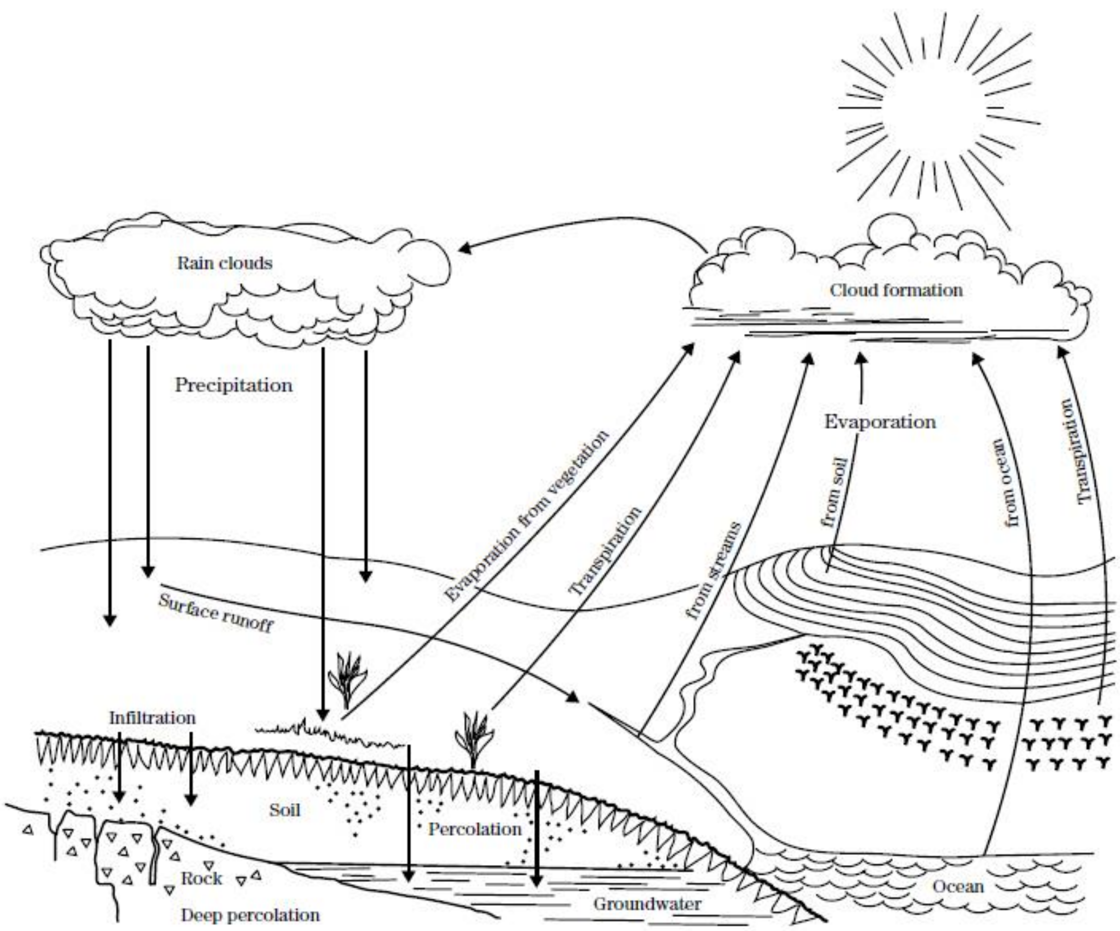
United States Department of Agriculture

Natural Resources Conservation Service

Part 630 Hydrology

National Engineering Handbook

Chapter 4: Storm Rainfall Depth and Distribution



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Acknowledgments

Chapter 4 was originally prepared by **Victor Mockus,** former hydraulic engineer, U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS), and published in 1964. It was reprinted with minor revisions in 1969 and with major revisions in 1993.

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630.0400 Introduction

This chapter applies to specific rain events and their analyses as well as monthly and annual rainfall. The chapter gives a brief account of the sources, variability, and preparation of storm rainfall or precipitation data. This chapter is used with Natural Resources Conservation Service (NRCS), NEH Part 630.010, Estimation of Direct Runoff from Storm Rainfall and NRCS, NEH Part 630.016, Hydrographs, NRCS, Engineering Field Handbook Chapter 2 Estimating Runoff and Peak Discharge, and Soil Conservation Service (SCS), NEH 4, Chapter 21, Design Hydrographs for estimating the runoff volumes and peak discharges needed to size conservation and water control structures. Probable maximum precipitation (PMP) is discussed in SCS NEH 4, Chapter 21, Design Hydrographs, and NRCS Technical Release No. 60, Earth Dams and Reservoirs. Various National Oceanic and Atmospheric Administration (NOAA) documents cover areal reduction of rainfall.

Storm rainfall depth is defined as the quantity of rain falling within a storm of a specific duration distributed uniformly over the watershed area. Rainfall depth is commonly expressed in inches when using English units and millimeters when using SI units. Rainfall distribution is defined by the quantity of rain falling in successive time increments of the total storm duration. In this chapter, the cumulative fraction of rain falling at successive times up to the storm duration is used to develop the rainfall distribution. Thus, the rainfall distribution begins at a value of zero at the beginning of the storm and ends at a value of 1.0.

NRCS hydrologic models WinTR-20, WinTR-55, and SITES, referenced at various places in this chapter, utilize storm rainfall depth and rainfall distribution to calculate runoff hydrographs. Principles described in this chapter are useful in many hydrologic computer models of Federal, state, local governments, universities, consulting engineers, and others that use a distribution of rainfall throughout a storm. The rainfall distribution concept applies to a design or synthetic storm or to an actual storm and is discussed in this chapter. Standard use of these hydrologic models assumes rain falls on the watershed uniformly with respect to spatial and temporal distributions. This represents a standard use of the hydrologic models, however, WinTR-20 and SITES may also be used to analyze watersheds with non-uniform spatial and temporal distributions.

The examples in this chapter illustrate analyses of storm depths and temporal distributions using calculators, spreadsheets, computer programs and Geographic Information Systems (GIS). Values calculated by these methods may differ slightly based upon the method used. Numerical precision is a function of the number of significant digits and the algorithms used in data processing, so some differences in numbers may also be found when the examples are checked by other means.

This document provides website addresses for some data sources and reference items. If a given web address has expired, the user can usually find the information needed with a search engine and appropriate keywords.

630.0401 Sources of data

Hydrometeorological data are important elements of NRCS planning, design, and operation of water related structures and systems. There are a number of data sources for hydrometeorological data including:

- NRCS National Water and Climate Center (NWCC);
- United States Geological Survey (USGS);
- the NOAA; National Weather Service (NWS) and; the NOAA National Climatic Data Center (NCDC),
- Six Regional Climate Centers (RCCs);
- State climatologists;
- the USDA sister agencies, the Agricultural Research Service (ARS) and the Forest Service (FS);
- Other Federal, state, and local agencies with planning responsibilities for water related projects, operational responsibilities, or both.

Rainfall data and related statistical analyses used to design NRCS engineering measures are generally those amounts measured and published by the National Oceanic and

Atmospheric Administration's (NOAA) National Weather Service (NWS). The choice of NWS data is due to their availability, lengths of record, and consistency on a national basis. Numerous other organizations publish data, research reports, and analyses. Use of data from other sources is justified if the data are more recent or more applicable to a specific project purpose and/or location. Rainfall data sources should always be documented and justification for use of non-NWS data should be provided.

Collection of hydrometeorological data is not discussed in this chapter, however, for those interested in data collection, a comprehensive account and bibliography of rain gage designs, installations, and measurement research is given by Kurtyka (1953), NOAA (1989 and 1995), NWS (2010), NOAA (2005), and others. Vasquez (1998) gives an overview of general weather station operation. Gages used in the NWS network are described by the United States Department of Commerce (NOAA 1989), Linsley, Kohler, and Paulhus (1982), Brakensiek, et al. (1979), meteorological textbooks such as Holtan (2004), NOAA and NWS documents, and similar publications.

(a) Published data

Precipitation analysis methods, data quality and quantity, data limitations, and recommended uses of data contained in technical papers are given in the papers themselves. Understanding these methods and limitations aids in proper usage of the data and in drawing better conclusions from using the data.

(1) NWCC

The NRCS National Water and Climate Center (NWCC) obtains, evaluates, manages and disseminates climatic data to support agency programs and activities nationwide. The NWCC oversees the availability of agency-wide climatic data management and analysis services through the Field Office Technical Guide (FOTG). The FOTG Section II contains climatic data for specific counties, including historical data delivered through the Agricultural Applied Climate Information System (AgACIS). The FOTG website at http://efotg.sc.egov.usda.gov/efotg_locator.aspx allows the user to access data for any state and county. The NWCC also provides a number of products, including the Parameter-elevation Regressions on Independent Slopes Model (PRISM) model, which uses point measurements of precipitation, temperature, and other climate elements to produce continuous digital coverage for the United States. Some of their other products include climate reports for soil survey regions, wetlands climate table documentation, climate data including weather generator technology, Generation of weather Elements for Multiple applications or GEM, climate data sets, and wind data for the United States.

NWCC supports hourly and 15-minute time series, along with other climatic variables off-line. Make requests for these special data types to the NWCC through the appropriate state office. Equivalent data are available to the general public through the NCDC.

(2) NOAA and NWS

Daily amounts of rainfall measured at gages in the official networks operated by the NWS are processed and published in monthly issues of "Climatological Data" for each state by the National Climatic Data Center (NCDC) in Asheville, NC. The NCDC website at http://www.ncdc.noaa.gov/ maintains station, climate, and radar data for stations throughout the continental U.S., Hawaii, Guam, Puerto Rico, and the Virgin Islands. Most states have a State Climatologist, who can provide information for specific storms, local data trends, and climatic data. State climatologists also coordinate observations made by weather observers throughout the States before the data are sent to the NCDC.

The times of daily measurements at stations vary as indicated in the publications. More detailed observations of storm totals and durations are available from the hourly precipitation data, also published by the NCDC for each state. Other Federal and State agencies, and universities, publish rainfall data at irregular intervals, often in a special storm reports or as research data.

Climatic data, such as precipitation, evaporation, and temperature are available for the continental United States and the Pacific and Caribbean Islands. Annual, monthly, and daily data are available in a variety of formats.

Precipitation-frequency data are available from NOAA Atlas 14 for both annual and partial duration series at the NWS website http://hdsc.nws.noaa.gov/hdsc/pfds/. Annual series data are based on the analysis of precipitation data representing the maximum value occurring within a calendar year. The partial duration series data are based on analysis of the X or more largest values occurring in X years. For example, if the record length is 80 years, the highest 80 or more values are selected even though there may be two or more events in any given year and there may be years with no values selected.

Standard hydrology reference books (such as Chow, 1964 and Maidment, 1993) discuss the difference between annual and partial duration series and how to convert from one to the other. The annual and partial duration values are significantly different for the more frequent storms such as the 2-year and 5-year frequencies, with the partial duration value greater than the annual series value. At the 10-year and lesser frequencies, or greater return periods, differences are insignificant. The partial duration series includes the 1-year precipitation frequency whereas the annual series does not.

