HAWAII PRECIPITATION FREQUENCY PROJECT

Update of *Technical Paper No. 43*

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Hydrometeorological Design Studies Center
Hydrology Laboratory

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DISCLAIMER

The data and information presented in this report are provided only to demonstrate current progress on the various technical tasks associated with this project. Values presented herein are NOT intended for any other use beyond the scope of this progress report. Anyone using any data or information presented in this report for any purpose other than for what it was intended does so at their own risk.

Table of Contents

1. Introduction 4
2. Highlights 6
3. Progress in this Reporting Period 7
4. Issues 17
5. Projected Schedule and Remaining Tasks 17
References 19

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1. Introduction

The Hydrometeorological Design Studies Center (HDSC) within the Office of Hydrologic Development of NOAA's National Weather Service plans to update its precipitation frequency estimates for Hawaii. Current precipitation frequency estimates for Hawaii are contained in *Technical Paper No. 43,* "Rainfall-Frequency Atlas of the Hawaiian Islands for Areas to 200 Square Miles, Durations to 24 Hours, and Return Periods from 1 to 100 Years" (U.S. Weather Bureau, 1962) and *Technical Paper No. 51*, "Two- to Ten-Day Rainfall for Return Periods of 2 to 100 Years in the Hawaiian Islands" (U.S. Weather Bureau, 1965). The update includes collecting data and performing quality control, compiling and formatting datasets for analyses, selecting applicable frequency distributions and fitting techniques, analyzing data, mapping and preparing reports and other documentation.

The project will determine annual precipitation frequencies for durations from 5 minutes to 60 days, for average recurrence intervals from 1 to 1,000 years. The project will review and process rainfall data for the project area and use accepted statistical methods. The project results will be published as Volume 4 of NOAA Atlas 14 on the Internet (http://www.nws.noaa.gov/ohd/hdsc) using web pages with the ability to download digital files.

The project area covers the Hawaiian Islands including Hawaii, Maui, Lanai, Molokai, Oahu, and Kauai. The project area including preliminary regions is shown in Figure 1.

