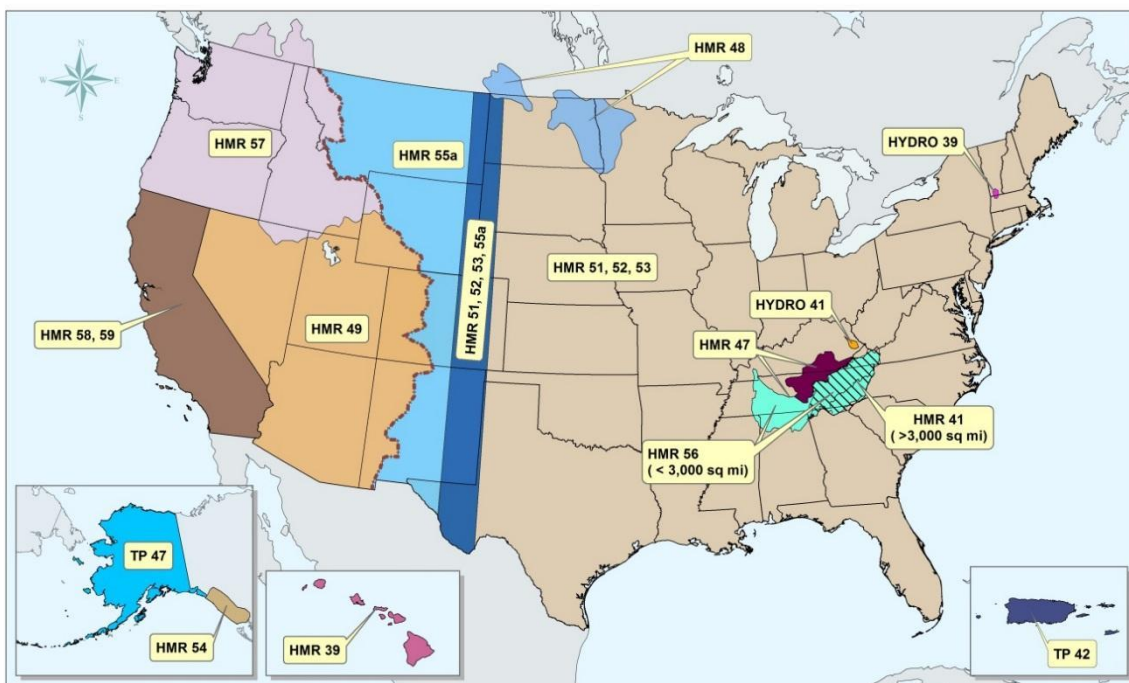


# Extreme Rainfall Product Needs

*Subcommittee on Hydrology*

Extreme Storm Events Work Group



Map of the regions covered by various National Weather Service Probable Maximum Precipitation products (National Weather Service, 2017b)

Prepared by:

The Extreme Storm Events Working Group of the  
Subcommittee on Hydrology of the  
Advisory Committee on Water Information

October 10, 2018

Special thanks to the members of our review team:  
L. Gwen Chen, Dongsoo Kim, and Chandra Pathak

# Executive Summary

The Subcommittee on Hydrology (SOH) requested the Extreme Storm Event Work Group (ESEWG) to develop a proposal for “Extreme Rainfall Product Needs” at a national level. The initial need identified was the updating of the HydroMeteorological Reports (HMRs) of the National Oceanic and Atmospheric Administration’s (NOAA’s) National Weather Service (NWS). However, due to funding issues, this need was tabled for later consideration. When the SOH reported to the Advisory Commission on Water Information (ACWI) in 2013 on work group accomplishments, an earlier version of the proposal was presented and discussed. ACWI directed SOH to modify the original proposal to include the resources needed to implement the strategy.

The SOH leadership worked with the ESEWG to convene a “Workshop to Define Needed Extreme Storm Products” which was held May 15, 2014 at the NOAA/NWS Headquarters (SOH-ESEWG, 2017). The workshop was based upon a questionnaire sent to SOH’s Federal Agencies, and a similar questionnaire sent to the States involved in dam safety as identified by the Interagency Committee on Dam Safety (ICODS). At the workshop, responses from the Federal Agencies and States were presented and discussed. Following the workshop, a proposal writing team was formed to begin reviewing the workshop presentations and establish a national strategy to address extreme rainfall product needs. Numerous proposal outlines were developed and discussed. This report provides the technical basis for the identified product needs, and an estimate of the staff resources necessary to fulfill those needs. The three product needs identified by the writing team are:

- NOAA Atlas 14 Completion and Future Updates;
- U.S. Extreme Precipitation Database; and
- An Update to NOAA/NWS HMRs and updated specific instruction for the creation and review of Site-Specific PMP (SSPMP) studies.

The following list includes the specific recommendations for the national strategy to:

1. Extend NOAA Atlas 14 coverage to the remaining five northwestern States and development of an enhanced suite of products for the whole country simultaneously using improved methodology capable of accounting for the non-stationary climate.
2. Create an archive of extreme precipitation events to be hosted at a publically-accessible location for the use in the creation of Probable Maximum Precipitation (PMP) studies across the country. Additional to this archive will be data collections covering difficult/semi-arid terrain where radar coverage may be limited in the form of remote sensing data and atmospheric models. This data, currently being collected and housed by the U.S. Army Corps of Engineers (USACE), would be available for use in the updating of the HMRs, with the archive also available to the public in the future.

3. Create new and updated versions of the HMRs which include updated methodology that accounts for modern weather observations without arbitrary limitations. These new methods will utilize the updated weather and precipitation data used in modern NWS data collection available from the National Centers for Environmental Information (NCEI) including gridded precipitation data, updated forecast model data and modern gridded atmospheric data to account for environmental factors such as temperatures, winds and dewpoints at all elevations of the atmosphere. Along with updating HMR PMPs, the recommendation is to prepare and distribute a National Guidance Document for State-wide/Regional and Site-Specific PMP Studies.

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# 1. Introduction

*Thomas Nicholson, U.S. NRC, ESEWG Chair, and William Otero, USACE, ESEWG Co-Chair*

This proposal aims to identify several specific recommendations and the appropriate staff resources needed to address currently identified national needs regarding the assessment of extreme storm events. This document was prepared in response to the Advisory Committee on Water Information (ACWI) request of a detailed proposal identifying needed extreme storm products for the nation. Extreme storm data has a direct impact on the operations of several Federal agencies as well as States, cities and other governments. Preparedness for extreme weather events involves being able to account for the events that have passed in history, as well as being able to reasonably estimate the threat of extreme events into the future.

In all, the following three recommendations are identified along with the staff resources required to satisfy those needs:

- Current and future updates for the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Point Precipitation Frequency Estimates (Atlas 14);
- A national extreme precipitation database; and
- An updated approach to the Hydrometeorological Reports (HMRs) with specific instructions for the creation of Site-Specific Probable Maximum Precipitation (PMP) studies.

## 1.1. Background

The Extreme Storm Events Work Group (ESEWG) of the Subcommittee of Hydrology (SOH) of the ACWI held a workshop to define the needs of Federal agencies, States, cities, and local governmental entities regarding extreme-storm related products. This workshop took place on May 15, 2014 at the NOAA National Weather Service (NWS) Headquarters in Silver Spring, Maryland. The content and results from the workshop were summarized in the *Workshop Synthesis Report* (SOH-Extreme Storm Events Work Group, 2017).

From the workshop discussions, it was clear that there is a great necessity of methodologies to account for extreme precipitation events, especially, for the appropriate planning and maintenance of the country's infrastructure. Current methods of estimating or forecasting PMPs are in dire need of updating, and statistical methods for estimating extreme events need improvements to better estimate future hazards and non-stationarity that can impact projects across the country. Additionally, data from studies to update these methods need to be available from digital sources over the internet to expand their availability and usability. The following extreme-storm-product needs were identified at the ESEWG workshop.

- Numerous States need updated guidance on processes to estimate PMP values and studies to support their dam safety and flood risk operations;
- Federal agencies such as the U.S. Bureau of Reclamation (USBR) and U.S. Army Corps of Engineers (USACE) need updated and modernized guidance for determining extreme

precipitation and PMP values to support their risk assessment, dam safety, and flood hazard programs; and

- Federal agencies, such as the U.S. Nuclear Regulatory Commission (NRC), FERC, USGS, and NRCS are consumers of extreme storm data and users of PMP studies and guidance incorporated into their operations. They need updated information and methods to most effectively use the latest available extreme storm data to assess the needs of their programs and to mitigate risk.

## **1.2. Recommendations**

The following recommendations are proposed to address gaps and needs further described in the subsequent chapters of this proposal.

1. Recommended approaches, improved methodologies, product improvements, and implementation goals for NOAA Atlas 14 updates and upgrades,
2. Creation of an archive of extreme precipitation events to be hosted at a publically-accessible location for use in the creation of PMP studies across the country. Additional to this archive will be data collections covering difficult/semi-arid terrain where radar coverage may be limited in the form of remote sensing data and atmospheric models. This data, currently being collected and housed by the USACE, would be available for use in the updating of the HMRs, with the archive also available to the public in the future, and
3. Plans for new and updated versions of the HMRs to include updated methodology that accounts for modern weather observations without arbitrary limitations. These new methods will utilize the updated weather and precipitation data used in modern NWS data collection available from the National Centers for Environmental Information (NCEI) including gridded precipitation data, updated forecast model data and modern gridded atmospheric data to account for environmental factors such as temperatures, winds and dew points at all elevations of the atmosphere. The recommendation is to commission an independent, objective and creditable panel of experts (such as the National Academy of Science) through the National Dam Safety Research Board, to develop, prepare, and distribute a National Guidance Document for State-wide/Regional and Site-Specific PMP Studies.



