DESIGN RAINFALL DISTRIBUTIONS BASED ON NOAA ATLAS 14 RAINFALL DEPTHS AND DURATIONS

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Abstract

For hydrologic design purposes, the Natural Resources Conservation Service (NRCS) has historically used rainfall distributions derived from rainfall-frequency data. The rainfall distribution represents the cumulative rainfall from the beginning to the end of the design storm. The rainfall distribution is non-dimensional, and begins at a value of zero and ends at a value of 1.0. The Type I, Type IA, Type II, and Type III rainfall distributions are in general use throughout the United States. NRCS hydrologic models including Engineering Field Handbook Chapter 2 EFH-2, USDA (2014), WinTR-55 Small Watershed Hydrology, USDA (2010) and WinTR-20 Project Formulation Hydrology, USDA (2010) make use of these rainfall distributions.

The Type I, Type II, and Type III rainfall distributions were developed from rainfall-frequency data contained in the United States (US) Department of Commerce publications US Weather Bureau Technical Paper 40 (1961) and National Weather Service (NWS) Hydro-35 (1977). USDA NRCS Technical Paper 149 (1973) describes the way in which the Type I and Type II distributions were developed and shows plots of rainfall versus duration at several locations. These legacy rainfall distributions are being replaced with rainfall distributions developed from data contained in the NWS National Oceanic and Atmospheric Administration (NOAA) Atlas 14. Volumes 1 (2006) through 9 (2013) have been released and cover 37 states, Puerto Rico, US Virgin Islands, and selected Pacific Islands.

The standard design rainfall distributions are based on nesting the high intensity short durations within the longer lower intensity durations. For example, the maximum rainfall in 5 minutes is assumed to be within the maximum 10-minute rainfall, which is within the maximum 15-minute rainfall. This process is continued until the 24-hour duration is reached. The non-dimensional aspect of the rainfall distribution is that the durations from 5 minutes through 12 hours are represented as a ratio of that duration rainfall to the 24-hour rainfall.

Maps of these rainfall ratios were developed using Geographic Information System (GIS) technology. The goal was to identify regions of similar rainfall distribution. A map of a multi-state area with a group of regional rainfall distributions was developed along with 24-hour rainfall tables for use in hydrologic models.

Site-specific rainfall distributions based on NOAA Atlas 14 rainfall-duration-frequency data for a location may be developed. This approach preserves the intensities within a rainfall distribution with minimum error. A computer program was written to use NOAA Atlas 14 partial duration rainfall-frequency data at a specific site to develop a set of rainfall distributions for WinTR-20. A unique rainfall distribution may be developed for each return period from 1 year (100% chance) through 500 years (0.2% chance). When developing these rainfall distributions, rainfall at durations of 5, 10, 15, and 30 minutes and 2, 3, 6, and 12 hours are smoothed in order to make sure

the rainfall distribution and resulting runoff hydrographs are smooth. The 60 minute and 24 hour values are not changed in the smoothing process.

INTRODUCTION

The four components of the NRCS hydrologic model are 1) runoff curve number, 2) time of concentration, 3) dimensionless unit hydrograph, and 4) rainfall magnitude and distribution. Each of these has been the subject of many technical papers by authors within the government and private sectors. As research and new data have become available, analysis techniques for these components have been improved individually. The authors' opinion is that if each of these components is analyzed according to the best available data and research, collectively they will produce the most accurate estimate of hydrologic response from a watershed. This concept is important because so many applications of the NRCS hydrologic model are for ungaged watersheds. In the case of gaged watersheds, the input data for each model component may be calibrated. This paper describes significant updates to both the rainfall magnitude and distribution as proposed for use in the NRCS hydrologic models (Engineering Field Handbook Chapter 2 (EFH-2), WinTR-55, and WinTR-20). Before the publication of NOAA Atlas 14 Volumes 1 through 9, NRCS used rainfall data from Weather Bureau Technical Paper 40 and NOAA Atlas 2 (in western states) for evaluation and design of engineering projects. The rainfall data and design rainfall distributions based on these data were used for so many years by NRCS and engineers in the general public that their use been considered standard operating procedures. The publication of NOAA Atlas 14 has caused serious consideration as to how to move forward in this age of highly advanced computers, GIS data, and software. Implementing such changes has taken significant time and work with respect to both developing technical procedures, and informing and training engineers within the government and private sectors.

