Initial and Interim Use of Regional Extreme Precipitation Study (REPS) Tools for Probable Maximum Precipitation and Annual Exceedance Probability Rainfall Estimation
New Mexico Office of the State Engineer (NMOSE) Dam Safety Bureau
(January 2019 rev 0.2)

BACKGROUND: The Colorado and New Mexico dam safety programs have completed work on the Regional Extreme Precipitation Study (CO-NM REPS). The REPS was a multi-year effort to update rainfall estimates for spillway design at dams and other sensitive hydraulic infrastructure. New probable maximum precipitation (PMP) estimates and previously unavailable risk-based Annual Exceedance Probability/Precipitation Frequency (AEP/PF) estimates were developed for the study region. Technical analysis of the extreme precipitation tools is complete with respect to rainfall depths. Additional evaluation and guidance for the application of the new rainfall for hydrologic analysis is forthcoming in 2019-2020 depending on funding availability. This document provides guidelines for use of the tools in the interim period as an evaluation of hydrologic analysis techniques proceeds in parallel.

REPS analyses were supported with dynamical weather modeling by the National Oceanic and Atmospheric Agency (NOAA). CO-NM REPS was developed using the best available science and practice and it was overseen through a robust project review board process. Significant effort was made to evaluate temporal and spatial behavior of extreme storms and additional work is needed as described below to provide guidance on the use of this information for dam safety engineers. As this work continues, the New Mexico Dam Safety Bureau recognizes that there are immediate benefits in public safety and improved spillway design to be realized by use of the REPS rainfall estimates on a case-by-case basis. The application of the new tools for runoff modeling must be carried out in close coordination with the NMOSE in order to expedite the modeling and review. Engineers and hydrologists are always encouraged to meet with the dam safety bureau at the beginning of their project.

Documentation for the REPS is hosted on the OSE website at:
http://www.ose.state.nm.us/Dams/conmplf.php

The report is provided in seven volumes with documentation for the PMP tool contained in Volume II and the AEP/PF tool documentation found in Volume III.

REPS Tools:
Two main deliverables were developed in the CO-NM REPS: a PMP estimation tool (REPS PMP Tool) that runs in a Geographic Information System (GIS) environment and a PF estimation tool (MetPortal PF Tool) that runs on a web-based platform. The tools are briefly described here:

1) **REPS PMP Tool:** This GIS-based tool can be used to calculate deterministic PMP depths anywhere in New Mexico. It runs as a tool in ArcGIS version 10.4 or higher. The tool calculates inter-durational PMP depths for Local Storms (LS), General Storms (GS) and Tropical Storms (TS) using a basin shapefile provided by the user. Output is written to GIS grid and attribute table files, which can be opened in ArcGIS.

2) **MetPortal PF Tool:** This web-based tool calculates point and watershed precipitation frequency estimates for $10^{-1}$ through $10^{-7}$ Annual Exceedance Probability (AEP) for LS, Meso-scale Embedded Convection (MEC), and Mid-Latitude Cyclone storms (MLC). The key durations for each storm are 2-hours for LS, 6-hours for MEC and 48-hours for MLC. This probabilistic tool
has applications in Risk Informed Decision Making, Incremental Damage Assessment analyses (with PMP as an upper bound) and design of Low Hazard Potential dams. Estimates can be made for a point or for a user-entered basin shapefile. The tool also provides temporal distributions derived from statistical analysis of extreme storms, along with spatial patterns and freezing level information.

**Interim Hydrologic Modeling:**

Acceptable hydrologic analysis practices for NM dams are described in the August 15, 2008 *Hydrologic Analysis for Dams* white paper. Certain practices found in that white paper may be modified with NMOSE concurrence for the interim until new guidance is available. The NMOSE hydrologic analysis white paper is available here:

http://www.ose.state.nm.us/Dams/submittal.php

Interim modifications to accepted practice include application of certain new precipitation distributions as described below.

**Instructions for Installation and Use of the REPS tools:**

1) **REPS PMP Tool:** Download v1.10 from the following OSE webpage and unzip it. Note the location of the "PMP_Evaluation_Tool" folder:

   http://www.ose.state.nm.us/Dams/conmpf.php

   Launch ArcMap and use the ArcCatalog window to navigate to the "Gridded PMP Tool" (see below):

   ![PMP_Evaluation_Tool folder](http://www.ose.state.nm.us/Dams/conmpf.php)

   Please delete all previous versions of the PMP Tool that you may have on your computer to avoid confusion in the future.

