A PROPOSAL FOR

UPDATING

U.S. PRECIPITATION FREQUENCY ESTIMATES

Prepared by

Hydrometeorological Design Studies Center
Office of Hydrologic Development
National Weather Service
National Oceanic and Atmospheric Administration

Version 1.7.Northeast
9/16/10

Version History:

Version Number	Date	Comment
1.0	6/22/05	Initial Version
1.1	8/22/05	Added Versioning
1.2	10/25/06	FY07 Costs and update project map
1.3	8/20/07	FY08 Cost and minor wording
1.4	9/6/07	Minor wording, added Acronym List
1.5	8/28/08	FY09 Costs and wording to limit to remaining unfunded states
1.6	5/27/10	FY10 Costs
1.7	10/16/10	FY11 Costs and updated wording reflecting progress to date

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INTRODUCTION

NOAA's National Weather Service (NWS) proposes updating precipitation frequency estimates for the northeast States of New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine. The update will be published as a subsequent Volume of NOAA Atlas 14 "Precipitation-Frequency Atlas of the United States" on the web at "www.nws.noaa.gov/ohd/hdsc".

The AASHTO Technical Committee on Hydrology and Hydraulics rated this study as a high priority for funding and it has been endorsed by the Transportation Research Board's Technical Committee on Hydrology, Hydraulics and Water Quality (AFB60) and the Federal Advisory Committee on Water Information's Subcommittee on Hydrology.

