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D. Randerson

Air Resources Laboratory
Silver Spring, Maryland
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Special Operations and Research Division
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## Notice

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## Abstract

Extreme-event precipitation data tabulated and analyzed in this report clearly demonstrate the dramatic spatial and temporal variability of precipitation in southern Nevada. There is a marked seasonal difference in the monthly frequency distributions of these events between extreme southern Nevada and the northern most stations. The southern most stations exhibit a strong preference for heavy, convectively-driven precipitation events in July and August while the northern most stations have cyclonically-driven peaks in the November - March time frame. Warm-season extreme events can pose a prompt threat to life and property because the time periods for warning and action are much shorter; thereby challenging our forecast capabilities and warning communications systems.

A frequency analysis of set-hour precipitation events for Las Vegas shows that 72% of all warm-season, set-hour precipitation events result in totals of 0.05 in (1.3 mm) or less. However, hourly precipitation rates of 0.5 in/hr (12.7 mm/hr) up to nearly 1.5 in/hr (28.1 mm/hr) have been measured. Precipitation rates of as much as 2.0 to 4.0 in/hr (51 to 101 mm/hr) are thought to be possible in the more extreme cases and in very small areas.

Data clearly illustrate that daily precipitation totals of 2.0 to 6.0 in ( 50.8 to 152.4 mm) have occurred in southern Nevada. Dangerous flash flooding can accompany these intense storms, threatening life and damaging property.

Frequency analyses of extreme daily precipitation events are presented for eleven different sites in southern Nevada. Both normal and log Pearson Type III frequency analyses are presented. In a similar manner, extreme hourly precipitation events are analyzed for Las Vegas. The results are compared with those found in NOAA Atlas 2.

Projections for the 100-yr 24-hr extreme precipitation events found in NOAA Atlas 2 match most of those calculated in this report. However, there are important exceptions. Large differences were found over the southern part of the NTS. Precipitation observations and frequency analyses both show that NOAA Atlas 2 underestimates the 100-yr 24-hr/daily precipitation event for this area by approximately one inch (25.4 mm). The reason for this difference is due to the fact that the database used to make the estimates in NOAA Atlas 2 did not contain historical-type events that have occurred since the Atlas was prepared in the early 1970s.

# ANALYSIS OF EXTREME PRECIPITATION EVENTS IN SOUTHERN NEVADA

Darryl Randerson

ARL/SORD
Las Vegas, Nevada

## I. INTRODUCTION

Deserts have distinctive climatic patterns. One of these is the dramatic variability in precipitation, both spatially and temporally. To emphasize this characteristic, Griffiths and Driscoll (1982) note that desert climates are those having 1) little precipitation, 2) large variability of interannual precipitation amounts, 3) significant spatial variability, 4) low relative humidity, and 5) annual evapotranspiration exceeding precipitation. Southern Nevada clearly falls within this type climatic regime. Average annual precipitation varies from 3 to 8 in (7.6 to 20 mm), with the larger amounts falling at higher elevations. In extreme cases, some annual amounts can be exceeded in one, brief, heavy storm event (e.g. Glancy and Harmsen, 1975, Smith, 1986, Randerson, 1986). The consequences of such events can be catastrophic, causing loss of life, personal injury, and significant property damage. These type storms are not as uncommon as they were once thought to be (Hales, 1975, Randerson, 1976, Maddox _et al_., 1980, Cylke, 1984, Bartels, _et al_., 1984, Scott, 1990, and others).

People seeking new life styles have been moving to the mild, dry climate of the desert southwest. For this and other reasons the population of the southwestern United States has been increasing rapidly for the past 25 years. For example, the population of the metropolitan Las Vegas area is nearly 1,000,000; that of Phoenix, Arizona, nearly 2,000,000; and Tucson, approximately 1,000,000. Smaller desert communities such as St. George, Utah, Laughlin and Mesquite, Nevada, Bullhead City, Arizona, and many others are showing steady population growth and economic development. These factors create a vital need for knowledge of extreme rainfall events for input to the identification of potential flood hazards, design of flood mitigation systems, development of flood control strategies and design standards, and for improving our ability to forecast these significant natural events.

Tourism adds another noteworthy dimension to this problem. Annually, millions of families visit the recreational attractions of the mountainous desert southwest. Many people like to tour, hike, and camp in isolated and sparsely populated areas of Nevada, Arizona, southern Utah, and in the desert area of southern California. Communication of weather warnings to these individuals is difficult, but vital to their safety.

The level of experience and awareness of the potential dangers of desert thunderstorms may be minimal with many people who have recently moved to the southwestern desert area. Upon seeing the dry desert, some may assume that heavy rain, flash flooding, intense lightning, and strong winds with blowing dust don't occur often, or, are not a serious threat to life and property. An educational program may be needed to increase public awareness.

An additional requirement for information on extreme precipitation events is the need to develop a more complete characterization of the climatology of the Department of Energy (DOE) Nevada Test Site (NTS), located 75 mi northwest of Las Vegas. A key part of this characterization is the precipitation climatology of the NTS. The climatological data record for the NTS is now long enough to permit robust statistical analyses of precipitation to be conducted.

The history of precipitation from the NTS and from the growing population centers of southern Nevada can be used to define weathering effects and to identify future potential flood drainage impacts. Drainage refers to the movement of water, resulting from precipitation, either over the ground or into the soil and bedrock. Moving water is a dominating factor in modifying land forms by erosion. In the desert, warm season rainfall is often intense and infiltration minimal so that runoff tends to be rapid and fluvial erosion and deposition are remarkably effective and dramatic.

## II. PRECIPITATION DATA

Good quality observations and complete records of precipitation are not as abundant or as lengthy for the western desert area of the United States as they are for the more densely populated and long inhabited areas of the eastern half of the United States. However, as we approach the end of the twentieth century, some continuous records now include periods of nearly 60 years. The primary data bases for precipitation in southern Nevada are the National Weather Service (NWS) office in Las Vegas, the Air Resources Laboratory raingage network on the NTS, observations from cooperative observers at Beatty, Searchlight, Boulder City, Pahrump, NV, other communities, and Nevada State Parks. There are other sources of precipitation data in southern Nevada; however, the records for shorter periods or are incomplete for research and statistical analysis purposes. The locations of all the sites analyzed or referenced in this report are shown in Fig. 1. Emphasis was placed on selecting individual data sets that were homogeneous and independent.

Precipitation-frequency analyses for the western United States have been conducted in the past. The most complete are those prepared by scientists of the former U.S. Weather Bureau (USWB) and the present National Oceanic and Atmospheric Administration (NOAA). A rainfall frequency atlas (Technical Paper 40) was prepared by

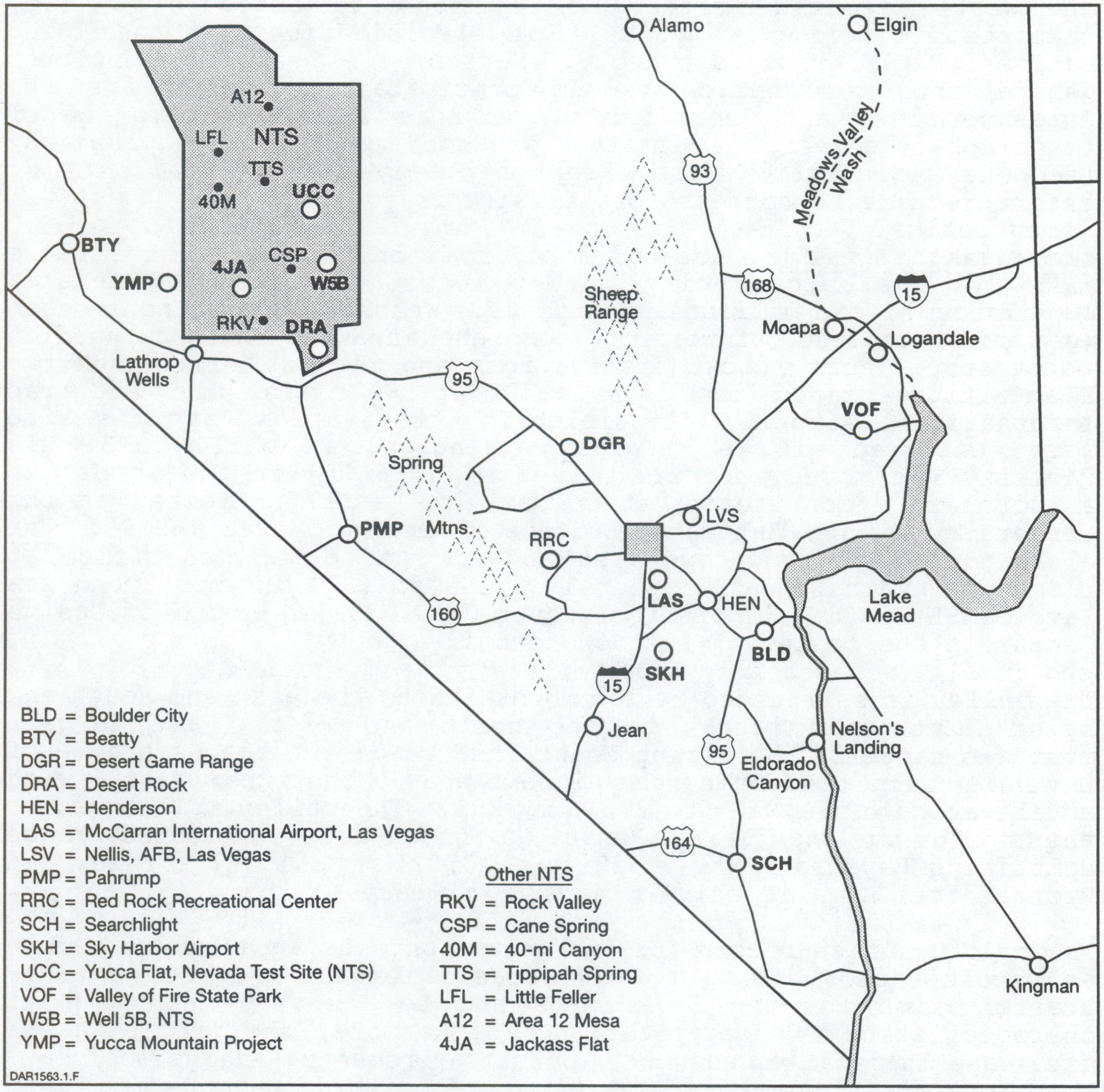


Figure 1. Locations of stations whose precipitation data were analyzed in this report (bold letters), other sites and cities, locations of geographical features referred to in this report, and locations of principal highways and roads.

Hershfield (1961) and has been accepted as the standard source of precipitation frequency information for the United States. More recently, Miller, Frederick, and Tracey (1973, hereafter referred to as NOAA Atlas 2) updated precipitation-frequency estimates based on additional data and on the significant effects of topography in the western United States. More recently, Sagendroff (1996) completed a frequency analysis of precipitation for the Idaho National Engineering Laboratory. Hansen et al. (1977) calculated general storm probable maximum precipitation events for the Colorado River and Great Basin drainages with consideration of topographic effects. In the present report, precipitation-frequency calculations are based on observed precipitation. No effort is made to correct for terrain.

Las Vegas, NV (LAS): Located in a broad desert valley, Las Vegas (LAS) is the largest city in Nevada with a metropolitan area population of one million inhabitants. Weather observations began just prior to 1900 but were not comprehensive enough to be used in this study. More robust observations and records began when the NWS office opened in late 1948 at what is now McCarran International Airport. Precipitation observations at this site were collected with a recording raingage. In early 1995 this facility was moved approximately 3 mi (4.8 km) southwest of the airport; however, precipitation data are still collected at the airport by the NWS Automated Surface Observing System (ASOS). The elevation of the downtown area and of the former NWS office at McCarran International Airport is 2,200 ft (670 m) above mean sea level (MSL). The airport is located 7 mi (11 km) south of Casino Center in the center of the downtown area.

The valley is surrounded by low mountains to the east and south and by high mountain ranges to the north and west. The largest mountain range is the Spring Mountains, bordering the west side of the valley and containing the highest peak, Mount Charleston, with an elevation of 11,918 ft (3,633 m) MSL. The valley is bounded to the north by the Sheep Range, a north-south oriented range containing Hayford Peak (9,920 ft or 3,024 m MSL). The Lake Mead Recreational Area is only 18 mi (29 km) east of the city.

The precipitation record for Las Vegas contains an adequate number of precipitation events to make reasonable estimates of extreme precipitation for the local area and to identify the temporal characteristics of precipitation. Furthermore, the precipitation data base is detailed enough to permit a frequency analysis of set-hour precipitation events. Set-hour precipitation events are those that occur within (between) the cardinal (standard observation) hours. Tabulation of annual maximum 1-hr and 24-hr precipitation extremes from Las Vegas are listed in Tables 1 and 2.

Nevada Test Site (NTS): The NTS is located approximately 75 mi (120 km) northwest of Las Vegas, and encompasses an approximate rectangular area of 1350 sq mi (3500 sq km). The topographic setting is complex with mountains and plateaus ranging to 7,600 ft (2,300 m) MSL to basins and dry lake beds 4,000 ft (1,220 m) to 2,500 ft (760 m) MSL. The local climate is arid with sparse vegetation, except at the higher elevations. Records of precipitation commenced in the late 1950's. A more complete record of precipitation began when the Yucca Flat Meteorological Observatory (UCC) became fully operational in January 1962 and remained operational until April 1978 when the facility was closed and moved approximately 25 mi (40 km) south to Desert Rock, in the extreme southeastern part of the NTS (see Fig 1). The Desert Rock Meteorological Observatory (DRA) has been operational since June 1978. Both of these stations operated on 24-hr per day schedules. Daily precipitation totals were obtained from standard, eight-inch, stick-type raingages at DRA and from a standard eight-inch weighing gage at UCC. The elevation of DRA is 3304 ft (1007 m) MSL. In addition, the Air Resources Laboratory has maintained an active array of instrumented meteorological towers and precipitation gages on the NTS since the early 1960's. Relatively long climatological records of daily precipitation totals are available from sites such as Desert Rock (DRA, 17 yr), Jackass Flat (4JA, 21 yr), and Yucca Flat (UCC, 34 yr). The Yucca Flat station is located on the western edge of a dry lake bed near the center of the NTS at an altitude of 3924 ft (1196 m) MSL. Station 4JA is located approximately 15 mi (24 km) northwest of Desert Rock at an altitude of 3422 ft (1043 m) MSL. The summary of annual maximum daily precipitation extremes from these stations are listed in Tables 3,4,and 5.

Searchlight, NV (SCH): This small desert community is located approximately 50 mi (80 km) south of Las Vegas, in the southern tip of Nevada at an elevation of approximately 3540 ft (1079 m) MSL. Precipitation data have been collected by the Nevada State Highway Department for many years. Daily totals of precipitation were extracted from the Desert Research Institute (DRI) climatological data base for Nevada for the 46-yr period from 1949 through 1994. This station is of particular importance because of some of the heavy, warm-season precipitation events that have occurred here. The annual maximum daily extreme events for Searchlight (SCH) are tabulated in Table 6.

Boulder City, NV (BLD): Is a planned model city built in the 1930's by the federal government to house personnel working on the construction of Hoover Dam. The community is located approximately 25 mi (40 km) southeast of Las Vegas at an altitude of 2500 ft (762 m) MSL. A strict zoning code is enforced within the city limits to maintain its residential character. As with many cities in southern Nevada, there is considerable construction and development in the area surrounding the city. The population of the metropolitan area is approximately 25,000 people. Daily totals of

Table 1. Maximum annual set-hour precipitation events for Las Vegas, NV, for the period 1952 through 1994. The mean value for these extreme events is 0.43 in (10.9 mm) and the standard deviation is 0.30 in (7.6 mm). P(%) represents the plotting position based on the relationship suggested by Weibull (1939), m/n+1, where m is the rank and n is the total number of observations (43). Amounts are in inches; to convert to millimeters multiply inches by 25.4.

| YEAR | AMOUNT | RANK | P% | YEAR | AMOUNT | RANK | P% |
|---|---|---|---|---|---|---|---|
| 1957 | 1.23 | 1 | 97.7 | 1959 | 0.30 | 23 | 47.7 |
| 1955 | 1.13 | 2 | 95.5 | 1989 | 0.30 | 24 | 45.5 |
| 1956 | 0.97 | 3 | 93.2 | 1988 | 0.29 | 25 | 43.2 |
| 1976 | 0.95 | 4 | 90.9 | 1958 | 0.29 | 26 | 40.9 |
| 1954 | 0.95 | 5 | 88.6 | 1986 | 0.26 | 27 | 38.6 |
| 1979 | 0.91 | 6 | 86.4 | 1973 | 0.25 | 28 | 36.4 |
| 1984 | 0.88 | 7 | 84.1 | 1983 | 0.24 | 29 | 34.1 |
| 1990 | 0.70 | 8 | 81.8 | 1981 | 0.23 | 30 | 31.8 |
| 1963 | 0.68 | 9 | 79.5 | 1974 | 0.21 | 31 | 29.5 |
| 1977 | 0.57 | 10 | 77.3 | 1980 | 0.21 | 32 | 27.3 |
| 1970 | 0.53 | 11 | 75.0 | 1964 | 0.20 | 33 | 25.0 |
| 1975 | 0.52 | 12 | 72.7 | 1969 | 0.20 | 34 | 22.7 |
| 1952 | 0.49 | 13 | 70.5 | 1993 | 0.20 | 35 | 20.5 |
| 1991 | 0.49 | 14 | 68.2 | 1961 | 0.19 | 36 | 18.2 |
| 1967 | 0.45 | 15 | 65.9 | 1994 | 0.17 | 37 | 15.9 |
| 1960 | 0.41 | 16 | 63.6 | 1966 | 0.16 | 38 | 13.6 |
| 1992 | 0.41 | 17 | 61.4 | 1965 | 0.15 | 39 | 11.4 |
| 1987 | 0.40 | 18 | 59.1 | 1962 | 0.13 | 40 | 9.1 |
| 1978 | 0.40 | 19 | 56.8 | 1968 | 0.13 | 41 | 6.8 |
| 1971 | 0.40 | 20 | 54.5 | 1985 | 0.12 | 42 | 4.6 |
| 1972 | 0.32 | 21 | 52.3 | 1953 | 0.09 | 43 | 2.3 |
| 1982 | 0.31 | 22 | 50.0 | | | | |

Table 2. Annual maximum 24-hr precipitation events for Las Vegas, NV, for the period 1949 through 1994.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1957 | 2.59 | 1 | 1974 | 0.90 | 24 |
| 1960 | 1.78 | 2 | 1958 | 0.90 | 25 |
| 1979 | 1.56 | 3 | 1970 | 0.90 | 26 |
| 1984 | 1.36 | 4 | 1986 | 0.81 | 27 |
| 1977 | 1.34 | 5 | 1981 | 0.81 | 28 |
| 1955 | 1.32 | 6 | 1969 | 0.80 | 29 |
| 1956 | 1.32 | 7 | 1989 | 0.78 | 30 |
| 1993 | 1.30 | 8 | 1978 | 0.77 | 31 |
| 1992 | 1.27 | 9 | 1991 | 0.74 | 32 |
| 1976 | 1.25 | 10 | 1983 | 0.73 | 33 |
| 1954 | 1.18 | 11 | 1994 | 0.71 | 34 |
| 1952 | 1.14 | 12 | 1949 | 0.65 | 35 |
| 1959 | 1.09 | 13 | 1964 | 0.62 | 36 |
| 1965 | 1.09 | 14 | 1950 | 0.62 | 37 |
| 1990 | 1.09 | 15 | 1971 | 0.60 | 38 |
| 1963 | 1.07 | 16 | 1988 | 0.58 | 39 |
| 1967 | 1.06 | 17 | 1961 | 0.50 | 40 |
| 1980 | 1.06 | 18 | 1973 | 0.50 | 41 |
| 1972 | 1.01 | 19 | 1962 | 0.45 | 42 |
| 1951 | 0.98 | 20 | 1966 | 0.43 | 43 |
| 1975 | 0.92 | 21 | 1968 | 0.31 | 44 |
| 1982 | 0.92 | 22 | 1985 | 0.30 | 45 |
| 1987 | 0.92 | 23 | 1953 | 0.11 | 46 |

Table 3. Annual maximum daily precipitation events for Desert Rock, NV, (DRA), for the period 1979 through 1995, in inches.

| YEAR | AMOUNT | RANK |
|---|---|---|
| 1983 | 3.52 | 1 |
| 1984 | 2.03 | 2 |
| 1990 | 1.95 | 3 |
| 1982 | 1.57 | 4 |
| 1981 | 1.53 | 5 |
| 1986 | 1.27 | 6 |
| 1985 | 1.25 | 7 |
| 1993 | 1.15 | 8 |
| 1988 | 1.10 | 9 |
| 1987 | 0.92 | 10 |
| 1979 | 0.87 | 11 |
| 1995 | 0.78 | 12 |
| 1994 | 0.74 | 13 |
| 1991 | 0.71 | 14 |
| 1980 | 0.63 | 15 |
| 1992 | 0.57 | 16 |
| 1989 | 0.27 | 17 |

Table 4. Annual maximum daily precipitation for Jackass Flat, NV, (4JA), for 1976 through 1995, in inches.

| YEAR | AMOUNT | RANK |
|---|---|---|
| 1983 | 3.22 | 1 |
| 1984 | 2.47 | 2 |
| 1987 | 2.04 | 3 |
| 1992 | 1.59 | 4 |
| 1977 | 1.46 | 5 |
| 1993 | 1.26 | 6 |
| 1986 | 1.18 | 7 |
| 1982 | 1.18 | 8 |
| 1988 | 1.07 | 9 |
| 1995 | 1.00 | 10 |
| 1978 | 0.91 | 11 |
| 1976 | 0.89 | 12 |
| 1994 | 0.74 | 13 |
| 1980 | 0.72 | 14 |
| 1990 | 0.69 | 15 |
| 1985 | 0.66 | 16 |
| 1981 | 0.62 | 17 |
| 1979 | 0.60 | 18 |
| 1991 | 0.57 | 19 |
| 1989 | 0.36 | 20 |
| 1975 | 0.36 | 21 |

Table 5. Annual maximum daily precipitation for Yucca Flat, NV, (UCC), for 1962 through 1995, in inches.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1977 | 2.18 | 1 | 1966 | 0.97 | 18 |
| 1983 | 2.15 | 2 | 1987 | 0.97 | 19 |
| 1969 | 2.13 | 3 | 1980 | 0.90 | 20 |
| 1991 | 2.12 | 4 | 1994 | 0.90 | 21 |
| 1982 | 1.79 | 5 | 1963 | 0.76 | 22 |
| 1979 | 1.65 | 6 | 1993 | 0.69 | 23 |
| 1984 | 1.52 | 7 | 1962 | 0.65 | 24 |
| 1978 | 1.33 | 8 | 1985 | 0.64 | 25 |
| 1965 | 1.31 | 9 | 1981 | 0.63 | 26 |
| 1974 | 1.26 | 10 | 1995 | 0.58 | 27 |
| 1992 | 1.25 | 11 | 1990 | 0.57 | 28 |
| 1973 | 1.17 | 12 | 1967 | 0.50 | 29 |
| 1970 | 1.10 | 13 | 1975 | 0.48 | 30 |
| 1971 | 1.07 | 14 | 1979 | 0.46 | 31 |
| 1986 | 1.07 | 15 | 1964 | 0.43 | 32 |
| 1972 | 1.03 | 16 | 1968 | 0.42 | 33 |
| 1988 | 1.00 | 17 | 1989 | 0.20 | 34 |

Table 6. Annual maximum daily precipitation events for Searchlight, NV, (SCH), 1949 through 1994. Amounts are in inches.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1982 | 4.50 | 1 | 1966 | 1.29 | 24 |
| 1978 | 3.81 | 2 | 1970 | 1.27 | 25 |
| 1976 | 3.20 | 3 | 1949 | 1.20 | 26 |
| 1986 | 2.44 | 4 | 1972 | 1.16 | 27 |
| 1952 | 2.26 | 5 | 1967 | 1.15 | 28 |
| 1960 | 2.25 | 6 | 1963 | 1.04 | 29 |
| 1974 | 2.07 | 7 | 1969 | 1.03 | 30 |
| 1979 | 2.00 | 8 | 1990 | 1.00 | 31 |
| 1980 | 1.97 | 9 | 1965 | 1.00 | 32 |
| 1954 | 1.74 | 10 | 1981 | 0.90 | 33 |
| 1975 | 1.70 | 11 | 1968 | 0.84 | 34 |
| 1955 | 1.62 | 12 | 1977 | 0.81 | 35 |
| 1993 | 1.59 | 13 | 1988 | 0.81 | 36 |
| 1992 | 1.53 | 14 | 1985 | 0.80 | 37 |
| 1984 | 1.52 | 15 | 1989 | 0.75 | 38 |
| 1991 | 1.50 | 16 | 1950 | 0.75 | 39 |
| 1994 | 1.48 | 17 | 1961 | 0.69 | 40 |
| 1951 | 1.46 | 18 | 1953 | 0.66 | 41 |
| 1958 | 1.43 | 19 | 1956 | 0.62 | 42 |
| 1959 | 1.40 | 20 | 1971 | 0.57 | 43 |
| 1957 | 1.32 | 21 | 1973 | 0.53 | 44 |
| 1983 | 1.30 | 22 | 1962 | 0.44 | 45 |
| 1987 | 1.30 | 23 | 1964 | 0.33 | 46 |

precipitation for Boulder City (BLD) were extracted from the Desert Research Institute (DRI) climatological data base for Nevada for the 55-yr period from 1940 through 1994 and are listed in Table 7.

Pahrump, NV (PMP): This rapidly developing desert community is located approximately 45 mi (72 km) west of Las Vegas in the central Pahrump Valley. Elevation above sea level is 2700 ft (825 m). The Spring Mountains form the eastern border to this north-south oriented valley. The smaller Nopah Range forms the western boundary. Precipitation records began in late 1948 but were not continuous until 1969. Daily totals of precipitation were extracted from the DRI climatological data base for Nevada for the 27-yr period from 1969-1995.

Beatty, NV (BTY): Lies on the margin of the Mojave Desert and the great Basin ecosystems (McCracken, 1992). The city was settled near the turn of the century and served as a supply base for mining camps. Most of the area traffic and freight flowed though Beatty which was known locally as the "Chicago of the West". The city is located roughly 105 mi (170 km) northwest of Las Vegas at an altitude of 3344 ft (1019 m) and has a population of approximately 1500 inhabitants. The Armagosa River (normally dry) drains through the city. During the unusually wet winter of 1969, six inches of wet snow, followed by a steady, warm rain caused the river to flood, severing State Highway 95, washing out a bridge, flooding the lower sections of the town, and isolating the community for several days (McCracken, 1992). Daily maximum totals of precipitation for Beatty were extracted from the DRI climatological data base for Nevada for the 48-yr period from 1948 through 1995. To form this record, the data from two sites, eight miles apart and at nearly the same elevation, were combined. These data are listed in Table 8.

Table 7. Annual maximum daily precipitation for Boulder City, NV, (BLD), 1940 through 1994, in inches.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1984 | 3.72 | 1 | 1947 | 0.88 | 29 |
| 1976 | 2.62 | 2 | 1971 | 0.87 | 30 |
| 1981 | 2.00 | 3 | 1972 | 0.87 | 31 |
| 1952 | 1.92 | 4 | 1942 | 0.86 | 32 |
| 1960 | 1.92 | 5 | 1943 | 0.84 | 33 |
| 1952 | 1.66 | 6 | 1985 | 0.80 | 34 |
| 1992 | 1.62 | 7 | 1990 | 0.80 | 35 |
| 1970 | 1.56 | 8 | 1975 | 0.79 | 36 |
| 1989 | 1.30 | 9 | 1946 | 0.79 | 37 |
| 1977 | 1.27 | 10 | 1949 | 0.77 | 38 |
| 1974 | 1.23 | 11 | 1963 | 0.76 | 39 |
| 1978 | 1.13 | 12 | 1955 | 0.73 | 40 |
| 1993 | 1.13 | 13 | 1950 | 0.72 | 41 |
| 1951 | 1.12 | 14 | 1954 | 0.72 | 42 |
| 1945 | 1.11 | 15 | 1964 | 0.70 | 43 |
| 1994 | 1.11 | 16 | 1973 | 0.62 | 44 |
| 1958 | 1.08 | 17 | 1966 | 0.62 | 45 |
| 1969 | 1.05 | 18 | 1983 | 0.59 | 46 |
| 1965 | 1.05 | 19 | 1944 | 0.57 | 47 |
| 1980 | 1.04 | 20 | 1986 | 0.57 | 48 |
| 1991 | 0.99 | 21 | 1979 | 0.55 | 49 |
| 1982 | 0.98 | 22 | 1961 | 0.54 | 50 |
| 1962 | 0.98 | 23 | 1988 | 0.46 | 51 |
| 1940 | 0.96 | 24 | 1968 | 0.36 | 52 |
| 1941 | 0.95 | 25 | 1953 | 0.30 | 53 |
| 1987 | 0.94 | 26 | 1948 | 0.29 | 54 |
| 1959 | 0.92 | 27 | 1956 | 0.22 | 55 |
| 1967 | 0.89 | 28 | | | |

Table 8. Annual maximum daily precipitation for Beatty, NV, (BTY), 1948 through 1995, in inches. Observation site moved 8 mi (12.9 km) north in 1973.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1984 | 1.90 | 1 | 1973 | 0.82 | 25 |
| 1977 | 1.75 | 2 | 1968 | 0.80 | 26 |
| 1975 | 1.73 | 3 | 1985 | 0.79 | 27 |
| 1967 | 1.65 | 4 | 1986 | 0.79 | 28 |
| 1954 | 1.60 | 5 | 1963 | 0.74 | 29 |
| 1990 | 1.50 | 6 | 1957 | 0.73 | 30 |
| 1988 | 1.49 | 7 | 1967 | 0.72 | 31 |
| 1948 | 1.46 | 8 | 1953 | 0.71 | 32 |
| 1995 | 1.32 | 9 | 1992 | 0.71 | 33 |
| 1960 | 1.28 | 10 | 1950 | 0.69 | 34 |
| 1976 | 1.27 | 11 | 1991 | 0.67 | 35 |
| 1972 | 1.20 | 12 | 1956 | 0.64 | 36 |
| 1983 | 1.19 | 13 | 1974 | 0.63 | 37 |
| 1987 | 1.16 | 14 | 1959 | 0.62 | 38 |
| 1969 | 1.02 | 15 | 1979 | 0.54 | 39 |
| 1951 | 1.00 | 16 | 1958 | 0.53 | 40 |
| 1965 | 0.94 | 17 | 1993 | 0.52 | 41 |
| 1982 | 0.94 | 18 | 1981 | 0.51 | 42 |
| 1962 | 0.92 | 19 | 1964 | 0.51 | 43 |
| 1971 | 0.88 | 20 | 1989 | 0.48 | 44 |
| 1955 | 0.87 | 21 | 1952 | 0.41 | 45 |
| 1966 | 0.85 | 22 | 1994 | 0.35 | 46 |
| 1978 | 0.84 | 23 | 1949 | 0.25 | 47 |
| 1980 | 0.83 | 24 | 1970 | 0.20 | 48 |

## III. BASIC PRECIPITATION CLIMATOLOGY

Two fundamental physical factors drive precipitation events in southern Nevada; those resulting from cool-season, mid-tropospheric cyclones and those resulting from summertime convection. Summer is the thunderstorm season (July through September) for the desert southwest which includes southern Nevada. Thunderstorms and severe thunderstorms generally occur during July and August when moist tropical air can flow (surges or *seeps*) northward over the lower Colorado River valley and into Arizona, southern Nevada, and Utah. This seasonal event is referred to as the southwestern monsoon by many researchers and weather forecasters (Bryson and Lowery, 1955, Hales, 1972, Brenner, 1974, Carleton, 1985, Balling and Brazel, 1987, Douglas, et al., 1993, and others). McCollum et al. (1995) have shown that low-level moisture from the Gulf of California can increase the convective instability of the atmosphere over Arizona dramatically. Large north-south oriented mountain ranges in central Mexico and central Baja California block the zonal advection of low-level moist air, thereby creating an artificial channel for boundary-layer flow toward the north (or south). Intense heating of the southwestern desert during Summer creates low surface pressures that can establish southerly flow over the Gulf of California, driving moist tropical air northward into the desert southwest. On occasion, this phenomenon is associated with significant thunderstorm development and heavy precipitation in Arizona, Nevada, and Utah.

