May 19, 2015

Mr. Bill Kappel
President, Chief Meteorologist
Applied Weather Associates, LLC
P.O. Box 175
Monument, CO 80132

SUBJECT: REPORT FOR THE AUDIT OF APPLIED WEATHER ASSOCIATES, LLC, REGARDING SITE SPECIFIC PROBABLE MAXIMUM PRECIPITATION DEVELOPMENT IN SUPPORT OF NEAR-TERM TASK FORCE RECOMMENDATION 2.1 FLOOD HAZARD REEVALUATIONS (TAC NO. MF5609)

Dear Mr. Kappel:

On February 23, 2015, to February 25, 2015, the U.S. Nuclear Regulatory Commission (NRC) staff conducted a regulatory audit of Applied Weather Associates, LLC (AWA) at NRC Headquarters, in Rockville, MD. On March 11, 2015, the NRC staff conducted a webinar with AWA to gather additional information. This technical audit was performed consistent with NRC Office of Nuclear Reactor Regulation Office Instruction LIC-111, “Regulatory Audits,” dated December 29, 2008 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML082900195). This audit report documents the staff’s observations and conclusions.

The audit provided the NRC staff with a better understanding of site-specific probable maximum precipitation (ssPMP) estimates that AWA has done in support of licensee flood hazard reevaluation reports (FHRRs). The intent of the audit was to support staff reviews of FHRRs that include ssPMP estimates. The audit successfully addressed each of the topics listed in the audit plan (ADAMS Accession No. ML15041A080).

The enclosed audit report provides a summary of the NRC staff activities related to AWA’s work as it applies to ssPMP estimates in support of Near-Term Task Force Recommendation 2.1 flood hazard reevaluations.

If you have any questions, please contact me at 301-415-2915 or by e-mail at Victor.Hall@nrc.gov.

Sincerely,

/RA/

Victor E. Hall, Senior Project Manager
Hazards Management Branch
Japan Lessons-Learned Division
Office of Nuclear Reactor Regulation

Enclosure:
Audit Report

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Enclosure:
Audit Report

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ADAMS Accession No.: ML15113A029 ***via email**

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NAME	VHall	BHayes	KQuinlan	JKanney	CRoque-Cruz
DATE	04/23/2015	05/06/2015	05/05/2015	05/06/2015	05/11/2015
OFFICE	NRR/JLD/JERB/BC	NRR/JLD/LA*	NRO/DSEA/RHM1/BC	NRR/JLD/JHMB/BC	NRR/JLD/JHMB/PM
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DATE	05/18/2015	05/12 /2015	05/14/2015	05/18/2015	05/19/2015

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AUDIT REPORT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

OF APPLIED WEATHER ASSOCIATES, LLC

REGARDING SITE SPECIFIC PROBABLE MAXIMUM PRECIPITATION DEVELOPMENT

IN SUPPORT OF NEAR-TERM TASK FORCE

RECOMMENDATION 2.1 FLOOD HAZARD REEVALUATIONS

BACKGROUND

By letter dated March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information to all power reactor licensees and holders of construction permits in active or deferred status, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.54(f) “Conditions of license” (hereafter referred to as the “50.54(f) letter”). The request was issued in connection with implementing lessons-learned from the 2011 accident at the Fukushima Dai-ichi nuclear power plant as documented in The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident. Recommendation 2.1 in that document recommended that the staff issue orders to all licensees to reevaluate seismic and flooding for their sites against current NRC requirements and guidance. Subsequent Staff Requirements Memoranda associated with Commission Papers SECY 11-0124 and SECY-11-0137, instructed the NRC staff to issue requests for information to licensees pursuant to 10 CFR 50.54(f).

General Design Criterion 2 in Appendix A of Part 50 states that structures, systems, and components important to safety at nuclear power plants must be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, floods, tsunami, and seiches without loss of capability to perform their intended safety functions. The design bases for these structures, systems, and components are to reflect appropriate consideration of the most severe natural phenomena that have been historically reported for the site and surrounding area. The design bases are also to have sufficient margin to account for the limited accuracy, quantity, and period of time for which the historical data have been accumulated. NUREG-0800, “Standard Review Plan,” states that the staff’s estimates of flooding potential are based on Probable Maximum Precipitation (PMP) estimates from appropriate Hydrometeorological Reports (HMRs) published by the National Oceanic and Atmospheric Administration (NOAA).

The NRC staff is reviewing reevaluated flooding effects for operating reactor sites using present-day information. A number of NRC licensees have submitted, or are planning to submit, Flood Hazard Reevaluation Reports (FHRRs) that contain site-specific probable maximum precipitation (ssPMP) estimates. The ssPMPs can be used as input for estimating site flooding due to short-duration, local intense precipitation (LIP) storm events, and/or longer-duration watershed scale (WS) storm events.

Applied Weather Associated, LLC (AWA) has performed the analyses for all sites that have chosen to submit ssPMPs as part of FHRRs. The NRC staff conducted this regulatory audit of AWA to inform its generic review of ssPMPs. This audit did not focus on any particular FHRR submittal. The results of this regulatory audit will serve as the foundation for staff's review of ssPMP estimates submitted in FHRRs, which may involve future regulatory audits.

AUDIT ACTIVITIES

The audit was conducted at NRC Headquarters in Rockville, MD on Monday, February 23, 2015 through Wednesday, February 25, 2015. On March 11, 2015, the NRC staff conducted a webinar with AWA to gather additional information. The NRC audit team staff present was as follows:

Title	Team Member
Team Leader, NRR/JLD	Victor Hall
Branch Chief, NRR/JLD	Sheena Whaley
Technical Lead	Barbara Hayes
Technical Support	Carla Roque-Cruz
Technical Support	Scott DeNeale
Technical Support	Joseph Kanney
Technical Support	Shih-Chieh Kao
Technical Support	Kevin Quinlan

The audit focused on evaluating AWA's general methods, software, and evaluation of key storms that drive ssPMP estimates for specific regions. The technical objectives of the audit included evaluating and assessing AWA methods for:

1. Validation and verification of software used by AWA to analyze storm data;
2. Identifying and quantifying actual and potential storm moisture sources;
3. Determining storm transposition limits;
4. Adjusting available moisture during storm transposition, and;
5. Key areas where professional judgment is used.

AUDIT SUMMARY

The NRC staff conducted an audit of AWA methods for determining ssPMP estimates for both LIP and WS PMP. The audit successfully addressed each of the topics listed in the audit plan (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15041A080) and identified areas in the AWA process that may be applicable to all of its PMP studies. In these areas the staff may be able to generically resolve any concerns, and thus reduce the number of requests for additional information (RAIs) for its FHRR reviews. The staff also identified areas where case-by-case information that will be necessary to complete its reviews. This audit report summarizes the NRC staff's observations and highlights the areas where additional information may be needed to complete the FHRR reviews. This report does not constitute NRC endorsement of AWA's program. AWA does not maintain a quality assurance program that meets the requirements of Appendix B, "Quality Assurance Program Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities."

