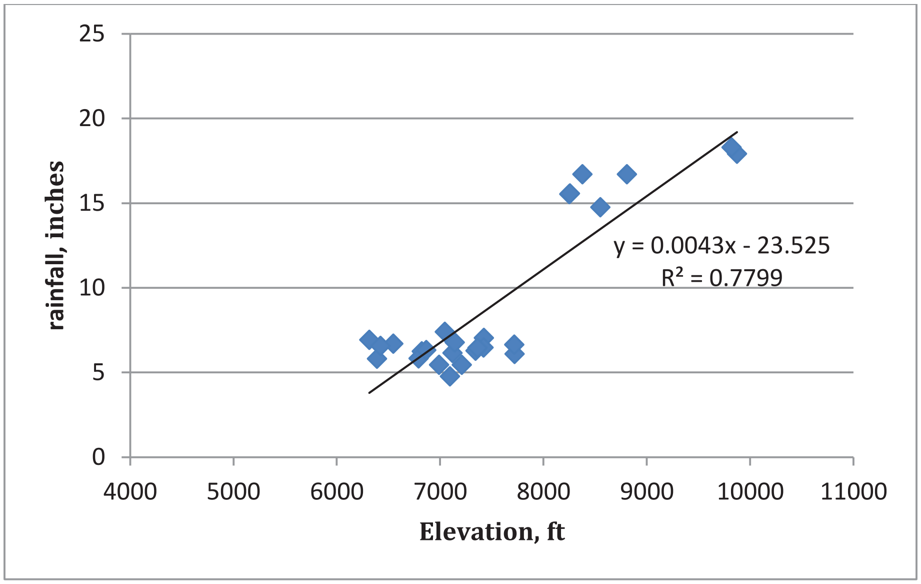

Figure D.3 September 10–15, 2013, rainfall totals by elevation.

The 2-hour data in Figure D.4 indicate that the 2013 precipitation event is a potential outlier. The GEV gives a good fit for all of the data except 2013. Return levels are within uncertainty bounds for all data except for the 2013 event. The highest 2-hour rainfall recorded during the September 2013 storm was 2.34 inches. This value is within the 100-year return period rainfall values calculated by NOAA (Bonnin et al. 2011) from the longer 1910 to 2000 dataset, and is within the uncertainty bounds for the 100-year return level based on the current data set. As with the snow outlier evaluation, an outlier analysis that excludes the potential outlier shows that there is no significant impact on the predicted return levels or their uncertainty bounds. There is a light shift lower with differences in the tenths of inches.