Topography, of course, can play a critical role in augmenting precipitation near mountain ranges. Mass convergence can also be a significant producer of locally heavy precipitation in tropical air masses.

A rare, but significant phenomenon that can contribute to extreme rainfall is the arrival of deep tropical air masses over the southwestern United States. These unusual events are associated with dissipating (or dissipated) tropical cyclones that develop in the tropical eastern North Pacific Ocean and move into the southwestern United States (Smith, 1986). The arrival of this moist air mass over the southwestern deserts can result in record setting rainfall and extensive flooding.

These causes of precipitation are clearly evident in the climatological data base. The basic climatology for some key southern Nevada stations, from the southern-most site to the northern-most, is as follows:

**Searchlight, NV (SCH):**

This small desert community averages 7.6 in (15.2 mm) of precipitation annually (based on the period 1949-1994). However, the interannual variation is large, ranging from as little as 1.64 in (41.7 mm) in 1956 to as much as 14.83 in

(377.7 mm) in 1983. Average monthly precipitation depths are represented in graphical form in Fig. 2. June is the driest month, averaging only 0.11 in (2.8 mm) for the 46-yr record. Two periods of maximum precipitation occur. The primary peak is in August with a monthly average of 1.09 in (28.7 mm) and the secondary peak is in January with 0.97 in (24.6 mm). Each maximum is associated with a specific dynamic process. The cool season maximum (November through March) is driven by mid-latitude (500-mb) troughs and cold core (cutoff) lows while the warm season maximum is caused by intense surface heating, convection, and the advection of moisture northward from the tropical Pacific Ocean into the southwestern U.S. (Hales, 1972 and Douglas, 1995). The August maximum is associated with relatively brief, intense precipitation while the January peak is primarily the result of relatively long periods of steady precipitation accompanying cold-core, cyclonic circulations that occur off the southern California coast between October and April. If these systems tap into a sub-tropical moisture fetch, they can produce substantial precipitation in the desert of the southwestern United States. Thunderstorm precipitation is highly focused, intense, and lasts for only one to three hours while the heavier, cool-season precipitation tends to last for six to eighteen hours with periods of steady, light to moderate rain.

To focus on the more intense precipitation events for Searchlight, the daily maximum precipitation event was identified for each month and the annual maximum daily event was selected for each year for the period 1949 through 1994. The results of this process are summarized in Table 6 and portrayed in Fig. 3a. This figure contains a frequency distribution quite different from the one representing the monthly totals. Figure 3a shows that for the 46-yr record, 52% of these annual extreme precipitation events occur during thunderstorm season (June through September) while only 26% occur during the winter season (November through March). Moreover, Fig. 3a shows that 24% of the annual maximum daily events have occurred in August.

Figure 3a describes the monthly distribution of annual maximum daily precipitation events for six southern Nevada stations. By contrast, the monthly distribution of annual maximum daily precipitation events for four northern stations are presented in Fig. 3b but are referenced and discussed later. These two figures are shown together to make it easier for the reader to compare the monthly distributions of extreme daily precipitation events for southern and northern Nevada.

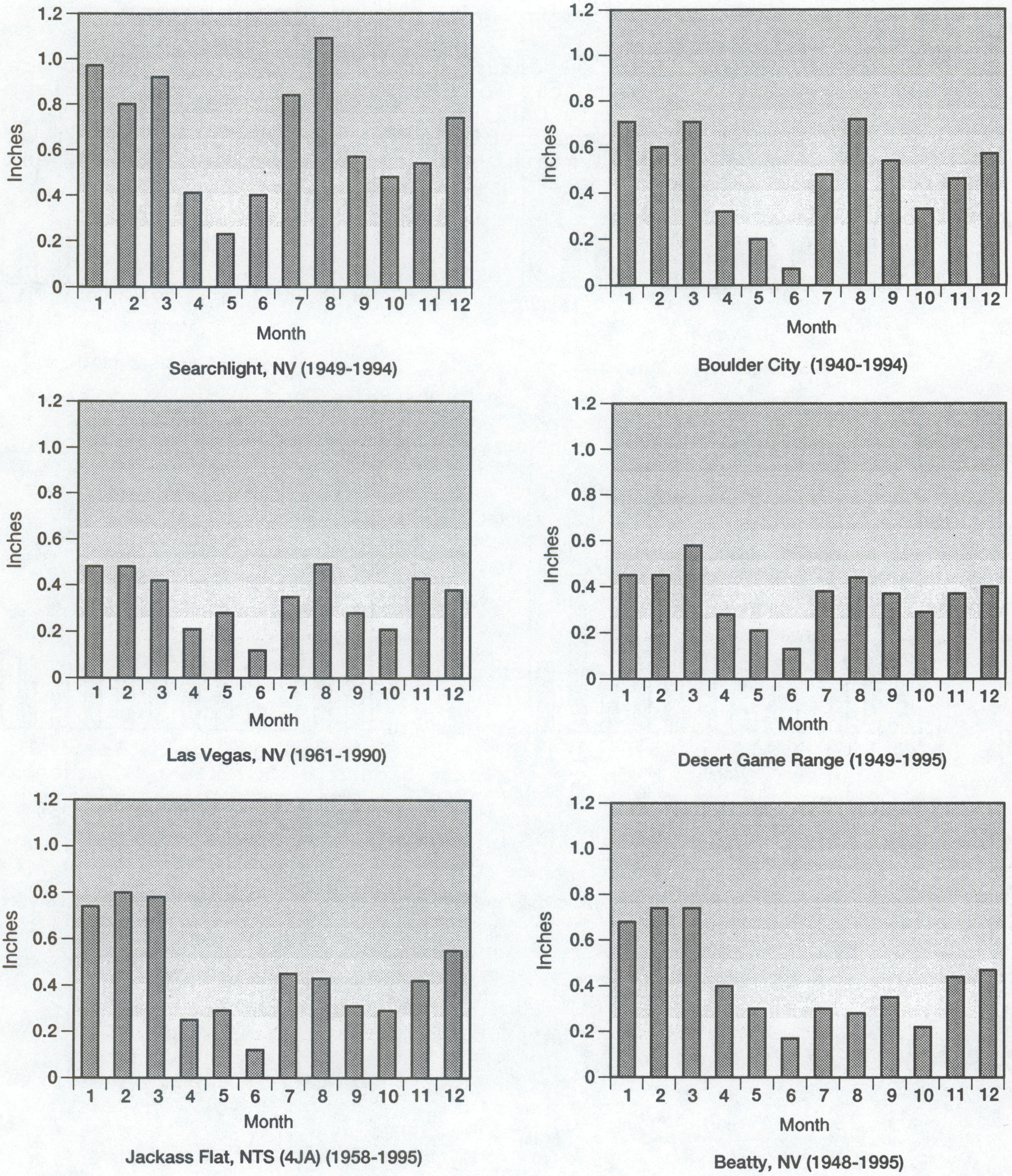


Figure 2. Annual distribution of mean monthly precipitaiton for six southern Nevada stations.

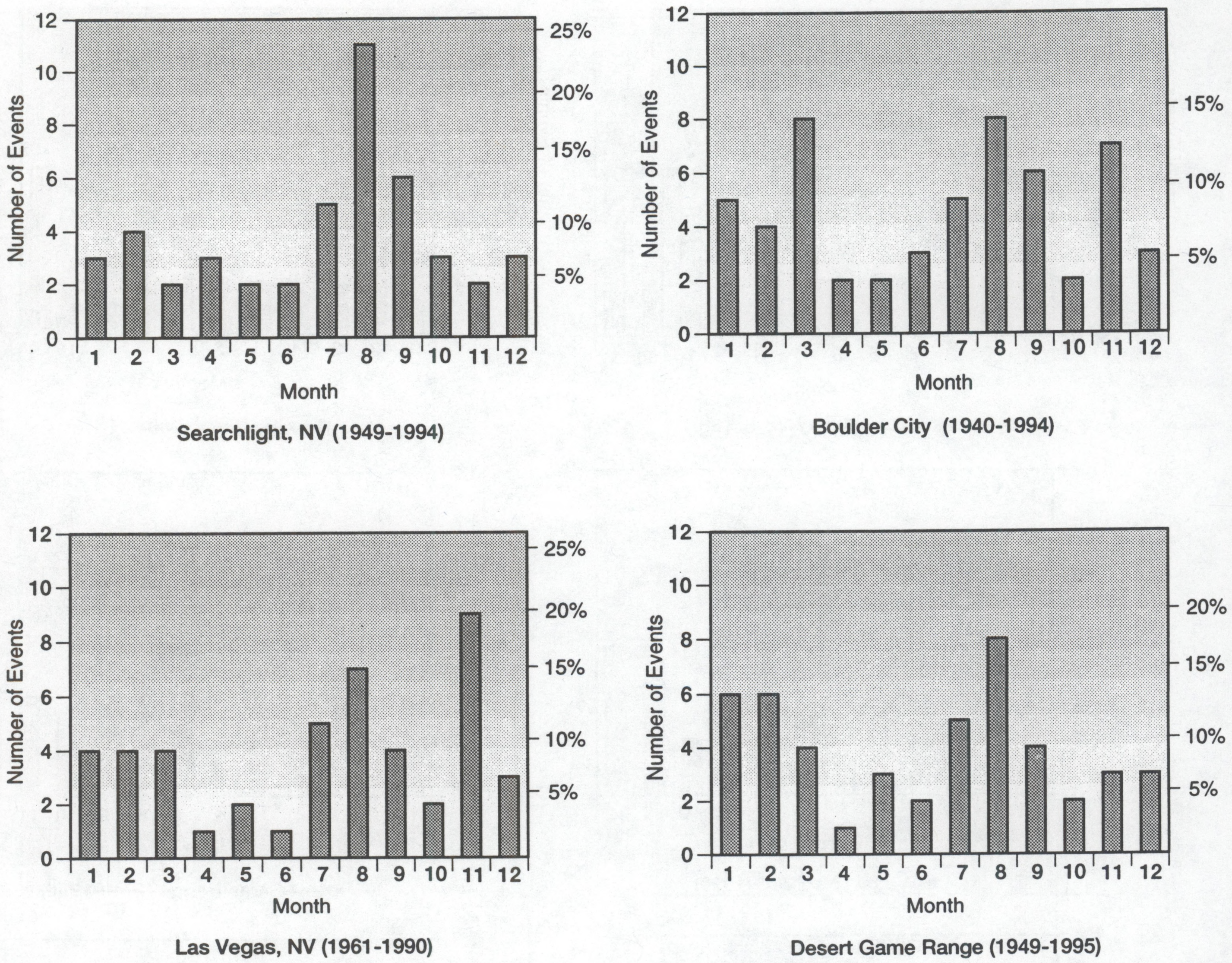


Figure 3a. Distribution of annual maximum daily precipitation events in southern Nevada (southern stations)

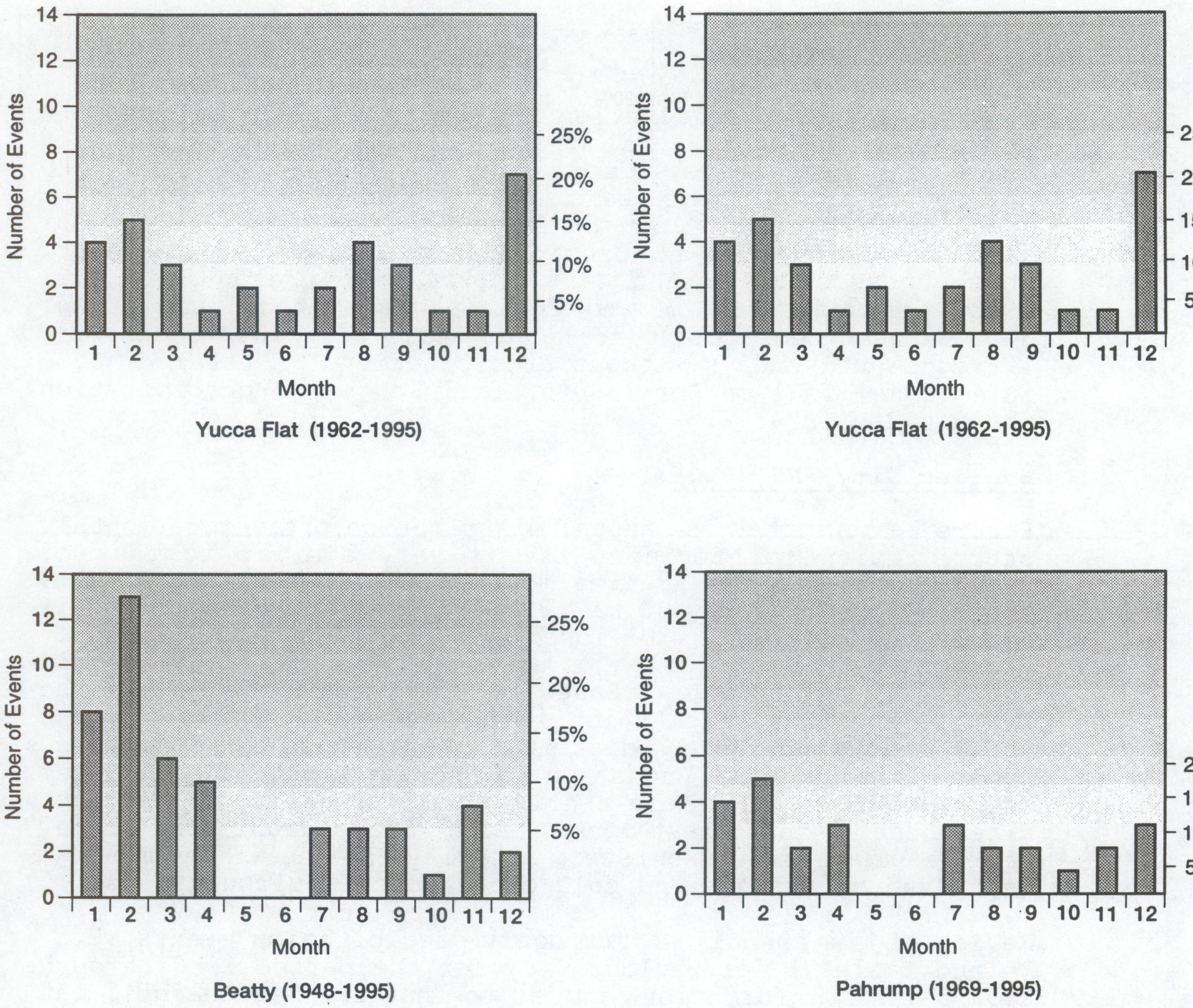


Figure 3b. Distribution of annual maximum daily precipitation events in southern Nevada (northern stations)

When reviewing precipitation extremes at all the stations included in this study, sight should not be lost of the fact that, in some years, many months can pass without any precipitation. In some years, only a trace may be reported in a six-month period. At Searchlight there have been four calendar years when no precipitation fell over, at least, three consecutive months (1950, 1954, 1964, and 1984). In 1960, only 0.11 in (2.8 mm) fell between March 1 and August 31. Between December 26, 1983 and April 20, 1984, there were 116 consecutive days without precipitation. A total of 0.06 in (1.5 mm) fell on April 20th, followed by no precipitation through May 1984.

**Boulder City, NV (BLD):**

Figure 2 shows that the annual distribution of average monthly precipitation for Boulder City is very similar to that of Searchlight but with smaller monthly means. Boulder City is located approximately 40 mi (64 km) north of Searchlight, is nearly 1000 ft (305 m) lower in elevation, and slightly farther way from the moisture sources; the Gulf of California and the Pacific Ocean. Based on the period 1932-1994, the average annual precipitation is 5.74 in (146 mm). Figure 2 shows that the monthly distribution has a bimodal pattern. However, the summer (August, 0.72 in) and winter (January and March, 0.71 in) peaks are nearly equal in magnitude. At both sites June is the driest month. As at Searchlight, the summer peak results from thunderstorm activity and the winter maximum is caused by troughs and cold-core cyclonic circulations.

Review of the annual maximum daily precipitation events (Fig. 3a and Table 7) for Boulder City for the period 1940 through 1994 reveals information similar to that for Searchlight, but with some different nuances. The thunderstorm maximum in August is still present; however, two cool season, extreme-event, peaks appear, in March and November. Overall, the distribution of warm-season thunderstorm events and cool-season cyclonic precipitation events are more equally balanced than at Searchlight with 40% of the extreme events associated with warm season convection and 49% with cool season events. Consequently, for this 55-year record, slightly more annual extreme daily events have occurred during the cool season than during the warm season.

**Las Vegas, NV (LAS):**

Annual Overview

As at Searchlight and Boulder City, the average monthly precipitation signature for Las Vegas (Fig. 2) is bimodal with maximums in winter (January/February) and summer (August) and with the primary minimum in June. However, the distribution is somewhat more uniform than those for Searchlight and Boulder City. Each seasonal maximum is associated with the corresponding dynamic process described above. Based on the standard 30-yr climatological summary for 1961-1990, the average annual precipitation for Las Vegas is 4.13 in (105 mm). Over the Las Vegas valley, the most active period for thunderstorms is primarily from mid-July to mid-August. Cool season precipitation tends to peak in the January-February time frame; however, November and March can occasionally be quite wet. In fact, March 1992 was the wettest month ever measured in Las Vegas with 4.8 in (122 mm), exceeding the average annual precipitation by nearly 0.7 in (18 mm).

Maximum 24-hr Events

The monthly distribution of annual **maximum** 24-hr precipitation events for Las Vegas were identified for the period 1949-1994 and are graphically summarized in Fig. 3a. This figure shows that 52% of these extreme events are associated with winter cyclones and 37% with summertime convection. Notice that the available data indicate 20% of these extreme events have occurred in November. In addition, this distribution is quite different from the one for Searchlight which contains only a pronounced August maximum.

Use of the maximum 24-hr precipitation record for heavy summertime events can be quite misleading since this type rainfall is the result of intense thunderstorms having time periods of only one to three hours. To reveal the attributes of these brief storms, the hourly precipitation data should be analyzed. However, hourly precipitation data are scarce. One of the good records is from the NWS office in Las Vegas.

Set-Hour Precipitation

Analysis of the thunderstorm season (June through September, 1952-1994) set-hour precipitation data for Las Vegas yields several intriguing results and raises some fascinating scientific issues. The data used in this analysis are from the National Climatic Data Center summary of hourly precipitation[1] for Nevada for June through September. Figure 4 and Table 9 illustrate the diurnal distribution of set-hour precipitation for Las Vegas. Figure 4 reveals that the temporal distribution of measurable set-hour precipitation is bimodal with the primary peak at 1600 PDT (2300 UTC) and the secondary maximum at local midnight, PDT (0700 UTC). Table 9 shows that heavy, set-hour precipitation has occurred within

[1]Hourly Precipitation Data, Nevada, National Climatic Data Center, ISSN-036-6262, Ashville, NC.

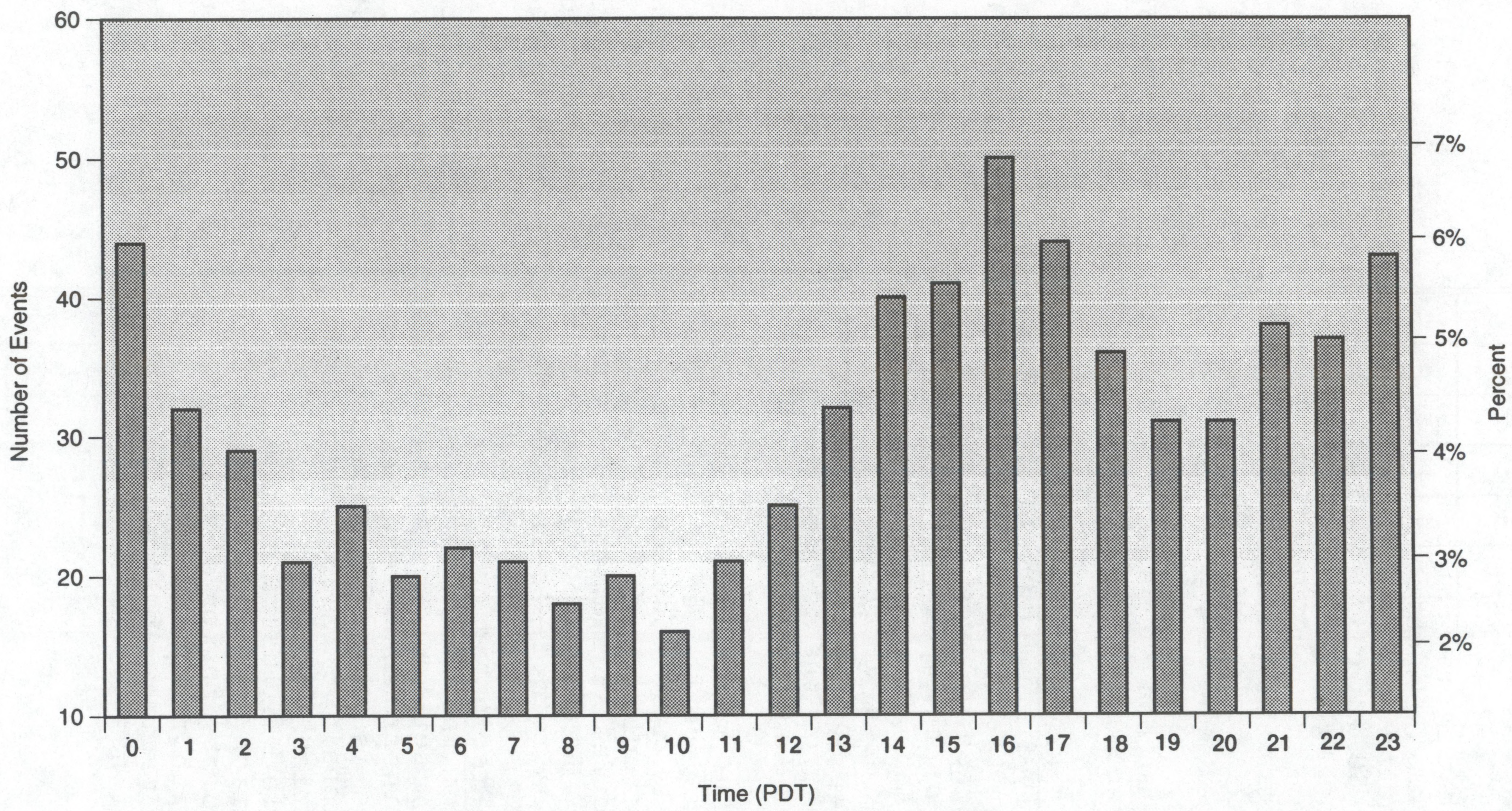


Figure 4. Number of measurable (≥0.01 in), warm-season set-hour, precipitation events as a function of time of day for Las Vegas, Nevada, June-September 1952-1995. A set-hour event is one that occurs within the cardinal hours, for example, between 9 and 10 am local time as opposed to a 60-min event, say between 9:18 an 10:18 local time.

Table 9. Summary of statistical analysis of the hourly, measurable (≥0.01 in) precipitation for Las Vegas, NV, for June through September 1952 - 1994.

| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # EVTS | 44 | 32 | 29 | 21 | 25 | 20 | 22 | 21 | 18 | 20 | 16 | 21 | 25 | 32 | 40 | 41 | 50 | 44 | 36 | 31 | 31 | 38 | 37 | 43 |
| TOT PCP | 2.80 | 2.07 | 1.59 | 0.93 | 1.80 | 1.03 | 0.78 | 0.80 | 1.86 | 2.25 | 1.73 | 1.83 | 1.50 | 2.72 | 3.44 | 3.69 | 3.93 | 3.62 | 2.44 | 1.88 | 2.16 | 2.66 | 2.53 | 3.00 |
| AVG (IN) | 0.06 | 0.06 | 0.05 | 0.04 | 0.07 | 0.05 | 0.04 | 0.04 | 0.10 | 0.11 | 0.11 | 0.09 | 0.06 | 0.08 | 0.09 | 0.09 | 0.08 | 0.08 | 0.07 | 0.06 | 0.07 | 0.07 | 0.07 | 0.07 |
| MEDN (IN) | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.04 | 0.04 | 0.06 | 0.01 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.03 | 0.04 |
| MAX (IN) | 0.95 | 1.13 | 0.28 | 0.21 | 0.57 | 0.21 | 0.21 | 0.20 | 0.91 | 1.23 | 0.85 | 0.37 | 0.35 | 0.82 | 0.70 | 0.95 | 0.88 | 0.68 | 0.34 | 0.21 | 0.41 | 0.49 | 0.97 | 0.40 |
| S.D. (IN) | 0.17 | 0.20 | 0.07 | 0.06 | 0.13 | 0.06 | 0.05 | 0.04 | 0.22 | 0.27 | 0.20 | 0.09 | 0.09 | 0.15 | 0.12 | 0.18 | 0.15 | 0.14 | 0.08 | 0.06 | 0.09 | 0.11 | 0.17 | 0.08 |

every hour of the day during the warm season. The maximum number of precipitation events is clearly evident for the hour beginning at 1600 PDT (2300 UTC). This activity is driven by the intense heating of the ground. However, the physical reason for the secondary maximum near midnight is unknown and requires further study. It may be related to the maintenance of strong convective instability until long after sunset over the desert in summer.

Another result of the analysis of warm-season, set-hour precipitation data is that 99% of the heavy[2] precipitation events fell within a 6-hr period. An analysis of all sequential, warm-season precipitation events for 1952-1994 showed that 57% were 1-hr events (the precipitation fell within the set hour), 27% were 2-hr events, 7% were 3-hr events, 5% were 4-hr events, and the remaining 4% were greater than 4-hr in length but less than 7 hr duration. For the heaviest events, most of the precipitation falls during the first two consecutive hours. Only the heavy rainfall on August 21, 1957, focused 2.29 in (58.2 mm) into a 3-hr period and 2.43 in (61.7 mm) into a 6-hr period. During this event, 1.23 and 0.85 in (31.2 and 21.6 mm) were measured in sequential hours (beginning at 0500 PDT, the total set-hour precipitation sequence, in inches, was: .01, .02, .07, .21, 1.23, 0.85, .07, .01 in). For this event, the maximum average 3-hr precipitation rate was 0.76 in/hr and the 6-hr rate was 0.40 in/hr. No other extreme event in the entire annual record of hourly precipitation has exceeded this average hourly rate for a 3-hr period or for a 6-hr period. However, similar rainfall rates were measured and estimated for the thunderstorm that moved over the western part of Las Vegas on July 3, 1975 (Randerson, 1976). Shorter duration rates can be much greater. Some set-hour events have been measured in the 0.5 to 1.0 in/hr (12.7 to 25.4 mm/hr) range (see Tables 1 and 9). Rainfall rates of 3.0 to 4.0 in/hr (76.2 to 101.6 mm/hr) were estimated for the thunderstorm of August 10, 1981 (Randerson, 1986), northeast of Las Vegas. Based on this analysis of hourly precipitation totals and on review of the entire hourly precipitation data base for Las Vegas, **annual maximum daily precipitation events and annual maximum 24-hr precipitation events are assumed to be synonymous for the analyses in this report.**

An analysis of the summertime, total, set-hour precipitation depths demonstrates the general character of the rainfall intensity. Figure 5a portrays this frequency distribution. The figure clearly demonstrates that one-third of all set-hour rainfall is in the 0.01-in (0.25-mm) category. In fact, 72% of all total set-hour rainfall depths are 0.05 in (1.3 mm) or less, approximately 85% are 0.10 in (2.5 mm) or less, and 98.6% are less than or equal to 0.25 in (6.4 mm).

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[2]Defined as ≥0.33 in/hr in the National Weather Service Observing Handbook No. 7, Federal Meteorological Handbook No. 1.

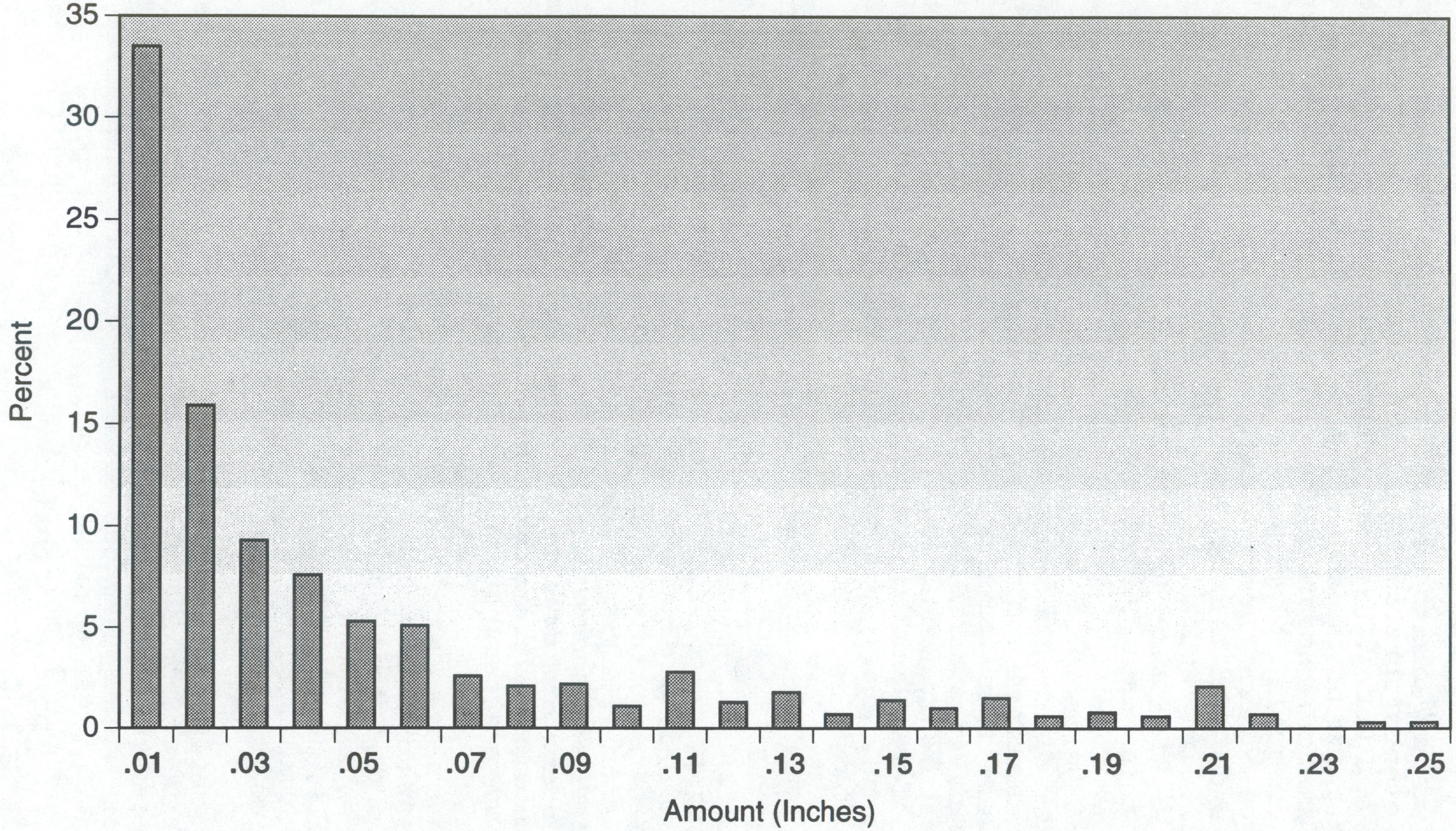


Figure 5a. Frequency distribution of warm season (June through September) set-hour precipitation totals for Las Vegas, NV, for 1952 through 1995.

The data listed in Table 9 demonstrate that the average and median summertime, set-hour precipitation is generally less than 0.10 in (2.5 mm) for all hours. In fact, the median values are probably more representative of the set-hour precipitation than are averages for desert climates. However, these results must not detract from the key characteristic of desert thunderstorms - extreme spatial and temporal variability and focusing of the precipitation. Tables 1 and 9 also show that the maximum set-hour rainfall for Las Vegas is 1.23 in (31.2 mm) and that heavy precipitation can occur at any time of day. The 1.23-in event occurred at 0900 PDT and was associated with a dissipating tropical cyclone.