   Detailed documentation for the PMP tool is provided in Volume II, Appendix G – GIS PMP Tool, available through the link listed above.

2) **MetPortal PF Tool:** Precipitation frequency estimates are finalized, but the tool remains in development as final improvements are made to the application. The web-based tool may be used at the following link:

   https://conm-reps-gui.shinyapps.io/metportal/

   A user's guide can be downloaded from the MetPortal home page, as shown in Figure 1.
Either point or watershed precipitation frequency estimates can be calculated by the tool. Watershed
shapefiles must be in geographic coordinate system WGS84 format for input into the MetPortal tool.
On-screen display of frequency curves, tabular precipitation frequency estimates for $10^1$ through $10^7$
AEP, and 90% uncertainty bounds are provided.

Precipitation increments and distribution. Current practice applies a number of temporal rainfall
distributions to the analysis of hydrologic response for spillway design. The purpose of this approach is to
find a rainfall pattern that appropriately stresses the watershed and produces the largest runoff (in terms of
volume and/or runoff peak) that can be reasonably expected to occur. Current New Mexico practice applies
a minimum of four distributions for spillway inflow design flood analysis—a front-loaded and a balanced
6-hour duration local storm, and a center- and a late-peaking 72-hour duration general storm.

The CO-NM REPS project made evaluations of temporal behavior of historic storms and over 20
potential temporal distributions were developed. The process of LS analysis in the PMP task yielded
two additional durations that must be modeled—a 2-hour LS PMP distribution was identified, and a 24-
hour Hybrid behavior was identified. Additional information is provided in Volume II of the REPS
documentation. The 24-hour hybrid storm must be modeled in certain regions using the REPS synthetic
distribution where the 24-hour duration LS output depth exceeds the General or Tropical Storm depth
at the 24-hour duration; or in cases where the 24-hour total depth exceeds the LS 6-hour depth by 10%.

As mentioned previously additional effort is needed to streamline the application of temporal
distributions that will appropriately stress a given basin while reducing the effort and expense needed
to complete an analysis. This follow up work will occur in 2019-20 depending on funding availability.

INTERIM PMP TOOL USE:
Local, General and Tropical storm PMP must be calculated using the REPS PMP Tool. Local storm
durations must be calculated for 1, 2, 3, 4, 5, 6, 12, and 24-hour durations. General and Tropical Storm
durations must be calculated through 72-hours. An example REPS GIS output table for a Local Storm
showing all inter-durational PMP estimates is shown in Figure 2.
In the example shown the local storm rainfall interdurational depth continues to increase after 6-hours. This example illustrates the hybrid local storm behavior that could occur at some locations in New Mexico and Colorado. In this case the 24-hour depth exceeds the 6-hour depth by 16% and the hydrologic analysis for this location must include the 24-hour hybrid using the REPS synthetic distribution. More case-by-case analysis is needed to understand if this hybrid behavior is significant to dam safety practice in New Mexico.

At a minimum, rainfall distributions identified in Table 1 on Page 10 are to be applied to hydrologic analysis for the basin of interest. Runoff hydrographs should be modeled using USBR methodology as described in Hydrologic Analysis for Dams (NMOSE 2008), and the USBR Flood Hydrology Manual (Cudworth 1989), and runoff peak and volume should be reported for each simulation.

**Local Storm:** Inter-durational PMP estimates should be used to create both a front-loaded and balanced alternating block temporal pattern for the local storm (Table 1). For local storm analysis this can be performed in HEC-HMS using a Frequency Storm Meteorological Model with 33 percent and 50 percent Intensity Positions and a negligible Storm Area size (e.g. 0.01 square mile, to prevent redundant application of areal reduction factors). REPS PMP is calculated for a specific basin area and accounts for basin size. Therefore, no further areal reductions need be applied. For the REPS PMP synthetic Local Storms, sub-hourly rainfall for the first hour should be calculated as follows:

<table>
<thead>
<tr>
<th>Duration (minutes)</th>
<th>Percent of 1-hr REPS PMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>15%</td>
</tr>
<tr>
<td>15</td>
<td>39%</td>
</tr>
<tr>
<td>30</td>
<td>65%</td>
</tr>
<tr>
<td>45</td>
<td>84%</td>
</tr>
</tbody>
</table>

REPS Local Storm PMP synthetic temporal curves (2-hour LS, 6-hour LS, and 24-hour Hybrid) are provided in the tool output as cumulative distributions and can be entered into HEC-HMS as “Specified Hyetograph” Meteorological Models.

