Water Information Coordination Program

Advisory Committee on Water Information

Subcommittee on Hydrology (SOH)
Extreme Storm Events Work Group (ESEWG)

ESEWG Workshop Synthesis Report

Workshop to Define Needed Extreme Precipitation Products

May 15, 2014

National Weather Service Offices

Silver Spring, MD

Introduction

The Extreme Storm Events Work Group (ESEWG) held a workshop to define needed extreme storm products on May 15, 2014 at the NOAA, National Weather Service Headquarters, Silver Spring, Maryland. The workshop was in response to a request from the Advisory Committee on Water Information (ACWI) to prepare a detailed proposal identifying needed extreme storm products for the nation. The requested proposal aims to incorporate the needs of the Federal and State agencies for assessing extreme storm events, and the resources needed to satisfy those identified agencies' needs. The workshop was developed by the ESEWG over a six month period, and in consultation with the Subcommittee on Hydrology (SOH) leadership. Thomas Nicholson, ESEWG Chair and U.S. NRC representative to the SOH organized the workshop.

As directed by the ACWI secretariat, the workshop was open to the public. Victor Hom, SOH Chair and NOAA/NWS representative to SOH was the workshop host. Victoria Sankovich-Bahls, U.S. Bureau of Reclamation was the workshop facilitator. Robert Mason, SOH Vice-Chair and U.S. Geological Survey representative to SOH was also present. Mark Perry, Dam Safety Engineer, State of Colorado led the discussion of the State dam safety officials on their current application of extreme precipitation data and information from their States' perspective. The workshop agenda and participant list are included as attachments.

The workshop objective was to clearly define extreme storm products that are needed for deterministic and risk-informed infrastructure decision making by State and Federal agencies, now and in the future. In meetings prior to the workshop, the ESEWG had discussed a range of product needs: primarily, updating the Hydrometeorological Report (HMR) series which provide estimates of Probable Maximum Precipitation (PMP); completing NOAA Atlas 14 which provides precipitation frequency estimates; further developing and completing a national storm catalogue which provides detailed maps of precipitation distribution over a watershed, and meteorological analysis for historic storms that produced rainfall likely to influence estimates of PMP.

Questionnaires

To facilitate the workshop objective, the ESEWG prepared and sent to the SOH leadership, two questionnaires, one for the Federal Agencies (attachment #3); and one for the State agencies involved in dam safety assessments (attachment #4). Victor Hom and Robert Mason sent the questionnaires to all of the Federal agencies on the SOH, and to the State agencies identified by the Interagency Committee on Dam Safety (ICODS) and National Dam Safety Review Board (NDSRB). Victor Hom and Tom Nicholson, Chair, ESEWG had earlier met with and presented to the ICODS and NDSRB members on April 24, 2014 at their quarterly meeting, to inform them of the planned ESEWG workshop and questionnaires to be circulated prior to the workshop. These questionnaires were developed earlier by the ESEWG members through many teleconferences, along with a review of the Federal and State surveys in Appendix D of FEMA's "Summary of Existing Guidelines for Hydrologic Safety of Dams," in FEMA report P-919 issued in July 2012.

The Federal questionnaire (see attachment #3) provided a preamble to inform the Federal agencies as to the reason for the questionnaire, and the utility of its responses in developing the proposal requested by ACWI. The preamble states:

> "Extreme storm hydrometeorology studies impact extreme flood estimates and assessments for dams, nuclear power plants, levees, and other high-hazard structures within the United States. Additionally, environmental impacts from extreme storm events

> are of increasing concern. The Extreme Storm Events Work Group is responsible for reviewing and improving methodologies and data collection techniques used to develop design precipitation estimates of large storm events up to and including the Probable Maximum Precipitation. The charter for the Work Group states that it will develop a detailed scope of work/plan of study and determine the necessary funding requirements to update the Catalog of Extreme Storms and Hydrometeorological Reports (HMRs). The Work Group is also tasked with developing a list of individual Federal Agency extreme storm product needs. From ongoing discussions and recent advances to probabilistic methodologies for risk-assessment, it is evident that updates to the Catalog of Extreme Storms and Hydrometeorological Reports may not fully address the national needs. This questionnaire asks each Agency to critically evaluate their views, methods, data sources, tools, etc. regarding extreme storm events and to identify any needs and/or gaps in extreme storm event information. In a Writing Workshop scheduled for later this year, the answers to the questionnaires will be synthesized to define extreme storm product(s) that are needed for deterministic and risk-informed infrastructure design. The product(s) and corresponding schedule(s) and cost(s) will be presented in a proposal to ACWI-SOH."

For example, the Federal questionnaire requested the responder to:

> "Discuss your agency methods and extreme precipitation needs for decision making, assessments, and designs (extreme precipitation is defined as those events with a return period of 1,000-years or greater, up to and including PMP):
>
> a. What extreme precipitation data do you use in your decisions?
>
> b. How is this extreme precipitation data used?
>
> c. What is the scale and resolution of this data (regional, site-specific, watershed-specific)?
>
> d. What is the spatial extent to which this data is applied?
>
> e. Would it be beneficial if this data were updated? And why is that?
>
> f. What decisions are made by utilizing this data? Discuss your agency methods and extreme precipitation needs for decision making, assessments, and designs (extreme precipitation is defined as those events with a return period of 1,000-years or greater, up to and including PMP)."

These and other questions set the focus and content of the Federal agencies' responses which was reflected in their presentations at the workshop.

Similarly, the State questionnaire (attachment #4) provided a preamble and list of questions to the State dam safety officials to learn of their needs for extreme storm information and analysis. This information was discussed in the afternoon's panel discussion by the State dam safety officials lead by Mark Perry.

Workshop Presentations

Victor Hom's opening remarks identified the mission of the SOH and the history of the ESEWG. He described the ESEWG charter (http://acwi.gov/hydrology/extreme-storm/ESEWG_Charge_SOW_final_24July2008.pdf) and the reason for the workshop.

He mentioned that the overall purpose of the Extreme Storm Events Work Group is to coordinate studies and databases for reviewing and improving methodologies and data collection techniques used to develop design precipitation estimates of large storm events up to and including the Probable Maximum Precipitation (PMP).

As stated in the ESEWG Charter, ACWI has charged the Work Group to develop a detailed scope of work/plan of study, and determine the necessary funding requirements to update the Catalog of Extreme Storms and Hydrometeorological Reports (HMR) for estimating PMP.

Victor also referenced the recommendations that came out of ***the Workshop on Probabilistic Flood Hazard Assessment*** (proceedings posted at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/conference/cp0302/) which was supported by many of the SOH agencies. These recommendations were:

- Explore the use of "Expert Assessments (Elicitation)" to formulate flooding scenarios, estimate modeling parameters;
- Work cooperatively with other Federal Agencies to develop PFHA strategies for coastal storm surges and riverine flooding at the site-specific and watershed scales;
- Investigate available hydrometeorological databases and analysis methods related to NOAA Atlas 14 and the USACE Storm Catalogue for use in PFHA; and
- Review U.S. and international technical approaches to identify strategies to fill information gaps in PFHA (e.g., paleofloods, paleo-oceanography, dam and levee failure analyses).

Victoria Sankovich-Bahls provided an overview of the workshop objective, goal, program and expected products to be discussed. She identified the general areas of mutual interest as:

- Extreme Storms Catalog
- Probabilistic Flood Hazard Approaches
- Probable Maximum Precipitation
- Site-Specific Guidelines for Estimating PMP

The workshop activity is to refine these general areas into the following tasks:

- Determine the product needs and requirements for a National Catalog of Extreme Storms;
- Determine a path forward for updating Hydrometeorological Reports (HMR);
- Develop recommendations and gather requirements for site-specific PMPs; and
- Develop national recommended guidelines for Probabilistic Flood Hazard Assessment in design, analysis, or safety evaluations.

Each Federal agency presenter presented their responses to the Federal questionnaire with a focus on current application of extreme precipitation data and information.

1. Natural Resources Conservation Service (NRCS)

The first presenter was Claudia Hoeft, National Hydraulic Engineer, NRCS. She provided a short history of NRCS's predecessor, the Soil Conservation Service (SCS). The SCS was formed in 1935 to address soil erosion due to severe drought conditions. To stabilize the soil during the "Dust Bowl" years, SCS encouraged development of conservation plans. These plans would assist in addressing many natural resources problems including soil erosion; flooding; animal waste management; wetland and wildlife habitat preservation, and restoration and management. In the 1940s and 50s, the SCS, now the NRCS, assisted in the design and construction of over 11,000 dams to reduce flooding and minimize erosion. The peak of dam construction was in 1963. 605 dams reached their 50 year life in 2013. Victor Mockus, an early hydrologist working for the Civilian Conservation Corps and SCS, was known as the father of SCS hydrology. He focused on rainfall and runoff issues.

In 1956, ARS and SCS, began to develop standardized hydrologic procedures for small, ungaged, agricultural watersheds which led to the publication of Section 4 of the National Engineering Handbook in 1964 (now the National Engineering Handbook, Part 630 - http://directives.sc.egov.usda.gov/viewDirective.aspx?hid=21422). The concepts in the National Engineering Handbook, Part 630 included: (1) a system for grouping soils according to infiltration capacity; (2) a standard system of determining runoff potential of watersheds according to soils and land use (Runoff Curve Number procedure); and (3) use of a dimensionless unit hydrograph in estimation of peak rates of runoff. Victor Mockus, who started his career with the CCC is responsible for the development, or at least the refinement of many of the NRCS hydrology procedures in use today. While the runoff curve number procedure in particular has received a lot of scrutiny and review by the scientific and academic communities, it seems to be withstanding the test of time and is still probably the most widely used procedure for making estimates of runoff volume. Today, NRCS maintains a number of documents which have become standard hydrology references world-wide.

Approximately 160 NRCS conservation practice standards provide information on and where the NRCS practices are applied. The NRCS standards set forth the minimum quality criteria including hydrologic criteria where applicable. (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps/)

For example, the minimum auxiliary spillway capacity for POND (Conservation Practice Standard Number 378) is provided in the table below:

Drainage area (acre)	Effective height of dam[1] (ft)	Storage (acre-ft)	Minimum design storm[2]	
			Frequency (Years)	Minimum duration (hours)
20 or less	20 or less	< 50	10	24
20 or less	> 20	< 50	25	24
> 20		< 50	25	24
All others			50	24

NRCS Technical Release (TR) 60 “Earth Dams and Reservoirs” issued in July 2005 sets their policy on design of dams. TR60 describes design procedures and provides minimum requirements for planning and designing earth dams and associated spillways. It is essential that these dams be constructed with uniform criteria to ensure consistent performance. TR-60 specifies the PMP event to generate freeboard hydrograph (FBH) for High Hazard Dams; to analyze the integrity, or erosion resistance, of earthen materials in auxiliary spillway; and to set top of dam elevation.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=24937.wba

The TR-60 Minimum Auxiliary Spillway Hydrologic Criteria is provided in the table below:

Class of Dam	Product of storage x effective height	Existing or planned upstream dams	Precipitation data for [1]	
			Auxiliary spillway hydrograph	Freeboard hydrograph
Low[2]	less than 30,000	none	P_{100}	$P_{100} + 0.12(PMP - P_{100})$
	greater than 30,000		$P_{100} + 0.06(PMP - P_{100})$	$P_{100} + 0.26(PMP - P_{100})$
	all	any[3]	$P_{100} + 0.12(PMP - P_{100})$	$P_{100} + 0.40(PMP - P_{100})$
Significant	all	none or any	$P_{100} + 0.12(PMP - P_{100})$	$P_{100} + 0.40(PMP - P_{100})$
High	all	none or any	$P_{100} + 0.26(PMP - P_{100})$	PMP

[1] P_{100} = Precipitation for 100-year return Period. PMP = Probable maximum precipitation
[2] Dams involving industrial or municipal water are to use minimum criteria equivalent to that of Significant Hazard Class.
[3] Applies when the upstream dam is located so that its failure could endanger the lower dam

Claudia stated that there is a need for updated/current PMP (and other) rainfall data to address: (1) flood hazard and other studies that rely upon hydrologic analyses; (2) project design; (3) the need to use the most current and available information; (4) climate change considerations; (5) questions from project sponsors and others about why NRCS may not be using the must currently available data; and (6) questions about using Special Studies developed outside the Federal realm.

NRCS issues and concerns are: (1) NRCS is a technical Agency providing assistance to landowners; (2) NRCS is a consumer of rainfall data, including PMP studies, and (3) Very few personnel within NRCS have knowledge or ability to develop or evaluate PMP studies.

NRCS Primary Needs are: (1) Updated PMP estimates; (2) Access to studies and accompanying background information (such as historical extreme storms databases); and (3) access to and support in using tools developed by other Federal Agencies (HEC-MetVue); and (4) clear guidance on development of regional and site-specific studies to ensure consistency of studies developed outside of the Federal realm.

2. U.S. Geological Survey (USGS)

Robert Mason, USGS discussed the uses of extreme precipitation estimates by the USGS. The USGS operates and maintains over 8,000 streamgages across the U.S. There are 24,000 sites with historical records (annual peaks dating to 1700's). The USGS also deploys temporary gages and sensors as part of its observational system. To provide effective situational awareness to the public, government agencies, and industry, the USGS maintains numerous online Websites: WaterWatch, WaterAlert, WaterNow, Flood Inundation Mapping (FIM), and many contributions to the missions of other agencies. The USGS also conducts studies and surveys for fundamental understanding of hydrology through research and interpretation, and methods development. The USGS also provides regional characterization and regionalization data and information through StreamStats.

Robert explained that regionalization was a systematic process of explaining flood-frequency characteristics (1-percent chance flood, 7Q10, etc.) by linking them to basin characteristics through regression. The regression analysis was a statistical analysis that defines a relationship between a dependent variable and one or more explanatory variables. An example dependent variable would be the 1-percent chance flood. The example explanatory variables include: drainage area, mean annual precipitation, and main channel slope. This analysis is used to estimate flows for ungaged sites. The potential errors are defined when applied within known bounds.