Thunderstorm Days

A thunderstorm day is defined as one on which audible thunder and/or a thunderstorm occurred at the reporting station. These observations are found in the Local Climatological Data, Monthly Summary - Las Vegas, Column 8, Weather Type 3 and the local ARL/SORD climatological data base. For Las Vegas (LAS), the annual distribution of thunderstorms days by month is graphed in Fig. 5b for 1952 through 1995. A similar plot for Desert Rock (DRA) is shown in Fig. 5c.

During the past 44 yr (1952-1995), there have been 575 thunderstorm days at the NWS facility for an average of 13 thunderstorm days/year. Of these, 78% occurred during the warm season with 58% in July and August (Fig. 5a). If an extreme precipitation event is specified as one producing a storm total of, at least, 10% of the average annual precipitation (assumed to be 4.0 in, 102 mm, for Las Vegas), or 0.4 in (10.2 mm), then nearly 5% of these storms could be characterized as extreme events. In other words, **approximately 5% of the thunderstorm days in Las Vegas have been associated with this definition of extreme precipitation events**. In addition, seven of the warm-season storms were accompanied by hail.

A summary of warm-season thunderstorm days for LAS for 1952 through 1995 was constructed from the available data base. To smooth the data and to help identify potential periodicities, daily totals of thunderstorm days for the 44-yr record were summarized as five-day running totals centered on the third day. These data are graphically summarized in Fig. 5d (and DRA, in Fig 5e). The characteristics of the plot in Fig. 5d are as follow:

a. In early June there appear to be weak maximums with periods of 12-13 days (at DRA too). It is proposed that these thunderstorm events are driven by mid-latitude short waves that occasionally produce thunderstorms in June. These events are not associated with the "surge" of tropical moisture northward through the Gulf of California,

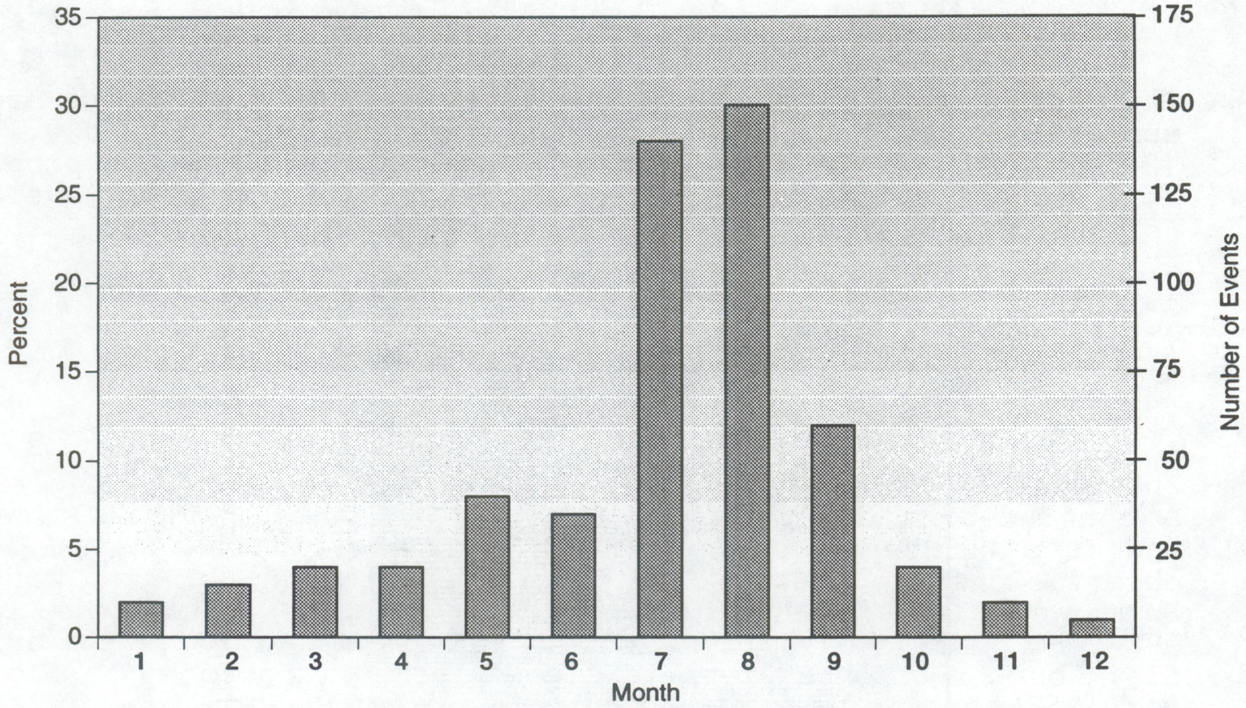


Figure 5b. Annual distribution of monthly thunderstrom days for Las Vegas, Nevada, for 1952 through 1995.

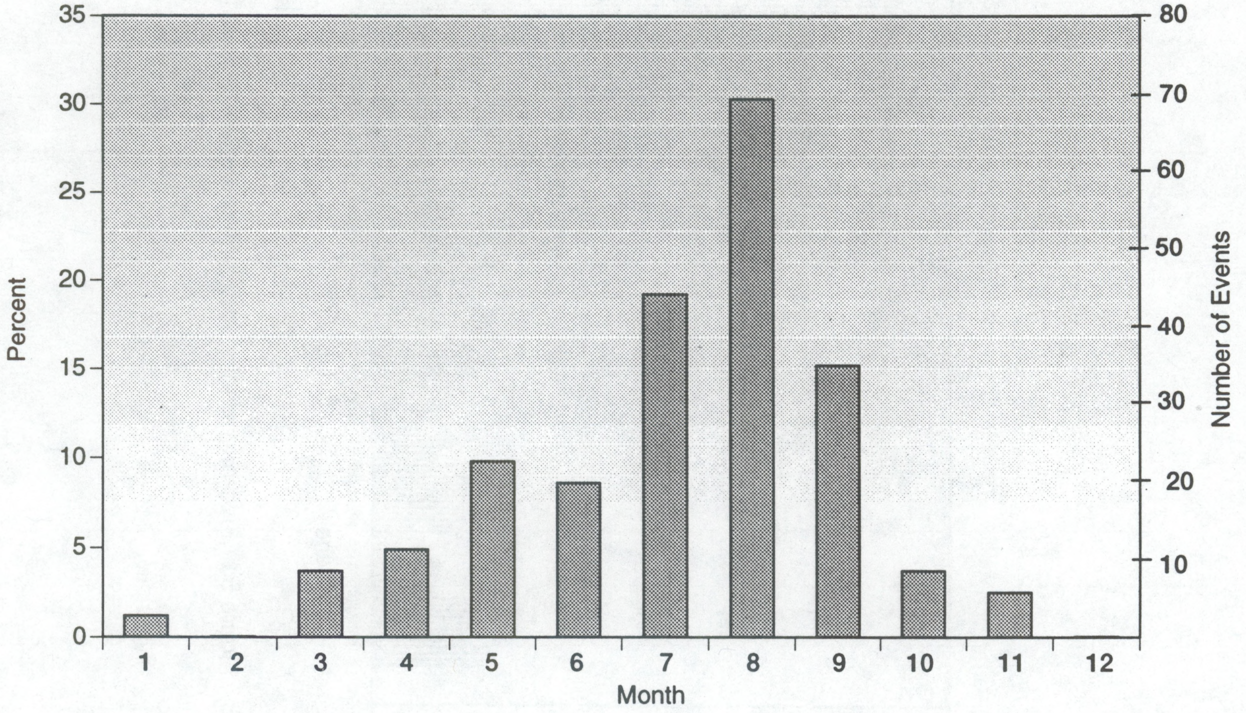


Figure 5c. Annual distribution of monthly thunderstorm days for Desert Rock, Nevada, for 1978 through 1995. January through April 1978 missing.

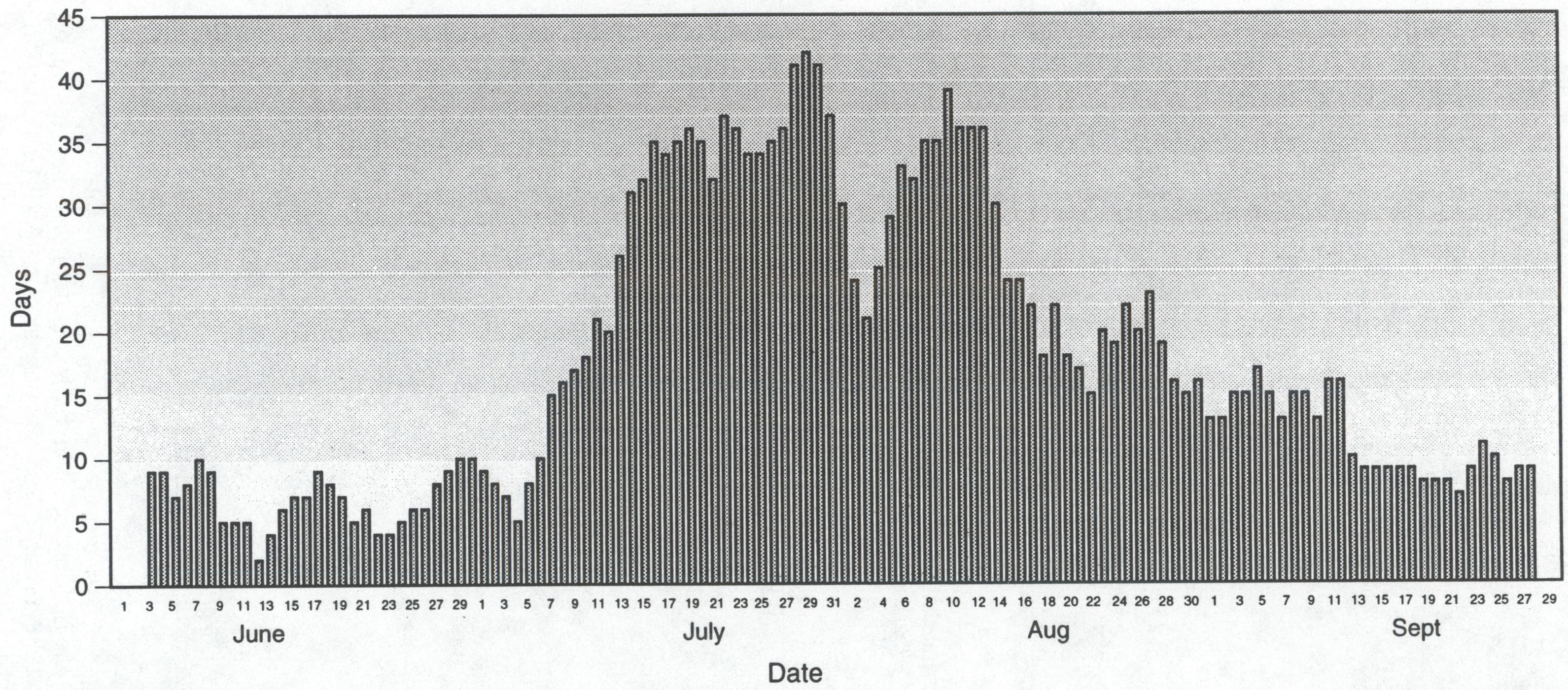


Figure 5d. Five-day running total of thunderstorm days for Las Vegas, Nevada, for June through September, 1952-1995.

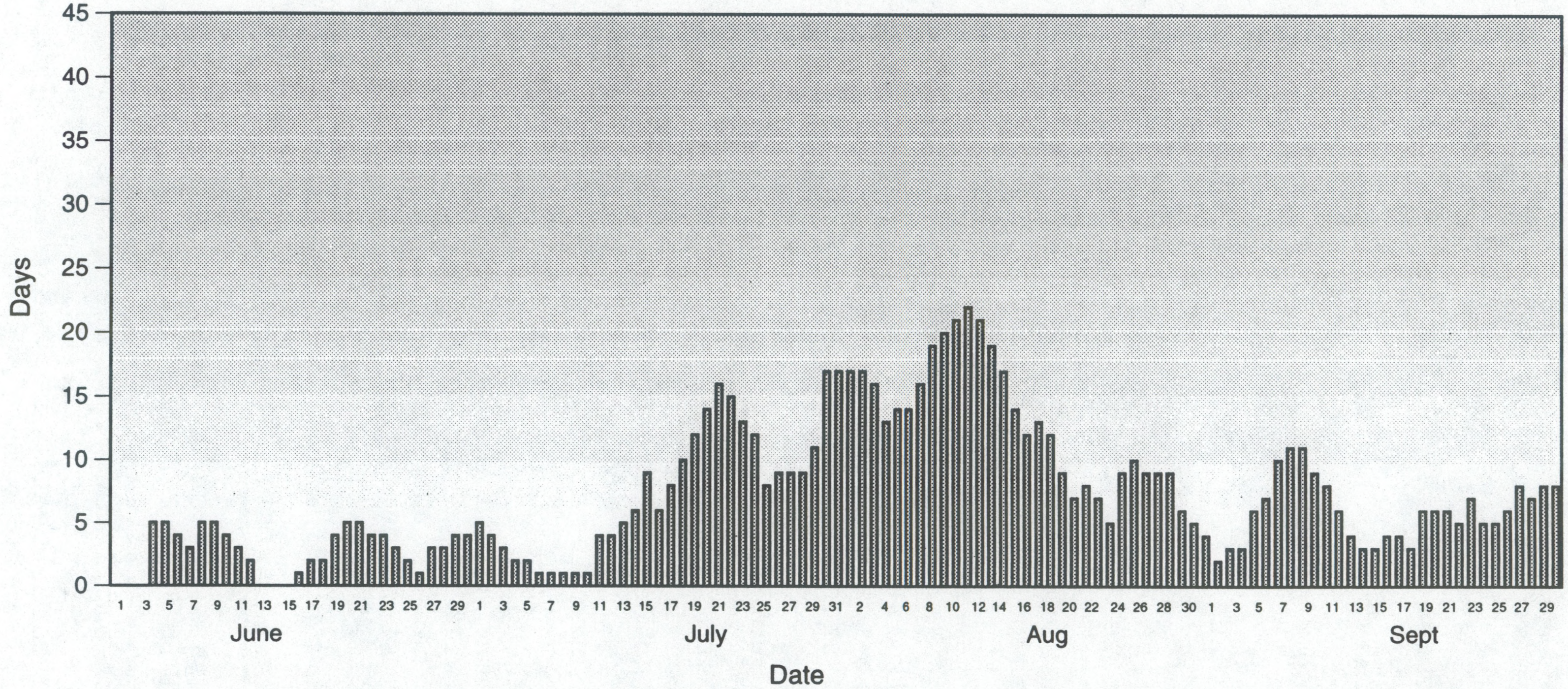


Figure 5e. Five-day running total of thunderstorm days for the Desert Rock Meteorological Observatory, for June through September, 1976 through 1995.

b. A dramatic increase in thunderstorm days during the first two weeks of July as tropical moisture begins to penetrate into the desert southwest,

c. A potential initial peak close to July 19th,

d. The primary peak between July 28 and 30th,

e. A decrease in activity the first several days of August,

f. A secondary maximum on August 10. The time period between the peaks in thunderstorm activity in July and August is approximately 10 to 11 days. This frequency may relate to the climatological frequency distribution of "surges" of tropical moisture into southern Nevada. Maddox et al. (1995) reported "breaks in the "monsoon" that lasted "weeks". Similar periodicities appear in the warm season cloud-to-ground lightning data analyzed by Watson et al. (1994a) for Arizona. and,

g. Minor maximums in late August, early September, and possibly late September may be related to a dissipating synoptic-scale pattern that can no longer produce or sustain significant "surges" of tropical moisture.

Tropical Cyclones

Another special warm season phenomena that can cause significant precipitation is dissipating tropical cyclones that occasionally enter the southwestern United States, usually during August and September (Smith, 1986). The most spectacular year on record for these tropical storms was 1939 when three separate storms entered the southwestern United States. These systems can recurve northward and eastward in September, although they have occurred as early as June and as late as October (Smith, 1986). These storm systems generally spread air with high mixing ratios into the southwestern deserts so that clouds, high humidities, and precipitation from these systems generally persists for two to three days. Several tropical depressions entered the southwestern United States in 1951 and in 1976, causing heavy precipitation.

**Desert Game Range (DGR)**:

The annual distribution of mean monthly precipitation for the DGR is shown in Fig. 2. This graphic is very similar to that for Las Vegas and also contains warm-season and cool-season maximums with amplitudes that are much smaller than those for Searchlight and Boulder City. In fact, the data graphed in Fig. 2 indicate that Las Vegas and DGR may be in a climatological transition zone separating a dominate warm-season precipitation regime to the south from a dominate cold-season regime to the north. In addition, the monthly totals are more uniformly distributed at Las Vegas and DGR than at stations to the north and south.

For the period 1949 through 1995 the average annual precipitation for this site is 4.35 in (110 mm). As with the above stations, the interannual variability is large, ranging from a minimum annual total of 0.85 in (22 mm) in 1956 to 10.38 in (263.6 mm) in 1984. The greatest monthly total measured at this site is 4.03 in (102 mm) in March 1992 with a secondary maximum of 3.88 in (98.6 mm) in July 1984.

A summary of the annual maximum daily precipitation events for this station is given in Fig. 3a. This figure shows that for the 47-yr period of record, 40% of the extreme events occur during the warm-season and 47% occur during the cool season; very similar to the distribution for Las Vegas. However, this site does have a noticeable peak of 17% in August which is probably related to the proximity of two large mountain ranges; the Spring Mountains to the west and the Sheep Range to the east. Annual maximum daily precipitation events for this station are listed in Table 10.

**Nevada Test Site (NTS)**:

The average monthly precipitation signature for the NTS is similar to that of Las Vegas and for the DGR (Fig. 2). Figure 6 shows this annual cycle for several stations on the NTS. Notice that the mean monthly precipitation depths are greatest during the cool season (October through April) except at the Desert Rock Meteorological Observatory (DRA). As at the DGR, the August peak at DRA is believed to be modulated by moist convection that develops over the Spring Mountains during the summer months and moves northeastward over the southern part of the NTS. The figure also demonstrates that the precipitation on the NTS is bimodal with cool-season peaks in January - March and warm-season peaks in July or August.

Comparison of the plots in Fig. 6 with those in Fig. 2 reveals that the average maximum monthly precipitation shifts from the summer months, in extreme southern Nevada, to winter months in the vicinity of the NTS and Beatty. Two exceptions are at the DGR station and at DRA, where the August peaks are probably enhanced by proximity to large mountain ranges.

Mean annual precipitation amounts on the NTS range from approximately 13.0 in (330 mm) over the high terrain in the northwest part of the NTS to near 5.0 in (127 mm) at the lower elevations in Jackass Flat (4JA, Fig. 2) and Frenchman Flat (W5B). However, interannual variations can be great (Quiring, 1983). For example, 4JA has received as much as 11.62 in (296 mm) in one year (1978) and as little as 1.54 in (40 mm) in 1975. Even monthly and daily totals can be extreme. At DRA,

Table 10. Annual maximum daily precipitation for the Desert Game Range, DGR, 1949 through 1995, in inches.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1951 | 2.05 | 1 | 1986 | 0.87 | 25 |
| 1984 | 1.72 | 2 | 1975 | 0.85 | 26 |
| 1969 | 1.55 | 3 | 1978 | 0.83 | 27 |
| 1972 | 1.50 | 4 | 1955 | 0.79 | 28 |
| 1949 | 1.45 | 5 | 1980 | 0.78 | 29 |
| 1957 | 1.44 | 6 | 1988 | 0.68 | 30 |
| 1994 | 1.40 | 7 | 1995 | 0.65 | 31 |
| 1966 | 1.37 | 8 | 1982 | 0.64 | 32 |
| 1963 | 1.31 | 9 | 1991 | 0.63 | 33 |
| 1961 | 1.14 | 10 | 1979 | 0.62 | 34 |
| 1965 | 1.13 | 11 | 1985 | 0.62 | 35 |
| 1990 | 1.11 | 12 | 1974 | 0.61 | 36 |
| 1987 | 1.10 | 13 | 1977 | 0.57 | 37 |
| 1958 | 1.03 | 14 | 1973 | 0.55 | 38 |
| 1976 | 1.03 | 15 | 1950 | 0.53 | 39 |
| 1983 | 1.02 | 16 | 1989 | 0.48 | 40 |
| 1952 | 1.02 | 17 | 1962 | 0.45 | 41 |
| 1992 | 1.00 | 18 | 1953 | 0.36 | 42 |
| 1960 | 0.98 | 19 | 1968 | 0.34 | 43 |
| 1959 | 0.97 | 20 | 1964 | 0.32 | 44 |
| 1967 | 0.95 | 21 | 1970 | 0.31 | 45 |
| 1981 | 0.93 | 22 | 1956 | 0.29 | 46 |
| 1954 | 0.91 | 23 | 1971 | 0.23 | 47 |
| 1993 | 0.90 | 24 | | | |

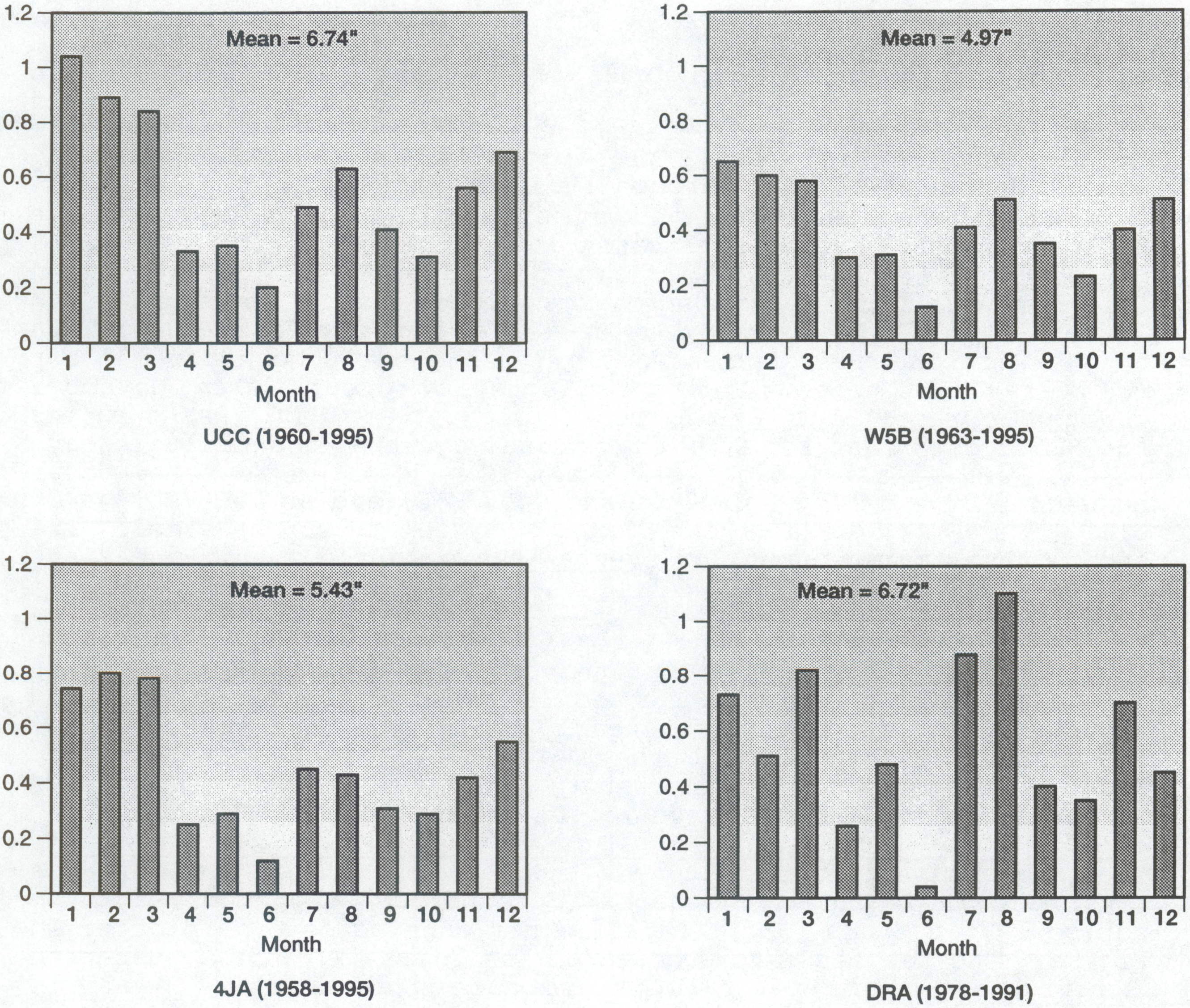


Figure 6. Annual distribution of mean monthly precipitation for some stations on the Nevada Test Site.

as much as 5.37 in (136 mm) fell during August 1983, with 3.52 in (89.4 mm) falling on August 18, 1983. No thunder was heard or lightning observed during this event. Most of this rain fell between midnight and 0400 PDT.

Quiring (1977) also completed an analysis of thunderstorm days based on hourly observations taken at UCC for the period 1962-1975. He found that thunderstorm activity increased dramatically between July 1st and 25th with the maximum frequency of occurrence on August 11th. Thunderstorm days decreased rapidly from August 12th to the 28th and then decreased slowly into early November, as for Las Vegas. Little thunderstorm activity occurs from November through February, but then increases slowly into May. Based on the 1962-1975 data base for UCC, the diurnal cycle of thunderstorm days in July and August was not well-defined. Peaks in activity occur between 1400 and 1700 PDT (2100 and 0000 UTC) and at 2000 PDT (0300 UTC). The lack of a definite maximum may relate to the sample size and to the limited number of events that occurred within the 14-yr period of record.

For the 18-yr record at DRA, a total of 244 thunderstorm days have occurred for an average of 13.6 thunderstorm days/year. Of these, 73% have occurred between June and September with July (19.2%) and August (30.3%) accounting for nearly 50% of the thunderstorm days. The annual distribution of these events is graphed in Fig. 5c. Figures 5b-e show that thunderstorm activity tends to occur later in the summer at DRA relative to Las Vegas.

The frequency distribution of thunderstorm days for DRA was constructed for the warm seasons (June through September) for the period 1976 through 1995. The five-day running mean is plotted in Fig 5e. The results match those for Las Vegas (Fig. 5d). Based on the five-day running totals, there are three definite peaks in thunderstorm days at Desert Rock; namely July 20th, July 30/31, and August 11, close to the primary peak reported by Quiring (1977) for UCC and a shorter data record. The distribution in Fig. 5c yields an approximate 11-day period between peaks, similar to that for Las Vegas. More resolution may appear in this data base than in that for UCC because it contains six more years of record.

Annual maximum daily precipitation events on the NTS show a seasonal preference for the cool season (Fig 3b). In fact, when compared with Fig. 3a, the northern most stations (4JA and Yucca Flat) have large, cool-season, extreme daily precipitation peaks while the southern most station (Searchlight, Fig. 3a) has a marked warm season peak, indicating different dynamical processes driving these precipitation events. The winter extremes are associated with large-scale cyclonic circulations and the warm-season events with moist convection. The greatest daily precipitation measured on the NTS is 3.63 in (92 mm) at Mercury on August 18, 1983. Data on the annual extreme daily precipitation events for several sites on the NTS are listed in Table 11.

Table 11. Annual maximum daily precipitation at sites on the NTS (1975 through 1995). Amounts are in inches. The observed maximum for each data record is identified in bold numerals and listed at the bottom of the table. The Area 12 site is on a mesa at an elevation of 7500 ft (2286 m). NA indicates that the observation site did not exist. See Fig. 1 for locations.

| YEAR | Rock Valley | Cane Springs | Well 5B | 40-Mi Canyon | Tippipah Springs | Little Feller | Area 12 |
|---|---|---|---|---|---|---|---|
| 1995 | 0.88 | 0.75 | 0.54 | 2.28 | 1.42 | 1.35 | 2.02 |
| 1994 | 1.16 | 0.57 | 0.85 | 0.98 | 0.82 | 0.80 | 1.24 |
| 1993 | 1.50 | 1.16 | 0.78 | 1.20 | 1.33 | 1.21 | 1.35 |
| 1992 | 1.72 | 1.39 | 0.55 | 0.92 | 1.34 | 1.21 | 0.95 |
| 1991 | 0.64 | 1.99 | 0.45 | 0.60 | 0.90 | 0.75 | 2.19 |
| 1990 | 1.45 | 1.17 | 0.49 | 1.20 | 0.50 | 0.61 | 0.65 |
| 1989 | 0.17 | 0.25 | 0.21 | 0.80 | 0.35 | 0.41 | 0.64 |
| 1988 | 1.11 | 1.21 | 0.93 | 0.83 | 0.78 | 0.57 | 1.10 |
| 1987 | 1.14 | 1.63 | 1.21 | 1.11 | 1.65 | 1.29 | 1.10 |
| 1986 | 0.89 | 1.27 | 0.92 | 0.74 | 1.07 | 0.87 | 1.07 |
| 1985 | 0.54 | 0.69 | 0.30 | 1.27 | 1.08 | 1.01 | 0.92 |
| 1984 | 1.20 | 1.36 | 1.64 | 1.29 | 1.68 | 1.71 | 0.93 |
| 1983 | **2.98** | **3.47** | **1.86** | **2.99** | 0.86 | 2.04 | 2.75 |
| 1982 | 2.25 | 2.26 | 1.26 | 1.83 | 1.85 | 1.19 | **2.99** |
| 1981 | 1.13 | 0.80 | 0.89 | 0.78 | 0.86 | 0.58 | 1.02 |
| 1980 | 0.72 | 0.68 | 0.67 | 0.51 | 0.82 | 0.77 | 0.96 |
| 1979 | 0.43 | 0.63 | 0.44 | 0.80 | 0.83 | 0.69 | 0.76 |
| 1978 | 1.39 | 1.81 | 0.74 | 1.15 | 1.44 | 0.98 | 1.52 |
| 1977 | 2.16 | 0.78 | 1.04 | 2.07 | 1.95 | **2.34** | 2.80 |
| 1976 | 1.60 | 1.78 | 1.13 | 2.00 | **2.03** | 1.24 | 2.69 |
| 1975 | 0.34 | 0.59 | 0.38 | 0.34 | 0.63 | NA | 0.72 |
| **MAX** | **2.98** | **3.47** | **1.86** | **2.99** | **2.03** | **2.34** | **2.99** |

**Pahrump (PMP)**

Based on the 1969-1995 record, the average annual precipitation for this site is 5.24 in (133 mm). The wettest months are January, February, and March. February is the wettest month with an average of 0.85 in (21.6 mm) and the driest month is June with 0.09 in (2.3 mm). The warm-season peak is in August with an average of 0.44 in (11.2 mm). Annual and monthly precipitation totals vary dramatically from year to year. For the period of record, the wettest year was 1983 when 8.55 in (217 mm) fell while the driest years were 1971 and 1975 when only 2.04 in (51.8 mm) fell each year. However, during the period of incomplete records (1948-1968), the data for 1965 and 1966 were complete. In 1965 the annual total precipitation was 9.12 in (232 mm) and in 1966 only 1.58 in (40.1 mm) fell. The greatest monthly total measured is 3.87 in (98.2 mm) which fell in January 1995. The largest daily total, 2.40 in (61 mm) was in February 1979. Figure 3b shows that the annual maximum daily precipitation events are nearly uniformly distributed; however, a winter peak does occur in February; and May and June have not experienced an annual extreme daily event for the period of record. As with the other desert sites, there can be long periods (90-100 days) with no precipitation.

**Beatty (BTY)**:

Based on the combined records for the two cooperative stations near Beatty, the average annual precipitation is 5.09 in (129 mm) for the 48-yr period from 1948 through 1995. The annual distribution of mean monthly precipitation (Fig. 2) is quite different from those stations located farther south (Searchlight, Boulder City, and Las Vegas). The summertime totals and the August maximum are small compared to the dominant cool season totals.