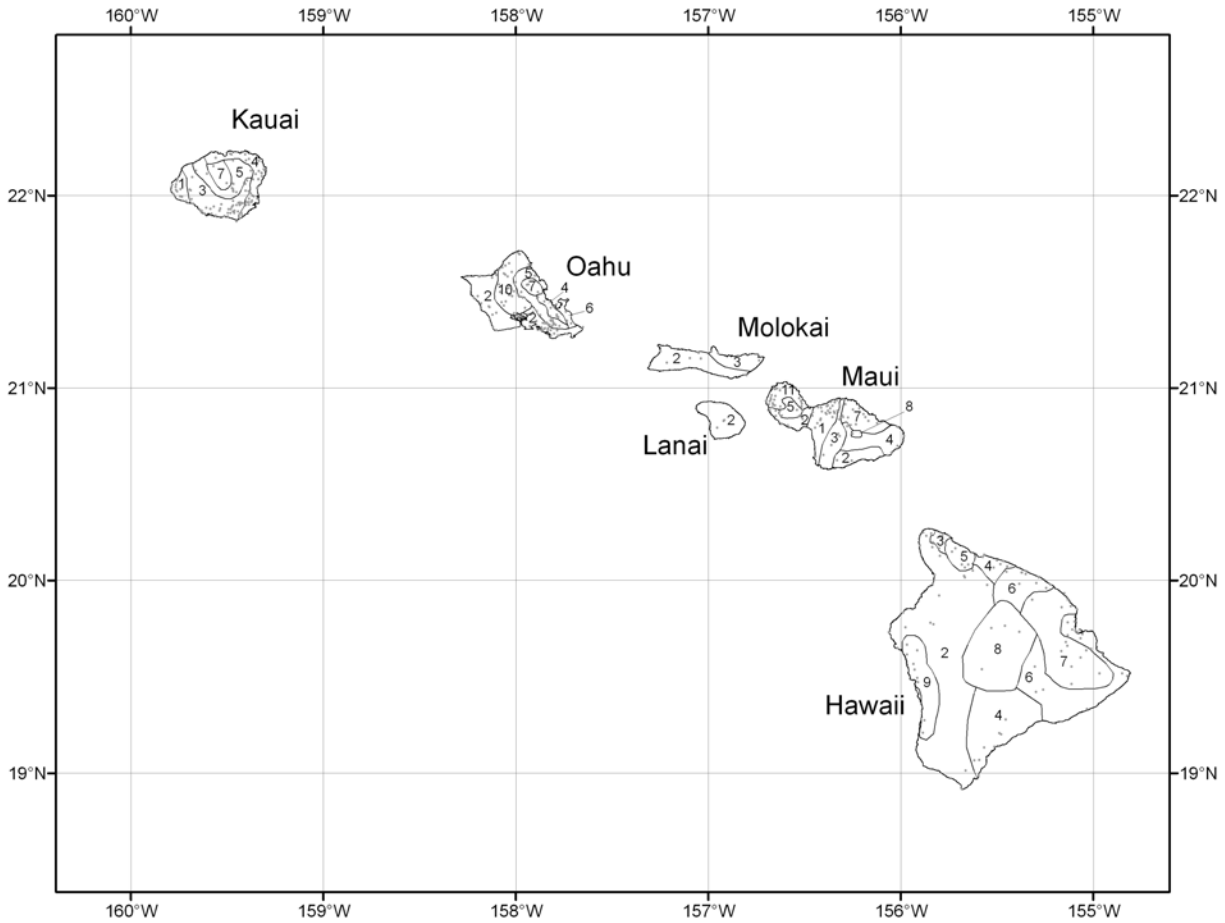


Figure 1. Hawaii Precipitation Frequency Project area, new daily regional divisions and daily station locations.

2. Highlights

15-minute data for stations with at least 10 years of data were obtained from the USGS and examined for inclusion in the analysis. Hydronet 15-minute data were quality controlled and accumulated to hourly data for consideration. Co-located n-minute and 1-hour data were reviewed for data quality. Stations with anomalous data at the 1-day and longer duration were examined, particularly during the regionalization stage, and some data corrections and station deletions resulted. Additional information is provided in Section 3.1, Data Collection and Quality Control.

The conversion factor for 1-day to 24-hour data was computed as 1.195. Additional information is provided in Section 3.2, Conversion Factors.

After a review of the initial 16 regions and climatology, it was decided to use a spatial cluster analysis to develop the basis for new daily regions using the 24-hour data. Subsequent re-grouping of some stations occurred to yield 11 statistically homogenous regions that were climatologically sound. Wet seasons were refined for these new regions to be used in the series extraction. Additional information is provided in Section 3.3, Regionalization.

An objective clustering technique was investigated and used to guide the delineation of homogenous L-moment regions for daily durations. Final regions were digitized as polygons to ensure proper station assignments to regions. Additional information is provided in Section 3.4, Spatial Interpolation.

Modifications to L-moment software are complete to accommodate additional data field width in the data archives due to values at various durations exceeding the previously allowable maximum of 99.99 inches. Additional information is provided in Section 3.5, Software.

HDSC continuously monitors the integrity and performance of the Precipitation Frequency Data Server (PFDS), the on-line portal for all NOAA Atlas 14 deliverables and information. Additional information is provided in Section 3.6, PFDS.

Work continues on the development of geographically fixed Areal Reduction Factors (ARFs) for area sizes of 10 to 500 square miles and durations of 30-minutes to 48-hours for the United States. Additional information is provided in Section 3.7, Areal Reduction Factors.

3. Progress in this Reporting Period

3.1 Data Collection and Quality Control

15-minute data for stations with at least 10 years of data were obtained from the United States Geological Survey (USGS). A sufficient number of data years are necessary to reliably compute precipitation frequency estimates. After careful consideration, it was decided not to use these data in the L-moment computations due to short periods of record (the longest record was 11 years) and concerns about time increments changing from 15-minute to 30-minute in a few cases. The data will be revisited for possible use in the computation of n-minute ratios which convert 60-minute estimates to shorter duration estimates.

Some Hydronet 15-minute data at seven stations were re-checked due to a minor software error when compiling questionable values. This resulted in twelve additional corrections. The Hydronet data were accumulated to a 1-hour duration to evaluate data quality by spatially interpolating the means and coefficient of L-variation statistic and comparing with nearby hourly National Climatic Data Center (NCDC) stations. After considering the spatial consistency of the data, it will be decided how to best incorporate the data into the project. If the data are consistent with NCDC data, then the minimum number of data years may be set to 12 for hourly stations to include more stations in the hourly L-moments computation. If not all stations are consistent, then only some stations needed for spatial coverage may be selected for inclusion in the hourly analysis. Finally, if appropriate, the stations may be treated as supplemental and only their mean annual maximums would be used with regional growth factors developed from the NCDC stations to compute precipitation frequency estimates at those locations (i.e., the Hydronet data would not be used in the L-moment computations).

Co-located n-minute and 1-hour NCDC data were reviewed for data quality at the four n-minute stations. Accuracy of the data was confirmed for concurrent maximum values that differed by 50% or more. Seven errors were found in the n-minute ASOS data that were corrected, generally by setting the year to missing because a large event was not recorded properly.