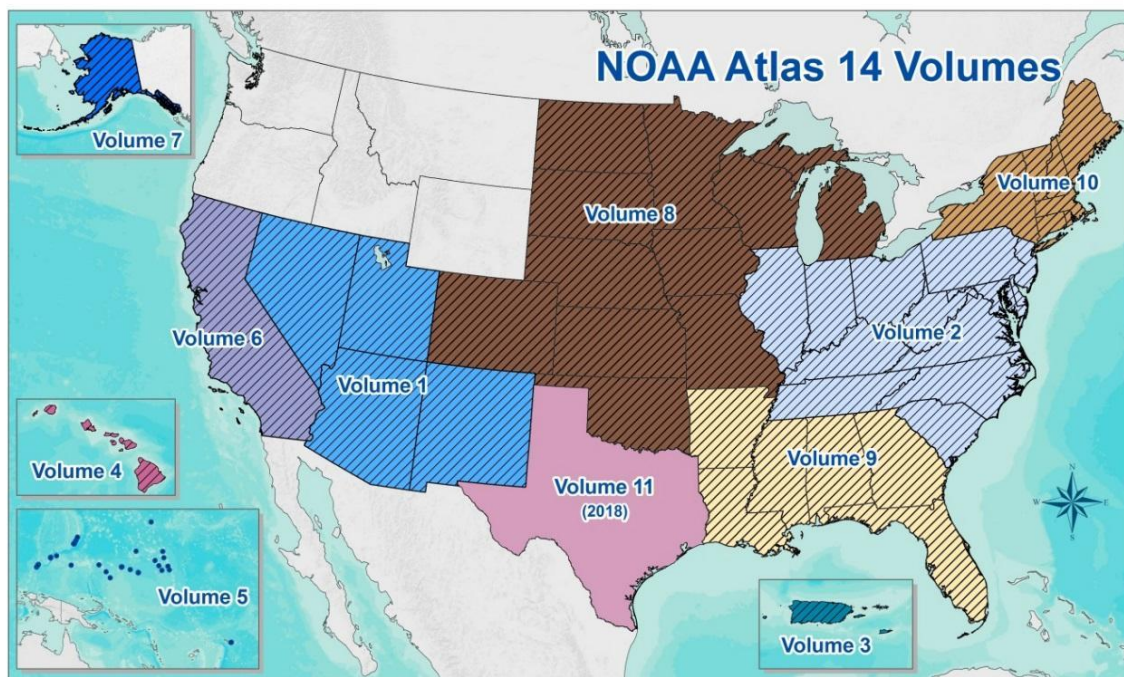
## 2. NOAA Atlas 14 Updates and Upgrades

*Sanja Perica, NOAA/NWS*

### 2.1. Product Background

The Hydrometeorological Design Studies Center (HDSC) within the Office of Water Prediction of NOAA's NWS has been updating precipitation frequency estimates for various parts of the United States and affiliated territories in its Atlas 14 since the early 2000s. Precipitation frequency estimates with corresponding upper and lower bounds of the 90% confidence interval are produced at 30 arc-second resolution grid for durations from 5 minutes to 60 days for average recurrence intervals (ARIs) from 1 to 1,000 years. Additionally, for areas with significant snowfall contribution, separate rainfall (i.e., liquid precipitation) frequency estimates are provided for durations between 60 minutes and 24 hours. Estimates are accompanied by relevant information on temporal distribution of heavy precipitation, analysis of seasonality and trends in annual maximum series data, documentation, etc.

Typically, several States are updated as a group to reduce costs and their estimates are published as a volume. States and territories associated with each of the volumes are illustrated in Figure 2-1. Volume 10 is the most recent Atlas 14 volume published. This volume covers seven northeastern States and was released in September 2015. As of this writing, HDSC is updating estimates for the State of Texas that will be published in Volume 11 in late 2018. No funding is available to update estimates for the five remaining northwestern States with no NOAA Atlas 14 coverage.

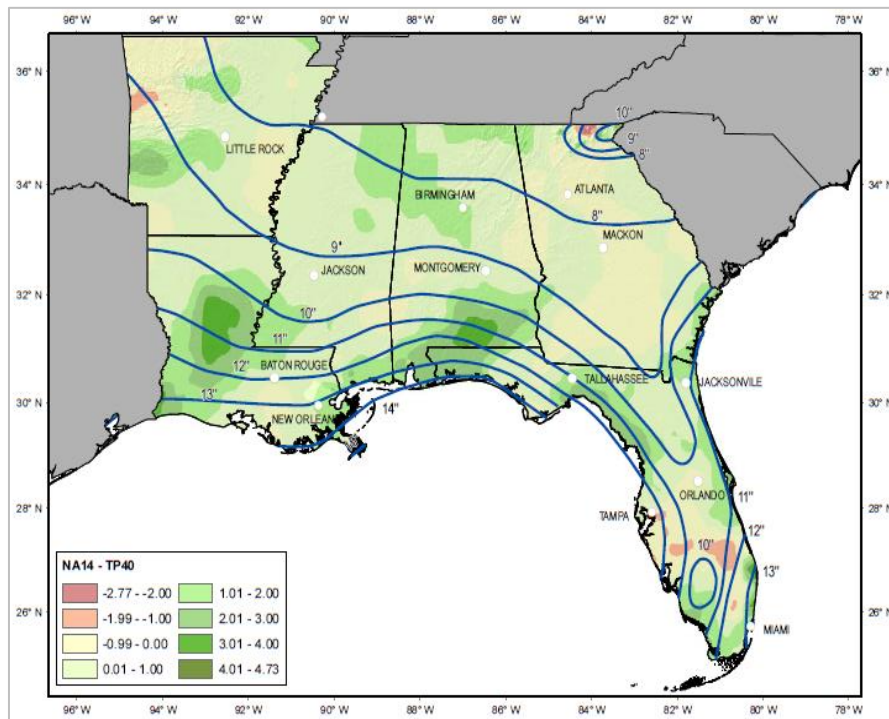


**Figure 2-1.** States and territories associated with each NOAA Atlas 14 volume



Precipitation frequency estimates in NOAA Atlas 14 have been computed using a regional frequency analysis approach based on L-moment statistics calculated from annual maximum series (AMS). These estimates are greatly improved compared to the corresponding estimates from superseded publications in terms of accuracy, reliability, and resolution. Figure 2-2 shows, as an example, the map of differences in 100-yr 24-hr estimates between NOAA Atlas 14 Volume 9 and superseded estimates from TP-40 (U.S. Weather Bureau, 1961). The updated estimates benefit from:

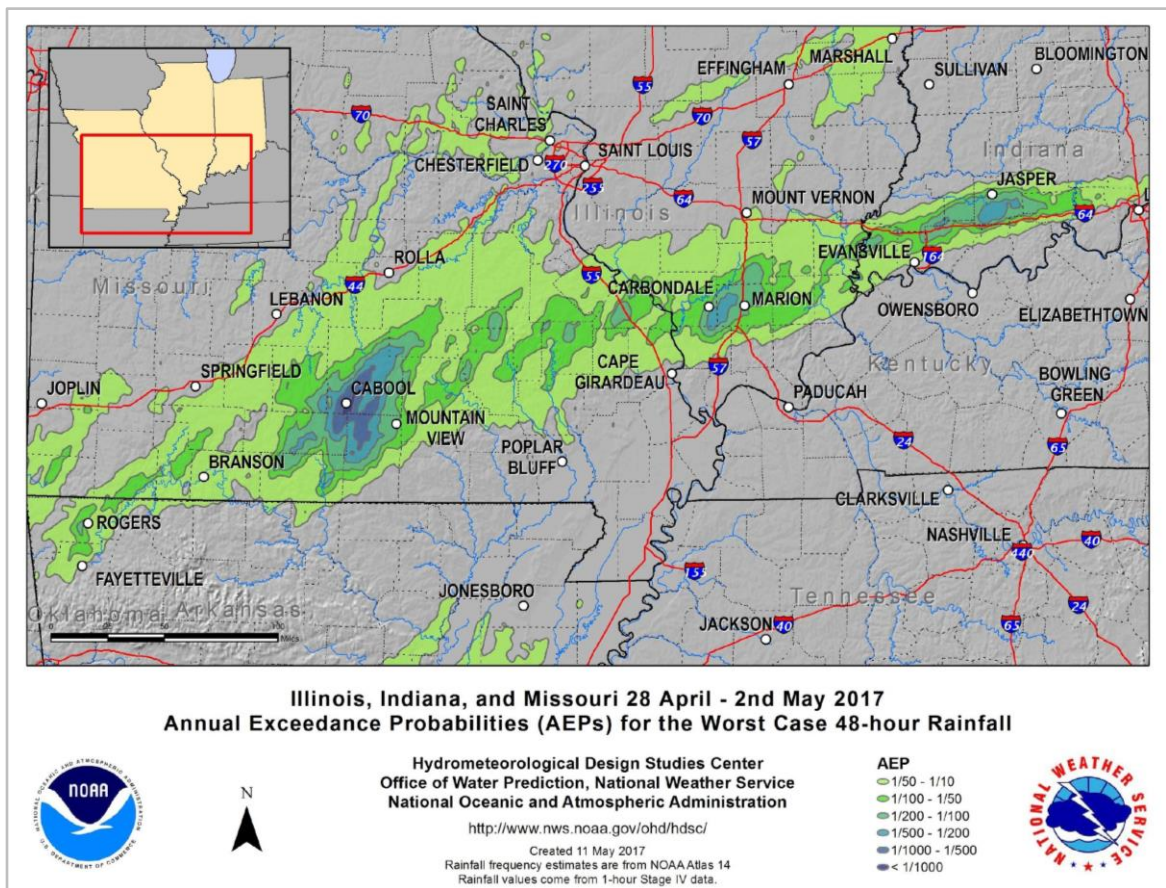
- Denser rain gauge networks with longer periods of record including extensive quality control of pertinent data
- Use of regional frequency analysis methods that allow for the development of rare frequency estimates, a wider range of frequencies and durations, and are capable of addressing uncertainty around those estimates
- Numerous internal consistency checks across frequencies and durations in the production of intensity-duration-frequency curves
- Use of the latest techniques for spatial interpolation and mapping that take into account variations in terrain, coastal proximity, etc.
- Estimates provided at high spatial resolution (30 arc-seconds; ~800 m) grids, which eliminates a need for interpolation from cartographic maps
- All deliverables accessible electronically



**Figure 2-2.** Differences in 100-year 24-hour estimates (in inches) between NOAA Atlas 14 Volume 9 and TP-40; superimposed blue lines on the map are isoplusials from TP-40

All Atlas 14 products are accessible through the Precipitation Frequency Data Server (PFDS) (National Weather Service, 2017a). Other products that can be accessed through the PFDS web page include:

- Probable Maximum Precipitation (PMP) documents – Due to a lack of funding, HDSC has discontinued all PMP activities since the early 2000s, but copies of all NWS PMP-related documents are available for download (National Weather Service, 2017b).
- Frequency maps for selected significant storm events – HDSC creates these maps for selected events which typically exceed 1000-yr ARI (i.e., below 1/1,000 annual exceedance probability -AEP) over larger areas (see an example in Figure 2-3). The underlying data for the analyses are typically grids of observed precipitation data and the NOAA Atlas 14 CONUS product. This product combines precipitation frequency estimates for durations between 60 minutes and 7 days from NOAA Atlas 14 volumes that cover contiguous US States.



