PADEP DAM SAFETY'S SPREADSHEET FOR TEMPORAL DISTRIBUTION OF THE PROBABLE MAXIMUM PRECIPITATION

GUIDANCE, INSTRUCTIONS AND APPLICATION IN HEC-HMS

A "PMP tool", which determines the Probable Maximum Precipitation (PMP) at dams, has been developed for the Pennsylvania Department of Environmental Protection (PADEP), Division of Dam Safety. The computer tool was developed by Applied Weather Associates (AWA) during an 18-month study of Probable Maximum Precipitation in Pennsylvania. The tool, which is executed by the ArcGIS computer program, provides updated estimates of the probable maximum rainfall depths and durations applicable to a specified watershed in Pennsylvania. These estimates are based on historic storm data that can be transposed to watersheds located in the variable regions across Pennsylvania.

This precipitation data provided by the PMP tool is then applied in the hydrologic and hydraulic modelling of storm runoff to a dam. This watershed model of the "Probable Maximum Flood" (PMF) provides a basis for determining spillway requirements under Pennsylvania's dam safety regulations. Generally, the Army Corps of Engineers HEC-HMS computer model is used for the hydrologic and hydraulic modelling.

The PMF at a dam is based not only on the PMP rainfall depths (as determined by the PMP tool), but also on the temporal distribution of the rainfall. Due to variations in watershed sizes and locations, PA DEP Dam Safety has determined that multiple runs of the hydrologic model are necessary to apply and compare a selection of possible temporal rainfall distributions. The rainfall distribution that results in the highest peak water surface elevation in the reservoir is then selected as the PMP storm, and the associated inflow hydrograph to the dam is the PMF ("Probable Maximum Flood") pertaining to dam safety regulatory requirements. It is noted that AWA advised against the use of a stacked distribution of PMP rainfall depths, which would have resulted in higher estimates of the PMF.

To supplement the PMP tool, PA DEP Dam Safety has developed a PMP distribution spreadsheet for determining five rainfall distributions that are to be applied to the tool's rainfall depths and durations. Along with several alternatives, these five distributions were tested on more than 25 dams located in various regions of the state. Based on testing and comparison of results, the five distributions were selected for analyzing the PMF in Pennsylvania. These five distributions are listed and described as follows:

1. **The 2-hour synthetic distribution**
2. **The 3-hour storm specific distribution**
3. **The 6-hour storm specific distribution**
4. **The 12-hour storm specific distribution**

5. The 24-hour storm specific distribution

The 2-hour Synthetic Distribution

This shorter duration distribution was developed by Applied Weather Associates based on historic storms where gage data is available for durations less than 1 hour. This distribution provides incremental depths for 5-minute intervals. PA DEP Dam Safety expects this to be the controlling distribution for many of the state's dams that have smaller drainage areas or minimal storage volumes above normal pool elevation.

The Storm Specific Distributions (3-hour, 6-hour, 12-hour and 24-hour)

The PMP tool determines the depth and duration data for a watershed in Pennsylvania by transposing historic storm data to the geographical location of that watershed. In this regard, the transposed, historic storm that would result in the greatest rainfall depth for a 3-hr duration may be different than the historic storm producing the greatest depth at 6, 12 or 24 hours. Therefore, the PMP spreadsheet calculates "storm specific" distributions of the PMP rainfall based on historic records for the specific storm that controls maximum depth at each duration. The storm specific distributions provide rainfall depths at hourly intervals. Generally, these storm specific distributions will define the PMF for dams with larger drainage areas and dams with large storage volumes above normal pool.