Stations with anomalous data at the 1-day and longer duration were examined. 1-day data were closely scrutinized in maps of spatially interpolated mean annual maximums, particularly when compared to Technical Paper 43, and in maps of preliminary 100-year 24-hour estimates. In addition, stations that have annual maximum series with at least 20 years of data for some durations but not others, due to the treatment of accumulated data during the series extraction, were closely examined. Several actions were taken when appropriately justified: erroneous values were corrected, stations were deleted, or stations were assigned to be used for only certain durations due to the accumulated nature of its data. A station was only deleted where the record was clearly missing extreme events or had suspect data, and there were other stations in the area to provide spatial coverage.

Additional quality control of the 24-hour data was conducted as part of the regionalization process (see Section 3.3, Regionalization). In evaluating regions, a discordancy measure (Hosking and Wallis, 1997) is used to determine if a station has been inappropriately assigned to a region. It is based on L-moment statistics and provides a measure of a station's consistency with the set of stations in the region. Specifically, the measure is based on the coefficient of L-variation, L-skewness and L-kurtosis, which represent a point in 3-dimensional space for each station. It is a measure of the distance of each point from the cluster center of the points for all stations in a region. The cluster center is defined as the unweighted mean of the three L-moments for the stations within the region being tested. Some stations that captured a single high event or had a short data record were discordant but were accepted in a homogeneous region since no climatological or physical reason was found to justify their exclusion. Stations with a discordancy measure greater than 3.0 were also checked as a quality control method. In another quality control method during the regionalization, all cases where the maximum observed rainfall exceeded the preliminary 1,000-year average recurrence interval estimates were investigated for data quality and appropriate regionalization.

3.2 Conversion Factors

Daily data have varying observation times. Maximum 24-hour amounts seldom fall within a single daily observation period. In order to make the daily and hourly data comparable, a conversion is necessary from 'observation day' (constrained observation) to 24 hours (unconstrained observation).

Both Technical Paper 43 (U.S. Weather Bureau, 1962) and Technical Paper 51 (U.S. Weather Bureau, 1965) used the empirically derived value of 1.13 from previous studies of other study areas to convert daily data to 24-hour data. The conversion factor for this project, 1.195, was developed from only data in Hawaii using two methods: ratios of the 2-year quantiles computed from annual maximum series and monthly maximum series and regression slopes of concurrent annual maxima and monthly maxima pairs. Results are shown in Table 1.

The annual maximum series at 28 co-located stations and the monthly maxima series at 52 co-located stations with at least 15 years (or months) of concurrent hourly and daily data in the project area were used to compute the ratios. Time series for concurrent time periods were generated for 24-hour precipitation values summed from hourly observations and co-located daily precipitation observations. The series were analyzed separately using L-moments. Ratios of 2-year 24-hour to 2-year 1-day quantiles were then generated and averaged. The conversion factor was the same using different distributions (GNO, GEV, GLO).

A linear regression was applied to daily/24-hourly annual maxima and separately to monthly maxima that occurred on the same day. The linear regression was based on

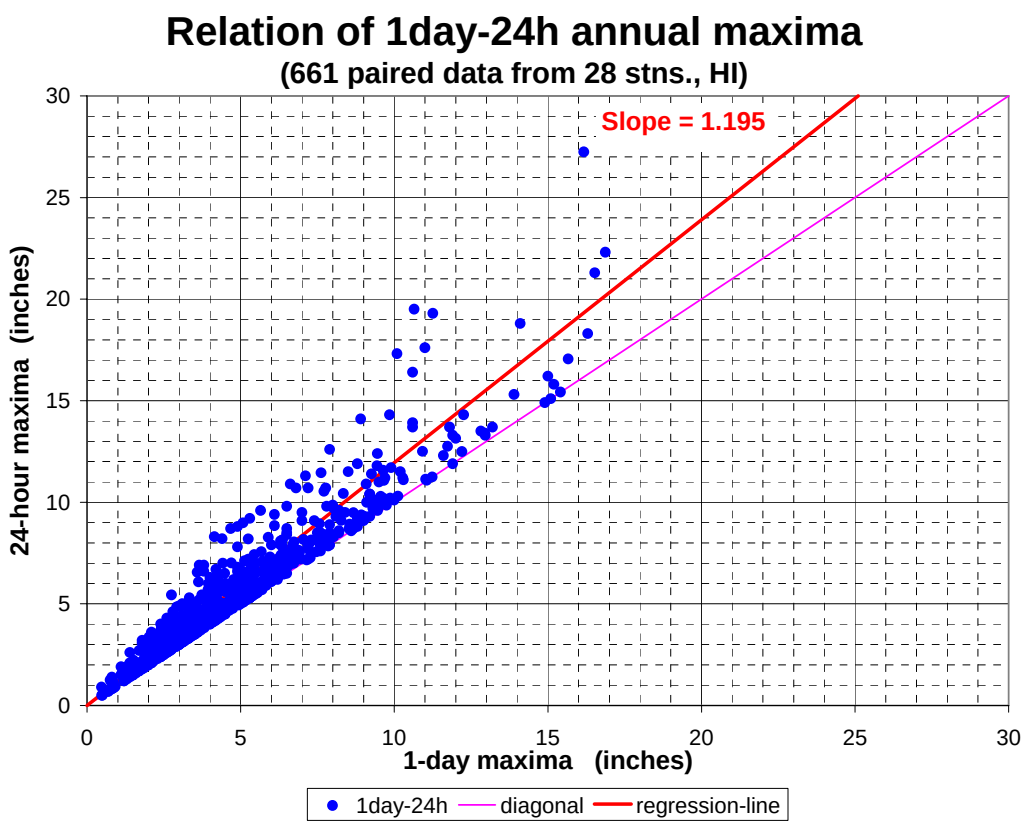
661 annual pairs and 10,304 monthly pairs of concurrent data. In Table 1, the "Calculate" ratio was obtained based on the paired station-average values while the "Plot" ratio was obtained based on all paired real data. Figure 2 illustrates the regression using paired real data from the annual maximum series.