**Figure 2-3.** Frequency map example

## 2.2. Proposed Updates and Upgrades

### 2.2.1. Funding Approach

Under the current model, funding for NOAA Atlas 14 work comes from external sources via cost reimbursements made possible by Memoranda of Understanding between NOAA and a changing set of partner and customer agencies. This approach generally dictates that updates are done in volumes based on State boundaries, which are produced in a serial, non-parallel workflow stretching over many years. Funding must be regularly pursued well in advance of volume development, via time-consuming freshly developed solicitations and interactions with new contributors for each volume. This results in a somewhat quilted-in-space and staggered-in-time approach to developing these independent volumes.

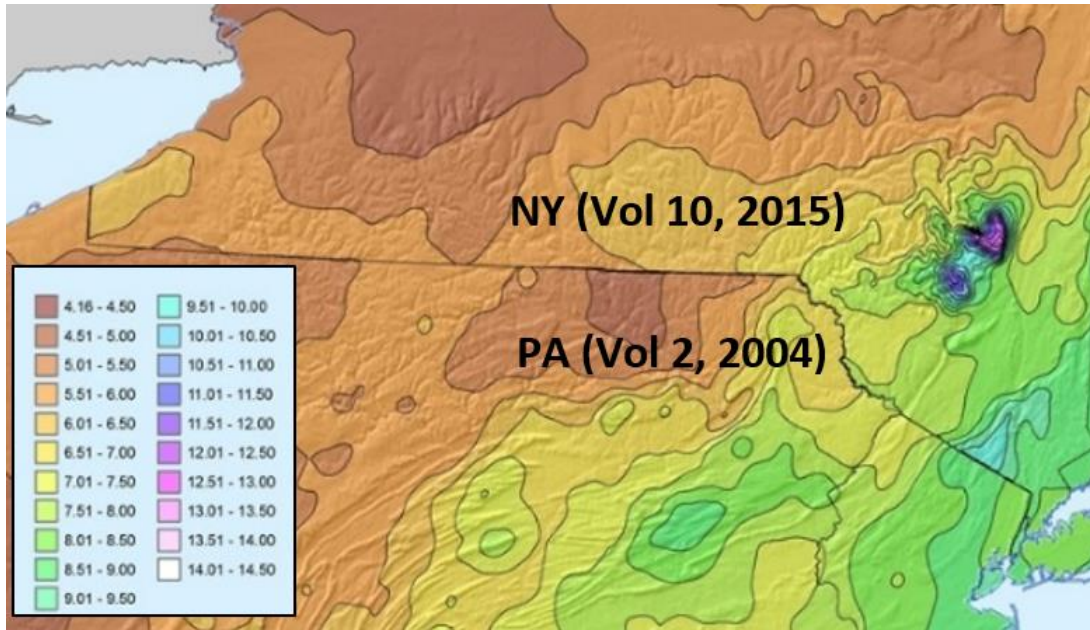
This funding model ultimately leads to concerns over data continuity and currency. Because of inevitable challenges to securing needed funding, there are existential concerns over the continued ability of NOAA to satisfy the essential need for these precipitation frequency estimates. An improved funding model is needed to ensure a sustainable, cost-effective approach for developing these estimates.

Specific concerns arising from the current funding model include:

- *Currency of Information:* Atlas 14 estimates are not updated as often as needed. They should be updated on a regular cycle of approximately every 10 years. Half of the country was last updated in the early 2000s and estimates for the five northwestern States (ID, MT, OR, WA, WY) are more than 50 years old, as funding for an update has not been secured.
- *Consistency of Estimates:* Values near geographic boundaries of each volume are not always consistent. Each volume is completed independently and at different times. This results in discontinuities in estimates at boundaries of adjacent volumes (Figure 2-4), which in turn creates an issue for users as they typically consider watershed and not political boundaries.
- *Retention of Knowledge Base:* It is a challenge to retain experts and associated information technology and datasets with the sometime inconsistent rhythm of the workflow. The current Atlas 14 team has been together for several years and has built a wealth of knowledge. Uncertainty over funding could lead team members to search out other opportunities.
- *Efficiency of Volume Development:* The unpredictable and uncertainty in defining a schedule tasking development makes it difficult to optimize and streamline the workflow required for development. Even with the many local variations in historical data sets and precipitation patterns and customer needs, much of the work for developing volumes can be done more efficiently with some level of mass-production applied to larger areas, rather than the current work practice of individual volumes.

Changing the Atlas 14 funding approach from an ad-hoc approach to a defined, consistent, reliable approach would address the serious concerns. This small investment would result in significant return and benefits for infrastructure design in the United States.





**Figure 2-4.** Inconsistencies in 100-year 24-hour estimates at the boundary of Volumes 2 and 10

### 2.2.2. Methodology Improvements

The current approach used in NOAA Atlas 14 to calculate precipitation magnitude-frequency relationships assumes stationarity in the annual maximum series (AMS) data used for frequency distribution selection and fitting. Several parametric and non-parametric statistical tests are used to detect trends in the AMS, but so far, tests have shown very little geographically consistent trends across considered durations (for more information, see any NOAA Atlas 14 document).

However, it is questionable if use of stationary methods relying on AMS data is appropriate for the analysis of extreme precipitation in the presence of non-stationary climate. In an effort to understand the potential impact of non-stationary climate conditions on precipitation frequency estimates, the Federal Highway Administration tasked HDSC to conduct a pilot project, but preliminary findings were inconclusive. With help from academia, HDSC continues to look into this issue with the goal of developing a modeling framework that will allow non-stationary climate effects to be integrated into the NOAA Atlas 14 process, and will produce credible precipitation frequency estimates which can be relied upon by Federal water agencies. With that goal in mind, four major tasks were identified: (1) selection of non-stationary frequency analysis method(s) appropriate for NOAA Atlas 14 process; (2) testing the feasibility of incorporating climate projections into precipitation frequency analysis; (3) implementation of selected non-stationary method(s) using historical and future precipitation data on a designated project area; (4) assessing the added value of new precipitation frequency estimates with respect to traditional NOAA Atlas 14 estimates and recommending an approach for national implementation.

### 2.2.3. Products Improvements

- Areal reduction factors (ARFs). NOAA Atlas 14 provides point estimates, which represent a limited area around a given point. For applications requiring areal estimates, these point estimates must be converted to areal estimates and typically that conversion is done by using ARFs. Despite many proposed methods for calculating ARFs, most engineers continue using a single set of curves produced by the Weather Bureau in 1958, which are assumed applicable for any location in the contiguous United States. HDSC made some strides in determining that ARFs have regional characteristics and depend on average recurrence interval that allowed the identification of methods suitable for coupling with NOAA Atlas 14. However, due to lack of funding, this work has not progressed. NOAA proposes to develop regional ARFs and to develop a web tool that will delineate a watershed for any selected location and provide the ARFs for the selected location.
- NOAA Atlas 14 design storm product. While Atlas 14 provides precipitation frequency estimates for a given duration, designers are often interested in precipitation hyetographs and not just the total amount. Therefore, they have to find a way to distribute Atlas 14 estimates over time. NOAA Atlas 14 provides information on the varying temporal distributions for selected durations, but only to show a range of possibilities and does not provide guidance on how to use them. NOAA proposes to develop a more reliable design storm product that can be used in engineering design together with guidance on how to use the product.
- Confidence intervals of varied width. The current NOAA Atlas 14 method provides only bounds of 90% confidence interval (i.e., 5% and 95% confidence limits) and several state and federal agencies indicated that other widths are of interest for their applications. Also, current approach for calculating confidence limits fails to account for all sources of uncertainty in estimates, such as distribution selection and parameterization method and likely underestimate the “true” confidence intervals. NOAA proposes to provide estimates for lower and upper bounds of confidence interval of for any width and to improve the methodology so that it addresses more sources of uncertainty.

### 2.3. Implementation

A summary of future goals and their timeframe, responsible agency, funding source, and funding amounts required for the remaining work is presented in Table 2-1.

**Table 2-1.** Recommended Tasks to be completed for the NOAA Atlas 14 updates and upgrades

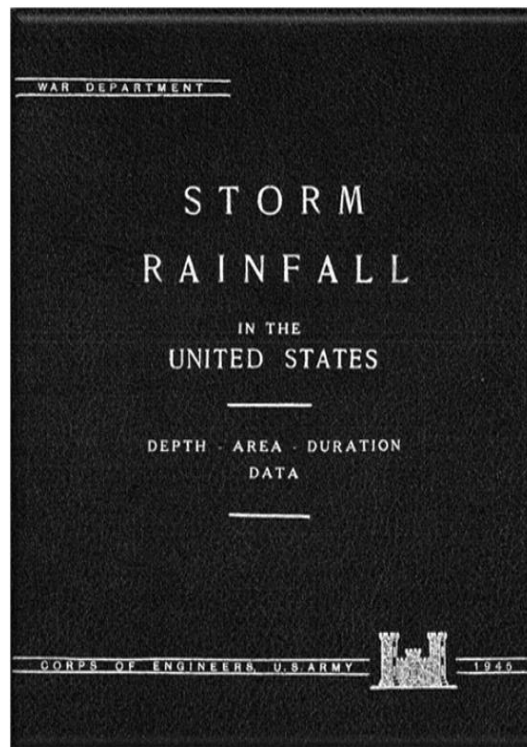
<b>Task</b>	<b>Timeframe</b>	<b>Responsible Agency</b>	<b>Funding Source</b>	<b>Needed Resources</b>
Complete NOAA Atlas 14 for the Northwestern USA	3 years	NOAA	Various federal and state agencies	5 scientists
Update the whole country simultaneously using improved methodology capable of accounting for the non-stationary climate	4 years	NOAA	Various federal and state agencies	10 scientists
Enhance products' suite (ARFs, design storms, variable confidence limits)	2 year	NOAA	Various federal and state agencies	3 scientists

## 3. U.S. Extreme Precipitation Database

*Marian Baker, NOAA/NWS; George Hayes and Charles McWilliams, USACE*

### 3.1. Product Background

In February of 1946, the USACE in cooperation with the US Weather Bureau (USWB) and the US Bureau of Reclamation (USBR) published the first version of the Extreme Storm Catalog (Figure 3-1). The catalog was comprised of a collection of unusually large storms based on precipitation data, meteorological information and anecdotal reports collaborated by all three agencies.



**Figure 3-1.** Front cover of the first version of the Extreme Storm Catalog

The Extreme Precipitation Database (EPD) will build on this history of archiving storms for use in dam safety and planning, providing a repository for exceptional precipitation event data. Once completed, the EPD will provide a source of digital historical storm data in several formats ranging from simple text files to detailed depth-area-duration curves of extreme events. GIS data will be included in the database in various formats for download. Future plans would include the creation of a permanent digital repository for all future storm data analysis.



## 3.2. Product Description

The EPD will be developed to digitally archive the pertinent data of the storms contained in the Extreme Storm Catalog (Figure 3-2), as well as from additional storm events that have occurred since 1973. For the older storms, the database will include digital transcriptions of information from the catalog alone. This information will include scans of the original isohyetal maps (Figure 3-3), depth-area-duration (DAD) data, mass curves for each storm, and scans of the original bucket survey forms. For more recent events, the River Forecast Center (RFC) hourly quality controlled radar rainfall estimates will be archived for large events using a gridded GIS format, along with a depth area analysis in an Excel spreadsheet format. The modern analysis will include the supporting meteorological data for the event, collected from observations surrounding the storm location downloaded from the National Centers for Environmental Information (NCEI). The design of the EPD archive of storm information will allow the user to confirm the original data for each storm event, or for users to create their own new storm analysis.

Tasks to develop this storm archive system include:

- Compiling historic data for extreme storms from the NWS, USBR, USACE, state climatologists, and other agencies; updating the extreme storm catalog to include extreme storms that have occurred since 1973.
- Scanning historical files and reports, and digitizing the isohyetal maps. In addition to the historical isohyetal maps, detailed storm analysis of exceptional storms based on RFC multi-sensor radar precipitation estimates will be included in the database dating from the late 1990s to the present.
- Developing a website to provide a centralized location for sharing extreme storm information between all agencies as well as the public. The website will also include electronic versions of the HMRS, site specific PMP studies, and other pertinent references for extreme storm studies that will be available for download. The layout, format, and location of this website for long term maintenance will be developed by the ESEWG.

Starting in 2013, the USACE began the development of a prototype website and database to aid in the initial development of the EPD. Since this time, the database has undergone several revisions to the current version as of 2018 (Figure 3-4) which allows the user to select which columns to display of specific storm information. This specific data include the storm Assignment Number; Location of the Storm Center; the USACE Division and District in which the storm center was located; Start Date; End Date; Maximum Rainfall; Duration of Storm; Storm Area; Average Rainfall over Storm Area; 24-hour 100-square mile rainfall; Storm Dew point Temperature; Maximum Dew point Temperature, In-place Maximization Factor; Reference location and direction for Storm Dew point Temperature; Latitude and Longitude of Storm Center; HMR's the storm was used for; Elevation of storm center; and types of data available including Depth-Area-Duration Curve, Isohyet Map, Storm Study, etc. Each field can be searched or sorted as desired by the user. Any of the columns can be exported to a Microsoft® Excel file for further processing.

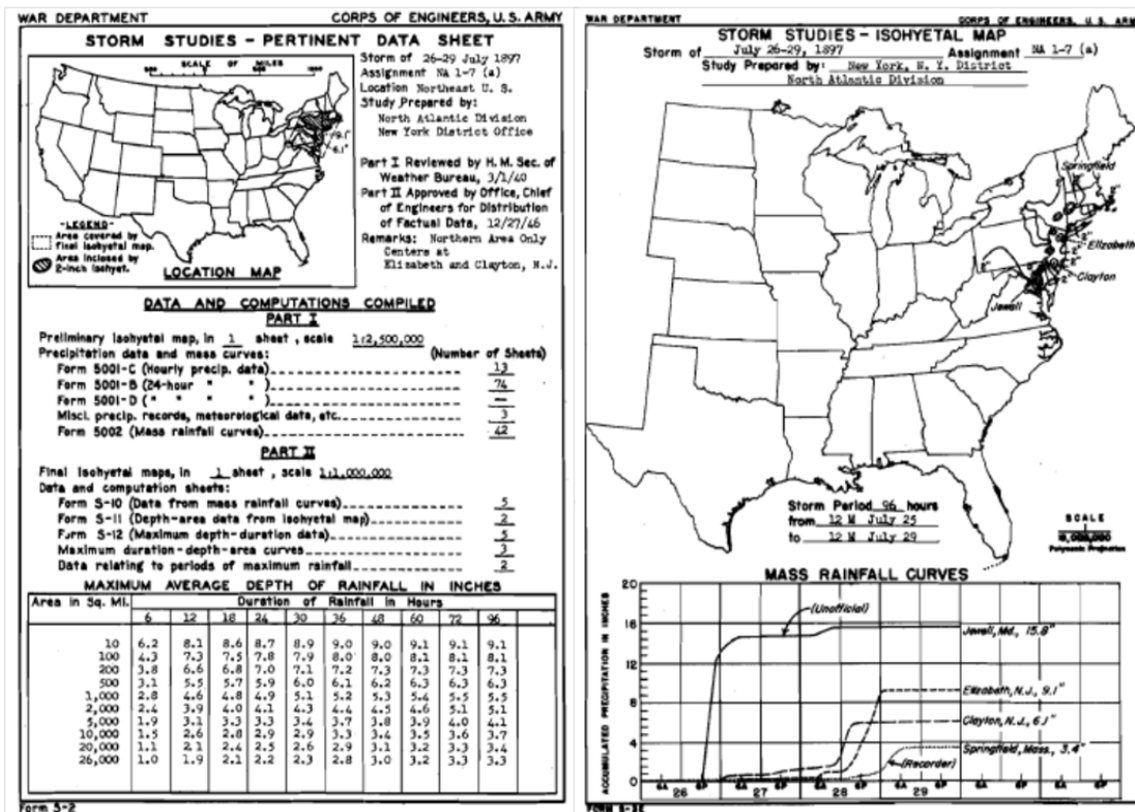


Figure 3-2. Sample pertinent data sheets in the Extreme Storm Catalog

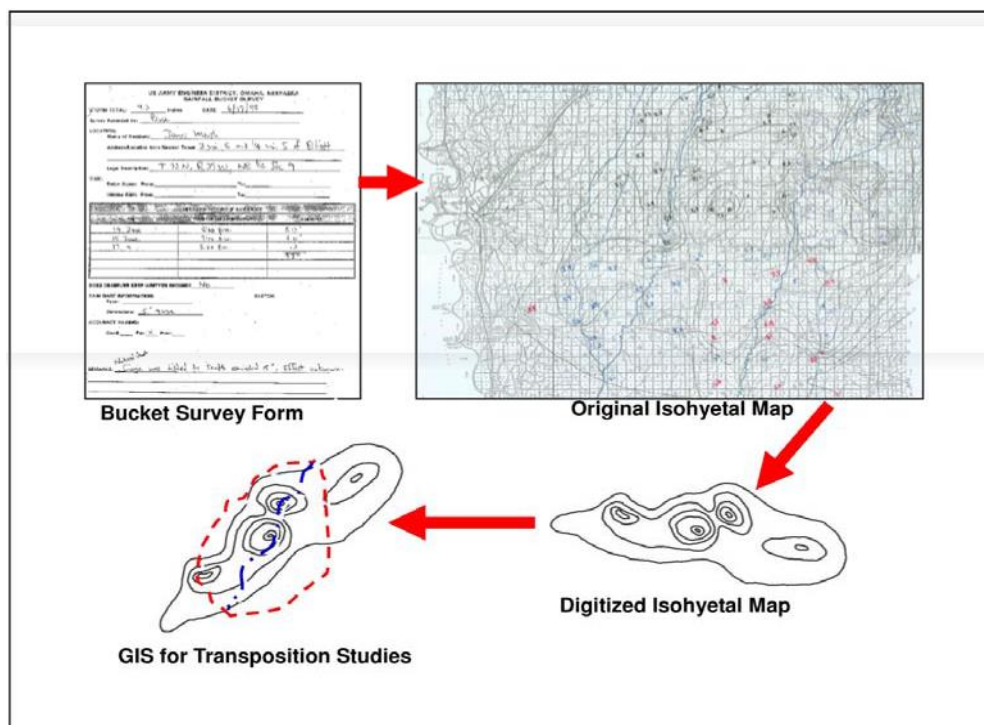
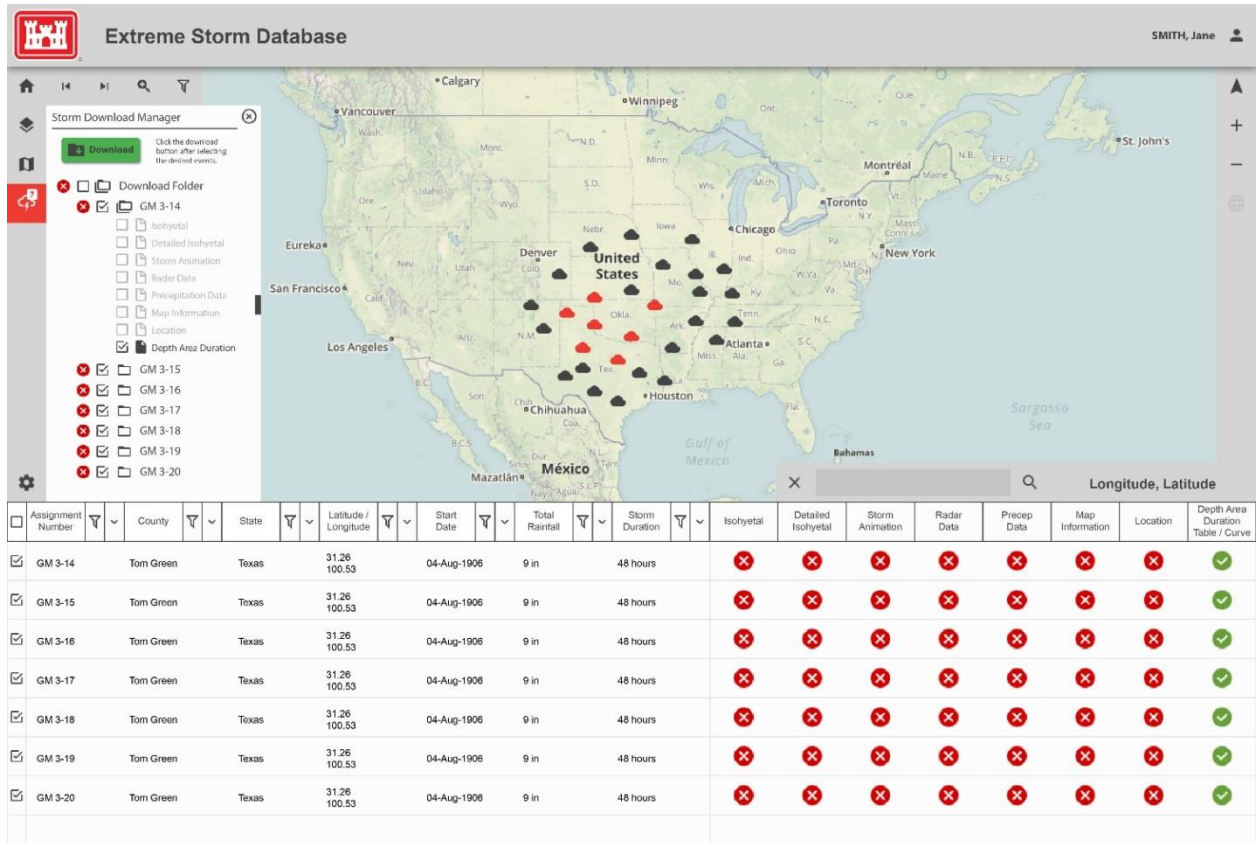