PMP Spreadsheet Adjustments of the storm specific distributions

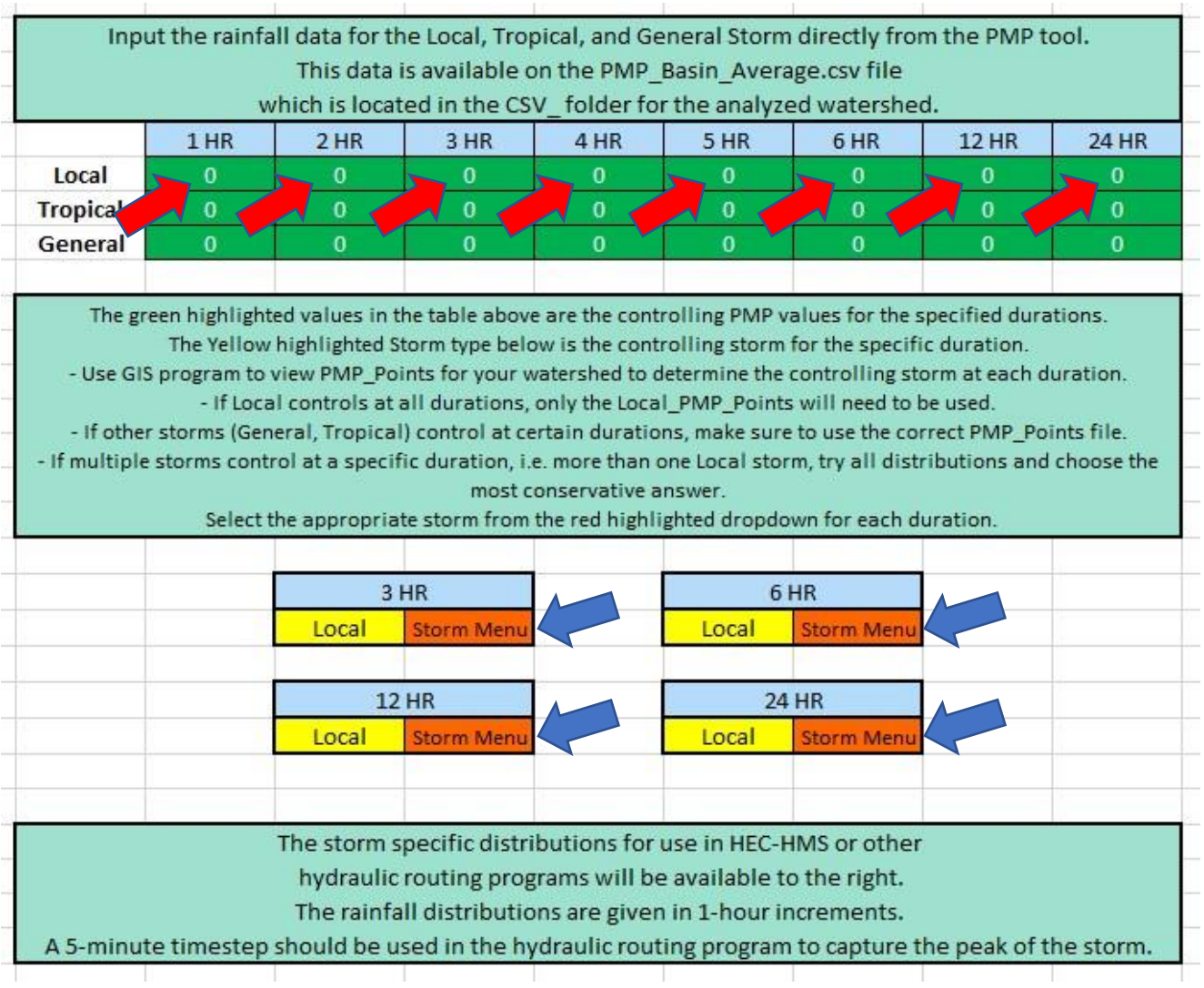
For a number of the historic storms, it was necessary to compute minor adjustments to the actual storm distribution. These adjustments were necessary because when the storm specific duration is applied for a certain duration (say 6-hours), the PMP rainfall depth might be exceeded for another duration. For example, say the PMP tool determined a 20-inch depth for 6 hours, and a 12-inch depth for 3 hours. Application of the storm specific distribution based on the 20-inch depth at 6 hours might result in a 3-hour depth which exceeds the 12-inch depth for 3 hours (say 14 inches). The spreadsheet addresses this issue by adjusting the storm specific distributions as follows:

> The distribution percentage for the storm specific distribution is first applied at the 6hour duration. An error check determines whether the depths at the other durations are exceeded. If so (using the example above), the 3-hour depth is reduced from 14inch to 12 inches, and the additional 2-inches of rainfall are distributed to other evenly hourly intervals. This is done within the distribution spreadsheet using error checks and calculations of the adjustments to the hyetograph. This procedure