NRCS has historically used the partial duration series for design of engineering projects. Engineering projects will be subject to all storm events and not just the largest storm of any given year. For projects where results are needed for frequent storms, the partial duration series may also be used because it includes the 1-year frequency.

The Hydrometeorological Design Studies Center (HDSC) of the NWS has a number of reports that summarize many years of weather observations over the country. The NWS uses refined statistical and error analyses to make these publications as reliable as possible. In many kinds of hydrologic work, it is unnecessary to use actual rainfall data because published analyses of data provide the required information in more usable form.

In 1975, the SCS West Regional Technical Service Center released Technical Note Hydrology PO-6, which includes a procedure to determine the 10-day precipitation for 11 western states (NRCS, 1975). The 10-day rainfall values are based on NOAA Atlas 2 data. NOAA Atlas 14 updates the data for a number of these states. However, NOAA Atlas 2 is still the most recent rainfall-frequency information for Idaho, Montana, Oregon, Washington, and Wyoming. When NOAA Atlas 14 is complete for these states, procedures and information in NOAA Atlas 14 will replace PO-6.

The NOAA-NCDC collect Next Generation Weather Radar (NEXRAD) radar data and make the data and associated products available at the web site www.ncdc.noaa.gov/oa/radar/radardata.html. The site includes an inventory and product search link that will lead to available data, as well as a Weather and Climate Toolkit software system for download. The Toolkit allows the user to import and view various radar and precipitation data. A storm event database with national publications by month and annual summary with an interactive search by date and location of a storm event database are also available.

The NWS published the following rainfall-data analyses, many in cooperation with NRCS. The most up-to-date documents for a state or area are to be used for a rainfall reference unless a special study applies to that location. The list below is not a complete list of precipitation frequency and PMP publications. Most of these publications are available at the NWS website http://hdsc.nws.noaa.gov/hdsc/pfds/. Other sources of published data include State and local agencies, and groups with interests in irrigation, electric supply, agricultural water use, reservoir operations, and dam safety, to name a few. The engineer should ensure that the use of alternative data is acceptable to the relevant technical and regulatory authorities.

Documents covering durations from 5 minutes to 60 days and storm return periods up to 1,000 years and Probable Maximum Precipitation (PMP)

- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. 2004, rev 2006. Volume 1, Version 4.0: Semiarid Southwest.
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, 2004, rev 2006. 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.
- NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, 2006, Volume 3, Version 4.0: Puerto Rico and the U.S. Virgin Islands.

- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, 2009, rev. 2011. Volume 4, Version 3: Hawaiian Islands.
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, 2009, rev. 2011. Volume 5, Version 3.0: Selected Pacific Islands.
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, 2011, Volume 6, Version 2.0: California.
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, 2012, Volume 7, Version 1.0: Alaska.
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, 2013, Volume 8 Version 2.0 :Midwestern States
- NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, 2013, Volume 9 Version 2.0: Southeastern States
- "Rainfall Frequency Atlas of the United States," United States Weather Bureau, Technical Paper No. 40; 115p, 1961. This reference is to be used for States east of the Rockies, except for durations of 60 minutes or less or where NOAA Atlas 14, Volumes 1 through 9 provide updated coverage.
- "Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States," NOAA Technical Memorandum NWS HYDRO-35, 36 p, 1977. This reference is to be used for States east of the Rockies, except for states where NOAA Atlas 14, Volumes 1 through 9 provide updated coverage.
- National Oceanic and Atmospheric Administration Atlas 2. Precipitation Atlas of the Western United States, 1973: Vol. 1, Montana, Vol. 2, Wyoming, Vol. 5, Idaho Vol. 9, Washington, Vol. 10, Oregon.
- Two- to Ten-Day Precipitation for Return Periods of 2 to 100 years in the Contiguous United States, United States Weather Bureau, Technical Paper No. 49, 29 p, 1964. Includes the 48 contiguous states. (Use SCS West National Technical Center Technical Note- Hydrology PO-6, Revised 1975, for States covered by NOAA Atlas 2 and not covered by NOAA Atlas 14, Vols. 1-9).

- Short duration rainfall relations for the western United States, 1986. Arkell, R.E. and F. Richards. Preprint volume of the Conference on Climate and Water Management, AMS, pp 136-141.

- Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska. United States Weather Bureau, Technical Paper No. 47, 74 p, 1963.

- Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands, United States Weather Bureau, Technical Paper 42, 101 p, 1961.

- Probable Maximum Precipitation in California, Calculation Procedure. United States Weather Bureau Hydrometeorological Report No. 58, Report and Plates 1 and 2, 91 p, 1998.

- Probable Maximum Precipitation in California, Calculation Procedure. United States Weather Bureau Hydrometeorological Report No. 58, Shapefiles, 1998.

- Probable Maximum Precipitation in California, Report. United States Weather Bureau Hydrometeorological Report No. 59, Report and Plates 1 and 2, 392 p, 1999.

- Probable Maximum Precipitation in California, Calculation Procedure. United States Weather Bureau Hydrometeorological Report No. 59, Shapefiles, 1998.

- Probable Maximum Precipitation in the Hawaiian Islands United States Weather Bureau Hydrometeorological Report No. 39, 108 p, 1963.

- Probable Maximum and TVA Precipitation over the Tennessee River Basin above Chattanooga. United States Weather Bureau Hydrometeorological Report No. 41, 153 p, 1965.

- Probable Maximum Precipitation and Snowmelt Criteria for Red River of the North above Pembina, and Souris River above Minot, North Dakota. United States Weather Bureau Hydrometeorological Report No. 48, 80 p, 1973.

- Probable Maximum Precipitation Estimates, Colorado River and Great Basin drainages, United States Weather Bureau Hydrometeorological Report No. 49, 176 p, reprint 1984.

- Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, NOAA Hydrometeorology Report No. 51, 100 p, 1978.

- Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian, NOAA Hydrometeorology Report No. 52, 182 p, 1982.

- Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska, NOAA Hydrometeorological Report No. 54, 125 p, 1983.

- Probable Maximum Precipitation Estimates -United States Between the Continental Divide and the 103rd Meridian, NOAA Hydrometeorological Report and Plates I-VI, No. 55A, 262 p, 1988.

- Seasonal Variation of 10-Square-Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. United States Weather Bureau Hydrometeorological Report No. 53, 96 p, 1980.

- Probable Maximum and TVA Precipitation Estimates with Areal Distribution for Tennessee River Drainages Less Than 3,000 Mi^2 in Area.. United States Weather Bureau Hydrometeorological Report No. 56, 238 p, 1986.

- Probable Maximum Precipitation - Pacific Northwest States: Columbia River (including portions of Canada), Snake River and Pacific Coastal Drainages. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, U.S. Department of Interior, Bureau of Reclamation, U.S. Department of Army Corps of Engineers, United States Weather Bureau Hydrometeorological Report No. 57, p, 1994.

- Probable Maximum Precipitation Maximum Precipitation for the Upper Deerfield Drainage Massachusetts/Vermont. NOAA Technical Memorandum NWS Hydro 39. 48 p, 1984.

- Probable Maximum Precipitation Estimates for the Drainage above Dewey Dam, Johns Creek, Kentucky. United States Weather Bureau Hydrometeorological Report No. 41, 46 p, 1985.

- Meteorological Conditions for the Probable Maximum Flood on the Yukon River above Rampart, Alaska. United States Weather Bureau Hydrometeorological Report No. 42, 104 p, 1966.

- Meteorological Criteria for Extreme Floods for Four Basins in the Tennessee and Cumberland River Watersheds. United States Weather Bureau Hydrometeorological Report No. 67, 104 p, 1973.

- Meteorology of Important Rainstorms in the Colorado River and Great Basin Drainages. United States Weather Bureau Hydrometeorological Report No. 50, 181 p, 196l.

- Relationship between Storm and Antecedent Precipitation over Kansas, Oklahoma, and Eastern Colorado. NOAA Technical Memorandum United States Weather Bureau Hydrometeorological Report No. 45, 92 p, 1995.

- A Climatic Analysis of Orographic Precipitation over the Big Horn Mountains. NOAA Technical Memorandum United States Weather Bureau Hydrometeorological Report No. 46, 76 p, 1995.

- Interduration Precipitation Relations for Storms – Southeast States. NOAA Technical Report NWS No. 21, 72 p, 1979.

- Interduration Precipitation Relations for Storms – Western United States. NOAA Technical Report NWS 27, 159 p, 1981.

- Comparison of Generalized estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls. NOAA Technical Memorandum United States Weather Bureau Hydrometeorological Report No. 25, 74 p, 1980.

The NOAA and NWS publications are available from the HDSC web sites: http://www.nws.noaa.gov/oh/hdsc/currentpf.htm and http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html. The engineer is encouraged to visit these web sites to download reports and data as well as look for periodic updates of reports.

(3) NRCC

The Northeast Regional Climate Center (NRCC) completed a precipitation-frequency analysis for New York and New England states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island in 2012. Rainfall data for New York and the New England states are found at the Northeast Regional Climate Center (NRCC) website http://precip.eas.cornell.edu/. The NWS published the updated NOAA Atlas 14 volume for New York and the New England states in 2015. The updated NOAA Atlas 14 should be used for NRCS projects in these states.

(b) Unpublished data

Various Federal and State agencies sometimes make field surveys after an unusually large storm to collect bucket-survey data. Bucket surveys are measurements of rainfall caught in narrow-bore tubes such as those available in hardware or agricultural supply stores, buckets, watering troughs, bottles, and similar containers. Ordinarily, these data are used to give more detail to rainfall maps based on standard gage data. The bucket gage data should be carefully evaluated. Data from bucket surveys are generally not published, but are available in the offices of the gathering agency.

Narrow-bore tubes used by many farmers and ranchers have given results almost equal to those from standard gages. These tube gages must be properly exposed and serviced to obtain such results. Many farmers, ranchers, and individuals keep a daily or storm record of measured rainfall amounts.

Newspaper offices, banks, water-treatment plants and municipal offices often collect measurements at their own gages and keep daily records. These data are recommended for use with hydrologic model calibration for a historical storm or as a reference to historical storms. Use of unpublished data for design purposes is not recommended.

630.0402 Rainfall over a watershed

In watershed studies, it is often necessary to know the average depth of rainfall over an area. The methods described in the following pages apply to both the estimation of average storm event rainfall and average rainfall or precipitation for a certain time period, such as annual or monthly.

The average depth can be determined in various ways, depending on the kind of data used. If the rainfall amount is taken from one of the NWS documents, it is for a specific point and the point-area relationship given in the paper is used to estimate the average depth over the area. It is difficult to obtain an average depth from data of several rain gages because the results are influenced by the number and locations of gages and the storm variability. Manual and geospatial methods of using such data are given in this section. The choice of methods depends to some extent on what data are available and where data are available and to some extent on the background and preference of the user.

(a) Methods of estimating average depths

(1) Use of one gage

How well the rainfall measured at a single gage represents the average depth over an area depends on:

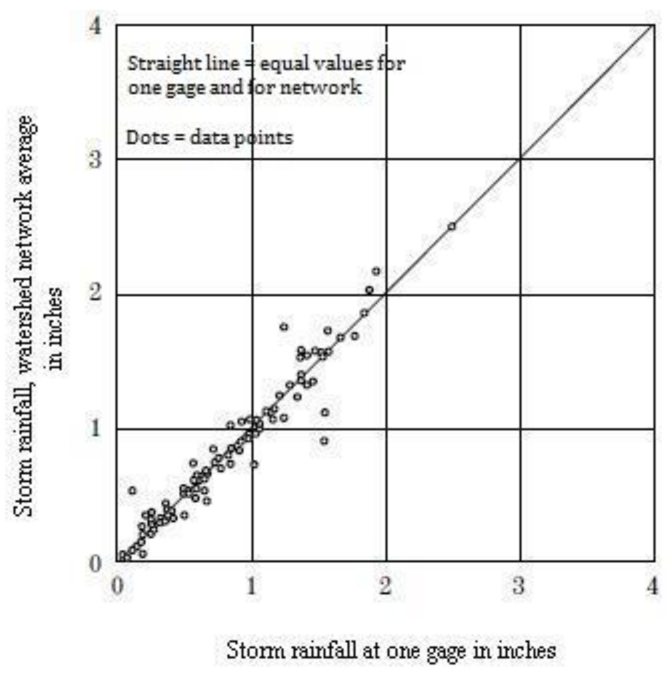
- distance from the gage to the center of the area,
- size of the area,
- relative areal extent of significant storm rainfall with respect to the watershed area,
- duration and frequency of rainfall amounts being analyzed, and

- orographic and other effects of the topography of the locality.

Figures 4-1 through 4-4 illustrate the effects of the first two influences. Since areal extent, duration, and frequency of rainfall amounts are not directly apparent in figures 4-1 through 4-4, they are two of the reasons why there may be significant scatter in the plotted points. The fifth is described later in this section under the heading (c) Orographic influences.

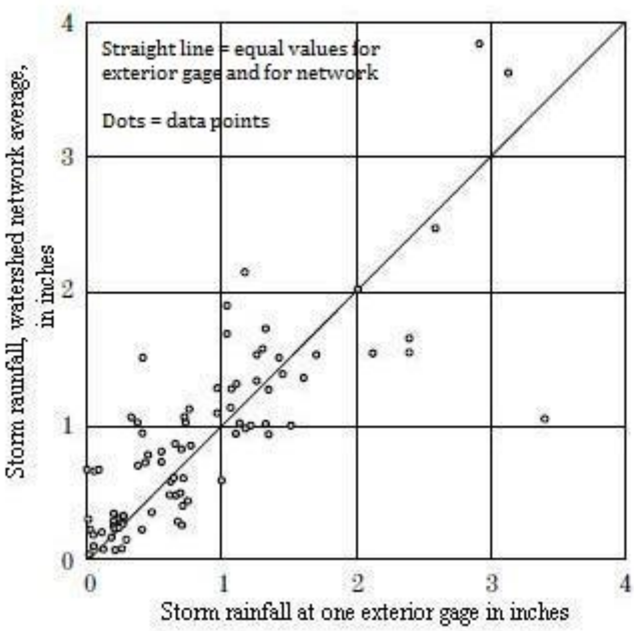
The effect of distance is shown in figures 4–1 and 4–2. In 4–1, a single gage is located near the center of a 0.75 square mile watershed. Measured storm rainfalls at the gage are seen to be quite close to the watershed averages, which were determined using a dense network of gages.

Figure 4- 1. Measured storm rainfall at one interior watershed gage compared to an interior network



However, in figure 4–2, where the gage is located 4 miles outside the watershed boundary, the measured storm rainfalls at the gage often differ significantly in the statistical sense from the watershed averages.

Figure 4- 2. Measured storm rainfall at one interior watershed gage compared to an outside gage



A similar effect occurs when the area of application is increased, as shown in figure 4–3, where the storm rainfall measured at a gage on the boundary of a 5.45 square mile watershed is compared to the results from a denser net of gages. In figure 4-4 the watershed average annual rainfall measured at the single gage on the watershed boundary is compared to the watershed average annual rainfall measured by the denser network of gages. Figures 4-1 through 4-4 are all from data from ARS Experimental Agricultural Watersheds in Hastings, Nebraska.

Figure 4- 3. Measured storm rainfall at one gage on the watershed boundary compared to average storm rainfall

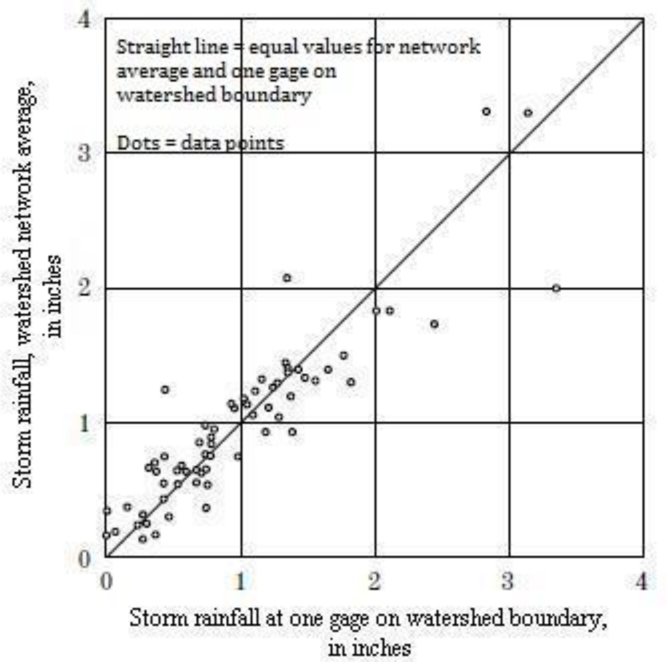
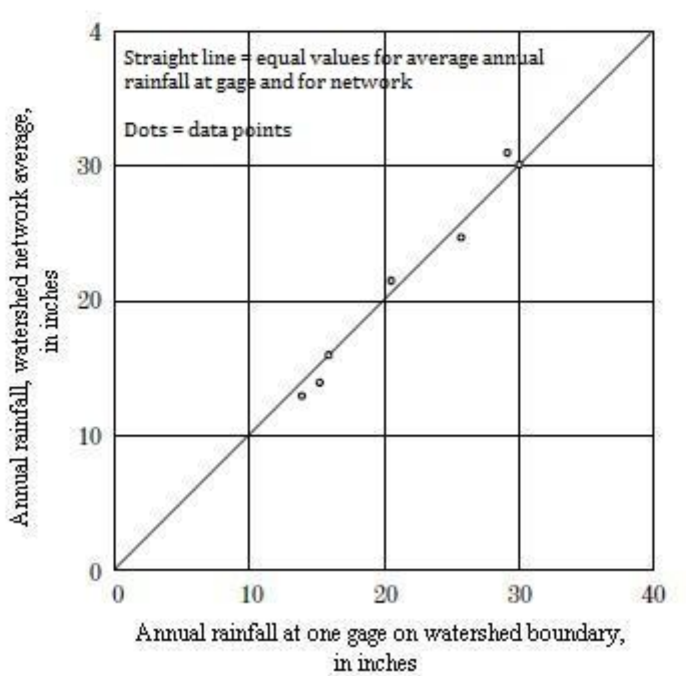


Figure 4- 4. Measured annual rainfall at one gage on the watershed boundary compared to average annual network rainfall



The correspondence between measured storm rainfall and area averages is close where the rainfall amounts being used are sums, such as monthly or annual rainfalls, because the variations for single storms tend to offset each other. The gage and watershed used for figure 4–3 are also used in figure 4–4 where annual rainfalls are plotted. The differences between gage and watershed amounts in figure 4-4 are considerably smaller than those for the individual storm comparisons of figure 4–3.

The correspondence between gage and area amounts is also close if the storm rainfalls are used with the methods shown in NEH 630 Chapter 18 (NRCS) to construct frequency lines for gage and area amounts. The correspondence occurring then is for amounts having the same frequency.

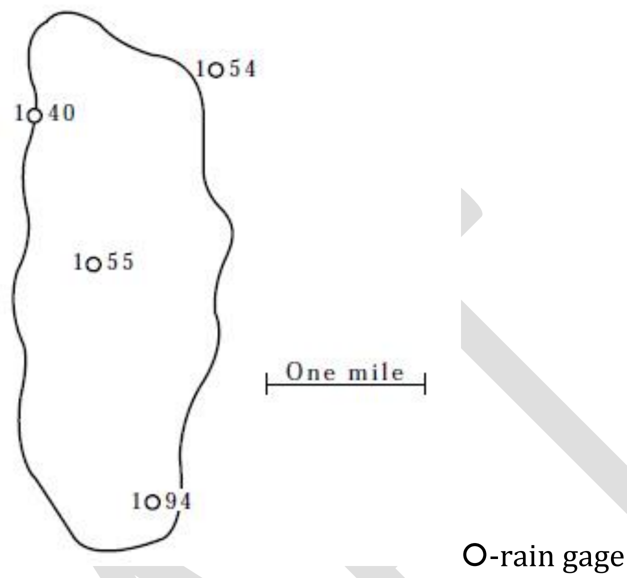
The examples use data taken from a non-mountainous region where orographic influences are not significant; otherwise, the results might be very different. The examples show that the use of a single gage may lead to errors in areal estimates and raises the question of how much error is permissible. Accuracy of rainfall estimates is discussed in section 630.0402(b).

(2) Isohyetal method

The spacing of gages in an areal network is seldom sufficiently uniform to permit use of the numerical average of the gage measured storm rainfall as the area average. An isohyet is a line connecting points of equal rainfall depth. Isohyetal maps are often used, with networks of any configuration, to get area averages or for studies of rainfall distributions. The map is made by drawing the lines in the same manner that contour lines are drawn on topographic maps, using the gage locations as data points.

Example 4-1. Figures 4–5 through 4-8 illustrate the construction and application of the isohyetal method to a research watershed in Nebraska. Four rain gages are associated with the watershed; two are within the watershed boundaries, one is on the boundary, and a fourth is just outside the watershed, as in Figure 4-5. The open circles are centered on the gage locations, and serve as decimal points for the rainfall amounts. These are 1.40, 1.54, 1.94, and 1.55, going clockwise from the upper left.

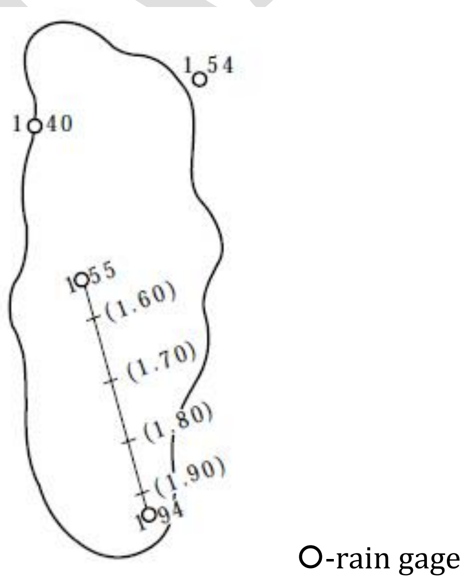
Figure 4- 5. Rain gage locations and amounts in a small Nebraska watershed



Step 1: Locate the rain gages on the watershed map and plot the rainfall amounts.

Step 2: Interpolate the amounts falling between the rain gages. Figure 4-6 shows one such line.

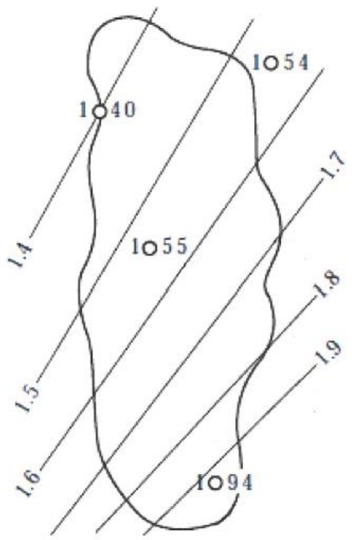
Figure 4- 6. Estimate the rainfall amounts falling between the gage locations



Step 3: Using the estimated rainfalls of step 2, develop isohyets to cover the whole watershed.

Determination of the orientation of the lines is very subjective with the limited data shown in this figure. Data from local bucket surveys may contribute significantly to locating the lines, if the bucket survey data are carefully evaluated. For the good quality bucket survey data collected, plot the location on the map and record the rainfall volume. Use these values as additional rain gage locations and measurements in the method selected to determine the average watershed rainfall.

Figure 4- 7. Isohyetal map developed from figures 4-5 and 4-6



O-rain gage

Step 4: Determine the land area between each adjacent isohyet and get the watershed average by weighting the rainfall depths for the parts as in Table 4- 1. For this example, the area covered by each isohyet was measured using a dot counter. A dot counter is a transparent sheet with dots placed in a gridded format of equal horizontal and vertical spacing. Prior to general use of GIS, it was a good quick method to estimate areas of land delineated on maps. For this example, the total area is the sum of all the individual parts, or 174 dots. The percentage of the total area in each isohyet is the number of points in column 3 divided by 174 and is listed in column 4. The weighted amount of rainfall in each isohyetal area is calculated as column 2 times column 4 and is listed in column 5. The sum of the weighted amounts gives the average watershed rainfall, 1.61 inches.

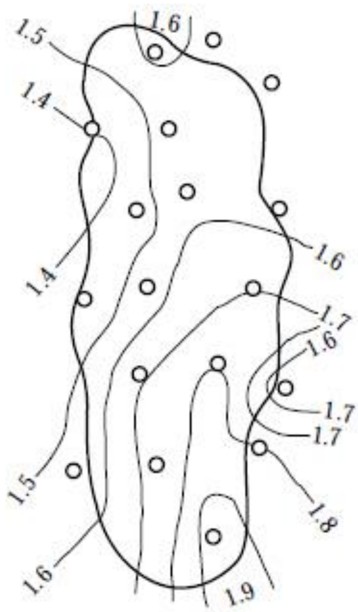
Table 4- 1. Tabulation of watershed rainfall from isohyetal map, figure 4-7.

Rainfall Limits Inches	**Rainfall Inches**	**Number of points***	**Fraction of area**	**Rainfall weighted by area**
(1)	(2)	(3)	(4)	(5)
<1.4	1.4	5	0.03	0.042
1.4 – 1.5	1.45	38	0.22	0.319
1.5 – 1.6	1.55	47	0.27	0.418
1.6 – 1.7	1.65	37	0.21	0.346
1.7 – 1.8	1.75	28	0.16	0.28
1.8 – 1.9	1.85	11	0.06	0.111
>1.9	1.9	8	0.05	0.095
Totals		174	1.00	1.611
			Average Rainfall	1.61 inches

* The number of points was determined by a dot counter, a method of estimating areas.

A denser network may give a more complicated isohyetal map as in figure 4-8, where the total rain gage network on this research watershed is used to depict the storm.

Figure 4- 8. A denser rain gage network providing a more detailed isohyetal map



O-rain gage

Table 4-2 tabulates the data for figure 4-8. There are changes in depth on parts of the watershed, but the watershed average of 1.63 inches is not significantly different from the estimate derived from figure 4-7 and computed in Table 4-1. Generally, the more gages or rainfall depth measurements there are, the more accurate the estimate of mean precipitation over an area. A particular network may be excessively close for one kind of estimate at the same time that it is too open for another kind. The relative error of an area average obtained through use of a network can be estimated as shown in section 630.0402(b) Accuracy.

Table 4- 2. Tabulation of isohyetal weights from figure 4-8.

Rainfall Limits Inches	Rainfall Inches	Number of points*	Fraction of area	Rainfall weighted by area
(1)	(2)	(3)	(4)	(5)
<1.4	1.4	3	0.02	0.028
1.4 – 1.5	1.45	25	0.14	0.203
1.5 – 1.6	1.55	58	0.33	0.511
1.6 – 1.7	1.65	31	0.18	0.297
1.7 – 1.8	1.75	34	0.20	0.35
1.8 – 1.9	1.85	17	0.10	0.185
>1.9	1.9	6	0.03	0.057
Totals		174	1.00	1.631
			Average Rainfall	1.63 inches

* The number of points was determined by a dot counter, a method of estimating areas.

(3) Thiessen method

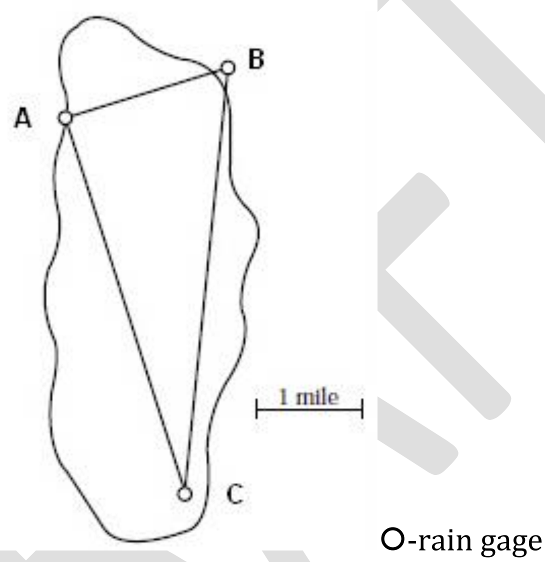
Another method of using a rain gage network for estimating watershed average depths especially suitable for electronic computation is the Thiessen method, shown in figures 4–9 through 4-12. In this method, the watershed area is divided into subareas using rain gages as hubs of polygons. The subareas are used to determine ratios that are multiplied by the subarea rainfall and summed to get the watershed average depth. The ratios are the percentages of area in the basin represented by each rain gage. Construction of the polygon diagram is illustrated in figures 4–9 and 4–10.

The Thiessen weights are the ratio of the gage's polygon area divided by the area of the entire watershed, as indicated in figure 4–11. Watershed average depths are computed as shown in table 4–3. If a gage is added or removed from the network, a new diagram must be drawn and new weights computed. Figure 4–12 shows the Thiessen method for a denser rain gage network.

Example 4-2. This example demonstrates the Thiessen method using three rain gages.

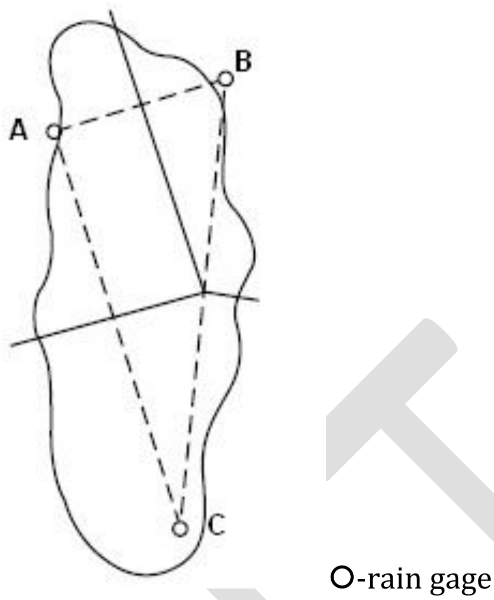
Step 1: Draw lines connecting the rain gages, as in Figure 4-9.

Figure 4- 9. Watershed with three rain gages analyzed by the Thiessen method



Step 2: Draw lines bisecting the lines connecting the gages, as in Figure 4-10.

Figure 4- 10. Thiessen weights method step 2



Step 3: Compute the weight of each polygonal section within the polygon as shown in figure 4-11 and table 4-3. The total area of the watershed was computed to be 199 acres. The rainfall at gage A is 1.40 inches, that at gage B is 1.54 inches, and that at gage C is 1.94 inches. The areas of each individual polygon were computed to be 81, 31, and 87 acres, with Thiessen weights of 0.407, 0.156, and 0.437 respectively. Each area weight multiplied by the gage rainfall yields the weighted rainfall for that gage, as shown in Table 4-3.

Figure 4- 11. Third step in the determination of Thiessen weights

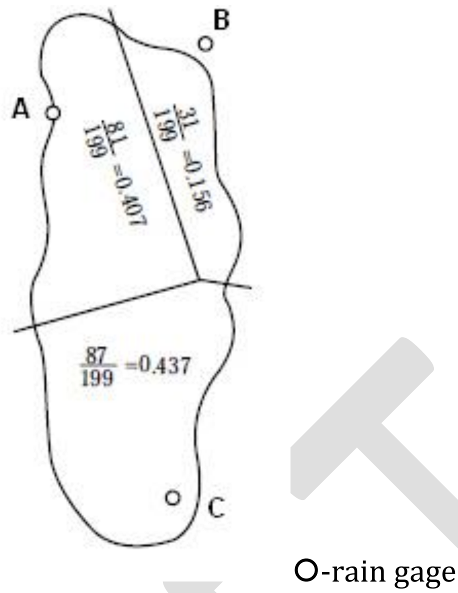
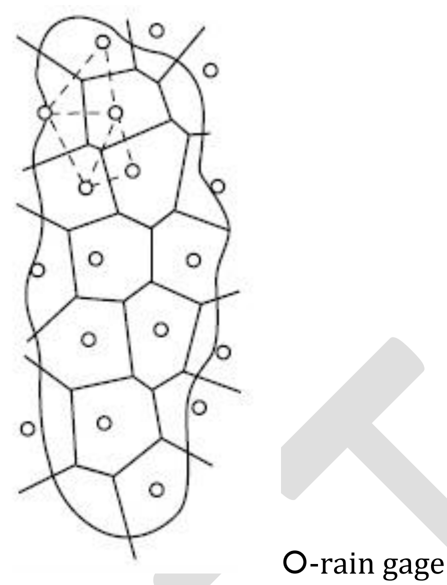


Table 4- 3. Watershed rainfall depth by the Thiessen method applied to figure 4-11

Rain Gage ID	Measured rainfall, in	Thiessen weight	Weighted rainfall, in
A	1.40	0.407	0.570
B	1.54	0.156	0.240
C	1.94	0.437	0.848
Sum		1.000	1.658

The watershed weighted rainfall depth is 1.658 inches, which is rounded to 1.66 inches.

Figure 4- 12. A denser Thiessen network



The denser Thiessen network will generally yield a slightly different answer. The Thiessen method is not used to estimate rainfall depths of mountainous watersheds since elevation is a strong factor influencing the areal rainfall distribution (see section 630.0402(c), Orographic influences).

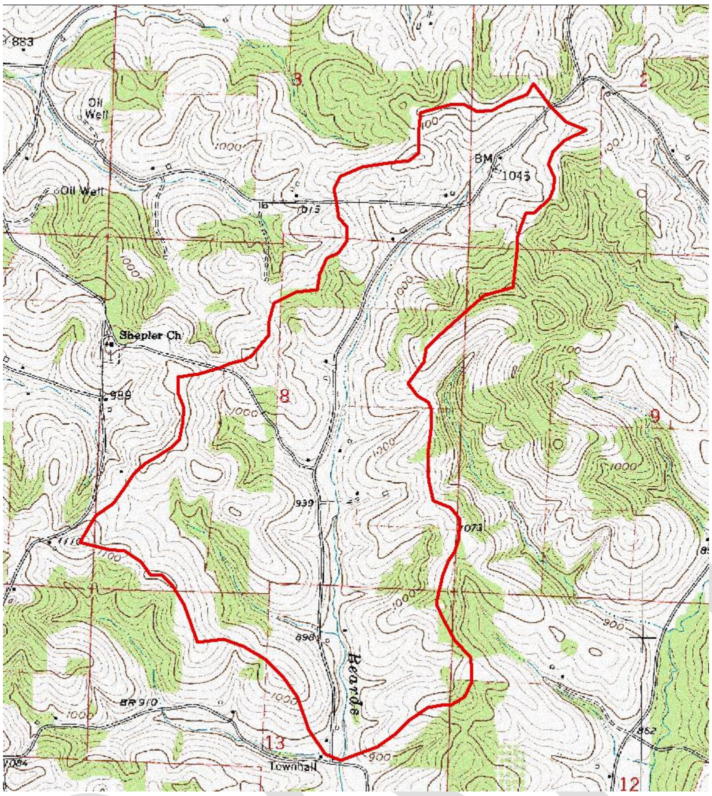
(4) Use of GIS to create an isohyetal map and compute mean precipitation

An isohyetal map may be created for a layer of points each with a rainfall amount using GIS. There are various options using GIS software to develop a surface based on the rainfall points. The surface, a product of this technology, is a grid layer with a rainfall value for each cell. A specific cell size such as 10 meters or 30 meters or larger must be selected. From this grid layer of rainfall and a GIS layer of the watershed boundary, statistics including the maximum, minimum, and mean rainfall for the watershed may be computed.

The example below was developed for a small watershed in Coshocton County, Ohio using GIS methods.

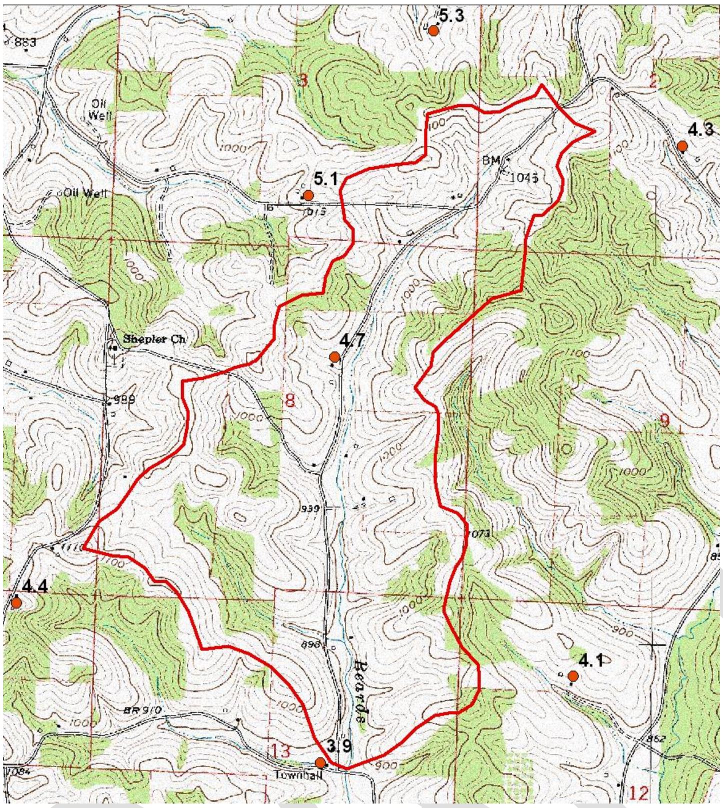
Step 1. The watershed boundary in Figure 4-13 is digitized first.

Figure 4- 13. Digitized watershed boundary for a watershed in Coshocton County, Ohio



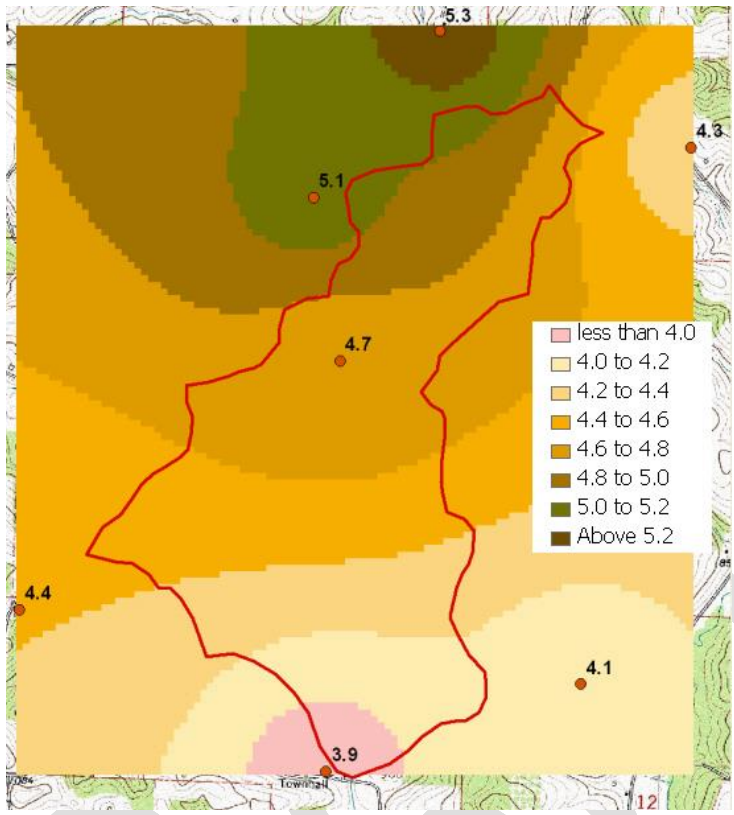
Step 2. A point layer with the rainfall point measurements in inches is developed next in figure 4-14.

Figure 4- 14. Point rainfall measurements for a watershed in Coshocton County, Ohio



Step 3. Since many NRCS offices use Environmental Sciences Research Institute (ESRI) GIS software, the example refers to commands in the ESRI GIS software. The Spatial Analyst Interpolation command in ArcGIS is used to generate the isohyetal map in figure 4-15. Other GIS software should have similar capabilities.

Figure 4- 15. Isohyetal map based on the point rainfall measurements in figure 4-14



Step 4. The Spatial Analyst Zonal Statistics as Table command executed in ArcGIS produces figure 4-16 where the minimum, maximum, range, and mean rainfall for the watershed are computed in the last four columns. The mean rainfall is 4.54 inches. The first two columns contain GIS identifiers. The next two columns are the number of rasters inside the watershed and the area of the watershed in square meters. The last four columns give the minimum, the maximum, the range, and the mean of the rainfall values.

Figure 4- 16. Table of zonal statistics generated by Spatial Analyst Zonal Statistics in GIS program

Table

zone_rainfall

Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN
1	0	3423	3080700	3.902358	5.116686	1.214328	4.54379

(5) Use of NOAA Atlas 14 GIS data to derive mean watershed precipitation

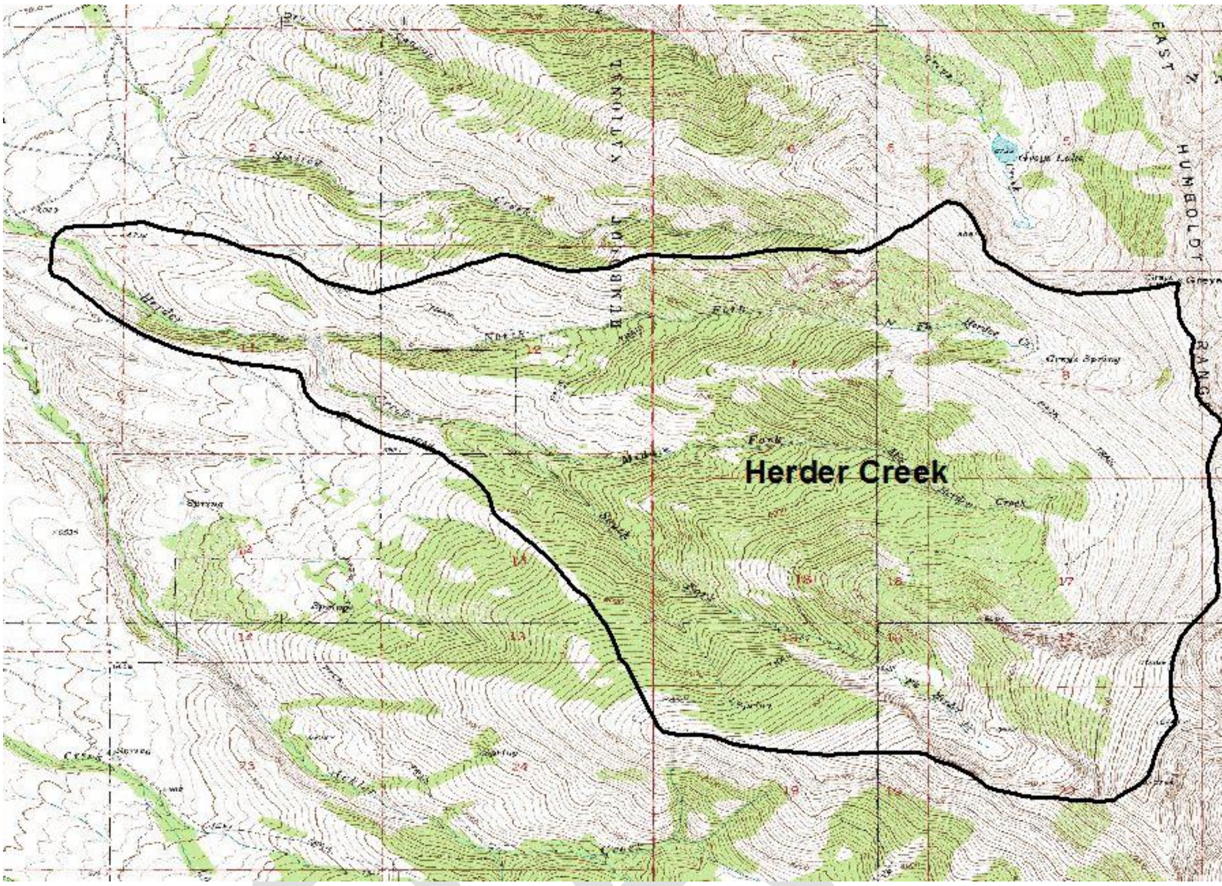
If the watershed is of significant size, more than about 1 square mile, a point value of rainfall may not be accurate. Instead, a mean rainfall for the watershed may be more representative. If the storm event rainfall varies within the watershed, an areal mean may be calculated using GIS.

The following example illustrates how to calculate an areal mean 25-year 24-hour rainfall for a watershed using NOAA Atlas 14 GIS data and data from Herder Creek in Elko County, Nevada.

Step 1: Download and prepare the GIS rainfall grid for desired durations and return periods. For this example, download the 25-year 24-hour GIS grid for the western state region (which includes Nevada) was from the NOAA Atlas 14 web site. Prepare the grid according to instructions available from the National Water Quality and Quantity Team West National Technology Support Center web site http://go.usa.gov/rXYw under Technical Information.

Step 2: Digitize the watershed boundary on a base map such as a digital raster graphic map (DRG), and develop the drainage area from GIS commands such as ESRI ArcHydro Tools or Spatial Analyst, or from the Watershed Boundary Dataset (WBD) available for watersheds with defined hydrologic unit codes. For the Herder Creek watershed in figure 4-17, digitize the boundary directly from a DRG.

Figure 4-17. Watershed boundary for Herder Creek, Nevada



Use the ESRI Identify icon to determine that the 25-year 24-hour rainfall at the far western edge of the watershed is 2.78 inches and at the far southeastern edge of the watershed is 4.07 inches. This is a significantly large range of rainfall. Treating this watershed as a homogeneous unit assumes a single runoff curve number, time of concentration, and uniform rainfall. An alternative is to divide the watershed into subareas and determine the mean rainfall for each subarea. This allows for each subarea to have its own individual runoff curve number and time of concentration and rainfall value. Figure 4-18 shows the watershed divided into 8 subareas.

Figure 4-18 Herder Creek watershed Nevada divided into 8 subareas

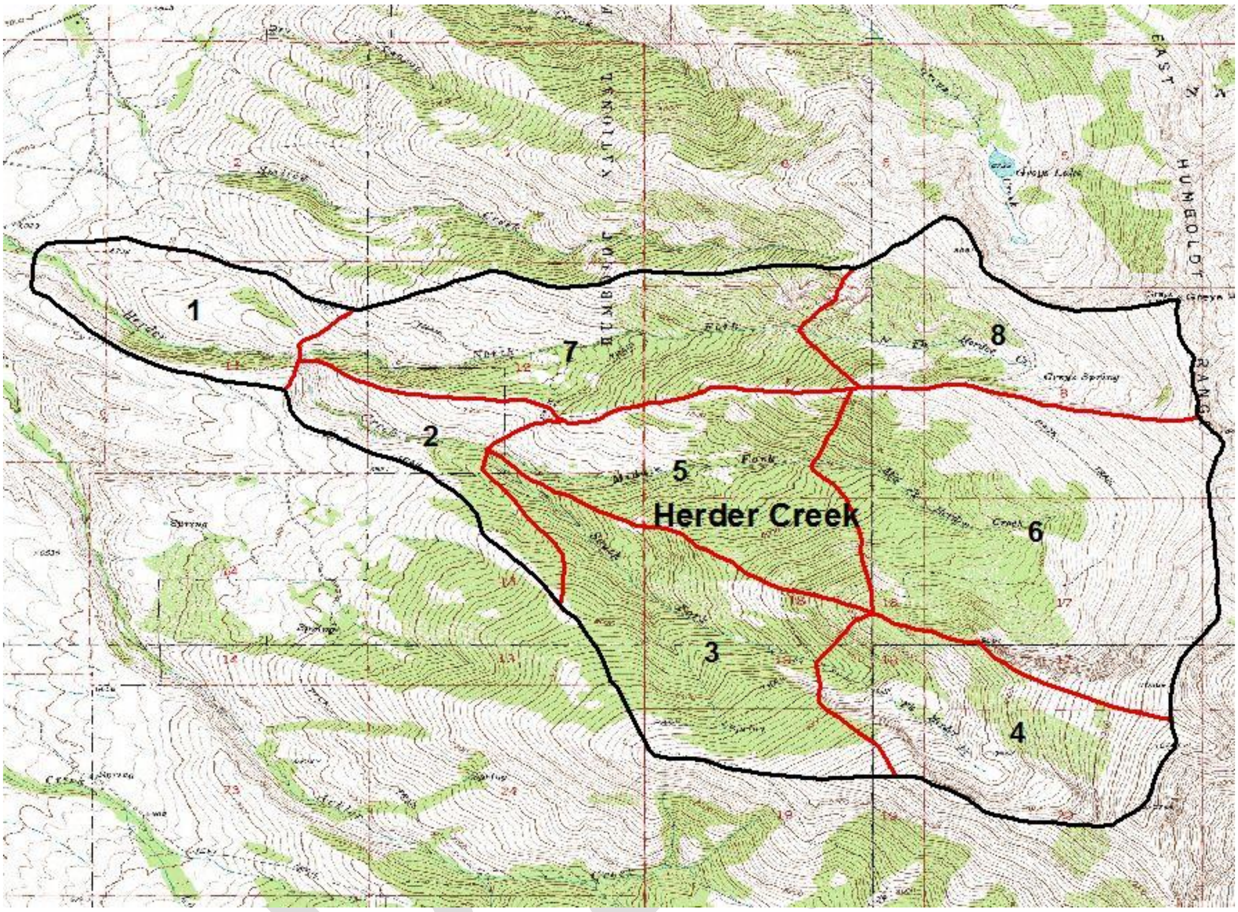
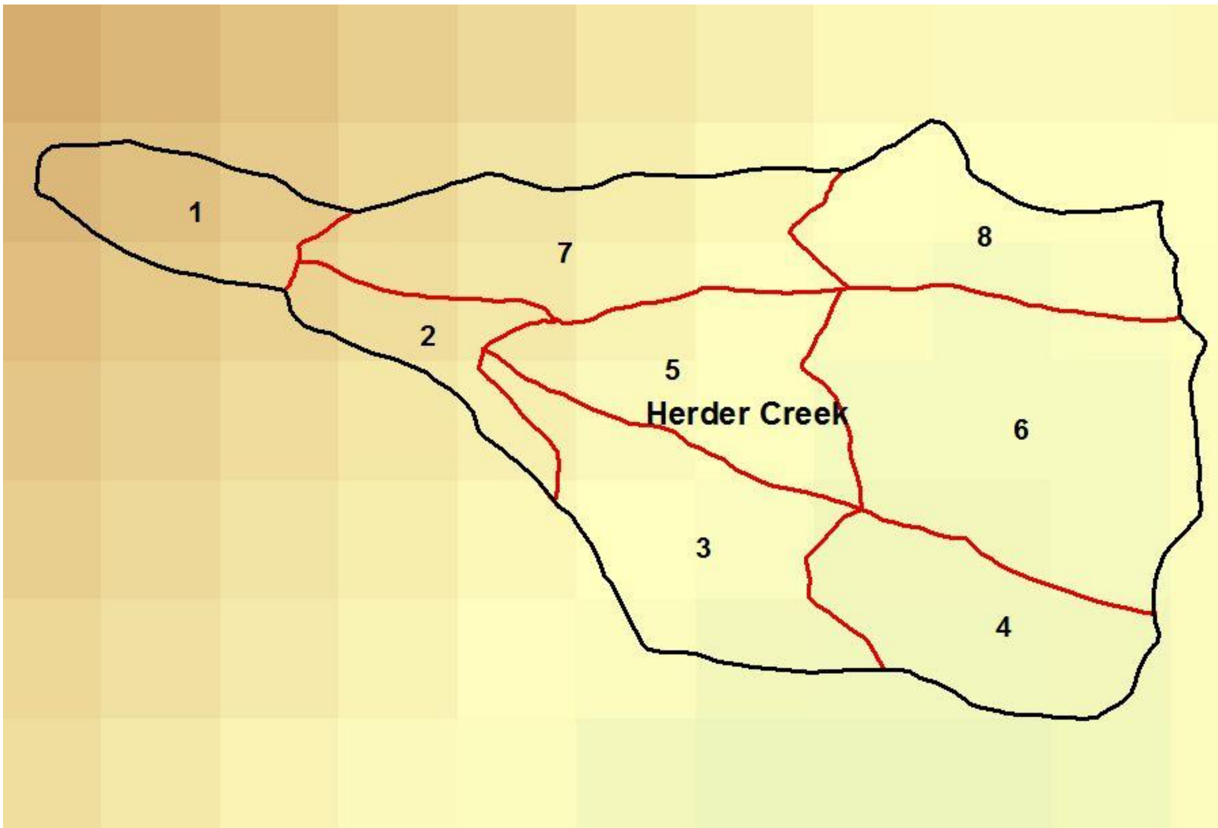


Figure 4-19 shows the watershed boundary divided into subareas overlaid on the GIS rainfall grid. The rainfall grid has about a half-mile or about 800-meter resolution.

Figure 4-19 Watershed boundary overlaid on the rainfall grid.



A rainfall value is assigned to each raster has a rainfall value assigned. The beige colors on the western edge represent the lowest rainfall values and the yellow-green rasters on the southeastern edge of the watershed represent larger values. Execute the ESRI GIS command Spatial Analyst Zonal Statistics to derive the statistics for each of the eight subareas. These statistics include area, maximum, minimum, range, mean, and standard deviation. In table 4-4 only the area and mean rainfall are shown.

Table 4- 4. GIS areal and rainfall statistics for Herder Creek, Nevada

Area Number	Area – square miles	Mean 25-yr, 24-hr rainfall (in)
1	0.49	2.86
2	0.36	3.32
3	0.96	3.89
4	0.76	4.05
5	0.79	3.82
6	1.63	4.00
7	1.00	3.66
8	0.75	3.94

The total watershed area is 6.74 square miles. The mean rainfall calculated for the total watershed is 3.79 inches.

(6) Other methods

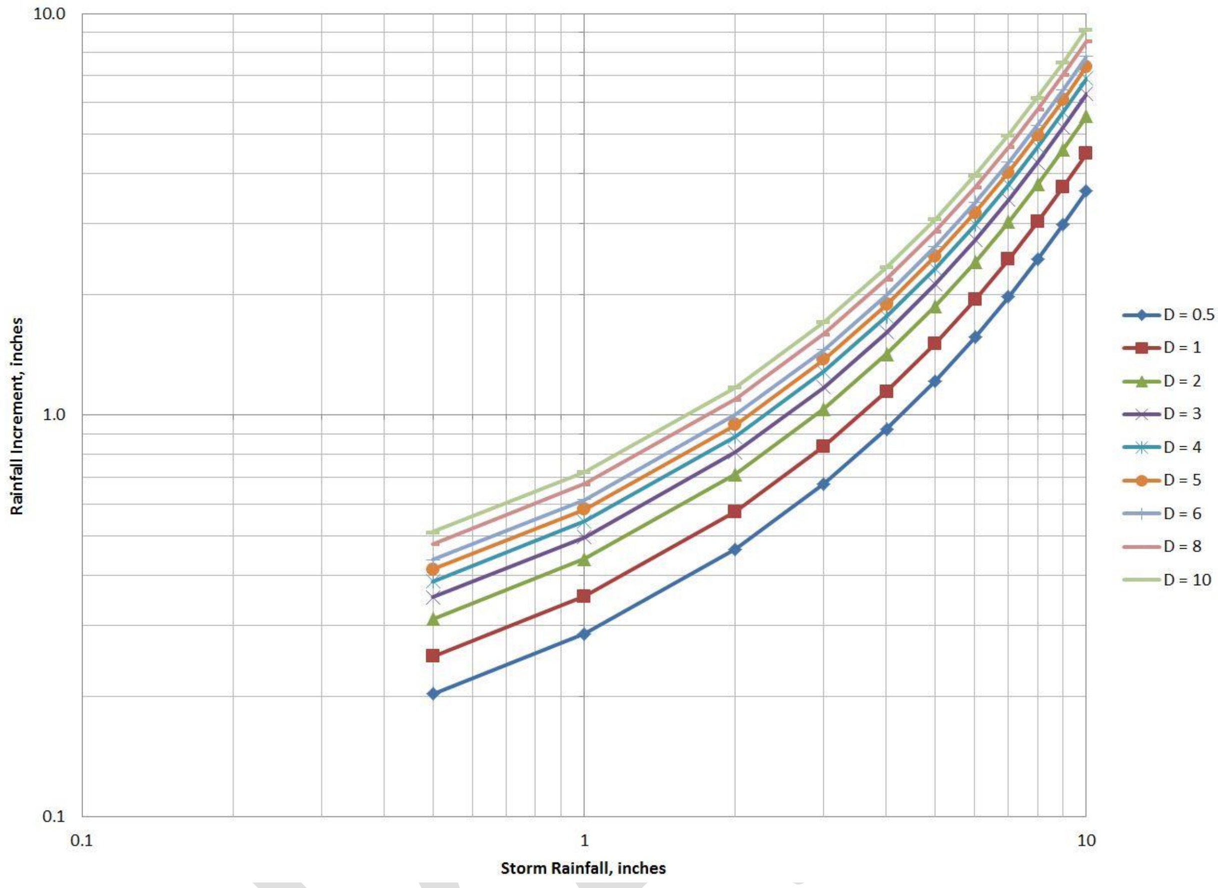
Other methods for estimating areal average rainfall from a system of point rain gage measurements include the Reciprocal-Distance-Squared method (Wei and McGuiness 1978; Singh and Chowdhury 1986) and use of geostatistics (kriging) (McCuen and Snyder 1986; Bras and Rodriguez-Iturbe 1985).

(b) Accuracy

Accuracy of any rainfall estimate depends mainly on the distance between a gage and the point of application of the estimate, regardless of the method used. In mountainous areas, the vertical distance may be more important than the horizontal, but for flat or rolling terrain, only the horizontal distance typically matters. Exceptions occur where rain shadows and lake effect precipitation may vary greatly across a large watershed that does not have large relief variability. For a network, both distance and arrangement of gages affect the accuracy. Unless special studies at a gage site have been made, the possible differences between gage and average watershed rainfalls are generally ignored.

Figure 4–20 can be used to estimate the range of possible difference likely to occur seven times out of ten if the measured storm rainfall at a single gage is used as a depth for a location some distance away. It was developed from information given by Huff and Neill (1957) for small areas in Illinois. The watersheds studied ranged from 19 acres to 400 square miles. Even though this report includes watersheds located in Illinois, the procedures may be applicable in neighboring states. Figure 4-20 has limits on storm rainfall of 10 inches and horizontal distance of 10 miles. Equation 6 on page 31 of the Huff and Neill reference represents one standard deviation and is included in this chapter. One standard deviation is added and subtracted from the storm rainfall to represent the 70% probability. Horizontal distance is used, so figure 4-20 does not apply in mountainous areas or high desert country (see 630.04.02 (c), Orographic effects). The following examples show how the diagram can be used.

Figure 4-20. Estimating the possible difference in transposed rainfall amounts (modified from Huff and Neill 1957)



The equation used to develop figure 4-20 is:

$$RI = 10^{\left(0.31\,\text{Log}\,D + 0.51P^{(0.5)} - 0.961\right)} \qquad \text{(eq. 4-1)}$$

Where:

RI = rainfall increment

D = distance from gage in miles

P = storm rainfall in inches

Log = base 10 logarithm.

Example 4–3. The storm rainfall depth at a gage is 3.5 inches. What rainfall depth is likely to have occurred, with a probability of 0.7 (7 chances out of 10), at a point 5 miles away from the gage?

Step 1: Enter figure 4–20 with the storm rainfall of 3.5 inches, and at the intersection of the 5-mile line, read a rainfall increment of 1.62 inches.

Step 2: Compute the range of rainfall likely to have occurred seven chances out of ten. The limits are 3.5 + 1.62 =5.12 inches, and 3.5 - 1.62 = 1.88 inches. Therefore, where the gage has a measured storm rainfall of 3.5 inches, there is a probability of 0.7 (7 chances out of 10) that the rainfall depth at a point 5 miles away from the gage is between 1.88 and 5.12 inches.

In example 4–4, figure 4-21 shows the variations to be expected when data from two gages are used to estimate the rainfall depth and also when the gages are nearer or farther apart.

Example 4–4. Rain gages B28R and G42R, on the Agricultural Research Service watershed in Webster County, Nebraska, are 4.3 miles apart. Given any storm rainfall of 0 to 4 inches depth at G42R, compute the range of difference to be expected if the rainfall at B28R is to be estimated from that at G42R using figure 4-20. After plotting the difference lines on Figure 4-21, compare the computed range with the plotting of actual data points for the two gages.

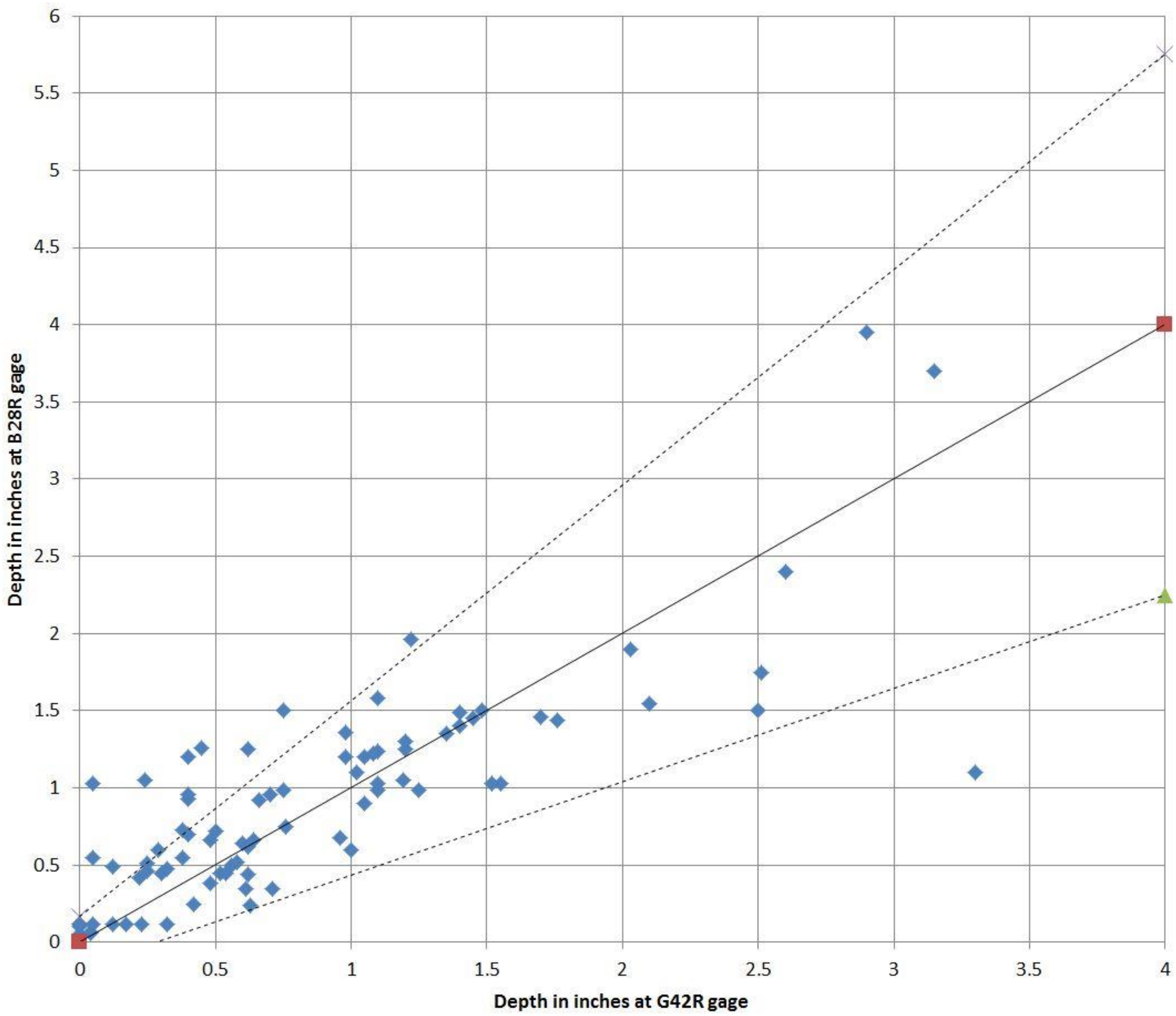
Step 1: Plot a line of equal values, which is the middle line on figure 4–21.

Step 2: Select four values on the G42R depth scale. These values will be used with figure 4–20 or equation 4-1. For this example, the selected values are 0, 1, 2, and 4 inches.

Step 3: Enter figure 4–20 or use equation 4-1 with the distance of 4.3 miles, and at the intersections of the 1-, 2-, and 4-inch rainfall lines read plus and minus differences of 0.55, 0.90, and 1.80 inches, respectively. Use equation 4-1 to calculate a value for zero inches of 0.17".

Step 4: At 1 inch of rainfall depth at gage G42R plot points at rainfall depths of 0.45 inches and 1.55 inches (1 inch plus and minus 0.55 inches). At 2 inches of rainfall depth at gage G42R plot points at rainfall depth of 1.10 inches and 2.90 inches. At 4 inches of rainfall depth at gage G42R plot points at rainfall depth of 2.20 inches and 5.80 inches. At zero inches of depth at gate G42R plot the points plus and minus 0.17 inches of depth for gage B28R.

Figure 4- 21 Storm rainfall at gages 4.3 miles apart



Step 5: Connect the four plus difference points and four minus difference points by dashed lines as shown on figure 4–21. The plot of the lower limit line in Figure 4-21 is not shown below zero inches of rainfall. The plotted points in the figure are for actual measurements at the gages. One point is less than the lower difference line and 13 points are above the upper difference line. Since there are 82 points, 17% of the points fall outside the 70 % confidence interval. This could be expected because there is generally more variation of storm rainfall when considering a limited number of events at two gages than when considering many events at many rain gages.

One advantage in using figure 4–20 is that where a rainfall estimate is to be made for some distant point, the difference lines can be drawn in advance to give an idea of the value of the estimate.