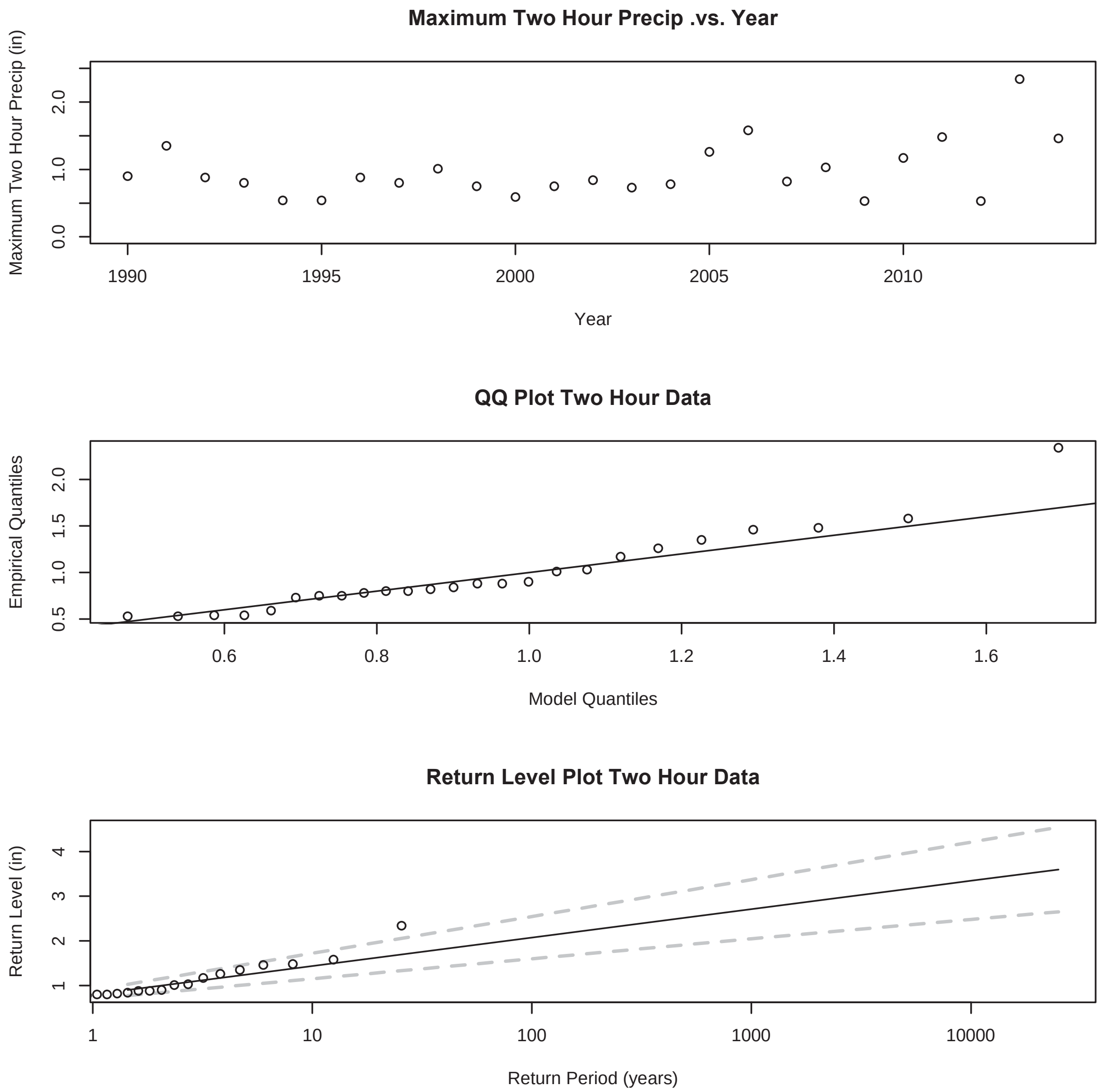

Figure D.4 Analysis plots for the 2-hour data.

The GEV in Figure D.5 continues to give an excellent fit to all data except the 2013 precipitation. Again, the outlier analysis, which excludes this potential outlier from the analysis, shows that there is no significant impact on the predicted return levels or their uncertainty bounds (a slight shift lower with differences in the tenths of inches).

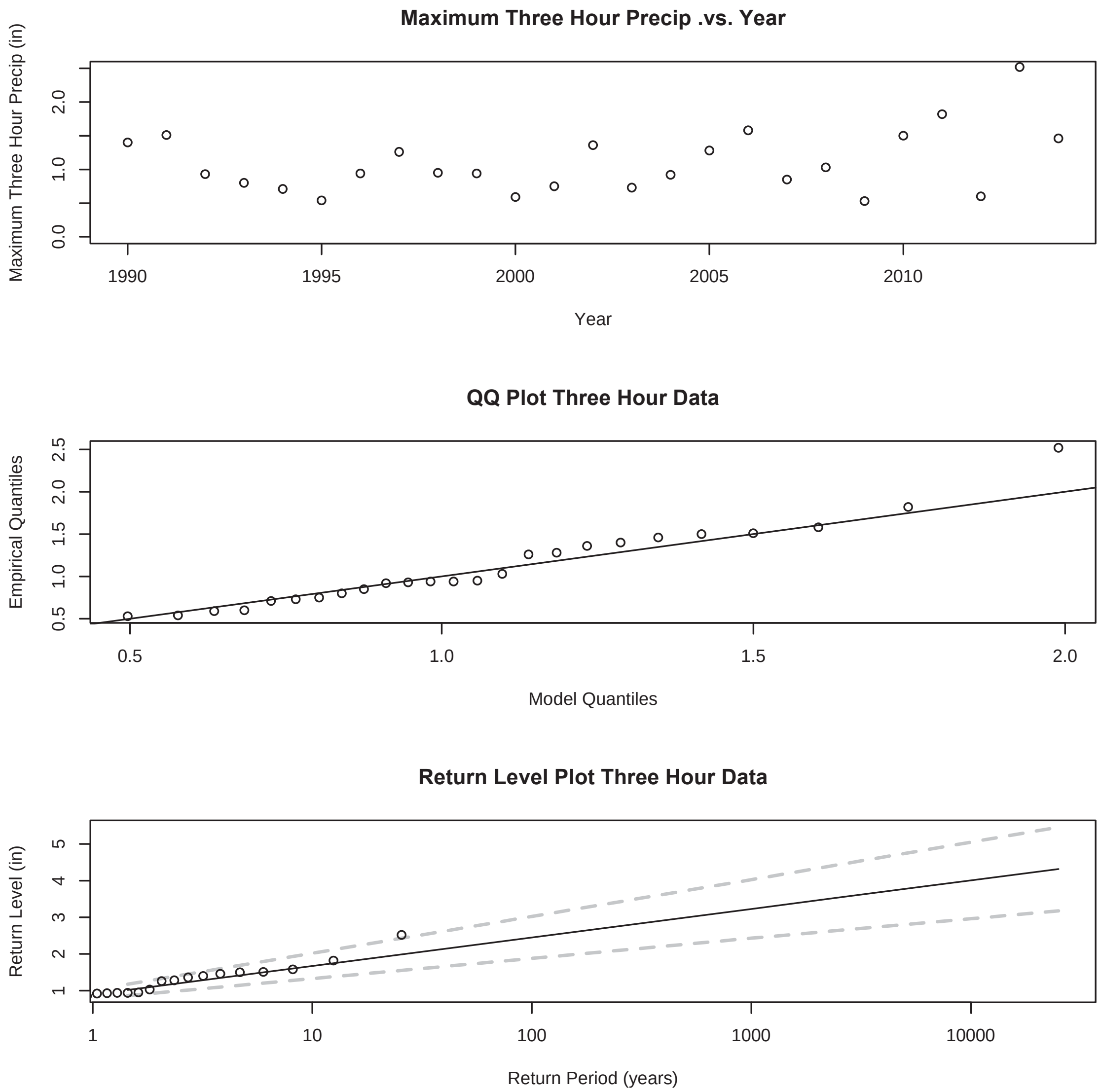

Figure D.5 Analysis plots for the 3-hour data.

The GEV in Figure D.6 continues to give an excellent fit to all data except 2013, indicating that for 6-hour precipitation 2013 is a potential outlier. The maximum 6-hour rainfall recorded during the September 2013 event was 2.76 inches. This value is within the 100-year return period rainfall values calculated in the NOAA 2004 report (Bonnin et al. 2011) from the longer 1910 to 2000 dataset and is within the uncertainty bounds on the 100-year return levels based on current data. Again, the outlier analysis, which excludes this potential outlier from the analysis, shows that there is no significant impact on the predicted return levels or their uncertainty bounds (a slight shift lower with differences in the tenths of inches).

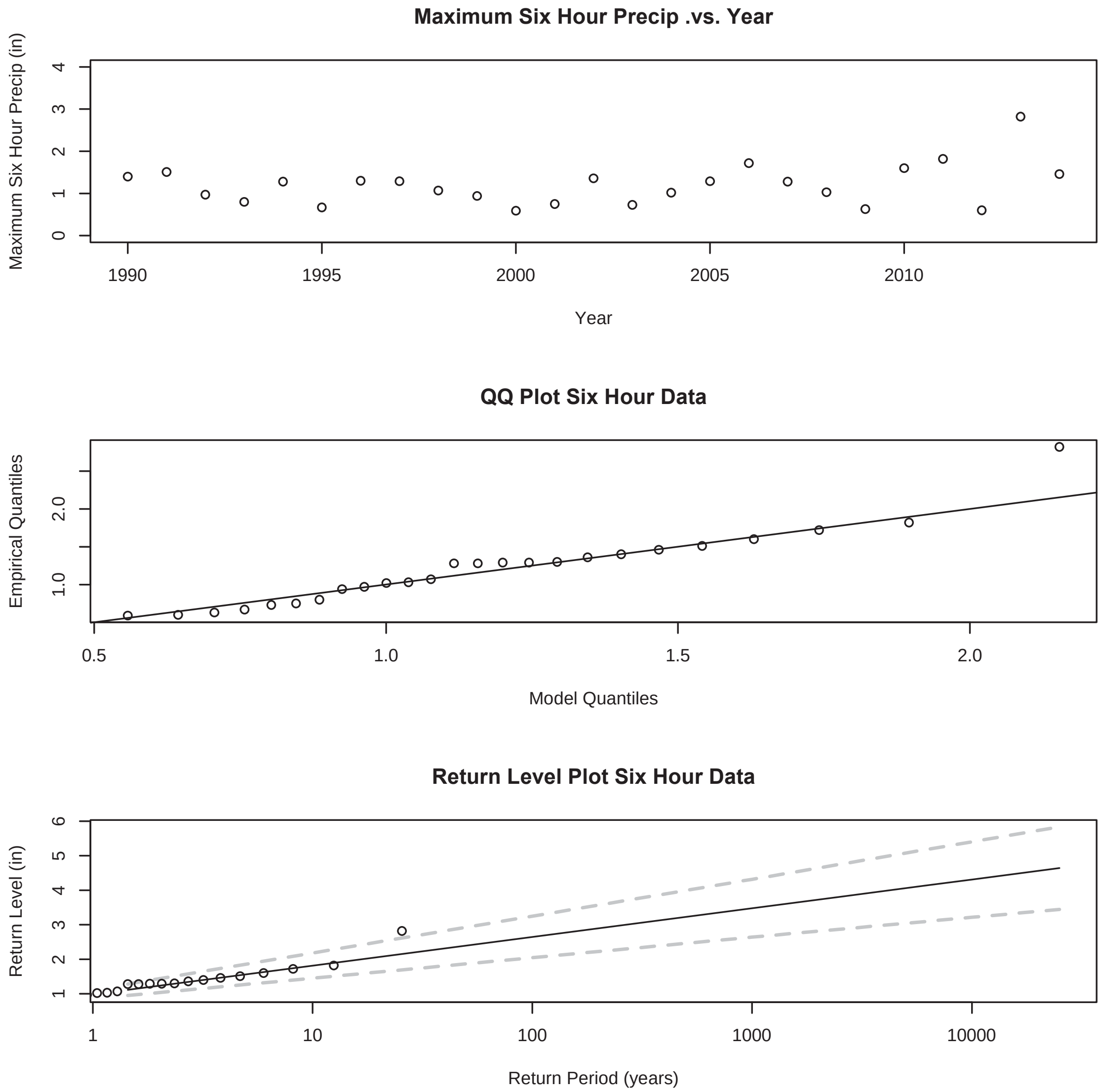

Figure D.6 Analysis plots for the 6-hour data.

The GEV in Figure D.7 continues to give an excellent fit to all data except 2013, indicating that for a 12-hour precipitation event 2013 is an outlier. The highest 12-hour rainfall recorded during the September 2013 rainstorm was 3.50 inches. This value is within the 200-year return period rainfall values calculated by NOAA (Bonnin et al. 2011) from the longer 1910 to 2000 dataset and is within the uncertainty bounds for the 200-year return levels based on current data. Again, the outlier analysis, which excludes this potential outlier from the analysis, shows that there is no significant impact on the predicted return levels or their uncertainty bounds (a slight shift lower with differences in the tenths of inches).