The conversion factor used in this project will be 1.195, which is the average of the computed factors from all methods. This factor is higher than the conversion factors used in NOAA Atlas 14 Volumes 1 (semiarid southwestern U.S.) and 2 (Ohio River basin and surround states) and in Technical Papers 43 and 51, but it is in close agreement with NOAA Atlas 14 Volume 3 for Puerto Rico and the U.S. Virgin Islands which used 1.21.

Table1. 24-hour to 1-day conversion factors for the Hawaii data

Duration	Data type	2-year ratio			Regression slope		**Suggested**
		GEV	GLO	GNO	Calculate	Plot	
1day-24hou	Annual	1.189	1.188	1.189	1.179	1.195	**1.195**
	Monthly	1.200	1.200	1.200	1.196	1.212	

Figure 2. Linear regression of 661 concurrent annual maxima from co-located daily and hourly stations in Hawaii.



3.3 Regionalization

The underlying assumption of the regional approach using L-moments is that stations can be grouped in sets or "regions" in which stations have similar frequency distribution statistics except for a site-specific scale factor. Regions which satisfy this assumption are referred to as "homogeneous." The key to the regional approach is to construct a set of homogeneous regions for the entire project area. Hosking and Wallis (1997) make the case that homogeneous regions should be identified based on factors other than the statistics used to test the assumption of homogeneity. The heterogeneity measure, H1, tests between-site variations in sample L-moments for a group of sites with what would be expected for a homogeneous region based on coefficient of L-variation (Hosking and Wallis, 1997). Earlier studies (Hosking and Wallis, 1997; also, personal discussion with Hosking at NWS, 2001) indicated that a threshold of 2 is conservative and reasonable. Therefore, we use an H1 measure greater than 2 (H1>2) to indicate heterogeneity and H1<2 to indicate homogeneity.

The stations with 24-hour data in this project were first delineated into 16 regions, subjectively, based on climate, season(s) of highest precipitation, type of precipitation (e.g., general storm, convective, tropical storms or hurricanes, or a combination), topography and the homogeneity of such characteristics in a given geographic area. These regions were investigated using statistical homogeneity tests and other checks. During this investigation, various combinations of appropriate windward and leeward regions on different islands were attempted in order to create homogeneous regions that were more consistent with climatological expectations. This approach met with little success.

Therefore, HDSC investigated an objective clustering method. Section 3.4, Spatial Interpolation, provides the details of the objective clustering method. After testing the method and considering the results, it was decided to use this spatial cluster analysis using three characteristics (mean annual precipitation, mean annual maximum 24-hour precipitation and maximum observed 24-hour precipitation) to develop new initial daily regions for the 24-hour data. The resulting regions generally fell into the expected climatological categories:

1) Windward lowlands
2) Leeward lowlands
3) Interior lowlands
4) Rainy windward slope
5) Leeward slopes
6) High Mountains above the trade wind inversion
7) Kona coast of the Big Island.

As suggested in Hosking and Wallis (1997), adjustments of regions, such as moving stations from one region to another or subdividing a region, were then made to reduce heterogeneity and also to reduce spatial bull's eyes and unreasonable spatial gradients in estimates. This subsequent re-grouping yielded 11 statistically homogenous regions

that were climatologically sound (Figure 1 and Table 2). These regions will be used for the durations 24-hour through 60-day.

Table 2. Number of daily and hourly stations and the heterogeneity measure (H1) for each daily region.

region	# daily	# hourly	Total # stns	H1
1	40	3	43	1.63
2	78	24	102	0.83
3	56	7	63	-0.81
4	61	12	73	1.43
5	41	5	46	0.63
6	30	5	35	0.60
7	31	7	38	0.60
8	5	1	6	-0.53
9	9	1	10	0.95
10	28	6	34	0.98
11	22	2	24	-0.31
	401	**73**	**474**	

Wet seasons were then refined for these new regions (Table 3) to be used in the series extraction (additional details regarding the method for this are discussed in the previous Progress Report 22, http://www.nws.noaa.gov/ohd/hdsc/current-projects/HIPR22.pdf). Criteria ensure that each year in a series has a sufficient number of data, particularly in the assigned “wet season”, to accurately extract statistically meaningful values.