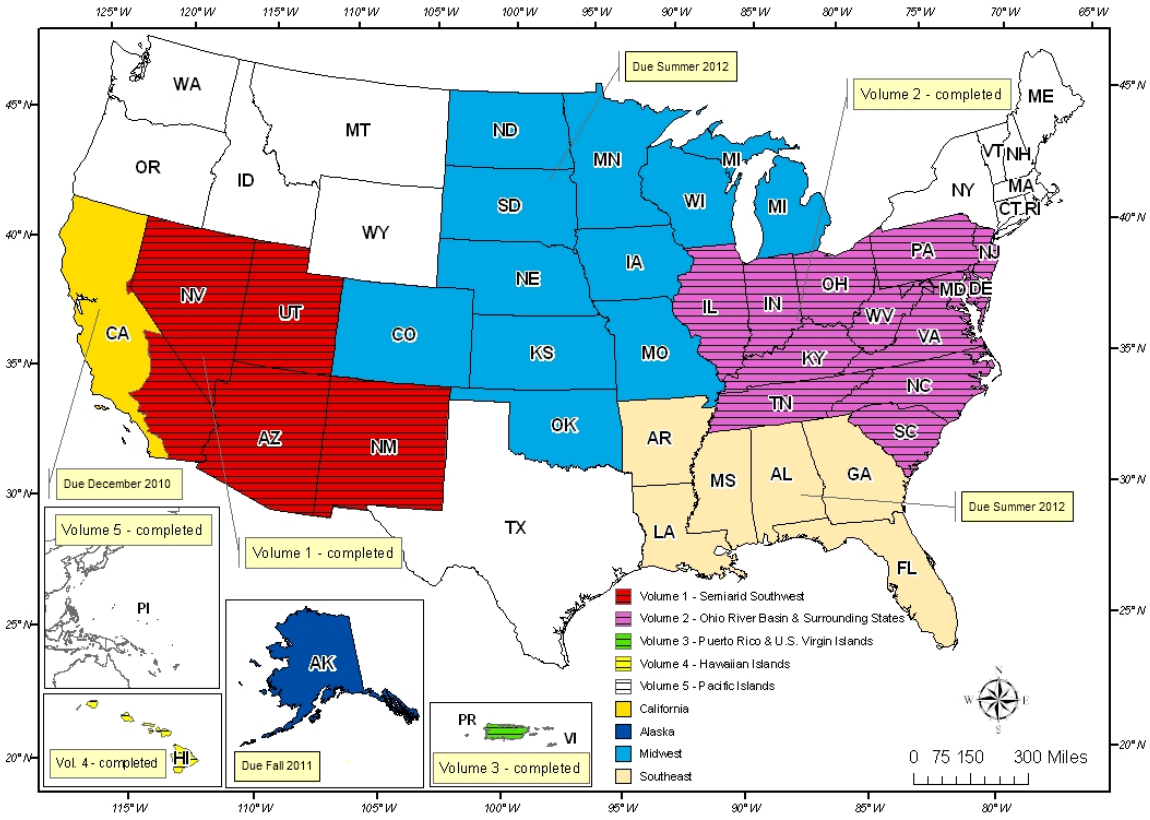

Figure 1. Updates will be done in groups of states

Figure 1 above shows states that have already been updated by marking them with horizontal lines. NOAA Atlas 14 Volume 1 (2004) for the semiarid southwest, Volume 2 (2004) for the Ohio River basin and surrounding states and Volume 3 (2006) for Puerto Rico and the U.S. Virgin Islands, Volume 4 (2009) for Hawaii, and Volume 5 (2009) for selected Pacific Islands have been well received. Projects to prepare volumes for California, Alaska, the southeastern states and the Midwestern states are underway as shown in Figure 1. The new NOAA Atlas 14 estimates represent vastly improved data in terms of both period of record and station density, state of the art statistical techniques, and a new approach to spatial interpolation that accounts for variation in terrain. The

technologies used so far in NOAA Atlas have been recognized as state of the art. Those technologies with potential improvements will be applied to the development of subsequent volumes.

It is proposed that the northeastern states be updated as a group to reduce costs as discussed in Section 5 Budget. The proposed grouping is shown in Figure 1.

OBJECTIVE

The purpose of this study is to determine annual exceedance probabilities (AEP) and average recurrence intervals (ARI) for durations ranging from 5 minutes to 60 days and for ARIs from 1 to 1,000 years. The point estimates will be spatially interpolated to a spatial resolution of approximately 4km x 4 km. The study results will be published as volumes of NOAA Atlas 14, a wholly web based publication available at www.nws.noaa.gov/ohd/hdsc. The publication will include the artifacts provided in previous Volumes, including access through the Precipitation Frequency Data Server, base grids in standard formats, electronic copies of maps, results of trend analyses, charts of seasonal distributions and probabilistic temporal distributions, and detailed documentation. Updated areal reduction factors are being developed as a separate appendix to NOAA Atlas 14 for the entire U.S. including Alaska.

The project will review and process all reasonably available rainfall data. It is recognized that the rainfall data archived by NOAA's National Climatic Data Center (NCDC) may not be sufficient to accomplish the objectives of this project. Therefore, other data available from sources such as State Climatologists and other Federal, State and local agencies will be examined and included if appropriate.

The state of the art techniques and processes developed and applied for previous NOAA Atlas 14 Volumes will be applied with updates as appropriate. They include regional frequency analysis based on L-moments with the possibility of maximum likelihood techniques, including error estimates, a combination of PRISM based techniques and cascade residual add-back (CRAB) for spatial interpolation which may be updated with region of influence approaches, techniques for the analysis of climatic trend, temporal distribution and seasonality, internal consistency checks and variety of automated processes designed to enhance productivity.

Intermediate results in the form of hourly and daily estimates at several ARIs will be distributed for peer review as will the final documentation.

WORK PLAN

Task 1 - Data Collection and Quality Control

A. Background

Many years of data have accumulated since the completion of the current estimates. In addition many new stations have been installed. Furthermore, unknown quantities of additional data exist as a result of networks and stations maintained by Federal, State, local and private agencies, and not archived by NCDC. These data must be obtained in digital form and quality controlled both to determine their suitability for use in this project and to ensure the quality of the resulting estimates.

While quality control of data is the subject of this task specifically, it is an ongoing byproduct of later tasks. For example, the L-moment statistics provide an opportunity to examine the data for "discordant" stations. As do the results of spatial interpolation if questionable spatial patterns appear. The specific analyses and products of this task focus only on the initial quality control processes whereas ongoing quality control is included as part of later tasks of it is a byproduct.