Figure 3b shows that the annual maximum daily precipitation events for this station are dramatically skewed to winter. The maximum frequency of occurrence (18%) is in February and no annualized extreme events have occurred in May or June. Furthermore, the frequency distribution of the extreme daily precipitation events for Beatty is quite different from those of stations located farther south. Figure 3b shows that the majority (69%) of these extreme events occur between November and March with the monthly maximum in February (27%). The greatest daily precipitation event for Beatty is 1.9 in (48 mm) which fell on December 18, 1984. Heavy summertime precipitation does occur, but such events are rare. The heaviest observed warm-season event occurred on August 17, 1977, when 1.75 in (44 mm) fell.

As with the other stations in this arid climatic zone, interannual precipitation totals can have large variability. In the Beatty area, as much as 11.49 in (292 mm) fell in one year (1983) and as little as 0.69 in (15.5 mm) fell in 1953. Monthly totals can also be large and have great variability. At this station the largest monthly total is 3.5 in (89 mm) in March 1995 and 3.18 in (81 mm) in January 1995. In addition, there have been many months with no precipitation.

In summary, intense thunderstorms and heavy precipitation events do occur in southern Nevada. Available data show that heavy precipitation is associated with synoptic-scale cyclonic flow during the cool season (November through March) and with moist convection in the warm season (June through September). Heavy winter precipitation is generally widespread while intense summer precipitation is driven by strong surface heating and moisture advection. Summer extreme precipitation events are of great concern because of the focusing of the precipitation, frequent cloud-to-ground lightning, strong outflow winds, dense blowing dust, and flash floods that can have very short time scales for emergency response.

Heavy warm-season precipitation and flash floods in southern Nevada have a diurnal cycle with a peak in mid-afternoon or early evening. Maddox et al. (1980) and Balling and Brazel (1987) note that this cycle is different from that of eastern United States flash floods which exhibit a pronounced nocturnal character. Topography complicates forecasting these events and contributes to focusing their energy and impacts to confined drainage basins. Precipitation produced during these extreme events is thought to be less than that produced by eastern storms. This view may be a little weak on being entirely correct; precipitation events that produce 2 to 4 in (50 to 100 m) in 1 to 3 hours are heavy for any geographical location. Improvements in documenting these heavy storms is demonstrating that they may not be as infrequent as we once thought. The new 88D Doppler radars should provide a more comprehensive look at these storms over the next several years.

## IV. MACROSCALE PATTERN CHARACTERIZATIONS

Maddox et al. (1980 and 1995) presented synoptic characterizations of the meteorological conditions that contribute to the development of heavy precipitation events in the southwestern United States. Experience in forecasting thunderstorms over the NTS and southern Nevada suggests that the Maddox et al. (1980) Type IV or Type II (1995) pattern is solidly related to heavy precipitation and active thunderstorm development over southern Nevada. This climatological 500-mb flow pattern has been modified slightly to include experience for southern Nevada and is shown in Fig. 7a as Type A. The principal difference between Type A and the Maddox Type IV is the presence of a trough off the California coast (between 120° and 130°W). Flow around this trough and the 500-mb anticyclone over the four-corners area combine to form a region of strong confluence throughout the lower and middle troposphere over the lower Colorado River Valley and southern Nevada. Furthermore, this pattern is particularly effective in driving low-level tropical moisture northward into central and western Nevada. Other meteorological

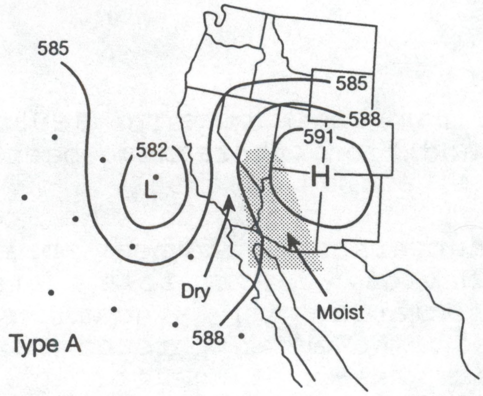


Figure 7a. Conceptualized 500-mb pattern for heavy precipitation events over southern Nevada. Region of low-level advection of tropical moisture northward is shown as a shaded area.

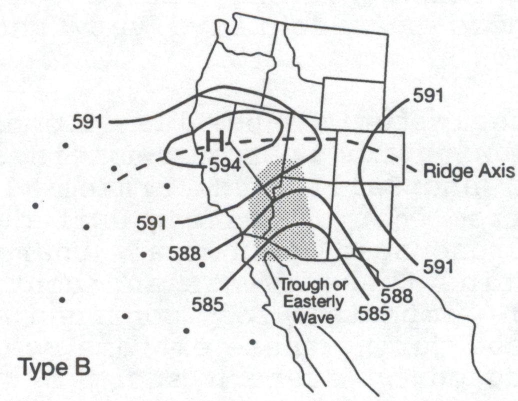


Figure 7b. Conceptualized 500-mb pattern for development of mesoscale convective systems and locally heavy precipitation over southern Nevada. Shaded area represents region of the northward advection of low-level, moist tropical air.

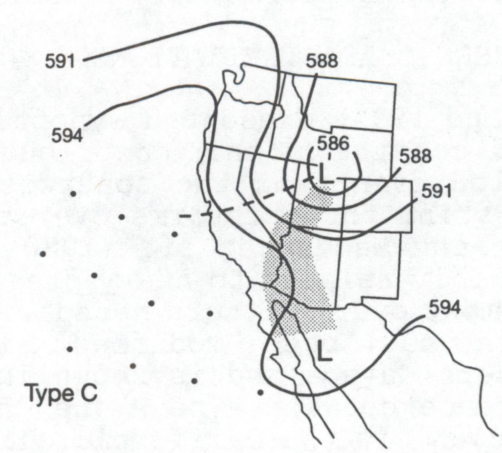


Figure 7c. Conceptualized 500-mb pattern for mesoscale convective system development ahead of a mid-latitude short-wave trough over southern Nevada. Shaded area represents area of the northward advection of low-level, moist tropical air.

characteristics that can contribute to severe storm development with this pattern are: a) a progressive short wave (Maddox et al. 1980, Type I) and/or b) strong southerly flow between the 500- and 300-mb levels through and over the zone of confluence. The position of the mid-tropospheric (500-mb) high (or ridge) appears to be critical in augmenting or suppressing moisture advection into the desert southwest (Carleton, 1986). Locally heavy precipitation, flash flooding, strong outflow winds, blowing dust, and intense cloud-to-ground lightning are characteristics of thunderstorms that develop in this type synoptic pattern in the vicinity of southern Nevada. Storm motion is generally between north-northwest and northeast, depending on the mean cloud-layer flow. Examples are the thunderstorms of July 19, 1969; July 3, 1975; August 12, 1978; August 18, 1983; August 8, 1989; and the microburst at Mercury, NV, on May 30, 1984. These, and other events, are described in Section V.

A second pattern, defined as Type B, also tends to be associated with very active thunderstorms and is portrayed in Fig. 7b. This flow regime is also similar to the Maddox et al. (1980) Type IV pattern, but with the ridge axis displaced northward. Type B is characterized by an inverted tough (or easterly wave) over Arizona and by an east-west oriented ridge and/or anticyclonic circulation located between Reno and Denver. The inverted trough propagates westward. Observational evidence suggests that the inverted troughs may really be the northern extremities of easterly waves that have moved westward through the Gulf of Mexico and southern Texas into central and northern Mexico. Significant mesoscale convective systems (MCSs) can develop over the Sierra Madres Mountains of northwestern Mexico with this pattern. In addition, intense heating of the deserts ahead of this trough helps drive low-level tropical air northward into southern Nevada and Utah. As the upper-level trough moves westward, intense thunderstorms can develop over the high terrain in northwestern Arizona and southern Utah and move westward, or southwestward, into southern Nevada late in the evening. MCSs that develop over northwestern Mexico can also produce significant boundary-layer outflow winds that can enhance the Gulf surge phenomena. The cooler outflow air can produce anomalously high surface pressures over the Gulf of California which can accelerate the northward push of high theta-e air into the lower Colorado River Valley.

A climatological summary of cloud-to-ground lightning data by Watson et al. (1994b) suggests that there is a tendency for lightning activity to move westward from northwestern Arizona into southern Nevada between 2200 UTC and 0400 UTC (1500 to 2100 PDT). Strong outflow winds with dense blowing dust, intense cloud-to-ground lightning, and isolated heavy precipitation are characteristics of this pattern in southern Nevada. A curious feature of this pattern is that cloud-layer flow between approximately 10,000 ft (3000 m) and 30,000 ft (10,000 m) MSL is predominantly easterly while the cloud-top or anvil-level flow has a well defined westerly component. Consequently, as the main cloud mass moves westward, the anvil blows off to the east, creating an impressive convective cloud wall and electrical display (at night) as the storm system moves westward into the moist, southerly low-level flow. Examples of these type storms are those of June 30, 1984 (Cylke, 1984) and July 18, 1994. Occasionally this pattern may exist without a well defined trough so that the 500-mb flow is mostly easterly over Arizona and slightly north of east over southern Nevada. In either case, MCSs can develop, especially over northwestern Mexico.

The Maddox et al. (1980) Type II pattern has been "retrograded" to fit southern Nevada heavy thunderstorms or mesoscale convective systems (MCS). This type mid-tropospheric flow field is shown in Fig. 7c and is classified as Type C. It is accompanied by strong dynamics and vertical motion ahead of a southward moving short-wave trough located along a line from Salt Lake City to San Francisco. As the trough moves over low-level moisture flowing northward, strong thunderstorms can begin to develop along an east-west line through the central point on the border between Utah and Nevada. These storms tend to form into an MCS and move southward or southeastward into southern Nevada and Utah and into northwestern Arizona. The right flank of this MCS can develop westward along the outflow boundary. Heavy thunderstorms can also form over the high plateaus and mountains of southern and central Utah. Locally heavy precipitation, flash flooding, strong outflow winds with dense blowing dust, large hail, and intense cloud-to-ground lightning are characteristics of thunderstorms that develop in this type synoptic pattern in the vicinity of southern Nevada. Examples of these type storms are the ones of September 14, 1974 (Glancy and Harmensen, 1975) and August 10, 1981. This pattern is unusual over the southwestern United States in summertime and is therefore an infrequent synoptic condition.

Another potential type would involve dissipating tropical cyclonic circulations that approach southern California and Arizona from the southwest. These appear to be rare, but can produce significant periods of steady rain and flooding. In addition, satellite water vapor imagery suggests that small-scale cyclonic systems, with few if any clouds, occasionally move northward into the southwestern United States from off the west coast of Baja California. These systems can tap low-level tropical air over the Gulf of California, drive it northward, and create strong conditional instability as the low-level air, with large mixing ratios (and large equivalent potential temperatures), moves under dry, cool air aloft. Intense moist convection can be released if the moist air is lifted by topography or by mass convergence.

## V. SOME EXTREME PRECIPITATION EVENTS

Extreme precipitation events in southern Nevada are quite dramatic and cover phenomena from heavy snowfalls (Randerson, 1975) to heavy thunderstorms (Glancy and Harmsen, 1975, Randerson, 1976 and 1986, Cylke, 1984, Scott, 1990, and others). One of the earliest accounts of heavy rain and property damage in southern Nevada appeared in the Las Vegas Age, a local newspaper, dated January 8, 1910. The front-page feature story was entitled "Rushing Torrents" and reported that 100 mi of railroad were destroyed by an "unprecedented flood" due to "torrential rains" and "melting mountain snow." Approximately $1,000,000 in damage was done to railroad tracks and facilities in Meadow Valley Wash located northeast of Las Vegas, between Moapa and Elgin (Fig. 1). Much property damage from this winter storm was also reported in California, Arizona, and Utah.

In this study the focus is on heavy precipitation amounts in southern Nevada. **Some** examples of these significant events are discussed next only to illustrate the magnitudes and impacts of these events:

June 13, 1955: The 1500 UTC atmospheric sounding taken in Las Vegas by the NWS indicated a K-index of 33, a lifted index (LI) of -1, 0.63 in (16 mm) of precipitable water, and strong southeast to south winds aloft ahead of an energetic shortwave trough. According to a Corps of Engineers report[3], thunderstorm activity commenced to the south and west of the city at approximately 1630 PDT (2330 UTC) and moved northeastward across the valley. All thunderstorm activity ceased by 2100 PDT (0400 UTC). This intense storm was accompanied by small hail and strong surface winds. The full impact of the storm was confined to an area of approximately 500 sq mi (1,300 sq km) to the southwest and west of the downtown area. Estimated maximum rainfall was 3.4 in (86.4 mm). An eight-inch raingage, located near the area of heaviest rainfall, collected 1.87 in (47 mm) of precipitation. Following this intense thunderstorm, heavy runoff and flash flooding were reported throughout the city. No deaths were reported; however, property damage was estimated at $1,500,000 to $2,000,000. The population of Las Vegas was approximately 60,000 people in 1955. One interesting aspect of this storm was that it occurred during the driest month, climatologically speaking.

August 21, 1957: On this date, a heavy rainfall event set the 24-hr precipitation record for the McCarran International Airport site in Las Vegas. Heavy rain began falling at 1400 UTC and lasted for approximately three hours. The rainfall was widespread, covering most of the Las Vegas valley. The storm total rainfall measured at McCarran International

[3]Corps of Engineers, U.S. Army, Los Angeles District, "Report on Flood of 13 June 1955 Las Vegas and Vicinity, Nevada, 6 July 1955.

Airport was 2.59 in (66 mm) and 2.09 in (53 mm) at Nellis Air Force Base located northeast of the downtown area. Extensive flooding occurred throughout the Las Vegas Valley but property damage was estimated at only $365,000. There was no loss of life. Based on available information, it appears that this precipitation event was associated with a dissipating tropical cyclone. The 1200 UTC atmospheric sounding from Las Vegas showed 1.72 in (43.7 mm) of precipitable water from the surface to the 400-mb level, K = 35, and LI = -2.

<u>July 19, 1969</u>: Southeasterly flow aloft spread a very moist tropical air mass over southern Nevada and the NTS. The combination of daytime heating and the presence of low-level moisture contributed to the development of an intense thunderstorm over mountainous terrain. This thunderstorm formed in an air mass with K = 36, LI = -2, and 0.78 in (19.8 mm) of precipitable water. Storm total precipitation amounts of 1.0 to 2.0 in (25 to 50 mm) fell over the west central part of the NTS (see Fig. 8). The maximum measured storm total was 2.28 in (58 mm). Total area of rainfall exceeding 0.25 in (6.4 mm) was approximately 150 sq mi (390 sq km). The isopluvial analysis in Fig. 8 reflects the typical tight gradient and intense focusing of precipitation that is characteristic of desert thunderstorms.

<u>September 16, 1969</u>: In contrast to the thunderstorm described above, this storm occurred over the lowest part of Yucca Flat on the NTS. Moreover, the thunderstorm developed ahead of a north-south oriented 500-mb trough that moved eastward from near 35°N, 125°W to near 35°N, 115°W. The storm formed in an unstable air mass (K = 34, LI = -2) and was accompanied by hail and surface wind gusts to 31 mph (15 m/s). The maximum storm precipitation total was 2.13 in (54.1 mm) measured at the Yucca Flat Meteorological Observatory (UCC). Most of the precipitation fell within a 100 sq mi (260 sq km) area in Yucca Flat (see Fig. 9).

<u>September 14, 1974</u>: An intense thunderstorm created a catastrophic flash flood in Eldorado Canyon, totally destroying the Nelson's Landing marina facility and killing nine people. The storm track followed the canyon, thereby focusing the precipitation along the axis of the primary drainage channel. Glancy and Harmsen (1975) estimated a peak flow rate of approximately 76,000 $ft^3/s$ (2150 $m^3/s$). This thunderstorm developed ahead of a vigorous short-wave trough that extended south-southwest from a deep (5750-m) 500-mb low located over Ely, NV. Rainfall rates we estimated to have been 3.0 to 6.0 in/hr (76 to 152 mm/hr) for approximately 30 min.

<u>July 3, 1975</u>: An intense thunderstorm with a precipitation pattern very similar to that of the storm of June 13, 1955,

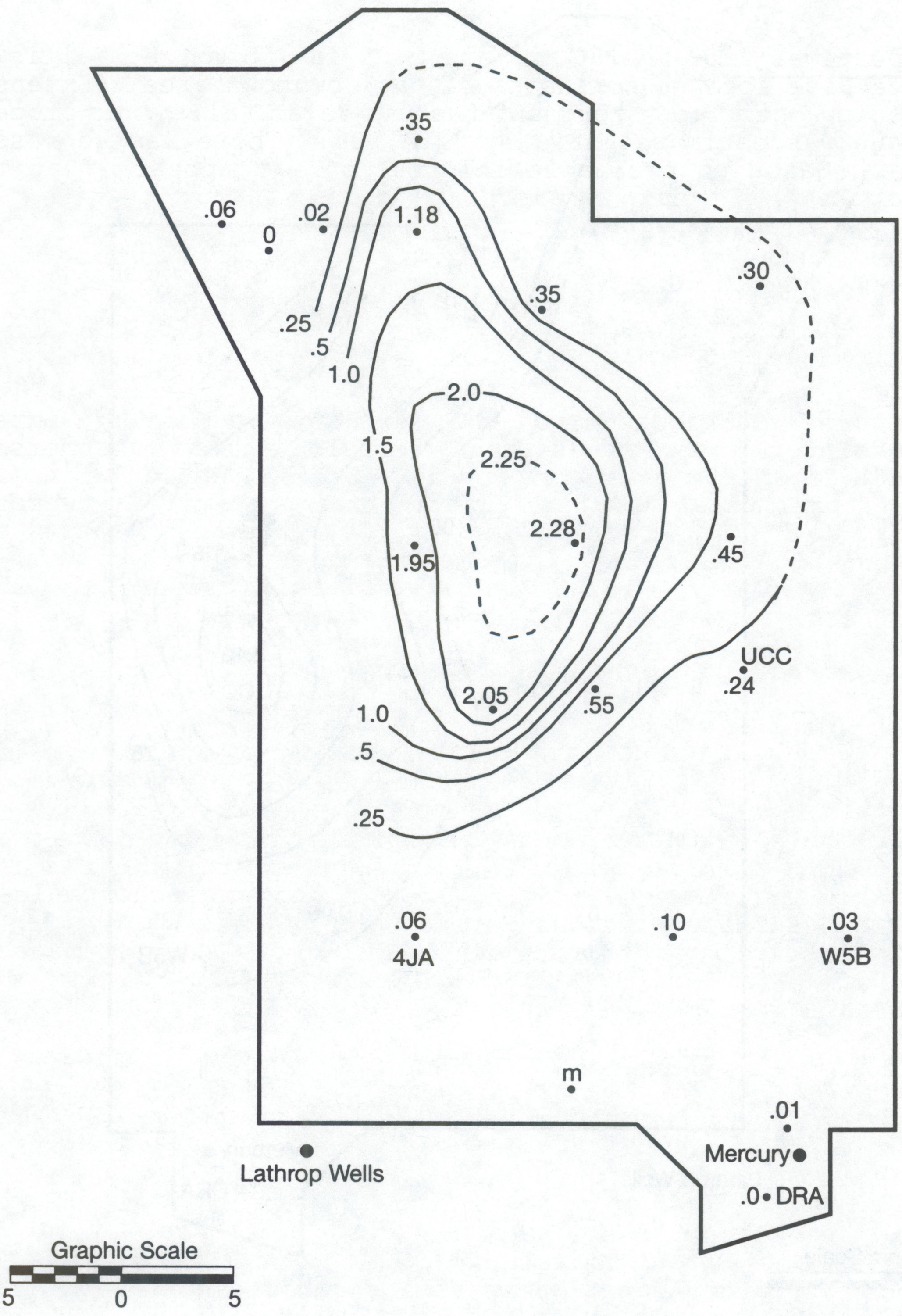


Figure 8. Isopluvial analysis of the daily precipitation totals, in inches, for the Nevada Test Site for July 19, 1969. Dashed contours are estimated positions.

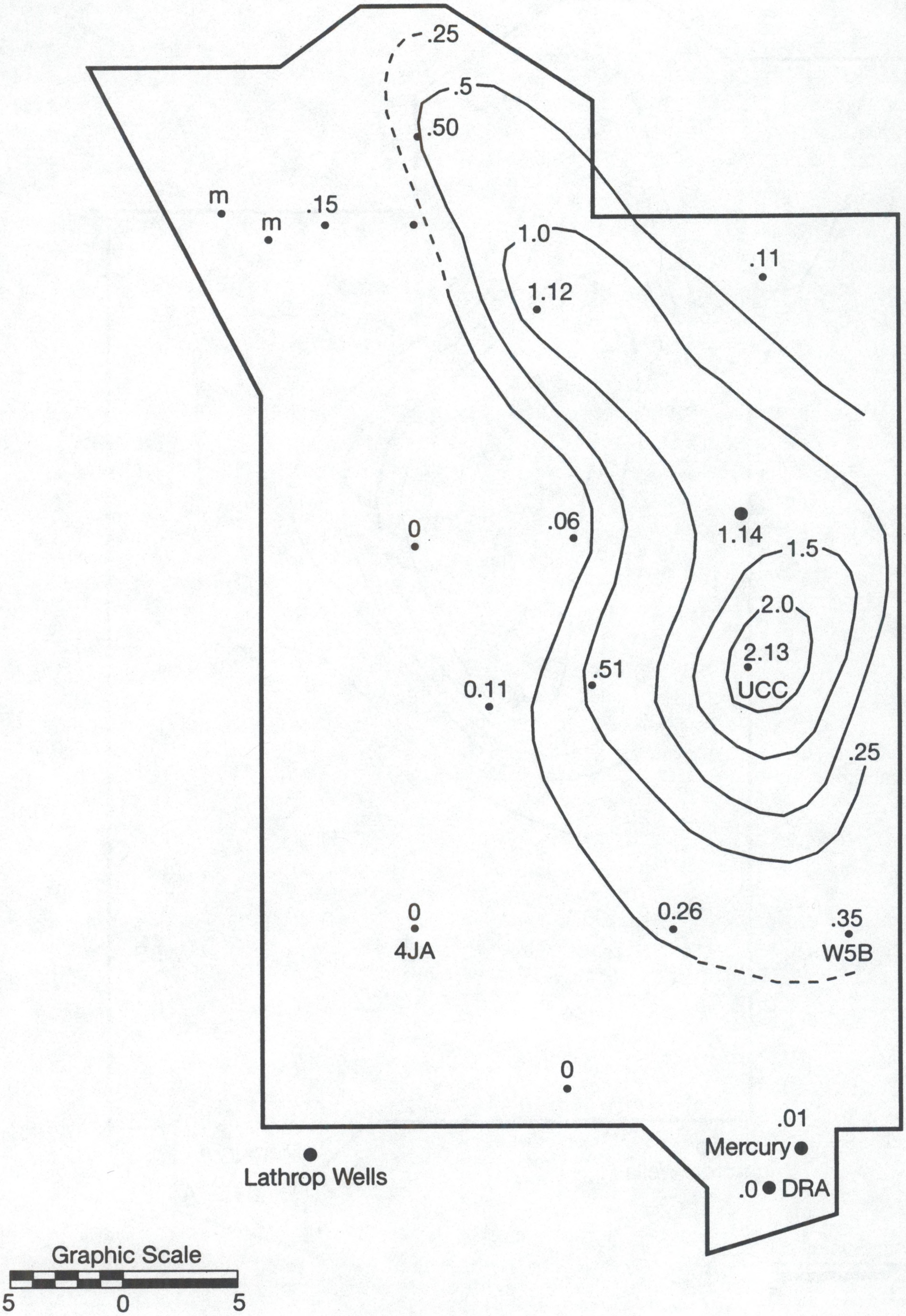


Figure 9. Isopluvial analysis of the daily precipitation totals, in inches, for the Nevada Test Site for September 16, 1969. Dashed contours are estimated positions.

struck the western part of Las Vegas. The storm caused flash flooding within the city and resulted in approximately $4.5 million in property damage. The effective precipitation contributing to the flooding covered an area of 550 sq km. Maximum rainfall amounts of 3.0 in (76 mm) were estimated to have occurred. A weighing-bucket precipitation gage located below an active part of the thunderstorm recorded a rainfall rate of 1.0 in/hr (25.4 mm/hr). Hail and surface wind gusts to approximately 60 mph (25 m/s) were observed in the northwestern part of the city. An isohyetal analysis of the storm indicated that, at least, $2.3 \times 10^7$ $m^3$ ($1.9 \times 10^4$ acre ft) of water were available before infiltration. To emphasize the focusing and isolated nature of these type storms, it is worth noting that the official rainfall for Las Vegas for the date was 0.07 in (1.8 mm) which was observed at the NWS office at McCarran International Airport, located approximately 8 mi (12.8 km) east of the storm center. A detailed report on this storm was prepared by Randerson (1976).

August 12, 1978: A very significant convective event developed in the vicinity of Searchlight, NV, during the evening of the 12th. Available meteorological data indicate that a region of strong confluence developed in the middle troposphere over southern Nevada and drifted southward during the evening. Low-level southerly flow from the tropical Pacific Ocean drove very moist air into this confluence zone. As a result heavy and persistent thunderstorms developed, causing 3.81 in (97 mm) of rain to fall on Searchlight within a 24-hr period.

August 10, 1981: An intense mesoscale convective system (MCS) developed during the early afternoon over extreme east central Nevada. The storm complex developed rapidly and moved southeastward across the mean mid-tropospheric flow. The kinematics of the air flow regime associated with this storm may offer insight into why the thunderstorm became so intense. Sub-cloud air was quite moist and had a dramatic component of motion directly into the storm. Consequently, a zone of strong enhancement of vertical motion and condensation existed along and to the right of the track of the MCS.

As the storm reached its maximum intensity in the vicinity of Moapa and Logandale, NV, large hail, strong surface winds, blowing dust, and intense rain were reported along the storm track (Randerson, 1986). Maximum total rainfall amounts of 3.0 to 6.0 in (76 to 152 mm) were believed to have soaked the desert to the northeast of Las Vegas. There was considerable damage to boats and harbor facilities on Lake Mead, 500 dairy cows were drowned in Logandale, Interstate 15 was temporarily closed due to flash flooding, and sections of the road through Valley of Fire State Park (VOF) were washed away. This storm traveled approximately 500 km and affected an area of nearly

20,000 sq km, including the Las Vegas metropolitan area and cities throughout the western half of Arizona and the lower Colorado River valley. Based on the volume of rain water produced, this storm was estimated to be, at least, 30 times larger that the Las Vegas storm of July 3, 1975 (Randerson, 1986). A maximum stream flow of approximately 50,000 $ft^3/s$ (1,557 $m^3/s$) was estimated to have occurred in the California Wash located to the south of Moapa.

August 18, 1983: On the 17th and 18th of August, a significant precipitation event occurred over southern Nevada as very moist tropical air spread across the desert southwest. Surface dew-point temperatures in Las Vegas and on the NTS were in the low to mid 60s. Aloft, the general 500-mb flow was dominated by a large, warm-core anticyclone centered over Kansas with a weak closed low near 37°N and 127°W, just off the central California coast. It is important to note that this flow pattern is similar to that associated with the intense thunderstorm that developed over the Las Vegas valley on July 3, 1975. The 1200 UTC sounding from the Desert Rock Observatory (DRA) only reached the 700-mb level so that convective indices could not be calculated. However, the 0000 UTC sounding for the 18th yielded a K=37, LI=-3, and 1.37 in (34.8 mm) of precipitable water.

Heavy precipitation fell on the NTS between 0000 and 0400 PDT (0700-1100 UTC) on the 18th. The most intense rainfall was centered over the southern and western parts of the NTS (see Fig 10a). A raingage located in Mercury, NV, recorded 3.63 in (92 mm) for the 18th and a daily total of 3.52 in (89 mm) was measured at DRA. According to the surface observations taken at DRA, moderate precipitation began at midnight and continued until 0500 PDT (1200 UTC). A total of 2.21 in (56 mm) of rain fell during this four-hour period which included 20 min of heavy rain between 0220 and 0240 PDT (0920 and 0940 UTC). Notice that if the precipitation had fallen at a constant rate for this four-hour period, the rainfall rate would have been 0.55 in/hr (14 mm/hr). Other large measured amounts were 3.22 in (82 mm) in Jackass Flat (4JA), 3.47 in (88 mm) in Mid Valley, and 2.98 in (76 mm) in Rock Valley. In addition, 3.65 in (93 mm) were observed at the Red Rock Canyon Recreational area located just west of Las Vegas, NV. The isopluvial analysis in Fig. 10a is based on the measured totals, on winds aloft, and on the motion of cloud elements derived from satellite imagery.

Satellite imagery for the period of heaviest precipitation is reproduced in Fig 10b. This figure shows that cloud elements were moving northward at approximately 10 m/s. In addition, some cold cloud tops passed over the NTS during the period of into central Nevada. Figure 10b also shows that cold cloud

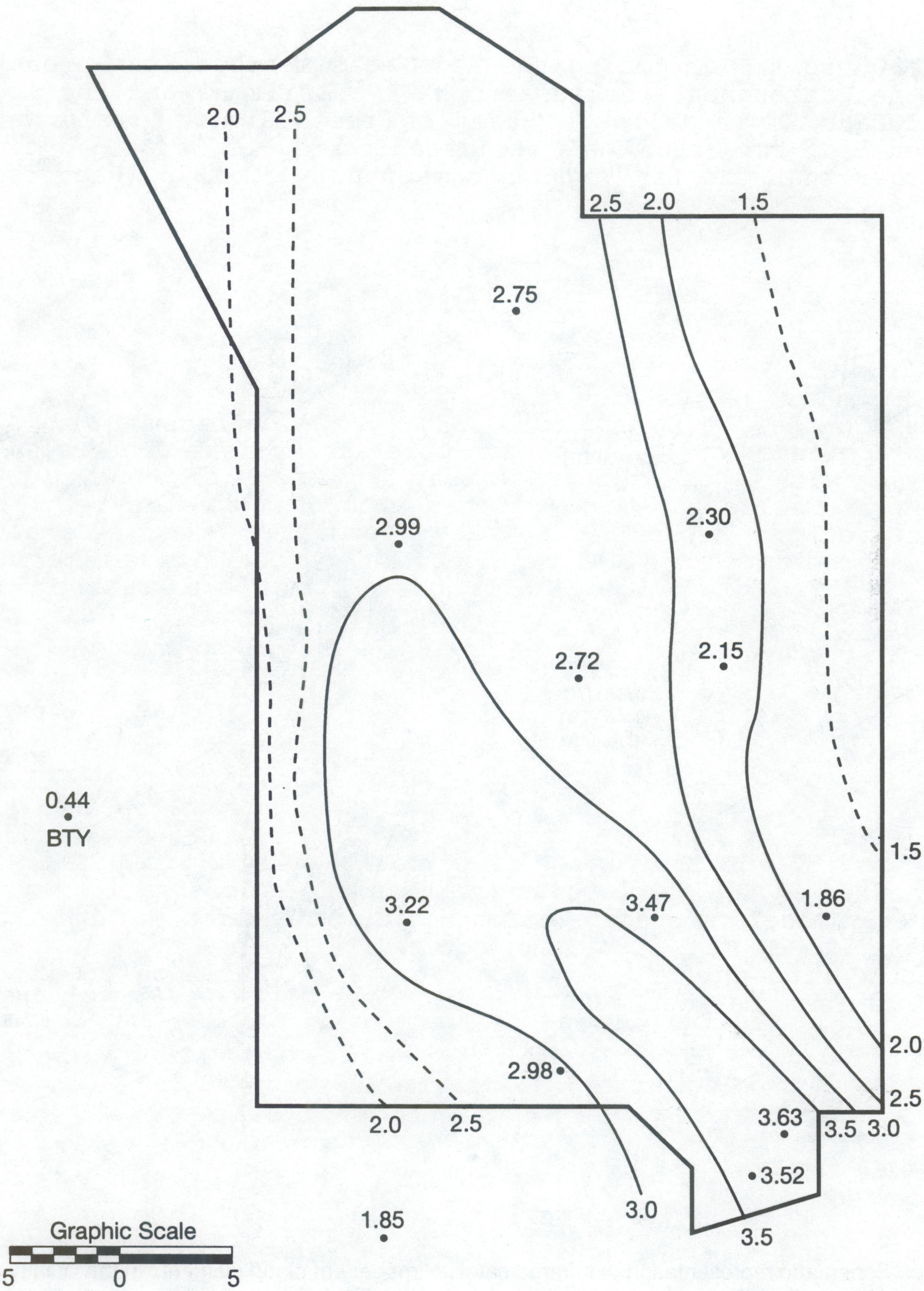


Figure 10a. Isopluvial analysis of the daily precipitation totals, in inches, for the Nevada Test Site for August 18, 1983. Dashed contours are estimated positions.