Traditional principles and new technology and data have been combined to produce the rainfall data and rainfall distributions to replace the legacy rainfall data and rainfall distributions used for so many years.

This paper describes the treatment of NOAA Atlas 14 data after it is acquired for a given project site. The two major concepts explained are data smoothing and development of the design rainfall distribution. These methods are described in USDA-NRCS NEH Part 630 Chapter 4 Storm Rainfall Depth and Distribution (2014 draft).

DATA SMOOTHING

Since precipitation durations were analyzed independently in NOAA Atlas 14, there are cases when the precipitation intensity between successive durations does not uniformly decrease as duration increases. In developing a design rainfall distribution, this factor is of critical importance.

Several mathematical techniques were investigated to develop a procedure which is computationally efficient, accurate, practical, stable, and robust. The relationship of rainfall intensity (inches/hour) and duration is smoothed since the generated hydrograph is primarily dependent on the relationship of precipitation intensity with duration.

The relationship of intensity and duration is based on a factor called incremental intensity. Incremental intensity is defined as the difference in precipitation divided by the difference in duration. The incremental intensity for the 5-minute duration is equal to the 5-minute precipitation divided by 1/12 in inches per hour. The incremental intensity for the 10-minute duration is the 10-minute precipitation minus the 5-minute precipitation divided by 1/12 (the difference between 5 and 10 minutes in units of hours). Incremental intensity is calculated and smoothed for each return period independently. Plotting this relationship on a log-log scale, it may be a straight line, have slight curvature, or have several dips or waves. An example of plot of original data is shown in figure 1.