B. Analyses

Both daily and hourly data will be used, and where available 15-minute data other data of 1 hour or less will be collected for use in short-duration relations. The data will be assembled in digital form in a manner that is amenable to manipulation and collation in a variety of different ways. The specific form of the storage will follow the techniques and formats refined during the development of previous NOAA Atlas 14 Volumes.

Data which may contribute to annual or monthly maximums, partial duration series, or temporal distributions will be reviewed for quality, period of record, completeness and independence. Questionable data will be investigated using original historical records and newspaper accounts. Data whose quality is not satisfactory will be removed from the database and will not be used in subsequent analyses. In cases where data are changed, the change will be maintained in a log for future reference. Data will not be generated synthetically except in cases where adjustment factors are applied such as in the case of adjusting between constrained daily measurements and unconstrained 24 hour measurements.

The data will be analyzed to determine the seasonality of heavy rainfall. Seasonality will be used as a measure of quality control by excluding years in which there are insufficient observations during the heavy rainfall months.

The data records will also be examined to ensure a minimum number of data years at each station. Stations with an insufficient number of data years will be excluded. The minimum number of data years will be determined as a trade off between a sufficient number of data years and a sufficient density of stations included in the analysis. Stations with large gaps in the period of record will be examined to ensure that there is no change

in statistics across the gap. Nearby stations with complementary periods of record that would otherwise have an insufficient number of data years will be examined as candidates for merging.

The data will also be examined to determine if temporal trends of shifts exist in the statistics relevant to precipitation frequency estimation. Analysis during the development of previous NOAA Atlas Volumes demonstrated that such trends and shifts were relatively small. This finding led to the conclusion that the entire period of record was suitable for analysis as opposed to attempting to select a smaller and specific period of record that might be representative of some future climate.

C. Product

This task will result in a data base of observations and extracted time series that will be used in subsequent analyses. Observations found lacking in quality in subsequent analyses, will be excluded from the database at that time and any time series such data contributes to will be re-extracted.

Task 2 – Regionalization

A. Background

The statistical approach to be used relies on the development of regions (or sets of observing locations) which are homogeneous according to certain specific statistical criteria. However in order to avoid artificial development of these regions, they must make sense from a climatological point of view.

B. Analysis

The regions will be initially defined using a variety of objective and subjective climatological techniques and advice will be sought from expert sources such as State Climatologists. The initially defined regions will then be tested for homogeneity using specific statistical criteria. Those regions which do not satisfy homogeneity criteria will be re-examined and adjusted by considering the transfer of observing locations among regions based on climatology and the heterogeneity of at site statistics with other sites within the region. Other regionalization techniques may be evaluated and applied if appropriate.

The purpose of regionalization is to reduce the error associated with the estimates. There may be cases where the most reduction in error is obtained by treating an observing site individually rather than as part of a region. Such cases, should they exist, will be identified for as-site, rather than regional analysis.

C. Product

This step will result in the definition of regions which satisfy the specific homogeneity criteria of the analysis technique as well as make sense from a climatological point of

view. There may also be a small number of cases to be analyzed at-site rather than as part of a region

Task 3 - Frequency Distribution Selection and Fitting Studies

A. Background

The statistical techniques being used for this project do not rely in pre-selection of a single probability distribution function. Rather a range of candidate functions are examined and the function that best represents the distribution of the population represented by the sample data is initially selected. Implicit in the selection process is also the process of determining parameters for the distribution so that it best represents the underlying population.

B. Analysis

L-Moments statistics will be computed for each region or at-site case and both hourly and daily durations. Based on the statistics, and a variety of tests, an initial distribution will be selected for each region or at-site case. The spatial distribution of selections will then be examined and sensitivity testing will be performed to ensure that there is a smooth transition between selected distributions across regions. The same approach will then be applied to the longer durations however weight will be given to the distributions selected at shorter distributions.

C. Product

The outcome of this task will be the selection of a fitted frequency distribution for each region or at-site case and each duration. The parameters of the selected distributions will have been computed.

Task 4 - Frequency Calculations

A. Background

Once the probability distributions for each region and duration have been selected and parameterized it is a simple matter to compute the precipitation frequency estimates at each observing location.

B. Analysis

Precipitation frequency values for durations between 60 minutes and 60 days at average recurrence intervals from 1 to 1,000 years will be computed. The equations for the distribution functions will be applied at each location using mean of the time series at the specific site and the regional values for the higher order parameters.

C. Product

The product from this task will be a set of precipitation frequency values for duration from 60 minutes to 60 days at each observing location.

Task 5 - Short Duration Estimates

A. Background

Due to the scarcity of data with duration of less than 1 hour, precipitation frequency estimates for those durations will be computed as a ratio of hourly duration estimates. The ratio will be computed as an average for those sites where both hourly and sub-hourly duration observations exist.

B. Analysis

Locations with both hourly, and either 5, 10, 15 or 30 minute data will be identified. At those locations, the selected hourly distribution function will be fitted to each of the sub-hourly durations. Quantiles for each of the sub-hourly durations will be computed and then ratios of each or these quantiles to the hourly quantiles will be computed. The ratios will be examined for consistency across the project area and with other studies and will then be averaged over the study area. The final ratios for each duration will then be applied to the hourly quantiles computed for each hourly station in the study area to compute quantiles for the sub-hourly durations.

C. Product

The final products of this task will be sub-hourly precipitation frequency estimates at each hourly station in the project area.

Task 6 – Internal Consistency at Observing Locations

A. Background

The estimates must satisfy a series of internal consistency constraints. For example, a 24 hour estimate of depth must not be higher than a 48 hour estimate of depth at a particular average recurrence interval. Similarly at a particular duration an estimate for a 50 year average recurrence interval cannot be higher than the estimate for the 100 year average recurrence interval.

B. Analysis

Algorithms for testing internal consistency at observing locations and making adjustments when necessary were developed and demonstrated during the production of previous NOAA Atlas 14 Volumes. These same algorithms will be tested, revised if necessary, and applied in this task. The results will be examined to ensure that the adjustment techniques developed earlier are successful.

C. Product

The product from this task will be a set of precipitation frequency values for each duration at each observing location that satisfy at-site internal consistency.

Task 7 – Spatial Interpolation and Consistency

A. Background

Precipitation frequency estimates computed at observing locations will be spatially interpolated to grids with a spacing of approximately 1 to 4 miles. The spatial interpolation process will account for variations in terrain and will produce grids which are consistent form one grid to the next. The spatial interpolation process, developed during the preparation of previous NOAA Atlas 14 Volumes will be examined along with alternate techniques.

B. Analysis

NWS has worked with the University of Oregon PRISM Group to produce a modified version of PRISM suitable for spatial interpolation of precipitation frequency estimates over varying terrain. This process will be verified and modified as necessary during this task. The process is expensive and so is applied only to spatial interpolation of the distribution means at each duration. The less expensive CRAB process developed by NWS is then used with the spatially interpolated grids of distribution mean to produce spatially interpolated grids for all average recurrence intervals. Both the PRISM process and the CRAB process include a variety of internal consistency checks and noise filters. Other spatial interpolation techniques may be applied.

C. Products

Spatially interpolated high resolution grids of precipitation frequency estimates for each combination of average recurrence interval and duration across the project area domain.

Task 8 – Mapping and other Spatial Artifacts

A. Background

A variety of spatial artifacts will be developed to assist users in interpreting and using the precipitation frequency estimates. The primary artifacts will be digital versions of the spatially interpolated grids, vector representations of the contoured grids, and high quality cartographic maps in pdf format. Each of these artifacts will be made available via the web through the Precipitation Frequency Data Server. Such availability will allow users to incorporate digital versions of the estimates directly in their applications without having to go through an expensive and error prone digitizing step as in past publications.

B. Analysis

The grids of precipitation frequency estimates developed in Task 7 are the preferred source. In order to enhance the use of the data in this form, the grids will be converted to ArcInfo© ASCII grids and ESRI© shapefiles. ArcInfo ASCII grids are a specific interchange format originally developed for ArcInfo© rasters in ASCII format. The format consists of a header that specifies the geographic domain and resolution, followed by the actual grid cell values. The ESRI© shapefile format is used for vector data in a GIS environment. The vectors in this case will be contours of the gridded data. They will consist of a minimum of three files: main file (.shp), index file (.shx), and a database file (.dbf). The shapefiles will be bundled into a single compressed, tar file. In addition, these files will be accompanied by Federal Geographic Data Committee-compliant metadata.