Figure 3-3. Extreme Storm Database data-archiving and analysis schematic



**Figure 3-4.** Sample screen image of the USACE Extreme Storm Database

Clicking on a line of storm information will bring up the more detailed storm summary page (Figure 3-5), with an overview of the highlighted storm event and a list of downloadable data files for this storm located on the lower part of the screen (Figure 3-6). Clicking on the data listed in a selected storm will go to a download interface. Currently, the USACE database is populated with data from all storms in the USACE Extreme storm catalog; all storms analyzed for the current HMR's; and a few additional storms that have occurred since 1973.

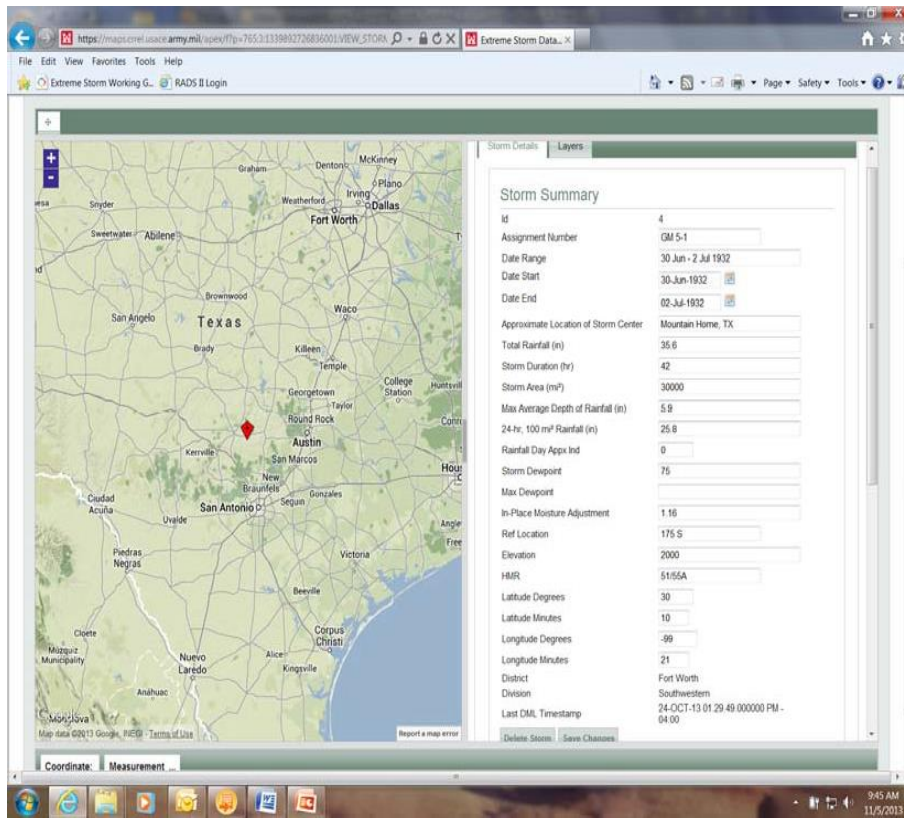


Figure 3-5. Detailed Storm Summary (DSS)

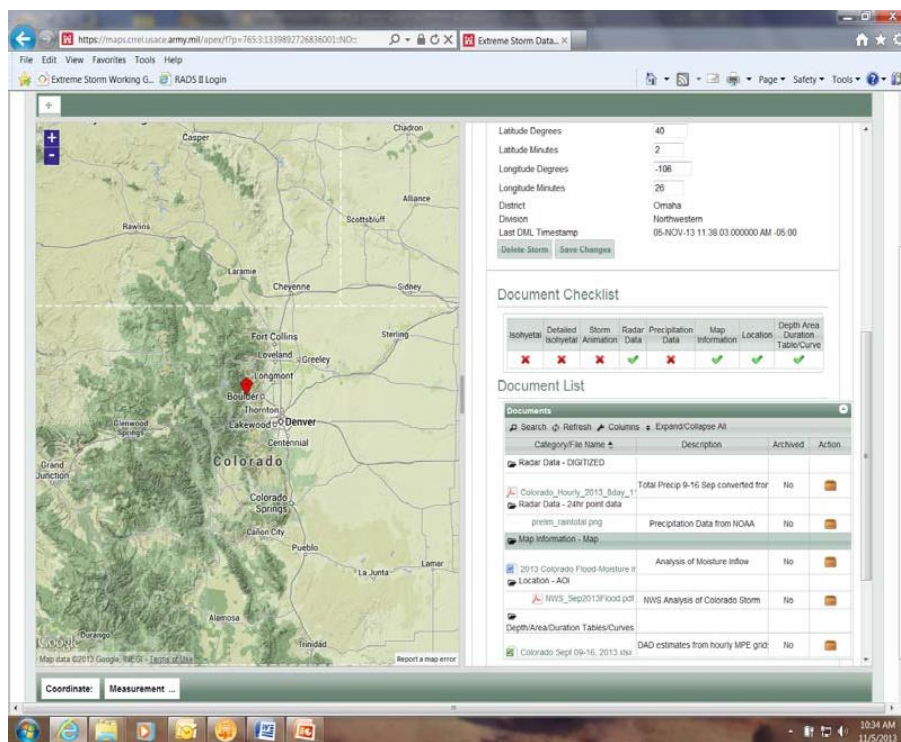


Figure 3-6. Listing of available data files for the selected storm



Radar Data or isohyetal maps for a particular storm, if available, can be downloaded from the database in several formats including XMRG, DSS, ESRI shapefiles or as ASCII gridded data. For the sample storm in [Figure 3-7](#), several different file types have been made available for the event. An example display of the radar data in a DSS format for a storm that occurred in Kansas during 2012 is shown in [Figure 3-8](#).