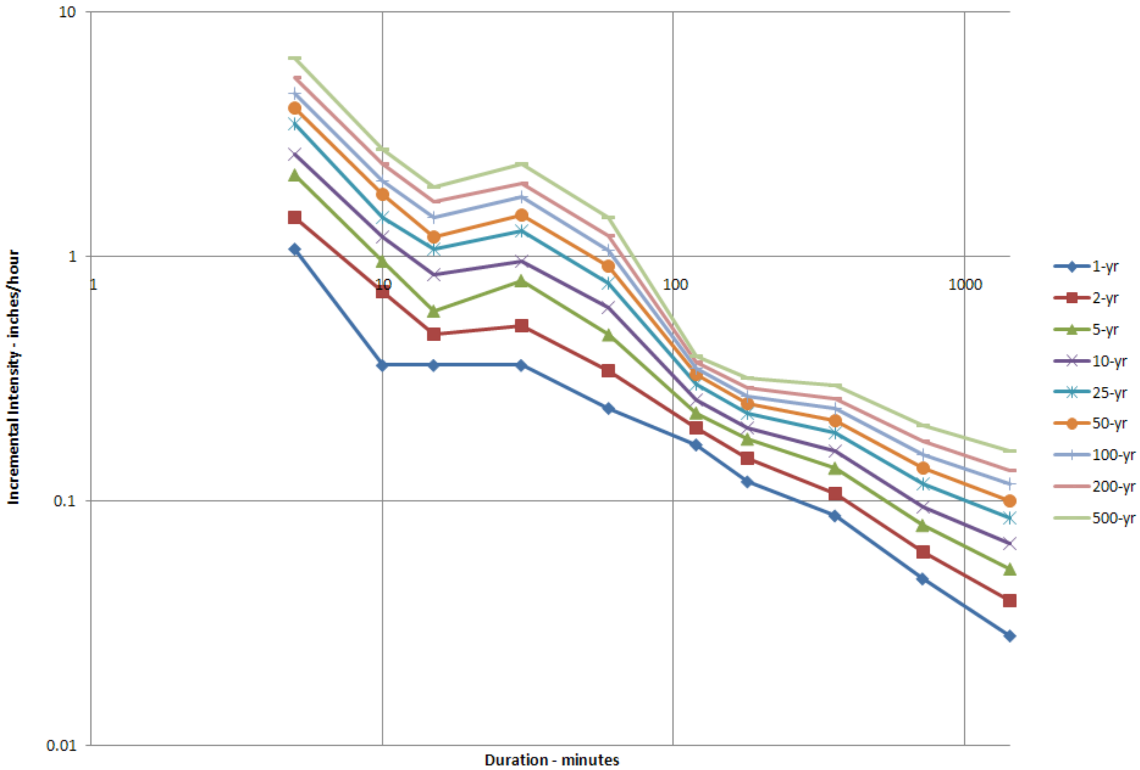

Figure 1 Incremental Intensity plot for original data for Sun City California, not smooth between 10 minutes and 6 hours.

The smoothing procedure keeps the 60-minute and 24-hour precipitation unchanged from the original NOAA Atlas 14 partial duration values. The 5-, 10-, 15-, 30-minute, and the 2-, 3-, 6-, and 12-hour values are open to adjustment. The smoothing procedure computes a straight line on the log-log plot which extends from 5-minute to 60-minute durations. The line is placed such that the squared difference between the smoothed 5-, 10-, 15-, and 30-minute incremental intensity values and the original values is minimized and the 60-minute precipitation is equal to the original value. A second straight-line segment is computed on the log-log plot that extends from the 60-minute value to the 24-hour value. This line is placed such that the incremental intensity for 60-minute duration is the same as calculated for the first line segment and the 60-minute and 24-hour precipitation values are unchanged. Calculating the adjusted values of precipitation involves a trial and error optimization procedure. An example of data smoothing is shown in figure 2.