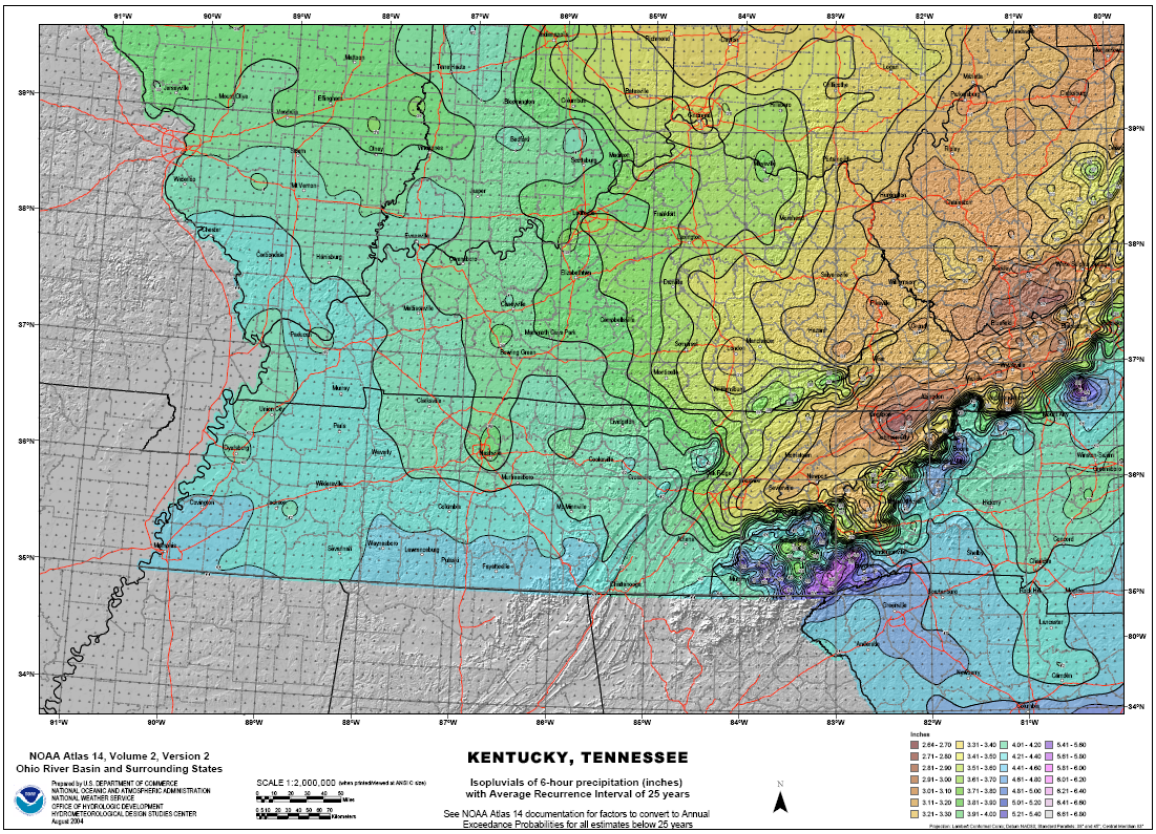

Figure 2. High quality cartographic map

In addition to digital versions of the grids and contours, high quality cartographic maps will be produced for each combination of frequency and duration. The maps will be produced either in Adobe© Portable Document Format© and made available on the web through the Precipitation Frequency Data Server or will be delivered through an Internet based map server or equivalent.

C. Products

Grids, contours and cartographic maps in digital form for each combination of duration and frequency with appropriate metadata files.

Task 9 - Temporal Distributions

A. Background

The Natural Resources Conservation Service has developed curves that are commonly used to describe the temporal distribution of rainfall. These curves are single valued distributions designed synthetically to approximate extreme cases. NWS has adopted a technique for describing the many temporal distributions of natural rainfall in probabilistic terms.