The Regression Equation is:

$Q_{100} = 5.\mathbf{39DA}^{\mathbf{0.874}}(E/1000)^{\mathbf{-1.13}}P^{\mathbf{1.18}}$

where:

Q_{100} is the 100-year flood, in cubic feet per second

DA is Drainage Area, in square miles

E is mean basin elevation, in feet

P is mean annual precipitation, in inches

Precipitation is strong explanatory variable in only 40 regression equations (out of about 5,000). It is used only in 18 States, generally for a 24-hour duration with 2, 25, 50, 100-year Recurrence Intervals in approximately equal frequency.

3. Federal Energy Regulatory Commission (FERC)

Ken Fearon, FERC, discussed FERC's application, need and support of ESEWG products. FERC has responsibility for regulating non-federal dams with hydroelectric power plants. FERC reviews the design, construction, operation, maintenance, use, repair, or modification of any project works which are subject to FERC jurisdiction under the supervision of the Regional Engineer or any other authorized Commission representative for the purpose of:

(i) Achieving or protecting the safety, stability, and integrity of the project works or the ability of any project work to function safely for its intended purposes, including navigation, water power development, or other beneficial public uses; or

(ii) Otherwise protecting life, health, or property.

FERC is responsible for the safety and adequacy of 2,523 non-Federal, jurisdictional dams (i.e., 803 high-hazard potential dams, 176 significant-hazard potential dams and 1,544 low-hazard potential dams). The Commission, through its dam safety program requires jurisdictional dams to have adequate spillway capacity to pass the project's Inflow Design Flood (IDF).

> The IDF is *the flood flow above which the incremental increase in flow and water surface elevation due to a failure of a dam or other water impounding structure is no longer considered to present an additional, unacceptable threat to downstream life or property*.

Spillway adequacy determinations are based on the results of an IDF, Probable Maximum Flood (PMF), and site-specific PMP studies. The IDF is selected based on hydraulic computer modeling and uses an incremental hazard potential evaluation to determine the consequences of dam failure. The PMF is considered the upper limit of an IDF analysis.

The PMF is determined using the guidance in Chapter 8 of FERC's Engineering Guidelines (see: http://www.ferc.gov/industries/hydropower/safety/guidelines/eng-guide/chap8.pdf), and utilizes the appropriate Hydrometeoroglical Reports (HMRs) to estimate the PMP. The general and local PMP values chosen are those for the 6, 24 and 72-hour durations. In some cases, a licensee may request to perform an optional site-specific PMP study to determine the PMP. These studies may be approved when refinement of PMP values in HMR is considered beneficial, particularly for areas considered less reliable due to orographic effects (also known as the *Stippled Region*); or when new extreme storm data is available and was not included in the existing HMR.

FERC requirements for site-specific PMP studies are: (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) approval of the BOC by FERC; and (4) FERC representatives must be involved throughout the study and BOC process. Several site specific PMP studies have been performed at FERC jurisdictional projects including but not limited to the following: Deerfield-Harriman Dam, 1987; Upper and Middle Dams, 2002; Brassua Dam, 2012; and Santa Felicia, 2012. In addition, a series of state-wide studies have been completed, including Nebraska, 2011; Ohio, 2012; and Arizona, 2013 with additional state studies underway (Wyoming and Virginia),

FERC's site-specific studies methodologies follow procedures outlined in the HMR's with updated procedures including: (1) updated rainfall analysis of recent extreme events; (2) use of Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model; (3) use of average dew points; (4) use of Sea Surface Temperatures; (5) use of the Storm Precipitation Analysis System (SPAS); (5) use of Next Generation Weather Radar (NEXRAD); (6) consideration of orographic influences; and (7) use of GIS tools.

Additional extreme storm resources used by FERC include: (1) NOAA Atlas 2 is used for 100-yr frequency estimates for those areas not covered by NOAA Atlas 14; (2) NOAA Atlas 14 is used for 100-yr and 1,000-yr frequency estimates; and (3) State-wide site-specific studies provide updated storm information and methodology.

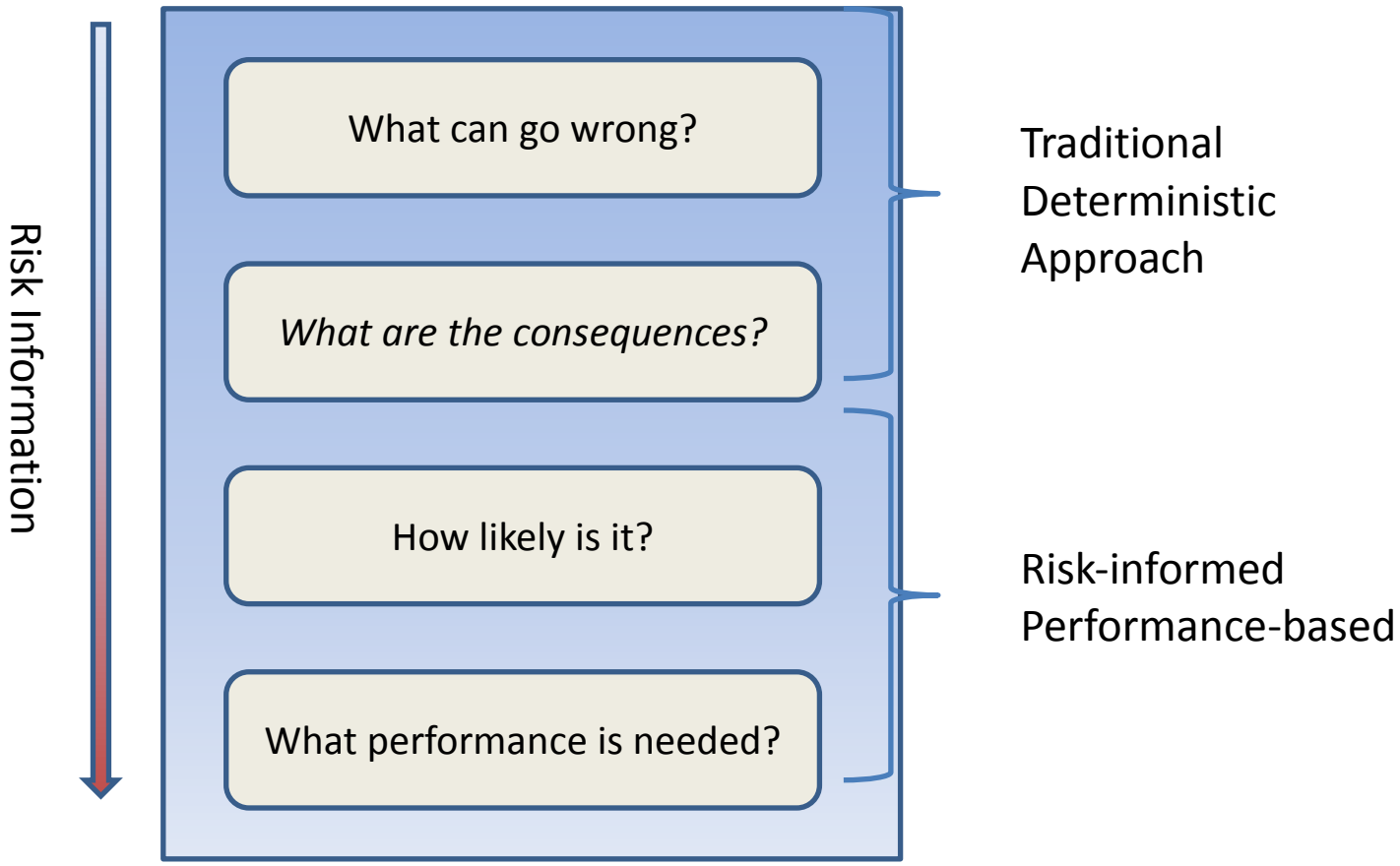
FERC identified the benefits of updated HMR's as: (1) inclusion of additional storm records; (2) Inclusion of advancements in science and technology; (3) nationally consistent application of PMP methodology; (4) uniform application by HMR users; and (5) reduced agency and dam owner costs.

Improvements sought by FERC are: (1) an updated storm catalog presently being developed by USACE; (2) reduced subjectivity in procedures; (3) transparent and consistent procedures; (4) an ability to assess large basin areas; (5) provide seasonal guidance; (6) consideration of snowmelt; (7) assess orographic effects; (8) provide full documentation; (9) estimate frequency of PMP values for use in risk analyses; and (10) development of more consistent methodologies. Although FERC has no budget provisions for funding research, FERC could provide r technical and peer review assistance.

Thus the Federal Energy Regulatory Commission has an interest in any coordinated effort to review extreme storm data and update HMR's for use in extreme storm development. Currently the engineering profession is developing PMF values for extreme storm events based on outdated storm information. The Commission supports the efforts of the Extreme Storm Events Work Group to promote the cooperation and coordination among agencies to improve methodologies and data collection techniques to develop estimates of large storm events up to and including the Probable Maximum Precipitation (PMP).

4. U.S. Nuclear Regulatory Commission (NRC)

Joseph Kanney, NRC discussed NRC's goal of developing and implementing risk-informed and performance-based regulation. Dr. Kanney used the following diagram to illustrate the relationship between the traditional deterministic approach and the increased value of risk-informed, performance-based regulations.



NRC regulations require that structures, systems, and components (SSCs) of nuclear facilities important to safety be designed to withstand the effects of natural phenomena (e.g., earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches) without loss of capability to perform their safety functions. The design bases for these SSCs must reflect: (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated; (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and (3) the importance of the safety functions to be performed.

The types of facilities/sites for which extreme precipitation estimates are needed to support flood hazard assessments covers a wide range (e.g., nuclear power plant sites and designs, fuel cycle facilities, interim spent fuel storage facilities, nuclear waste repositories, watersheds in which nuclear facilities are located, reservoirs and dams upstream of nuclear facilities, and tailings dams).

Analysis of flooding hazards submitted for licensing of new facilities is currently almost entirely deterministic, commonly applying a progressive refinement of conservative assumptions referred to as the Hierarchical Hazard Assessment (HHA) approach. Concepts such as Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) are typically used. NRC regulatory guidance and standard review plans specifically call for use of PMP estimates developed using NWS Hydrometeorological Reports (HMRs).

For new reactor licensing using the HHA approach, PMPs from the HMRs used to construct extreme flood scenarios for two common scenarios: (1) application of the PMF for riverine flooding; and (2) local intense precipitation (LIP) for evaluation of site drainage. PMP values from the HMRs are also used to determine design basis loads on structures due to rain, ice and snow events. The 48-hour cool season PMP is typically used for estimating snow/ice loads. HMR 51 and 52 are used most often HMR 49, 53, 55A, 57 and 59 have also been used. Recently NRC licensees have submitted “site-specific” PMP analyses performed under contract by private consultants, which pose a challenge for NRC staff reviewers.

Oversight of operating nuclear facilities uses more an explicitly risk-informed approach known as the significance determination process (SDP). SDP is used for decision-making in light of new information that comes up after initial licensing. SDP activities have often included attempts to quantify risks due to natural hazards such as extreme precipitation and flooding. NOAA Atlas 14 and its precursor, Weather Service Technical Report 40, have been used to review frequency estimates of extreme precipitation at the facility site. With respect to flooding hazards, the SDP focus is on estimating the frequency of an initiating event. The initiating event frequency is combined with system fragility information to obtain risk insights (often qualitative, and not rigorous).

In summary, the decisions being made that rely on extreme precipitation estimates involve licensing of proposed projects and oversight of operating facilities. Licensing decisions for proposed projects focus on the suitability of specific sites and the design basis of facilities at those sites (e.g., design basis flood estimates, and design loads on structures due to both liquid and solid precipitation). For the oversight of operating facilities under the SDP process, decisions involve assigning a significance/severity to identified deficiencies. Depending on the identified severity, orders to modify facilities can be issued and fines can be assessed.

Following the earthquake and severe tsunamis flooding of the Fukushima Daiichi nuclear plants in Japan in March 2011, NRC issued a “Request for Information” instructing all licensees of

operating commercial nuclear power plants to develop and report updated earthquake and flood risk information for comparison against original licensing information. For sites where flood elevations and associated effects exceed the original licensing basis, licensees are expected to perform an integrated assessment to evaluate their flood protection features and procedures, as well as any flood mitigation strategies. The flood hazard reevaluations and integrated assessments will form the basis for regulatory decisions. The potential decisions range from changes in regulations regarding hazard assessment, protection and mitigation to modification of individual licenses.

For the requested Post-Fukushima flood re-evaluations, licensees and their contractors use PMP values from the HMRs in some cases and in others, rely on site-specific PMPs. During this review period, some licensees are actively revising protection and mitigation measures that depend in part on the HMR's PMP estimates. Licensees are interested in using probabilistic methods to support integrated assessments.

Dr. Kanney stated that an "update" to the HMRs, and particularly HMR51, which applies to the majority of NRC-licensed facility locations would be beneficial for NRC's current deterministic methods. These updates should include a review of potential storm model improvements that could be used to improve estimates. Simply plugging new data into an old method without considering adjustments to that method based on decades of experience since the last update of the HMR 51-52, for example, doesn't seem appropriate. The updating should address limitations on basin size and the questionable applicability in the "stippled" regions affected by orographic effects. Other recommendations include; (1) more focus on the probabilities associated with PMP estimates (critical component to risk informed decision making); (2) give attention to cool season precipitation (useful for determining design basis snow and ice loads on structures); (3) provide guidance with regard to site-specific PMP values (an increasing regulatory challenge); and (4) provide online digital product similar to the NOAA Atlas 14 Precipitation Frequency Data Server.