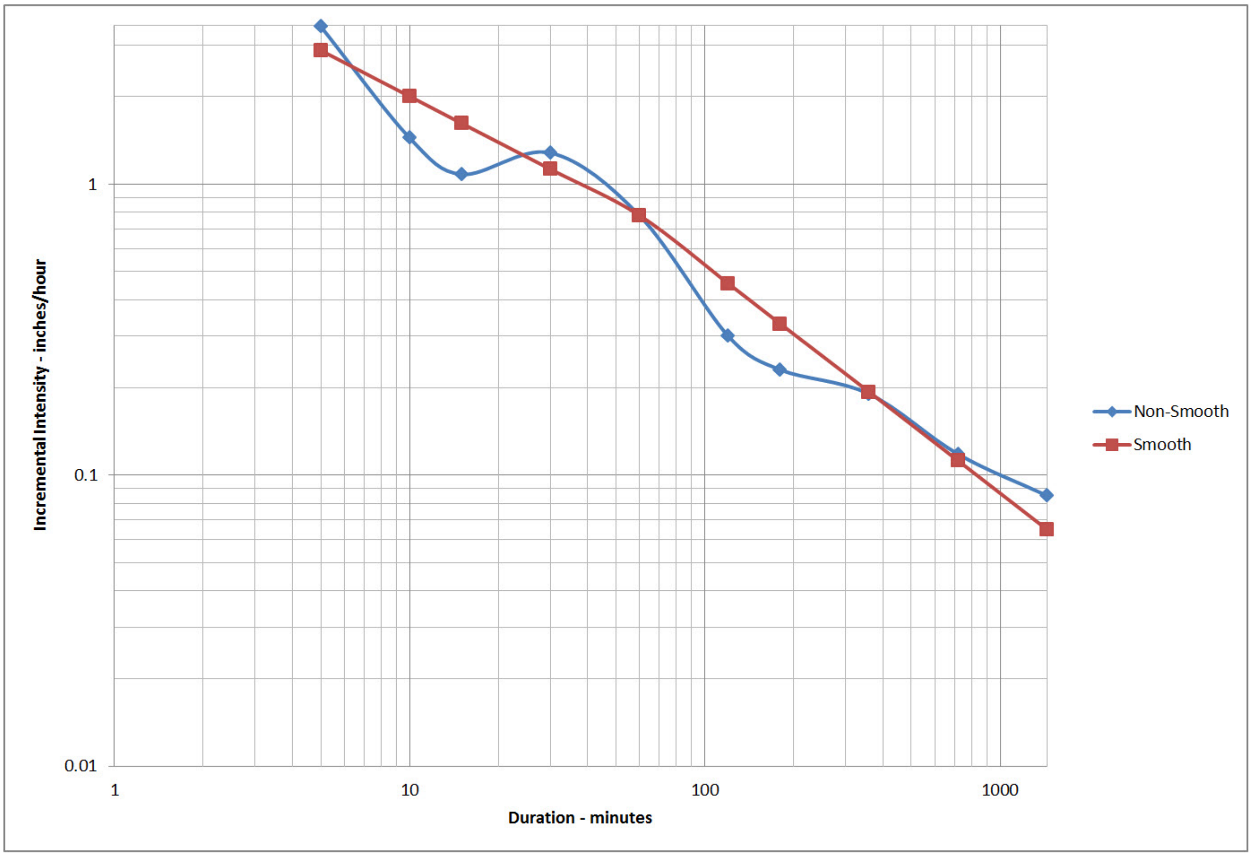

Figure 2 Plot of 25-year (4% chance) smoothed and non-smoothed incremental intensity at Sun City, California.

TEMPORAL DISTRIBUTION

A procedure has been developed that will derive rainfall distributions to cover the wide range of climatic conditions from tropical to arctic that occur in the US (Merkel, 2006).

The method used to construct the 24-hour rainfall distribution insures that the maximum rainfall of any duration less than 24 hours is included in the distribution. One of the principles of hydrology is that the peak discharge for a watershed is determined primarily by rain falling in a duration that equals the time of concentration (see USDA NEH Part 630 Chapter 15, 2010). The 24-hour rainfall distribution has the maximum 5-minute rainfall occurring at 12 hours. The maximum 10-minute rainfall is centered around 12 hours, and includes the maximum 5-minute rainfall, and so on. In this way, a single rainfall distribution for 24 hours may be used for any watershed with time of concentration less than 24 hours.

Input to the method consists of a set of rainfall values at durations of 5, 10, 15, 30 and 60 minutes and 2, 3, 6, 12, and 24 hours. These data may be original or smoothed. Naturally, the smoothness of the rainfall distribution depends on the smoothness of the relationship of duration and incremental intensity as shown in figure 2. The plot of the smooth rainfall distribution based on data in figure 2 is shown in figure 3.