Table 3. Start and End months for wet seasons assigned to Hawaii daily regions.

Region	Daily Wet Season months
1	10 to 3
2	10 to 4
3	10 to 4
4	10 to 5
5	10 to 5
6	8 to 4
7	8 to 4
8	7 to 3
9	1 to 12
10	10 to 4
11	11 to 4

3.4 Spatial Interpolation

An objective clustering technique was used to guide the delineation of homogenous L-moment regions for daily durations of 24-hour through 60-days. The clustering process utilized built-in GRASS GIS functions (i.cluster, i.maxlik and i.group), collectively called "image clustering," and normalization techniques as discussed in relevant journal articles (e.g., Lin and Chen, 2006). The image clustering technique generates an unsupervised image classification using a maximum-likelihood discriminate analysis classifier. In unsupervised classification, pixels are clustered based on statistics only, without any user-defined training classes. The maximum-likelihood classifier utilizes cluster means and covariance matrices to determine to which category each cell in the image has the highest probability of belonging.

The first step in the clustering process was to normalize all of the potentially relevant variables to values between 1 and 100. The variables and their normalizing equation are outlined in Table 4.

Table 4. Transformation of site characteristics.

Site characteristic X	**Cluster variable Y**
Mean annual precipitation (inches)	$Y = X/X_{max}$
Mean annual maximum 24-hour precipitation (inches)	$Y = X/X_{max}$
Maximum observed 24-hour precipitation (inches)	$Y = X/X_{max}$
Latitude (decimal degrees)	$Y = (X-X_{min})/(X_{max}-X_{min})$
Longitude (decimal degrees)	$Y = (X-X_{min})/(X_{max}-X_{min})$
Elevation (feet)	$Y = X/X_{max}$

Once each of the site cluster variables was computed, they were interpolated to a uniform grid using inverse-distance-weighting (IDW). Since grids of elevation and mean annual precipitation (Daly et al., 1997, 2002) were already available, the IDW step was not necessary for those variables.

GRASS's clustering algorithm allows the user select (1) how many clusters (i.e., regions) to create and (2) different combinations of cluster variables. After iterating through a number of different combinations of settings, it was concluded that the following parameters provided the best initial objective clusters:

- Number of clusters: 7
- Cluster variables: Mean annual precipitation, mean annual maximum 24-hour precipitation and maximum observed 24-hour precipitation.

The results provided an objective and effective means for creating initial regions.

The final regions were digitized as polygons to ensure proper station assignments to regions and to facilitate later assignment of stations with only longer duration data into

appropriate regions. As noted in Section 3.3, these initial regions were then manually refined to result in 11 distinct homogeneous regions.

3.5 Software

Some values at various durations exceed the previously allowable maximum of 99.99 inches in HDSC software due to accumulated data. Modifications to all L-moment software are now complete to accommodate this additional data field width. The functions of the software requiring modification included data series extraction, L-moment analysis, internal consistency adjustment, and confidence limit computation.

3.6 PFDS

HDSC continuously monitors the number of inquiries (hits), integrity and performance of the PFDS, which continues to receive a steady number of hits per month. The graph (Figure 3) below summarizes the number of individual data inquires made since December 2004, while the map (Figure 4) indicates the locations of inquires during the past quarter.