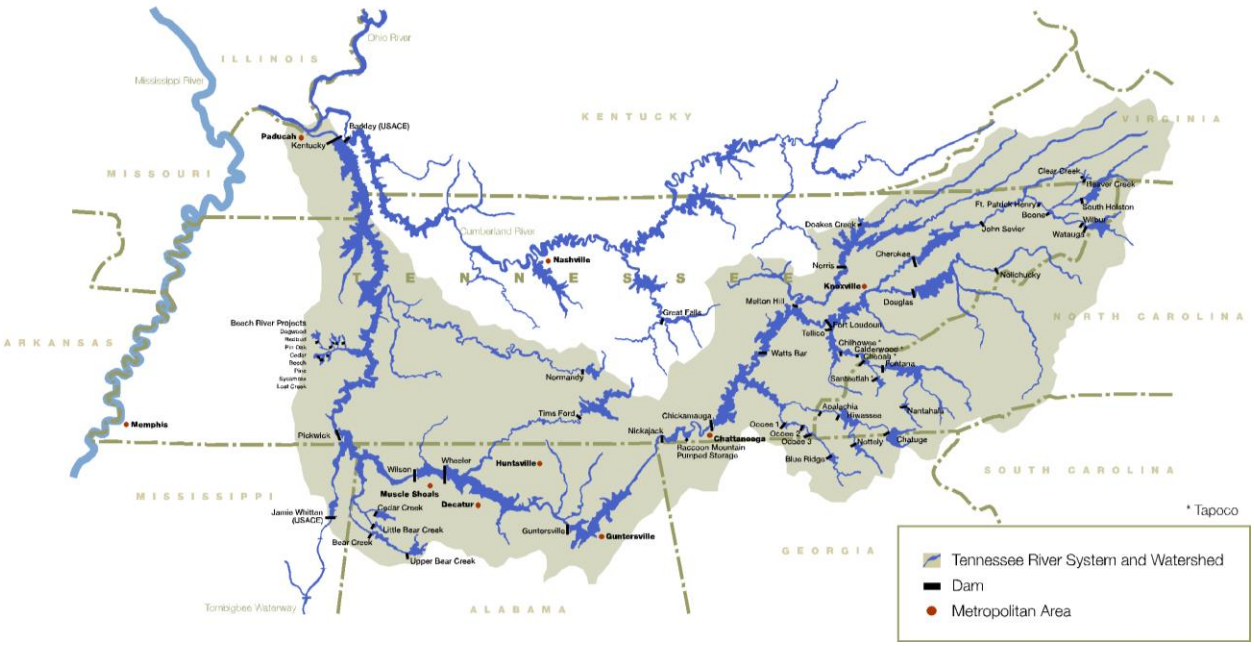
With respect to NOAA Atlas 14, NRC currently makes limited use of the precipitation frequency estimates it provides in safety oversight of operating commercial nuclear facilities. Concerning extrapolation of NOAA Atlas 14 estimates beyond the currently available average return intervals of 1,000 years, they are performed on a limited basis and as a risk-informed exercise to evaluate information submitted to the NRC, since multiple licensees have performed such extrapolations on NOAA Atlas 14 and other hydrologic databases, as a way to respond to NRC regulatory activities. NRC staff is not necessarily interested in pursuing these limited credibility extrapolations, but rather responding to requests to consider risk insights based on submitted information. NRC staff is aware of the limited technical justification for doing so and therefore uses significant caution in these cases. In order for NOAA Atlas 14 to be of broader use to NRC staff, it would need to address more useful return periods usually in excess of 1,000 years (i.e., up to and beyond 1,000,000 years) of interest to the NRC.

Research efforts are being implemented to develop probabilistic flood hazard assessment (PFHA) technical basis to support risk-informed design basis flood estimation guidance.

5. Tennessee Valley Authority (TVA)

Mike Eiffe, TVA portrayed the Tennessee River system and watershed to include its numerous dams and reservoirs. He identified the HMRs and special study reports used by TVA. The list included: (1) HMR-41 issued June 1965; 6- to 72-hour TVA and PMP estimates for two watersheds above Chattanooga; (2) HMR-47 issued May 1973; 6- to 72-hour TVA and PMP estimates for two watersheds below major tributary dams; (3) Special study issued in 1979 and

revised in 1983; 6- to 72-hour PMP estimates for Cherokee Dam watershed (3428 mi2); (4) Special study issued in 1984; 6- to 72-hour PMP estimates for Douglas Dam watershed (4541 mi2); (5) HMR-56 issued in October 1986; 1- to 72-hour TVA and PMP estimates for TN River basins < 3,000 mi2; which replaced HMR-45 issued in May 1969.



Tennessee River watershed showing tributaries, dams and reservoirs locations.

The primary usage of HMRs at TVA is to provide the design rainfall basis for PMF evaluations at TVA's high hazard dams and nuclear power plants. The HMRs and special study reports provide the design rainfall basis for MPF evaluations at TVA's significant and low hazard dams. Mike Eiffe noted that the PMF and MPF probabilities are not known.

An important challenge for TVA is the reduced staffing levels of hydrologists over the years. In September 1979, the Flood Control Branch had 15 staff in hydrology, 20 staff in hydraulics and 15 staff in floodplain management. Today, there is only 4 staff in river management to cover the same topics as in 1979. These staffing changes were due to reductions in the operations and management budget.

The current ESEWG-related work at TVA includes: (1) updating PMP and TVA Precipitation Estimates by TVA's contractor, Applied Weather Associates which is on schedule and within budget. This effort is scheduled for completion in calendar year 2014, and provides input for the assessment of 27 dams involving five nuclear power plant locations. Work is also underway for the development of basin-average precipitation frequency relationships by TVA's contractor, Riverside Technology Inc. Phase 1 of this work is on schedule and within budget, whereas, Phases 2 and 3 have not yet been funded. This work is likely to be completed in fiscal year 2015 depending upon funding levels. The work targets 10 watersheds in the Tennessee River system.

Recent studies involve basin-averaged rainfall estimates using observed precipitation from the Lower Mississippi River Forecast Center's (LMRFC) multi-sensor precipitation estimates (MPE), National Severe Storm Laboratory's (NSSL) next generation (Q2) quantitative precipitation estimation (QPE) product; and climatology-weighted gage interpolation. This study will provide forecasted precipitation using the LMRFC quantitative precipitation forecasts (QPF), and the high-performance computing (HPC) products at the 5% and 95% levels.

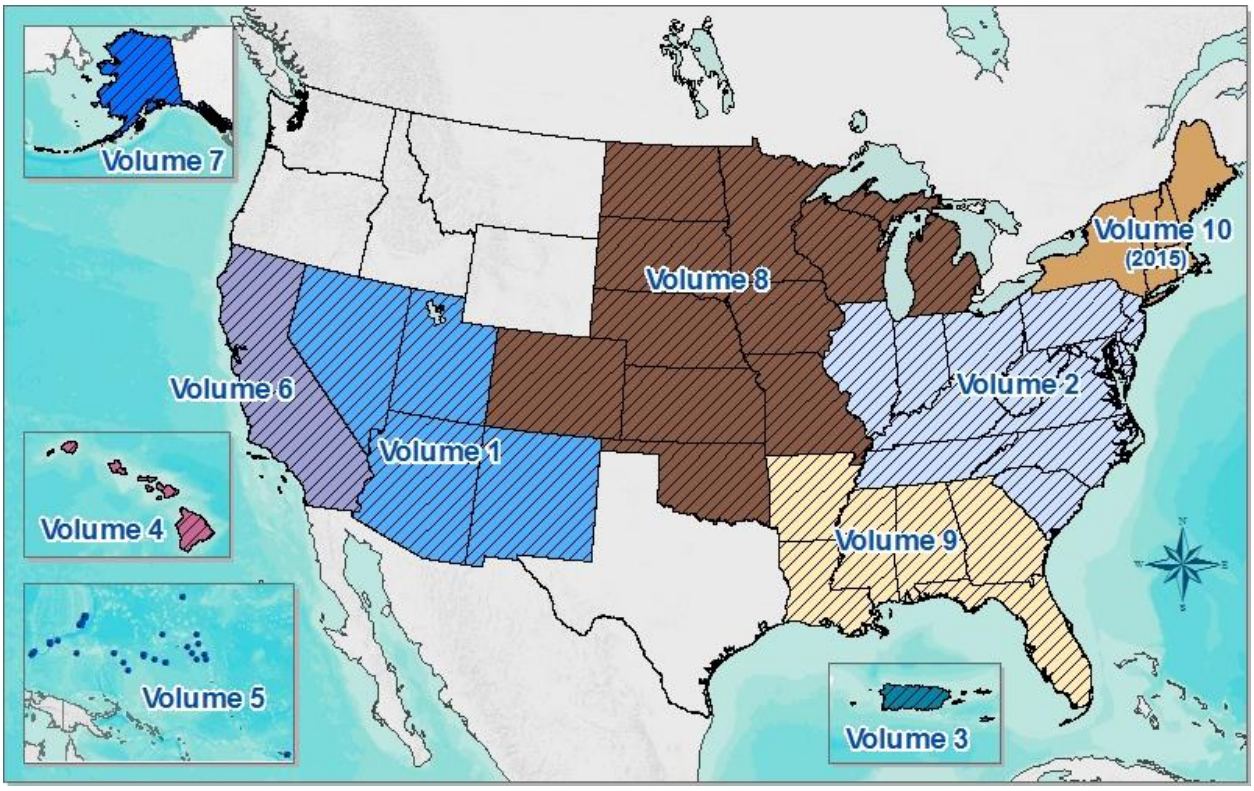
TVA is developing and utilizing new runoff models in conjunction with the LMRFC. These models include the Sacramento – Soil Moisture Accounting (SAC-SMA) runoff model, and the Lag and K (Lag/K) routing model. The earlier-mentioned precipitation studies will provide input to these models for assessing floods. For hydraulics modeling, TVA is applying the HEC-RAS model (version for major rivers involving dam break analysis) to the 1900 miles of river courses of the Tennessee River Basin which includes 28 dams. TVA plans to calibrate the model across a range of flows, and will incorporate the calibrated model into their river management operations.

TVA's short term goals include: (1) complete the PMP update study; (2) revise PMF estimation as required; (3) complete the precipitation frequency study; (4) complete the SAC-SMA model calibration; (5) complete the HEC-RAS model calibration; and (6) begin development of the Risk-Informed Decision Making (RIDM) simulation models.

6. NOAA/National Weather Service (NWS)

Geoffrey Bonnin, NWS, discussed lessons learned from the development, publication and application of NOAA Atlas 14 (http://www.nws.noaa.gov/oh/hdsc/index.html). NOAA Atlas 14 begun in 2000 was developed by the NWS on behalf of the Federal Government to provide precipitation frequency (PF) estimates for various durations (less than 1 hour; between 1 and 24 hours; and beyond 24 hours through 60 days) for various areas of the U.S. These estimates are published as volumes in the NOAA Atlas 14 series by States/Territory.

The status of the published volumes (at the time of the workshop) (see: http://www.nws.noaa.gov/oh/hdsc/currentpf.htm) is provided in the map below:



Along with NOAA Atlas 14, the NWS has developed and maintained a "Precipitation Frequency Data Server" (PFDS) (see http://hdsc.nws.noaa.gov/hdsc/pfds/index.html) which is web-based interface developed to deliver NOAA Atlas 14 precipitation frequency estimates and associated information. Upon clicking a State on the map above or selecting a state name from the drop-down menu, an interactive map of that state will be displayed. From there, a user can identify a location for which precipitation frequency estimates are needed.

Estimates and their confidence intervals can be displayed directly as tables or graphs via separate tabs. Links to supplementary information (such as ASCII grids of estimates, associated probabilistic temporal distributions of heavy rainfall, time series data at observation sites, cartographic maps, extensive documentation, etc.) can also be found.

NOAA Atlas 14 is a single source which supersedes various publications developed since late 1940s including earlier Technical Papers, Technical Memoranda and special papers which contained the superseded information.

The first lesson learned was that funding is the controlling factor. NWS had to line-up reimbursable funding from various sources such as Federal, State and local government agencies to develop the piecemeal projects (e.g., Volumes 1, 2, 3, etc.). This piecemeal funding caused great difficulties. The same science was developed, and applied area by area with no guarantee of achieving full coverage for the U.S. NWS applied state-of-the art methodologies in preparing NOAA Atlas 14 and provided information (such as confidence limits) that was not provided in previous publications. The primary changes in methodology involved new statistical techniques, improved methods for spatial interpolation between observing locations, new approaches to data quality control, and a much larger set of historical observations, both spatially and temporally and from a variety of new data sources. The funding approach

necessitated Volumes based on State boundaries rather than watersheds or geographic climate regimes. The analysis for each Volume was extended beyond each Volume's geographic domain, so that overlapping analyses between adjoining Volumes could be used to provide continuity at Volume boundaries.

The second lesson learned was that assembling funds from many sources was tricky in that it was difficult to identify a specific, separable work package for each funding source. To work through this challenge, funding agencies often collaborated through existing formal mechanisms so that a single Memorandum of Understanding and project plan could be developed and executed. For example, the Ohio River Basin Commission provided a vehicle for collaboration on Volume 2 for the Ohio River Basin and surrounding States. The Federal Highway Administration's Pooled Fund Program was used for combining resources for Volumes 8 through 10.

The third lesson learned focused on project management. There needed to be a critical mass of management expertise dedicated to that role in the long term to ensure completion in accordance with the vision. In addition, the production of the precipitation frequency estimates involved combining skills from a variety of disciplines. As a result, project management needed a proper (multi-disciplinary) grasp of all aspects of the project. Project management also needed the usual attributes of properly understanding the users, the products they rely on and the different communities being served.

The fourth lesson learned focused on technical capabilities. Similar to project management, there needed to be a critical mass of technical expertise, namely: hydrology, meteorology, statistics, software development, configuration management, and quality control. The people providing the expertise needed to be dedicated to their roles for the duration of each project in order to meet project schedules and quality. Again, these experts had to have a proper grasp of the product(s), the users and the communities being served.