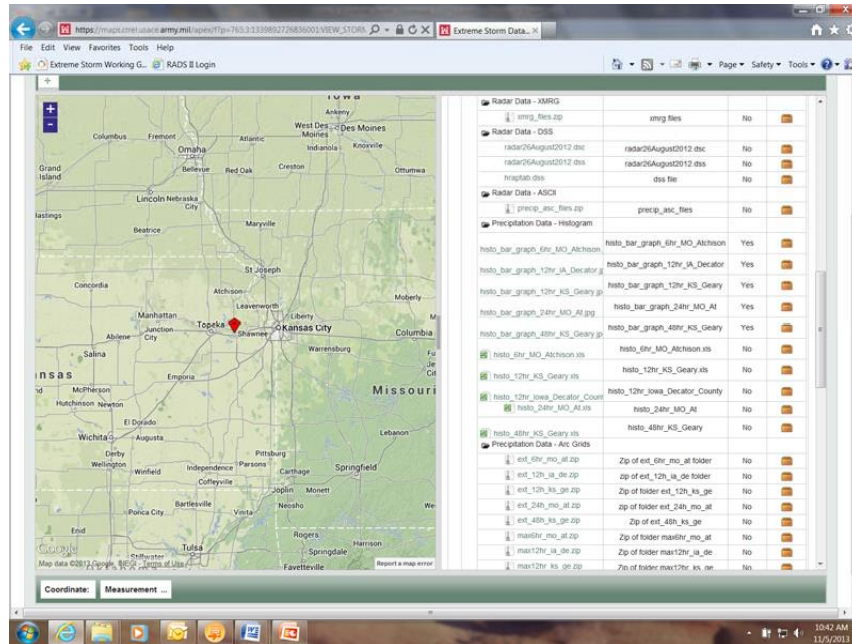


Figure 3-7. Types of files uploaded for a sample storm

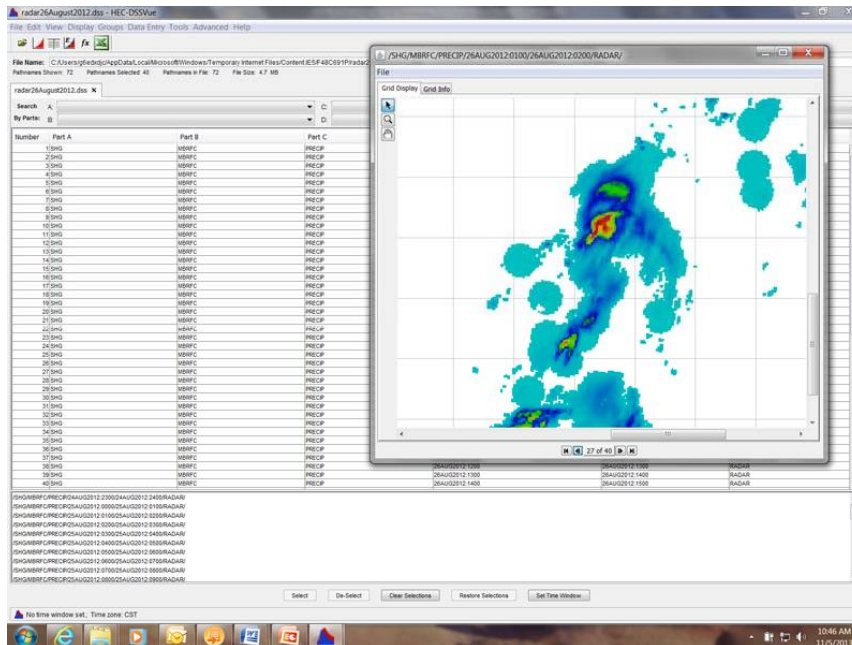


Figure 3-8. Radar-display example in DSS format

Applications of the data from the Extreme Storm Database include using the data for site-specific Probable Maximum Precipitation (PMP) studies; updating the HMR reports; computing regional areal reduction factor relationships; storm maximization transpositions studies; linking with a hydrologic model for Stochastic Extreme Flood Model (SEFM) analysis; and updating the USACE Standard Project Storm criteria in EM 1110-2-1411 (USACE, 1965).

### **3.3. Implementation**

Over the last several years, the USACE has been working on enhancements to the database, including the ability to input the entire depth-area-duration table for each storm; capability to plot the depth-area-duration curves; functionality to search for storms by drawing a box on a map or specifying a latitude and longitude location and radius; as well as an ability to specify several meteorological parameters. The database will also allow searches for all storms that exceed a certain precipitation value for a given area, size and duration.

A long-term goal is for the database architecture to become capable of linking to other USACE software that can utilize the data on the storms in the database. These links are expected to include Hydrologic Engineering (HEC) Software DSSVue and MetVue. HEC-MetVue is storm analysis software being developed by the USACE for the purpose of analyzing storms, computing depth area duration curves, transposing storms, and computing PMP using the existing techniques outlined in the HMR's. HEC-MetVue will be linked with the HEC-HMS model to create an input file of flood runoff on transposed and maximized storms for use in a hydrologic model.

A significant amount of work remains to continue populating the database with digital data from the NWS, USACE and USBR, along with other cooperating agencies. In addition a library of storm data collected as a part of detailed storm studies filed at the NWS Hydro-Met Library are also planned to be added to the database.

Once completed, this prototype database developed by USACE may provide access to external entities pending approval from DOD Information Management regulations. Future hosting of such a database to allow a wider distribution would require a general archive location, such as the National Centers for Environmental Information (NCEI). NCEI considers all requests to archive data through the ATRAC (Advanced Tracking and Resource tool for Archive Collections) system. If users meet the requirements of the ATRAC, funding requirements, and the NCEI internal review system, there should not be a problem of archiving data.

Details for the long-term maintenance and hosting of the database would need to be determined by the federal interagency Extreme Storm Events Work Group. In addition, the long-term maintenance of the database would need to include a plan for collection and analysis of data from future extreme storms for inclusion into the database. Supporting data for storm analysis, in the form on an hourly archive of native RFC-gridded Multi-sensor Precipitation Estimation (MPE) data would serve as a foundation for future extreme storm analysis. Table 3-1 shows a list of future tasks, timeframe, responsible agency, funding sources and funding amounts required for the remaining work to complete the Extreme Precipitation Database.

**Table 3-1.** Tasks to be completed for the Extreme Precipitation Database

<b>Task</b>	<b>Timeframe</b>	<b>Responsible Agency</b>	<b>Funding Source</b>	<b>Needed Resources</b>
Database modifications	2 years	USACE	USACE	1 Technician
Process recent storms	1 year	NOAA	USACE	1 Technician
Populate extreme storms database	1 year	NOAA	USACE	1 Technician
Scan and upload storm studies	1 year	USACE/Partners	USACE/Partners	1 Technician
Test the database and link the database to HEC-MetVue	2 year	USACE	USACE	1 Scientist
Move database to permanent location	1 year	USACE/Partners	USACE/Partners	1 Technician
Long-term maintenance and storm processing/ Develop plan for future storms	3 years	USACE/ NOAA/Other Federal Agencies	USACE/ NOAA/other Federal Agencies	1 Scientist  1 Technician



## 4. Updated Probable Maximum Precipitation Estimates

*John Onderdonk and Ken Fearon, FERC; Mark Perry, State of Colorado*

### 4.1. Product Background

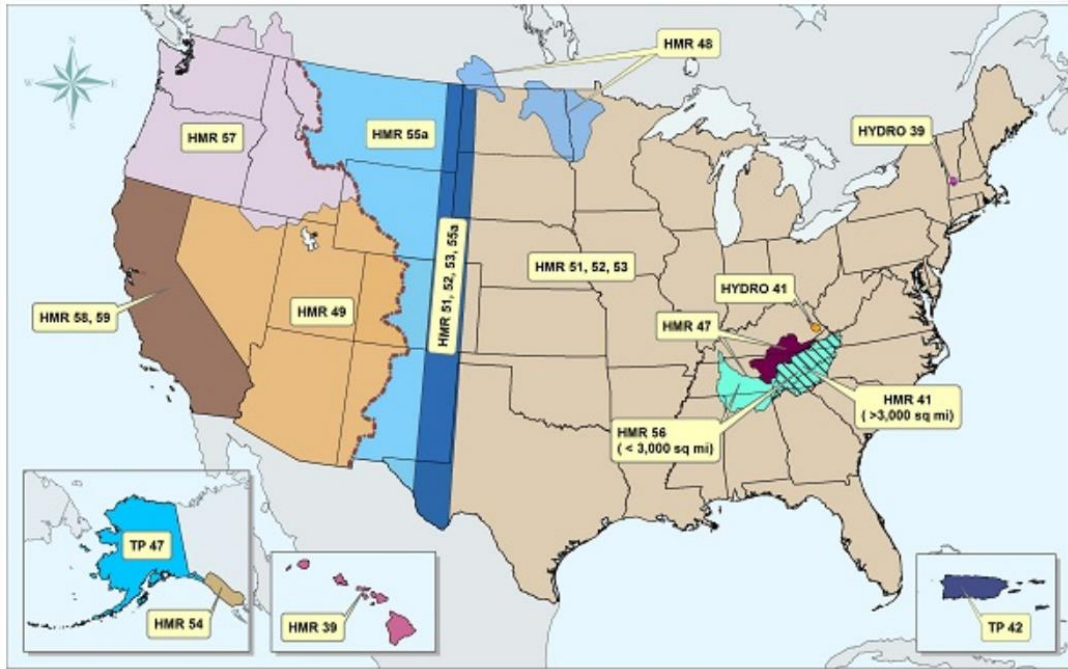
The “Charge of the Subcommittee on Hydrology’s (SOH) Extreme Storm Events Work Group (ESEWG)” tasks the group to develop a scope of work/plan of study and funding requirements to update the Catalog of Extreme Storms (see Chapter 3) and the NOAA/NWS Hydrometeorological Reports (HMRs) for estimating PMPs. This chapter addresses updating of PMP estimates and development of guidance for reviewing site-specific PMP estimates.

PMP is defined as the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of year (World Meteorological Organization, WMO-No. 1045, 2009). PMP is typically used by Federal and State agencies for designing and regulating critical infrastructure such as dams and nuclear facilities. Stakeholder agencies include U.S. Army Corps of Engineers (USACE), U.S. Bureau of Reclamation (USBR), U.S. Nuclear Regulatory Commission (NRC), Federal Energy Regulatory Commission (FERC), and State dam safety agencies, among others.

PMPs are used by engineers to derive Probable Maximum Floods (PMFs) as part of spillway designs for High and Significant Hazard dams. By Federal and State regulations, dam spillways must be designed to safely convey an inflow design flood (IDF) above which failure of the dam would not be expected to result in additional damage. The upper limit of an IDF is typically the PMF, and hence the PMF is used as the basis of spillway sizing for many of the nation’s largest and highest hazard dams.

During the 1970’s through the 1990’s NOAA, with assistance from USACE and USBR, developed and published various HMR atlases of PMP estimates for the United States. HMRs represented the state-of-the-art when they were published; however, they have not been consistently updated for many years. NOAA does not presently have the funding or resources to update the HMRs or PMP estimates. Yet the need still exists as engineers continue to design critical national infrastructure in many cases based on outdated PMP estimates from the HMRs. Figure 4-1 shows HMRs boundaries that have been developed for the United States. Table 4-1 shows that the majority of the country is covered by HMRs that are approximately 40 years old. HMRs covering the U.S. west coast areas are the most recently published (i.e., 18-23 years old).

The FERC is responsible for the safety and adequacy of 2,523 non-Federal, jurisdictional dams and FERC has an interest in any coordinated effort to review extreme storm data and update HMRs for use in development of extreme storm precipitation estimates. The FERC supports the efforts of the ESEWG to promote the cooperation and coordination among agencies to improve the methodologies and data collection techniques to better estimate large storm events up to and including the PMP.