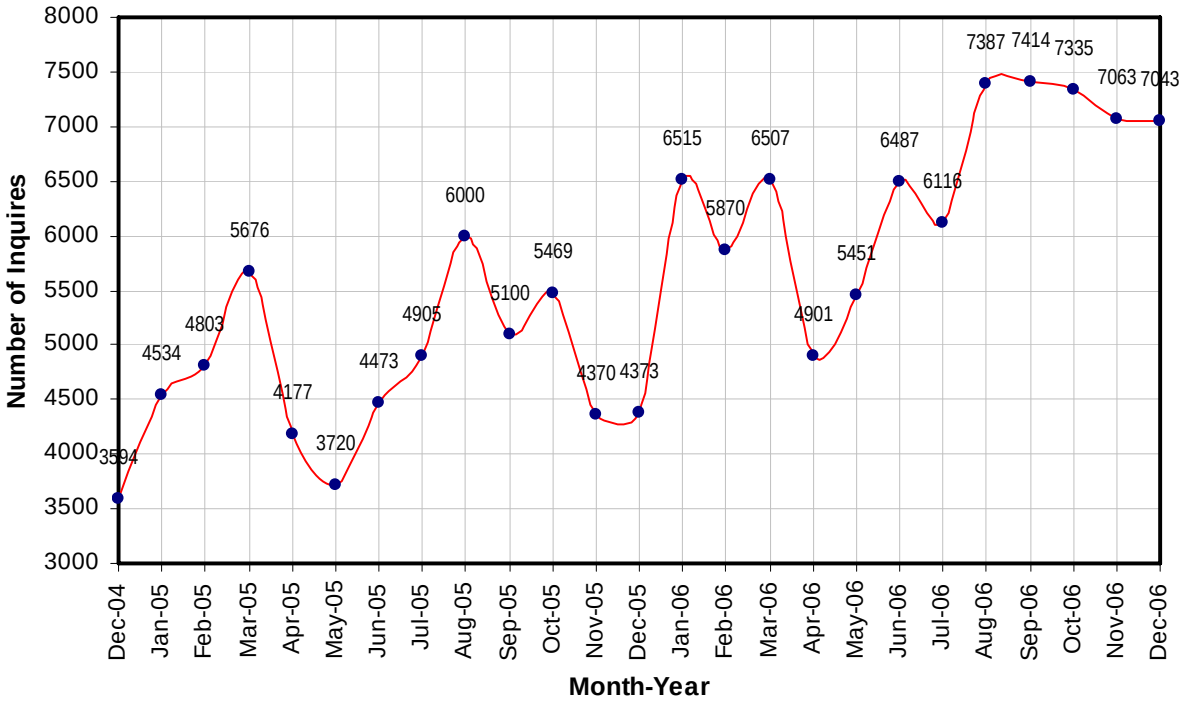


Figure 3: Number of individual PFDS data inquires per month.

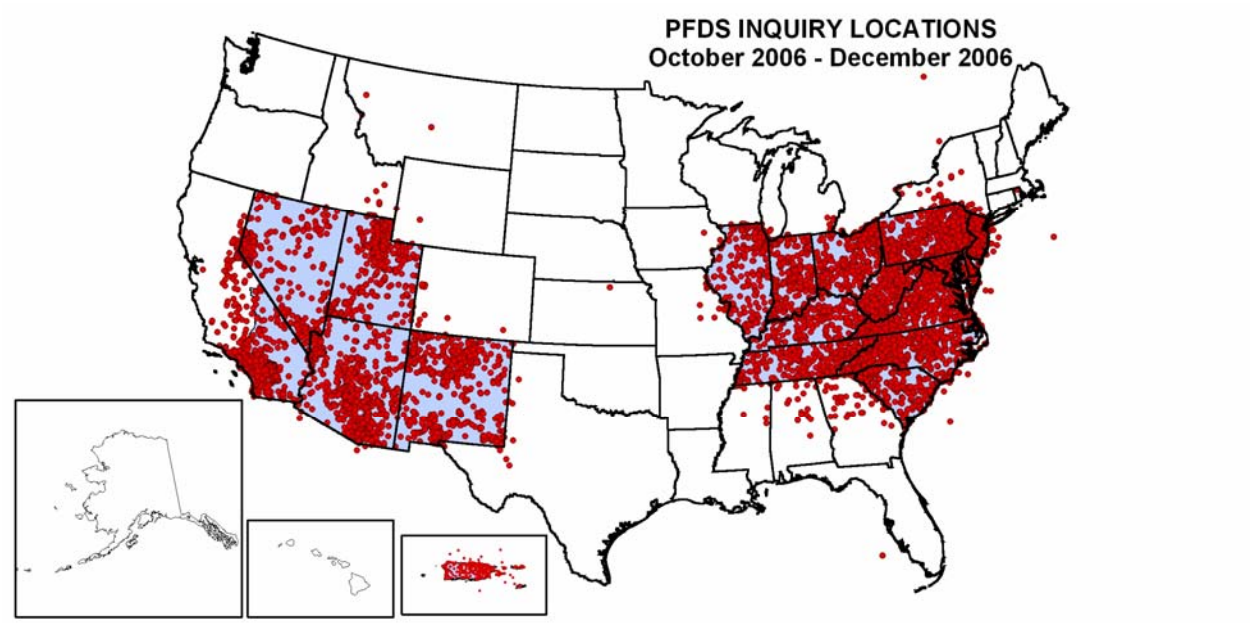


Figure 4: Map of 21,441 PFDS data inquiry locations during the period October-December 2006.

3.7 Areal Reduction Factors

Work continues on the development of geographically-fixed Areal Reduction Factors (ARFs) for area sizes of 10 to 500 square miles and durations of 30-minutes to 48-hours for the United States. The results of this supplementary study will be applicable to all volumes of NOAA Atlas 14.

