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Recommended Procedures for Selecting the Controlling Probable Maximum Precipitation Storm

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1. Introduction

This document provides guidance to engineers in Maryland on how to effectively use the results from the latest Maryland Probable Maximum Precipitation (PMP) Study to assess combinations of rainfall depths and distributions, as well as storm types and durations to develop inputs necessary to compute the Probable Maximum Flood (PMF).

When using information derived from Hydrometeorological Reports 51 and 52, the Maryland Dam Safety program generally considered a single storm type, rainfall depth, duration (6 hours) and distribution (critically stacked). The new Maryland PMP study recognizes that due to variations in watershed sizes and locations, multiple variables must be assessed to determine the controlling PMP storm, and the associated inflow hydrograph for the PMF. The controlling PMP storm is that which results in the highest peak water surface elevation in the reservoir.

2. Generating PMP Data Necessary for Analysis

The Maryland PMP tool is available for download on the Maryland Dam Safety program webpage. Job aids and tutorials have been developed to assist the user with creating an input drainage area and generating an output from the tool.

If the ArcGIS software necessary to run the PMP tool is not available to the user, they can provide a drainage area shapefile created using the USGS StreamStats web application and request that the Dam Safety program run the tool. This work will be completed based on the availability of Dam Safety staff and programmatic priorities. It should be noted that in some cases, especially for small drainage basins, review and subsequent editing of the drainage area delineation may be necessary to generate an accurate polygon, which is the sole responsibility of the user.

The user must select the desired storm durations for each storm type, with the recommended durations indicated in the table below. The local 2-hour storm is generally only used for drainage areas under 10 square miles.

Table 1: Recommended Storm Durations by Storm Type

Storm Type	Storm Durations
Local	2, 6 hours
General	6, 24, 48, 72 hours
Tropical	6, 24, 48, 72 hours

3. PMP Tool Output

The PMP tool will create a number of output files for further inspection and use, including comma-separated values (CSV), a file geodatabase, and an image file indicating storm-type specific depth-duration data. In the output destination folder, the PMP tool will create three folders separated by storm type. The PMP tool file geodatabase output is not discussed in this section.
Five CSV files are generated for each storm type. A description of the information contained in each file is provided below.

Storm Types:

- **Local Storms:** High-intensity, short-duration events, typically convective.
- **General Storms:** Larger-scale, longer-duration events, often associated with synoptic weather systems.
- **Tropical Storms:** Precipitation related to tropical cyclones and their remnants.

**StormType*_PMP_Basin_Average_*BasinSize*.csv:* This file provides the total rainfall depths for various storm durations. Column heading "PMP_06" indicates the total precipitation, averaged over the basin, for a 6-hour storm.

**StormType*_Temporal_Distributions_*Timestep*.csv:* This file provides the temporal distribution of all selected storm durations, with various temporal patterns (which are described in a later section). The data is generally provided in 5-minute increments for Local storms, and 15-minute increments for General and Tropical Storms.

**StormType*_Temporal_Distributions_*Timestep*_Check.csv:* This table provides a check on the reasonableness of the precipitation value for an interim storm duration within a particular temporal distribution. If the precipitation value exceeds the PMP value for that duration by greater than 5%, the check is noted as "EXCEED" otherwise it is indicated as "OK".

**StormType*_Temporal_Distributions_60min_Controlling_Storms.csv:* This table provides the temporal distribution for the specific historic storm that controlled for a specific storm type, location, and *watershed size.*

**StormType*_Temporal_Distributions_60min_Controlling_Storms_Check.csv:* This table provides a check on the reasonableness as described above.

An image file is also generated for each storm type that graphically portrays the total PMP rainfall depth over the selected durations.

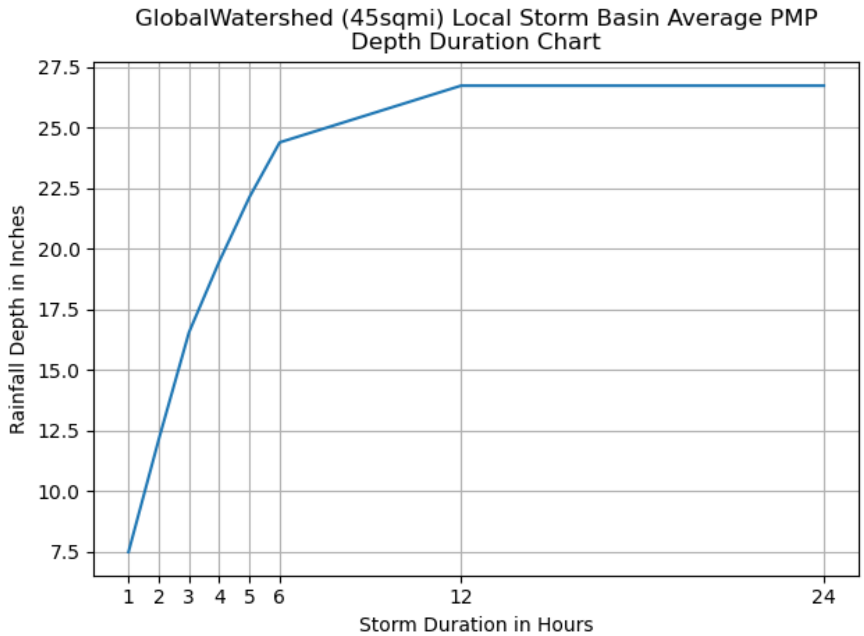

Figure 1: Local Storm Basin Average PMP Depth Duration Chart for Atkisson Dam (MD Dam No. 47)

4. Selecting Storm Types and Durations to Carry Forward in Analysis

While the user may elect to complete hydrologic analyses for all storm types, durations, and temporal distributions to determine the controlling PMP storm, this may result in significant unnecessary effort. The following section provides decision-making advice to reduce the number of storms that are necessary to use in the hydrologic analyses.

2-hour Local Storm: Carry this storm type and duration forward if the drainage area is 10 square miles or less.

6-hour and 24-hour Storms: It is recommended to compare the total rainfall depth for each storm type by duration. The controlling storm type(s) is the storm with the greatest precipitation. Where multiple storm types have similar rainfall depths (typically within 10% of each other), it is recommended to carry both forward. The examples below are outputs from the Maryland PMP tool for 2 dams. Dam A has a 1 square mile drainage area and is located in Garrett County, and Dam B has a 4 square mile drainage area and is located in Wicomico County.

Table 2: 6-hour Basin Average PMP Depth by Storm Type, Dam A

Storm Type	Rainfall Depth (in.)
Local	**29.55**
General	8.56
Tropical	11.54

Table 3: 24-hour Basin Average PMP Depth by Storm Type, Dam A

Storm Type	Rainfall Depth (in.)
General	12.74
Tropical	**16.1**

Table 4: 6-hour Basin Average PMP Depth by Storm Type, Dam B

Storm Type	Rainfall Depth (in.)
Local	**28.91**
General	14.47
Tropical	20.77

Table 5: 24-hour Basin Average PMP Depth by Storm Type, Dam B

Storm Type	Rainfall Depth (in.)
General	19.1
Tropical	**32.01**

For Dam A, the controlling 24-hour storm (Tropical) produces significantly less rainfall depth than the 6-hour Local storm, so it may not be necessary to carry the 24-hour storm forward for further analysis. Conversely, for Dam B, the 24-hour controlling storm produces rainfall depths that are more than 10% greater than the 6-hour storm. While the 6-hour storm may control, it is advisable to also carry forward the 24-hour storm. Given the location of Dam B on the Eastern Shore of Maryland, it is not unreasonable to see the Tropical storm type have a greater influence when compared to Dam A, located to the west of the Eastern Continental Divide.

48-hour and 72-hour Storms: It is recommended to review storms of this duration in a similar manner as one would review the 6 and 24-hour storms if the graphical output from the PMP tool suggests significant additional rainfall accumulation after 24 hours. If the additional accumulation remains less than the controlling 24-hour storm, no further analysis is needed and these storm durations can be discarded.

5. Selecting Temporal Distributions for Storms Carried Forward.

Selecting and applying the appropriate temporal distribution is the final step required to enter the storm data into hydrologic analysis software (e.g., HEC-HMS). In the examples provided in Section 4, the following three storm types and durations would be carried forward: 2-hour Local, 6-hour Local, and 24 hours Tropical. This list is culled from a possible 11 storm types and durations.

The Maryland PMP Study considers the following temporal distributions:

<u>The 2-hour Synthetic Distribution</u>
The 2-hour synthetic distribution was developed based on historical storms utilized in PMP development which combined NEXRAD weather radar data at 5-minute increments along with hourly and sub hourly rain gauge data and were analyzed using SPAS. This SPAS-NEXRAD 5-minute data was used to derive ratios of the greatest 15-, 30-, and 45-minute accumulations during the greatest 1-hour rainfall accumulation. The first hour precipitation is placed in the middle and utilized the stacked 5-min-interval sub-hourly data. The second hour is evenly distributed both in the front and at the end.

<u>10th / 90th Percentile Distributions</u>
Both 10th and 90th percentile distributions are derived based on Huff Curve Methodology which is a probabilistic representation of accumulated storm depths for corresponding accumulated storm durations expressed in dimensionless form. The curves generated in this study can be generically described as:

- 90th curve - the 90th curve indicates that 10% of the corresponding SPAS storms had distributions that fell above and to the left of the 90th curve (front-loaded)

- 10th curve - the 10th curve indicates that 10% of the corresponding SPAS storms had distributions that fell below and to the right of the 10th curve (back-loaded)

Alternating Block (Critically Stacked) Distribution
This distribution is not recommended for use in design of dams in Maryland.
A “critically stacked” temporal distribution was developed as a synthetic rainfall distribution based on HMR 52 procedures. The critically stacked temporal pattern yields a significantly different distribution than actual distributions associated with the storms used for PMP development in this study and in similar analysis of adjacent PMP studies. The critically stacked pattern embeds PMP depths by duration within one another, i.e., the one-hour PMP is embedded within the 3-hour, which is embedded within the 6-hour, which is in turn embedded in the 24-hour PMP. The critically stacked procedure (i.e., HMR 52 distribution) has often been chosen in the past for PMP runoff modeling because it represents a worst-case design scenario and ensures PMP depths are equaled at all durations. However, it does not represent a physically possible storm environment.

USACE Engineer Manual EM 1110-2-1411 Distribution
This distribution is not recommended for use in design of dams in Maryland.
The USACE developed a temporal distribution as presented in Engineer Manual 1110-2-1411 (March 1965), which assumes a 24-hour standard project storm duration. The 24-hour storm period is divided into four 6-hour periods. The maximum 6-hour period is placed in the 3rd 6-hour period of the 24-hour storm. The remaining rainfall is evenly distributed around the maximum 6-hour period with the 12-hour PMP rainfall occurring over 12 hours and 24-hour PMP rainfall occurring over the 24-hour storm duration. The EM 1110-2-1411 distribution is similar to the critically stacked pattern as described above.

It is recommended that users apply both the 10th and 90th Percentile Distributions for storms carried forward from Section 4 with durations of 6 hours or greater. The 2 hour local storm uses the 2 hour synthetic distribution. Each of the temporal patterns were derived through visual inspection, meteorological analyses, and comparisons with similar work. Analysis was completed after separating each event by storm type (e.g., general, local, tropical, hybrid). The temporal patterns reflect the meteorological conditions that produce each storm type. These represent observed extreme rainfall accumulation characteristics. It is assumed that similar patterns would occur during a PMP event. Therefore, it is recommended that the PMP temporal patterns included in the tool be used as they represent Maryland specific temporal patterns derived from extreme rainfall events used in this study.

Where an “EXCEED” is indicated in the temporal pattern check output (described in Section 3), the user may disregard that specific temporal pattern if they chose, as this may result in a conservative (i.e.., larger) PMF. If both the 10th and 90th Percentile Distributions generate an “EXCEED”, the Critically Stacked distribution can be applied.

6. Documentation

It is important that the methods and parameters used, the results obtained, and supporting justification for the hydrologic analysis be documented in a coherent report. This will allow Maryland Dam Safety program to verify that minimum requirements for the hydrologic analysis have been satisfied and evaluate whether the proposed design adequately addresses the required design storm. A secondary, but equally important purpose is to provide documentation of methods and assumptions to assist future stakeholders in understanding the basis for design and assessing adequacy and safety of the structure. As a general principle, the information submitted should be adequate to allow an independent analyst, possibly at some point in the future, to replicate the analysis with comparable results. The information must be transparent and independent of the software program used for computation.

The following are some of the items that should be included in the report and supporting documentation to facilitate review:

a. Location map and topographic map of drainage area contributing to the dam and reservoir, with drainage boundary and total area indicated. Subbasin boundaries and areas should also be identified, if applicable.
b. Tables of all basin and channel characteristics used in the analysis or input in the modeling software.
c. Narrative discussion of unit hydrograph and loss rate methodology and parameters.
d. Narrative discussion of watershed model. For watershed models with multiple subbasins, this discussion should be accompanied by a schematic showing the interrelation of various components of the model.
e. Discussion of modeling software and version information.
f. Elevation-storage (or elevation-area) and elevation-discharge tables for reservoir, outlets, and spillways.
g. Discussion of precipitation data and temporal distributions including whether the modeled distributions pass or fail the PMP depth check.
h. Discussion and tabulated results of all modeled temporal distributions used to identify the controlling storm event. This should include a summary of all factors used to determine the controlling storm.
i. Inflow and outflow hydrographs plotted on same figure of appropriate scale.
j. Discussion of reasonableness of results, including any validation, calibration or other comparison information that is available (e.g., calibration methods provided by the Maryland Hydrology Panel).
k. Discussion of any parameter adjustments or sensitivity analysis performed to validate or improve reasonableness of results.
l. An electronic copy of the report and supporting documents must be provided with the submittal. At a minimum, this should include:
   - PDF copy of entire report including appendices
   - Watershed model files. Everything must be packaged such that the model can be copied onto a local computer and run without issue.

Disclaimer: This guidance document is intended for informational purposes only and should not be considered a substitute for professional engineering judgment. Users are responsible for ensuring the accuracy and appropriateness of their PMF analyses. Always consult with the latest official publications from MDE and other relevant agencies