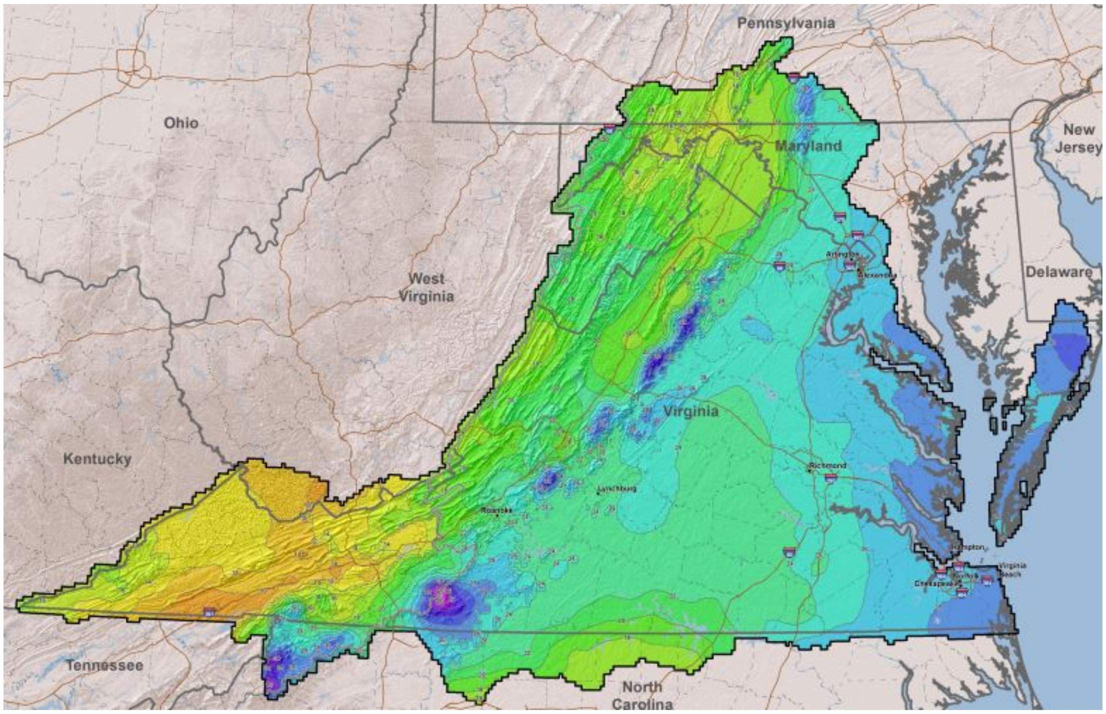
Probable Maximum Precipitation Study for Virginia



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Executive Summary

During the 2014 Virginia General Assembly Session, the legislature passed (House Bill 1006 and Senate Bill 582) and the Governor approved on April 1, 2014 (Chapters 475 and 489 of the 2014 Virginia Acts of Assembly), legislation that authorized a new Virginia Probable Maximum Precipitation Study to be completed by December 1, 2015. The legislation directed "*[t]hat the Department of Conservation and Recreation, on behalf of the Virginia Soil and Water Conservation Board, shall utilize a storm-based approach in order to derive the Probable Maximum Precipitation (PMP) for locations within or affecting the Commonwealth. The PMP revisions shall be based on accepted storm evaluation techniques and take into account such factors as basin characteristics that affect the occurrence and location of storms and precipitation, regional and basin terrain influences, available atmospheric moisture, and seasonality of storm types. The results shall be considered by the Virginia Soil and Water Conservation Board in its decision to authorize the use of the updated PMP values in Probable Maximum Flood calculations, thus replacing the current PMP values.*"

In accordance with this legislative direction, Applied Weather Associates (AWA), on behalf of the Virginia Soil and Water Conservation Board, completed a statewide Probable Maximum Precipitation (PMP) study for Virginia. A Technical Review Board of experts, with additional ad-hoc participation by cooperating state and federal agencies, was established by the Department to provide advice and expertise throughout the development of the study. The Technical Review Board met to review and discuss study progress and results in July and November of 2014 and April and October of 2015 and accepted AWA's estimates for probable maximum precipitation (PMP) for Virginia.

This study produced gridded PMP values for the project domain at a spatial resolution of approximately 2.5-square miles. Variations in topography, climate and storm types across the state were explicitly taken into account. A large set of storm data were analyzed for use in developing the PMP values. These values replace those provided in Hydrometeorological Reports (HMRs) 40, 51, 52, and 56 (1965, 1978, 1982, and 1986 respectively). The full PMP values for regions east of the Appalachian crest are valid from June through October. For areas west of the Appalachian crest, the seasonality is similar, except that 100% of PMP from the general storm type can occur from September 15 through May 15 and the local storm can occur as early as April 15. Results of this analysis reflects the most current practices used for defining PMP, including comprehensive storm analyses procedures, extensive use of geographical information systems (GIS), explicit quantification of orographic effects, updated maximum dew point climatologies for storm maximization and transposition, and an updated understanding of the weather and climate throughout the state.

The approach used in this study followed the same philosophy used in the numerous site-specific, statewide, and regional PMP studies that AWA has completed in the last fifteen years. This was the storm-based approach and it follows the same general procedures used by the National Weather Service (NWS) in the development of the HMRs. The World Meteorological

Organization (WMO) Manual on Estimation of PMP recommends this same approach. The storm based approach identified extreme rainfall events that have occurred in regions considered transpositionable to locations in Virginia. These are storms that had meteorological and topographical characteristics similar to extreme rainfall storms that could occur over any location within the project domain. Detailed storm analyses were completed for the largest of these rainfall events.

The data, assumptions, and analysis techniques used in this study have been reviewed and accepted by the Technical Review Board and the Virginia Department of Conservation and Recreation. Although this study produced deterministic values, it must be recognized that there is some subjectivity associated with the PMP development procedures. Examples of decisions where scientific judgment was involved include the determination of storm maximization factors and storm transposition limits. For areas where uncertainties in data analysis results were recognized, conservative assumptions were applied unless sufficient data existed to make a more informed decision. All data and information supporting decisions in the PMP development process have been documented so that results can be reproduced and verified.

Sixty-six rainfall events were identified as having similar characteristics to rainfall that could potentially control PMP values at various locations within the state. Several storm events had multiple Depth-Area-Duration (DAD) zones (also referred to as SPAS DAD zones) that were used in the PMP determination process. A total of 78 storm DAD centers were used in the development of PMP for the state. This includes 31 tropical storm rainfall centers, 25 general storm rainfall centers, and 23 local storm rainfall centers. Note, the storm centered near Big Meadows, VA during October 1942 exhibited characteristics of both local and general storm types and was therefore evaluated as part of both the general and local storm PMP determination process.

Seventy-eight individual storm centers were analyzed using the Storm Precipitation Analysis System (SPAS), which produced several standard products, including DAD values, storm center mass curves, and total storm isohyetal patterns. National Weather Service (NWS) Next Generation Weather Radar (NEXRAD) data were used in storm analyses when available (generally for storms which occurred after the mid-1990's).

Standard procedures were applied for in-place maximization and moisture transposition adjustments (e.g. HMR 51 Section 2.3 and Section 2.4). New techniques and new datasets were used in other procedures to increase accuracy and reliability when justified by utilizing advancements in technology and meteorological understanding, while adhering to the basic approach used in the HMRs and in the WMO Manual. Updated precipitation frequency analyses data available from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 were used for this study. These were used to calculate the Orographic Transposition Factors (OTFs) for each storm. The OTF procedure provided explicit evaluations of the effects of terrain on rainfall and corrected for the lack of analysis in the "stippled' region of HMR 51. The OTF procedure, through its correlation process, provided quantifiable and reproducible analyses of the effects of terrain on rainfall. Results of these three factors (in-place maximization, moisture transposition, and orographic transposition) were applied for each storm at each of the grid points for each of the area sizes and durations used in this study to define the PMP values.

Maximization factors were computed for each of the analyzed storm events using updated dew point and sea surface temperature climatologies representing the maximum moisture equivalent to the 100-year recurrence interval for dew points or +2 sigma for sea surface temperatures that could have been associated with each rainfall event. The dew point climatology included the maximum average 6-, 12-, and 24-hour 100-year return frequency values, while the SST climatology provided the +2 sigma values. The most appropriate duration consistent with the duration of the storm rainfall was used. HYSPLIT model trajectories and NWS weather maps were used as guidance in identifying the storm representative moisture source region.

To store, analyze, and produce results from the large datasets developed in the study, the PMP calculation information was stored and analyzed in individual Excel spreadsheets and a GIS database. This combination of Excel and GIS was used to query, calculate, and derive PMP values for each grid point for each duration for each storm type. The database allowed PMP to be calculated at any area size and/or duration available in the underlying SPAS data.

When compared to previous PMP values provided in HMRs 40, 51, 52, and 56, the updated values from this study resulted in a wide range of reductions at most area sizes and durations, with some regions recognizing minor localized increases. PMP values are highest near the coast and along the Blue Ridge. These regions have exhibited past extreme rainfall accumulations that are the result of both moisture availability and topographic enhancement. Regions along and near the coast are also affected by coastal convergence processes which act to enhance lift and provide an additional mechanism for enhanced rainfall production versus other locations in the study domain. Minimum values are seen in the most protected interior valleys and in the transition region of the Piedmont between the coast to the Blue Ridge. This is expected because of the lack of decrease in moisture and reduced or negative orographic effects relative to other regions.

Commonwealth-wide it was found that on average, PMP values for local storms showed a 16% reduction at 6-hour 10-square miles and a 21% reduction at 12-hour 10-square miles. For the longer durations, larger area sizes, Commonwealth-wide reductions were 30% at 24-hour 200-square miles and 1000-square miles, and 25% at 72-hours 200-square miles and 1000-square miles. Tables E.1-E.3 provide the average percent difference (negative is a reduction) from HMR 51 across each of the transposition regions analyzed. After adoption of the study by the Virginia Soil and Water Conservation Board, and upon the effective date of associated regulations, impounding structure owners will have the opportunity to utilize this new data to review their spillway design capacity needs and determine rehabilitation requirements for their structures.

Table E.1 Local storm PMP percent difference from HMR 51 PMP at 6-hour and 12-hour 10-square miles. Grayed out rows represent regions where either tropical or general storm PMP values were controlling.

Local Storm 10 Sq Mi Average PMP						
Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr
1 - Interior Valley	27.6	19.7	-28.7%	32.2	21.2	-34.3%
2 - Cumberland Plateau	28.7	19.2	-33.2%	33.8	21.5	-36.6%
3 - Great Valley	28.9	17.1	-40.7%	34.1	19.2	-43.9%
4 - Blue Ridge West	28.9	19.7	-31.8%	34.1	22.1	-35.5%
5 - Blue Ridge East	27.8	19.8	-28.8%	32.5	21.3	-34.5%
6 - Piedmont	28.5	26.1	-8.5%	33.7	29.0	-13.9%
7 - Coastal Plain	28.6	29.6	3.7%	33.8	33.1	-2.1%
Statewide Domain	**28.4**	**23.8**	**-16.2%**	**33.4**	**26.3**	**-21.4%**

Table E.2 Tropical storm PMP percent difference from HMR 51 PMP at 24-hour and 72-hour 200- and 1000-square miles. Grayed out rows represent regions where either tropical or general storm PMP values were controlling.

Tropical Storm 200 Sq Mi Average PMP						
Transposition Zone	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	26.5	16.7	-37.1%	31.5	19.3	-38.8%
2 - Cumberland Plateau	27.4	12.3	-54.9%	33.1	16.0	-51.7%
3 - Great Valley	27.8	10.8	-61.1%	33.6	14.0	-58.4%
4 - Blue Ridge West	28.1	19.2	-31.9%	33.8	21.0	-38.2%
5 - Blue Ridge East	26.7	20.0	-25.0%	31.7	22.1	-30.4%
6 - Piedmont	28.4	20.3	-28.5%	33.8	25.9	-23.3%
7 - Coastal Plain	29.3	22.9	-21.6%	34.7	29.1	-16.1%
Statewide Domain	**28.0**	**19.5**	**-30.3%**	**33.3**	**23.8**	**-28.7%**

Tropical Storm 1000 Sq Mi Average PMP						
Transposition Zone	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	21.2	12.0	-43.5%	25.0	14.8	-41.1%
2 - Cumberland Plateau	22.2	10.8	-51.2%	26.5	14.3	-46.0%
3 - Great Valley	22.8	9.5	-58.1%	27.1	12.5	-53.8%
4 - Blue Ridge West	23.1	13.9	-40.1%	27.3	18.0	-34.4%
5 - Blue Ridge East	21.3	14.5	-32.2%	25.2	18.3	-27.8%
6 - Piedmont	23.4	17.5	-24.7%	27.5	23.1	-15.5%
7 - Coastal Plain	24.3	19.7	-18.6%	28.6	26.1	-8.6%
Statewide Domain	**22.9**	**15.9**	**-30.5%**	**27.0**	**20.8**	**-23.3%**

Table E.3 General storm PMP percent difference from HMR 51 PMP at 24-hour and 72-hour 200- and 1000-square miles. Grayed out rows represent regions where either tropical or general storm PMP values were controlling.

General Storm 200 Sq Mi Average PMP						
Transposition Zone	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	26.5	14.3	-46.1%	31.5	14.9	-52.6%
2 - Cumberland Plateau	27.4	16.0	-41.5%	33.1	17.9	-46.0%
3 - Great Valley	27.8	13.7	-50.6%	33.6	16.1	-52.2%
4 - Blue Ridge West	28.1	16.2	-42.4%	33.8	18.9	-44.3%
5 - Blue Ridge East	26.7	14.9	-44.0%	31.7	15.8	-50.2%
6 - Piedmont	28.4	17.9	-37.0%	33.8	19.3	-42.8%
7 - Coastal Plain	29.3	17.6	-39.9%	34.7	21.3	-38.7%
Statewide Domain	**28.0**	**16.6**	**-40.9%**	**33.3**	**18.4**	**-44.9%**

General Storm 1000 Sq Mi Average PMP						
Transposition Zone	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	21.2	12.5	-41.1%	25.0	14.2	-43.2%
2 - Cumberland Plateau	22.2	13.3	-40.0%	26.5	14.9	-44.0%
3 - Great Valley	22.8	11.4	-50.0%	27.1	14.3	-47.1%
4 - Blue Ridge West	23.1	13.7	-40.9%	27.3	17.4	-36.8%
5 - Blue Ridge East	21.3	13.1	-38.9%	25.2	14.9	-41.0%
6 - Piedmont	23.4	15.6	-32.9%	27.5	17.8	-35.1%
7 - Coastal Plain	24.3	15.7	-35.3%	28.6	18.3	-35.9%
Statewide Domain	**22.9**	**14.4**	**-36.9%**	**27.0**	**16.7**	**-38.2%**