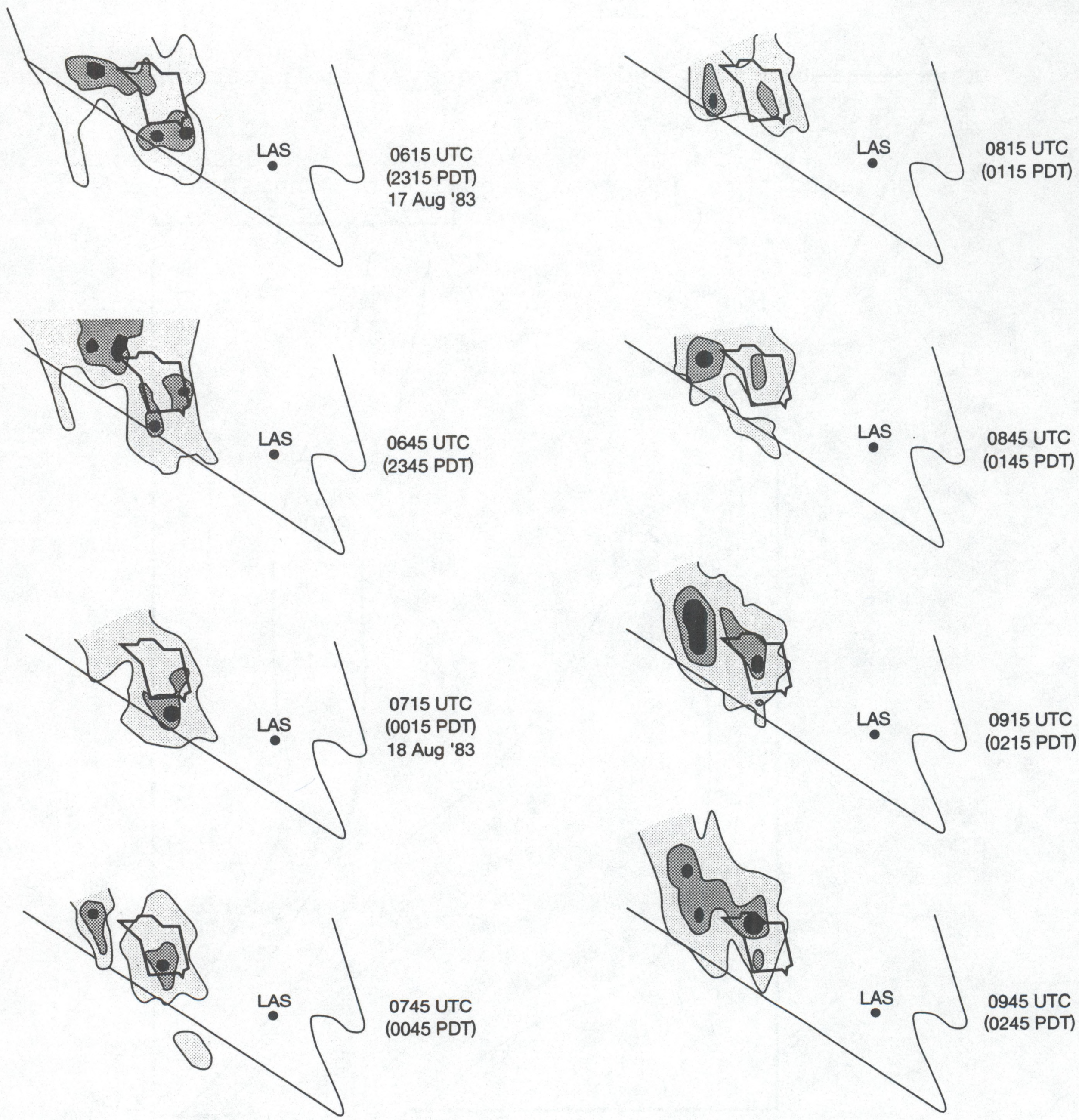


Figure 10b. Schematic representation of infrared satellite imagery of cloud elements in the vicinity of the Nevada Test Site (outline shown) August 17-18, 1983, prior to and during the time of heavy precipitation. Light shading includes cloud top temperature between -30° and -39°C, moderate shading -40° and -44°C, and black shading -45° and -49°C.

tops persisted over the area of heavy precipitation for three to four hours.

<u>1984</u>: The 1984 thunderstorm season over the desert southwest was extraordinary and would require a monumental effort to describe and document. Only a brief overview is given here. In Las Vegas, 1984 began as the driest year on record with only 0.07 in (1.8 mm) of precipitation falling between January 1 through June 28 (180 days) at the NWS station at McCarran International Airport (LAS). There was no measurable precipitation for 83 consecutive days (April 8 through June 28); then it began to rain. The summer of 1984 was the wettest on record over parts of the desert southwest, and, in Las Vegas, 1984 ended as the sixth wettest summer on record (6.85 in, 174 mm). July 1984 was the wettest July on record (2.48 in, 63 mm) for Las Vegas, and the seventh wettest month overall. Between June 30 and September 11 there were at least nine major flash flood episodes somewhere in the Las Vegas Valley. Three of these floods covered most of the valley.

In July and August, some observed rainfall amounts were exceptional for the southern Nevada region and the duration of rainy weather was extreme. During the 57-day period from June 30 through August 25, there were at least 15 days with heavy thunderstorms and/or flooding. Most of this activity was focussed within two lengthy periods; namely, July 15 through 28 and August 13 through 20. In Las Vegas, extensive flooding occurred over large parts of the valley on July 15, 22, 27, and 28th. Two people died in a flash flood on July 22. Flood damage was estimated in excess of $5,000,000 and some individual losses were great. Thunderstorms on these days were widespread over most of southern Nevada. Storm total rainfall amounts of 1.0 to 2.0 in (25.4 to 50.8 mm) were measured at many sites; however, the greatest daily observed total was at Elgin, NV, on July 23rd, with 4.09 in (104 mm) reported. The greatest hourly precipitation rate, 1.29 in/hr (32.8 mm/hr) was measured at the NWS office in Las Vegas during the thunderstorm on July 28th. Several significant heavy rain and flood events also occurred in August, on the 13, 14, 19, and 25th. The greatest daily total reported was 3.72 in (94.5 mm) at Boulder City on August 14th. The final major thunderstorm event of the summer occurred during the afternoon of September 10. Within a 45-min period, 0.68 in (17.3 mm) of rain fell in a heavy thunderstorm accompanied by small hail at the author's home in Las Vegas, flooding was reported in Henderson, and the cooperative observer in Boulder City recorded a daily total of 2.63 in (66.8 mm).

Preceding the wet summer, on May 30, a strong, thunderstorm-generated microburst occurred on the NTS between Desert Rock (DRA) and Mercury. Mercury is located 3 mi (5 km) northeast of DRA. The data documenting this event are compelling.

Between 0400 and 0415 UTC (2100 and 2115 PDT) a thunderstorm developed near Desert Rock. At 0413 UTC the weather observation for DRA was TRW- with wind from the northeast 20 kts (10 m/s) with gusts to 43 kts (22 m/s). At 0415 UTC the surface wind measured by an anemometer on a wind tower in Mercury was west-southwest 17 kts (9 m/s) with a peak gust of 76 kts (39 m/s). The observer at DRA reported the thunderstorm was moving northeastward. In addition, 30 vehicles were damaged in Mercury along with damage to roofs and windows. There was one report that 16 windshields were "popped out" of some vehicles.

August 8, 1989: A severe thunderstorm, accompanied by microbursts (Scott, 1990), developed near McCarran International Airport and Sky Harbor Airport (SKH) at approximately 1800 PDT (0100 UTC). Both airports are located south of downtown Las Vegas; however, Sky Harbor is approximately 10 mi (16 km) south of McCarran. A peak wind gust of 78 kts (40 m/s) was detected at 1805 PDT (0105 UTC) by a NWS anemometer prior to power loss and a wind gust to 90 kts (46 m/s) was measured by an FAA wind sensor at mid-field. Weather conditions changed rapidly during the microburst incident. At 1750 PDT (0050 UTC) the NWS weather observation at McCarran was TRW- with surface wind gusts to 42 kts which became W0X0 T+RW+ with gusts to 78 kts and continuous cloud-to-ground lighting all quadrants at 1805 PDT (0105 UTC). By 1815 PDT (0115 UTC) conditions had improved to TRW- with calm winds. The thunderstorm produced 0.41 in (10.4 mm) of rain and dense blowing dust. Total damage at both airports was estimated at 14 million dollars which included damage to 82 aircraft. There were no deaths or serious injuries; however, two aircraft experienced dangerous wind shear conditions on takeoff and landing at McCarran.

July 18, 1994: A mesoscale convective system similar to that of August 10, 1981, developed in early afternoon (approximately 2100 UTC) near the Desert Range Experimental Station in west central Utah. As this thunderstorm system developed, it moved southwestward into southern Nevada, reaching the northeastern part of the Las Vegas valley at approximately (0200 UTC). Intense and persistent convection developed within a region of significant low-level convergence created by the storm mesoscale outflow boundary and near-surface southwesterly flow.

Based on the 0000 UTC upper-air sounding from Desert Rock, NV, the atmosphere was unstable with a K index of 30 and a lifted index of -2. In addition, sub-cloud-layer winds were southwesterly 10-15 kts (5-8 m/s) and cloud-layer winds (between 700 and 200 mb) were, in general, light northeasterly. Consequently, sub-cloud air had a strong component of relative motion toward the approaching storm.

Furthermore, prior to storm arrival, surface dew-point temperatures were in the mid to upper 50s and dry-bulb temperatures reached 102°F (39°C).

First official weather reports from the vicinity of the storm came from Nellis Air Force Base (LVS), located northeast of downtown Las Vegas. At 0245 UTC, Nellis observers reported T+RW+ with visibility 1/16 mi, wind gusts to 60 kts (30 m/s), 1/8 in (3.2 mm) hail, and frequent lightning. A total of 1.24 in (31 mm) of rain fell over a two-hour period during the storm. At 0312 UTC the NWS office at McCarran International Airport reported a TRW- with wind gusts to 62 kts (32 m/s). Only 0.1 in (2.5 mm) of rain fell at the NWS office. Surface temperatures cooled by approximately 35°F (19°C) from the afternoon maximum to the minimum measured during the thunderstorm. Based on lightning detection data (Fig. 11a) and satellite imagery (Fig. 11b), the storm system appears to have reached maximum intensity between 2300 and 0100 UTC (1600 and 1800 PDT).

The ARL/SORD lightning detection system began to detect storm related cloud-to-ground lightning at approximately 2000 UTC (1300 PDT). The hourly lightning flash rate from this storm is plotted in Fig. 11a. This figure shows a dramatic increase in hourly flash rate from 2000 UTC (1300 PDT) to 0000 UTC (1700 PDT) when the peak flash rate (590 flashes/hr) was detected. In addition, the data reveal that during the period of flash rate growth, there were few positive flashes. The great majority of the positive flashes occurred between 0000 and 0400 UTC (1700 and 2100 PDT). Based on the available satellite imagery (Fig. 11b), the coldest IR cloud-top temperature (approximately -65°C) was reached at roughly 0300 UTC (2000 PDT). At this time the areal extent of the MCS reached maximum size. The area enclosed within the -32°C contour was approximately 100,000 sq. km, the minimum requirement proposed by Maddox (1980) for a MCS.

There was no loss of life associated with this intense thunderstorm; however, some individuals were injured by flying debris. There was some local street flooding and damage to power lines, trees, homes, and structures. Approximately 50,000 residents lost electrical power as a result of storm damage. The most costly damage was to the 362-ft marquee at the Las Vegas Hilton Hotel. This marquee was advertised as the largest free-standing sign in the world.

August 23, 1995: Runk (1996) melded Doppler radar observations with satellite imagery, mesonet wind data, and synoptic weather observations to study the development of a heavy thunderstorm that formed within a locally generated convergence zone. This storm produced hail up to 1.0 in

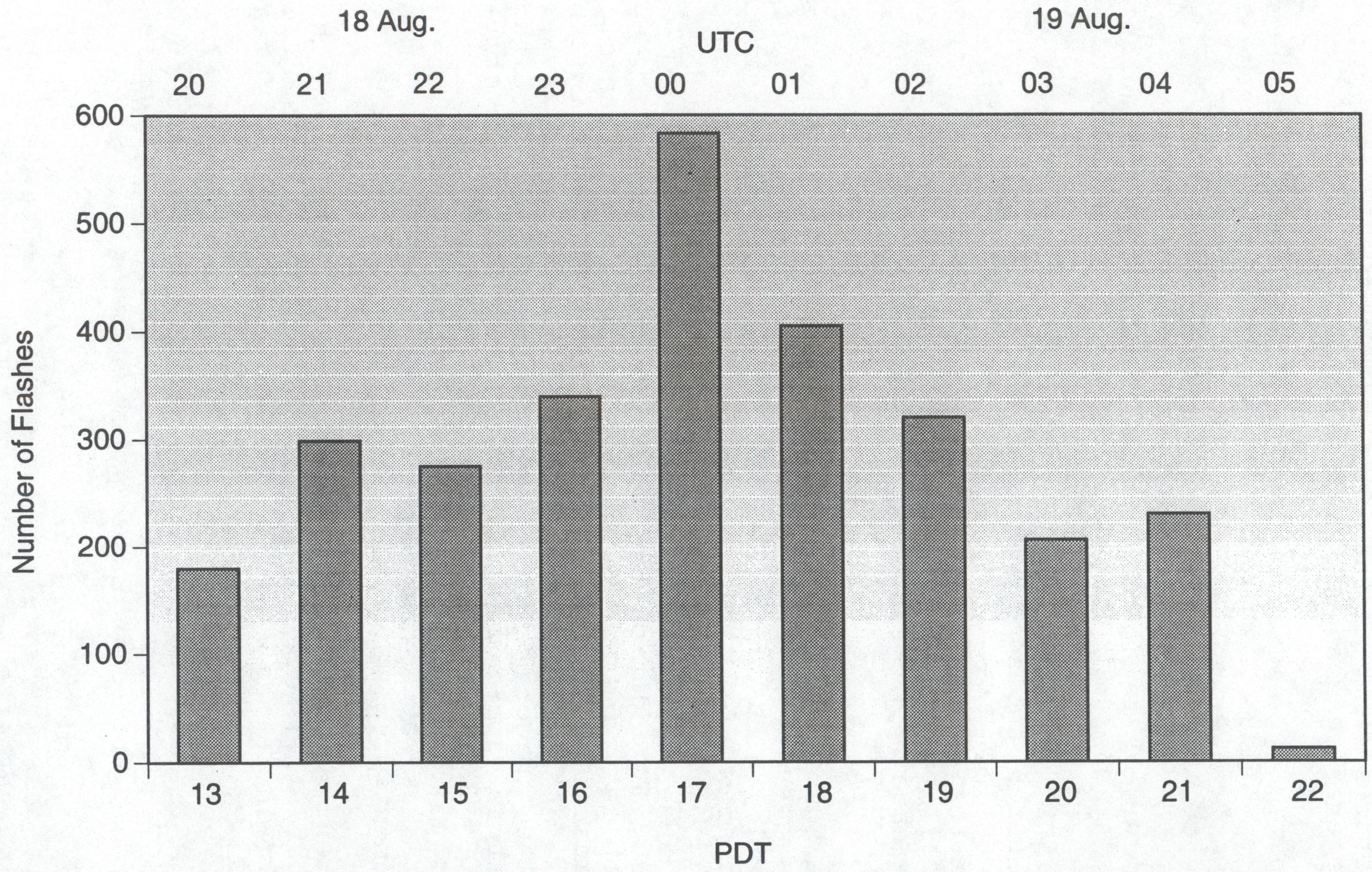


Figure 11a. Cloud-to-ground lightning flash rate in the southern Nevada area July 18, 1994 (PDT).

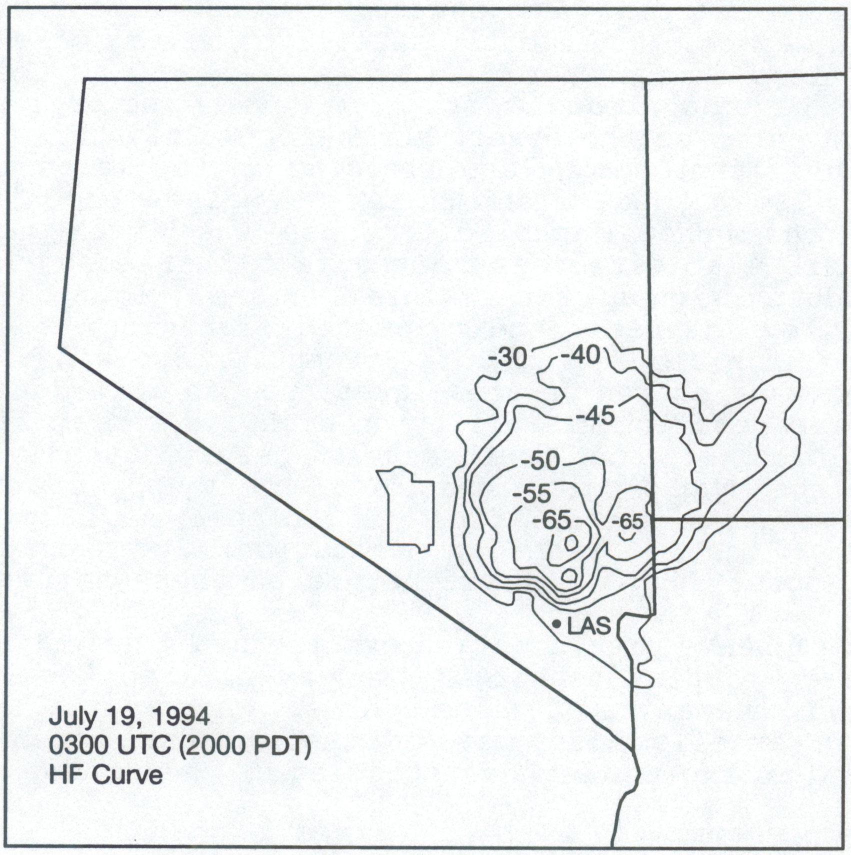


Figure 11b. Schematic representation of infrared satellite imagery of the mesoscale convective system over southern Nevada on July 19, 1994 (UTC). Isotherms are in °C.

(25.4 mm) in diameter and damaging downburst winds over the western part of the Las Vegas valley.

The cases listed above are only a few of those in which heavy precipitation, flooding, and severe storm conditions have occurred in southern Nevada. Radar data, satellite imagery, lightning flash data, and flood damage in remote areas also tell us that many more such storms have developed in southern Nevada and over isolated and uninhabited parts of the desert southwest. Only those storms that produce significant damage and flooding in the large metropolitan areas or in small desert communities receive recognition by the media and the general public. Those who live in the desert southwest are also witnesses to the fact that many thunderstorms don't produce significant rainfall (see Fig. 5a), but are accompanied by intense cloud-to-ground lightning, strong surface winds, and thick blowing dust. Strong surface winds can produce significant wave action on area lakes and can loft dense clouds of dust that can restrict visibility on highways and at airports. As the population of the southwestern desert area continues to increase, the hydrologic impacts of heavy precipitation will emphasize the vulnerabilities of people, of property, of communities, and of the communication, transportation, and electrical power supply infrastructure to these natural events.

Prediction of heavy precipitation events in the desert southwest is compounded by complex topography and by limited knowledge on the dynamics and kinematics of these storms. Maddox et al. (1995) have provided an excellent summary of the forecast problem and the growing need to expand our understanding of these dangerous storms.

## VI. FREQUENCY ANALYSES

Frequency analysis is a procedure for estimating the frequency of occurrence or probability of occurrence of past as well as future events. In frequency analysis, the length of the period of record significantly affects the results. To perform sound frequency analyses, the data must be homogeneous and independent. Homogeneity assures that the data are from the same instrument, site, and exposure for the duration of the record. Independence assures that only the extreme annual precipitation event enters the data set for each year, defined as a calendar year in this study. In addition, for the projection of potential future events, the restriction of homogeneity requires the data be representative of future events (e.g. no climatic change).

With regard to identifying an appropriate theoretical distribution, the Water Resources Council (1967) recommended the log Pearson Type III distribution as the basic method for flood frequency analysis. In a follow-up report by Benson (1968), a working group of twelve federal agencies showed that the log Pearson Type III, and Hazen methods all produced equally acceptable results. The group recommended that the log Pearson Type III method be used unless there was a logical reason to use another frequency analysis method. Beard (1974) also recommended the use of the log-normal or the log Pearson Type III distribution with a regionalized skew coefficient to filter bias in flood frequency data. Consequently, in this report, the Pearson Type III distribution is applied to only the primary precipitation data bases in accordance with the procedure described by Benson (1968) and outlined by Haan (1977) and by Viessman et al. (1989). In addition, the normal distribution, as described by Haan (1977), is applied to all data sets used in this report. A normal distribution was used because it was found to fit the data reasonably well, it was simple to apply, and it served as a baseline check for the log Pearson results. Furthermore, since flood events are products of heavy precipitation events, the analyses that follow are based on the assumption that the frequency analysis techniques proposed for flood events can be applied to extreme annual precipitation events.

In the log Pearson distribution, the curve fitting technique required the transformation of n annual maximum daily (or hourly) precipitation depths, $X_i$, to their logarithmic values ($Y_i = \log X_i$) and finding the mean logarithm, standard deviation of the logarithms, $s_y$, and skew coefficients of the logarithms, $C_s$. The transform $Y_i = \log X_i$ is used to reduce skewness. If the skewness is zero, the log Pearson type III distribution reduces to the log-normal distribution. Since $C_s$ has a greater variability than the mean or standard deviation, Beard (1962) suggested the use of only averaged regional coefficients of skew for flood analysis for a single station unless the length of record exceeded 100 yr. In this study, none of the data bases exceeded 60 yr and Beard's concept was adapted.

Detailed records of precipitation from meteorological observatories in the desert southwest are limited. Consequently, assessments of set-hour and daily totals, precipitation rates, and point and regional frequency relations are not easily identifiable for large areas. This limitation is not only due to sparse data but also to significant variations in terrain and to the climatological characteristics of the area (Quiring, 1965 and 1983).

## Las Vegas

### Frequency Analysis: Set-Hour

Annual, set-hour, extreme precipitation events were tabulated and analyzed to determine probability distributions and to assess recurrence intervals or return periods. These data were collected in a standard 8-in recording precipitation gage sited at the NWS office located at McCarran International Airport in Las Vegas, NV, between 1952 and 1994. Hourly precipitation data were collected from the NCDC publication, Hourly Precipitation Data, Nevada. An annual series, consisting of the largest value per year, was then created by ranking the set-hour extremes which are listed in Table 1. This table shows that the maximum set-hour precipitation observed at the NWS office at McCarran International Airport is 1.23 in (31.2 mm). Probability plotting positions were calculated from the commonly used Weibull formula (see Chow, 1964). The results are plotted in Fig. 12. A theoretical normal line is drawn through the mean plus one standard deviation at 84.1% and the mean minus one standard deviation at 15.9%. The normal distribution fits the data reasonably well.

Calculations for the log Pearson distribution were made in accordance with the procedure outlined by Haan (1977) and by Viessman et al. (1989). This procedure is designed to determine the weighted factor for minimizing the variance of the skew. The results are itemized in Table 12 and are plotted in Fig. 13. The data tabulated in Tables 1 and 12, and the data plotted in Figs. 12 and 13 show that both the normal and Pearson Type III distributions fit the observations well. However, there appears to be more data scatter about the Pearson than about the normal line which is due to the scaling. For a recurrence interval of 100 years the Pearson yields a set-hour value of 1.66 in (42.2 mm) while the normal line gives 1.44 in (36.6 mm). At 200 yrs, the difference is even greater, the Pearson is 1.97 in (49.3 mm) and the normal line 1.60 in (40.6 mm). Limited climatological data are available to validate these amounts. Only the maximum one-hour precipitation rate of 1.98 in (50.3 mm) that fell within a 1-hr period during an intense thunderstorm on July 23, 1923, is available for independent comparison. The measurement of precipitation from this storm was taken in the downtown part of Las Vegas, approximately 6 mi (10 km) north of McCarran International Airport. This precipitation rate corresponds with the Pearson calculated value (1.97 in, 50 mm) for a return period of 200 yr. Based on this limited comparison, the extreme values developed from the log Pearson Type III distribution should provide useful guidance for flood control design in southern Nevada.

## Frequency Analysis: 24-hr

Annual 24-hr maximum precipitation data for Las Vegas for 1949 through 1994 were extracted from the NCDC publications, Local Climatological Data: Monthly Summary. The data for this 46-yr period are tabulated and ranked in Table 2. The data in this table show that the maximum 24-hr precipitation total for Las Vegas is 2.59 in (65.8 mm). This heavy rainfall event was associated with a dissipating tropical storm that entered the desert southwest in August 1957. The minimum 24-hr maximum precipitation for Las Vegas was 0.11 in (2.8 mm) in October 1953, the driest year on record with a total annual precipitation of only 0.56 in (14.2 mm).

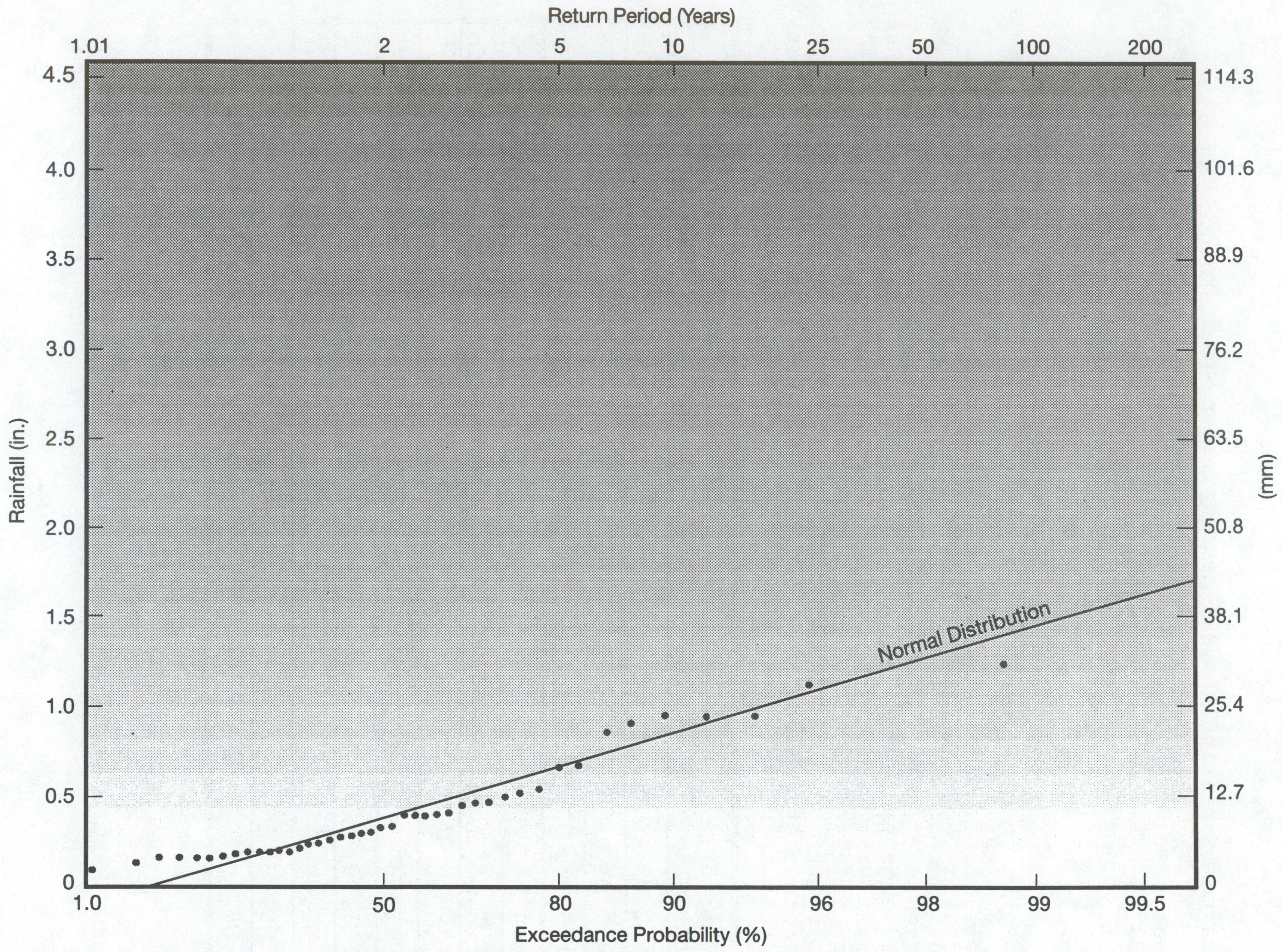


Figure 12. Annual maximum set-hour precipitation versus return period for Las Vegas, Nevada, 1952 through 1994 with a fit to a normal distribution.

Table 12. Tabulation of calculated values of Las Vegas, NV, set-hour extreme precipitation based on the log Pearson Type III distribution and weighted skew, $S_w = \alpha S_s + (1-\alpha) S_m$, where N = 43, $S_s = 0.1602$, $S_m = 0$, and $V(S_m) = 0.03025$ so that $S_w = 0.03$. Also, $Log_{10}P = M + KS$ where M is the mean $log_{10}$ of the data (-0.4638) and S is the standard deviation $log_{10}$ (0.2915). The recurrence interval is in years and P is the calculated set-hour precipitation for the specified recurrence interval.

| Recurrence Interval | Percent Chance | Frequency Factor, K | $Log_{10}P$ | P (in) |
|---|---|---|---|---|
| 1.01 | 99 | -2.3038 | -1.1350 | 0.07 |
| 1.05 | 95 | -1.6363 | -0.9408 | 0.11 |
| 1.11 | 90 | -1.2784 | -0.8364 | 0.15 |
| 1.25 | 80 | -0.8408 | -0.7088 | 0.20 |
| 2.00 | 50 | 0.0030 | -0.4646 | 0.34 |
| 5.00 | 20 | 0.8402 | -0.2189 | 0.60 |
| 10.00 | 10 | 1.2850 | -0.0892 | 0.81 |
| 25.00 | 4 | 1.7610 | 0.0495 | 1.12 |
| 50.00 | 2 | 2.0699 | 0.1396 | 1.38 |
| 100.00 | 1 | 2.3482 | 0.2207 | 1.66 |
| 200.00 | 0.5 | 2.6042 | 0.2953 | 1.97 |

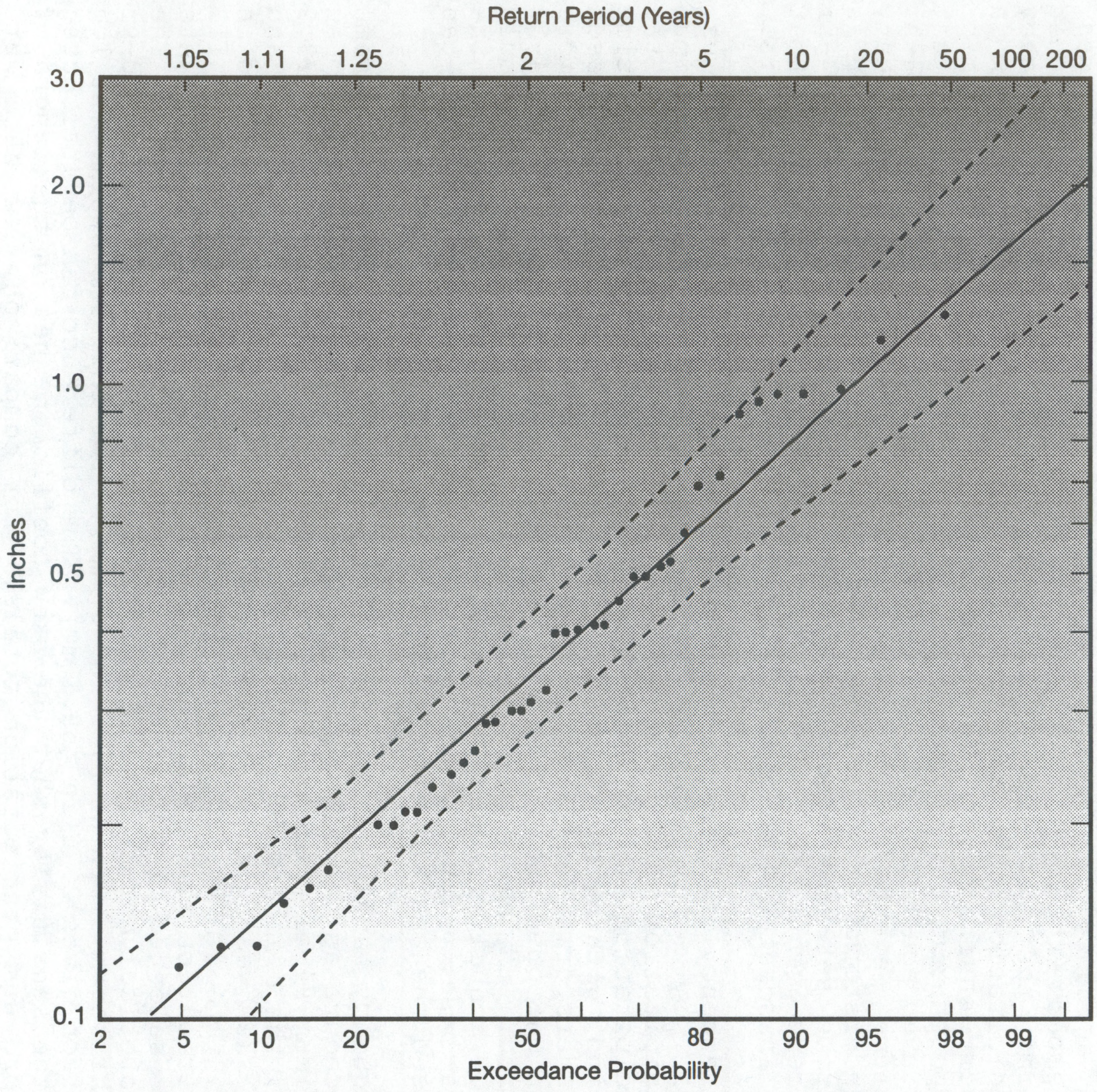


Figure 13. Log Pearson Type III fit for annual maximum, set-hour precipitation events for Las Vegas, Nevada, for 1952 through 1994. Observations are plotted as black dots. Dashed lines enclose 95% confidence limits. Solid line is the log Pearson Type III fit to the data.