Although ARF software development has been slow, it continues to move forward. The continuing goal is to develop ARF software based on the NOAA Technical Report NWS 24 (Myers, V.A. and R.M. Zehr, 1980) methodology and obtain the same results published in TR-24 for the Chicago rain gauge network. The ARF computations are a function of six variables that vary in time and space. Fitting functions (curves) to these six variables so that the results are equal to those in TR-24 has been difficult.

Figure 5 shows the locations of all used, not used and considered rain gauge networks. Meanwhile, Table 5 provides additional details of the preliminary study areas. Unless we are made aware of quality rain gauge networks that meets our criteria (10+ years of concurrent hourly precipitation data at 10+ gauges over an area of ~100 to ~500 square miles), we are not actively seeking additional networks. We have identified, pre-processed and quality controlled hourly precipitation data for 15 networks that we believe will anchor the final ARF results. Seven additional networks have the potential of being added to the base ARF database.

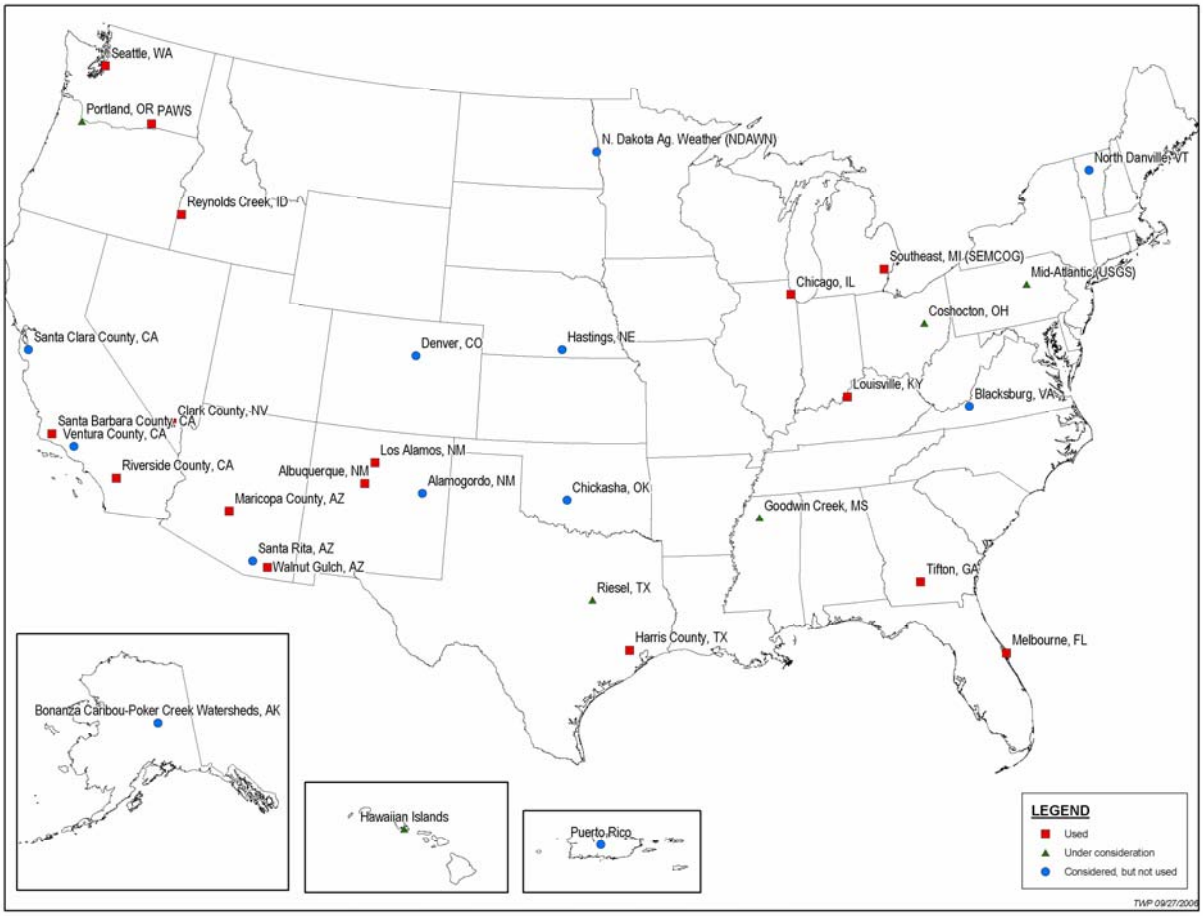


Figure 5. Map of ARF study areas.

Table 5. Preliminary ARF study areas.