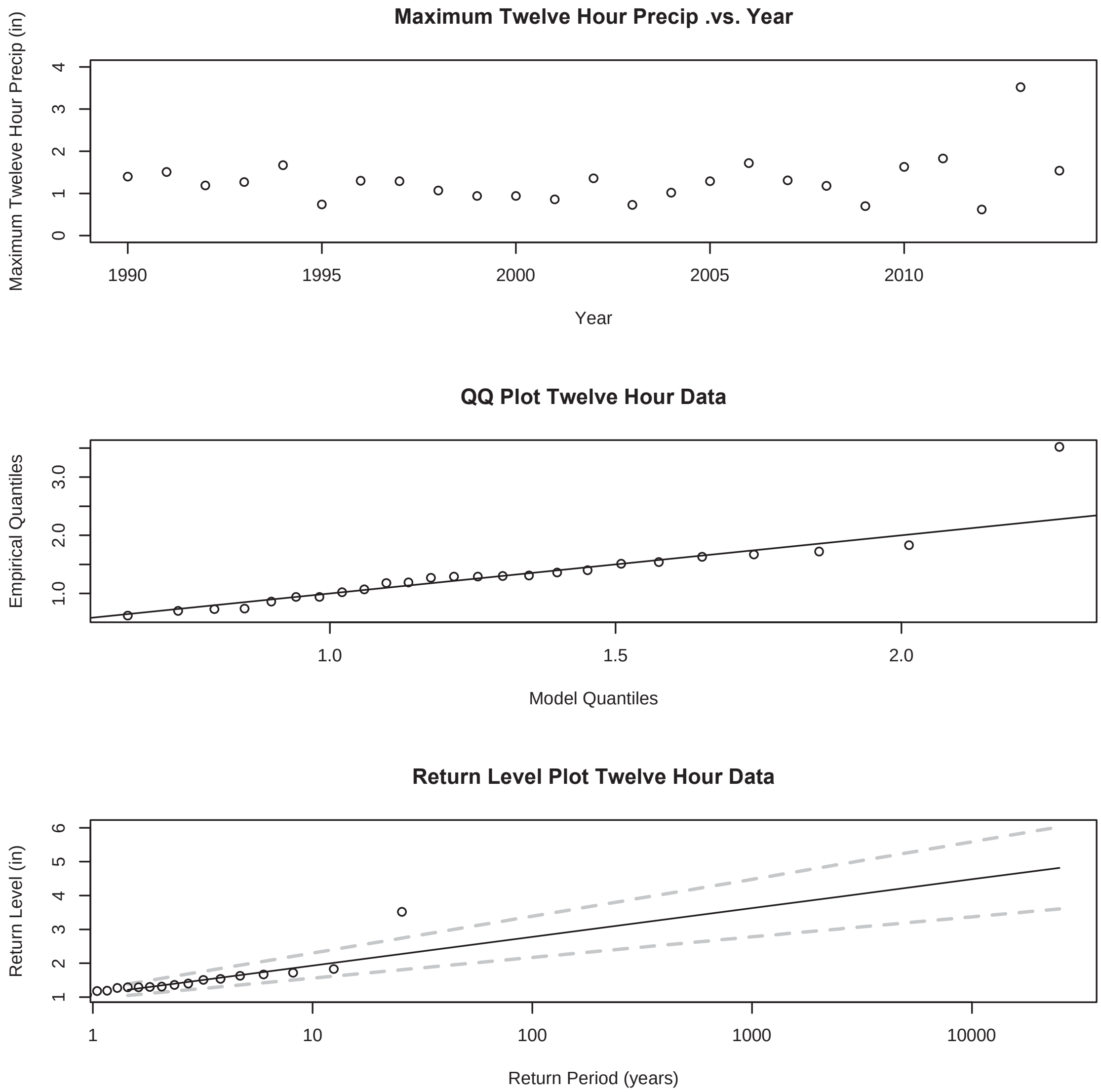

Figure D.7 Analysis plots for the 12-hour data.

The GEV in Figure D.8 continues to give an excellent fit to all data except 2013, indicating that for a 24-precipitation event 2013 is an outlier. The highest 24-hour rainfall recorded during the September 2013 rainstorm was 3.52 inches. This value is within the 100-year return period rainfall values calculated in 2004 (Bonnin et al. 2011) from the longer 1910 to 2000 dataset and is within the uncertainty bounds on the 125-year return levels based on current data. Again, the outlier analysis, which excludes this potential outlier from the analysis, shows that there is no significant impact on the predicted return levels or their uncertainty bounds (a slight shift lower with differences in the tenths of inches).