The audit team discussed previous review and acceptance of AWA PMP estimates by other entities. AWA's work has been reviewed and accepted by other State and Federal agencies for dam safety studies and state-wide PMP studies. The audit team noted that the context of previous audits by other entities should be examined in order to draw any conclusions related to the 50.54(f) letter. This audit report includes details regarding AWA procedures and the use of professional judgment that is not available in other public reports.

1. Storm Precipitation Analysis System

   a. Audit Scope

   The audit team used the following set of questions to discuss Software Quality Management and Verification of the Storm Precipitation Analysis System (SPAS) system, which is the software used by AWA to analyze storm data:

      a. Describe what internal controls were and are included in the development, maintenance and addition of new functionality for SPAS.

      b. Describe any quality management system standards such as International Standards Organization (ISO) 9000 or American Society of Mechanical Engineers NQA-1 that AWA adheres to either for development and maintenance of the SPAS system or for ssPMP estimation projects.

      c. Describe how to verify SPAS storm depth-area-duration (DAD) curves for:
         i. Pre-radar period
         ii. Post-radar period

      d. Has an independent verification of SPAS been performed and are the results available?

      e. Has AWA done internal verifications of SPAS using NOAA HMR or other reports to demonstrate consistency of results with similar established ssPMP or other projects?

      f. Has SPAS and/or SPAS results been presented in peer reviewed journals?

      g. Be prepared to discuss reviews of ssPMP products done by states, or other federal entities.

   b. Observations

AWA provided a description of the SPAS software and its development. The purpose of SPAS is to process precipitation data (e.g., point rain gauge observations and gridded radar data) and generate Depth-Area and Depth-Duration curves, as well as DAD tables. SPAS is not a unitary software application. Instead, it is a collection of Geographic Resources Analysis Support System Geographic Information Systems (GIS) modules in combination with Python scripts used to automate workflow (data input, output, formatting, etc.). SPAS is a Linux-based package and was developed jointly by AWA and MetStat in 2002.

AWA stated that a version control system (Apache Subversion) is used for software versioning and source code control. However, AWA did not implement a verification and validation (V&V) program, or apply 10 CFR Part 50, Appendix B controls for development of the software.

AWA stated that it performed a limited verification procedure for the initial version of SPAS and repeated the procedure for major software revisions. The verification procedure consisted of reproducing the DAD table for a single synthetic storm with a simple, well-defined spatial and temporal precipitation distribution (referred to as the "Pyramidville storm"). AWA performed additional testing for these revisions by generating DAD output for two previously analyzed storms (Westfield, MA and Ritter, IA). This testing included adjustment using professional judgment to match the SPAS output to the published DAD tables. AWA stated that when a new version of SPAS is developed, previously analyzed storms are routinely re-analyzed using the new version. AWA stated that differences of ± 5- to 10-percent in DAD amounts have been observed in these comparisons.

AWA stated that SPAS has been reviewed and approved in various settings such as the Board of Consultants (BOC) process used in Federal Energy Regulatory Commission (FERC) dam safety studies and Technical Review Boards (TRBs) used by several states for dam safety studies and for state-wide PMP studies. AWA noted that the FERC BOCs typically consisted of a team of two to three people, including one meteorologist or climatologist. For State studies, TRBs are typically similar in composition to FERC BOCs, however, some TRBs have included two meteorologists or climatologists.

c. <u>Conclusions</u>

The NRC staff did not identify any open items regarding AWA's use of the SPAS software. The audit team noted that Verification and Validation of SPAS has not been performed. The staff did not identify any issues for the use of SPAS for the purposes of its ongoing FHRR reviews. As part of its future reviews, the staff may review past reports from BOCs and TRBs to determine the level of review and scrutiny applied to SPAS for each referenced study. The staff may also examine the level of documentation, independence and relevance of past reviews by BOCs and TRBs as they relate to FHRR review needs.

2. Identification of Moisture Sources

a. Audit Scope

The audit team used the following set of questions to discuss identifying and quantifying actual and potential storm moisture sources:

a. Demonstrate the usage of the NOAA Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (http://ready.arl.noaa.gov/HYSPLIT.php) using selected storms.

b. Describe the subjective judgments of storm representative dew points selection along HYSPLIT tracks. In particular, when multiple gauges are co-located in the region of moisture sources, what are the criteria to follow?

c. Describe the current collection of historic dew point data (for both gauges and sea surface temperatures). In particular, describe the sufficiency of this data to support dew point selection.

d. Describe the rationale to examine 6-, 12-, and 24-hour average dew points rather than 12-hour persistent dew point used in NOAA's HMRs. Also explain the reason for selecting 6-, 12-, and 24-hour rather than some other durations. Has a comprehensive analysis been conducted and peer-reviewed to support the conversion from 12-hour persistent dew point to average dew point? In at least one submission, 7-degree °Fahrenheit (F) was added onto the U.S. Army Corps of Engineers (USACE) Black Book storms which may result in an over 30 percent reduction of PMP depth. Explain the rationale for this addition, whether it follows standard practice within AWA's approach, and whether it applies to other sites or studies.

e. Describe further related data requirements for site-specific PMP reviews, e.g.,
    i. HYSPLIT map of each short list storm
    ii. The original data of storm representative dew point

b. Observations

AWA demonstrated the use of the NOAA HYSPLIT model and indicated that it typically used the wind data from National Centers for Environmental Prediction (NCEP) global re-analysis version 1 to drive HYSPLIT. The purpose of this HYSPLIT analysis is to generate trajectories backtracked from the storm center at three different levels in the atmosphere. AWA uses these trajectories to identify a search region from which a representative storm dew point temperature can be selected, either from weather stations (on land) or from ship/buoy reports (on ocean). AWA's selection of this search region is determined by backtracking along the storm trajectories from the storm center to a point representative of the storm's moisture source (typically a lead time after which approximately 90 percent of the storm's rainfall occurs). Given that NCEP reanalysis version 1 is unavailable before 1948, AWA applied HYSPLIT analysis for post-1948 storms.

The final determination of what stations to use in assigning the storm representative dew point temperature is subject to professional judgment. AWA explained that the localized area of storm representative dew point temperature is selected based on a few general assumptions, including specifically that the moisture source responsible for a historically extreme rainfall event should correspond with a historically high dew point temperature and should be noticeable across multiple gauge stations for consecutive hours. AWA stated that it does sensitivity analysis to ensure that it chooses an appropriately conservative dew point temperature. AWA noted that, for all else being equal, a lower storm representative dew point temperature would result in a higher in-place moisture maximization adjustment to the observed precipitation compared with a higher storm representative dew point temperature.

