NOAA Atlas 14

Precipitation-Frequency Atlas of the United States

Volume 1 Version 4.0: Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah)

Geoffrey M. Bonnin, Deborah Martin, Bingzhang Lin, Tye Parzybok, Michael Yekta, David Riley

U.S. Department of Commerce

National Oceanic and Atmospheric Administration

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1. Abstract

NOAA Atlas 14 contains precipitation frequency estimates with associated confidence limits for the United States and is accompanied by additional information such as temporal distributions and seasonality. The Atlas is divided into volumes based on geographic sections of the country. The Atlas is intended as the official documentation of precipitation frequency estimates and associated information for the United States. It includes discussion of the development methodology and intermediate results. The Precipitation Frequency Data Server (PFDS) was developed and published in tandem with this Atlas to allow delivery of the results and supporting information in multiple forms via the Internet.

2. Preface to Volume 1

NOAA Atlas 14 Volume 1 contains precipitation frequency estimates for Arizona, Nevada, New Mexico, Utah, and southeastern California (Imperial, Inyo, Eastern Kern, Eastern Los Angeles, Riverside, San Bernardino and Eastern San Diego counties). These areas were addressed together in a single project focused on the semiarid southwestern United States. The Atlas supercedes precipitation frequency estimates contained in Technical Paper No. 49 "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller et al., 1964), NOAA Atlas 2 "Precipitation-Frequency Atlas of the Western United States" (Miller et al., 1973), "Short Duration Rainfall Frequency Relations for California" (Frederick and Miller, 1979) and "Short Duration Rainfall Relations for the Western United States" (Arkell and Richards, 1986). The updates are based on more recent and extended data sets, currently accepted statistical approaches, and improved spatial interpolation and mapping techniques.

The work was performed by the Hydrometeorological Design Studies Center within the Office of Hydrologic Development of the National Oceanic and Atmospheric Administration's National Weather Service. Funding for the work was provided by the National Weather Service, U.S. Army Corps of Engineers, Natural Resources Conservation Service, Bureau of Reclamation, Arizona Department of Transportation, and Riverside County, California. Any use of trade names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Citation and Version History. This documentation and associated artifacts such as maps, grids, and point-and-click results from the PFDS, are part of a whole with a single version number and can be referenced as: "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 1, Version 4.0, G. M. Bonnin, D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley, NOAA, National Weather Service, Silver Spring, Maryland, 2006.

The version number has the format P.S where:

P is an integer representing successive releases of primary information. Primary information is essentially the data – the values of precipitation frequencies (in ASCII grids of the precipitation frequency estimates and output from the PFDS), shapefiles, cartographic maps, temporal distributions, and seasonality.

S is an integer representing successive releases of secondary information. S reverts to zero (or nothing; i.e., Version 2 and Version 2.0 are equivalent) when P is incremented. Secondary information includes documentation and metadata.

When new information is completed and added, such as draft documentation, *without changing any prior information*, the version number is not incremented.

The primary version number is stamped on the artifact or is included as part of the filename where the format does not allow for a version stamp (for example, the grids). An examination of any of the artifacts available through the Precipitation Frequency Data Server (PFDS) provides an immediate indication of the primary version number associated with all artifacts. All output from the PFDS is stamped with the version number and date of download.

Several versions of the project have been released. Table 2.1 lists the version history associated with the NOAA Atlas 14 Volume 1, the semiarid southwestern United States precipitation frequency project and indicates the nature of changes made. If major discrepancies are observed or identified by users, a new release may be warranted.

Table 2.1. Version History of the NOAA Atlas 14 Volume 1.

Version no.	**Date**	**Notes**
Version 1	October 30, 2002	Draft data used in peer review
Version 2	July 14, 2003	Final released data
Version 3	January 7, 2004	Updated final data
Version 3.0	October 22, 2004	Draft documentation released
Version 3.1	December 3, 2004	Final documentation released
Version 3.2	June 2, 2005	Edited final documentation released
Version 4	June 19, 2006	Updated final data (includes 1-year ARI)
Version 4.0	October 4, 2006	Updated final documentation released

3. Introduction

3.1. Objective

NOAA Atlas 14 Volume 1 provides precipitation frequency estimates for the semiarid southwestern United States which includes Arizona, Nevada, New Mexico, Utah, and southeastern California (Imperial, Inyo, Eastern Kern, Eastern Los Angeles, Riverside, San Bernardino and Eastern San Diego counties). Figures 4.1.1 and 4.1.2 show the project core area where estimates are available (enclosed in the bold line) and also include all stations used in the analysis, even those outside the core area. The Atlas provides precipitation frequency estimates for 5-minute through 60-day durations at average recurrence intervals of 1-year through 1,000-year. The estimates are based on the analysis of annual maximum series and then converted to partial duration series results. The information in NOAA Atlas 14 Volume 1 supercedes precipitation frequency estimates contained in Technical Paper No. 49 "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller, 1964), NOAA Atlas 2 "Precipitation-Frequency Atlas of the Western United States" (Miller et al., 1973), "Short Duration Rainfall Frequency Relations for California" (Frederick and Miller, 1979) and "Short Duration Rainfall Relations for the Western United States" (Arkell and Richards, 1986). The results are provided at high spatial resolution and include confidence limits for the estimates. The Atlas includes temporal distributions designed for use with the precipitation frequency estimates (Appendix A.1) and seasonal information for heavy precipitation (Appendix A.2). In addition, the potential effects of climate change were examined (Appendix A.3).

The new estimates are based on improvements in three primary areas: denser data networks with a greater period of record, the application of regional frequency analysis using L-moments for selecting and parameterizing probability distributions and new techniques for spatial interpolation and mapping. The new techniques for spatial interpolation and mapping account for topography and have allowed significant improvements in areas of complex terrain.

NOAA Atlas 14 Volume 1 precipitation frequency estimates for the semiarid southwestern United States are available via the Precipitation Frequency Data Server at http://hdsc.nws.noaa.gov/hdsc/pfds which provides the additional ability to download digital files. The types of results and information found there include:

- point estimates (via a point-and-click interface)
- ArcInfo© ASCII grids
- ESRI shapefiles
- color cartographic maps for each state
- associated Federal Geographic Data Committee-compliant metadata
- data series used in the analyses: annual maximum series and partial duration series
- temporal distributions of heavy precipitation (6-hour, 12-hour, 24-hour and 96-hour)
- seasonal exceedance graphs: counts of events that exceed the 1 in 2, 5, 10, 25, 50 and 100 annual exceedance probabilities for the 60-minute, 24-hour, 48-hour, and 10-day durations.

As discussed in Sections 4.8.4 and 4.8.5, the color cartographic maps and ESRI shapefiles were created to serve as visual aids and, unlike NOAA Atlas 2, are not recommended for interpolating final point or area precipitation frequency estimates. Users are urged to take advantage of the Precipitation Frequency Data Server or the underlying ArcInfo© ASCII grids for accessing estimates.

3.2. Terminology; Partial Duration and Annual Maximum Series

This publication adopts the terminology "average recurrence interval" (ARI) and "annual exceedance probability" (AEP) presented in Australian Rainfall and Runoff (Institute of Engineers, Australia, 1987) which in turn is based on Laurenson (1987). NOAA Atlas 14 is based on the analysis of annual maximum series data with the results converted to represent estimates based on partial

duration series. The results for these two types of series differ at shorter average recurrence intervals and have different meanings. Factors for converting between these results are provided in Section 4.6.4.

An annual maximum series is constructed by taking the highest accumulated precipitation for a particular duration in each successive year of record, whether the year is defined as a calendar year or using some other arbitrary boundary such as a water year. Calendar years are used in this Atlas. An annual maximum series inherently excludes other extreme cases that occur in the same year as a more extreme case. In other words, the second highest case on record at an observing station may occur in the same year as the highest case on record but will not be included in the annual maximum series. A partial duration series is constructed by taking all of the highest cases above a threshold regardless of the year in which the case occurred. In this Atlas, partial duration series consist of the N largest cases in the period of record, where N is the number of years in the period of record at the particular observing station.

Analysis of annual maximum series produces estimates of the average period between *years when a particular value is exceeded*. On the other hand, analysis of partial duration series gives the average period between *cases of a particular magnitude*. The two results are numerically similar at rarer average recurrence intervals but differ at shorter average recurrence intervals (below about 20 years). The difference can be important depending on the application.

Typically, the use of AEP and ARI reflects the analysis of the different series. However, in some cases, average recurrence interval is used as a general term for ease of reference.

3.3. Approach

The approach used in this project largely follows the regional frequency analysis using the method of L-moments described in Hosking and Wallis (1997). This section provides an overview of the approach. Greater detail on the approach is provided in Section 4.2.

This Atlas introduces a change from past NWS publications by its use of regional frequency analysis using L-moments for selecting and parameterizing probability distributions. Both annual maximum series and partial duration series were extracted at each observing station from quality controlled data sets. Because of the greater reliability of the analysis of annual maximum series, an average ratio of partial duration series to annual maximum series precipitation frequency estimates (quantiles) was computed and then applied to the annual maximum series quantiles to obtain the final equivalent partial duration series quantiles.

Quality control was performed on the initial observed data sets (see Section 4.3) and it continued throughout the process as an inherent result of the performance parameters of intermediate steps.

To support the regional approach, potential regions were initially determined based on climatology. They were then tested statistically for homogeneity. Individual stations in each region were also tested statistically for discordancy. Adjustments were made in the definition of regions based on underlying climatology in cases where homogeneity and discordancy criteria were not met.

A variety of probability distributions were examined and the most appropriate distribution for each region and duration was selected using several different performance measures. The final determination of the appropriate distributions for each region and duration was made based on sensitivity tests and a desire for a relatively smooth transition between distributions from region to region. Probability distributions selected for annual maximum series were not necessarily the same as those selected for partial duration series.

Quantiles at each station were determined based on the mean of the data series at the station and the regionally determined higher order moments of the selected probability distribution. There were a number of stations where the regional approach did not provide the most effective choice of probability distribution. In these cases the most appropriate probability distribution was chosen and parameterized based solely on data at that station. Quantiles for durations below 60-minutes (n-

minute durations) were computed using an average ratio between the n-minute and 60-minute quantiles due to the small number of stations recording data at less than 60-minute intervals.

For the first time, the National Weather Service is providing confidence limits for the precipitation frequency estimates in the area covered by NOAA Atlas 14. Monte Carlo Simulation was used to produce upper and lower bounds at the 90% confidence level.

In the regional approach, the second and higher order moments are constant for each region resulting in a potential for discontinuities in the quantiles at regional boundaries. In order to avoid potential discontinuities and to achieve an effective spatial interpolation of quantiles between observing stations, the data series means at each station for each duration were spatially interpolated using PRISM technology by the Spatial Climate Analysis Service (SCAS) at Oregon State University (Appendix A.4). Because the mean was derived directly at each observing station from the data series and independently of the regional computations, it was not subject to the same discontinuities. The grid of quantiles for each successive average recurrence interval was then derived in an iterative process using a strong linear relationship between a particular duration and average recurrence interval and the next rarer average recurrence interval of the same duration (see Section 4.8.2). The resulting set of grids were tested and adjusted in cases where inconsistencies occurred between durations and frequencies. Computations were made over a geographic domain that was larger than the published domain to ensure continuity at the edges of the published domain.

Both the spatial interpolation and the point estimates were subject to external peer reviews (see Section 6 and Appendices A.5 and A.6). Based on the results of the peer review, adjustments were made where necessary by the addition of new observations or removal of questionable ones. Adjustments were also made in the definition of regions.

Temporal precipitation patterns were extracted for use with the precipitation frequency estimates presented in the Atlas (Appendix A.1). The temporal patterns are presented in probabilistic terms and can be used in Monte Carlo development of ensembles of possible scenarios. They were specifically designed to be consistent with the definition of duration used for the precipitation frequency estimates.

The seasonality of heavy precipitation is represented in seasonal exceedance graphs that are available through the Precipitation Frequency Data Server. The graphs were developed for each region by tabulating the number of events exceeding the precipitation frequency estimate at each station for a given annual exceedance probability (Appendix A.2).

The 1-day annual maximum series were analyzed for linear trends in mean and variance and shifts in mean to determine whether climate change during the period of record was an issue in the production of this Atlas (Appendix A.3). The results showed little observable or geographically consistent impact of climate change on the annual maximum series during the period of record and so the entire period of record was used. The estimates presented in this Atlas make the necessary assumption that there is no effect of climate change in future years on precipitation frequency estimates. The estimates will need to be modified if that assumption proves quantifiably incorrect.