B. Analysis

The NWS uses a modified version of a technique developed at the Illinois Water Survey (Huff, 1990) that provides a temporal curve as proportion of total duration and total volume. There are curves provided for each cumulative probability based on an analysis of historical data. Curves will be developed for 6-, 12-, 24-, and 96-hour durations. The data from which the curves are drawn will be made available as ASCII files on the web through the Precipitation Frequency Data Server to allow users to incorporate the curves in their applications.

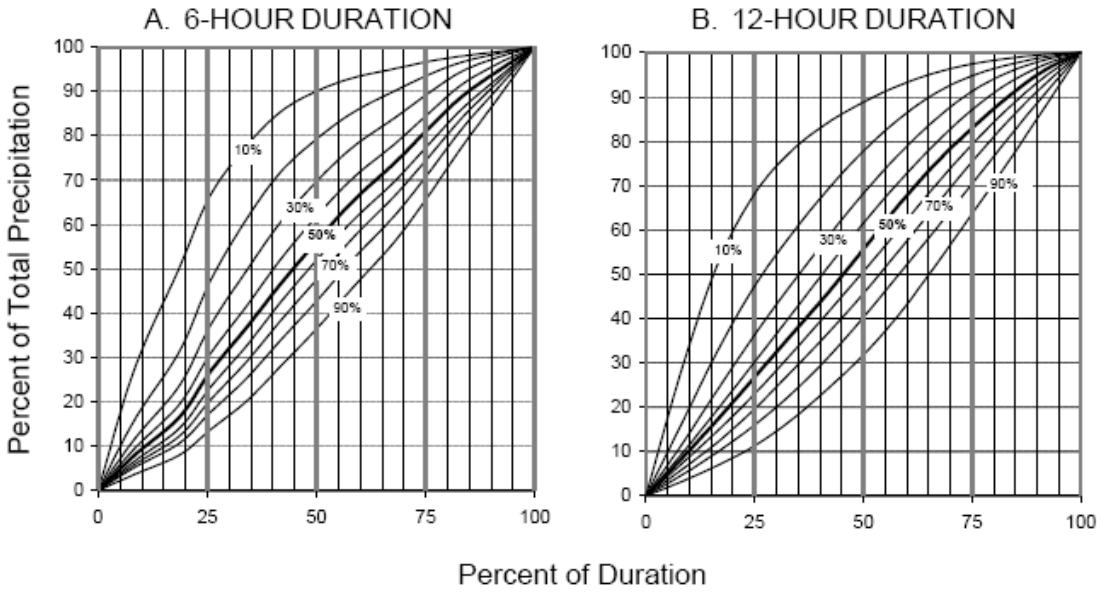

Figure 3. Probabilistic temporal distributions

C. Products

Probabilistic temporal distributions as charts for 6-, 12-, 24-, and 96-hour durations. ASCII files of data from which the curves are drawn.

Task 10 - Peer Reviews

A. Background

The development of precipitation frequency estimates benefits greatly by incorporating local climate knowledge. In order to incorporate this knowledge the initial spatial distribution of 1- and 24-hour daily estimates at 100 year ARI as well as the mean of the annual maximum series which represents an ARI of approximately 2.3 years. The full range of estimates at observing locations will also be included in this review. Later in the project, the documentation will also be distributed for review. Following the review period in each case, a document will be prepared and distributed that lists all comments and documents the action taken in response to each comment.

The invitation to review will be distributed widely to a list developed from suggestions made by funding sources as well as a list maintained by NWS which includes interested parties, recognized academics specializing in the field, and State Climatologists.

B. Analysis

Information will be distributed for review. After an appropriate period, NWS will analyze each comment received and will determine what action to take in response to the comments. Documentation of the comments and actions will be prepared and published.

C. Products

Improved estimates based on local knowledge, improved documentation, documentation of the review itself.

Task 11 - Documentation

A. Background

Precipitation frequency estimates are published with a target audience of knowledgeable users. These users require documentation in order to understand the basis of the estimates and their scope and applicability. The documentation will not attempt to be an academic text that replaces or reproduces published scientific work, rather it will reference such sources as appropriate. Similarly, the documentation will not attempt to provide basic education and so will not replace or reproduce basic academic texts developed for that purpose.

B. Analysis

All aspects of the development of each artifact will be described in sufficient depth to allow the knowledgeable user to understand the basis of the estimates and their scope and applicability. The documentation developed for previous NOAA Atlas 14 Volumes was approximately 250-300 pages for each volume, significantly more than has been provided in the past. Documentation for future volumes will be similar in layout, coverage and depth.

C. Products

Documentation of the basis of development of each of the NOAA Atlas 14 artifacts with a unique set of documentation for each volume.

Task 12 - Final Deliverables

A. Products

- Web based Precipitation Frequency Data Server for accessing each artifact
- Precipitation frequency estimates with upper and lower 90% confidence intervals at durations of 5, 15, 30, 60, and 120 minutes, 3, 6, 12, 24, and 48 hours, 4, 7, 10, 20, 30, 45, and 60 days, and ARIs of 1, 2, 5, 10, 25, 50, 100, 200, 500, and 1,000 years
- High resolution grids of precipitation frequency estimates and upper and lower 90% confidence intervals with one grid for each combination of frequency and duration for the expected value and upper and lower 90% confidence intervals
- Shapefiles of contours of the gridded estimates with one shapefile for each combination of frequency and duration for the expected value and upper and lower 90% confidence intervals
- Meta information in Federal Geographic Data Transfer Standard format
- Either cartographic maps of the estimates with one map for each combination of frequency and duration for the expected value and upper and lower 90% confidence intervals or equivalent information delivered through an Internet map server.
- Probabilistic temporal distributions for 6, 12, 24 and 48 hour durations in both chart and digital form
- Peer reviews of initial spatial distributions of estimates at 1 and 24 hour durations for 100 and approximately 2.4 year ARIs.
- Charts of the seasonal distribution of annual maxima.
- Documentation
- Status Reports

Task 13 – Status Reporting

A. Background

Progress for each volume will be reported each quarter in a Quarterly Status Report.

B. Analysis

Reports will be made available via the web and notification of their availability will be distributed by email to a list of addresses maintained by NWS and provided by funding sources. Reports will document progress in the preceding quarter, status of the entire project, issues, activities expected in the coming quarter and expected completion schedule.

C. Products

Quarterly Status Reports for each Volume delivered within 10 days of the conclusion of each quarter.

PROGRAM MANAGEMENT

Mr. Geoffrey Bonnin, Chief of the Hydrologic Science and Modeling Branch, Office of Hydrologic Development, NOAA's National Weather Service, will be the Program Manager for the development of each Volume prepared under this proposal. The Program Manager will be responsible for guiding the efforts of the NWS team and will ensure the preparation and distribution of progress reports. Progress will be reported to the funding sources through representatives identified in funding agreements.

BUDGET

The following budget table shows the estimated cost for each state. The estimate is based on the assumption an individual Volume of NOAA Atlas 14 is prepared for a group of states shown in the table. This significantly reduces the costs compared with doing a single state at a time. The reason for this is that the study area must extend well beyond a state's border to ensure continuity of the results at the border. By combining states, the area outside a core project area is significantly reduced.

	STATE	DAILY	HOURLY	Total	Area sqmi	Proj Cost K$	State Cost
Northeast	CT	112	33	145	5,544		$57,457
	MA	177	41	218	10,555		$88,027
	ME	163	47	210	35,387		$103,474
	NH	157	43	200	9,351		$80,513
	NY	632	182	814	54,475		$339,845
	RI	19	7	26	1,545		$10,711
	VT	123	33	156	9,615	$745	$64,519

The estimates are based on the costs incurred for production of prior NOAA Atlas 14 Volumes. The estimation metric itself is based on the number of daily and hourly stations in the NCDC archives and the area of the state. The costs do not include travel.

REFERENCES

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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AEP	Annual Exceedance Probabilities
ARI	Average Recurrence Interval
CRAB	Cascade Residual Add-Back
GIS	Geographic Information System
HDSC	Hydrometeorological Design Studies Center
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SCAS	Spatial Climate Analysis Service (University of Oregon)