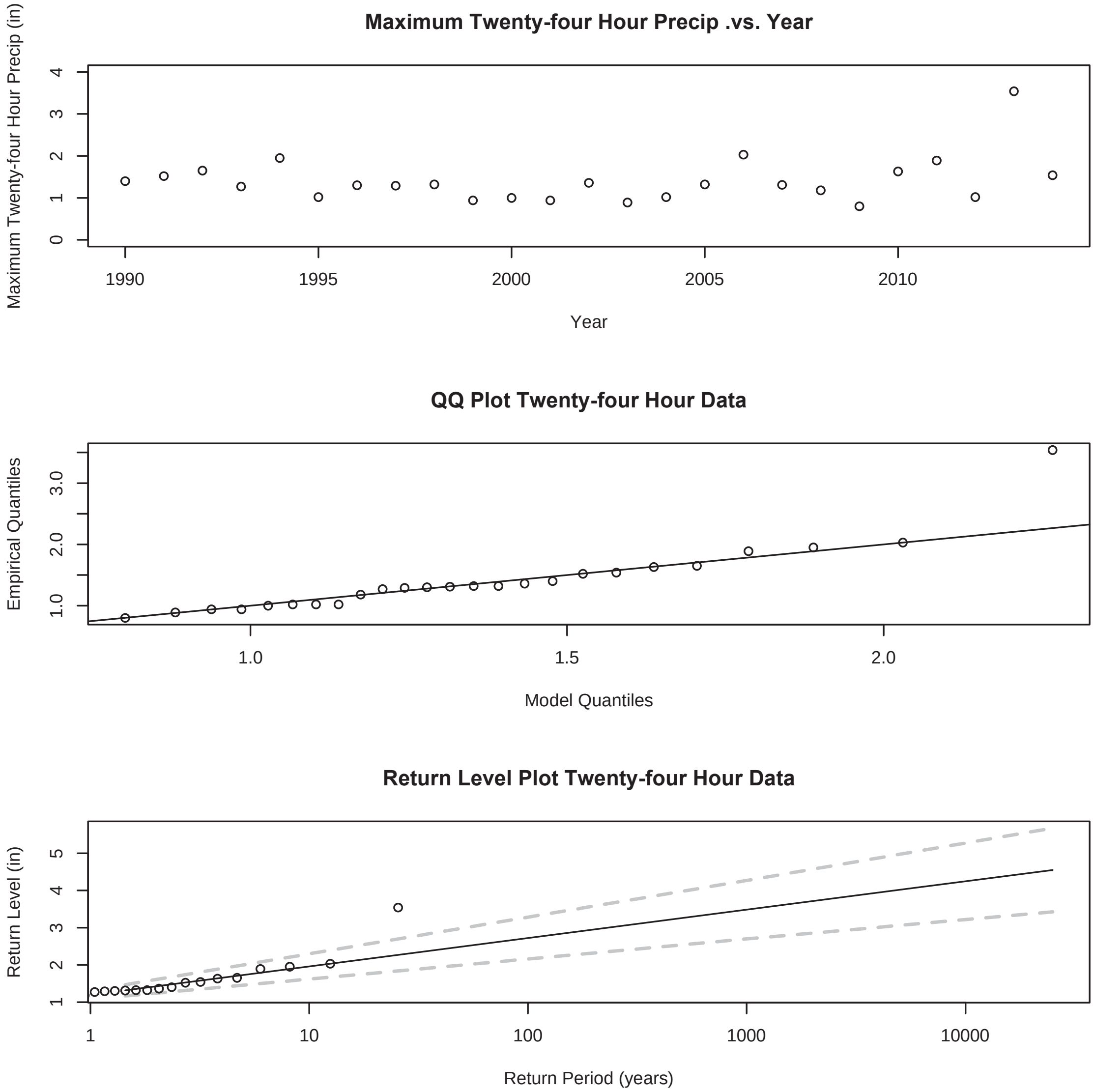

Figure D.8 Analysis plots for the 24-hour data.

As in the previous plots, the GEV in Figure D.9 continues to give an excellent fit to all data except 2013. The highest 48-hour rainfall recorded during the September 2013 rainstorm was 5.24 inches. Again, the outlier analysis, which excludes this potential outlier from the analysis, shows that there is no significant impact on the predicted return levels or their uncertainty bounds (a slight shift lower with differences in the tenths of inches).