AWA illustrated its "observational data sheet" that included various dew point temperature gauges in the moisture area projected by HYSPLIT, including specific gauges identified as the area of storm representative dew point temperature.

AWA applied its professional judgment to identify the storm moisture source and associated dew point temperature, which impacts PMP estimates. Instead of using maximum 12-hour persisting dew point temperatures at gauge locations to assign the storm representative dew point temperature (as used by National Weather Service (NWS) in various HMRs), AWA uses a maximum 6-, 12-, or 24-hour average dew point temperature. AWA stated that the choice of which averaging window used is based on the storm duration and that this approach is more appropriate than using a maximum 12-hour persisting dew point temperature for all storms. Applying this approach is straightforward when hourly dew point data is available. For storms without hourly dew point information available, AWA described its method for converting maximum 12-hour persisting dew point temperatures to 6- 12-, or 24-hour averages. AWA described the development of this method as part of an Electric Power Research Institute (EPRI) sponsored study (EPRI, 1993[1]). This heuristic method was developed and tested primarily using storms in the central United States. The main use of the method is to add 7 (or 2) degrees °F to the maximum 12-hour persisting dew point temperature to approximate maximum 6-hour (or 12- and 24-hour) average dew point temperatures (the smaller addition being more conservative). The heuristic's applicability to storms occurring along the Gulf and Atlantic coasts has not been investigated since observation data are typically sufficient, making such an adjustment unnecessary. AWA noted that one Atlantic coast storm, Jewell, MD (July 26, 1897), has received the 7 degree °F dew point adjustment.

AWA performed a demonstration of its heuristic using its analysis for Boyden, IA storm (September 17, 1926). The staff noted that the choice of what storm representative dew point temperature adjustment to apply had an effect on the in-place moisture maximization

[1] EPRI, 1993, TR-101554-V1 and TR-101554-V2; Probable Maximum Precipitation Study for Wisconsin and Michigan: Volumes 1 and 2, prepared by North American Weather Consultants. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=TR-101554-V1

result (approximately 30 percent higher with a 2 degree °F adjustment vs a 7 degree °F adjustment), which highlighted the importance of professional judgment for the selection of a representative duration. This could have a significant impact on LIP estimates for which most storms would include a 7 degree °F adjustment. This process has been reviewed by previous BOCs or state TRBs.

c. Conclusions

The NRC staff did not identify any open items regarding AWA's identification and quantification of actual and potential storm moisture sources. As part of its future reviews, the staff may review the dew point temperature adjustment on the controlling storms for each ssPMP. The 2 degree °F vs 7 degree °F adjustment is made on a storm-by-storm basis and should be independent of the study being evaluated. Since a significant amount of storms should not require this adjustment and many of the nuclear power plant sites across a region will have the same controlling storms, this may not be needed on a site-by-site basis, and may be done on a regional scale.

The staff noticed that the detailed hourly dew point temperature observation, as documented in the "observational data sheet," can help the staff evaluate AWA's ssPMP calculation more effectively. Such spreadsheets of storm representative dew point calculation will likely be requested during the review of FHRRs on a case-by-case basis.

3. Maximum Dew Point Climatology

a. Audit Scope

The audit team used the following set of questions to discuss maximum dew point climatology:

a. Describe the most current methodology in SPAS. So far, the most detailed description was only provided in the New England (NE)/Arizona (AZ) PMP reports. Were these maximum dew point climatology maps peer-reviewed?

b. Describe the procedures to select annual maximum dew point series at each gauge. How many years of records in general do these stations have and what is the minimum length of record.

c. Explain the purpose of "15th of the Month Adjustment" referenced in the NE PMP report. Was this done on the sample level, or conducted after fitting of a generalized extreme value (GEV) distribution?

d. Describe the procedures of GEV fitting. Has any goodness-of-fit tests been conducted to verify the results?

e. Describe the applicability and necessity of PRISM-based spatial interpolation. If a gauge station with estimated maximum dew point is available in the region of moisture sources, how would PRISM values compare? Also, discuss whether the current approach could result in excessive smoothing the maximum dew point climatology maps.

f. Describe further related data requirements for site-specific PMP reviews, e.g.
   i. Work sheet at gauge level (before spatial interpolation).
      1. Annual maximum dew point
      2. GEV fitting
      3. Goodness-of-fit test
      4. For each short list storm, this information should be provided for gauges nearest to the locations where the dew climate climatology is looked up for moisture maximization
   ii. Interpolated maps and analysis of bias at gauge locations

b. <u>Observations</u>

AWA described its method for maximum dew point climatology map development (AWA does not perform this analysis in SPAS). As with the storm representative dew points, AWA uses the maximum 6-, 12-, and 24-hour average dew point temperatures as opposed to the maximum 12-hour persistent dew point temperature used in most of the HMRs. As with the HMRs, these data are used to produce monthly dew point climatology maps for application across most of the conterminous United States; however, AWA's dew point climatology maps are based on 100-year average return interval dew point temperatures instead of maximum observed dew point temperatures used in the HMRs.

While generally described in the Nebraska state-wide PMP study final report, AWA's method for deriving the dew point climatology maps (which include continental United States, except for the West Coast and portions of South West for smaller time periods) was detailed during the audit.

AWA's approach consists of the following steps:

1. Extraction and calculation of annual maximum series (AMS) of monthly maximum dew points at each gauge station averaged to 6-, 12-, and 24- hour (data downloaded from the National Climactic Data Center, Integrated Surface Database (http://www.ncdc.noaa.gov/isd); and updated every 6 months.) AWA also performs quality control of these series to remove potential outliers and erroneous observations. These checks consist of visual inspection of histograms with a focus on the upper and lower 5-percent tails.

2. Calculation of the L-moment statistics (using the Hosking and Wallace method noted in "Regional Frequency Analysis: An Approach Based on L-Moments," Cambridge University Press).

3. AWA uses L-moment ratios as a guide to choose the GEV distribution (BOC review typically occurs at this point).

4. Extraction of 20-, 50-, and 100-year return interval maximum monthly dew points for each of the 6-, 12-, and 24-hour averages.

5. Adjustment of each of the maximum dew points to the 15th of the month: For each calendar month, assume that the estimated 20-, 50-, and 100-year dew points occur on the average occurrence date of all AMS. For example, if there are 35 years of maximum 6-hour May dew point data available for GEV fitting, their average occurrence day (say May 24th) is treated as the most likely occurrence date of the estimated 20-, 50-, and 100-year dew point. Linear interpolation across adjacent calendar months (i.e. April through June) is then performed to estimate the 20-, 50-, and 100-year maximum dew points occurring on the 15th of each month.

6. Adjustment to 1000 mb (i.e., adding 2.7 °F per 1000 ft elevation).

7. Spatially interpolate the maximum monthly 20-, 50-, and 100-year dew points using PRISM[2] gridded 30-year average monthly dew point data as a base map.

8. Automated smoothing using a block filter method (5x5 or 9x9 grid cells).

9. Manual smoothing using professional judgment (BOC review occurs at this point).

Staff noted that the PRISM dew point data is not adjusted to 1000 mb before being used for interpolation. This use of an unadjusted dataset for spatial interpolation of adjusted observed data may increase the need for manual smoothing, which includes professional judgment. The staff also observed that AWA did not perform the standard goodness-of-fit test, as suggested by Hosking and Wallis (2005)[3].

Staff noted that AWA chose to interpolate using PRISM data followed by two rounds of smoothing, instead of performing direct regional frequency analysis of dew point data. Regional frequency analysis is a widely used tool for estimating values at ungauged locations and is used by NWS for analysis of precipitation and by U.S. Geological Survey (USGS) and others for the analysis of peak flow.

c. Conclusions

The NRC staff did not identify any open items regarding maximum dew point climatology. The staff may request further sensitivity analysis for the impact of smoothing using unadjusted PRISM dew point data and if using the standard goodness-of-fit test has a significant impact on the final dew point climatology maps.

The staff may review past reports from BOCs and TRBs to determine the level of review and scrutiny applied to the dew point climatology map development, specifically related to the use of PRISM and manual smoothing.

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[2] PRISM Climate Group (www.prism.oregonstate.edu)
[3] Hosking and Wallis (2005), Regional Frequency Analysis: An Approach Based on L-Moments, Cambridge University Press

4. Storm Selection and Transposition

a. Audit Scope

The audit team used the following set of questions to evaluate AWA's determination of storm transposition limits:

a. Describe the storm screening methodology

b. Describe explicit vs. implicit transposition

c. Discuss how features of the large-scale atmospheric circulation (e.g., semi-permanent high-pressure systems, oscillations such as El Niño–Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO)) inform assignment of transposition limits.

d. Describe further related data requirements for site-specific PMP reviews, e.g.
   i. Long list (including all applicable HMR and Black Book storms)
   ii. Justification if not included in the short list

e. Describe the procedures for storm selection. Ultimately we would like to establish a workflow to check if all storms have been considered in a particular ssPMP study. Discuss:
   i. Considerations for storm selection for watershed-scale PMP
   ii. Considerations for storm selection for local intense precipitation

f. Discuss storm transposition limits

g. Discuss further documentation of storms that are omitted from short lists.

b. Observations

AWA described its initial screening process to develop the "long list" of storms for a specific study. There is little change in the long list from study to study, at least within homogeneous physiographic regions and for similar storm type and areas impacted. Sources of information for the long list include:

- HMRs
- USACE storm reports
- USGS flood reports
- journal articles
- books
- discussions with NWS personnel and state climatologists
- previous AWA studies

- a search of the NOAA Meteorological Assimilation Data Ingest System (MADIS) database for additional storms which, in general, exceed 100 year recurrence interval storms

AWA develops an initial “short list” of storms by considering which storms in the long list have the potential of being transpositioned to the area of interest. Considerations include location and seasonality of moisture sources, potential barrier effects, storm dynamics (such as changes in vorticity with latitude), topographic effects and general circulation patterns. Where available, AWA uses information from previous studies (e.g., HMR and previous AWA studies). For example, AWA described its use of maps from the working notes of the authors of HMR51, which illustrated transposition limits that were used in discussions by the NWS for important storms. After the initial short list has been discussed and reviewed (typically by the FERC BOC or state TRB), AWA formed a final short list for the further calculation of moisture maximization, transpositioning, and envelopment.

The staff asked how AWA’s storm selection differs between LIP and watershed studies. AWA explained that the two procedures are similar, but that storm duration and area play an important role. For example, for watersheds of less than 500 square miles, storms that include short duration/high intensity precipitation are the focus. Conversely for watersheds greater than 5,000 square miles, storms with long duration/high cumulative precipitation over large areas are the focus.

Factors that AWA uses related to the transposition limits and the final selection of storms on the short list include:

- Storms should not be transpositioned across significant barriers (e.g., Appalachian and Rocky Mountain ranges).

- Storms should not be transpositioned more than 5 or 6 degrees of latitude due to changes in storm dynamics (e.g., vorticity).

- Storms should not be transpositioned over unreasonable distances from moisture sources, and closest quality data should be used (e.g. storms associated with coastal hurricane flooding may be restricted from inland transpositioning).

- Storms types which would not occur in the area of interest may not be applicable (e.g., an extreme rainfall event occurring in March in the South-Central plains may not be appropriate for consideration in the Upper Midwest).

In previous AWA studies, the FERC BOC or State TRB was involved in the development of the final short list of storms used in estimating the PMP.

AWA demonstrated knowledge of how oscillations in the climate system (NAO, ENSO) may have influenced the behavior of specific storms; however, these oscillations are not used to inform explicit transposition limits.

AWA explained that "implicit transposition" refers to enveloping via smoothing across large areas for generalized PMP values as done in HMRs.

AWA discussed documentation on justifications for storms that were omitted from the final short list and showed one study's spreadsheet that contained columnar criteria used to screen/exclude storms. AWA explained that some storms had been excluded because they had been excluded in a previous study in a similar area.

c. Conclusions

The NRC staff did not identify any open items regarding AWA's determination of storm transposition limits. During the audit, AWA committed to provide a detailed outline of its workflow, which should help identify specific file requests to be made for "smart sampling" AWA's ssPMP process (i.e., a spreadsheet with the complete list of storms that have been considered during the development of ssPMP, including both the initial long list and the final short list, and a brief justification of why some major storms were omitted). The staff plans to use this information for its FHRR reviews.

5. Storm Envelopment

a. Audit Scope

The audit team used the following set of questions to evaluate AWA's adjustment of available moisture during storm transposition:

a. Discuss if undercutting can be allowed with regards to
    i. Envelopment across duration and area at individual points of analysis in the basin.
    ii. Envelopment across a region.
    iii. Describe further related data requirements for site-specific PMP reviews

b. Summary table stating when undercutting occurred and the corresponding meteorological justification.

c. Explain DAD envelopment as it was applied in the Nebraska statewide PMP study.

b. Observations

AWA presented the general approach for Depth-Area and Depth-Duration envelopment. AWA explained that its analyses never undercut storms (i.e., all relevant storm data points are bounded by the envelopment curves). AWA noted that it uses data in such a way as to maintain accuracy to the greatest extent possible. AWA explained that if envelopment results appeared questionable, it would review the previous steps for any key storms rather than consider undercutting. AWA stated this process has been reviewed by BOCs or state TRBs.

c. Conclusions

The NRC staff did not identify any open items regarding AWA's adjustment of available moisture during storm transposition. The staff may confirm that relevant storm data points are bounded by the envelopment curves for each FHRR.

6. Topographic Effects

a. Audit Scope

The audit team used the following set of questions regarding topographic effects:

a. Demonstrate AWA method for moisture adjustment for orographic regions including:
   i. Development and application of orographic transposition factor (OTF)
   ii. Use of precipitation frequency and climatology data including data sources, data properties (e.g., resolution, accuracy)
   iii. Use of topographic data including data sources, data properties (e.g., resolution, accuracy)
   iv. Detailed walk through for 2-3 case studies
   v. Description of scenarios under which the OTF would be implemented and why.

b. Demonstrate AWA method for moisture inflow barrier analysis including:
   i. Terrain elevation data set properties (e.g., resolution, accuracy)
   ii. GIS method for terrain analysis
   iii. Subjective aspects of determining "effective barrier height"
   iv. Provide quantitative examples of how implementing the effective barrier height influences the precipitation amounts.

b. Observations

AWA explained the development of the OTF and demonstrated how it is calculated and applied. AWA stated that the OTF been applied in AWA PMP studies for some sites. AWA referenced the AZ state-wide PMP study for general documentation of the OTF. AWA's development of the OTF was in reaction to the storm separation method used in HMR 55A, 57, and 59. AWA's judgment is that the development of the storm separation method in HMRs is not well documented, and the results obtained are not reproducible.

AWA described its OTF calculation approach and demonstrated the process using the Tennessee Valley Authority (TVA) watershed as an example (e.g., transpositioning the Smethport storm to the eastern Tennessee mountainous area). The OTF does not directly account for orography. Instead, it uses the variation in precipitation frequency between two points as a surrogate for differences in orographic influence on precipitation between these points. The orographically adjusted rainfall for a given storm at a target location is calculated by applying a coefficient of proportionality, determined by the relationship between NOAA Atlas 14 precipitation frequencies at the source storm location and the corresponding NOAA Atlas 14 precipitation frequencies at the target location. To develop this relationship for a particular duration, rainfall values for each location are determined across multiple recurrence intervals (typically ranging from 10 to 1000 years) using NOAA Atlas 14 data. The resulting values are plotted against each other, and a linear fit is performed. AWA explained that the typical duration used varies by study but is generally either 3 or 6 hours for small, high-intensity storms and 24 hours for larger storms. The underlying assumption is that the OTF's derived relationship is primarily a function of elevation effects, though barrier effects and climatology also play a role.

The OTF functions as an additional multiplicative factor applied to the observed rainfall in addition to the product of the in-place moisture maximization factor and the moisture transposition factor. Generally, storm transposition from less topographic to more topographic areas results in an OTF greater than one. The OTF is less than one when storm transposition is from more topographic to less topographic areas.

AWA explained that the transposition limits of OTF are storm dependent. The NOAA Atlas 14 divides the analysis region into meteorologically homogenous zones and may use different regional probability distributions to model precipitation frequency in each zone, but the OTF does not account for this. AWA applies OTF anywhere within a storm's transposition limits.

The NOAA Atlas 14 has been developed in stages (multiple volumes), with each volume providing updated precipitation frequency information for a given region. Results are not currently available for some regions of the United States (e.g., the Northeast, Texas, and the Pacific Northwest). In areas where NOAA Atlas 14 volumes have not been completed (i.e., contemporary precipitation frequency information is not available to support OTF), AWA uses a barrier approach to account for topographic effects. In general, AWA considers OTF to be the preferred method where precipitation frequency information is available. The barrier approach generally follows the methods described in various HMRs. The functionality of GIS has facilitated the rapid and accurate assimilation of elevation data. The barrier approach assigns an effective barrier height to topographic features between the basin of interest and the moisture source. The effective barrier height is determined by visually assessing the maximum and average barrier height with consideration of significant gaps in the barrier. The final determination involves significant professional judgment and a BOC/TRB is generally involved. AWA typically uses terrain elevation data from USGS National Elevation Dataset for barrier analysis. AWA has not done a comparison between OTF and barrier adjustment approaches.

c. <u>Conclusions</u>

The NRC staff did not identify any open items regarding topographic effects. The staff noted that the performance of fitting (e.g., R-square) could be one factor to judge the applicability of OTF. The staff also noted that the OTF is not purely based on orographics and may double count moisture adjustment since the influence of climatology is retained when using precipitation frequency analysis. The Wyoming statewide PMP report also documents its BOC's concern on this topic. The staff may review past reports from BOCs and TRBs to determine the level of review applied to the OTF, specifically related to the potential overlap among various rainfall adjustment factors

The staff observed that the OTF approach should reflect the impacts of topography in a climatological average sense. However, its accuracy in capturing topographic effects on PMP level storms has not been established. In addition, while it is demonstrated that the OTF fitting performed well for transpositioning storms between locations within the same NOAA Atlas 14 L-moment homogeneity region, it was not demonstrated that such a linear relationship will hold when transposing storms across multiple homogeneity regions. Further justification may be necessary for specific applications of interest.

The staff may review past reports from BOCs and TRBs to determine the level of review and scrutiny applied to the OTF, specifically related to the ability of a linear fit to represent OTF between different homogeneity zones. This may require site-by-site review.

Finally, the staff may perform a sensitivity analysis to determine the impact of assuming a linear fit between different homogeneity zones.

7. Sensitivity Analysis to Specific Storms

a. Audit Scope

For the ssPMP estimates (LIP and WS) for Indian Point Energy Center (IPEC) and the suite of Exelon sites in Illinois, the Smethport storm is a key driver in HMR values that is not included in the AWA storm short lists. The staff requested AWA to provide a sensitivity analysis to these results relative to the inclusion of the Smethport storm with variation related to amounts of undercutting. The staff requested that AWA identify transposition limits for this storm and explain how they were developed.

The staff asked AWA to describe the regions in which they are likely to influence ssPMP estimates, as well as explicit and implicit transposition limits for each, for the storms of interest. Finally, the staff requested that AWA define the appropriate scales of application: generalized estimates, watershed-based estimates, and local intense precipitation estimates.

b. Observations

AWA stated that the Smethport, PA storm was not included in the IPEC LIP and watershed storm short lists because it would be inappropriate to transposition this storm across the Appalachian Mountains to either the watershed centroid upstream of IPEC or to the IPEC site itself. AWA explained that transpositioning the Smethport storm, as was done in HMR51, would have a significant impact on ssPMP estimates. AWA added that such a sensitivity analysis would be easy to do and discussed its rationale for the transposition limits for the Smethport storm, referencing HMR51 and NWS internal working documents. AWA additionally referenced a recent article (Smith et al. 2011)[4] that supported its findings regarding the relatively small transposition limits for the Smethport, PA and Tyro, VA storms.

[4] James A. Smith, Mary Lynn Baeck, Alexandros A. Ntelekos, Gabriele Villarini and Matthias Steiner, Extreme rainfall and flooding from orographic thunderstorms in the central Appalachians, Water Resources Research, April 2011, http://onlinelibrary.wiley.com/doi/10.1029/2010WR010190/pdf

AWA discussed transposition limits regarding the following specific storms as follows:

- AWA outlined transposition limits for Slide Mountain, NY, Alley Spring, MO, Warner, OK.

- Tyro, VA: Tyro was also not on the IPEC short list or on the shortlist for Calvert Cliffs. Transposition is limited due to the Appalachian Mountains. AWA anticipates that Tyro will be in the shortlist associated with the Catawba watershed.

- Yankeetown, FL: AWA stated that they adopted the transposition limits established in HMR51 for this storm (along the Gulf Coast and along the Atlantic Coast as far north as Cape Hatteras, NC). However, AWA used sea-surface temperature (SST) data instead of dew point data to calculate the in-place moisture maximization factor.

- Hurricane Floyd (1999): Discussion centered on treatment of Floyd as 5 separate storm centers. Floyd is an important controlling storm for some areas of the Northeast.

c. Conclusions

The NRC staff did not identify any open items regarding sensitivity analysis to specific storms.

8. Uncertainty in ssPMP Estimates

a. Audit Scope

There is considerable uncertainty in PMP estimates. Until recently, there have been no systematic attempts to quantify this uncertainty. A recent paper (Micovic, et al. 2015)[5] identifies key variables which influence PMP estimates, discusses uncertainties in these variables and proposes a method for assessing overall PMP uncertainties. In light of the discussion and results presented in Micovic et al. (2015), the staff requested that AWA address the following topics:

a. How uncertainties in the key variables identified by Micovic et al. (2015) are addressed and accounted for in AWA ssPMP studies

b. Describe the level of uncertainty associated with AWA's ssPMP estimates and how they may vary by region or storm type.

b. Observations

AWA generally agreed with the key sources of uncertainties identified in the paper. AWA's approach to these uncertainties is to include conservativeness in their approach at the key

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[5] Micovic, Z., Schaefer, M. and Taylor, G. (2015), Uncertainty analysis for Probable Maximum Precipitation estimates, Journal of Hydrology, Vol 521, pp. 360-373, http://dx.doi.org/10.1016/j.jhydrol.2014.12.033

points of professional judgment while attempting to capture what is most representative, accurate and true to the data and nature of PMPs. AWA does not explicitly analyze or attempt to quantify these uncertainties. Examples of this conservatism are the processes of maximization and envelopment shared with the HMR development process. The staff asked AWA to compare the conservatism of a subset of their approaches to HMR:

- AWA uses the average storm representative dew point temperature rather than the 12 hour persisting dew point temperature. AWA acknowledged that this is less conservative than the HMRs but noted that it is more realistic.

- AWA breaks some large storms into smaller DAD zones. This, in general, is less conservative than using the total storm area as done in the HMRs. AWA acknowledged the lower conservativism but noted that it is more realistic, because it can better capture available information of moisture fluxes during the movement of storms.

- AWA limits the in-place moisture maximization factor when it exceeds 150 percent, which is consistent with the HMR development process. However, AWA does not undercut values as was done for Smethport in HMR51 and instead does further analysis regarding the storm in question.

With regards to measurement uncertainty, AWA noted that issues related to underestimation of rainfall at gauges affects HMR and AWA estimates equally. Available research indicates that each 1 mph increase in windspeed may result in approximately 1 percent undercatch. AWA noted the increased density of rain gauge data and the use of radar data in more recent portions of the database is captured by AWA for more recent storms.

With regards to level of uncertainty associated with AWA estimates by region, AWA noted that, in general, there is less uncertainty regarding PMP estimates for areas outside of the Intermountain West due to reduced density of measurements and complex orographic effects.

With regards to storm type, AWA stated that there is greater uncertainty associated with LIP type PMPs (high intensity/short duration storms). AWA also noted that generally, cool season PMP estimates have lower uncertainty because of less uncertainty in precipitation data for long duration/large area storms.

c. <u>Conclusions</u>

The NRC staff did not identify any open items regarding uncertainty in ssPMP estimates. For FHRR reviews, the staff may consider the impact of using average rather than persisting dew point temperatures, and breaking large storms into smaller DAD regions.

9. Climate Change

a. Audit Scope

Climate change has been associated with increases in extreme precipitation events. A recent report on climate change[6] relayed findings that significant increases in heavy precipitation events have been observed in the Northeast, Midwest and Great Plains and average United States temperatures are projected to increase from 2 to 4 degrees °F in most areas in the next few decades. Some approaches to extreme weather estimation (e.g., physically based regional atmospheric modelling as used in a recent paper[7]) are readily adaptable to nonstationary atmospheric processes that affect upper bounds to maximum precipitation.

The audit team used the following set of questions regarding climate change:

a. How are trends related to climate change addressed and accounted for in AWA's approach to estimating ssPMP?

b. Describe how this approach affects AWA's ssPMP estimates and the associated effects on the level of conservativeness. How might this vary by region or storm type?

c. Describe how a warmer and more humid climate affects moisture maximization methods for PMP type storms.

d. How may postulated changes of the climate affect the historical transposition limits of controlling storms?

b. Observations

AWA does not perform adjustments to reflect potential effects of climate change on PMP estimates, consistent with HMRs and the World Meteorological Organization report. AWA noted that the Manual on Estimation of Maximum Probable Precipitation (PMP), Report No. 1045, World Meteorological Organization, Geneva, Switzerland, 2009[8], does not recommend any adjustments. AWA stated that the rate of change in observed storms is slow and that periodically updating the database is an appropriate way to address climate change. AWA noted that a warmer and more humid climate, all other factors being equal, would increase the in-place moisture maximization factor and potentially increase

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[6] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2 (http://nca2014.globalchange.gov/downloads).

[7] Ishida, K., Kavvas, M., Jang, S., Chen, Z., Ohara, N., and Anderson, M. (2015). "Physically Based Estimation of Maximum Precipitation over Three Watersheds in Northern California: Relative Humidity Maximization Method." *J. Hydrol. Eng.*, 10.1061/(ASCE)HE.1943-5584.0001175 , 04015014.

[8] Manual on Estimation of Maximum Probable Precipitation (PMP), Report No. 1045, World Meteorological Organization, Geneva, Switzerland, 2009.

transposition limits. AWA also noted that response to climate change is complex and there could be counterbalancing effects. In AWA's estimation, there is no apparent trend regarding PMP level extreme precipitation that can be attributed to changes in the climate. AWA noted that older storms are still the controlling storms for many of its PMP studies.

c. Conclusions

The NRC staff did not identify any open items regarding climate change.

10. Selected Storms for Discussion

a. Audit Scope

The audit team selected several storms as general test cases. These storms covered various storm types, in which some have been included in the current FHRR submittals while others were only documented in NOAA HMR, the USACE Black Book, and the 2011 United States Bureau of Reclamation (USBR) report, "Review of Probable Maximum Precipitation Procedures and Databases Used to Develop Hydrometeorological Reports[9]."

Storm Name or Location	Storm Date	Storm Type	Note
Slide Mountain, NY	3/20/1980 – 3/24/1980	General (Cool Season)	IPEC WS cool season storm. (SPAS 1259)
Alley Spring, MO	3/17/2008 – 3/20/2008	General (Cool Season)	Quad Cities Nuclear Power Station (QCNPS) WS cool season storm. Specific questions related to the selection of storm representative dew point and dew point climatology.
Warner, OK	5/6/1943 – 5/10/1943	General (Warm Season)	QCNPS WS warm season storm. Specific questions related to the selection of storm representative dew point and dew point climatology.
Gorham, ME	10/19/1996 – 10/22/1996	General (Warm Season)	IPEC WS warm season storm. (SPAS 1025)
Edgerton, MO	7/18/1965 – 7/20/1965	General (Warm Season) / MCC[10]	QCNPS WS warm season storm. Specific questions related to the selection of storm representative dew point and dew point climatology.

[9] Review of PMP Procedures and Databases Used to Develop Hydrometeorological Reports, USBR report for the Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, John F. England, Jr., Victoria L. Sankovich, R. Jason Caldwell, 2011, ftp://s5ftp.usbr.gov/jengland/NRC/reports/Review_PMP_Procedures_SE_US.pdf

[10] Mesoscale Convective Complex (MCC)

Storm Name or Location	Storm Date	Storm Type	Note
Mounds, OK	5/15/1943 – 5/20/1943	MCC	Both QCNPS WS and LIP storms.
Tyro, VA	8/19/1969	MCC	USACE Black Book Storm (NA 2–23), not included in the current analysis for IPEC.
Port Allegheny, PA (Smethport)	7/17/1942 – 7/18/1942	MCC	World record rainfall event. Questions about transposition limits.
Yankeetown, FL (Hurricane Easy)	9/3/1950 – 9/7/1950	Hurricane	USACE Black Book Storm (SA 5-8), not included in current analysis for IPEC. Questions about transposition limits.
Zerbe, PA (Hurricane Agnes)	6/19/1972 – 6/23/1972	Hurricane	IPEC WS warm season storm.
Hurricane Irene	8/27/2011 – 8/29/2011	Hurricane	IPEC WS warm season storm (SPAS 1224)
Hurricane Floyd, areas of NC and VA	9/16/1999	Hurricane	

b. Observations

AWA discussed the storms listed in the table above. AWA provided detail for the controlling storms for many time durations in a given region (e.g., Slide Mountain, NY (cool season), Tyro, VA, Smethport, PA, Yankeetown, FL (Hurricane Easy), Zerbe, PA (Hurricane Agnes), and Hurricane Floyd (1999)). AWA provided the history of each storm and described how it analyzed each one for inclusion into the PMP reports. AWA described the synoptic setup and the resources available for analysis (e.g., analysis reported in HMRs, weather radar, rain gauges, etc.). AWA then showed how each storm was analyzed by SPAS to determine the depth-area and depth-duration curves, as well as the DAD tables. AWA explained the in-place moisture maximization for each storm, which included identification of moisture sources using HYSPLIT.

c. Conclusions

The NRC staff did not identify any open items regarding AWA's discussion on the list of storms.

11. Webinar Follow-up

a. Audit Scope

On March 11, 2015, the NRC staff conducted a webinar with AWA to gather additional information. Specifically, the staff focused on guidance that AWA has developed and provided on the application of PMP rainfall to watersheds for the purpose of developing probable maximum flood estimates. The staff asked questions on (a) how the guidance differs from that in the HMR(s); (b) the overall level of conservatism in the methods used; (c) range of uncertainty in the results; and (d) the sensitivity of the results to points of professional judgment. The audit team used the following set of questions for the webinar:

1. Please describe the extent to which AWA provided guidance on application of the PMP design storm to watersheds (i.e., for which sites has this guidance been developed).
    a. Has guidance on the same set of storm parameters (e.g., orientation, shape ratio, range of movement, temporal rainfall distribution) been prepared for each site?
    b. Does the guidance vary with region? If so what are the major differences from region to region?

2. Please describe the method for developing guidance on storm orientation
    a. Compare AWA's method to methods used in HMRs (in what sense is AWA method more or less conservative?)
    b. Were results compared to relevant HMRs?
    c. Describe any sensitivity analysis performed.
        i. Storm type/sample size
        ii. Average or typical dynamics and synoptic patterns vs the range observed in these parameters

3. Please describe the method for storm movement analysis
    a. Describe any sensitivity analysis performed.
        i. Storm type/sample size
        ii. Average or typical dynamics and synoptic patterns vs the range observed in these parameters
        iii. 12-hour increments vs 24 hour increments

4. Please describe AWA's guidance on temporal distribution
    a. Compare AWA's method to methods used in HMRs.
    b. Describe AWA's procedure for evaluating temporal distribution by storm type.
    c. Describe the application of temporal rainfall distribution and any sensitivity analysis performed.
        i. Moving storm
        ii. AWA guidance – results vs recommendations
5. BOC TRB evaluations – level of depth

b. <u>Observations</u>

AWA further described its approaches, methods used, and the types of recommendations provided for nuclear power plant related studies, as well as FERC and state studies. With respect to application of watershed scale PMP estimates for probable maximum flood analyses in storm orientation and storm movement, AWA has only performed analyses for

QCNPS and Arkansas Nuclear One FHRR submittals due to the very large upstream watersheds associated with those sites. For all other nuclear power plant related studies completed to date, AWA considers the HMR recommendations for storm orientation to be appropriate and recommends a stationary storm as opposed to a moving storm.

Among its nuclear power plant related, FERC, and state studies, AWA has primarily limited its temporal distribution analysis to LIP evaluations, and in most cases, the additional analysis that has been conducted does not support guidance different from the HMR recommendations.

While most AWA studies have not provided updated storm orientation, movement, or temporal distribution recommendations compared to the HMRs, AWA noted the following:

- For storms in the West, temporal and spatial rainfall distributions range widely and AWA assessed that there is not enough information to warrant deviation from practices established in the HMRs.

- For short, intense storms, back-end-loaded temporal distributions are generally not appropriate in the East. The staff noted that HMRs for Western regions suggest that back end loaded storms are rare for the West as well.

- The AZ study provided a recommended temporal distribution for LIP-like storms.

- The Wyoming study did not result in temporal changes but some additional analysis is planned to address BOC concerns.

- The Nebraska study resulted in changes to the recommended storm orientation, but there were no changes to temporal distributions.

- TVA is an exception since the analysis is based on a gridded approach which differs from the original HMR approaches and is only applicable to TVA watershed locations.

Regarding storm orientation, AWA's approach generally followed the HMR approach (e.g., HMR52 sections 3 and 4). Relevant storms that have been evaluated in SPAS are analyzed by fitting an elliptical shape (an inherently subjective process) and identifying the major and minor axes of the ellipse. Important differences in application are as follows:

- HMR52 is regional and nuclear power plant related watershed studies involve a more clearly defined subarea. Therefore, the collection of storms that AWA used for the purpose of storm orientation guidance is generally smaller than those used in HMR52.

- HMR52 uses a "minimum range" approach (e.g., section 4.2) to identify what numbering convention to use when averaging the storm orientation among multiple storms, while AWA stated that they use an "average" approach. The staff noted that this approach should generally be the same when the predominant storm orientation range is East-West rather than North-South (i.e., a false average would not be of concern) and that the end result of both processes would be the same, given care is taken.

- HMR52 does not distinguish between all-season and cool-season storm orientation, while AWA explicitly captures these differences, where appropriate. AWA described its rationale for the differences in typical orientation between all-season and cool season extreme storms (differences in persistent synoptic weather patterns).

AWA noted that the number of storms is limited, particularly for the cool season PMP estimates. For example, only three cool season storms were used for the QCNPS watershed. AWA did not add additional storms from the long list in order to increase sample size or use additional storms for sensitivity analysis for the following reasons:

- Only storms processed in SPAS were considered appropriate for analysis.

- The restriction to short list storms ensures that PMP-type storms are represented and do not become misrepresented by lesser storms.

- The orientation was qualitatively compared to HMR52 results, with similar results to support their approach and conclusions.

- The general trend in storm orientation is captured with just a few storms, and qualitative comparison suggested the predominant storm synoptic patterns were captured.

- As with the HMRs, the number of actual storms evaluated to derive the smoothed curves was limited (e.g., in HMR52, only three storms with orientation are near the QCNPS sites and two storms are near the Arkansas Nuclear One site). The smoothed curves presented in HMR52 Figure 8, were developed based on only 31 storms east of the 105th Meridian.

Regarding storm movement, AWA described its approach using QCNPS as an example. For a given study, AWA analyzed each critical storm by identifying the storm center location at both 12- and 24-hour increments and evaluating travel distances for each increment. The longest travel distance for each storm was recorded and then averaged with the other storms' distances. For QCNPS, results from the 24 hour analysis were ultimately adopted because AWA considered that more appropriate for the storm types. However, AWA noted that the 12 hour analysis and 24 hour analysis provided similar results. Analysis across storms suggested that storm speed tended to vary during the overall travel time of each storm but that no consistent pattern was apparent. AWA provides recommendations to hydrologists consisting of an average and range of storm velocities for both all-season and cool-season PMPs. The hydrologists are then responsible for assessing different options, conducting sensitivity analysis, and applying a conservative approach. AWA provides feedback to ensure appropriate final application.

With regard to seasonality, AWA stated that cool weather storms tended to travel faster, which is consistent with AWA's expectations related to storm dynamics.

AWA noted that for Arkansas Nuclear One and QCNPS, its findings demonstrated that storm movement would generally align with the downstream direction of the watershed. While this would generally result in higher river flows, the finding was the byproduct of storm analysis without any preconditioned intent to add conservatism.

Regarding temporal distribution, AWA discussed its storm-based approach for small, high-intensity (e.g., LIP) storms evaluated in some nuclear power plant related and state studies. Its approach followed the general approaches described in HMR52, and both were generally constrained by the availability of hourly data. The availability of weather radar data, typically on 5 minute intervals, has improved the database but only for more recent storms. Storms were evaluated by identifying the 6-hour period with the maximum rainfall, evaluating the rainfall depth at one hour increments, and evaluating the temporal distributions, classifying each storm as either front-loaded, center-loaded, or end-loaded. AWA stated that, based on their analysis, either front-loaded or center-loaded temporal distributions should be used. Their analysis did not support use of end-loaded distribution.

With regards to temporal distribution of the one hour peak rainfall period for one square mile, AWA noted that sample size was based on point precipitation and was dominated typically by a single storm. As an example, temporal analysis of the Tabernacle, NJ storm, which may bound LIP studies for some locations in the east (e.g., IPEC), revealed similar results to HMR52, indicating that no change in the recommendations should occur.

Storm orientation and temporal distribution has been included in independent reviews of recommendations by TRB or BOC. As an example, guidance for local storms was changed as part of the Arizona statewide PMP study based on the temporal analysis performed by AWA and independent review activities included an analysis of timing which was presented for discussion with AWA. The previous distribution had been relatively flat but AWA found that about 90 percent of the precipitation occurred in a 2 hour period for most storms. The Ohio study included temporal analysis but the TRB concurred that deviating from the existing HMR guidance was not appropriate. A similar finding was made for Nebraska which was later performed again related to a FERC regulated process.

c. <u>Conclusions</u>

The NRC staff did not identify any open issues during the webinar follow-up. The staff noted that, while the HMRs do not address temporal distribution arrangements for short-duration storms (i.e., one hour, one square mile analyses for FHRR submittals), data presented by AWA indicated that distributions other than front-loaded (e.g., center-loaded) are common and should be evaluated to ensure conservative application.

The NRC staff plans to review past reports from BOCs and TRBs to determine the level of review and scrutiny applied to temporal rainfall distributions, specifically related to the types of distributions common for LIP-type storms and recommended for LIP PMP application.

The staff may also conduct a sensitivity analysis with regard to the impact of storm orientation and forward speed.

Exit Meeting

On February 25, 2015, the NRC audit team conducted an exit meeting with AWA staff. The NRC staff highlighted items reviewed and noted that a detailed summary of the audit activities will be documented in this audit report.

CONCLUSION

The NRC staff conducted a technical audit of AWA methods and assumptions for determining ssPMP estimates for both LIP and watershed-scale PMP. The audit successfully discussed each of the topics listed in the AWA Audit Plan. The audit team identified areas of focus in the AWA process that may be generically applicable to all of AWA's PMP studies. In these areas the staff may be able to generically resolve any concerns, and thus reduce the number of RAIs that may otherwise be needed during FHRR reviews. The staff also identified areas where it is not possible to generically resolve the concern, and therefore will need to be resolved on a case-by-case basis. The staff highlighted each of these scenarios in the conclusions section related to each review topic.

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AUDIT PROCEDURES USED

This technical audit was performed consistent with NRC Office of Nuclear Reactor Regulation Office Instruction LIC-111, “Regulatory Audits,” dated December 29, 2008, (ADAMS Accession No. ML082900195)