Study area location	Included?	Date Range	Approx size (sq-mi)	No. of stations	Lat.	Long.	Average Elevation (ft)
Albuquerque, NM	Yes	1978-1992	400	13	35.161	-106.566	5311
Chicago, IL	Yes	1949-1980	n/a	18	41.830	-87.692	618
Clark County, NV	Yes	1990-2004	n/a	48	36.290	-114.978	940
Los Alamos, NM	Yes	1990-2005	150	9	35.858	-106.282	7011
Maricopa Cty, AZ	Yes	1980-2001	n/a	31	33.789	-112.303	2572
Reynolds Creek, ID	Yes	1962-1996	n/a	44	43.169	-116.769	5342
Riverside Cty, CA	Yes	1961-2001	n/a	45	33.793	-116.995	1987
Santa Barbara, CA	Yes	1968-2003	n/a	38	34.590	-119.957	1203
Seattle, WA	Yes	1978-2003	216	23	47.553	-122.333	152
South-central Washington state (PAWS)	Yes	1989-2005	700	15	46.071	-119.306	765
Southeast Michigan Council of Governments (SEMCOG)	Yes	1988-2002	n/a	50	42.518	-83.286	730
Melbourne, FL	Yes	1997-2005	450	35	28.545	-80.634	0
Harris County, TX	Yes	1997-2005	3800	165	29.779	-95.405	-999
Walnut Gulch, AZ	Yes	1954-1996	n/a	107	31.728	-110.024	4656
Jefferson County, KY	Yes	1991-2005	n/a	18	38.190	-85.670	-999
Chickasha (Micronet), OK	Maybe	1994-2005	1130	44	34.885	-98.075	398
Coshocton, OH	Maybe	1940-2001	n/a	22	40.435	-81.799	1044
Goodwin, MS	Maybe	1981-1996	n/a	32	34.232	-89.914	333
Portland, Oregon HYDRA	Maybe	1976-2005	200	45	45.537	-122.662	-999
Tifton, GA	Maybe	1968-1981	n/a	55	31.439	-83.590	-999
Ventura, CA	Maybe	n/a	n/a	134	34.370	-119.067	-999
Hawaii	Maybe	1948-2005	n/a	n/a	n/a	n/a	n/a
Alamogordo Creek, NM	No	1955-1962	67	64	34.920	-104.143	4898
Blacksburg, VA	No	n/a	n/a	<10	37.250	-80.417	-999
Denver, CO	No	n/a	n/a	n/a	39.750	-105.000	-999
Ft. Collins, CO	No	1999-2005	12		40.567	-105.093	5099
Riesel, TX	No	n/a	10	39	31.482	-96.880	544
Hastings, NE	No	1938-1967	n/a	19	40.255	-98.376	-999
North Danville, VT	No	1958-1975	n/a	27	49.678	-74.724	2118
Puerto Rico	No	1973-2003	500	10-18	18.260	-65.910	800
Mid-Atlantic DCP and Metar network	No	1990-2004					
Bonanza, Caribou-Poker Creeks Watersheds, AK	No	n/a	50	n/a	64.750	-148.230	1641

4. Issues

4.1 Upcoming Presentations

Geoff Bonnin will present a paper, *Updates to NOAA Precipitation Frequency Atlases*, (authors Geoffrey M. Bonnin, Deborah Martin, Bingzhang Lin, Tye Parzybok, Michael Yekta, David Riley, Lillian Hiner, Daniel Brewer) at the EWRI World Environmental and Water Resources Congress in Tampa, Florida, in May 2007. The paper was prepared and submitted.

5. Projected Schedule and Remaining Tasks

The following list provides a tentative schedule with completion dates. Brief descriptions of tasks that will be worked on during the next few quarters are also included in this section.

Data Collection and Quality Control [January 2007]
L-Moment Analysis/Frequency Distribution [March 2007]
Trend Analysis [January 2007]
Temporal Distributions of Extreme Rainfall [February 2007]
Peer Review of estimates [April 2007]
Spatial Interpolation [May 2007]
Precipitation Frequency Maps [June 2007]
Web Publication [May 2007]
Documentation [June 2007]

Areal Reduction Factors [June 2007]

5.1 Data Collection and Quality Control.

In the next reporting period, Hydronet data will be evaluated for use in the hourly analysis. Conversion factors (2-day to 48-hour, 1-hour to 60-minute and 2-hour to 120-minute) will be calculated.

5.2 L-Moment Analysis

Homogeneous precipitation frequency regions for the L-Moment analysis of the 60-minute data will be created. Software to treat supplemental longer duration data will be refined.

5.3 Trend Analysis and Cross-correlation Analysis

We will analyze the 1-day annual maximum time series for trends and cross-correlation between stations.

5.4 Areal Reduction Factors (ARF)

Either code will be completed to compute the ARF curves or alternative methods will be considered during the next quarter. Computations for the ARF curves will begin in the next quarter for 14 areas. The resulting curves will be tested for differences to determine if a single set of ARF curves is applicable to the entire U.S. or whether curves vary by region.

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