Extreme 24-hr precipitation events can occur in any month; however, there is a pronounced seasonal preference. Figure 3a contains a graphical representation of the monthly distribution of the annual maximum 24-hr precipitation events spanning the 46-yr period for this data base. The figure shows that 24-hr extreme events have occurred in every month; however, there are two obvious preferences; November and August. November is the primary maximum and accounts for approximately 20% of the total occurrences. November extreme events are the result of macroscale cyclonic storms that are associated with lengthy periods of steady precipitation that can accumulate to significant totals for a desert environment. These cold season storms are usually mid-tropospheric, cut-off, cold-core cyclonic systems that develop just off the southern California coast. By contrast, August 24-hr extreme events (15%) are usually associated with heavy thunderstorms (or rainshowers) so that many (35%) also appear as extreme set-hour events. However, some (<1%) summertime 24-hr extreme events are the result of dissipating tropical cyclones that are associated with continuous rain that can last for many hours.

A frequency analysis of these data does contain some ambiguities. First, by definition, the 24-hr maxima specify that the maximum precipitation fell during the 24-hr period; however, the precipitation was more likely to have fallen over a shorter time period **within** the 24-hr period; especially for warm season thunderstorms (see Fig. 5a). Second, there could have been more than one precipitation event (e.g. thunderstorm) within the 24-hr period. Third, more than one heavy precipitation event could occur annually; however, only the extreme event is included in the data base. Fourth, the second greatest event in one year can exceed the annual maximum for another year.

Frequency analysis of the 24-hr extremes followed the same procedure as described for the set-hour extreme events. The mean maximum 24-hr precipitation for the 46-yr period is 0.94 in (23.9 mm), the standard deviation of the sample is 0.43 in (10.9 mm), and the skew was calculated to be 1.22. The normal plot is graphed in Fig. 14. The calculated values for the log Pearson Type III distribution are listed in Table 13 and the precipitation amounts for selected return periods are plotted in Fig. 15. The theoretical normal line fits the data nicely and indicates a 100-yr 24-hr storm depth of 2.35 in (60 mm). For the same storm, the log Pearson gives 2.72 in (69.1 mm). The difference can be attributed to the sensitivity that the skew coefficient has on the length of record and precipitation totals. For comparison, the data were also fit to a log-normal distribution. The 100-yr, 24-hr event for the log-normal is 2.37 in (60.2mm), essentially the same as the normal distribution. The observed annual maximum 24-hr event for this location is 2.59 in (65.8 mm) which is approximately halfway between the normal and log Pearson estimates.

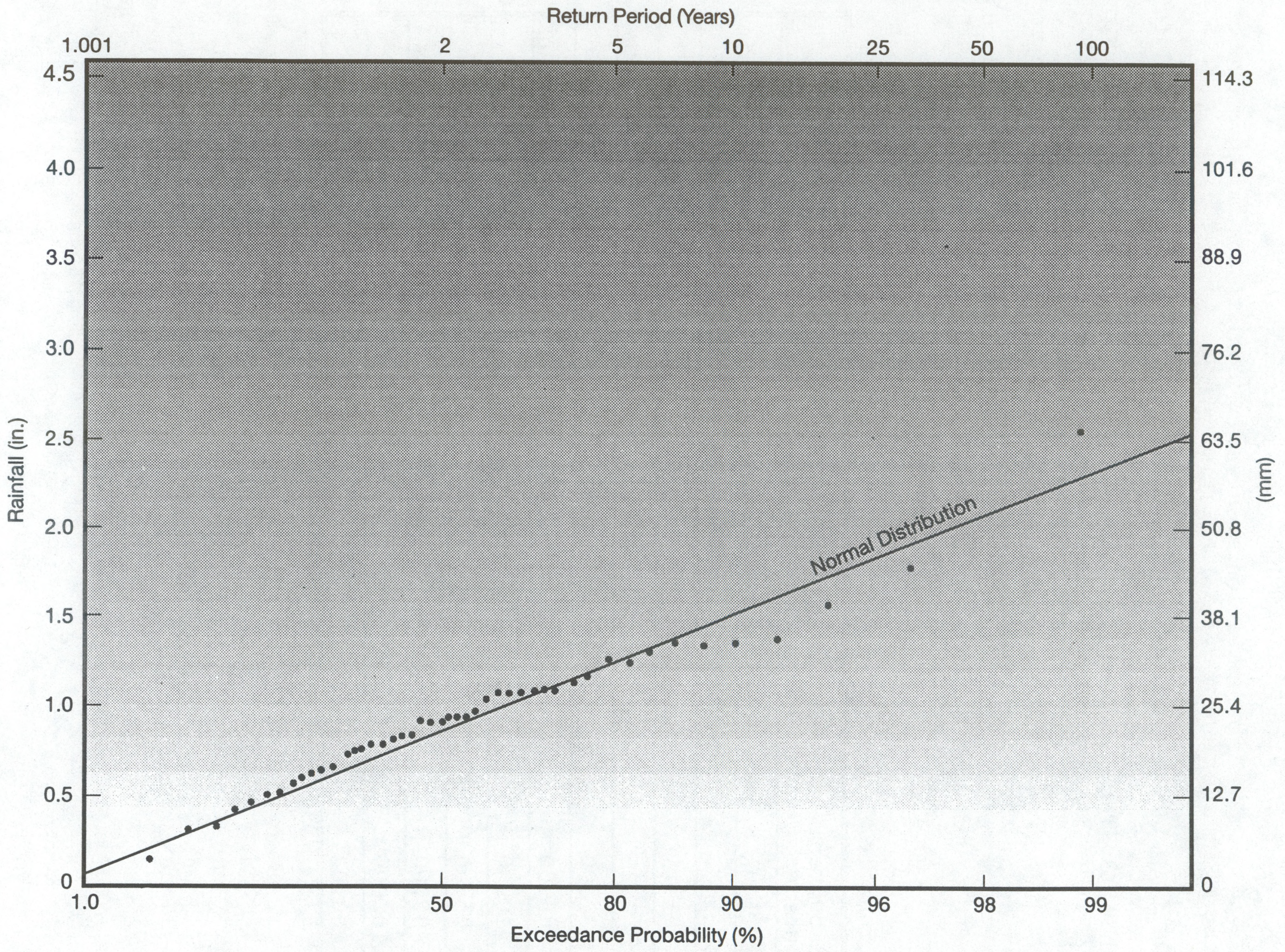


Figure 14. Annual maximum daily precipitation versus return period for Las Vegas, Nevada, 1949 through 1994 with a fit to a normal distribution.

Table 13. Tabulation of calculated values of Las Vegas, NV, 24-hour extreme precipitation events based on the log Pearson Type III distribution and weighted skew, $S_w = \alpha S + (1-\alpha) S_m$, where N = 46, $S_s = -1.3608$, $S_m = 0$, and $V(S_m) = 0.03025$ so that $S_w = -0.118$. Also, $Log_{10}P = M + KS$ where M is the mean $\log_{10}$ of the data (-0.0765) and S is the standard deviation $\log_{10}$(0.2283). The recurrence interval is in years and P is the calculated set-hour precipitation for the specified recurrence interval in inches.

| Recurrence Interval | Percent Chance | Frequency Factor, K | $Log_{10}P$ | P (in) |
|---|---|---|---|---|
| 1.01 | 99 | -2.4130 | -0.6270 | 0.24 |
| 1.05 | 95 | -1.6779 | -0.4596 | 0.35 |
| 1.11 | 90 | -1.2936 | -0.3718 | 0.42 |
| 1.25 | 80 | -0.8289 | -0.2657 | 0.54 |
| 2.00 | 50 | 0.0199 | 0.0720 | 0.85 |
| 5.00 | 20 | 0.8467 | 0.1168 | 1.31 |
| 10.00 | 10 | 1.2678 | 0.2129 | 1.63 |
| 25.00 | 4 | 1.7095 | 0.3138 | 2.06 |
| 50.00 | 2 | 1.9900 | 0.3778 | 2.39 |
| 100.00 | 1 | 2.2386 | 0.4346 | 2.72 |
| 200.00 | 0.5 | 2.4650 | 0.4862 | 3.06 |

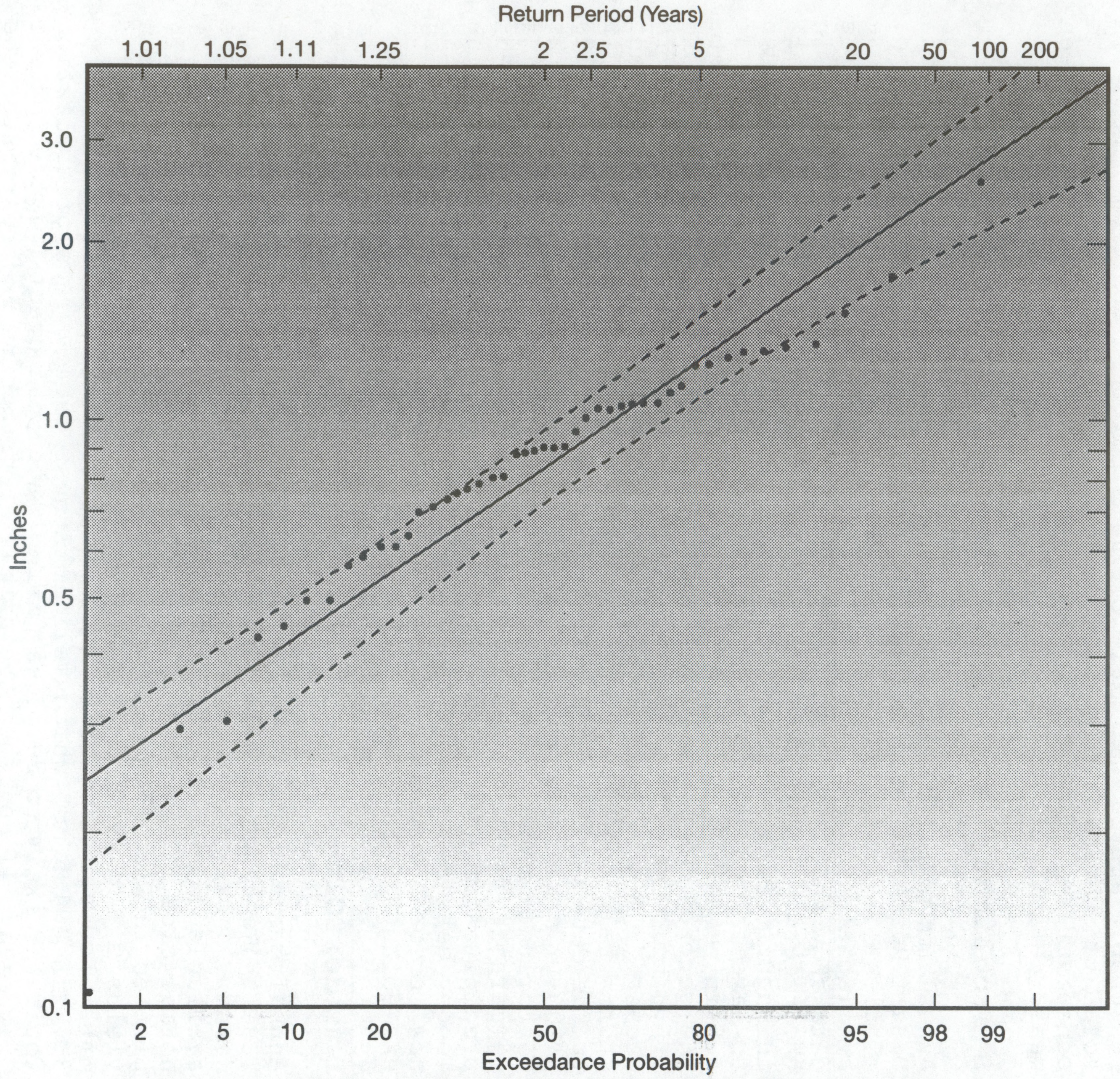


Figure 15. Plot of Log Peason Type III distribution of annual maximum 24-hr precipitation totals for Las Vegas, Nevada, for 1949 through 1994, with 95% confidence limits.

NOAA Atlas 2 (Miller, Fredrick, and Tracey, 1973), for Nevada, resents a 100-yr 24-hr precipitation depth of approximately 2.9 in (73 mm) for Las Vegas. This value is slightly larger than those calculated from the much longer data record used in this report. Consequently, for a design storm for the Las Vegas Valley, a reasonable approach would be to use the log Pearson projected storm total of 2.7 in (69 mm) or to round up to 3.0 in (76 mm) to be conservative. Remember, storm totals of 3.0 in (76 mm) have been measured in the Las Vegas Valley.

## Searchlight

Annual maximum daily precipitation amounts were obtained from the Desert Research Institute (DRI) climatological data base for Nevada (Table 6). Daily precipitation totals for 1949 through 1994 were available from a cooperative observer station in the city. The data show that several heavy precipitation events are contained in the record. The maximum daily event is 4.50 in (114 mm) which fell in August 1982. This event exceeds the 4.05 in (103 mm) reported to have fallen during a tropical storm in 1939. Consequently, the 4.5-in total may be viewed as the historical event for Searchlight. The second and third ranked events are also quite large, 3.81 in (96.8 mm) and 3.2 in (81 mm), with the larger event occurring in August 1978 and the other in September 1976. These significant storms help contribute to a rather steep slope for the normal fit to the data plotted in Fig. 16. The theoretical normal line yields a 100-yr maximum daily total of 4.25 in (108 mm) which is near the historical event for this site. NOAA Atlas 2 (1973) shows a comparable value of nearly 4.0 in (102 mm) for the 100-yr 24-hr precipitation event. The small difference can be explained by the longer data record used to develop Fig. 16 and to the fact that the new record contained three additional annual extreme events exceeding 3.0 in (76 mm).

## Boulder City

Annual maximum daily precipitation amounts were obtained from the Desert Research Institute (DRI) climatological data base for Nevada. Daily precipitation totals for 1940 through 1994 were available from a cooperative observer station in the city. The normal plot of the data along with the theoretical normal line are plotted in Fig. 17. This figure shows that the normal distribution yields a 100-yr daily extreme precipitation event of 3.0 in (76 mm). However, the 55-yr data record contains a daily maximum of 3.72 in (94.5 mm) which fell in August 1984. This precipitation total is likely to be close to the historical event for the Boulder City area. If so, then the normal distribution underestimates the 100-yr daily storm total by 0.72 in (18.3 mm). In a similar manner, NOAA Atlas 2 (1973) projects approximately 3.0 in (76 mm) as the 100-yr 24-hr extreme precipitation event; also a significant underestimate.

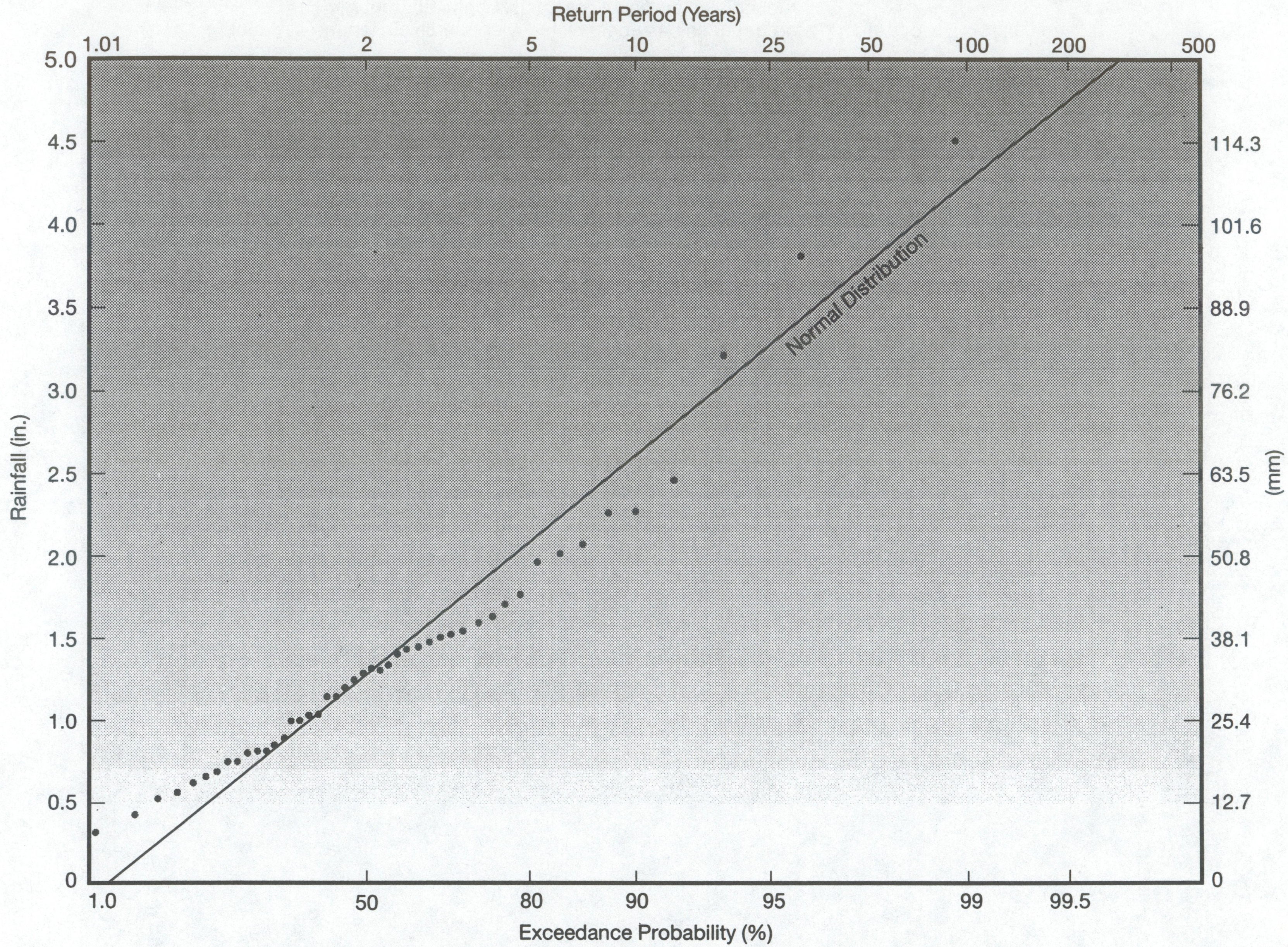


Figure 16. Annual maximum daily precipitation versus return period for Searchlight, Nevada, 1949 through 1994 with a fit to a normal distribution.

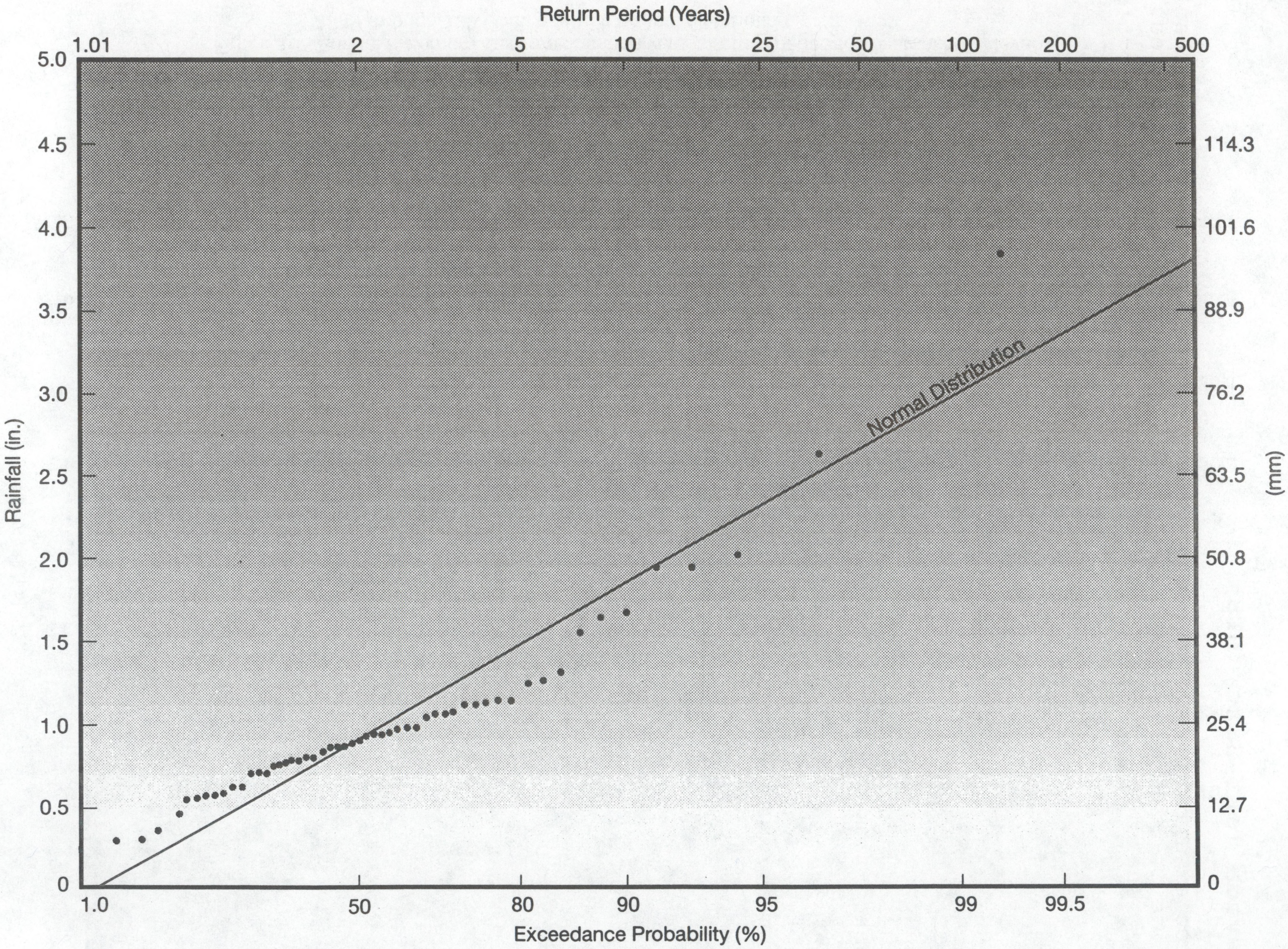


Figure 17. Annual maximum daily precipitation versus return period for Boulder City, Nevada, 1940 through 1994 with a fit to a normal distribution.

## Nevada Test Site (NTS)

Precipitation data for the NTS contain more spatial detail than those for the Las Vegas area but are for a shorter time period. Comprehensive observations and record keeping at a fully operational station did not begin until January 1962. Moreover, this observatory, located in Yucca Flat until April 1978, was moved to the Desert Rock facility in June 1978. The Desert Rock facility has been fully operational since this move.

Precipitation data for the NTS were collected from the ARL/SORD climatological data base. Data were retrieved from the Desert Rock Meteorological Observatory (DRA), the Yucca Flat Observatory (UCC), and from Station 4JA in Jackass Flat (see Fig. 1 for locations). The daily precipitation totals were extracted, tabulated, and ranked prior to frequency analysis. The station with the best record was 4JA and, therefore, the data from this station was subjected to both normal and log Pearson Type III frequency analyses. Data from DRA and UCC were only fit to a normal distribution. Although UCC has a longer record, the instrumentation was changed from a stick gauge to a tipping bucket in 1978. Therefore only the normal plots are shown for these two sites in Figs. 19 and 20. The normal plot for 4JA is shown in Fig. 18. Both DRA and 4JA experienced a historical type precipitation event on August 18, 1983, when 3.52 in (89.4 mm) fell at DRA and 3.22 in (81.8 mm) fell at 4JA. UCC received only 2.12 in (53.8 mm) from this event which focused precipitation on the southern and western parts of the NTS (Fig. 10a). The largest totals were over the southern third of the NTS. The greatest daily total measured on the NTS was 3.63 in (92.2 mm) at Mercury, just 2 mi (3.2 km) northeast of DRA. Due to this event, the slopes of the theoretical normal lines for DRA and 4JA are steeper than for UCC and, therefore, yield a 100-yr daily precipitation event that is approximately 1.0 in (25 mm) greater than that for UCC (Table 5). Consequently, the frequency analyses containing this assumed historical event are believed to be more representative of a future potential extreme event than other stations in the area. Figures 18 and 19 show that the 100-yr daily extreme precipitation event for DRA is estimated at 3.75 in (95.3 mm) and that for 4JA is 3.56 in (90.4 mm).

The log Pearson Type III analysis for 4JA is shown in Fig. 21. The log Pearson fit to the data is good. The 95% confidence limits are represented by the dashed lines. For a 100-yr daily precipitation event, the log Pearson yields 3.64 in (92.5 mm) and a 500-yr event gives 5.0 in (127 mm). The log Pearson 100-yr calculation exceeds the historical event by 0.42 in (10.7 mm) but matches the historical event for Mercury, 3.63 in (92.2 mm), within the precision of the instruments and the data base. Mercury is located 20 mi (32 km) southeast of 4JA.

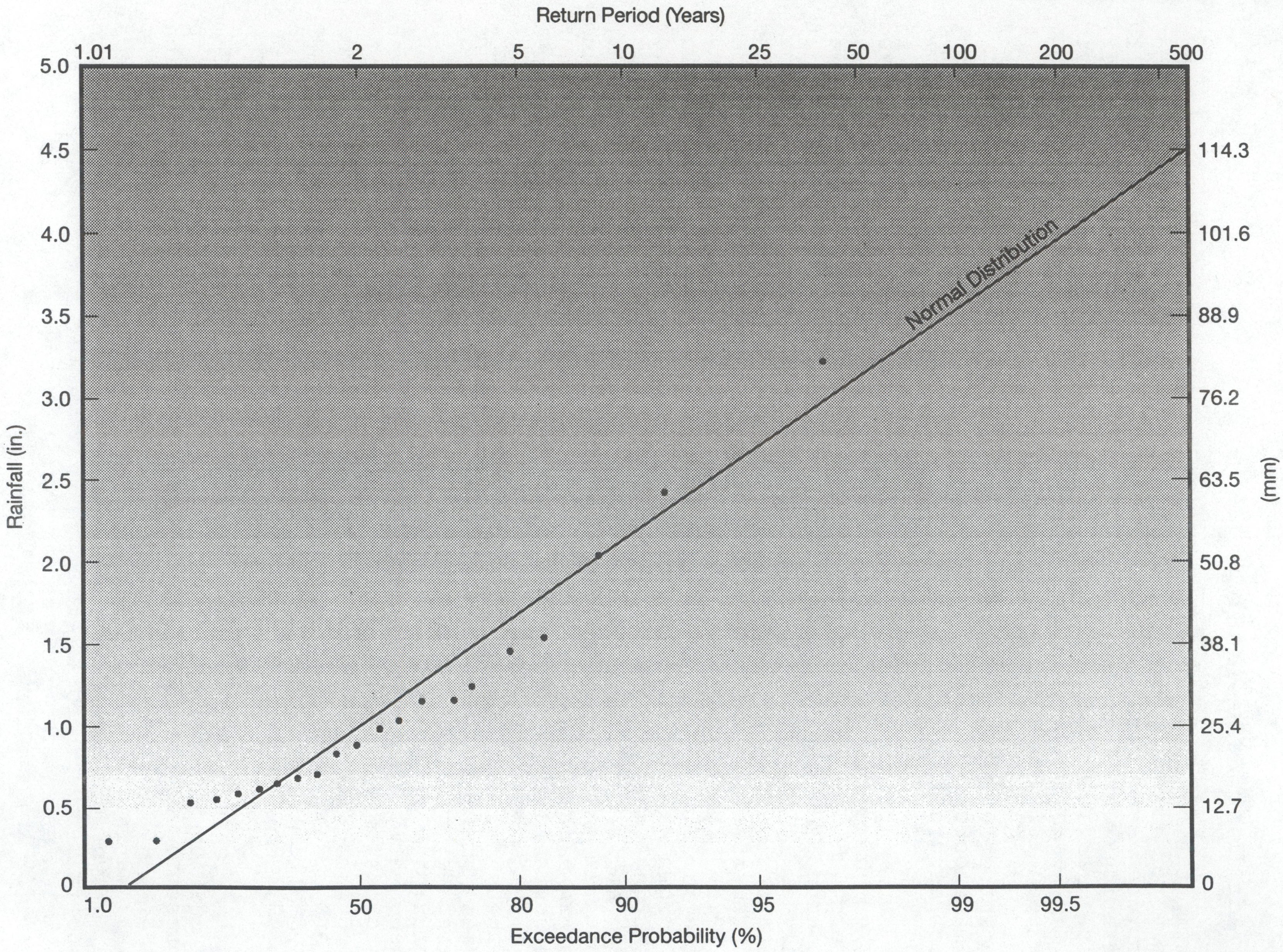


Figure 18. Annual maximum daily precipitation versus return period for Jackass Flats (4JA), 1976 through 1995, with a fit to a normal distribution.

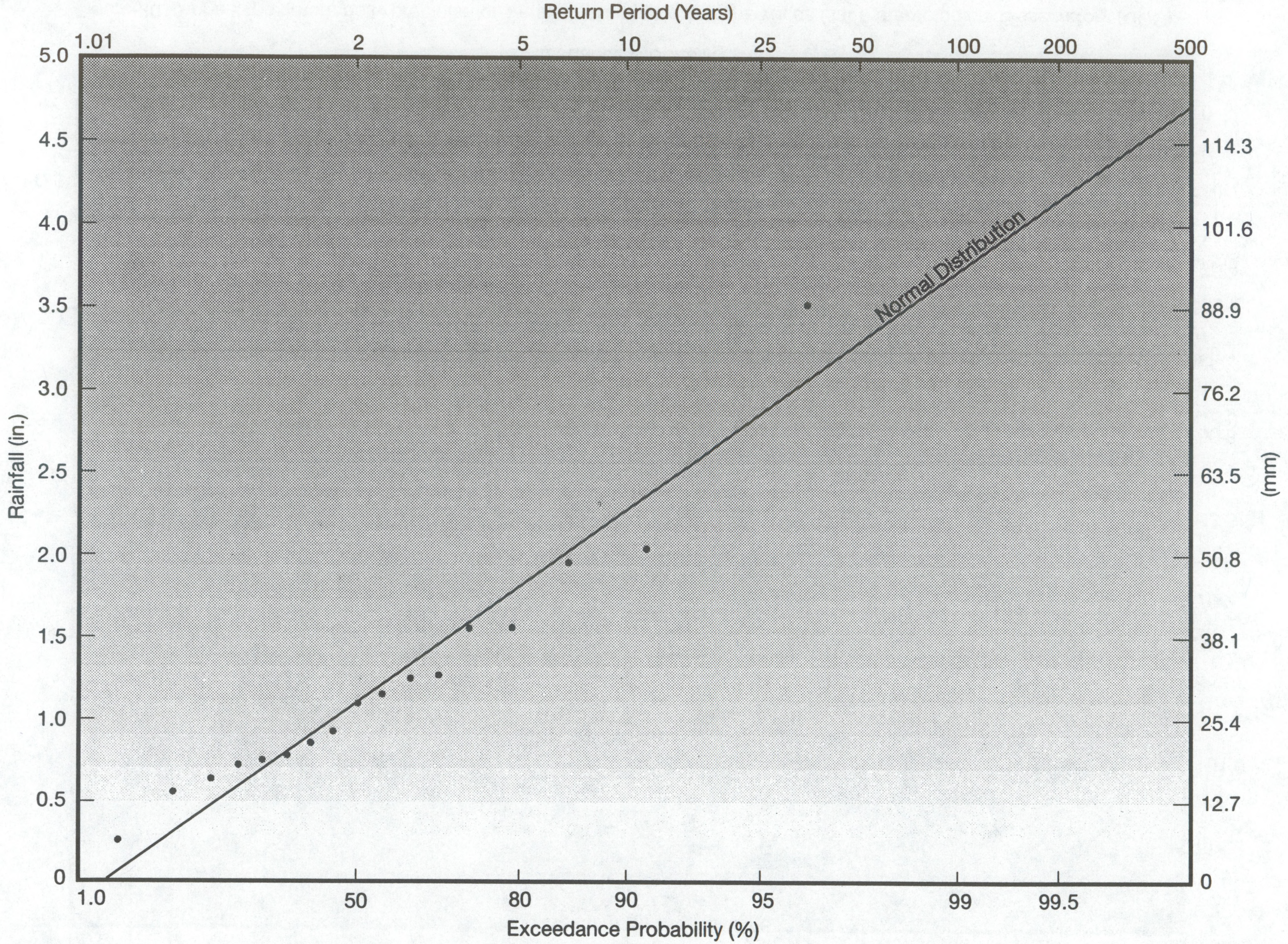


Figure 19. Annual maximum daily precipitation versus return period for Desert Rock, Nevada, 1979 through 1995 with a fit to a normal distribution.

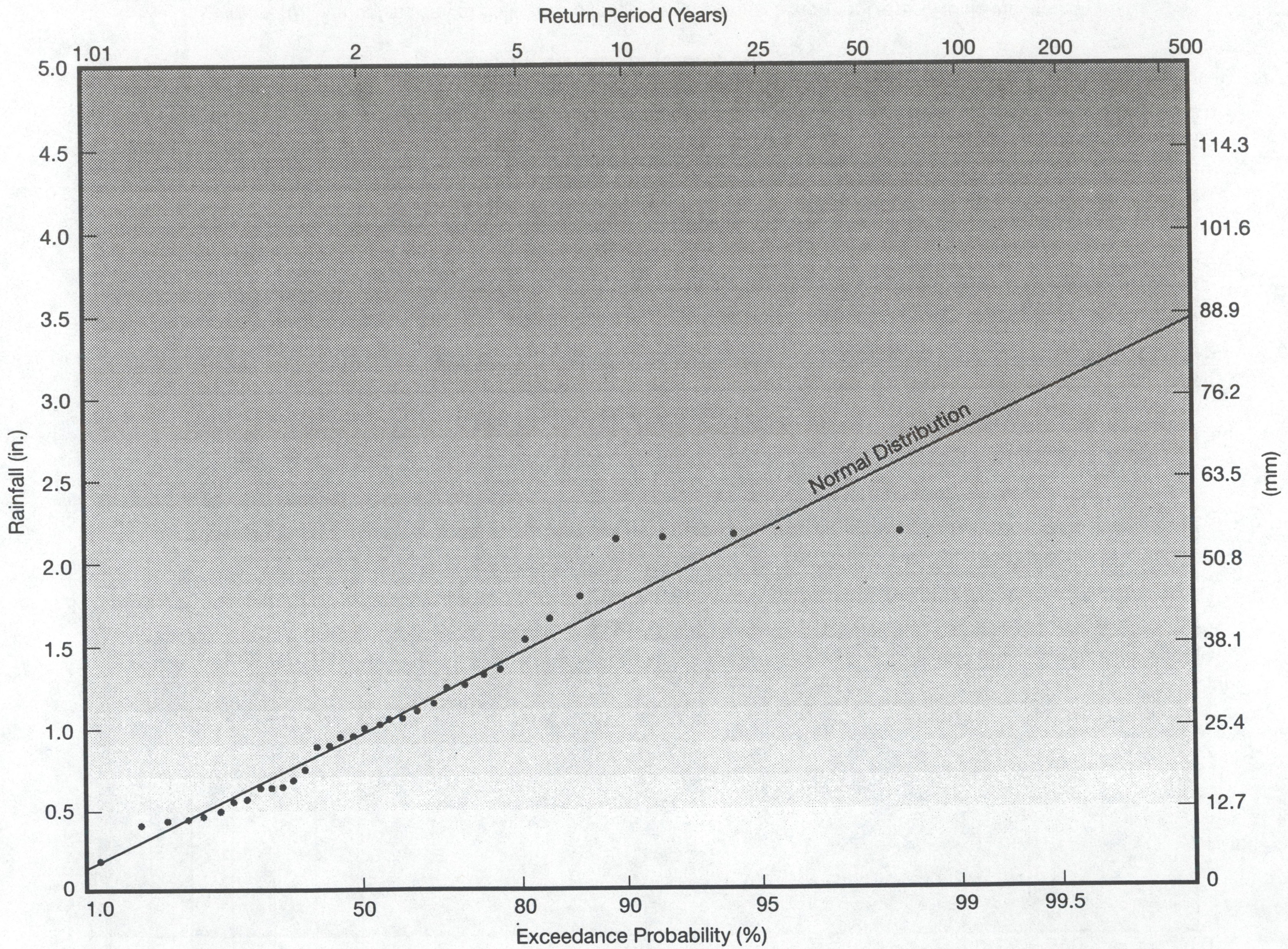


Figure 20. Annual maximum daily precipitation versus return period for the Yucca Flat Meteorological Observatory (UCC), 1962 through 1995, with a fit to a normal distribution.

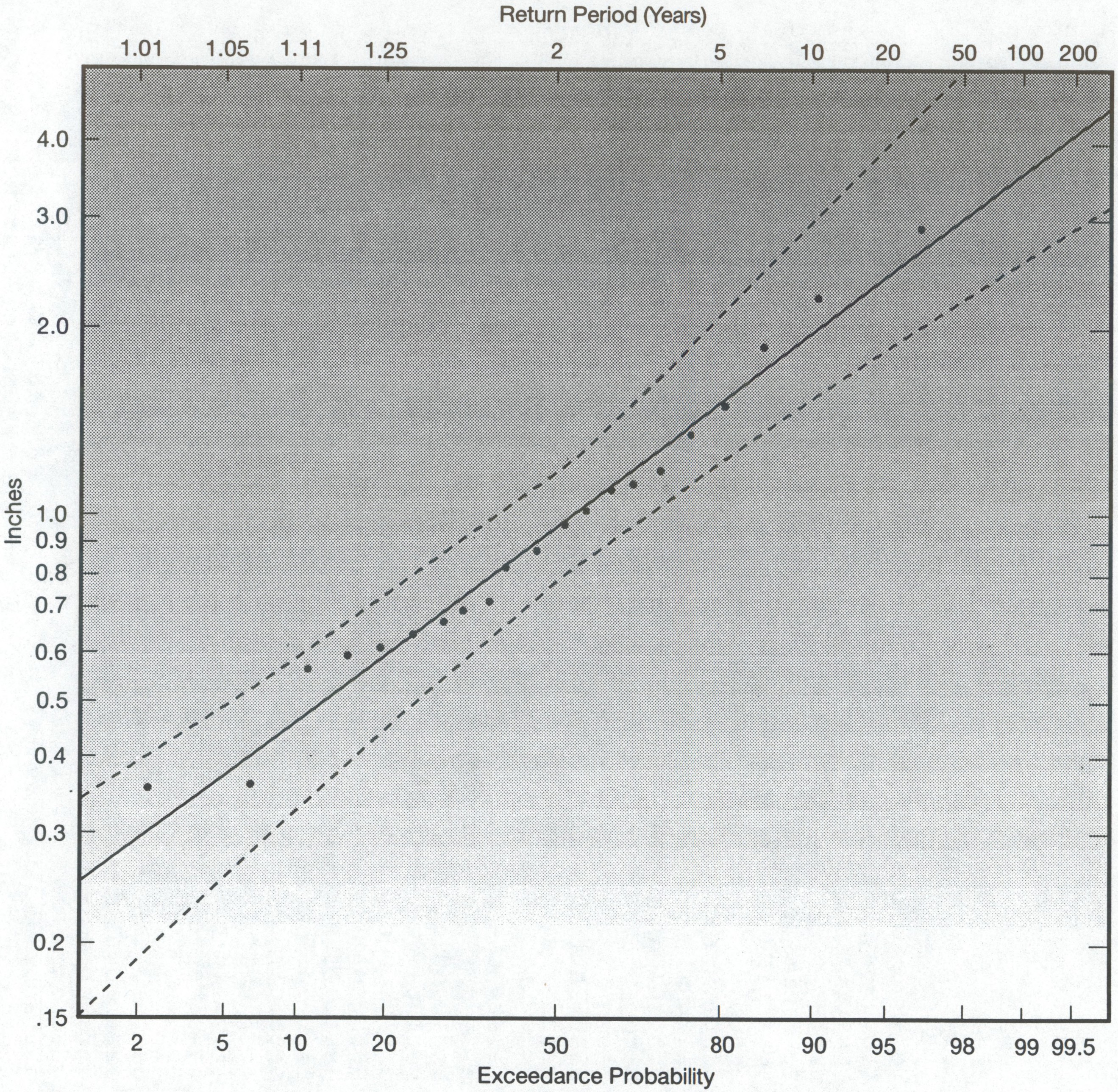


Figure 21. Log Pearson Type III fit to annual maximum daily precipitation totals for Jackass Flat, (4JA), 1976 through 1995. Dashed lines enclose 95% confidence limits.

NOAA Atlas 2 (1973) projects 2.6 in (66 mm) as the 100-yr 24-hr extreme precipitation event at 4JA and approximately 2.5 in (64 mm) for UCC and DRA. Consequently, **NOAA Atlas 2 seriously underestimates the 100-yr 24-hr extreme event for the southern half of the NTS.**

The differences between the precipitation frequency analyses presented above for the NTS and those described in NOAA Atlas 2 are of concern. Present and potential future activities on the NTS demand a more detailed analysis of extreme precipitation in this area. This analysis should help characterize extreme precipitation for the NTS region.

To contribute useful data to this characterization, additional frequency analyses of daily, extreme precipitation events were constructed for the Beatty-Desert Rock-Yucca Flat region. Annual series of precipitation data for DRA, UCC, and Beatty were combined to estimate return periods for the southern NTS; hereafter referred to as YM2 or YM3. Precipitation data from these three sites were assumed to be hydrologically and climatologically homogeneous. Station elevations range from 3314 ft (1019 m, BTY) to 3924 ft (1196 m, UCC) and general surrounding terrain is similar; however, precipitation at DRA maybe be modulated by the Spring Mountain Range to the south. Data from 4JA (Fig. 18) was used as a control. Based on these assumptions, three regionalized frequency distributions for extreme precipitation were constructed. The results are summarized in Table 14.

First, the precipitation data from DRA, UCC, and BTY (see Tables 3, 5, and 8) were combined into one common data mix, identified as YM3 and tabulated in Table 15. The combined data set covers the 48-yr period from 1948 through 1995. From this mix each annual maximum daily precipitation event was identified as part of the common mix. Both normal and log Pearson Type III distributions were fit to the data. The normal plot is shown in Fig. 22 and the log Pearson in Fig. 23. The normal projects a 100-yr maximum daily event with a precipitation total of 3.1 in (78.7 mm), the log Pearson, 3.39 in (86.1 mm), and the control, 4JA, 3.58 in (90.9 mm) for the normal (Fig. 18) and 3.64 in (92.5 mm) for the log Pearson (Fig.21). The results for YM3 are summarized in Table 14.

Second, the extreme event precipitation events from the log Pearson distributions for 4JA and BTY were used to produce another estimate of extreme event precipitation. Data from these two distributions were combined to define precipitation as a weighted average of distance (15 mi, 24 km) between the two stations. These weights are reciprocals of the sums of the squares of the distance between the mid-point (near Yucca Mountain) and 4JA and BTY, respectively, and identified as YM2. The 100-yr maximum daily precipitation event produced by this data mix is 3.02 in (76.7 mm) and is listed in Table 14 with the other results.

Table 14. Regionalized estimates of return periods for annual maximum daily precipitation events in the vicinity of the southern NTS.

RECURRENCE INTERVAL (YR)

| | Normal | | | | Log Pearson Type III | | |
|---|---|---|---|---|---|---|---|
| SITE | 50 | 100 | 200 | 500 | 50 | 100 | 200 |
| YM3 | 2.78 | 3.10 | 3.43 | 3.87 | 2.98 | 3.39 | 3.83 |
| YM2 | na | na | na | na | 2.68 | 3.02 | 3.55 |
| 4JA | 3.15 | 3.58 | 4.00 | 4.54 | 3.11 | 3.64 | 4.21 |
| BTY | 2.02 | 2.25 | 2.50 | 2.80 | 2.11 | 2.40 | 2.69 |
| GUM | 2.92 | 3.40 | 3.51 | 3.86 | na | na | na |

na = not applicable

Caution is advised in using data mixes because isohytal patterns are not usually symmetrical, are finite, and gradients are not isotropic (Figs. 8 and 9). However, the climatological regime, station elevations, and surrounding topography are similar.

Third, an estimate of the magnitude of the 100-yr daily maximum precipitation event for a Gumbel extreme-value distribution was calculated according to,

$$P_{100} = \bar{P} + Ks$$

where $\bar{P}$ is the mean for the 48-yr combined record (1.21 in), $K$ = 3.5 (the Gumbel extreme-value frequency factor for $n$ = 48), and $s$ = 0.59, so that $P_{100}$ = 3.4 in (86.3 mm), which is consistent with the magnitudes of the 100-yr events from the normal and log Pearson distributions.

Consequently, **a magnitude of 3.5 in (89 mm) for the 100-yr maximum daily precipitation event is consistent with the observations and with the above analyses and is recommended as the conservative estimate for use in design storm analyses for flood control and infiltration studies over the southern NTS.**

NOAA Atlas 2 (1973) greatly underestimates the extreme 100-yr 24-hr precipitation event for this area. NOAA Atlas 2 projects approximately 2.5 in (66 mm) as the 100-yr 24-hr extreme precipitation event for the southern NTS. The extreme events of August 1983 (Fig. 10a), July 1984 (2.47 in, 62.7 mm at 4JA), July

Table 15. Annual maximum daily precipitation data mix for the southern NTS (YM3). The data mix includes BTY (1948-1995), UCC (1962-1995), and DRA (1979-1995). Amounts are in inches.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1983 | 3.52 | 1 | 1987 | 1.16 | 25 |
| 1977 | 2.18 | 2 | 1993 | 1.15 | 26 |
| 1969 | 2.13 | 3 | 1970 | 1.10 | 27 |
| 1991 | 2.12 | 4 | 1971 | 1.07 | 28 |
| 1984 | 2.03 | 5 | 1951 | 1.00 | 29 |
| 1990 | 1.95 | 6 | 1966 | 0.97 | 30 |
| 1982 | 1.79 | 7 | 1962 | 0.92 | 31 |
| 1975 | 1.73 | 8 | 1980 | 0.90 | 32 |
| 1967 | 1.65 | 9 | 1994 | 0.90 | 33 |
| 1976 | 1.65 | 10 | 1955 | 0.87 | 34 |
| 1954 | 1.60 | 11 | 1979 | 0.87 | 35 |
| 1981 | 1.53 | 12 | 1968 | 0.80 | 36 |
| 1988 | 1.49 | 13 | 1963 | 0.76 | 37 |
| 1948 | 1.46 | 14 | 1957 | 0.73 | 38 |
| 1978 | 1.33 | 15 | 1961 | 0.72 | 39 |
| 1995 | 1.32 | 16 | 1953 | 0.71 | 40 |
| 1965 | 1.31 | 17 | 1950 | 0.69 | 41 |
| 1960 | 1.28 | 18 | 1956 | 0.64 | 42 |
| 1986 | 1.27 | 19 | 1959 | 0.62 | 43 |
| 1974 | 1.26 | 20 | 1958 | 0.53 | 44 |
| 1985 | 1.25 | 21 | 1964 | 0.51 | 45 |
| 1992 | 1.25 | 22 | 1989 | 0.48 | 46 |
| 1972 | 1.20 | 23 | 1952 | 0.41 | 47 |
| 1973 | 1.17 | 24 | 1949 | 0.25 | 48 |

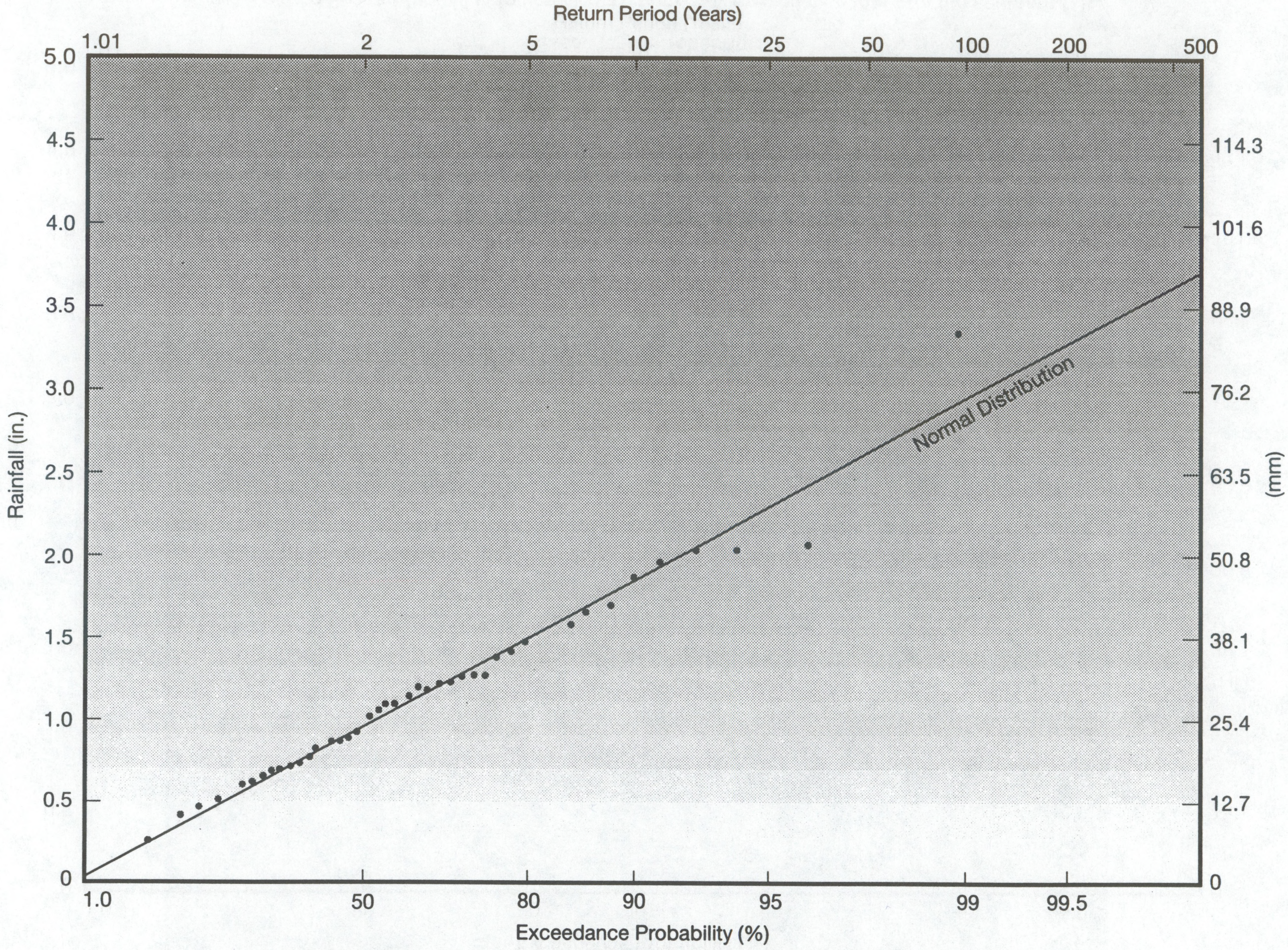


Figure 22. Normal fit to the annual maximum daily precipitation data mix for UCC, DRA, and Beatty for the period 1948 through 1995. Identified as YM3.

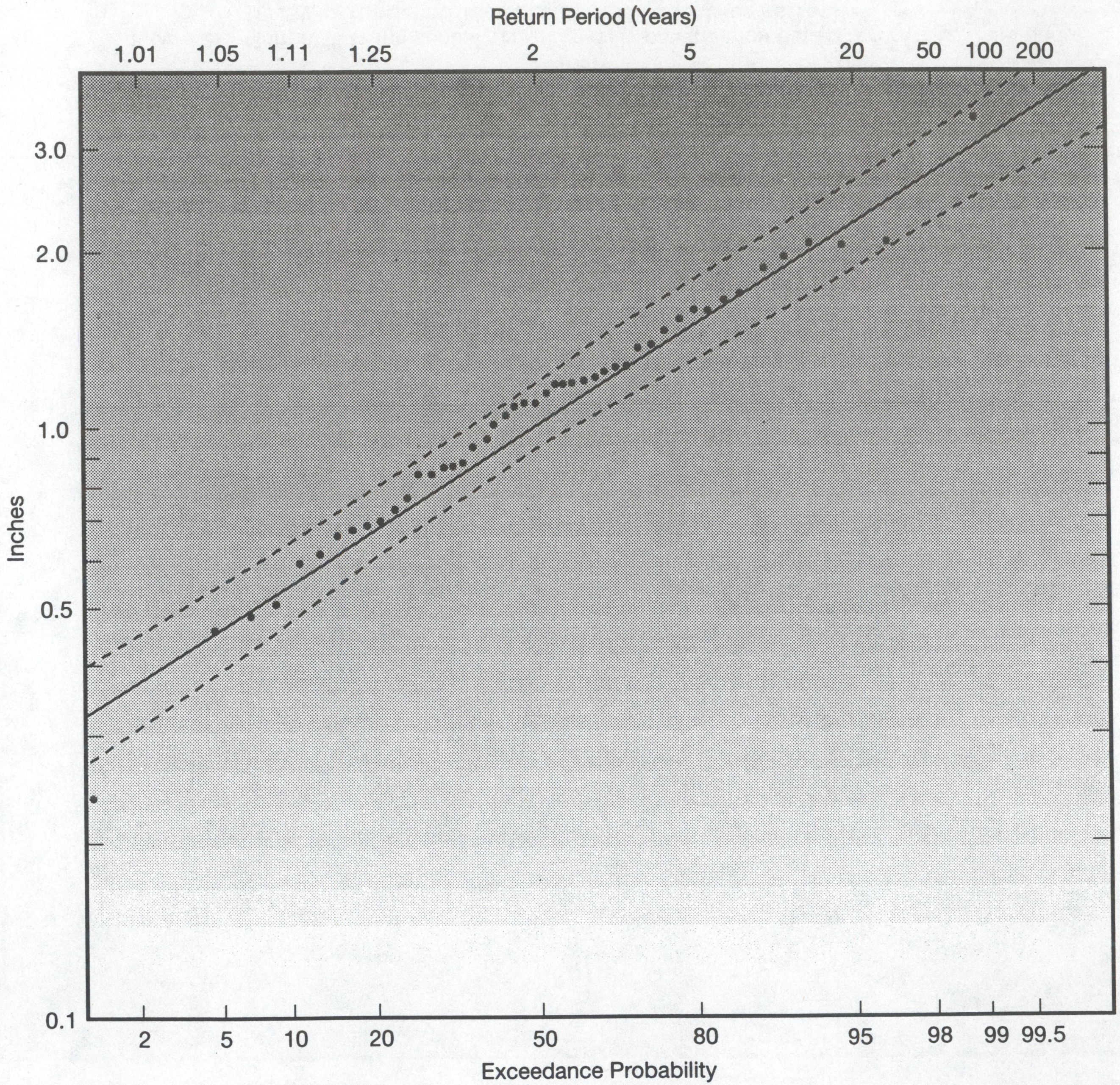


Figure 23. Log Peason Type III fit to annual maximum daily precipitation totals for the southern NTS area (YM3), 1948 through 1995. Dashed lines are 95% confidence limits.

1987 (2.04 in, 52 mm at 4JA), and September 1975 (1.73 in, 44 mm at Beatty) were not available when NOAA Atlas 2 was prepared. Consequently, **NOAA Atlas 2 seriously underestimates the 100-yr 24-hr extreme event for the southern NTS by approximately 1.0 in (25.4 mm)**. The data record suggests that this total may be valid only for the southern half of the NTS. To date, there have been no observations of heavy precipitation exceeding a daily total of more than 3.0 in (76 mm) over the northern half of the NTS (see Table 11).

## Beatty

Annual maximum daily precipitation amounts were obtained from the Desert Research Institute (DRI) climatological data base for Nevada. Daily precipitation totals for 1948 through 1995 were tabulated for two cooperative-observer stations in the Beatty area. From 1948 to 1972 precipitation was measured in a standard 8-in rain gage at the post office in the city at an elevation of 3314 ft (1010 m). From 1972 to the present the data have been collected in a standard 8-in gage located 8 mi (13 km) north of the city at an elevation of 3550 ft (1082 m). Observation time each day is near sunset. Since the local environmental setting is quite similar and the instrumentation the same, these two data sets were combined into one set. This merger may compromise homogeneity and independence but is assumed to have a negligible effect. The ranked precipitation data are listed in Table 8.

The extreme annual maximum precipitation events for Beatty range from a maximum of 1.90 in (48.3 mm) in December 1984 to a minimum of only 0.20 in (5.1 mm) in August 1970. The annual distribution of these extreme events is displayed in graphical form in Fig. 3b. This figure shows a very different monthly distribution than that for the stations located farther south. Beatty has a pronounced cold season peak in February. Frequency analyses were developed for this station using both the normal and log Pearson Type III distributions. The normal distribution is plotted in Fig. 24 and the Pearson is shown in Fig. 25. In Fig. 24 the theoretical normal line is drawn through the mean plus one standard deviation at 84.1% and the mean minus one standard deviation at 15.9%. By inspection, the data appear to fit the normal distribution well. The predicted 100-yr daily precipitation event varies from 2.25 in (57.2 mm) for the normal to 2.4 in (61 mm) for the log Pearson Type III distribution using n=48 to determine the frequency factor. NOAA Atlas 2 (1973) provides a slightly larger estimate of nearly 2.6 in (66 mm) for the 100-yr 24-hr extreme precipitation event. These calculations and the data record indicate that the historical event for this site probably has not occurred within the period of record.

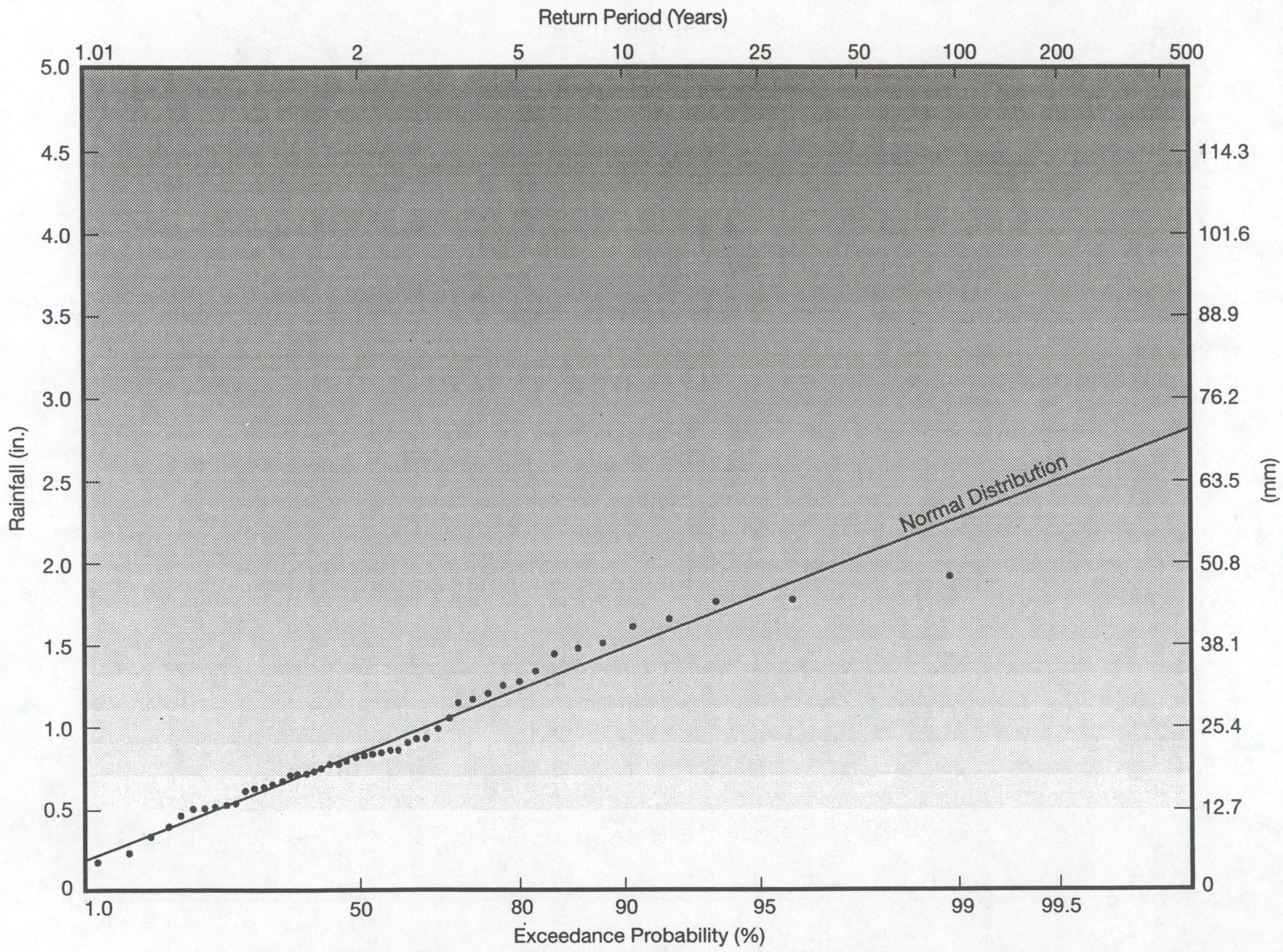


Figure 24. Annual maximum daily precipitation versus return period for Beatty, Nevada, 1948 through 1995 with a fit to a normal distribution.