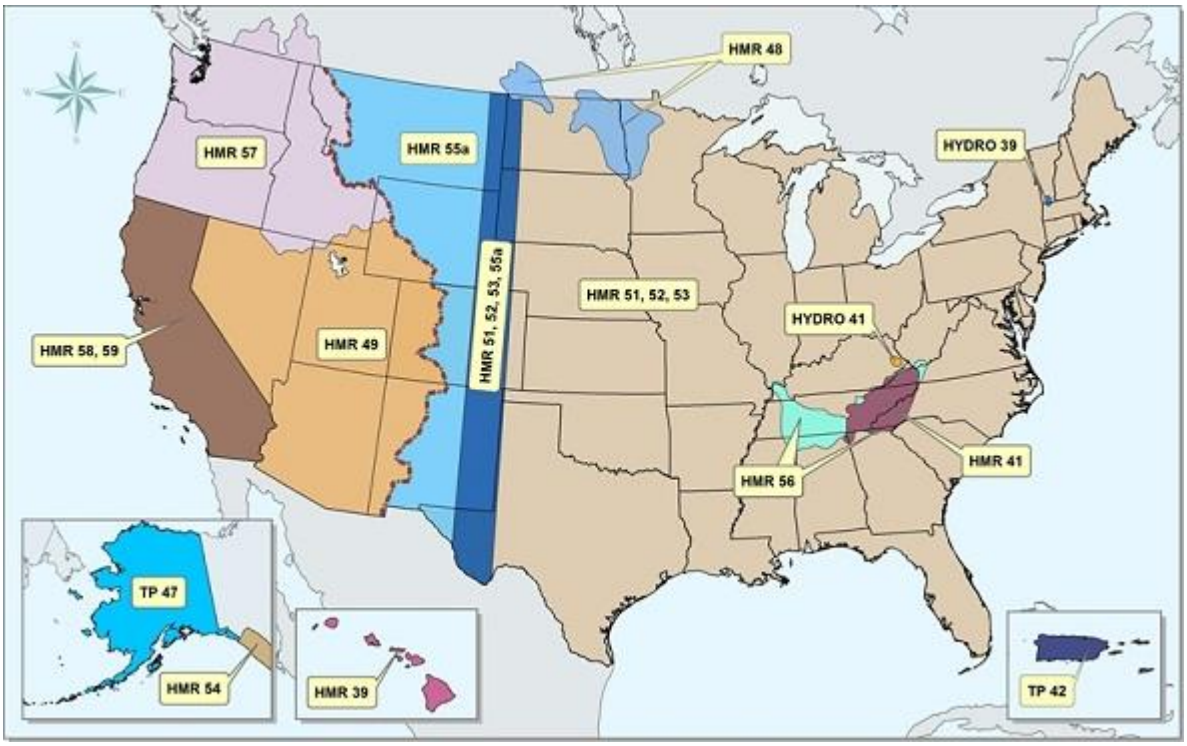
Mr. Bonnin also discussed the historical development and status of NWS's Hydrometeorological Reports (HMRs) (http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html).

The following table provides a listing of the HMRs with a document link, title, date and electronic document size.

Document link	Title	Date	Size (MB)
Hydrometeorological Report No. 39	Probable Maximum Precipitation in the Hawaiian Islands	1963	3.4
Hydrometeorological Report No. 41	Probable Maximum and TVA Precipitation over the Tennessee River Basin above Chattanooga	1965	5.7
Hydrometeorological Report No. 46	Probable Maximum Precipitation, Mekong River Basin	1970	16.2

Hydrometeorological Report No. 48	Probable Maximum Precipitation and Snowmelt Criteria For Red River of the North Above Pembina, and Souris River Above Minot, North Dakota	1973	1.6
Hydrometeorological Report No. 49	Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages	1977	6.2
Hydrometeorological Report No. 51	Probable Maximum Precipitation Estimates, United States East of the 105th Meridian Digitized maps	1978	3.5
Hydrometeorological Report No. 52	Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian	1982	7.8
Hydrometeorological Report No. 53	Seasonal Variation of 10-Square-Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian	1980	3.3
Hydrometeorological Report No. 54	Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska	1983	4.6
Hydrometeorological Report No. 55A	Probable Maximum Precipitation Estimates - United States Between the Continental Divide and the 103rd Meridian	1988	103.5
Hydrometeorological Report No. 56	Probable Maximum and TVA Precipitation Estimates With Areal Distribution for Tennessee River Drainages Less Than 3,000 Mi^2 in Area	1986	8.5
Hydrometeorological Report No. 57	Probable Maximum Precipitation - Pacific Northwest States. Columbia River (including portions of Canada), Snake River and Pacific Coastal Drainages	1994	28.3
Hydrometeorological Report No. 58	Probable Maximum Precipitation for California - Calculation Procedures	1998	10.9
Hydrometeorological Report No. 59	Probable Maximum Precipitation for California HMR58 and HMR59 shapefiles (2.9 MB)	1999	21.4

NOAA Technical Memorandum NWS HYDRO 39	Probable Maximum Precipitation for the Upper Deerfield River Drainage Massachusetts/Vermont	1984	1.9
NOAA Technical Memorandum NWS HYDRO 41	Probable Maximum Precipitation Estimates for the Drainage Above Dewey Dam, Johns Creek , Kentucky	1985	1.4
Technical Paper No. 42	Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands	1961	4.2
Technical Paper No. 47	Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska	1963	3.1



Regions covered by different NWS HMR documents (as of 2012).

The HMRs do need updating since many of the existing studies are old and some predate current understandings of the causal meteorological processes. The data used in the HMRs are several decades old or older, and need updating to consider recent storm data, and advances in hydrologic, meteorologic, and geospatial analytical techniques.

Geoff suggested new ideas to consider when updating the PMP estimation guidance: should a new form of guidance be developed to include automated estimation tools; should a new web-based publication/delivery mechanism similar to the PFDS for NOAA Atlas be developed? If

this work proceeds, should it provide Annual Exceedance Probabilities (AEP) between those provided in NOAA Atlas 14 and the PMP.

Geoff suggested any new effort should focus on: (1) socialization of the project and the need for appropriate resources among funders and users; (2) major project elements; (3) governance of the activities; (4) funding sources and agreements; and (5) project plans. The socialization and resourcing success path should be to first obtain SOH and ACWI approvals which includes buy-in from the various resource sources. Next, the project must also obtain buy-in directly from each agency through agency approval and resourcing mechanisms. These new efforts also need support from non-Federal stake-holders.

He foresees the first major project element as: (1) update the science starting with literature reviews to help define a well-targeted and time limited research program; then fund grants and in-house research for a period of approximately 2-4 years; consolidate the research findings; and then, synthesize the new approach(es). (2) re-analyze historical storms, probably with new science, and adding relevant rain events not already included. Finally, (3) modernize the Severe Storms Catalog with an understanding of the community's needs for availability, usability and product integrity.

The second major project element is to: (1) define the new products; (2) apply the new methodology with the focus on producing new products while transitioning from research to production; (3) define new publication/delivery mechanism(s) and build and test mechanisms; (4) publish new products; and (5) provide training on the new methodology and products.

With regard to governance and funding issues, first determine who the community is, then develop collaborative governance and funding mechanisms. The project(s) must obtain community acceptance. It is important to build-in opportunities for formal public review and comment. Project plans and accountability should be established and documented. Funding is fundamental to the process. Do not proceed without the prospect of funding success since second chances are rare. The governance needs to realize the need for a long-term commitment, and an understanding how costs will be shared.

The final challenge will be to determine who does the work activities, and what will be the relationship between the separate agency efforts, both current and planned? The project management needs to be integrated and coordinated within established accountability checks. To succeed, it needs strong management to avoid diffusion of responsibility, and community acceptance that requires integrity of the process and results. Geoff thinks it is better to have single project manager through the long-term.

7. U.S. Army Corps of Engineers (USACE)

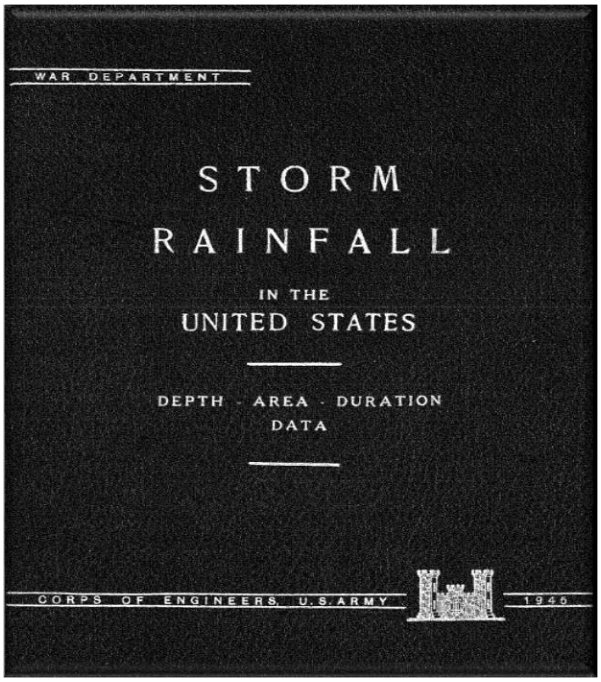
Doug Clemetson, Chief, Hydrology Section, USACE/Omaha District and Aaron Byrd, USACE/ERDC, Vicksburg, MS discussed the work of the USACE's Extreme Storm Team. Doug Clemetson is its Team Leader. The extreme storm data needs for the USACE can be grouped into three principal areas: the dam safety program; the levee safety program; and the developing program for the extreme storm database.

For the dam safety program, the needs center on site-specific PMP studies; Hydrometeorological Reports (HMR's) updates; and the HMR tools. For the levee safety program, the needs are for updating the Standard Project Storm Criteria, and precipitation frequency data derived from NOAA Atlas14 and its predecessors, Technical Paper (TP) 40, and NOAA Atlas 2. Finally, for the extreme storm database program, the needs related to extreme storm data archiving/retrieval; analysis of recent extreme storm events; and linking of the database to the USACE Hydrologic Engineering Center (HEC) models such as HEC-HMS, HEC-MetVue, and other models. Other USACE data needs relate to computation of areal reduction factors (ARF); calibration of various hydrologic models; the Stochastic Extreme Flood Modeling (SEFM); and atmospheric modeling of extreme precipitation.

The current extreme storm applications involve: (1) for the Extreme Storm Database development, use of process radar imagery and digitize the historic isohyetal maps from the HMRs; (2) for the site-specific PMP Studies, studies have been completed on the Moose Creek, Bluestone and Whittier Narrows projects, and studies are in progress for the Martis Creek, Fort Peck, Garrison, and Kajaki projects; (3) the HEC-MetVue Tool is being developed to process storms by developing Depth-Area-Duration (DAD) relationships, isohyetal maps, and gridded precipitation estimates. It will also be used to rotate, transpose and maximize extreme storm data, and link the results to the USACE's Data Storage System (HEC-DSS), and Hydrologic Modeling System (HMS). HMR 51/52 and the HMR55A plugins will be incorporated into the HEC-MetVue tool. The HMR 57 Tool is also used in extreme storm applications. A relatively new aspect is the use of atmospheric modeling to better understand extreme storms.

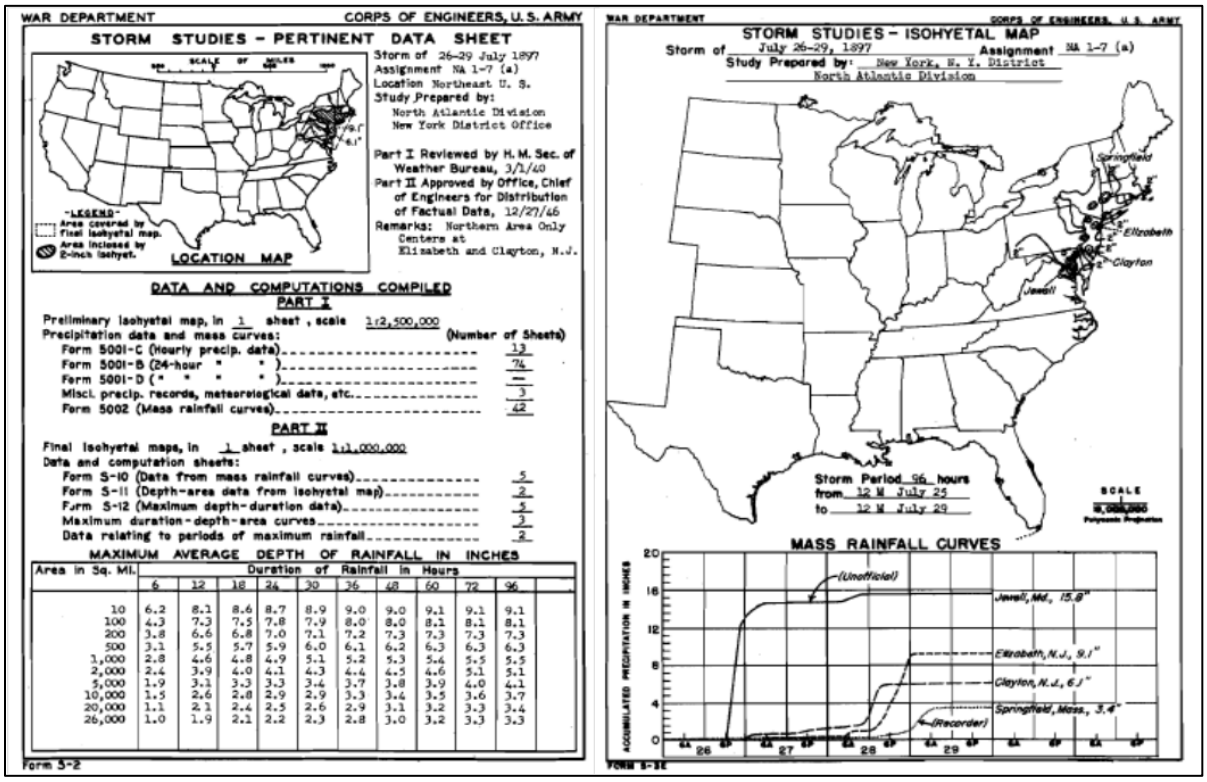
The development of the "Extreme Storm Database" is intended to provide a common database to be shared with all Federal and State agencies, academia, and private consultants. The database will include both historic (e.g., Extreme Storm Catalog and HMR storms) and future extreme storms, depth- area-duration tables, isohyetal maps, mass rainfall curves, meteorological characteristics of the storm event, radar data, and enabling interface with hydrologic models (e.g., HEC-RAS) and tools.

The Extreme Storm Database will incorporate information from the Extreme Storm Catalog developed by the USACE in cooperation with the U.S. Weather Bureau (USWB) and the U.S. Bureau of Reclamation (USBR).



Cover of Extreme Storm Catalog

The catalog consisted of a two-page Pertinent Data Sheet for each of the extreme storms analyzed. The Pertinent Data Sheet contained summary information on the Part I and Part II storm studies conducted for each storm including approval dates by the USWB and USACE. Also included were summaries of the depth-area-duration tables, mass rainfall curves and isohyetal maps for each of the storms. More detail on each of the storms is contained in the Part I and Part II storm studies. Updates to the Extreme Storm Catalog with additional storm analyzed were published by USACE in 1962 and 1973. Some additional storms were analyzed by the USWB and USBR for inclusion in HMR55A, HMR57, and HMR58/59 but were not included in the USACE Storm Rainfall publication.



WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES – PERTINENT DATA SHEET

Storm of 26-29 July 1897
Assignment NA 1-7 (a)
Location Northeast U. S.
Study Prepared by:
North Atlantic Division
New York District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 3/1/40
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 12/27/46
Remarks: Northern Area Only Centers at Elizabeth and Clayton, N.J.

LOCATION MAP

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:2,500,000
Precipitation data and mass curves: (Number of Sheets)
Form 5001-C (Hourly precip. data) 13
Form 5001-B (24-hour " ") 74
Form 5001-D (" " " ") —
Miscl. precip. records, meteorological data, etc. 3
Form 5002 (Mass rainfall curves) 42

PART II

Final isohyetal maps, in 1 sheet, scale 1:1,000,000
Data and computation sheets:
Form S-10 (Data from mass rainfall curves) 5
Form S-11 (Depth-area data from isohyetal map) 2
Form S-12 (Maximum depth-duration data) 5
Maximum duration-depth-area curves 3
Data relating to periods of maximum rainfall 2

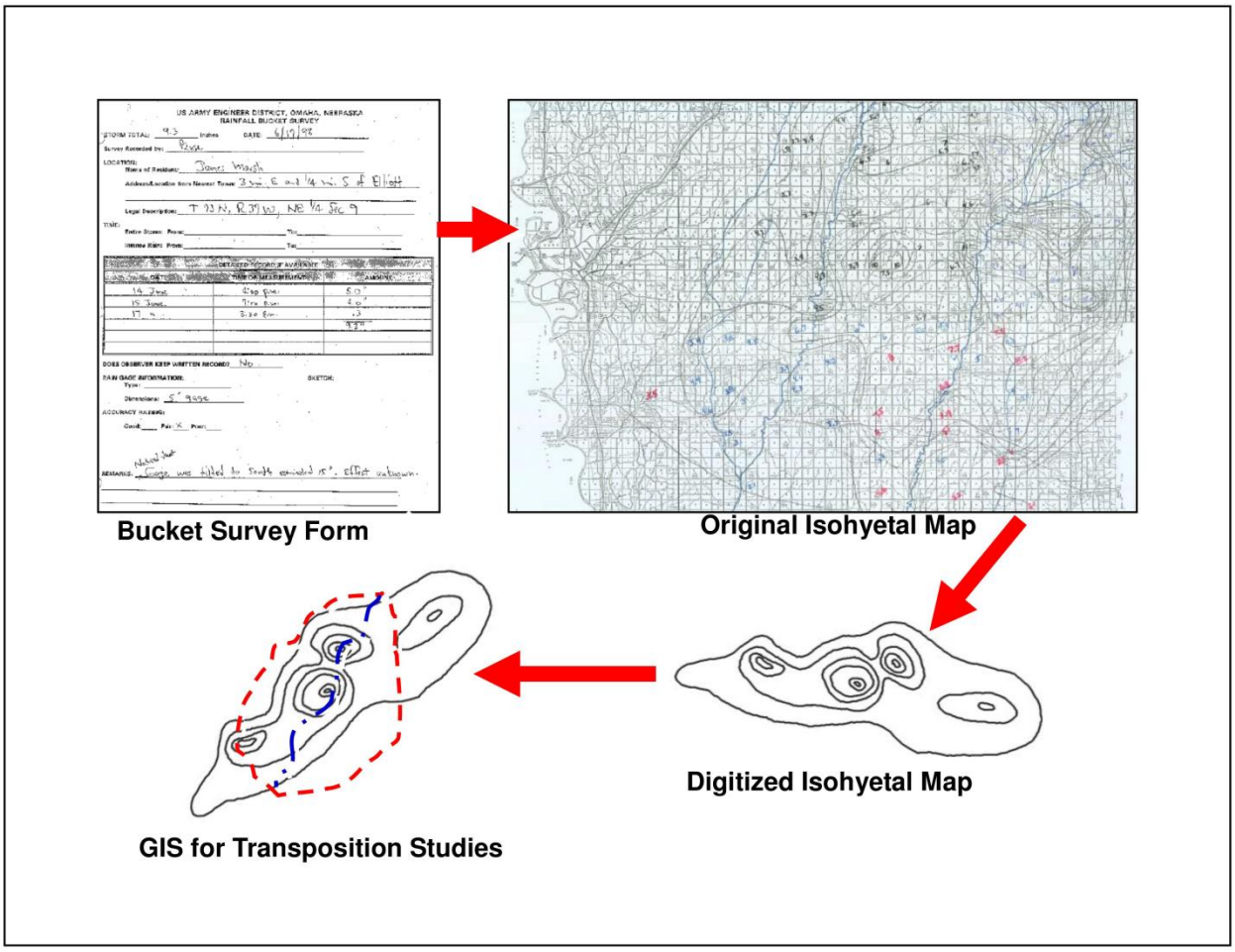
MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours									
	6	12	18	24	30	36	48	60	72	96
10	6.2	8.1	8.6	8.7	8.9	9.0	9.0	9.1	9.1	9.1
100	4.3	7.3	7.5	7.8	7.9	8.0	8.0	8.1	8.1	8.1
200	3.8	6.6	6.8	7.0	7.1	7.2	7.3	7.3	7.3	7.3
500	3.1	5.5	5.7	5.9	6.0	6.1	6.2	6.3	6.3	6.3
1,000	2.8	4.6	4.8	4.9	5.1	5.2	5.3	5.4	5.5	5.5
2,000	2.4	3.9	4.0	4.1	4.3	4.4	4.5	4.6	5.1	5.1
5,000	1.9	3.1	3.3	3.3	3.4	3.7	3.8	3.9	4.0	4.1
10,000	1.5	2.6	2.8	2.9	2.9	3.3	3.4	3.5	3.6	3.7
20,000	1.1	2.1	2.4	2.5	2.6	2.9	3.1	3.2	3.3	3.4
26,000	1.0	1.9	2.1	2.2	2.3	2.8	3.0	3.2	3.3	3.3

Form S-2

Sample Pertinent Data Sheet in Extreme Storm Catalog

The new Extreme Storm Database will include a "Data Archiving and Analysis System" which incorporates scanned images of original data collected from each storm event including the original ‘bucket survey’ forms, hand drawn isohyetal maps, and basic data collected from each storm event. This will allow the user to confirm the original data for each storm event. Also, the original isohyetal maps will be digitized into a GIS format for use in storm transposition studies and for computing depth area relationships. A schematic of the Data Archiving and Analysis System is shown below.



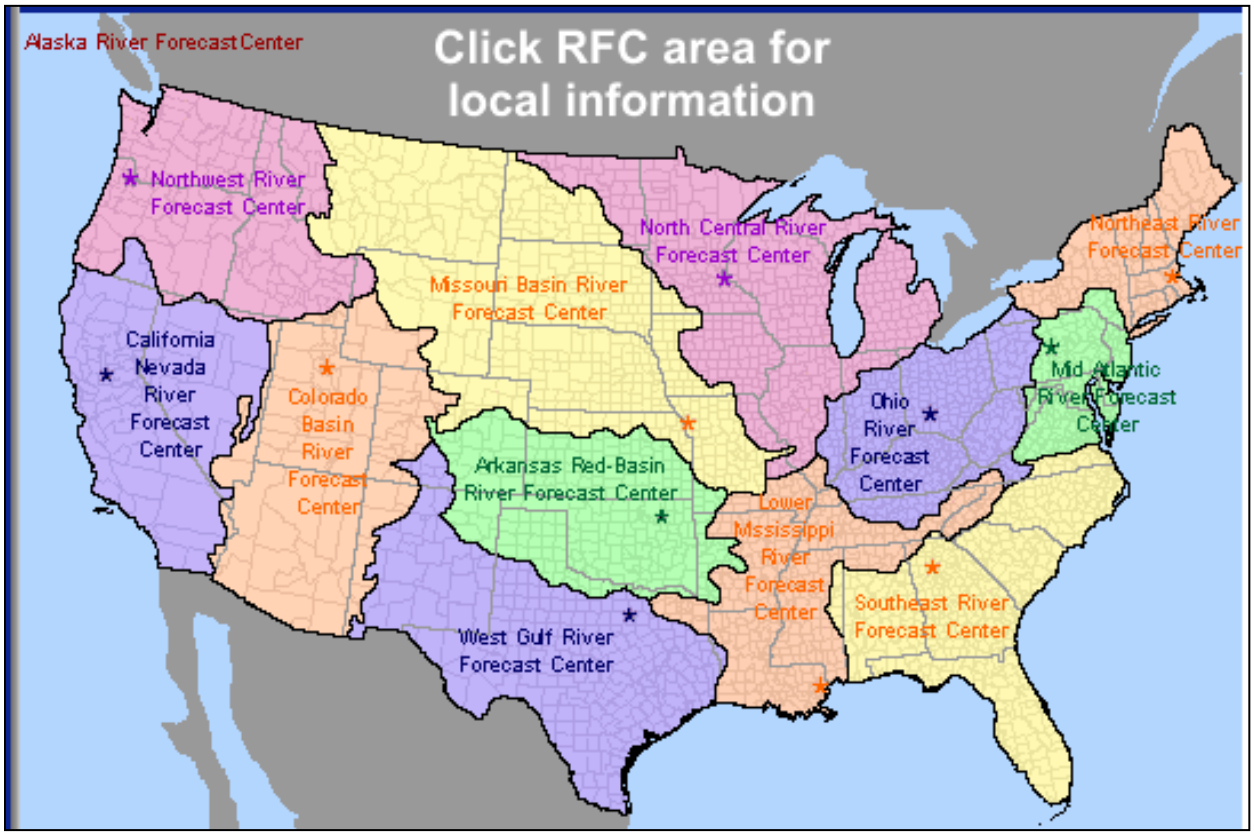
Extreme Storm Database Data Archiving and Analysis Schematic

The database will also include additional extreme storms that have occurred since 1973.

A major addition to the database is the radar data for the storms. NWS radar data can be downloaded from the NWS at: http://dipper.nws.noaa.gov/hdsb/data/nexrad/nexrad.html .

Another source of precipitation estimates used by USACE is the Stage III precipitation data developed by the Hydrometeorological Analysis and Service (HAS) forecasters at the River Forecast Centers (RFC). Stage III data are derived from the Digital Precipitation Array (DPA) products, operational hourly rain gauge data, and interactive quality control by the RFC forecasters. USACE cooperates with the NWS and other Federal agencies at the various RFC across the U.S. Precipitation data used by USACE includes the Multisensor Precipitation Estimate (MPE) which is a combination of radar and actual precipitation gauge recordings. MPE is valuable for estimating precipitation in areas between precipitation record gauges.

The following table provides the time periods covered by the Stage III and MPE information for the 12 River Forecast Centers.



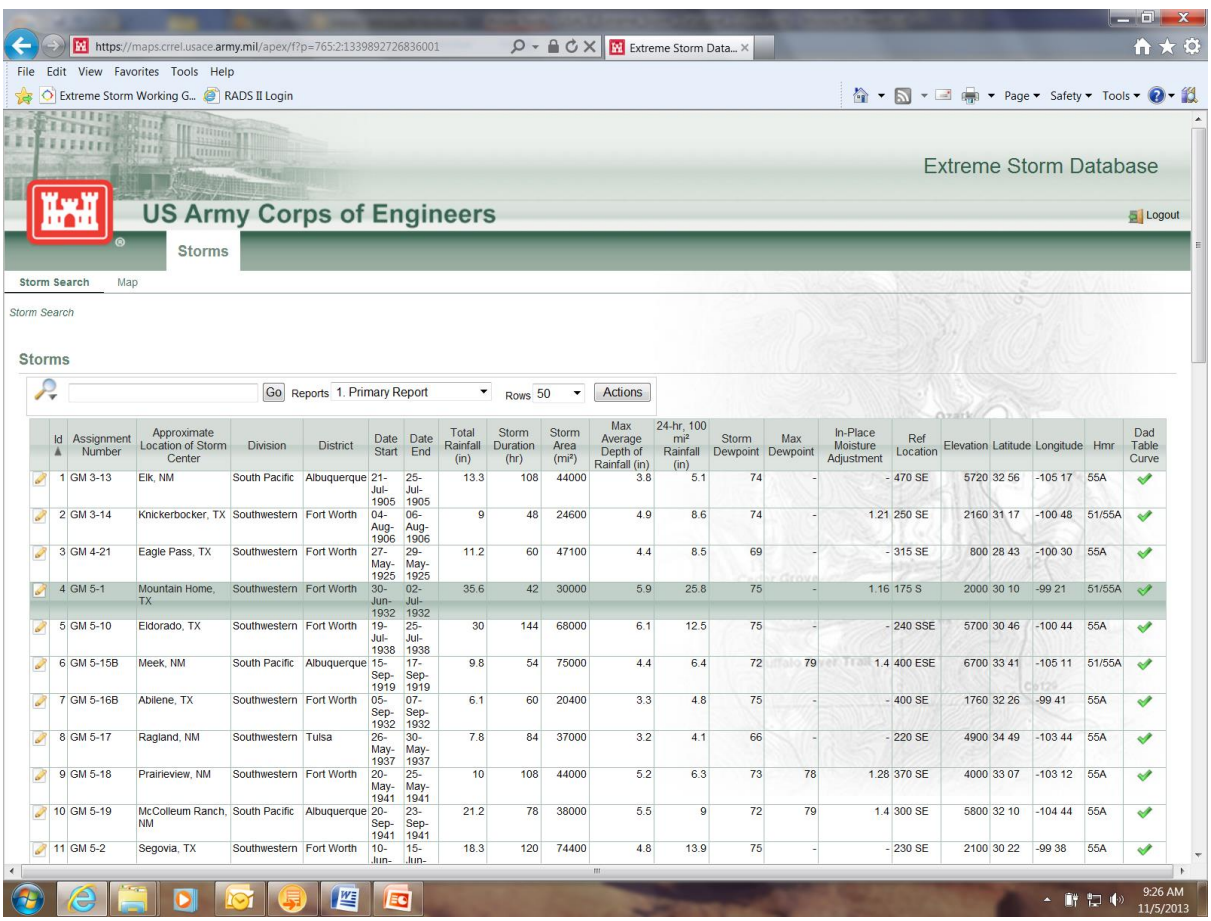
	Stage III	**MPE**
ABRFC	May 1993-Dec 2004	Jun 2003-Sep 2014
APRFC		Jul 2002-Sep 2014
CBRFC	Sep 1996-Mar 2002	Feb 2002-Sep 2014
CNRFC	Sep 1996-Jan 2005	May 2003-Sep 2014
LMRFC	Apr 1996-Aug 2003	Aug 2003-Sep 2014
MARFC	Oct 1995-Dec 2001	Oct 1999-Sep 2014
MBRFC	Nov 1994-Jun 2003	Jan 2003-Sep 2014
NCRFC	Dec 1994-Apr 2002	Feb 2002-Sep 2014

NERFC	Feb 1996-Aug 2002	Aug 2002-Sep 2014
NWRFC	Jan 1996-Nov 2002	Nov 2002-Sep 2014
OHRFC	Dec 1995-Jun 2003	Dec 2001-Sep 2014
SERFC	Dec 1995-Sep 2002	Jan 2002-Sep 2014

Table of Stage III and MPE information for the 12 River Forecast Centers

Recently the USACE began development of a prototype web site and database to aid in the initial development of the Extreme Precipitation Database. The web site will 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 the web site for long term maintenance will be developed by the federal interagency Extreme Storm Events Work Group.

A sample screen shot from the existing web interface is shown below:



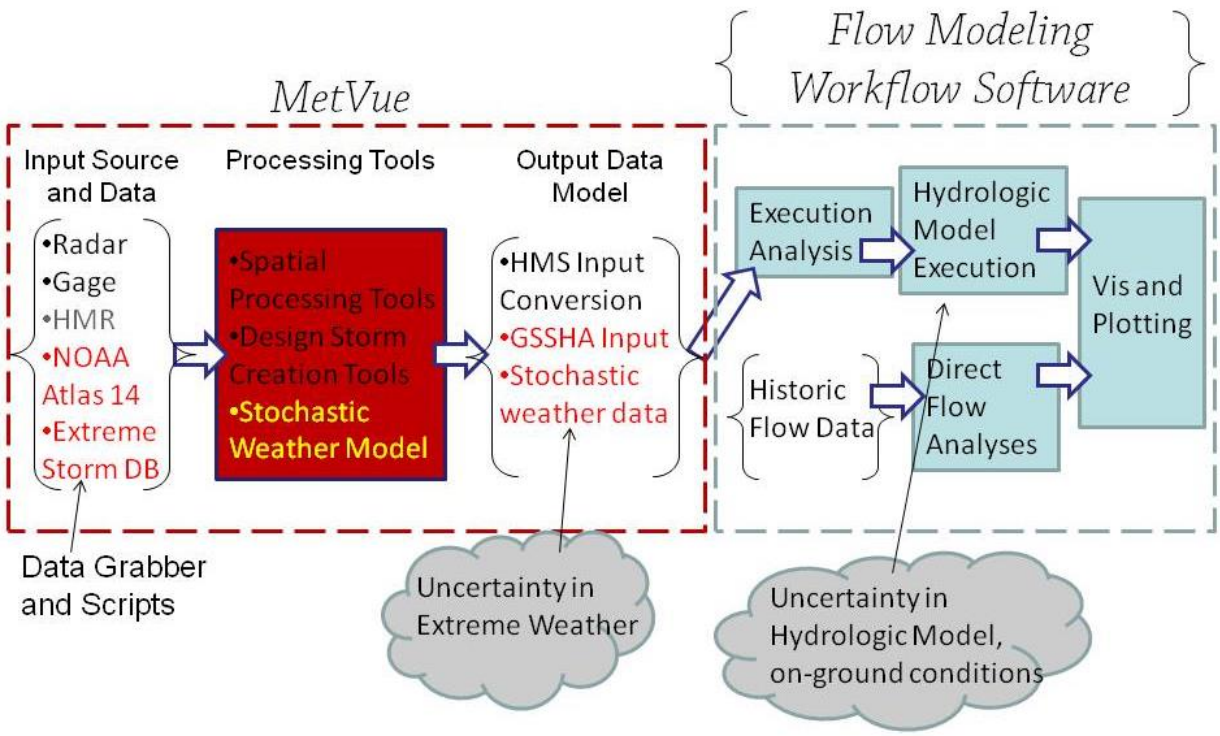
Id	Assignment Number	Approximate Location of Storm Center	Division	District	Date Start	Date End	Total Rainfall (in)	Storm Duration (hr)	Storm Area (mi²)	Max Average Depth of Rainfall (in)	24-hr, 100 mi² Rainfall (in)	Storm Dewpoint	Max Dewpoint	In-Place Moisture Adjustment	Ref Location	Elevation	Latitude	Longitude	Hmr	Dad Table Curve
1	GM 3-13	Elk, NM	South Pacific	Albuquerque	21-Jul-1905	25-Jul-1905	13.3	108	44000	3.8	5.1	74	-	-	470 SE	5720	32 56	-105 17	55A	✓
2	GM 3-14	Knickerbocker, TX	Southwestern	Fort Worth	04-Aug-1906	06-Aug-1906	9	48	24600	4.9	8.6	74	-	1.21	250 SE	2160	31 17	-100 48	51/55A	✓
3	GM 4-21	Eagle Pass, TX	Southwestern	Fort Worth	27-May-1925	29-May-1925	11.2	60	47100	4.4	8.5	69	-	-	315 SE	800	28 43	-100 30	55A	✓
4	GM 5-1	Mountain Home, TX	Southwestern	Fort Worth	30-Jun-1932	02-Jul-1932	35.6	42	30000	5.9	25.8	75	-	1.16	175 S	2000	30 10	-99 21	51/55A	✓
5	GM 5-10	Eldorado, TX	Southwestern	Fort Worth	19-Jul-1938	25-Jul-1938	30	144	68000	6.1	12.5	75	-	-	240 SSE	5700	30 46	-100 44	55A	✓
6	GM 5-15B	Meek, NM	South Pacific	Albuquerque	15-Sep-1919	17-Sep-1919	9.8	54	75000	4.4	6.4	72	79	1.4	400 ESE	6700	33 41	-105 11	51/55A	✓
7	GM 5-16B	Abilene, TX	Southwestern	Fort Worth	05-Sep-1932	07-Sep-1932	6.1	60	20400	3.3	4.8	75	-	-	400 SE	1760	32 26	-99 41	55A	✓
8	GM 5-17	Ragland, NM	Southwestern	Tulsa	26-May-1937	30-May-1937	7.8	84	37000	3.2	4.1	66	-	-	220 SE	4900	34 49	-103 44	55A	✓
9	GM 5-18	Prairieview, NM	Southwestern	Fort Worth	20-May-1941	25-May-1941	10	108	44000	5.2	6.3	73	78	1.28	370 SE	4000	33 07	-103 12	55A	✓
10	GM 5-19	McColleum Ranch, NM	South Pacific	Albuquerque	20-Sep-1941	23-Sep-1941	21.2	78	38000	5.5	9	72	79	1.4	300 SE	5800	32 10	-104 44	55A	✓
11	GM 5-2	Segovia, TX	Southwestern	Fort Worth	10-Jun-	15-Jun-	18.3	120	74400	4.8	13.9	75	-	-	230 SE	2100	30 22	-99 38	55A	✓

Doug provided examples of how the June 9 – 10, 1972 Rapid City, SD storm and flood; and the September 9 – 16, 2013 storm in Colorado along the Rocky Mountain front in the vicinity of Boulder would capture the precipitation data, radar and storm characteristics. He identified the data sources for these and other extreme storm database analyses to be posted on the USACE Website: U.S. Storm Rainfall (1882-1973); Bucket Surveys (USACOE, USBR, NWS); NOAA COOP Observations (1753-2014); NWS Radar Estimates (1993-2014); CoCoRaHS (1998-2014); and local and regional precipitation networks (NERain, SD-AWDN, NDAWN, DOT, ALERT, etc).

He discussed the planned database enhancements which could include: a latitude/longitude search box or use of location and radius descriptors; identify the storm type (e.g., synoptic, convective, etc.); conditions on how non-USACE users could access (read-only, edit, add rights); identify who entered/edited data; provide an entire DAD Table; ability to search and interpolate any area or duration; plot DAD curves; show reference location on map; extract Dew Points from storm map; extract PMP from map; and compute % of PMP.

Doug discussed the HEC-MetVue code and how it is used to catalogue historic storms and apply synthetics storms. HEC–MetVue is an Arc GIS-based meteorological/visualization model which accepts Shapefiles in any coordinate system (e.g., precipitation, basin). The model utilizes “Drop and Drag” or menu driven options. Its inputs include: QPE, QPF (XMRG, NetCDF) and rain gage data (ASCII, DSS). Its outputs include: DSS Hyetographs/ Gridded Precipitation (HRAP,SHG). The model is used to analyze historic storms; compute DAD; translate, rotate, and maximize storms; calibrate QPE to gage data or PRISM data; and aggregate/segregate storms. HEC-MetVue is also used to develop Design Storms whether for Hypothetical Frequency Based or PMP based using estimates in HMR51/52, HMR55A, HMR58/59. The model provides linkage with HEC-HMS and the Extreme Storm Database.

Dr. Aaron Byrd discussed an ongoing project that focuses on enhancing the ability of USACE engineers to conduct extreme event hydrologic studies. This project is part of the Water Resources Infrastructure Technology (WRITe) research program. The overall goal of the project is to create tools and techniques that enable extreme event flow frequency analysis, including uncertainty in the models and extreme precipitation estimates. As an initial step, the work will focus on enhancing the HEC-MetVue code to easily incorporate extreme event estimates from the online NOAA Atlas 14 data. Subsequent stages of the work will focus on stochastic weather simulators to estimate extreme events as well as sequences of events, that may or may not be extreme events, which together make for extreme flow situations. Tools to quickly estimate extreme flows based solely on the historic flows will also be developed to give another check on the results. The results will be a tool that can conduct studies for a range of extreme flood flows based on extreme precipitation events and place those results in the context with other extreme flow estimates, including PMF estimates. The figure below shows the overall parts of the project and how they fit together.



Overall picture of the proposed work for the WRITe extreme flow estimation work unit.

8. U.S. Bureau of Reclamation (BoR)

John England and Victoria Sankovich-Bahls, BoR discussed BoR's needs in extreme precipitation data and methods. This information supports their risk analysis and dam safety program, specifically their hydrologic hazard analysis (HHA) hierarchy and levels of study with a focus on the Issue Evaluation (IE) extreme precipitation, and Corrective Action Study (CAS) extreme precipitation. They identified numerous opportunities in the development and analysis of extreme rainfall observations and databases. These include the coupling of point rainfall data with the significant use of radar data to provide better spatial and temporal correlations, and the need to establish and maintain a national extreme storm catalog. They also discussed opportunities to incorporate advances in statistics and data processing methods using regionalization techniques, storm spatial and temporal patterns, mapping larger regions, accounting for seasonal variability, and quantifying uncertainty estimates. They also discussed possible improvements in physical and numerical modeling through the use of radar data resulting in better resolution models for better results; the use of models for hypothesis testing; modeling to evaluate past events such as the September 1970 and May 2010 storms in the Nashville, TN area. Finally, BoR addressed the needs to handle technical complexities related to watershed size and different storm mechanisms; create and utilize evolving computing resources; training of skilled personnel to conduct hydrometeorological studies needed to update the HMRs and risk analysis.

9. State Perspectives on Extreme Precipitation Uses in Dam Design Analyses

As discussed above under the *Questionnaires* heading of this Synthesis report, an Extreme Precipitation Needs questionnaire was distributed to State Dam Safety agencies. The State Needs questionnaire was developed by the Extreme Storm Event Work Group in support of the National Dam Safety Program, under which the Federal government supports State dam safety agencies to protect the public from dam failures.

During preparation of the *State Needs* questionnaire, Victor Hom and Tom Nicholson presented to the Interagency Committee on Dams (ICODS) and the National Dam Safety Review Board (NDSRB) on April 24, 2014 at their quarterly meeting, to inform them about the questionnaire prior to making an information request of the State agencies. ICODS and NDRSB requested that the ESEWG review FEMA P-919, *Summary of Existing Guidelines for Hydrologic Safety of Dams* (July 2012) to eliminate redundancy and minimize the burden on State respondents caused by the ESEWG questionnaire.

The Work Group reviewed FEMA P-919, specifically Section 9 *Summary of Current State Hydrologic Design Guidelines*, Section 10, *Receptiveness of States to Changing Guidelines*, and Appendix C, *Hydrologic Safety of Dams Surveys*. After review, the Work Group eliminated several redundant questions from their questionnaire, but in general determined the FEMA P-919 questionnaire dealt more generally with spillway sizing regulations, whereas the ESEWG's questionnaire deals specifically with Extreme Precipitation needs of the States to help them enforce such regulations. The States Needs survey was developed with input from Mark Perry, State of Colorado Dam Safety Branch and ESEWG member, and based on consultation with other State Dam Safety agencies.

Victor Hom and Robert Mason distributed the States Needs questionnaire to numerous State agencies participating in the NDSBR. Mark Perry worked with the Association of State Dam Safety Officials (ASDSO) to distribute the State Needs questionnaire to remaining State Dam Safety agencies. Due to the need for multiple levels of communication prior to distribution of the State Needs questionnaire there was a relatively short turnaround for State respondents. The States Needs questionnaires were distributed between April 25, 2014 and May 1, 2014, and responses were requested by May 6, 2014. Nevertheless, a strong showing was made by State Dam Safety agencies with 21 States responding, namely: Arizona, California, Colorado, Connecticut, Idaho, Maryland, Massachusetts, Minnesota, Mississippi, Montana, Nebraska, New Mexico, New York, Oklahoma, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, and Wyoming. The number and quality of State responses clearly communicated the importance of Extreme Precipitation Needs to State Dam Safety agencies. Following is an example State Questionnaire response:

6. Please discuss applicability of current Federal extreme precipitation publications, databases and tools:

a. Hydrometeorological Reports

xiv. Is updating the HMRs a priority to your State/agency? ***YES - AZ DWR considered updating of HMR-49 to be such a priority that it cost-shared with two dam-owning agencies and the State NRCS Office to independently fund 3-year, nearly $900,000 study to produce more reliable PMP depths for all regions of the State. AZ encourages the NWS to support the needs of its neighboring states, including Colorado, New Mexico, Nevada, CA and Utah by updating the woefully outdated HMR-49.***

All State questionnaires were reviewed by Mark Perry and Victoria Sankovich-Bahls prior to the ESEWG's May 15, 2014 Workshop and were summarized for presentation to Workshop participants. The Workshop agenda was distributed to State Dam Safety agencies prior to the meeting, and they were invited to participate either on-site or remotely via webinar. Five (5) State agencies (AZ, CA, CO, AZ and PA) were asked to present results to the questionnaire in order to represent the nature of State Extreme Precipitation Needs.

During the May 15th Workshop, Mark Perry moderated a panel discussion of State Dam Safety officials. Mr. Perry began by thanking the ACWI SOH, ESEWG, ICODS, NDSRB, ASDSO, State questionnaire respondents, and FEMA for recognizing the importance of the States' Extreme Precipitation Needs. He also qualified the States Needs summary by acknowledging that State Dam Safety agencies are independent and has unique needs; neither the ESEWG nor any Workshop participants claim to speak for all State agencies. With that qualifier, he presented the following general summary of State Extreme Precipitation Needs from the questionnaire (see Appendix D for a detailed summary of State questionnaire responses):

- Probable Maximum Precipitation (PMP) estimates are very important to the States; in most cases State spillway sizing regulations are based on NOAA Hydro-Meteorological Report (HMR) PMP. In some cases the requirement for States to use NOAA HMR PMP is codified in State statute. Around the year 2000 NOAA decided to no longer support its HMR PMP products, leaving the States in a difficult situation.
- Extreme Precipitation products included in the ESEWG's proposal to the ACWI need to consider workload of the State, which is generally hundreds of dams per staff member. Detailed site specific hydro-meteorological studies for each dam are simply not practical.
- States need Extreme Storm products that are technically and politically defensible to private dam owners and State legislators. Currently NOAA HMRs developed in the 1970s and early 1980s are difficult for States to defend while trying to enforce spillway safety regulations that could cost dam owners millions of dollars in modifications.
- A nationwide Extreme Precipitation product would be good for the dam safety industry and may help make regulations more defensible, as opposed to the piecemeal approach to Extreme Precipitation products by individual States that is currently occurring.
- The importance of updated Extreme Precipitation products, specifically updated PMP estimates, is urgent. At least eight States have moved forward with individual Extreme Precipitation or PMP studies in the absence of Federal action and more States are considering it. In some States the level of opposition to the outdated and unsupported NOAA HMR PMP has risen to the political level with one State legislature reportedly threatening to place a moratorium on its Dam Safety agency until the issue is resolved.

Mr. Perry highlighted the following specific State questionnaire responses:

- HMR 49, which covers parts of the Western U.S. including the Colorado Plateau and Great Basin States was published in 1977 and did not use modern PMP methods. The State of Arizona recently completed its own Statewide PMP updated study; their questionnaire response states that their 2008 study "concluded that PMP depths published in HMR 49 are outdated, unreliable, and not supported by data" and "the State of Arizona does not rely on PMP depths published in HMR 49 and discourages its continued use for other states."
- HMR 51 & 52 need to be updated due to their large areal coverage of the eastern U.S.
- States regulate many small dams, often with small drainage areas (<100 square miles).

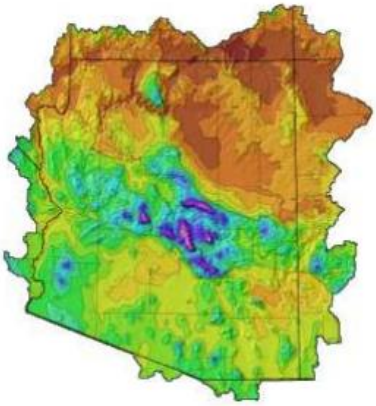
- States have seen an increase in Site Specific PMP (SSPMP) studies due to the outdated and unsupported NOAA HMRs. SSPMP studies put a burden on understaffed State Dam Safety agencies, which typically do not have in-house meteorological experts.
- Outdated and unsupported NOAA HMRs make it politically difficult for States to regulate spillway size
- Regarding questions about use of Risk-based Extreme Precipitation Products:
    - Some States expressed doubts about whether risk can be determined accurately for extreme hydrologic events
    - Some States questioned the practicality of risk-based methods in light of continually increasing development below many dams (so called, "hazard creep")
    - States may be constrained to use PMP, PMF, and specifically "NOAA HMR" PMP estimates by State statute, code, or regulations.
    - States may be receptive to a Risk-based Extreme Precipitation Product if it is accompanied by clear Federal guidelines on how to apply it to spillway sizing.

Following Mr. Perry's summary of States' Extreme Precipitation Needs, the following State panelists discussed their State-specific needs and questionnaire responses:

1) Michael Johnson, PhD, P.E., Arizona Department of Water Resources (by webinar): The State of Arizona, Division of Water Resources, Dam Safety Section commissioned a 2008 study by Applied Weather Associated LLC and Metstat Inc. that concluded HMR 49 PMP estimates are outdated, unreliable and not supported by data. The State of Arizona does not rely on HMR 49 PMP estimates and discourages the use of HMR 49 by other States. Arizona DWR considered updating HMR-49 to be such a priority that it cost-shared a Statewide PMP update study along with the NRCS. The study cost was $900,000 and duration was three years.

   The Arizona PMP Study was performed by Applied Weather Associates with review by various State and Federal Agencies. A companion report is publically available at the Arizona DWR website: http://www.azwater.gov/AzDWR/SurfaceWater/DamSafety/

Probable Maximum Precipitation Study for Arizona



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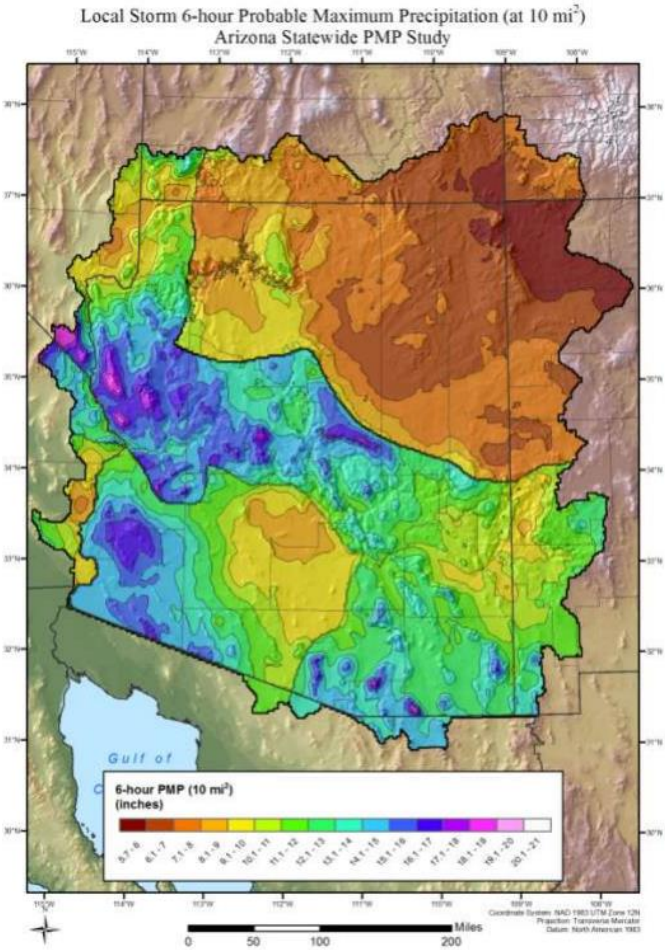
The 2013 AZ DWR study included development of a publically-available GIS-based application (ESRI add-on) for computation of basin-specific PMP depths for any user-defined drainage area within the State:

http://www.azwater.gov/AzDWR/SurfaceWater/DamSafety/DamSafetyTechnicalReferences.htm

Fifty-one extreme rainfall storm events were identified during the Arizona PMP Study, having rainfall centers with similar characteristic to extreme rainfall events that could control PMP values at locations within our state. This included 12 general winter storms, ten remnant tropical storms, and 29 local convective storms. Each of the 51 storms was analyzed using the Storm Precipitation Analysis System, which produced Depth-Area-Duration (DAD) values, mass curves, and total storm isohyetals. NEXRAD data was incorporated when available. NOAA Atlas 14 precipitation frequency data was used to calculate the Orographic Transposition Factor. HYSPLIT model trajectories and Sea

Surface Temperature (SST) data from NCAR and NOAA were also used in the storm adjustment processes. To house, analyze, and produce results from the large data set developed in the study, the PMP Evaluation Tool was developed. This tool uses a combination of Excel and GIS to query, calculate, and derive PMP values for each grid cell, for each duration, and for each storm type. For local convective storms, the durations analyzed were 1-, 2-, 3-, 4-, 5-, and 6-hours. For remnant tropical and general winter storms, the durations analyzed were 6-, 12-, 18-, 24-, 48-, and 72-hours. The figure to the right shows Local Storm 6-hour PMP estimates at 10 mi^2 resolution for the entire State.



Arizona DWR supports national guidelines for Extreme Precipitation Products but not national standards, stating that no single national standard would result in consistent levels of risk when applied to the range of human development and meteorological hazards across all fifty states.

Arizona DWR encourages the National Weather Service (NWS) to support the needs of California, Colorado, New Mexico, Nevada, and Utah by updating HMR 49.

2) <u>Ronald Mease, P.E., Pennsylvania Department of Environmental Protection, Division of Dam Safety (on-site participant):</u> Pennsylvania Division of Dam Safety understands that HMR 51 PMP estimates may be high due its handling of the extreme rain event at Smethport, PA, in the 1940s. High PMP estimates (generally about 36 inches in 24 hours) make it difficult for dam owners to comply with PA dam safety regulations for spillway sizing. Because the NOAA HMRs are outdated and unsupported, it makes it hard for State regulators to convince dam owners that spillway improvements are needed.

PA Dam Safety Regulation Chapter 105, Section 105.98, uses the Probable Maximum Flood (PMF) as the basis for spillway sizing; the regulations define *PMF* as being "derived from the probable maximum precipitation (PMP) as determined on the basis of the most recent data available from the National Oceanographic and Atmospheric Administration (NOAA)."

PA Dam Safety is holding discussions with meteorological consultants about performing a Statewide PMP update study (similar to what was done in Arizona and at least seven other states); however, funding and regulatory constraints need to be resolved.

Specifically, Regulation Section 105.98 would need to be changed to remove dependence on NOAA HMRs.

PA Dam Safety recently changed its regulations to require Incremental Damage Analysis for spillway sizing, which is a form of risk analysis. Their concern with using a true risk-based extreme precipitation product is that they regulate nearly 800 high hazard dams; so any new risk-based spillway sizing procedure would need to be simple to apply. It would also require changes to State regulations, for which it would be beneficial to have Federal guidelines.

Finally PA Dam Safety said it would be helpful to have a web-based PMP tool similar to the USGS Stream Stats, which could delineate a drainage basin and calculate the PMP hyetograph for the user. They cited the difficulty of applying HMR 52 and said they currently have to rely on an outdated MS DOS program to run HMR 52.

3) Robert Bennett, P.E., R.A., C.F.M., Virginia Department of Conservation & Recreation (by webinar): In 2008, Virginia Dam Safety began a program requiring dam owners to create or update dam breach inundation mapping. That effort exposed many cases of increased hazard potential due to recent downstream development (so called "hazard creep") and the need for increased hazard classification at many dams, which in turn resulted in increased spillway size requirements for those dams. There was political opposition from dam owners to the increased spillway size requirements. In response Virginia Dam Safety incorporated Incremental Damage Analysis and other alternatives into its regulations for spillway sizing.

   Nevertheless going into the commonwealth's 2014 legislative session, three Virginia legislators were proposing legislation to put the Dam Safety program under a moratorium until the spillway sizing issue could be resolved. The Dam Safety agency was able to negotiate a solution whereby a Statewide PMP study would be performed to replace NOAA HMR 51 and obtain modern, defensible PMP estimates; the Virginia Legislature funded the PMP update study. A contract was awarded to Applied Weather Associates, LLC (also performed the Arizona PMP update study) and has a Dec. 1, 2015, delivery date. Virginia Dam Safety is assembling a board of consultants to review their Statewide PMP update study and expressed their interest in Federal agency participation.

   Regarding risk-based approaches, Virginia Dam Safety has discussed it internally but does not have any plans to implement regulations based on risk. The biggest need for them is updated PMP.

4) Melissa Collord, P.E., California Department of Water Resources, Division of Safety of Dams (by webinar): California Division of Safety of Dams (CA DOSD) explained their partial risk-based method for spillway sizing, whereby the design rainfall varies between the minimum 1000-YR Average Recurrence Interval (ARI) and PMP, depending on the hazard classification of the dam. CA DOSD has traditionally used frequency storm data compiled internally, but has recently began allowing use of NOAA Atlas 14.

   CA DOSD expressed concern that they are receiving more Site Specific PMP studies for spillway sizing and attributes it to outdated and unsupported NOAA HMRs. They explained the burden SSPMP studies put on State agencies, which typically do not have in-house meteorological expertise. CA DOSD recently rejected a SSPMP study

performed by Applied Weather Associates LLC, which was performed under FERC Part 12 D. CA DOSD believes updated NOAA HMRs would preclude the need for most SSPMP studies.

CA DOSD made the point that a national Extreme Precipitation product and Federal guidelines would benefit dam owners who are regulated by both CA DOSD and the Federal Energy Regulatory Commission (FERC). Without a Federally supported product, such dual-regulated dam owners may be in a position where a State adopts new PMP estimates, but FERC does not accept the State study.

Regarding Risk-based Extreme Precipitation products, CA DOSD considers risk-based approaches to be complex and believes they are generally not valuable because of very large uncertainties in computing extreme precipitation and runoff at the large return intervals needed for risk analysis. They suggest that any risk-based Extreme Precipitation product needs to include an understanding of uncertainty. They do use a simplified risk-based spillway sizing method (described above).

CA DOSD pointed out that they do not use percentages of PMP to design spillways, as the resulting values may vary in terms of probability of occurrence. FEMA P-919 noted that many State dam safety agencies currently allow use of percentages of PMP (e.g. 50% PMP for a Significant Hazard Dam), and the FEMA report recommends discontinuing this practice.

Finally, CA DOSD is currently updating its procedures for hydrologic analysis and is very interested and supportive of the efforts being undertaken by the ESEWG.

5) Mark Perry, P.E., Colorado Division of Water Resources, Dam Safety Branch (on-site participant): The State of Colorado Dam Safety Branch (CO DSB) has a long history of trying to improve PMP estimates at high elevations and in mountainous terrain.

Following is an abridged list of CO DSB efforts:

- 1984: CO DSB questions the applicability of NOAA HMR 55 at high elevations, at least in part contributing to release of the revised report, HMR 55A, which allowed a greater elevation reduction for PMP Local Storms.
- 1989: CO DSB hosted a Workshop on Hydrologic Aspects of Dam Safety at Colorado State University to elicit expert discussion on high elevation extreme precipitation. (The workshop report reference is included at the end of this Synthesis report).
- 1997: CO DSB funded the Extreme Precipitation Data Study by Colorado State University Atmospheric Science Dept (CSU), which resulted in the publication of Climatology Report 97-1 (see References).
- 1999-2003: CO DSB funded numerical modeling study by CSU using their Regional Atmospheric Modeling System (RAMS) to develop a new method to estimate PMP in mountainous terrain (see References). In the end, the CO DSB decided not to pursue the numerical modeling method, likely because it was perceived as being too theoretical for regulatory purposes.
- 2005-2008: CO DSB contracted with HDR Engineering Inc. to develop a GIS-based Site Specific PMP program that became known as the Extreme Precipitation Analysis Tool (EPAT). The main contributions of EPAT were to be incorporating recent extreme rain events and NEXRAD data into the storm database, limiting storm transposition limits in mountainous terrain based on climate zones identified in CSU Report 97-1, and eliminating the HMRs reliance

on the complicated Storm Separation Method to account for orographic forcing. The following figures show storm analysis in EPAT, EPAT Climate Zones, and an example storm in EPAT's GIS storm library.

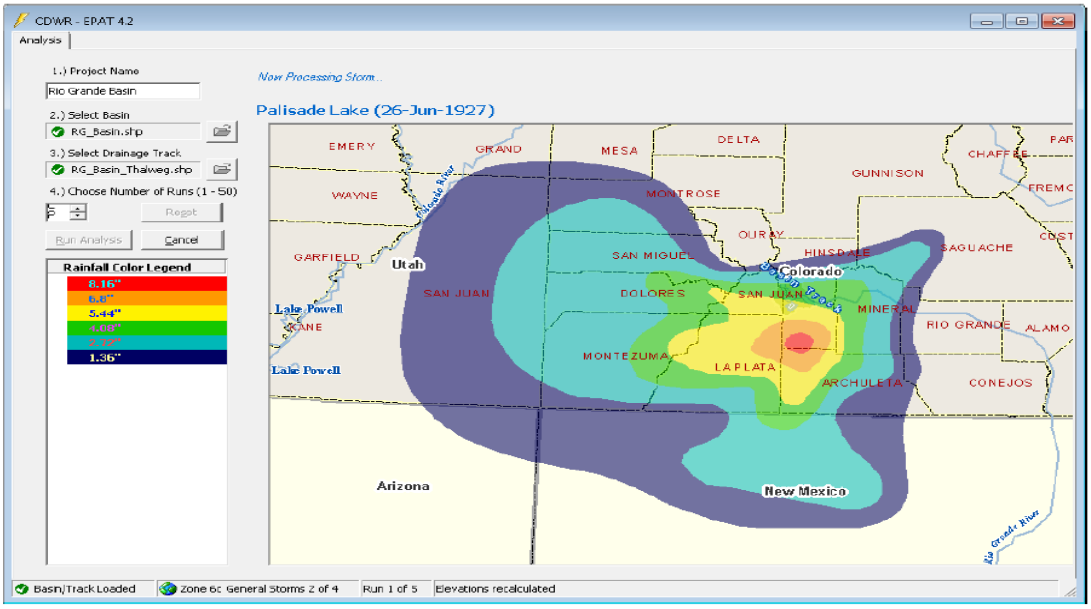


Figure 73. Screen shot of Palisade Lake storm of 1927 during EPAT analysis of Rio Grande basin

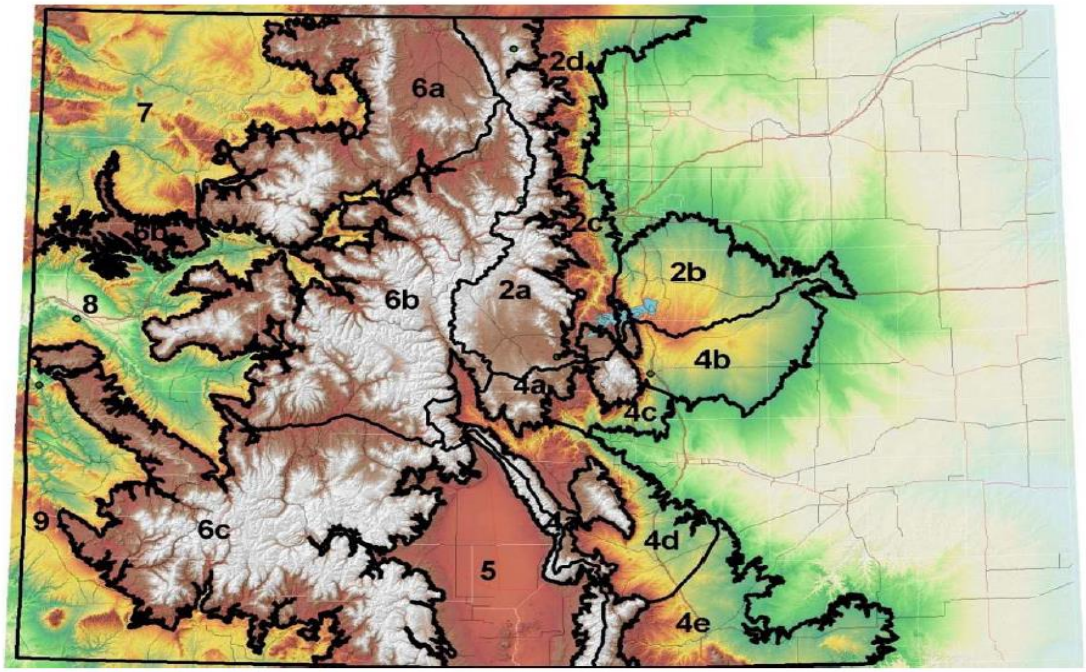
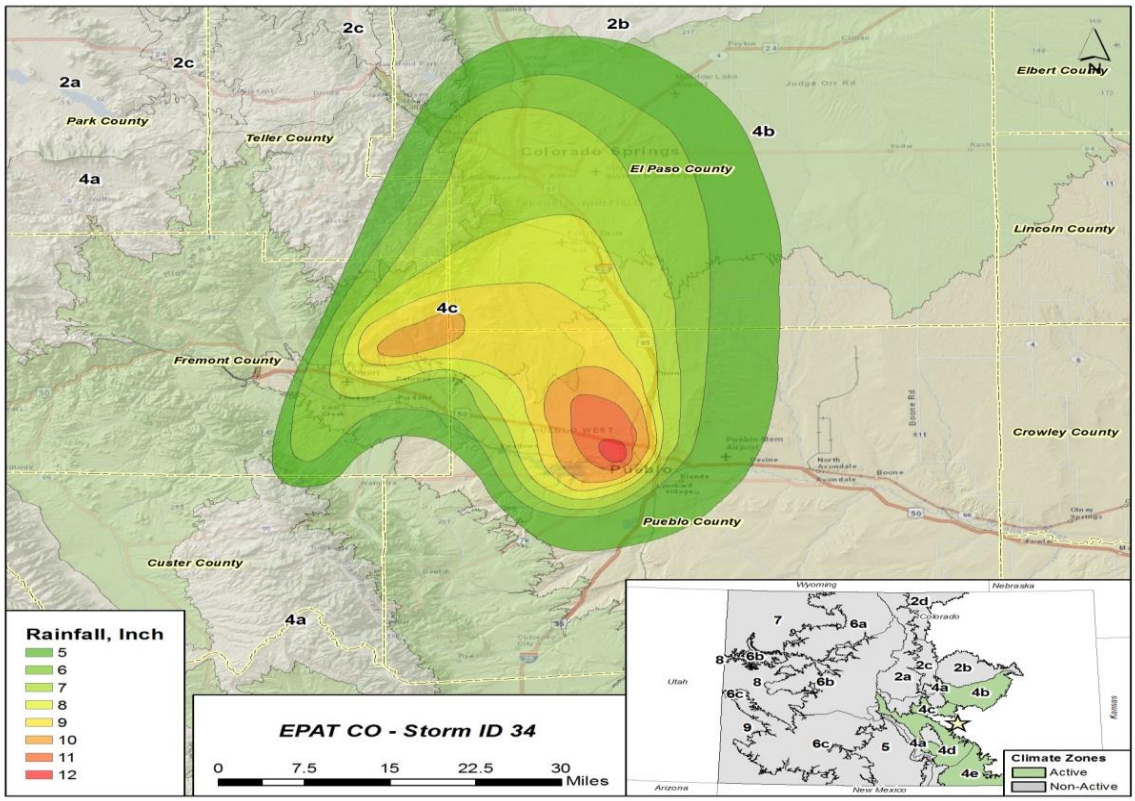


Figure 44. EPAT Version 4.2 climate zone map



EPAT Storm 34 (Pueblo/Penrose 1921) from EPAT's GIS storm library.

- 2013: The CO DSB completed Phase II of a quality control & independent meteorological evaluation of EPAT performed by Applied Weather Associates, LLC. Unfortunately the study found EPAT to be plagued by numerous errors (e.g. in-place maximization factors), inconsistencies (e.g. different durations used for storm reference dew points vs. maximum persisting dew points), unsupported deviations from NOAA HMR and WMO PMP procedures (e.g. barrier elevations were not accounted for in the storm transposition process), and unsupported deviations from the state of the practice (e.g. the narrow storm transposition limits are not supported by current meteorological knowledge).
- 2014: Based on results of the EPAT Phase II study the CO DSB is no longer using EPAT. Due to studies in neighboring states showing inadequacy of NOAA HMRs, specifically HMR 49, CO DSB is at a decision point and is considering whether to move forward with a Statewide PMP update study similar to that completed by Arizona and at least 7 other states.

CO DSB cited specific possible improvements for PMP estimates at high elevations & mountainous terrain that should be addressed in new Extreme Precipitation products:

- Better understanding of storm transposition limits based on physical processes, possibly numerical modeling, at work in mountainous terrain.
- Better elevation adjustments for General and Local storms (see discussion above about the revision made between HMR 55 and HMR 55A)
- Better aerial reduction factors based on actual storm data at high elevations and in mountainous terrain

- Finer resolution analysis to account for topographic barriers to moisture supply in highly variable mountainous terrain

Finally, CO DSB listed some of its specific Extreme Precipitation Needs:

- HMR 49 update
- Modern, improved methods for Extreme Precipitation estimates at high elevations including numerical modeling, paleo-hydrology, etc. (reference "Estimating Bounds on Extreme Precipitation Events: A Brief Assessment", National Research Council, 1994)
- Guidelines for Site Specific PMP Studies (CO regulations currently allow Site Specific PMP studies for spillway sizing, but CO has no guidelines for such studies. FEMA P-919 indicates that CO is not alone in the situation).
- CO DSB may be open to using Risk-based Extreme Precipitation products if they are accompanied by Federal guidelines on how to apply them to spillway sizing and are simple to use in light of our large number of regulated dams per staff person.
- Risk-based methods could help CO address the perceived disparity between urban and rural dams under current prescriptive approaches to spillway sizing, and could help us prioritize many needed repairs in the aging inventory of regulated dams.

Following the above State panel presentations; opportunity was provided for comments by other States participating remotely by webinar, namely Kentucky, Montana, and New Mexico dam safety agencies. Mr. Shane Cook of Kentucky, Division of Water, explained that Kentucky statute specifically requires use of NOAA HMR PMP for spillway sizing. Kentucky Dam Safety would like to pursue their own PMP update study, but they are caught in a regulatory dilemma: they cannot get funding for a PMP update study that cannot be used under current state statute, but at the same time the statute cannot be changed to allow use of a PMP update study that does not yet exist. Mr. Cook welcomed any feedback from other States that have dealt with this problem.

Finally, at least eight States have completed PMP update studies performed by consulting meteorologists, reviewed by boards of Federal and State experts, and funded by consortiums of State governments, regulatory agencies, and dam owners. Mr. Perry suggested these States have demonstrated an effective model for updating PMP. Possible problems to be solved are that no consistent PMP study guidelines exist, there are a limited number of meteorological consultants performing the work, and boundary issues between States exist. As a solution to these challenges, Mr. Perry proposed Federal oversight of the statewide PMP update process including the following:

- Cost-share grant program to the States for PMP update studies through FEMA's National Dam Safety Program, similar to funding mechanism of NOAA Atlas 14
- Create Federal guidelines for Statewide PMP studies that would be a condition of Federal grants and would allow Federal agencies to accept Statewide studies
- Procedures for dealing with boundary issues between States
- A grant program may help generate interest by more meteorological consultants

Conclusions and Recommendations

Victoria Sankovich-Bahls, workshop facilitator summarized the candidate products identified during the workshop presentations and discussions as:

- U.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 HMRs;
- Extreme Precipitation Estimates beyond 1:1,000-year (also known as the "Extreme Precipitation Analysis Tool");
- Completion of NOAA Atlas 14 (not beyond 1:1,000-year);
- Streamlined Updating of PMPs using statistical methods (workshop is recommended to fully develop);
- Interagency business process to analyze after-event data (an example would be the tornado damage assessment process as a model) tie to the Extreme Storm Catalogue; and
- Synthesis of workshop discussions on needed products.

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U.S. NRC, "Design Basis Floods for Nuclear Power Plants", Regulatory Guide 1.59, U.S. Nuclear Regulatory Commission, Washington, DC, 1977

APPENDICES TO WORKSHOP SYNTHESIS REPORT

Appendix A: Federal Agency Questionnaire for Needs in Extreme Precipitation

Appendix B: Summary of Questionnaire Reponses by Federal Agencies

Appendix C: State Dam Safety Agency Questionnaire

Appendix D: Summary of Questionnaire Responses by State Dam Safety Agencies

Appendix E: Program and Agenda

Appendix F: Workshop Attendees

Appendix G: Presentations