**Figure 4-1.** HMR publications covering the United States (National Weather Service, 2017)

**Table 4-1.** Summary of HMRs with publication date (National Weather Service, 2017b)

Document Link	Title	Year
<a href="#">Hydrometeorological Report No. 39</a>	Probable Maximum Precipitation in the Hawaiian Islands	1963
<a href="#">Hydrometeorological Report No. 41</a>	Probable Maximum and TVA Precipitation over the Tennessee River Basin above Chattanooga	1965
<a href="#">Hydrometeorological Report No. 46</a>	Probable Maximum Precipitation, Mekong River Basin	1970
<a href="#">Hydrometeorological Report No. 47</a>	Meteorological Criteria for Extreme Floods for Four Basins in the Tennessee and Cumberland River Watersheds	1973
<a href="#">Hydrometeorological Report No. 48</a>	Probable Maximum Precipitation and Snowmelt Criteria For Red River of the North Above Pembina, and Souris River Above Minot, North Dakota	1973
<a href="#">Hydrometeorological Report No. 49</a>	Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages	1977
<a href="#">Hydrometeorological Report No. 51 (Digitized maps)</a>	Probable Maximum Precipitation Estimates, United States East of the 105th Meridian	1978
<a href="#">Hydrometeorological Report No. 52</a>	Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian	1982
<a href="#">Hydrometeorological Report No. 53</a>	Seasonal Variation of 10-Square-Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian	1980
<a href="#">Hydrometeorological Report No. 54</a>	Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska	1983
<a href="#">Hydrometeorological Report No. 55A</a>	Probable Maximum Precipitation Estimates - United States Between the Continental Divide and the 103rd Meridian	1988
<a href="#">Hydrometeorological Report No. 56</a>	Probable Maximum and TVA Precipitation Estimates With Areal Distribution for Tennessee River Drainages Less Than 3,000 Mi <sup>2</sup> in Area	1986
<a href="#">Hydrometeorological Report No. 57</a>	Probable Maximum Precipitation - Pacific Northwest States. Columbia River (including portions of Canada), Snake River and Pacific Coastal Drainages	1994
<a href="#">Hydrometeorological Report No. 58</a>	Probable Maximum Precipitation for California - Calculation Procedures	1998
<a href="#">Hydrometeorological Report No. 59 (HMR58 and HMR59 shapefiles)</a>	Probable Maximum Precipitation for California	1999

In 2014 the ESEWG conducted a survey to assess extreme precipitation product needs of Federal and State agencies. State dam safety agencies voiced a particularly strong desire for updated PMP estimates. Twenty-one States responded to the survey on short notice, which may suggest the importance of updated estimates to State dam safety agencies. Further, six State dam safety agencies were represented at the *ESEWG's May 2014 Workshop*, held at NOAA/NWS Headquarters in Silver Spring, MD. One of the goals of the workshop was to identify extreme precipitation product needs. In their response to the survey, and as reported in their workshop presentations, the States articulated the following:

- PMP estimates are very important to the States; in most cases State regulations for determining spillway capacities are typically based upon PMFs using HMR PMPs. In some cases the requirement for States to use HMR PMP are codified in State statutes and regulations. In approximately the year 2000, the NOAA/NWS decided to no longer support the updating of HMR PMP products, leaving the States in a difficult situation.
- Extreme precipitation products should consider workloads of State dam safety agencies, which are typically hundreds of dams per staff member. Detailed site-specific hydro-meteorological studies for each dam are simply not practical.
- States would benefit from using PMP estimates that are technically and politically defensible to private dam owners and state legislators. Currently, HMRS developed in the 1970s and 1980s are difficult for the States to defend while trying to enforce spillway safety regulations that could cost dam owners millions of dollars in modifications.
- National extreme precipitation products and guidelines would be good for the dam safety industry, and are needed to provide water resources developers with the confidence needed to invest in multi-million dollar infrastructure projects.
- The importance of updated PMP estimates is urgent. In some States, the level of opposition in the use of outdated and unsupported NOAA HMR PMP has risen to the political level, with one State legislature requiring an updated State-wide PMP study, which has been recently completed. Another state dam safety agency has had a *de facto moratorium* on spillway evaluations at high elevations due to concerns about accuracy of HMR PMP estimates. At least eight (8) states have moved forward with their own PMP update studies in the absence of Federal action, and many more States are considering such studies.

Finally, in the absence of updated HMRS, many water development projects have moved forward with so-called “site-specific PMP” (SSPMP) studies, which are basin-scale meteorological studies, typically performed by private hydrometeorological consultants. The increase in SSPMP studies has put a burden on regulatory agencies, which often do not have the expertise or resources to review hydrometeorological studies. SSPMP analyses generally follow the guidance of the HMRS, but deviations from the HMR procedures are common. SSPMPs studies may use new storm data, improved data acquisition, GIS technology, new methods to represent storm maximization, orographic effects, and improved computer processing to develop estimates. Although SSPMP studies provide updated PMP estimates, results have not been unanimously accepted by the engineering community, typically due to lack of accepted standards. Questions concerning storm selection, storm reanalysis, deviations from the established HMR methods, and use of new technologies have been debated. Clearly there is a need for new methods and information;

nonetheless, the storm-based objective of an SSPMP study should remain consistent with the accepted definition of PMP.

In summary of the above assessment, two key products have been identified by the ESEWG in support of updated PMP estimates: (1) pooled Federal funding of updating HMRs for Federal needs; and (2) a national guidelines document to define best practices for State-wide/regional and Site-Specific PMP studies. In addition, a third product has been identified as “maintenance, research and development,” which should occur in support of the previous two products.

## **4.2. Updated Hydrometeorological Reports of Generalized Probable Maximum Precipitation Estimates**

### **4.2.1. Product Description**

Updated HMRs would take into consideration new technology that has evolved since the original HMRs were authored. New PMP studies can benefit from a wide range of data sources, updated observations, and radar data. Likewise new methods have been developed that take advantage of these data sources (e.g. new methods for storm maximization using new dew point climatology data). These new data and methods should be fully reviewed and investigated to document the impacts on PMP estimates. Additionally, updated HMRs should provide modern, defensible PMP estimates for the United States. Since the end of the HMR era, technology and methods have continued to advance through State-wide and site-specific PMP studies. Necessary HMR advancements should include:

1. PMP estimates available via web-based server to provide PMP estimates for a basin of interest, similar to the NOAA Atlas 14 Precipitation Frequency Data Server.
2. Gridded (raster) PMP estimates in GIS format to support distributed hydrological modeling.
3. Updated storm catalog to include analysis of recent extreme events (i.e., those that occurred within the past 30-40 years).
4. Use of Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model as a tool to determine inflow moisture supply associated with historic extreme storms.
5. Use of appropriate measures of storm efficiency and associated theoretical maximum values (e.g. vertically-integrated atmospheric moisture versus surface dew point).
6. Use of Next Generation Weather Radar (NEXRAD) for storms that occurred after 1995.
7. Consistent and reproducible methods to determine appropriate storm transposition limits.
8. Physically based methods to account for orographic effects on extreme precipitation during storm transposition process, possibly supported by dynamical modeling.
9. PMP estimates should be extended beyond the historically-provided duration of 72-hours, which is a lesson learned from numerous long-duration high volume rain events (e.g. Hurricane Harvey, August 2017, Texas).

10. Identify best-practices to address expected impacts of climate change on PMP estimates.
11. Quantification of uncertainty in input data and decisions and estimation of PMP confidence bounds.

#### **4.2.2. Product Implementation**

Updating the HMRs will require rebuilding a workgroup within an existing Federal agency with experience in meteorology, hydrology, and extreme precipitation studies. Currently no single agency possesses personnel of the size needed to update the HMRs, however, NOAA, USACE and the USBR have groups that could provide the building blocks. It may be efficient to contract with meteorological consulting firms on certain tasks where such firms have developed the necessary expertise.

HMR updates should be performed regionally based upon major drainage basin or meteorologically similar climate region. These updates should be prioritized, firstly for HMR 51/52, due to its large area and population coverage; then HMR 49, due to its age; then HMR55A, and so on. In the meantime, the ESEWG believes that consideration should be given to removal of existing HMRs from the NOAA Hydrometeorological Design Studies Center website, since they are no longer supported by NOAA.

HMR update studies would generally include the following task items:

1. Identify historic extreme storms relevant to the region of study.
2. Grouping of storms by independent storm type (i.e., separating those that would not occur simultaneously).
3. Construct depth-area-duration data for historic extreme storms.
4. Determine representative and maximum theoretical measures of efficiency for historic extreme storms.
5. Transposition storms over the study region according to agreed-upon limits and adjustment procedures, including physically-based procedures to account for orographic influence.
6. Spatially map PMP estimates for each independent storm type over the study area.
7. Spatially and temporally envelope PMP estimates to account for sample variation due to limited sample size of extreme storms.
8. Provide guidance on spatial and temporal patterns of PMP design storms for hydrological modeling.
9. Address climate change impacts if warranted by non-stationarity analysis.



10. Estimate annual exceedance probability for point PMP estimates based on regional extreme precipitation frequency analysis in order to provide a risk-based framework for PMP design criteria.
11. Estimate uncertainty and PMP confidence bounds.

Regardless of what agency assumes primary responsibility for updating the HMR PMP estimates, a multi-agency review board should be formed to peer review each new HMR study. A multi-agency approach for funding HMR updates should be established. FEMA’s National Dam Safety Program grants could be used as a conduit to provide funding for the HMR update effort via cooperating State dam safety agencies, much as Federal Highway Administration funding to State departments of transportation has been successfully used to fund NOAA Atlas 14 development. Table 4-2 shows recommended tasks, timeframe, responsible agency, funding source and resources needed to complete the recommended HMR updates.

Data from the new HMR PMP estimates could be served in a variety of ways including a multi-functional web-interface similar to that for NOAA Atlas 14. Also USACE has been working on possible methods of data exchange including programs like their HEC-MetVue.

**Table 4-2.** Tasks to be completed for HMR PMP updates and resources needed

<b>Task</b>	<b>Timeframe</b>	<b>Responsible Agency</b>	<b>Funding Sources</b>	<b>Resources Needed</b>
Update HMR PMP for HMR 51/52 study area (including HMRs 41, 47, 48, and 56, which lie within the larger 51/52 boundaries)	2 years	NOAA, USACE or USBR (lead agency to be determined)	USACE, USBR, NRCS, NRC and state dam safety agencies (by FEMA National Dam Safety Program grants)	Dedicated agency work group staffed with 5 meteorologists, 2 hydrologists, 3 GIS technicians, and 2 web application developers
Update HMR 49 study area	Same as above			
Update HMR 55A study area	Same as above			
Update HMR 39 (Hawaii) and HMR 54/TP47 (Alaska) study area	Same as above			
Update HMR 57-59 study area	Same as above			

### **4.3. National Guidance Document for Statewide/Regional and Site-Specific PMP Studies**

### 4.3.1. Product Description

Until the HMRs are completely updated, a need will continue for some States to move forward with their own Statewide/regional PMP studies. Also the need for site-specific PMP studies, which can address unique basins factors, will continue even after completion of HMR and State-wide PMP updates, which produce generalized PMP estimates.