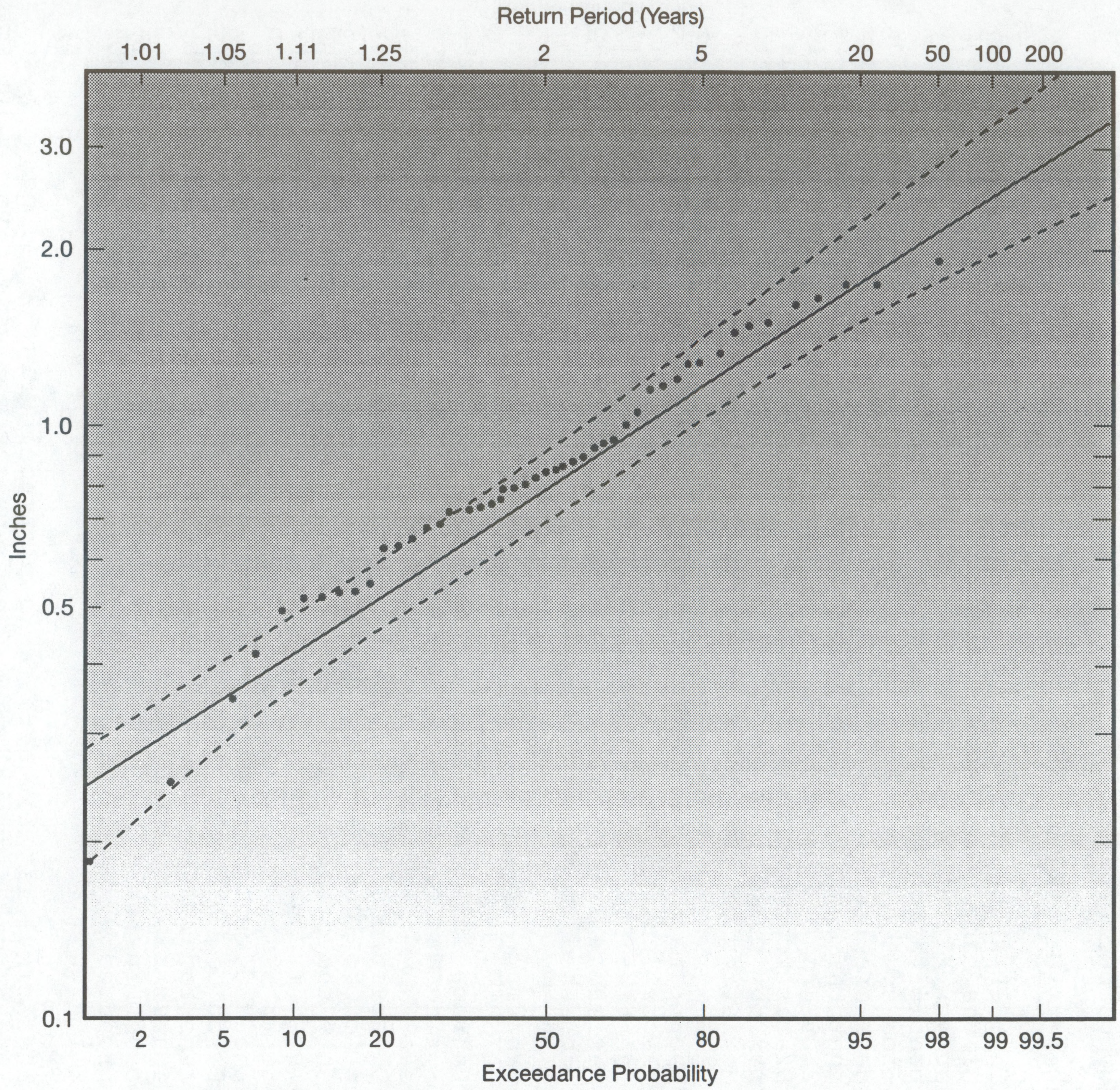


Figure 25. Log Peason Type III fit to annual maximum daily precipitation totals for Beatty, Nevada, 1948 through 1995. Dashed lines are 95% confidence limits.

## **Other Sites**

Annual maximum daily precipitation amounts for the following sites were obtained from the Desert Research Institute (DRI) climatological data base for Nevada. The data have been collected by cooperative observers.

Desert Game Range (DGR)

The DGR raingage is located approximately 25 mi (40 km) northwest of the former Las Vegas site at McCarran International Airport and at an elevation of 2922 ft (891 m) above sea level. Daily precipitation measurements from the DGR include the 47-yr period from 1949 through 1995. The annual daily extreme precipitation data are listed in descending order in Table 10. This table shows that the annual maximum daily precipitation event for this site is 2.05 in (52.1 mm). This event occurred in December 1951. Statistical analysis of the data in Table 10 produced a mean annual maximum precipitation total of 0.89 in (22.6 mm) with a standard deviation of 0.41 and a skew of 0.56.

The normal fit to the data is plotted in Fig. 26 along with the theoretical normal line. The fit to the data is essentially identical to that for Las Vegas (Fig. 14) and yields a 100-yr daily maximum event of 2.3 in (58.4 mm). This estimate matches that published in NOAA Atlas 2 (1973); 2.5 in (64 mm).

Pahrump

Pahrump is located in a large valley on the western edge of the Spring Mountains (Fig.1) at an elevation of 2670 ft (814 m) above sea level and approximately 50 mi (80 km) west of Las Vegas. Observations of precipitation began in November 1948; however, prior to 1969 there was considerable missing data. Consequently, only the data for the 27-yr period from 1969 through 1995 is used in this study. The greatest measured daily precipitation (2.40 in, 61 mm) from the entire record fell within the 27-yr period used in the following analysis. This event occurred in February 1979. Prior to 1969, the greatest daily precipitation total measured and reported was 1.69 in (42.9 mm) which fell in November 1960. The annual extreme daily precipitation data are listed in descending order in Table 16. Statistical analysis of the data in Table 16 produced a mean annual maximum precipitation total of 0.96 in (24.4 mm) with a standard deviation of 0.52 and a skew of 1.39.

The normal fit to the data is plotted in Fig. 27 along with the theoretical normal line. The frequency analysis gives a 100-yr daily maximum event of nearly 2.7 in (68.6 mm), approximately the same as that presented in NOAA Atlas 2 (2.8 in, 71 mm).

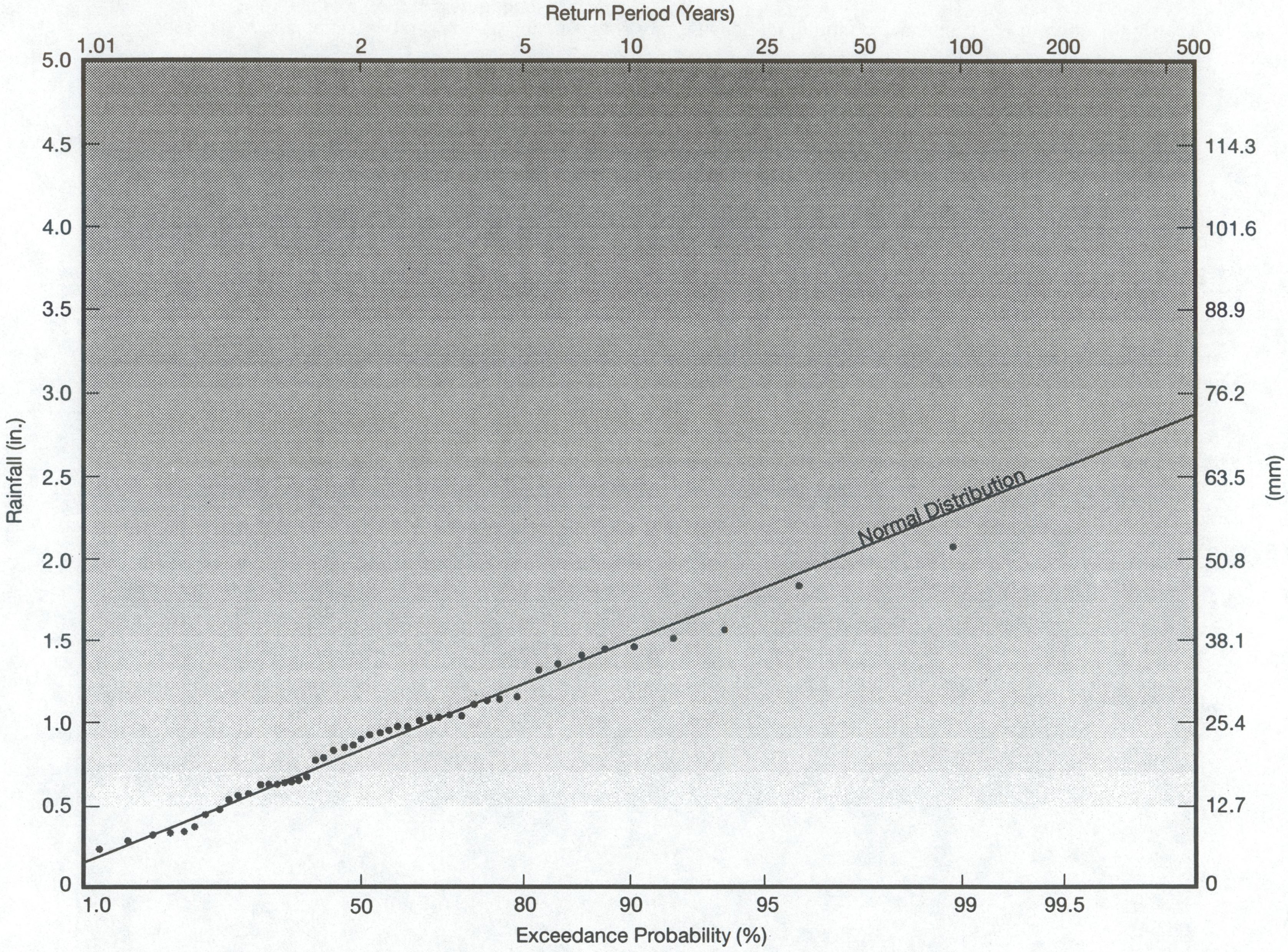


Figure 26. Annual maximum daily precipitation versus return period for Desert Game Range (DGR), 1949 through 1995 with a fit to a normal distribution.

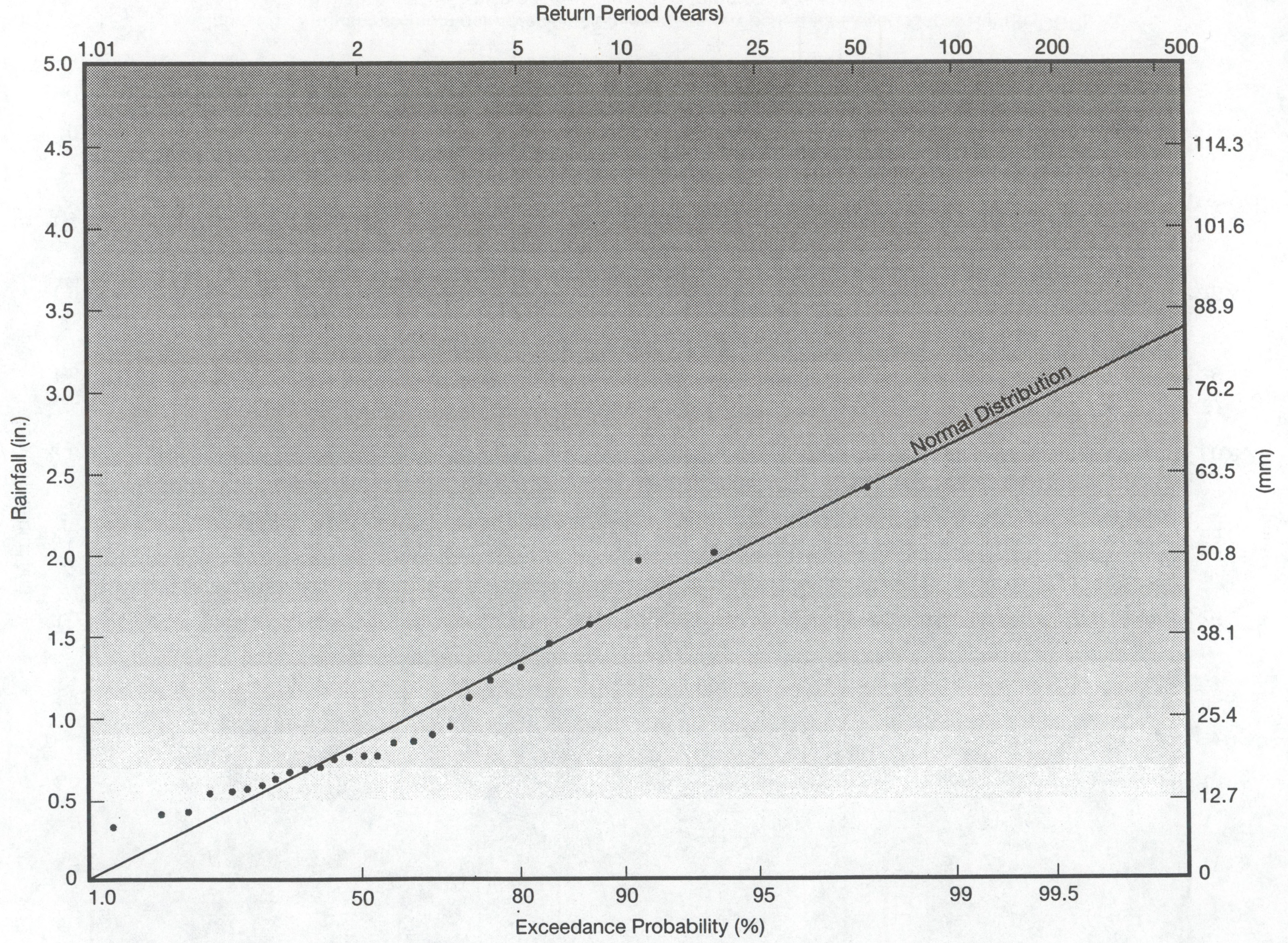


Figure 27. Annual maximum daily precipitation versus return period for Pahrump, Nevada, 1969 through 1995 with a fit to a normal distribution.

Table 16. Annual maximum daily precipitation events for Pahrump, NV, 1969 through 1995, in inches.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1979 | 2.40 | 1 | 1995 | 0.78 | 14 |
| 1990 | 2.00 | 2 | 1982 | 0.77 | 15 |
| 1984 | 1.95 | 3 | 1992 | 0.75 | 16 |
| 1972 | 1.55 | 4 | 1991 | 0.70 | 17 |
| 1988 | 1.44 | 5 | 1969 | 0.69 | 18 |
| 1983 | 1.30 | 6 | 1978 | 0.69 | 19 |
| 1980 | 1.22 | 7 | 1974 | 0.63 | 20 |
| 1976 | 1.11 | 8 | 1994 | 0.60 | 21 |
| 1986 | 0.94 | 9 | 1981 | 0.58 | 22 |
| 1977 | 0.90 | 10 | 1971 | 0.57 | 23 |
| 1993 | 0.87 | 11 | 1989 | 0.55 | 24 |
| 1987 | 0.86 | 12 | 1970 | 0.43 | 25 |
| 1973 | 0.78 | 13 | 1985 | 0.42 | 26 |
| | | | 1975 | 0.34 | 27 |

Valley of Fire State Park

This State Park is the eastern most station included in this study. It is located approximately 40 mi (64 km) northeast of the Las Vegas site at McCarran International Airport, at an elevation of 2001 ft (610 m) above sea level. The precipitation data base includes the 23-yr period from 1973 through 1995. The annual maximum daily precipitation data are listed in descending order in Table 17. This table shows that the annual maximum daily precipitation event for this site is 3.05 in (77.5 mm). This event was produced by the severe thunderstorm of August 10, 1981, which is described in Section V. Furthermore, this total is based on the amount of collected precipitation that was not spilled as the overflow precipitation caught was being transferred to the measurement cylinder. The actual total may have been near 3.5 in (89 mm).

Statistical analysis of the data in Table 17 produced a mean annual maximum precipitation total of 1.23 in (31.2 mm) with a standard deviation of 0.55 and a skew of 1.65. The normal fit to the data is plotted in Fig. 28 along with the theoretical normal line. The frequency analysis gives a 100-yr daily maximum event of nearly 3.0 in (76.2 mm). NOAA Atlas 2 (1973) gives a value of approximately 3.4 in (86 mm) for the same site.

Table 17. Annual maximum daily precipitation event for Valley of Fire State Park, NV, 1973 through 1995, in inches.

| YEAR | AMOUNT | RANK | YEAR | AMOUNT | RANK |
|---|---|---|---|---|---|
| 1981 | 3.05* | 1 | 1986 | 1.10 | 13 |
| 1985 | 2.01 | 2 | 1995 | 1.00 | 14 |
| 1983 | 1.67 | 3 | 1987 | 0.95 | 15 |
| 1990 | 1.60 | 4 | 1977 | 0.92 | 16 |
| 1978 | 1.53 | 5 | 1982 | 0.90 | 17 |
| 1976 | 1.53 | 6 | 1984 | 0.86 | 18 |
| 1975 | 1.44 | 7 | 1991 | 0.78 | 19 |
| 1980 | 1.44 | 8 | 1973 | 0.68 | 20 |
| 1988 | 1.42 | 9 | 1974 | 0.65 | 21 |
| 1993 | 1.35 | 10 | 1994 | 0.63 | 22 |
| 1992 | 1.17 | 11 | 1989 | 0.59 | 23 |
| 1979 | 1.11 | 12 | | | |

*At least this amount. Some water spilled during transfer from the overflow tank to the graduated cylinder.

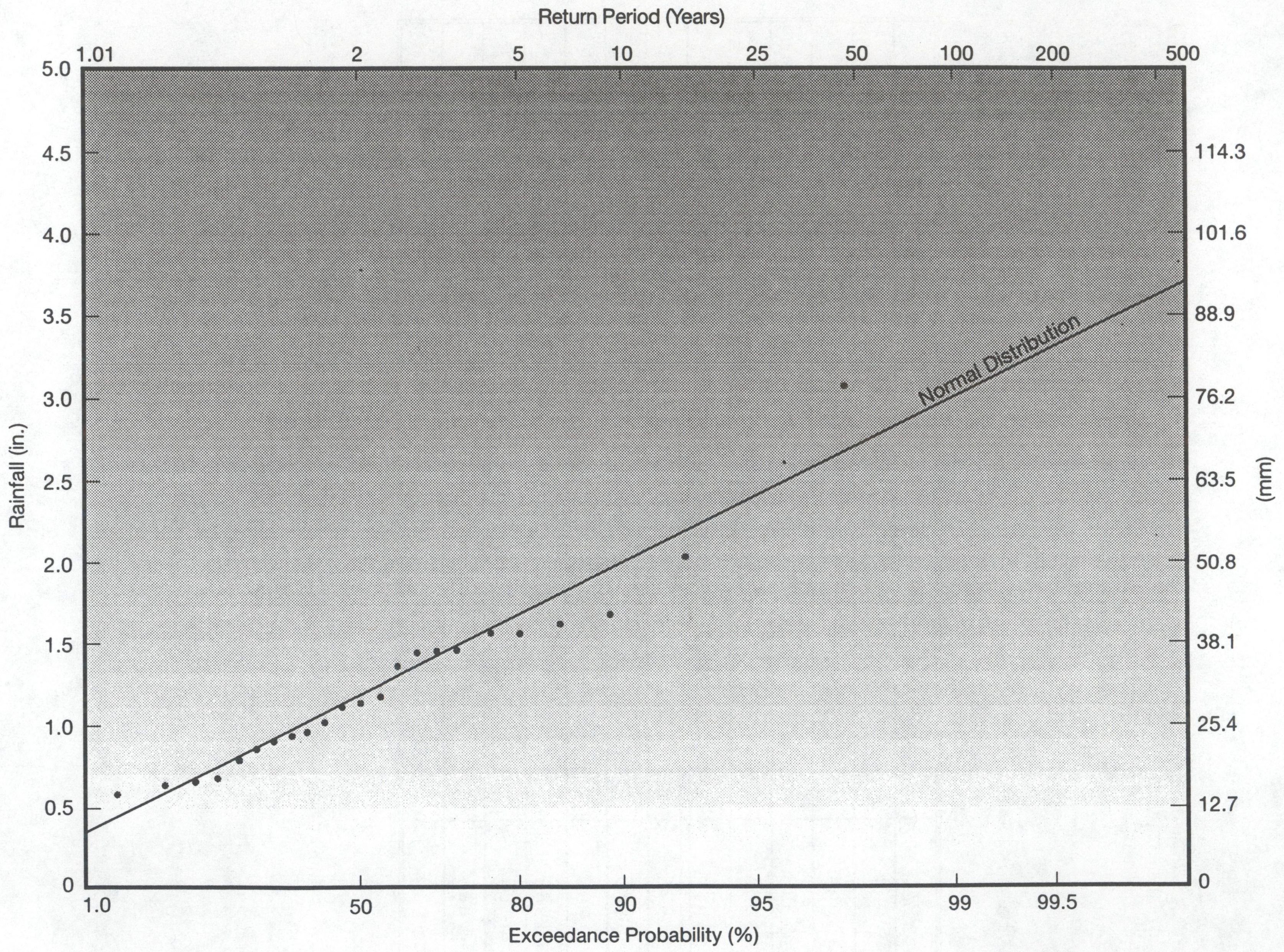


Figure 28. Annual maximum daily precipitation versus return period for Valley of Fire State Park (VOF), 1973 through 1995 with a fit to a normal distribution.

## VII. SUMMARY

Precipitation data listed and analyzed in this report clearly demonstrate the dramatic spatial and temporal variability in precipitation in southern Nevada. Extreme precipitation events can occur at any time of the day or on any day. However, there is a marked seasonal difference in the monthly frequency distributions of these events between extreme southern Nevada and the northern most stations analyzed in this report (Beatty and NTS). The southern most stations exhibit a strong preference for heavy precipitation events in July and August while the northern most stations have peaks in the November - March time frame. This distinction is important because it defines the differences in the dynamical processes that can spawn heavy precipitation. Cool-season heavy precipitation is associated with synoptic-scale cyclonic circulations that can produce wide-spread vertical motion and significant precipitation over large areas for time intervals of the order of 10 hr. By contrast, warm-season heavy precipitation events are convective in nature, are driven by surface heating, are highly focused, tend to be accompanied by much cloud-to-ground lightning, strong surface winds, hail, blowing dust, and usually lifetimes of less than three hours. Runoff from cool-season events can cause widespread flooding; however, they usually allow ample time to communicate warnings and to take emergency response actions. On the other hand, warm-season extreme events can pose a prompt threat to life and property because the time periods for warning and action are much shorter; thereby challenging our forecast capabilities and warning communications systems.

As is common with desert environments, the time intervals between extremely heavy precipitation events over southern Nevada tends to be large. Consequently, the length of record is critical when storm frequency is analyzed. Long records are essential to capture significant precipitation events for desert regions. Some of the records used here appear to have captured historical events.

A frequency analysis of all warm-season, set-hour precipitation events (see Fig. 5a) for Las Vegas, Nevada, shows that 72% produce precipitation totals of 0.05 in (1.3 mm) or less. In addition, Table 9 shows that the median set-hour precipitation event is less than 0.07 in (1.8 mm). However, heavy precipitation (≥0.3 in/hr, 7.6 mm/hr) has occurred within nearly every hour of the day, except for some of the early morning hours between 0200 and 0700 PDT (0900 and 1400 UTC).

An analysis of thunderstorm days for Las Vegas (Fig. 5d) and Desert Rock (Fig.5e) shows that:

a. there is a dramatic increase in thunderstorm days during the first two weeks of July as tropical moisture begins to penetrate into the desert southwest,

b. there is a potential initial peak close to July 19th in Las Vegas and near July 21st at Desert Rock,

c. there is a primary peak in late July in Las Vegas and a corresponding, but not primary peak, at Desert Rock on approximately August 1st. The primary peak at Desert Rock is on August 11th,

d. there is a sharp minimum in thunderstorm days in early August in Las Vegas,

e. there is a secondary maximum on approximately August 10, for Las Vegas, and,

f. the time period between the peaks in thunderstorm activity in July and August is approximately 10 to 11 days. This frequency may define the climatological frequency distribution of "surges" of tropical moisture into southern Nevada during the warm season.

Data clearly illustrate that daily precipitation totals of 2.0 to 6.0 in ( 50.8 to 152.4 mm) have occurred in southern Nevada. Hourly precipitation rates of 0.5 in/hr (12.7 mm/hr) up to nearly 1.5 in/hr (28.1 mm/hr) have been measured. Precipitation rates of as much as 2.0 to 4.0 in/hr (51 to 101 mm/hr) are thought to be possible in the more extreme cases and in very small areas. Dangerous flash flooding occurs with these intense storms. When heavy thunderstorms occur over mountains, extreme danger exists because the runoff can be focused into narrow drainage channels that may have steep topographic slopes, thereby amplifying the depth and speed of the flood water as it rushes toward lower elevations and possible population centers.

Over much of southern Nevada, the projections for the 100-yr 24-hr extreme precipitation event found in NOAA Atlas 2 match those calculated in this report (see Table 18). However, there are important exceptions. Of particular interest are the large differences over the southern part of the NTS. Precipitation observations and frequency analyses both show that NOAA Atlas 2 underestimates the 100-yr 24-hr/daily precipitation event for this area by approximately one inch (25.4 mm). The reason for this difference is due to the fact that the data base used to make the estimates in NOAA Atlas 2 did not contain the historical type event of August 1983 or several other heavy precipitation events that have occurred since the Atlas was prepared in the early 1970s. Therefore, **it is recommended that for design storm analyses over the southern NTS, a storm total precipitation amount of 3.5 in (89 mm) be used for the 100-yr 24-hr event.**

The 48-yr data base (YM3) used to define the annual extreme daily precipitation events for the southern NTS area (Table 15) defines the annual frequency distribution of these events (Fig. 29). This

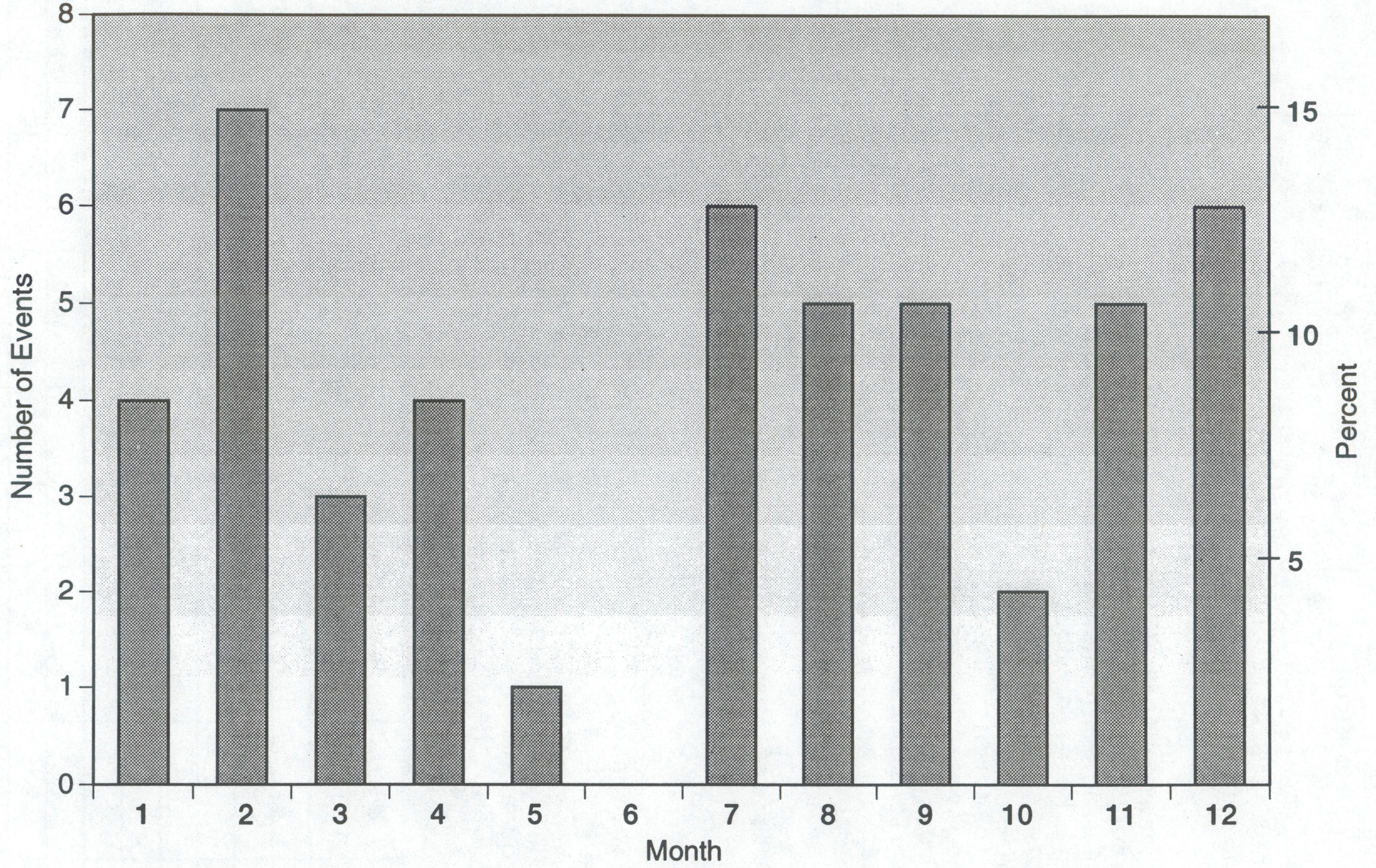


Figure 29. Annual distribution of monthly extreme precipitation events for the southern NTS area (YM3) data mix (see Table 15), for 1948 through 1995.

figure shows that extreme daily precipitation events have occurred principally in February (14.6%) and rarely in May and June. In addition, Fig. 29 also shows high occurrence possibilities in July(12.5%), August (10.4%), September (10.4%), November (10.4%), and December (12.4%). The magnitudes of these annual extreme events range from 0.25 in (July 1949) to 3.52 in (August 1983). The mean of the seven February events is 1.12 in (28.4 mm) and 1.06 in (27 mm) for the six July events. Of the top five extreme events, all exceeded 2.00 in (50.8 mm), all were summertime events, and three occurred in August. The heaviest event for February is 1.65 in (42 mm). Consequently, the most intense precipitation events are likely to occur in the summertime and thereby focus the precipitation in time and space.

The data presented in this report also document the occurrence of mesoscale convective systems (MCSs) and the micro-burst phenomena associated with intense thunderstorms. Knowledge of the occurrence of MCSs is vital because of the heavy precipitation, of the severe weather that accompany these storms, and of the threat they pose to life and property. In a similar manner, micro-bursts are a serious hazard to aviation and to high profile vehicles. The micro-burst that occurred in Las Vegas in August 1989 caused $14,000,000 in damage to aircraft parked at two local airports; fortunately there was no loss of life.

Table 18. Estimates of the risk that the 100-yr 24-hr/daily extreme precipitation events over southern Nevada, in inches, will occur at least once in the next t years. Hershfield (1973) notes that if $P^*$ is the risk that an event will occur with a return period T in the next t years, then the risk is given by $P^* = 1 - (1 - 1/T)^t$.

| SITE | Normal | Log Pearson | NOAA Atlas 2 | Observed Maximum | Record (yrs) | $P^*$ |
|---|---|---|---|---|---|---|
| Searchlight | 4.25 | na | 4.0 | 4.50 | 46 | 0.36 |
| Boulder Cty | 3.00 | na | 3.0 | 3.72 | 55 | 0.42 |
| Las Vegas | 2.35 | 2.72 | 2.9 | 2.59 | 46 | 0.37 |
| Desert Rock | 3.75 | na | 2.6 | 3.52 | 17 | 0.16 |
| 4JA | 3.56 | 3.64 | 2.6 | 3.20 | 21 | 0.19 |
| YM3 | 3.10 | 3.39 | 2.5 | na | na | na |
| Beatty | 2.25 | 2.40 | 2.6 | 1.90 | 48 | 0.38 |
| Pahrump | 2.70 | na | 2.8 | 2.40 | 27 | 0.24 |
| Valley/Fire | 2.98 | na | 3.4 | 3.05e | 23 | 0.21 |
| UCC | 2.77 | na | 2.5 | 2.18 | 34 | 0.29 |

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