As mentioned above, PMP depths at 24-hour duration provided in the local storm output must be compared to the 24-hour depth for the General and Tropical Storms. In cases where the 24-hour Hybrid LS storm depth exceeds the 24-hour depth for the General and Tropical Storm, or if the 24-hour Hybrid total depth exceeds the 6-hour depth by 10% the 24-hour duration Hybrid storm must also be analyzed as indicated in Table 1. Example HMS Frequency Storm input is shown in Figure 3.
**General Storm and Tropical Storm:** Inter-durational PMP tool output should be used in the development of 72-hour duration center-weighted (balanced) and 2/3 late-weighted distributions for general and tropical storm modeling. The development of precipitation increments from depth duration curves, rainfall distributions, and runoff hydrographs should be created as described in *Hydrologic Analysis for Dams* (NMOSE 2008). Note that the HEC-HMS frequency storm module does not allow for a direct application of a 72-hour duration storm so General and Tropical Storm distributions must be developed by the modeler external to HEC-HMS and then input as “Specified Hyetograph” Meteorological Models in HMS (with incremental precipitation entered as gage data). Figure 5 shows a typical depth-duration curve for general or tropical storm with interpolated ordinates for 12-, 18-, 30-, 36-, 42-, 48-, 54-, 60-, and 66-hours. Figure 6 shows typical center- and 2/3-weighted temporal distributions developed from the depth duration curve as described in *Hydrologic Analysis for Dams* (NMOSE 2008). Contact NM Dam Safety staff for guidance as needed.
The corresponding peak discharge in cubic feet per second, runoff volume in acre-feet, and peak reservoir stage as determined from the hydrologic model should be reported for each distribution. REPS synthetic 72-hour temporal distribution curves are provided in cumulative rainfall (mass curve) format in 15-minute increments and can be entered into HEC-HMS as “Specified Hyetograph” Meteorological Models.

**Figure 5 – Typical General or Tropical Storm Depth-Duration Curve – Interpolated Ordinates at 12-, 18-, 30-, 36-, 42-, 48-, 54-, 60-, and 66-hours**
Required Annual Exceedance Probability (AEP) Comparisons:

The MetPortal Precipitation Frequency tool has robust computational capabilities that can be applied to Risk Informed Decision Making for dam safety practice. The availability of PF depths with calculated probabilities could become an important tool in the preparation of Incremental Damage Assessments (IDA). It is now possible to understand the recurrence interval of a particular IDA design storm which provides insight into relative risk. These applications will be developed in the future as opportunities arise. In the interim, a comparison of PMP depths to rare PF depths should be made to establish the
approximate recurrence interval for PMP calculated at a given location. The MetPortal PF Tool provides that output and the process is described here:

REPS PMP total depth for individual storm types is manually entered on the Watershed PF Interface tab and plotted with the applicable precipitation frequency curve: 2-hr Local Storm PMP on the LS 2hr frequency curve, 6-hr Local Storm PMP on the MEC 6-hr frequency curve, and 48-hr General Storm PMP on the MLC 48hr frequency curve. An example for 48-hr PMP is shown in Figure 7.

ADDITIONAL VOLUNTARY COMPARISONS:
The New Mexico dam safety program is beginning a process of evaluating temporal distributions developed in the REPS to establish a consistent policy for use in developing inflow design floods. The additional comparisons described here are voluntary, but they will help the New Mexico dam safety program to reach a timely policy decision.

For additional beta testing, the rainfall distributions indicated in Table 2 on Page 11 should be calculated for the basin of interest. PMP depths for 2- and 6-hour LS depths and 48-hour General or Tropical depths are to be modeled using statistical distributions developed with the MetPortal tool. A runoff hydrograph for these durations should be modeled using USBR methodology (Flood Hydrology Manual, Cudworth 1989) as described in Hydrologic Analysis for Dams (NMOSE 2008). Distributions generated from the PF tool, peak discharge in cubic feet per second, and runoff volume in acre-feet should be reported for each distribution.