A national guidance document for State-wide/regional and site-specific PMP studies is recommended to provide best practices that can be followed by Federal and State regulatory agencies and private meteorological consultants in performing such studies. The objectives of the guidelines document should be to: (1) ensure consistency between PMP studies and study regions; (2) facilitate review of PMP studies by regulatory agencies; and (3) provide confidence in regional and site-specific PMP estimates. Based upon the feedback received by the ESEWG in their 2014 Federal and State surveys, a national guidelines document should not dictate standards or requirements, but should leave some flexibility to the regulatory agencies. Guidance should consider best practices from recent State-wide and site-specific PMP studies that have been performed across the country.

The States of Colorado and New Mexico are currently completing a multi-year, state-of-the-practice Regional Extreme Precipitation Study (CO-NM REPS). As part of this study, they have proposed to develop a standard-of-practice report, documenting the data and methods used. The ESEWG recommends that the CO-NM REPS report be considered in the development of a new national guidelines document.

The ESEWG recommends the guidance document to be developed by a panel of subject matter experts, led by an objective and credible independent organization such as the National Academy of Science, and published by FEMA as part of their “guidelines for dam safety” series of reports for the National Dam Safety Program.

The guidelines document should generally address the following topical areas:

1. Data needs and data sources,
2. Best practices in PMP estimation methods including storm reconstruction, storm maximization, transposition and orographic influence,
3. Quality control/quality assurance practices,
4. Oversight and review process,
5. Study documentation, and
6. Identification of items for future research.

The FERC has the following requirements for site-specific PMP studies, requirements which should be considered for incorporation into the State/regional and site-specific PMP study guidelines document:

1. The studies must be performed by a qualified hydrometeorologist.



2. The studies must be reviewed by a Board of Independent Consultants (BOC) consisting of three or more qualified professionals that usually include a meteorologist, hydrologist, and civil engineer.
3. The BOC should be approved by the FERC (or responsible regulatory agency).
4. FERC (or other responsible regulatory agency) representatives must be involved throughout the study and BOC review process.

#### **4.3.2. Product Implementation**

The ESEWG recommends that FEMA, as the lead agency for the National Dam Safety Program, sponsor the development of the national guidelines document, and assemble an expert committee to edit it. The ESEWG recommends the National Dam Safety Review Board (NDSRB) help guide the direction of the document, as they have done with other national dam safety guidance documents. The CO-NM REPS standard-of-practice report could be used as a starting place in order to ease the burden of developing a national guidelines document, with the FEMA-led expert committee reviewing and editing the CO-NM REPS report to meet the needs of a national audience.

It is expected that the large dam owners and agencies (i.e., NOAA, USACE, USBR, FERC and NRC) will participate; this should be easily accomplished because these agencies have participated closely on the CO-NM REPS Project Review Board. Table 4-3 provides a summary of tasks, timeframe, responsible agencies, funding sources, and resources needed for publication of a national guidelines document.

**Table 4-3.** Tasks to be completed for publication of the national-guidelines document for State-wide/regional and Site-Specific PMP studies and resources needed

<b>Task</b>	<b>Timeframe</b>	<b>Responsible Agency</b>	<b>Funding Source</b>	<b>Resources Needed</b>
FEMA-led expert committee to review and edit the CO-NM REPS standard-of-practice report in order to meet needs of a national audience	6 months	FEMA, USACE, USBR, NRC, NOAA, FERC and representatives from state dam safety agencies and ASDSO	FEMA National Dam Safety Program	7 hydro-meteorological and dam safety experts from responsible agencies (estimated 260 hours total over 6 months at 10 hours/week for each worker)
Review by National Dam Safety Review Board	2 months	NDSRB participants	NDSRB participants	NDSRB participants
Publication of guidance document	3 months	FEMA	FEMA	Technical writing staff, report publication staff

#### **4.4. PMP Maintenance, Research and Development, and Updates**

Finally, in support of the PMP products described above, the ESEWG recommends that long-term maintenance, research and development, and update tasks need to be performed in order to: (1) maintain the viability of PMP estimation products; (2) support continued critical infrastructure development; and (3) incorporate current large storm events.

The following on-going tasks are needed:

1. Coordination of HMR update methods and State/regional and site-specific PMP guidelines to ensure that the two approaches maintain consistency.
2. Compile, host, and maintain the various HMRS, State/regional, and site-specific PMP studies, which are performed in accordance with the national guidelines document.
3. Perform, fund, and promote continued research in the fields of PMP estimation and extreme precipitation estimation, relying on issues raised during HMR update studies and State/regional and site-specific PMP studies.
4. Determine criteria and frequency for review and update of PMP estimates, such that PMP estimates are kept current based on the occurrence of new storms, new methodologies, etc. Perform updates as are deemed necessary.

The research and development of PMP needs to consider alternative methods to develop PMP estimates, including statistical methods and dynamical modeling. Current PMP methodology relies on assumptions of linear scaling, storm transposition, and orographic adjustment factors that are imperfect. New methods should use physically-based models to explicitly estimate extreme precipitation at high resolution over an entire study area. Such approaches may require a revision of current definition of PMP.

Table 4-4 provides a summary of tasks, timeframe, responsible agencies, funding sources, and resources needed for long-term maintenance, research and development, and updates of PMP estimates.

**Table 4-4.** Tasks to be completed for Probable Maximum Precipitation (PMP) on-going maintenance, updates, and research and development

<b>Task</b>	<b>Timeframe</b>	<b>Responsible Agency</b>	<b>Funding Source</b>	<b>Resources Needed</b>
Coordination of HMR update methods and State/regional and site-specific PMP national guidelines	On-going	NOAA, FEMA, FERC, ASDSO, and NDSRB	FEMA National Dam Safety Program	Committee to meet annually and ensure the HMR and State/Regional-SSPMP approaches maintain consistency
Compile, host, and maintain HMR updates, State/regional, and site-specific PMP studies	On-going	NOAA, USACE or USBR (lead agency to be determined)	Same as responsible agency (TBD)	Dedicated data servers, databases, web and application programmers and database managers
Perform, fund, and promote PMP research and development	On-going	NOAA, FEMA	FEMA	FEMA Dam Safety Program with grant funding to other agencies, universities, and private consultants
Determine criteria and frequency for review and update of PMP estimates, and perform such updates	On-going	NOAA, USACE or USBR (same team that updates HMR PMP estimates)	USACE, USBR, NRCS, NRC and state dam safety agencies (by FEMA National Dam Safety Program grants)	Same team that updates HMR PMP estimates

## 5. Conclusions

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There are several important items that were identified at the “Workshop to Define Needed Extreme Storm Products” held in May 2014. Each agency had an opportunity to review their survey responses, identify their extreme storm product needs, and potential impacts from not addressing those identified needs. A list of priorities was distilled from the needs presented and organized. This list contained the “must-have products” needed to update and streamline the estimation of extreme precipitation processes within the context of the risks related to extreme precipitation events. Three top priority items were identified as crucial to the future of the estimation approach and risk mitigation for extreme precipitation.

- Completion of NOAA Atlas 14 remaining volumes and improvements to the methodology and uncertainty estimates.
- Loading and hosting of the U.S. Army Corps of Engineer’s Extreme Precipitation Database (including its long-term maintenance and hosting) to include electronic archiving of storm paper records that were the basis of the published HMRs and for future public access to the data.
- The updating of the HMR documents and PMP methodology into a modern digital method, using updated, modern data and a web-based interface, and the preparation and distribution of a National Guidance Document for State-wide/Regional and Site-Specific PMP Studies

Without action, the process for accounting for extreme precipitation data and events lags at the Federal level due to no updating of the HMRs and their methodology; incomplete NOAA Atlas 14; and lack of National Guidance for reviewing site-specific PMP studies. The old methods did not account for the modern availability of gridded data or high density data such as sub-hourly temperature, dew point and rainfall data, as well as modern storms that have occurred since the 1970s when the HMRs were last published. Many entities have taken upon themselves to try to develop new methods of accounting for extreme precipitation data and processes, but do not have a standard format or process. There is no accountability or standard method for peer-review of non-standard studies or data collection processes, or to identify inadequate studies that may not account for all relevant data applicable for extreme storms. These limitations and omissions could be mitigated by the creation of updated guidelines, methods, and processes to account for extreme precipitation data and risk. This would include a variety of methods from accounting for climate considerations to applying new methods for processing the storm data to estimate PMPs and identify risks related to the extreme precipitation events.

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## 7. ABBREVIATIONS / ACRONYMS

ACWI	Advisory Committee on Water Information
AEP	annual exceedance probability
AMS	annual maximum series
ARF	areal reduction factor
ARI	average recurrence interval
ATRAC	Advanced Tracking and Resource tool for Archive Collections
BOC	Board of Independent Consultants
DAD	depth-area-duration
DOD	U.S. Department of Defense
DSS	Detailed Storm Summary
EPD	Extreme Precipitation Database
ESC	Extreme Storm Catalog
ESEWG	Extreme Storm Events Work Group
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information Service
HDSC	Hydrometeorological Design Studies Center
HMR	Hydro Meteorological Report
HYSPLIT	Hybrid Single Particle Lagrangian Integrated Trajectory
ICODS	Interagency Committee on Dam Safety
MPE	Multi-sensor Precipitation Estimation
NCEI	National Centers for Environmental Information
NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
PF	Precipitation Frequency
PFDS	Precipitation Frequency Data Server
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
REPS	Regional Extreme Precipitation Study
RFC	River Forecast Center
SEFM	Stochastic Extreme Flood Model
SOH	Subcommittee on Hydrology
SSPMP	Site-Specific PMP
TP	Technical Paper issued by the U.S. Weather Bureau
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey