Recent Updates to NOAA/NWS Precipitation Frequency Estimates

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BIOGRAPHICAL SKETCH

Geoff Bonnin graduated B.E. (Civil) from the University of Queensland, Australia and M.S. (Engineering Management) from the University of Kansas. He is a Chartered Member of the Institution of Engineers Australia and a member of the American Society of Civil Engineers. He has extensive experience in flood forecasting and flood forecast systems development with the U.S. National Weather Service and the Australian Bureau of Meteorology. He also has extensive employment experience in software engineering and systems integration in private industry.

His primary areas of expertise are in data management as the integrating component of end-to-end systems, the science and practice of real time hydrologic forecasting, estimation of extreme precipitation climatologies, and the management of hydrologic enterprises. Mr. Bonnin is one of the developers, and the primary implementer, of Standard Hydrometeorological Exchange Format (SHEF).

Currently he is the Chief of the Hydrologic Data Systems Branch within the Hydrology Laboratory of the NWS Office of Hydrologic Development. He is the Director of the Hydrometeorological Design Studies Center within the branch and oversees activities such as the provision of over 1.3 million surface observations per day to NWS operations. Mr. Bonnin is responsible for current updates to NOAA/NWS precipitation frequency estimates.

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Abstract

The rainfall frequency atlases and technical papers published by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) serve as de-facto national standards for rainfall intensity at specified frequencies and durations in the United States. The NWS has updated the standards for the semiarid southwest and is working on updates for Ohio River basin and surrounding states, Hawaii, Puerto Rico, and the U.S. Virgin Islands. The Hydrometeorological Design Studies Center, located within the NWS Office of Hydrologic Development, is responsible for the updates and its work is funded by contributions from other Federal, State and local agencies. This paper provides an overview of the recent updates and the technology and data improvements used including: use of significantly longer data records emphasizing data quality control and consistency, use of the regional L-moments analysis technique, a spatial interpolation-based mapping procedure using a statistical-geographic approach, and web-based delivery of the final product. Discussion of new temporal distributions and areal reduction factors is included.

Introduction

Civil Engineers use probabilistic estimates of rainfall intensities for particular durations and locations for the design of a wide range of structures from urban storm water drainage systems to dams and spillways. More recently their use has extended beyond the realm of civil engineering to include a broad array of environmental management and analysis concerns. In 1953 the National Weather Service (NWS) began publishing rainfall-intensity-frequency-duration values or precipitation frequency estimates (Weather Bureau Technical Paper 24, 1953). These values have become de-facto national standards by inclusion or reference in design and planning standards of a wide variety of agencies at Federal, state, and local levels.

The current standards date from the 1960/70s. They are being updated based on a variety of improvements including: use of significantly longer data records, use of a regional L-moments analysis technique, an advanced spatial interpolation and mapping procedure, and web-based delivery of the final product.

This paper presents information from the recently published updates for the semiarid southwest (NOAA Atlas 14, Vol. 1, 2003). Current information from the NWS Hydrometeorological Design Studies Center can be found at "http://www.nws.noaa.gov/oh/hdsc".

History and Current Documents

As Federal agencies began building large dams, they looked to an independent agency to make rainfall climatology estimates for use in design standards. The NWS filled that role by producing probable maximum precipitation estimates (estimates of worst case rainfall scenarios). While other agencies such as the U.S. Department of Agriculture had produced earlier precipitation frequency estimates, the NWS role in worst case estimates was subsequently extended to probabilistic estimates over a range of durations and expectations.

The NWS updated the initial publications in the early 1960s and 1970s and most of the existing publications still date from that period.

Table 1. Most current precipitation frequency documents date from the early 1960/70s.

	5 – 60 minutes	**1 – 24 hour**	**2 – 10 day**
Western U.S.	Frederick & Miller (1979) Arkell & Richards (1986)	NOAA Atlas 2 (1973)	Tech Paper 49 (1964)
AZ, NV, NM, UT, southeast CA	NOAA Atlas 14 Vol. 1 (2003)	NOAA Atlas 14 Vol. 1 (2003)	NOAA Atlas 14 Vol. 1 (2003)
Eastern U.S.	Tech Memo 35 (1977)	Tech Paper 40 (1961)	Tech Paper 49 (1964)
IL, IN, OH, PA, NJ, DE, MD, DC, VI, WV, NC, SC, TN, and KY	NOAA Atlas 14 Vol. 2 (expected May 2004)	NOAA Atlas 14 Vol. 2 (expected May 2004)	NOAA Atlas 14 Vol. 2 (expected May 2004)
Hawaii	Tech Paper 43 (1962)	Tech Paper 43 (1962)	Tech Paper 43 (1962)
Alaska	Tech Paper 47 (1963)	Tech Paper 47 (1963)	Tech Paper 52 (1965)
Puerto Rico	Tech Paper 42 (1961)	Tech Paper 42 (1961)	Tech Paper 53 (1965)

Current Studies

The Hydrometeorological Design Studies Center, located within the National Weather Service Office of Hydrologic Development, published updated precipitation frequency estimates for the semiarid southwest United States (AZ, NV, NM, UT, southeast CA) (Bonnin et al. 2003) in August 2003. It is currently working on updates for the Ohio River basin and surrounding states (Raynault et al. 2003) (Tennessee, Kentucky, Illinois, Indiana, Ohio, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, North and South Carolina), Puerto Rico and the Virgin Islands, and the Hawaiian Islands.

The work of the Hydrometeorological Design Studies Center on both precipitation frequency and probable maximum precipitation is performed at the request of, and using funds provided by, a variety of Federal, state, and local agencies.

These projects provide precipitation frequency estimates for durations of 5 minutes to 60 days and return periods of 2 to 1000 years. For the first time the estimates are accompanied by assessments of the associated uncertainty, specifically, the upper and lower 90% confidence limits. They also provide probabilistic estimates of rainfall temporal distributions designed for use with the precipitation frequency estimates and updates to areal reduction factors for conversion of point estimates to areas of varying size. The projects improve on previous work by using a much longer period of rainfall observations, state-of-the-art statistical methods and methods of spatial interpolation, and the results will be delivered via the Internet. Each of these is discussed in greater detail below.

Data

NOAA Atlas 2, published in 1973 (Miller et al. 1973), and still in use today for a significant portion of the western United States, used data through 1969. The average length of record used in NOAA Atlas 2 for California was about twenty-eight years. Additional data available since 1969 allows us to eliminate from consideration stations with data lengths smaller than twenty years for daily gages. The semiarid southwest update project has an average record length of fifty-three years, nearly double the record length analyzed for NOAA Atlas 2. This clear improvement in the length of record available for analysis at individual observing stations significantly increases the return period beyond which the probability distributions need to be extrapolated. It also allows much greater confidence in determining the underlying probability distributions for the rainfall frequency estimates and thereby improves confidence in the extrapolation of the curves beyond the range of the observed data.

Statistical Approach

Hosking and Wallis (1997), describe regional frequency analysis using the method of L-moments. This general statistical methodology stems from work in the early 1970's. It only began seeing full implementation for precipitation frequency estimation in the 1990's but is now accepted as the state of the practice. The National Weather Service is using Hosking and Wallis, 1997, as its primary reference for the statistical approach in its current studies.

The method of L-moments (or linear combinations of probability weighted moments) provides great utility in choosing the most appropriate probability distribution function to describe the rainfall frequency distribution. It also provides tools for estimating the shape (higher order statistical moments) of the distribution and the uncertainty associated with the estimates.

The so-called "regional approach" recognizes that different observing stations can be assembled into groupings of similar climatic regimes or regions. It takes advantage of the similarity by assuming that stations within similar regions share the shape (not scale) of their rainfall frequency distribution curves. This assumption allows estimation of the shape parameters from a combination of data from all observing stations in a climatic region rather than from each station individually. The combination increases the sample data set used in the estimate producing much better estimates of the shape of the distribution and extends reliable extrapolations to more extreme events.

While the method derives the shape of underlying probability distribution function from groupings of observing sites, the mean of the distribution is estimated separately at each station. This feature is key to the approach the NWS is using for spatially interpolating estimates (discussed below). Also, while the shape of the probability distribution function is common amongst groups of stations, the fact that the scale estimated uniquely at each observing site means that the final precipitation frequency estimates are unique at each site. They are not "regional estimates" that are the same over regions.

Regional frequency analysis using the method of L-moments includes tools for determining whether the data are likely to belong to similar climatic regimes as well as tools useful in examining the quality of the data record. The method is particularly useful in that it accounts for the variation in period of record between individual observing sites, a common feature of the historical record.

Temporal Distributions

The projects provide possible temporal distributions for heavy rainfall (Figure 1) in a manner similar to the work of the Illinois State Water Survey, (Huff 1990). The information is provided for durations of 6-, 12-, 24- and 96-hours and at probability levels ranging from 10% to 90%. In the Semiarid Southwest project area, the NWS also divides the area into regions where heavy rainfall is dominated either by general rainfall mechanisms or by convective rainfall mechanisms.

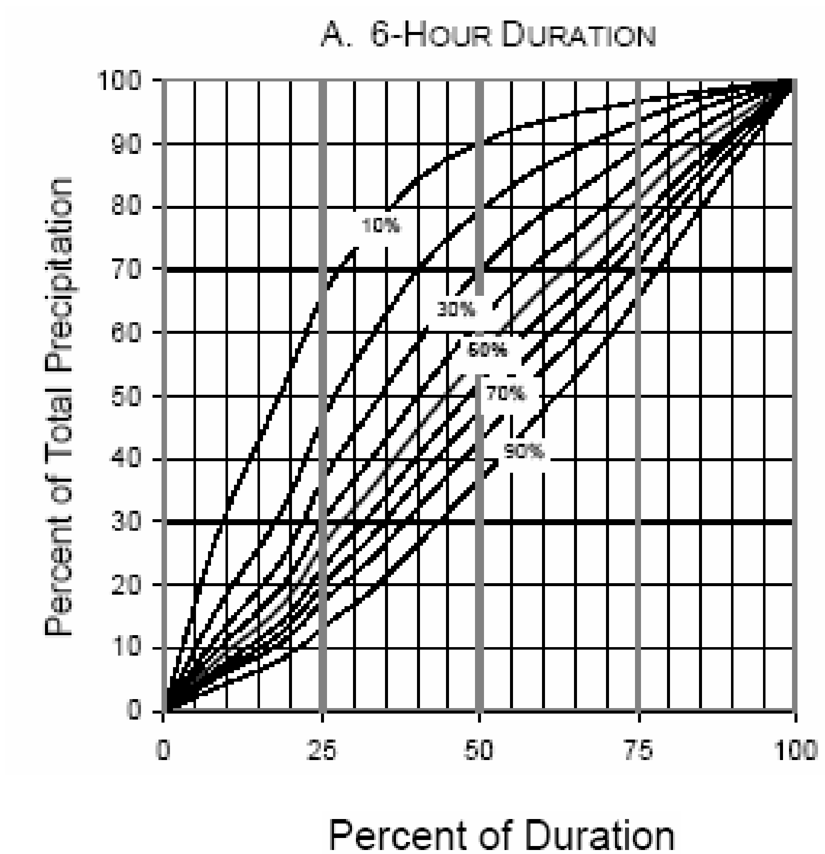

Figure 1. Possible temporal distributions for "general" rainfall of six hour duration in the Semiarid Southwest study area.

In order to be consistent with the definition of "duration" used in the precipitation frequency analysis, these distributions have been derived considering all rainfall occurring in fixed durations rather than for storm events per se. In other words, a specific duration may contain one or more storms or a part of a storm event.

The distributions apply specifically for heavy rainfall and do not necessarily apply to all rainfall. The project analyzed all rainfall cases exceeding the two-year average recurrence interval for the entire period of the data record using hourly recording stations.

Figure 1 shows probable temporal distributions for rainfall of six-hour duration in the Semiarid Southwest project area for regions where heavy rainfall was dominated by general rainfall mechanisms. The horizontal axis represents percent of total duration and the vertical axis represents percent of total rainfall. The various curves represent cumulative probabilities based on the sample data. For example, the 10% of cases whose distributions are closest to the beginning of the period are represented by the 10% curve. The 10% of cases whose distributions are closest to the end of the period are represented by the 90% curve.

Areal Reduction Factors

Precipitation frequency estimates are estimates at a point. Areal reduction factors are used to reduce the point estimates to values appropriate for particular area sizes such as a stream catchment area. The last major recomputation of areal reduction factors by the National Weather Service was published in 1957 (U.S. Weather Bureau 1957). Succeeding reanalyses by the NWS did not produce significantly different results and the same factors were carried forward. For this update, the NWS is conducting a new analysis using procedures applied to Chicago area data (Myers and Zehr 1980). We have selected a representative set of dense rain gauge networks across the United States. We will also examine whether the assumption of a single set of factors regardless of location is still appropriate given the greater amount of data available for analysis.