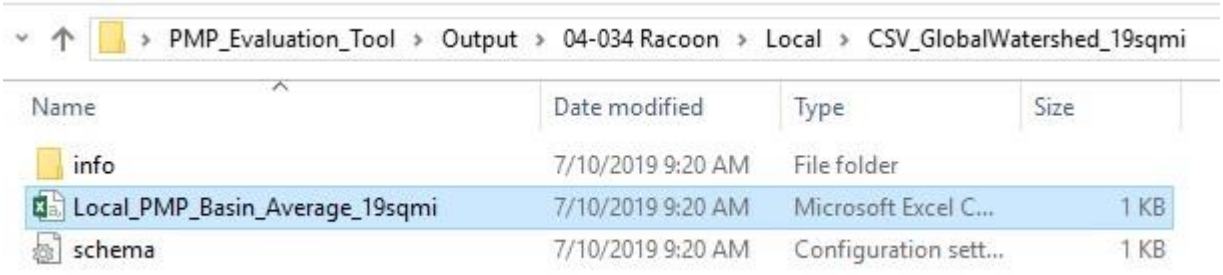
preserves the volume of the transposed storm while generally maintaining the shape of the hyetograph and the associated rainfall intensity of the specific storm.

Input Requirements for the PMP Spreadsheet

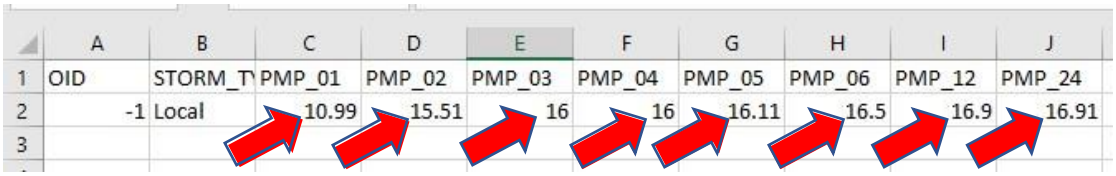
The inputs that are required for the PMP Distribution Spreadsheet are obtained from the PMP tool's output folder. Below is a view of the portion of the spreadsheet where input is required. "Input 1" below shows where to find the input needed at the red arrows. "Input 2" shows the source of the input needed at the blue arrows.



Input 1. Input the "Local" depth-durations from the PMP Tool basin average spreadsheet, which is located in the tool's output folder as shown below:

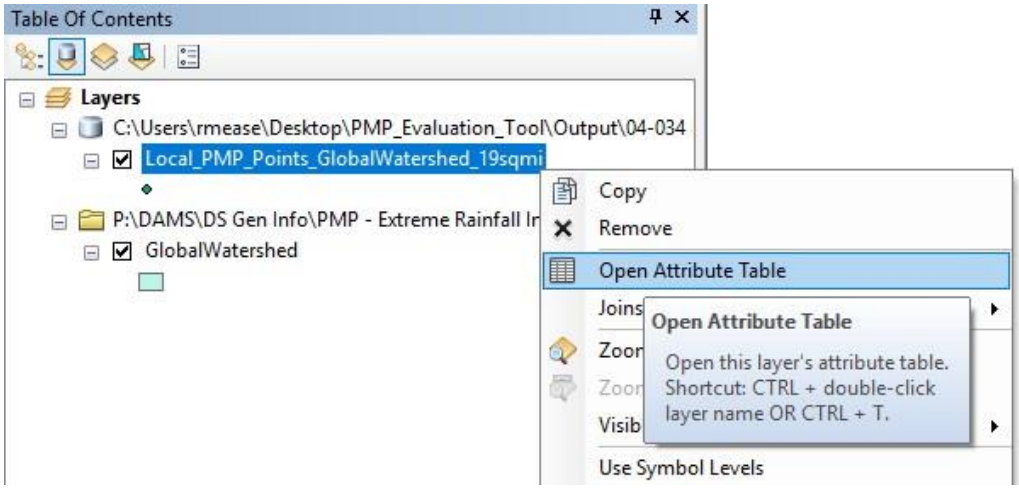


The spreadsheet highlighted above (Local_PMP_Basin_Average_19sqmi) when opened (see below) provides the Local Storm PMP rainfall depths for 1 through 24 hour durations. The rainfall depths to be copied into the PMP tool are designated by the red arrows.



	A	B	C	D	E	F	G	H	I	J
1	OID	STORM_T	PMP_01	PMP_02	PMP_03	PMP_04	PMP_05	PMP_06	PMP_12	PMP_24
2	-1	Local	10.99	15.51	16	16	16.11	16.5	16.9	16.91
3										

Input 2. Input the "specific storm" designation for each duration. Storm designations for each duration are specified on the PMP tool "Attribute Table" from the PMP Points layer in Arc-GIS.



The "Storm ID" for each duration is found on the Attributes Table shown below:

Storm ID 01-hour	Storm ID 02-hour	Storm ID 03-hour	Storm ID 04-hour	Storm ID 05-hour	Storm ID 06-hour	Storm ID 12-hour	Storm ID 24
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1546_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1546_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1
SPAS_1344_1	SPAS_1536_1	SPAS_1536_1	SPAS_1536_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1	SPAS_1344_1

Using the sample data, the spreadsheet's input and output is shown below:

SPREADSHEET INPUT:

Input the rainfall data for the Local, Tropical, and General Storm directly from the PMP tool.
This data is available on the PMP_Basin_Average.csv file
which is located in the CSV_ folder for the analyzed watershed.

	1 HR	2 HR	3 HR	4 HR	5 HR	6 HR	12 HR	24 HR
Local	10.99	15.51	16	16	16.11	16.5	16.9	16.91
Tropical	0	0	0	0	0	0	0	0
General	0	0	0	0	0	0	0	0

The green highlighted values in the table above are the controlling PMP values for the specified durations.
The Yellow highlighted Storm type below is the controlling storm for the specific duration.
- Use GIS program to view PMP_Points for your watershed to determine the controlling storm at each duration.
- If Local controls at all durations, only the Local_PMP_Points will need to be used.
- If other storms (General, Tropical) control at certain durations, make sure to use the correct PMP_Points file.
- If multiple storms control at a specific duration, i.e. more than one Local storm, try all distributions and choose the most conservative answer.

Select the appropriate storm from the red highlighted dropdown for each duration.

3 HR	
Local	1536_1

6 HR	
Local	1344_1

12 HR	
Local	1344_1

24 HR	
Local	1344_1

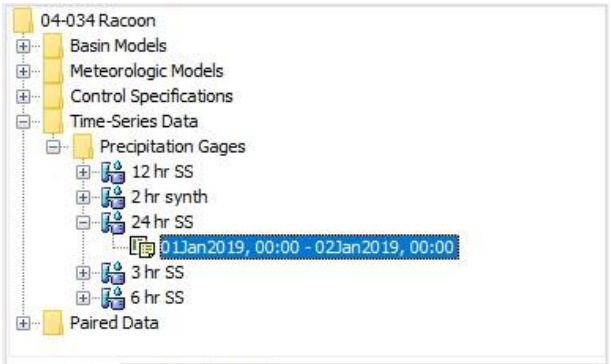
SPREADSHEET OUTPUT:

STORM SPECIFIC DISTRIBUTION								2 HR Synth	
3 HR		6 HR		12 HR		24 HR			
1536_1		1344_1		1344_1		1344_1			
MIN	INC	MIN	INC	MIN	INC	MIN	INC	MIN	INC
0	0.000	0	0.000	0	0.000	0	0.000	*0*	0.000
60	2.505	60	0.390	60	0.066	60	0.066	*5*	0.377
120	10.990	120	0.392	120	0.066	120	0.066	*10*	0.377
180	2.505	180	2.169	180	0.383	180	0.383	*15*	0.377
240	0.000	240	10.991	240	0.391	240	0.391	*20*	0.377
300	0.000	300	2.168	300	2.165	300	2.165	*25*	0.377
360	0.000	360	0.392	360	10.990	360	10.990	*30*	0.377
420	0.000	420	0.000	420	2.164	420	2.164	*35*	0.678
480	0.000	480	0.000	480	0.391	480	0.391	*40*	0.732
540	0.000	540	0.000	540	0.084	540	0.084	*45*	0.802
600	0.000	600	0.000	600	0.066	600	0.066	*50*	0.991
660	0.000	660	0.000	660	0.066	660	0.066	*55*	1.399
720	0.000	720	0.000	720	0.066	720	0.066	*60*	1.716
780	0.000	780	0.000	780	0.000	780	0.001	*65*	1.161
840	0.000	840	0.000	840	0.000	840	0.001	*70*	0.875
900	0.000	900	0.000	900	0.000	900	0.001	*75*	0.759
960	0.000	960	0.000	960	0.000	960	0.001	*80*	0.710
1020	0.000	1020	0.000	1020	0.000	1020	0.001	*85*	0.625
1080	0.000	1080	0.000	1080	0.000	1080	0.001	*90*	0.540
1140	0.000	1140	0.000	1140	0.000	1140	0.001	*95*	0.377
1200	0.000	1200	0.000	1200	0.000	1200	0.001	*100*	0.377
1260	0.000	1260	0.000	1260	0.000	1260	0.001	*105*	0.377
1320	0.000	1320	0.000	1320	0.000	1320	0.001	*110*	0.377
1380	0.000	1380	0.000	1380	0.000	1380	0.001	*115*	0.377
1440	0.000	1440	0.000	1440	0.000	1440	0.001	*120*	0.377

HEC-HMS INPUT:

After the five PMP distributions are computed by the spreadsheet, the incremental rainfall depths are copied as hyetographs (precipitation gages) into the HEC-HMS model of the dam and its watershed. Note that the "storm specific rainfall data" is in 60-minute increments and the 2-hour synthetic hyetograph is in 5-minute increments. The following shows the location and appearance of this data when it is copied into HEC-HMS:

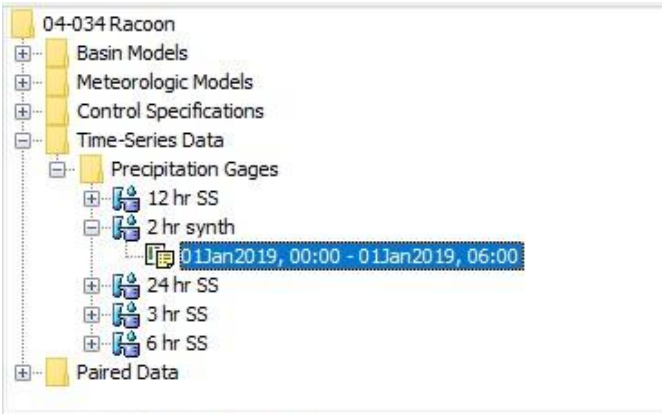
Input for the 24-hour Storm Specific Hyetograph:



Time-Series Gage | Time Window | Table | Graph

Time (ddMMMYYYY, HH:mm)	Precipitation (IN)
01Jan2019, 00:00	
01Jan2019, 01:00	0.066
01Jan2019, 02:00	0.066
01Jan2019, 03:00	0.383
01Jan2019, 04:00	0.391
01Jan2019, 05:00	2.165
01Jan2019, 06:00	10.990
01Jan2019, 07:00	2.164
01Jan2019, 08:00	0.391
01Jan2019, 09:00	0.084
01Jan2019, 10:00	0.066
01Jan2019, 11:00	0.066
01Jan2019, 12:00	0.066
01Jan2019, 13:00	0.001
01Jan2019, 14:00	0.001
01Jan2019, 15:00	0.001
01Jan2019, 16:00	0.001
01Jan2019, 17:00	0.001
01Jan2019, 18:00	0.001
01Jan2019, 19:00	0.001
01Jan2019, 20:00	0.001
01Jan2019, 21:00	0.001
01Jan2019, 22:00	0.001
01Jan2019, 23:00	0.001
02Jan2019, 00:00	0.001

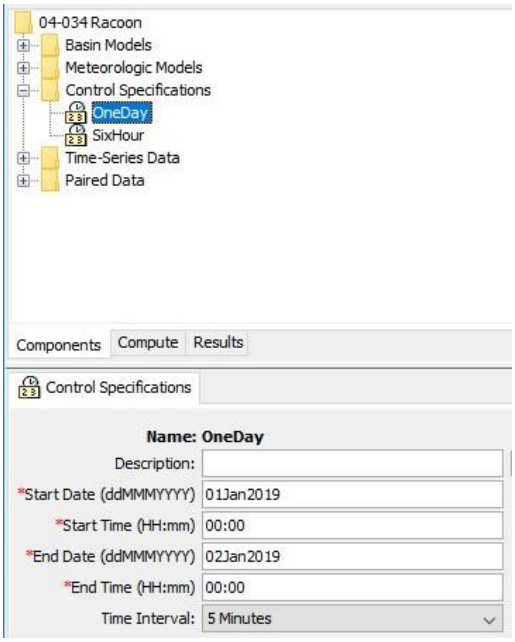
Input for the 2-hour Synthetic Hydrograph:



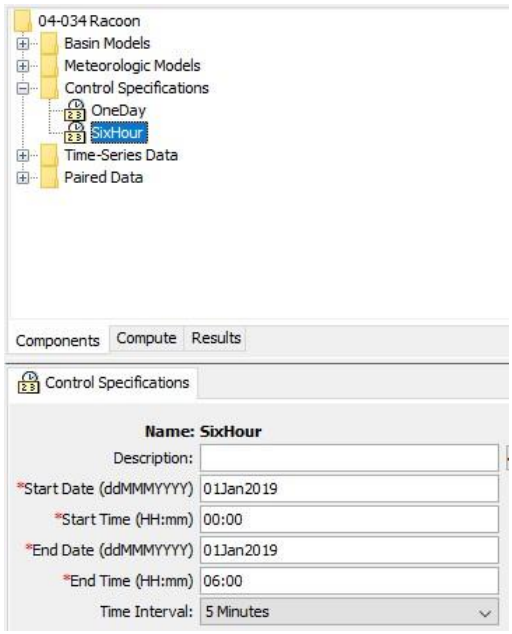
Time (ddMMMYYYY, HH:mm)	Precipitation (IN)
01Jan2019, 00:05	0.377
01Jan2019, 00:10	0.377
01Jan2019, 00:15	0.377
01Jan2019, 00:20	0.377
01Jan2019, 00:25	0.377
01Jan2019, 00:30	0.377
01Jan2019, 00:35	0.678
01Jan2019, 00:40	0.732
01Jan2019, 00:45	0.802
01Jan2019, 00:50	0.991
01Jan2019, 00:55	1.399
01Jan2019, 01:00	1.716
01Jan2019, 01:05	1.161
01Jan2019, 01:10	0.875
01Jan2019, 01:15	0.759
01Jan2019, 01:20	0.710
01Jan2019, 01:25	0.625
01Jan2019, 01:30	0.540
01Jan2019, 01:35	0.377
01Jan2019, 01:40	0.377
01Jan2019, 01:45	0.377
01Jan2019, 01:50	0.377
01Jan2019, 01:55	0.377
01Jan2019, 02:00	0.377
01Jan2019, 02:05	0.000
01Jan2019, 02:10	0.000
01Jan2019, 02:15	0.000

PA DEP Dam Safety recommends that the HEC-HMS models for all four PMP storm specific rainfalls should be run for a 24-hour time period. The 2-hour synthetic distribution may be run for a 6-hour time period. In all cases, a 5-minute calculation interval is appropriate. The relevant control specifications in HEC-HMS are shown below:

3, 6, 12 and 24-hour Storm Specific 24-hour control specification:



2-hour Synthetic 6-hour control specification:



The HEC-HMS model should be used to compute the conditions at the dam for all five of the distributions. These results should be compared. The PMF for the dam is the flood that results in the highest peak outflow and the maximum water surface elevation in the impoundment. The following spreadsheet shows these results at the sample dam, where the Storm Specific 3HR is designated as the PMF because it has the highest outflow and maximum water surface elevation.

PMP Distribution	Peak Flow In	Peak Flow Out	Maximum WSEL
Storm Specific 3HR	28734	28556	902.48
Storm Specific 6HR	28425	28244	902.43
Storm Specific 12 HR	28401	28220	902.43
Storm Specific 24 HR	28401	28220	902.43
2 hr synthetic	28588	28399	902.46

NOTE: The steps above should be repeated to enter the rainfall depths for the Tropical and General storms. If it is determined that the Tropical or the General storm is the controlling rainfall for a certain distribution (turns green on the spreadsheet), then the Storm ID for the Tropical or General storm should be entered, and additional HEC-HMS runs should be done for each controlling storm. For most dams in Pennsylvania, the Local Storm produces the maximum rainfall at each duration and the PMP tool computations for Tropical and General storms would not be needed in those cases.