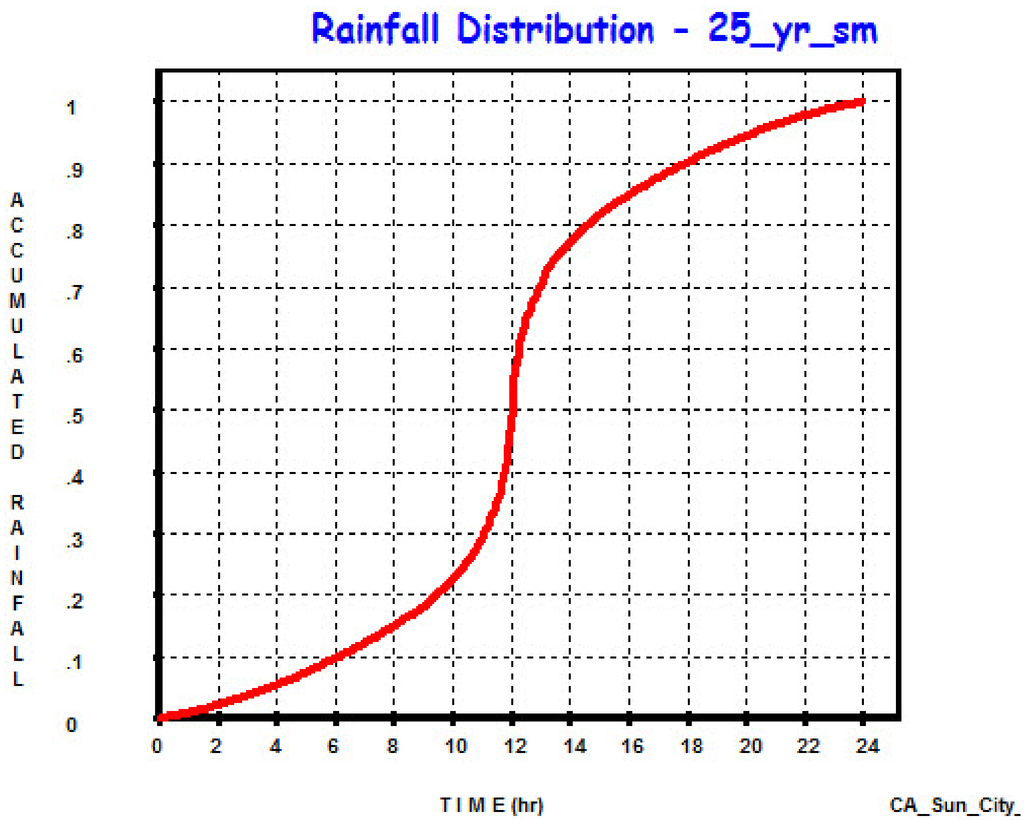

Figure 3 25-year (4% chance), 24-hour rainfall distribution for Sun City, California based on smooth data.

REGIONAL RAINFALL DISTRIBUTIONS

Figure 4 shows where to apply the regional rainfall distributions developed for the Ohio Valley and neighboring states and designated as A, B, C, and D.