Spatial Interpolation

Rainfall frequency statistics are extracted for the specific locations of the rainfall gauges where the data were collected. This raises the question of how to interpolate between observing sites. Traditionally the estimates have been manually contoured taking subjective account of the terrain and climatology. NOAA Atlas 2 (Miller et al. 1973) augmented the subjective approach by using regression analysis based on climate and terrain factors as predictors.

Oregon State University's Spatial Climate Analysis Service has developed PRISM, a hybrid statistical-geographic approach to mapping climate data (Daly et al. 1992, 1994, 1997). PRISM uses many of the predictive advantages of statistical techniques while integrating information concerning climate processes and variations, and patterns from geographical studies. It produces fine scale gridded interpolations of climatic variables suitable for use in geographical information system (GIS) applications. PRISM is seeing growing acceptance as an effective tool for spatial interpolation of climatic variables and is being used by the NWS as part of its system for spatially interpolating the precipitation frequency estimates to high resolution grids.

For precipitation frequency estimates, there is a linear relationship between the mean of the underlying probability distribution function for particular durations and the estimated precipitation at particular frequencies. As noted earlier, the mean of the distribution at each location is estimated based solely on the data observed at that location whereas the higher order moments are estimated from homogeneous groups of observing locations. The NWS has used this feature to achieve a cost effective approach to spatially interpolating the point estimates. PRISM is used to spatially interpolate only the means. The resulting fine scale grids of the distribution means are then converted to precipitation depth estimates at different frequencies using a multiplier computed as a function of the appropriate higher order moments. Adjustments are then made for potential spatial discontinuities between shape factors for different homogeneous regions. This approach allows us to make a single PRISM run for each duration rather than making estimates for each combination of duration and frequency.

One of the difficulties in spatially interpolating precipitation frequency estimates is the lack of quality observations covering a broad variation in elevation, particularly observations at higher elevations. The Semiarid Southwest project made use of data collected by the Natural Resources Conservation Service's SNOTEL network, generally located at high elevation in the western U.S. There are locations where the quality of the observed data is insufficient for estimating the higher order statistical moments but is sufficient for estimating the mean of the distribution. We have used this knowledge by including the estimates of distribution means from all locations in the PRISM runs at the same time as being more selective in the stations that contribute to the regional estimates of the higher order moments of the probability distribution functions.

We have identified a few locations where the shape of the distribution function is best estimated separately rather than in common with other stations. For these locations we include the distribution mean in the PRISM interpolation and then use the station's higher order moments when we operate on the resulting grids. We account for potential spatial discontinuities in these cases as well.

Products and Delivery

The NWS has developed the Precipitation Frequency Data Server for web-based delivery of precipitation frequency estimates (Parzybok and Yekta 2003). It is being used as the primary vehicle for delivery of precipitation frequency estimates (Figure 2) and associated documentation.

The documents themselves, including tables and maps, will available in Portable Document Format (PDF). They will be subdivided appropriately to avoid having to download massive data files to get specific information.

For more tailored information, the system allows a user with a standard web browser to download a variety of tables and graphs of precipitation frequency estimates. The estimates will be available for any user-selected point location in the United States and will also be available for user-selected areas up to 1000 km^2.

Color cartographic maps of precipitation frequency estimates will be prepared from grids of the estimates with a 30 arc-second grid resolution. These base grids will also be made available for download over the Internet. The grids are in a common ASCII grid format that is easily importable into most geographic information systems. We understand a variety of developers plan to incorporate the base grids directly into their own software.

Conclusion

The current National Weather Service precipitation frequency estimates are used as de-facto national standards. Improvements in the data record and the science provide significantly better estimates on which to base design decisions. The Internet provides a more accessible mechanism for delivery of precipitation frequency estimates. The National Weather Service, with financial support from a variety of Federal, state, and local agencies is working on updates for selected areas of the United States.

POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14

FLAGSTAFF WSO AP, ARIZONA (02-3010) 35.1333°N 111.6667°W 7086 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 1, Version 3
G.M. Bonnin, D. Todd, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2003

Extracted: Thu Mar 11 2004

Confidence Limits | Seasonality | Location Maps | Other Info. | Grids | Maps | Help | Docs | U.S. Map

Precipitation Frequency Estimates (inches)

return period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
2	0.28	0.43	0.53	0.71	0.88	1.02	1.11	1.34	1.72	2.15	2.59	2.97	3.53	3.98	5.32	6.51	7.79	9.08
5	0.38	0.58	0.72	0.97	1.20	1.34	1.43	1.66	2.09	2.67	3.23	3.72	4.38	4.90	6.42	7.83	9.40	10.87
10	0.46	0.70	0.87	1.17	1.45	1.61	1.69	1.94	2.40	3.10	3.75	4.34	5.08	5.63	7.28	8.85	10.63	12.20
25	0.58	0.88	1.09	1.47	1.82	2.00	2.08	2.35	2.83	3.69	4.46	5.22	6.07	6.63	8.39	10.12	12.22	13.87
50	0.67	1.02	1.27	1.71	2.12	2.33	2.40	2.68	3.16	4.15	5.03	5.91	6.85	7.41	9.21	11.06	13.40	15.07
100	0.78	1.18	1.47	1.98	2.45	2.69	2.73	3.03	3.51	4.64	5.61	6.66	7.68	8.19	10.01	11.97	14.56	16.23
200	0.89	1.36	1.68	2.27	2.81	3.08	3.13	3.42	3.87	5.13	6.21	7.43	8.54	8.98	10.79	12.84	15.68	17.32
500	1.05	1.60	1.99	2.68	3.31	3.65	3.70	3.97	4.34	5.80	7.04	8.51	9.74	10.05	11.79	13.94	17.10	18.67
1000	1.19	1.81	2.25	3.03	3.75	4.12	4.16	4.42	4.72	6.34	7.70	9.38	10.70	10.88	12.52	14.73	18.14	19.63

Text version of table

These precipitation frequency estimates are based on a partial duration maxima series. Please refer to the documentation for more information. NOTE: Formatting forces estimates near zero to appear as zero.

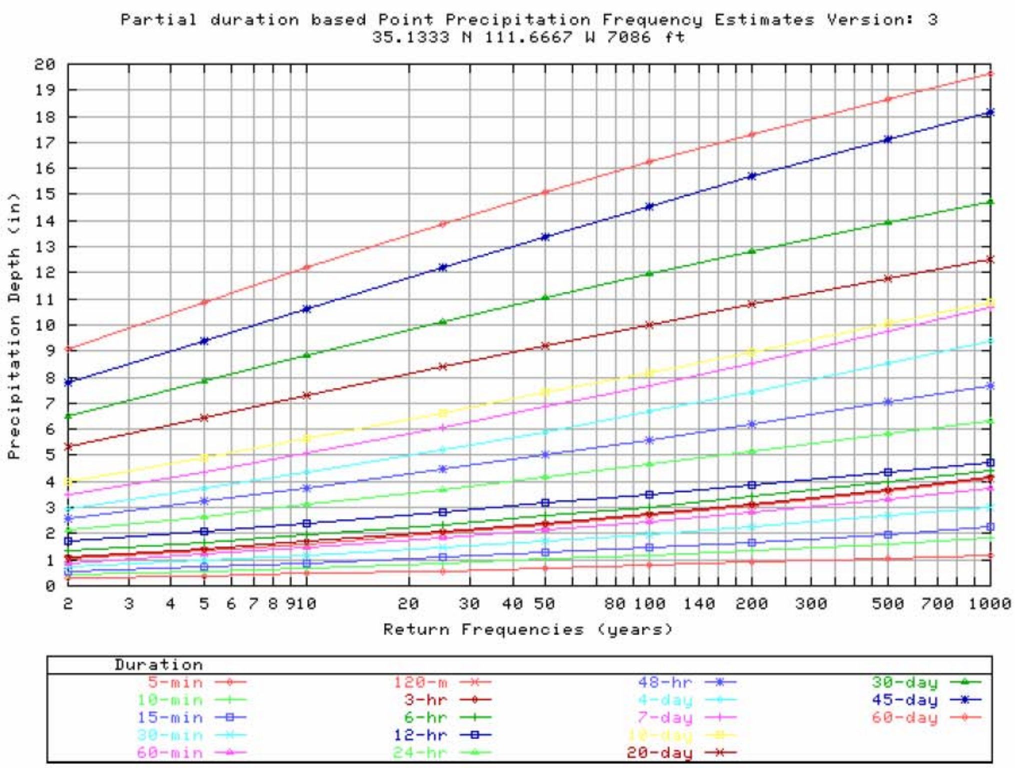

Figure 2. Data will be available at user-selected locations via the web

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