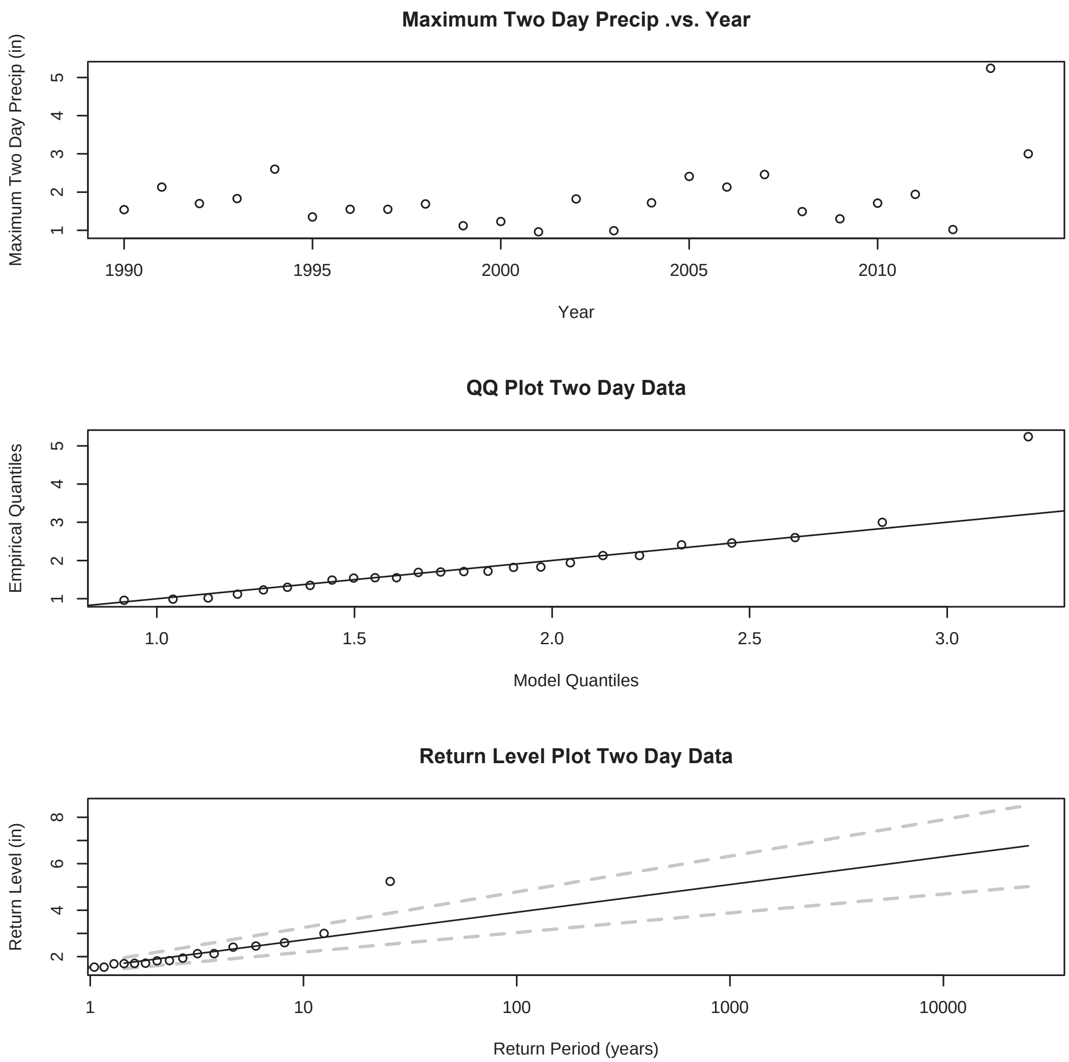

Figure D.9 Analysis plots for the 48-hour data.

References

Bonnin, G. M., D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley (2011). Precipitation-Frequency Atlas of the United States. NOAA Atlas 14, Volume 1, Version 5, Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Maryland, 2004 revised 2006, revised 2011.

Gilleland, E. and R.W. Katz. (2011). New software to analyze how extremes change over time. *EOS, Volume 92*, *Issue 2*, 13–14.

LANL(Los Alamos National Laboratory). (2014). LANL 2013 Annual Site Environmental Report. LA-UR-14-27564.