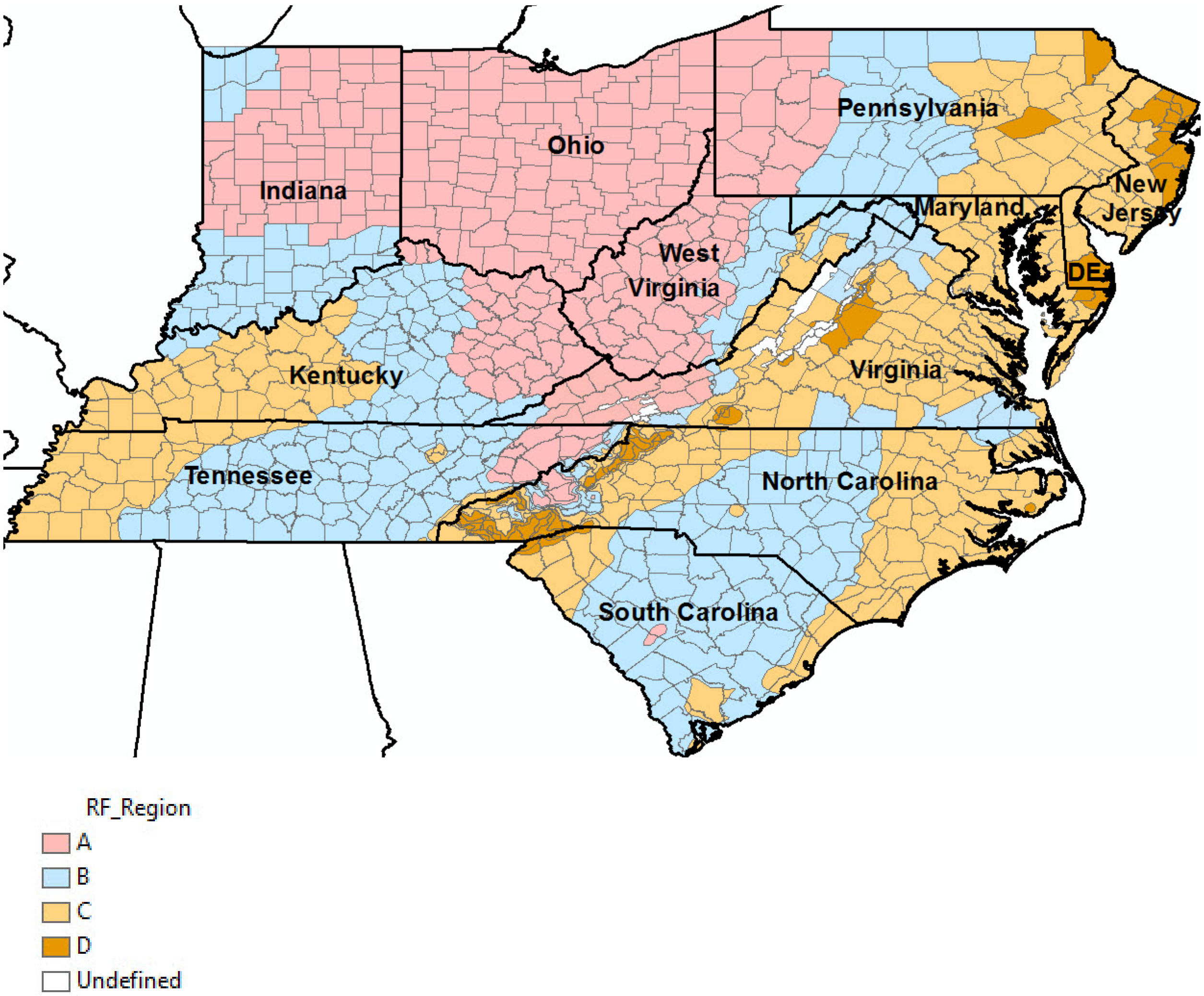

Figure 4 Regional rainfall distributions for the Ohio Valley and neighboring states.

Regional rainfall distributions were also developed from NOAA Atlas 14 data for California, Nevada, and 17 midwestern and southeastern states. Documentation and maps for these are available from the NRCS West National Technical Support Center at http://go.usa.gov/rXYw and clicking on "Technical Information".

The boundaries of the rainfall distribution regions are based on the ratio of the 25-year (4% chance), 60-minute rainfall to the 25-year (4% chance), 24-hour rainfall. Areas with a ratio greater than 0.48 are assigned rainfall distribution A. This is the most intense rainfall distribution. Areas with a ratio between 0.43 and 0.48 are assigned rainfall distribution B. Areas with a ratio between 0.38 and 0.43 are assigned rainfall distribution C. Areas with a ratio less than 0.38 are assigned rainfall distribution D. This is the least intense rainfall distribution. Once the boundaries were determined, the average ratio for each duration was determined based on the 25-year (4% chance) return period. These included the ratios of the 5, 10, 15, 30, and 60 minute to 24-hour ratio; and the 2, 3, 6, and 12 hour to 24-hour ratio. These average ratios were used to develop the 24-hour rainfall distribution for each of the four regions as shown in figure 5.

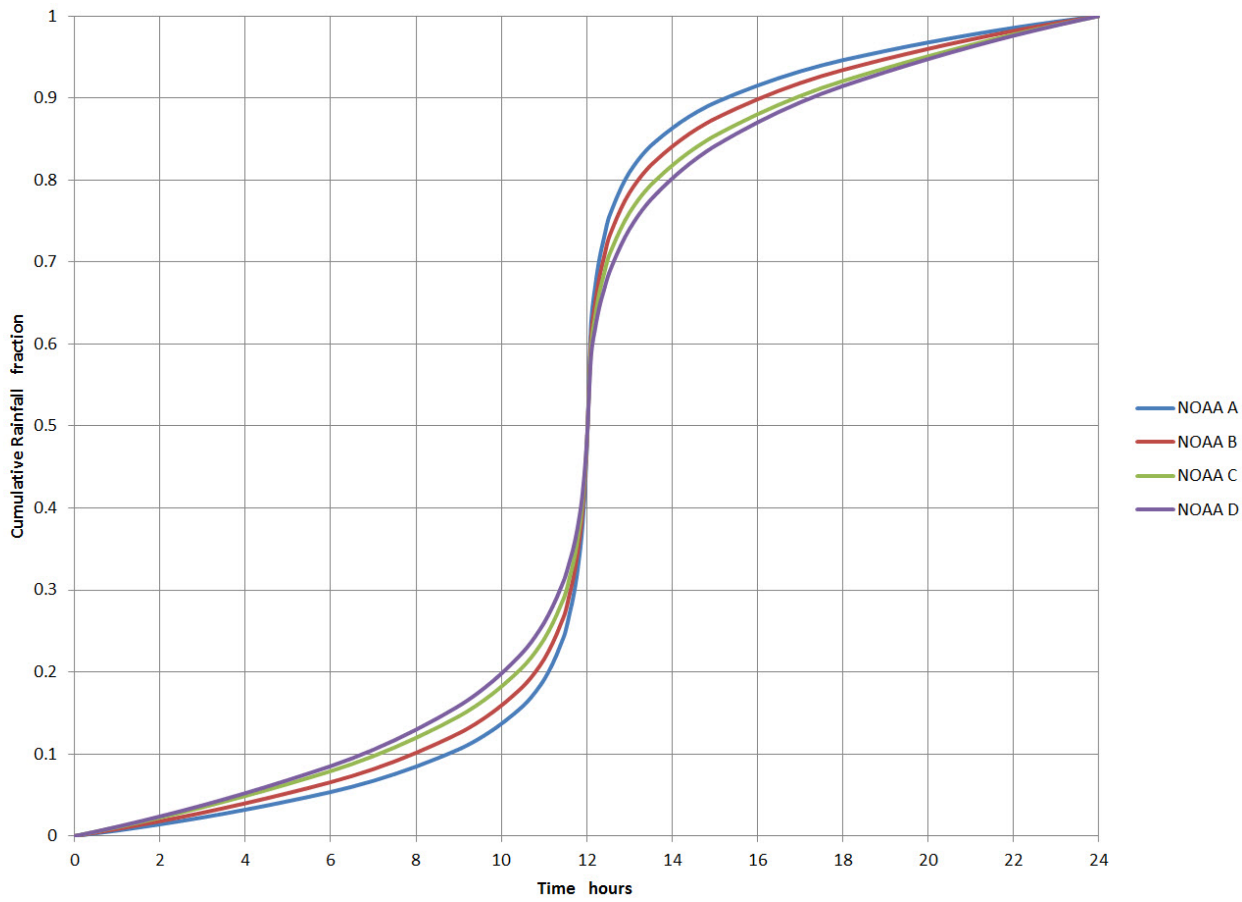

Figure 5 Plot of A, B, C, and D 24-hour rainfall distributions for the Ohio Valley and neighboring states.

These tables are available at a 0.1-hour time interval in the WinTR-20 User Documentation and WinTR-20 software.

SUMMARY

NRCS is replacing the use of its legacy rainfall distributions (Type I, Type IA, Type II, and Type III) with rainfall distributions based on NOAA Atlas 14 precipitation-frequency data. Regional rainfall distributions are being developed for use in the Engineering Field Handbook Chapter 2 computer program (EFH-2), Small Watershed Hydrology computer program (WinTR-55), and Project Formulation Hydrology computer program (WinTR-20). Site-specific rainfall distributions may also be developed using the WinTR-20 computer program.

These rainfall distributions are based on the 5-minute through 24-hour rainfall depths for a specific return period. Unique rainfall distributions may be developed for the 1-year (100% chance) through 500-year (0.2% chance) storms. Before the rainfall distribution is developed, the user has the opportunity to smooth the 5-minute through 24-hour rainfalls.

By developing new rainfall distributions using NOAA Atlas 14 data, the rainfall distributions will reflect the rainfall depth versus duration data at the project location more accurately. This will lead to more accurate estimates of peak discharges and hydrographs for design of projects.

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