The MetPortal tool storm patterns (distributions) can be downloaded from the “Spatial/Temporal/Temperature Analysis” tab of the MetPortal tool. Storm durations must be individually selected and saved for all of the types and key durations listed in Table 2 while the user is...
working in the Spatial/Temporal/Temperature Analyses tab page. The user must select the AEP and
Storm of Interest for each storm type/duration to access the distributions called for in Table 2.
Temporal distribution output is provided for a given duration in a zipped file that is accessed by
selecting the “Download Data for Selected Inputs” button as shown on Figure 8. The zip file contains
an Excel spreadsheet that provides the temporal distribution information for application to hydrologic
modeling. Incremental precipitation, mass curve points, Unscaled Increments and Unscaled
Accumulation are provided in tabular form. For beta testing of PMP depths with PF distributions, the
Unscaled ordinates are to be used to develop distributions based on PMP tool total depth output. The
zip file also contains a graphical representation of the incremental precipitation and accumulated
precipitation for that location, storm type and duration.

NOAA HMR PMP: During the trial implementation of REPS PMP, users can choose to provide comparison
to the applicable NOAA HMR (HMR 55A or HMR 49) PMP for the basin of interest (all storm types).
Table 1 - Interim PMP Temporal Distributions and Applicable REPS Rainfall.

<table>
<thead>
<tr>
<th>Local / Hybrid Storms</th>
<th>72-hour center-weighted (1)</th>
<th>72-hour 2/3 late-weighted (1)</th>
<th>72-hr General Storm REPS Synthetic Curve (2)</th>
<th>24-hr Hybrid REPS Synthetic Curve (2)</th>
<th>2-hr Local REPS Synthetic Curves (2)</th>
<th>6-hr Alternating Block, 33% Intensity Position (3)</th>
<th>6-hr Alternating Block, 50% Intensity Position (3)</th>
<th>6-hr REPS Synthetic Curve (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPS 6-hr PMP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REPS 2-hr PMP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REPS 24-hr Hybrid PMP</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>Locations where 24-hr Hybrid PMP depth exceeds the 24-hr rainfall depth for the General or Tropical Storm or the increase from the 6-hour depth exceeds 10%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Storms</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>REPS 72 hr General Storm PMP</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tropical Storms</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>REPS 72-hr Tropical Storm</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Locations where Tropical Storm total depth exceeds the General Storm total depth</td>
<td></td>
</tr>
</tbody>
</table>

NOTES:
(1) User developed (NMOSE 2008)
(2) PMP Tool generated
(3) May be Derived in HEC-HMS
<table>
<thead>
<tr>
<th>Local/Hybrid Storms</th>
<th>REPS 6-hr PMP</th>
<th>REPS 2-hr PMP</th>
<th>6-hr USACE EM1110-2-1411 (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

General Storms

| REPS 48-hr General Storm PMP | X | X | X |

Tropical Storms

| REPS 48-hr Tropical Storm | X | X | Locations where 48-hour Tropical Storm PMP depth exceeds 48-hour General Storm PMP depth |

NOTES:
1. User derived
2. PMP Tool generated
3. Derived in HEC-HMS
4. PF Tool Generated (Front-Loaded, Center-Loaded, and Back-Loaded Distributions may not all be available in all regions)
5. USACE 1965 and NMOSE 2008

Table 2 - Optional Additional PMP Temporal Distributions and Applicable REPS Rainfall for Beta Testing.
QUESTIONS AND FEEDBACK:
We appreciate your interest and patience as we implement the REPS tools. If you have questions about the application of the tools or have feedback please contact us:

Charles N. Thompson, P.E.  Bureau Chief, NM Office of the State Engineer: 505-383-4134, charles.thompson@state.nm.us

James Head, P.E., Dam Safety Engineer, NM Office of the State Engineer: 505-383-4138, james.head@state.nm.us

Sushil Chaudhary, P.E., D.Eng., Dam Safety Engineer, NM Office of the State Engineer: 505-383-4136, sushilk.chaudhary@state.nm.us

REFERENCES:

