Design Rainfall Temporal Distributions for 24 hour Rainfall Events Having Average Return Intervals of 1 to 100 Years

prepared by

Philip H. De Groot, Ph.D., P.E.; Principal Hydraulic Engineer
Michael C. Menoes, Ph.D., P.E.; Senior Hydraulic Engineer

Hydrosphere Engineering
PO BOX 360530
Cleveland, Ohio 44136-0009
330-721-2722 or 440-879-2049
hydrosphere-engineering.com

August 14, 2020

INTRODUCTION

During the inspection and evaluation of storm water detention basins over the years, we have heard the following observation on numerous occasions: “There is never any water in that detention basin.” These claims are frequently made to indicate that during typical rainfall events, there appears to be little to no storage occurring in the detention basin.

When designing detention basins, engineers typically rely on the following:

* Some type of software to compute runoff from a watershed based upon a rainfall event. Often times the software may be the NRCS (formerly the SCS) TR-20 or TR-55 programs.

* A method for converting rainfall depths to runoff volumes. The most commonly used method is the NRCS dimensionless unit hydrograph procedure.

* A rainfall depth associated with a storm recurrence interval. For design purposes, the length of the rainfall event is typically 24 hours. Current rainfall data can be found online at: https://hdsc.nws.noaa.gov/hdsc/pfds/ [NOAA Atlas 14].

* A temporal distribution of rainfall, or a time series indicating how much rain fell during a specific time period.

Most engineers are familiar with at least a couple of hydrologic computer programs, know where to find rainfall data, and have been at least exposed to the NRCS dimensionless unit hydrograph procedure either through their education or in their practicing careers. However, most practicing engineers are not familiar with rainfall temporal distributions. When performing hydrologic computations using some type of software, temporal distributions are typically selected by default with little input or thought by the software user.

The goal of this report is to provide current information and recommendations regarding the selection and use of rainfall temporal distributions. This report contains information related to the following:

1. The severity of the NRCS Type 2, 24 hour rainfall temporal distribution, and the fact that this distribution is typically applied to all of the rainfall events having average return intervals (ARI) of 1 to 100 years.

2. Due to the distribution’s severity, the NRCS Type 2, 24 hour rainfall temporal distribution over predicts the peak rate of storm water runoff for rainfall events having an ARI of 1 to 50 years.

3. The NRCS Type 2, 24 hour rainfall temporal distribution is being phased out, and some agencies are no longer recommending its use.

4. The NRCS has developed rainfall temporal distributions based on NOAA Atlas 14 Volumes 2 and 9 to replace the historical NRCS Type 2, 24 hour design rainfall temporal pattern.

5. Several additional 24 hour rainfall temporal distributions have been developed, including those by Hydrosphere Engineering, and the specifics are presented.

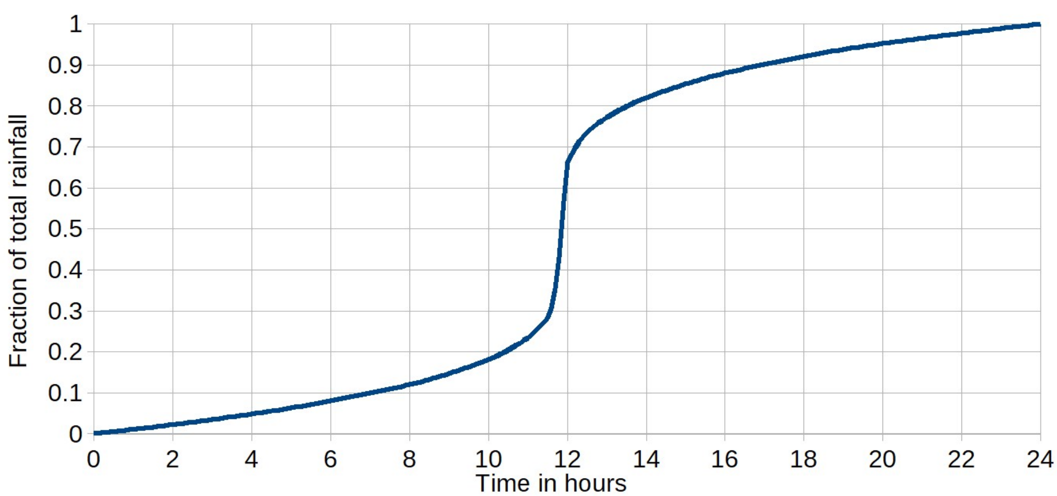
6. The 24 hour rainfall temporal distributions presented in this report have been evaluated for peak rates of storm water runoff from three watersheds located in the North Appalachian Experimental Watershed in Coshocton, Ohio.

7. Specific recommendations are provided for the use of the 24 hour rainfall temporal distributions.

NRCS TYPE 2, 24 HOUR RAINFALL TEMPORAL DISTRIBUTION

As discussed in the previous section, the typical default rainfall temporal distribution for most hydrologic computer programs is the NRCS Type 2, 24 hour rainfall temporal distribution. Merkel et al. (2015) provide an overview of the history of the NRCS rainfall temporal distribution type curves. The Type 2, 24 hour rainfall temporal distribution has been applicable to a large part of the eastern contiguous United States, and has been widely used in the hydrologic design of storm water management systems. Figure 1 shows a graph of the Type 2, 24 hour rainfall temporal distribution.

Figure 1. NRCS Type 2, 24 hour rainfall temporal distribution.



A review of Figure 1 demonstrates the severity of the distribution. From 11:45 to 12:15, nearly half of the total rainfall occurs. This type of distribution represents very severe (rare) rainfall events, but does this distribution represent much more frequent rainfall events? This question brings us back to the initial statement regarding the observation that there is little to no storage occurring in detention basins.

REPLACEMENT DESIGN RAINFALL TEMPORAL DISTRIBUTIONS

Merkel et al. (2015) note that these NRCS type curves are being replaced by rainfall distribution curves based on the NOAA Atlas 14. Merkel at al. (2015) present design rainfall temporal distributions identified as NOAA Types A through D for the Ohio Valley and neighboring states. Merkel and Moody (2015) present design rainfall temporal distributions identified as MSE Types 1 through 6 for the Midwest and Southeastern states.

Both the NOAA Types A through D and the MSE Types 1 through 6 rainfall temporal distributions are S curves similar to the NRCS Type 2, 24 hour curve shown on Figure 1, where a significant amount of the rainfall occurs at the 12 hour time period.

The HydroCAD program contains numerous rainfall temporal distributions from various sources. Tables and graphs are available for both the NOAA Types A through D and the MSE Types 1 through 6 rainfall temporal distributions. Examination of the graphs for both the NOAA and MSE rainfall temporal distributions reveal that NOAA Type A through D are nearly identical to MSE Types 3 through 6. Only the MSE Types 1 through 6 will be discussed below in this report

PREDICTING THE PEAK FLOW FROM GAGED WATERSHEDS

The USDA NRCS operated the North Appalachian Experimental Watershed in Coshocton, Ohio for a number of years, finally closing the facility in 2014. Numerous stream gage and rainfall gage data were collected from primarily agricultural watersheds. Three of those watersheds were selected to assess how effectively the NRCS Type 2 and the NRCS MSE design rainfall temporal distributions could predict the peak flow rates from rainfall events having an ARI from 1 year to 100 years.

A flood frequency analysis was performed on the stream flow data for Coshocton Watersheds 172, 177 and 196. See the summary by De Groot and Menoes (February 2020) for the specific details of the flood frequency analysis. The watersheds were then assigned curve numbers and times of concentration consistent with NRCS hydrologic TR-20 design procedures. The HydroCAD program was used to determine the peak rate of storm water runoff using the historical NRCS Type 2, the NRCS MSE Types 1 through 6, and the Hydrosphere 24 hour rainfall temporal distributions, Versions HY_00 to HY_10, discussed later in this report. Appendix A contains the tabulated results.

Appendix A can be downloaded from the Technical Notes section of the Hydrosphere Engineering website.

Examination of Tables A1 to A3 in Appendix A reveals that the historical NRCS Type 2 rainfall temporal distribution accurately predicted the peak flow rates for the rainfall events having an ARI of either 50 years or 100 years, but over predicted the peak flow rates for rainfall events having an ARI of 1, 2, 5, 10 and 25 years: the lower the ARI, the greater the over prediction.

Examination of Tables A4 to A6 in Appendix A reveals that the NRCS MSE rainfall temporal distributions accurately predicted the peak flow rates for the rainfall events having an ARI of either 10, 25, 50 years or 100 years, but over predicted the peak flow rates for rainfall events having an ARI of 1, 2 and 5 years: the lower the ARI, the greater the over prediction.

DETENTION BASINS THAT ARE NOT EFFECTIVE AT SMALL ARI

Over predicting peak flow rates for small values of the ARI can cause the outlet structures of the detention basins to be oversized resulting in the effectiveness of the detention basin being reduced during more frequent rainfall events.

Citing directly from the text from the OEPA critical storm method:

“If the volume of runoff from an area after development will be greater than the volume of runoff from the same area before development, it shall be compensated by reducing the peak rate of runoff from the critical storm and all more-frequent storms occurring on the development area to the peak rate of runoff from a one-year frequency, 24 hour storm occurring on the same area under predevelopment conditions.”

The peak flow rate from the 1 year, 24 hour storm is a design parameter that should not be over predicted, unless you expect to hear: There is never any water in that detention basin.

Using the historical NRCS Type 2, 24 hour rainfall temporal distribution to predict the peak flow rate for a rainfall event having an ARI of 1 year is probably the single most cause for detention basins that are not effective for small ARI. Using the NRCS MSE rainfall temporal distributions would provide some improvement, but what is needed are rainfall temporal distributions that can accurately predict peak flow rates for small ARI.

DEVELOPING RAINFALL TEMPORAL DISTRIBUTIONS FOR SMALL ARI

A family of rainfall temporal distributions curves were developed using the following guidelines:

a) Rainfall event with a 24 hour duration;
b) S curve similar to the NRCS MSE rainfall temporal distributions;
c) S curve which is symmetric about the time at 12 hours;
d) 50% of the rainfall depth occurs exactly at 12 hours;
e) Less severe than the NRCS Type 2;

The historical NRCS Type 2, 24 hour rainfall temporal distribution was used as a starting point. The time scale was adjusted by 0.15 hours so that 50% of the rainfall depth occurred at 12 hours. A curve was then fit to 6 known points on the final 12 hours of the adjusted NRCS curve using a method of least squares. Additional curves were developed by determining the difference between the S curve ordinates and the ordinates for a rainfall event having a uniform rainfall intensity. A uniform rainfall intensity event will produce the minimum peak flow rate. Appendix B contains the details and a table of coefficients which can be used in the equations. Appendix B can be downloaded from the Technical Notes section of the Hydrosphere Engineering website.

EXAMPLE OF A DIRECTIVE FROM ANOTHER STATE

The Minnesota Department of Transportation has directed design engineers to no longer use the NRCS Type 2, 24 hour temporal distribution.

The MnDOT Engineering Services Division, in Technical Memorandum 15-10-B-02 (December 2015), states:

Use the rainfall distribution derived from Atlas 14 data or use the NRCS MSE 3 rainfall distribution with the NRCS rainfall/runoff hydrology method. Do not use the NRCS Type II rainfall distribution.

RECOMMENDATIONS FOR IMPLEMENTATION

1. Perform hydrologic design using a separate rainfall temporal distribution for each average return interval (ARI).

2. Stop using the NRCS Type 2, 24 hour temporal distribution.

3. In its place, use one of the following alternatives:

Average Return Interval (Years)	Alternative 1: Use the Hydrosphere 24 hour Temporal Distributions	Alternative 2: Use the NRCS NOAA 24 hour temporal distributions	Alternative 3: Use the NRCS NOAA and Hydrosphere 24 hour temporal distributions
100	HY_00	NOAA A (MSE 3)	NOAA A (MSE 3)
50	HY_01	NOAA B (MSE 4)	NOAA B (MSE 4)
25	HY_02	NOAA C (MSE 5)	NOAA C (MSE 5)
10	HY_03	NOAA D (MSE 6)	NOAA D (MSE 6)
5	HY_04	NOAA D (MSE 6)	HY_04
2	HY_05	NOAA D (MSE 6)	HY_05
1	HY_06	NOAA D (MSE 6)	HY_06

4. Engineers that are responsible for the review of hydrologic calculations should require that for each ARI peak flow rate, the temporal distribution which was used for that ARI should be identified. A simple table should be included in the hydrologic report.

RAINFALL TEMPORAL DISTRIBUTIONS FOR MORE SEVERE EVENTS

If a design requires the determination of the peak rate of storm water runoff for rainfall events with ARI larger than 100 years, the NRCS MSE 1 and MSE 2 temporal distributions produce higher peak flow rates than MSE 3. Hydrosphere temporal distributions (HY-1 to HY-4) also produce peak flow rates higher than HY_00 and MSE 3. Hydrosphere temporal distributions HY-1 to HY-4 are available upon request.

REPORT CITATION

If you choose to use the temporal distributions developed by Hydrosphere Engineering, the following citation should be used in the reference section of your hydrologic design reports:

De Groot, Philip H. and Michael C. Menoes. August 14, 2020. Design rainfall temporal distributions for 24 hour rainfall events having average return intervals of 1 to 100 Years. Hydrosphere Engineering. www.hydrosphere-engineering.com

REFERENCES

HydroCAD Storm water Modeling Software Version 10.00

Keifer, Clint J. and Jenry Hsen Chu. August 1957. Synthetic Storm Patten for Drainage Design. ASCE Journal of the Hydraulics Division, HY 4, pp. 1332-1 through 1332-25. This paper describes the development of the 'Chicago Hydrograph Method' for developing a design storm from IDF data.

Merkel, William H. 2006. Design Rainfall Distributions based on NOAA 14 Volumes 1 and 2 data. Third Federal Interagency Hydrologic Modeling Conference (FIHMC), Reno, Nevada.

Merkel William H., Helen Fox Moody and Quan D. Quan. 2006. United States Department of Agriculture, Natural Resources Conservation Service. Rainfall Distribution for States Covered by NOAA Atlas 14 Volumes 1 and 2, NRCS internal publication (available upon request).

Merkel, William H. and Helen Fox Moody. April 29, 2015. NOAA Atlas 14 rainfall for Midwest and Southeast states: Statistics for NOAA Atlas 14 100 year 24 hour rainfall by state and county.

Merkel, William H., Quan. D. Quan, Q.D., and Helen Fox Moody. 2015, Design Rainfall Distributions based on NOAA Atlas 14 Rainfall Depths and Durations. Fifth Federal Interagency Hydrologic Modeling Conference (FIHMC), Reno, Nevada.

United States Department of Agriculture Natural Resources Conservation Service. September 2, 2015. National Engineering Handbook Part 630 Hydrology. Chapter 4: Storm Rainfall Depth and Distribution (draft).

U.S. Department of Commerce National Oceanic and Atmospheric Administration. 2004, revised 2006. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States Volume 2 Version 3.0: Delaware, District of Columbia, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia. Silver Spring, Maryland.

U.S. Department of Commerce National Oceanic and Atmospheric Administration. 2013. NOAA Atlas 14, Precipitation-Frequency Atlas of the United States Volume 8 Version 2.0: Midwestern States. Silver Spring, Maryland.

U.S. Department of Commerce National Oceanic and Atmospheric Administration. 2013. NOAA Atlas 14, Precipitation-Frequency Atlas of the United States Volume 9 Version 2.0: Southeastern States. Silver Spring, Maryland.