(c) Orographic influences

In hilly or mountainous terrain, the relief may be enough to affect the amount and distribution of precipitation so that measured storm rainfalls are influenced by physiographic variables, both local and distant. Some of these are:

- Elevation or altitude
- Local slope
- Orientation or aspect of the slope
- Distance from the moisture source
- Topographic barriers to incoming moisture
- Degree of exposure, which is defined as "the sum of those sectors of a circle of 20-mile radius centered at the station, containing no barrier 1,000 feet or more above station elevation, expressed in degrees of arc of circle (azimuth)" (Hiatt 1953).

In a typical watershed study, it is seldom possible to determine the influences of all these variables. Orographic effects can be simulated in a hydrologic model by dividing the watershed into subareas related to elevation. A different rainfall may be used for each subarea.

Figures 4–22 and 4-23 show an example of the influences of altitude and topographic barriers on rainfall in a local example. The rainfall amounts indicated by the points in figure 4–22 were recorded during the storm of February 27 to March 4, 1938, in southern California, in the vicinity of the Santa Ana, San Bernardino, and San Gabriel mountains, which lie roughly parallel to the California coast. The series of moisture-laden air masses associated with the storms swept in from the Pacific Ocean to encounter the mountain ranges at almost right angles to their path. The mountains acted as obstructions, thrusting the warm, moist air upward into colder air, and the resultant rapid condensation produced excessively heavy rainfall, particularly on the coastal side of the ranges. The desert side of the ranges (fig. 4–22) had significantly less rainfall. Much of the moisture had already been pulled out of the air mass by the time it reached the desert side of the ranges. As the air mass warmed moving down the desert side of the mountain slopes, it no longer had a ready moisture source and thus became drier.

Figure 4- 22. Orographic influences on rainfall (Source: USGS 1942)

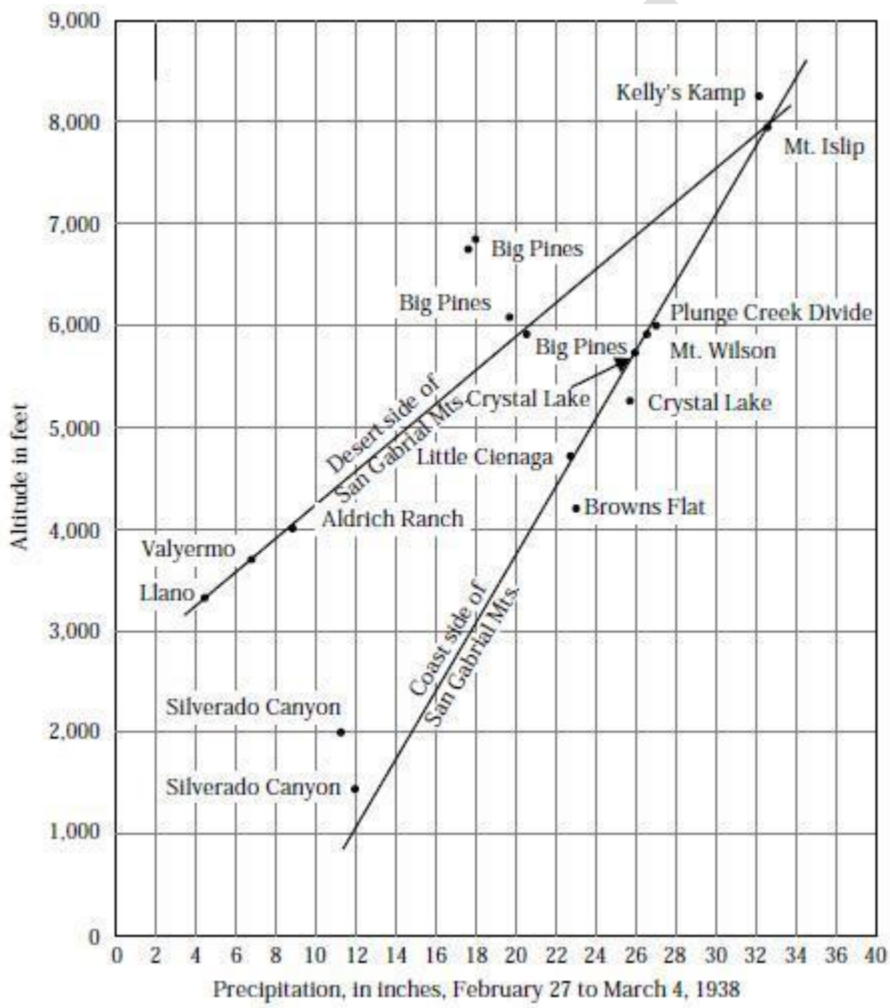
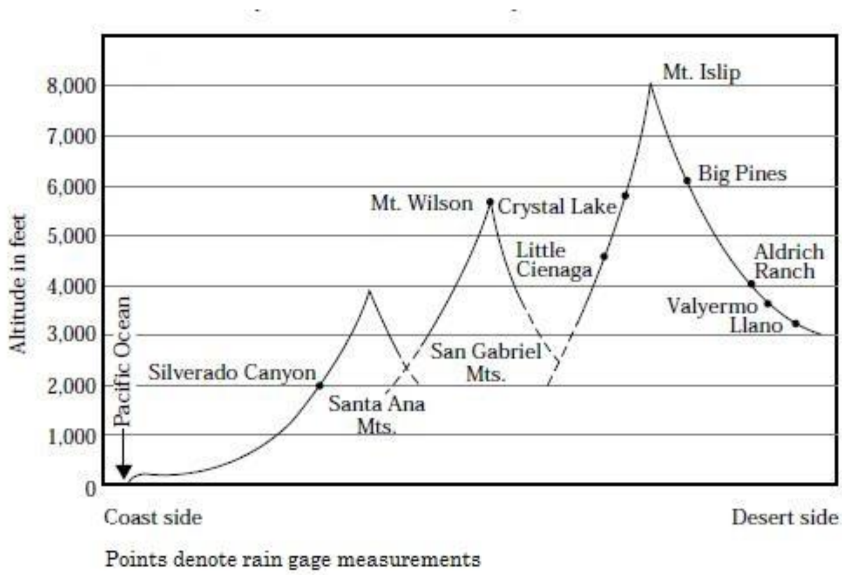


Figure 4- 23. Points denoting gage locations for rain gages in Figure 4-22



630.0403 Temporal distribution of rainfall

(a) Introduction

Section 630.0401, Sources of data, discusses various sources of precipitation-frequency data. These data were derived using various technical methods, for various purposes or objectives, over a period of many years. Using these data for hydrologic modeling as described in NEH Part 630, chapters 16 and 21, requires definition of the temporal distribution of the rainfall. In other words, how the precipitation is distributed over time throughout a storm of a particular duration. For example, a 24-hour rainfall distribution may be defined at a time interval of 0.1 hour by the cumulative distribution of rainfall, starting at the beginning of the storm and ending at the 24-hour rainfall value.

Rainfall distributions used for design of engineering projects are different from actual storms in several ways. One is that design rainfall distributions used by NRCS are generally 24 hours in duration. Actual storms have any duration from minutes up to days. Another major difference is the distribution of rainfall throughout the duration of the storm. The actual storm has variable rainfall during each increment and could even have increments of very high and/or very low intensity rainfall. The design rainfall distribution has an intensity starting very low and increasing to a maximum value then gradually reducing in intensity approaching the end of the storm. A third major difference between actual storms and design storms is that even though the actual event may have a 100-year 24-hour total rainfall, the actual storm may include the 10-year 3-hour rainfall and the 5-year 5-minute rainfall (or any combination of other durations and return periods). The design rainfall distribution is developed to have the 100-year 24-hour rainfall, the 100-year 12-hour rainfall, etc., down to the 100-year 5-minute rainfall imbedded in a single storm. This paragraph is summarized in table 4-5.

Table 4- 5. Differences between design storms and actual storms

Storm Characteristic	**Design Storms**	**Actual Storms**
Storm duration	24 hour duration	Any duration from minutes to days
Temporal rainfall distribution	Smoothly increasing and decreasing rainfall intensity	Irregular rainfall pattern with respect to time, possibly including intervals of no rainfall
Intensity/duration relationship	Based on intensity/duration data for a single return period such as 25-year	Generally include intensity/duration data for different return periods.

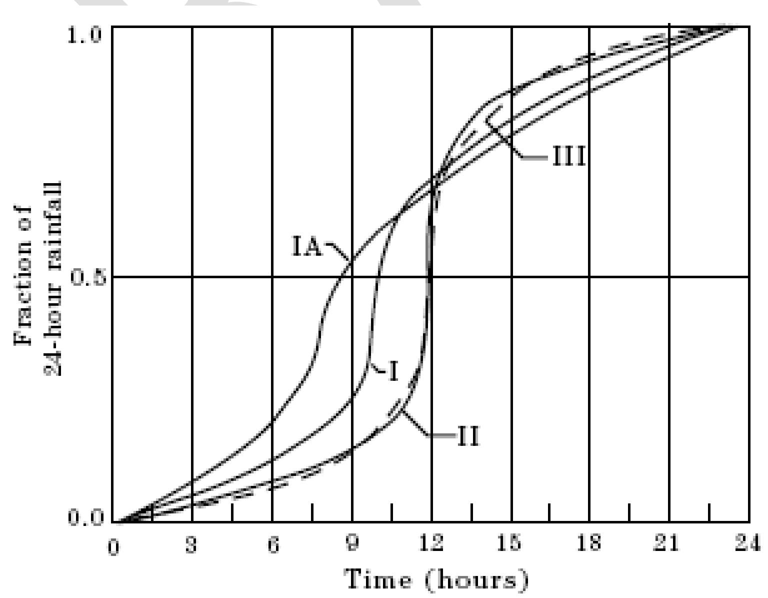
In the discussion below, development of historical and design storm distributions are described and application guidelines and methods presented. The history of the standard NRCS storm distributions is also described.

Methods for developing rainfall distributions for Probable Maximum Precipitation (PMP) are recommended in the various PMP documents listed in 630.0401(a) Sources of data.

However, the concepts used in developing rainfall distributions in this chapter may be applied to develop a PMP rainfall distribution.

The standard NRCS Type I and Type II synthetic rainfall distributions, used for design and planning of NRCS water-related projects, are based on TP-40 (1961) rainfall frequency maps. The only surviving documentation concerning development of the Type I and Type II rainfall distributions is TP-149 (SCS, 1973). The standard NRCS Type IA used in the Pacific Northwest was developed based on major storm cumulative rainfall distributions (Woodward, 1975). The NRCS Type III distribution (Cronshey and Woodward, 1989) is based on Hydro-35 (1977) and TP-40 (1961). Each of these four rainfall distributions has an intense rainfall period somewhere near the middle and lesser rainfall intensities at the beginning and end of the storm (see Figure 4-24). These and other standard NRCS rainfall distributions are listed and described in the WinTR-20 User Documentation. The rainfall distribution tables may also be requested as WinTR-20 computer program output which will place the tables in a file format for export to other software such as a spread sheet or for use in other hydrologic models.

Figure 4- 24. Plot of Types I, IA, II, and III synthetic rainfall distributions

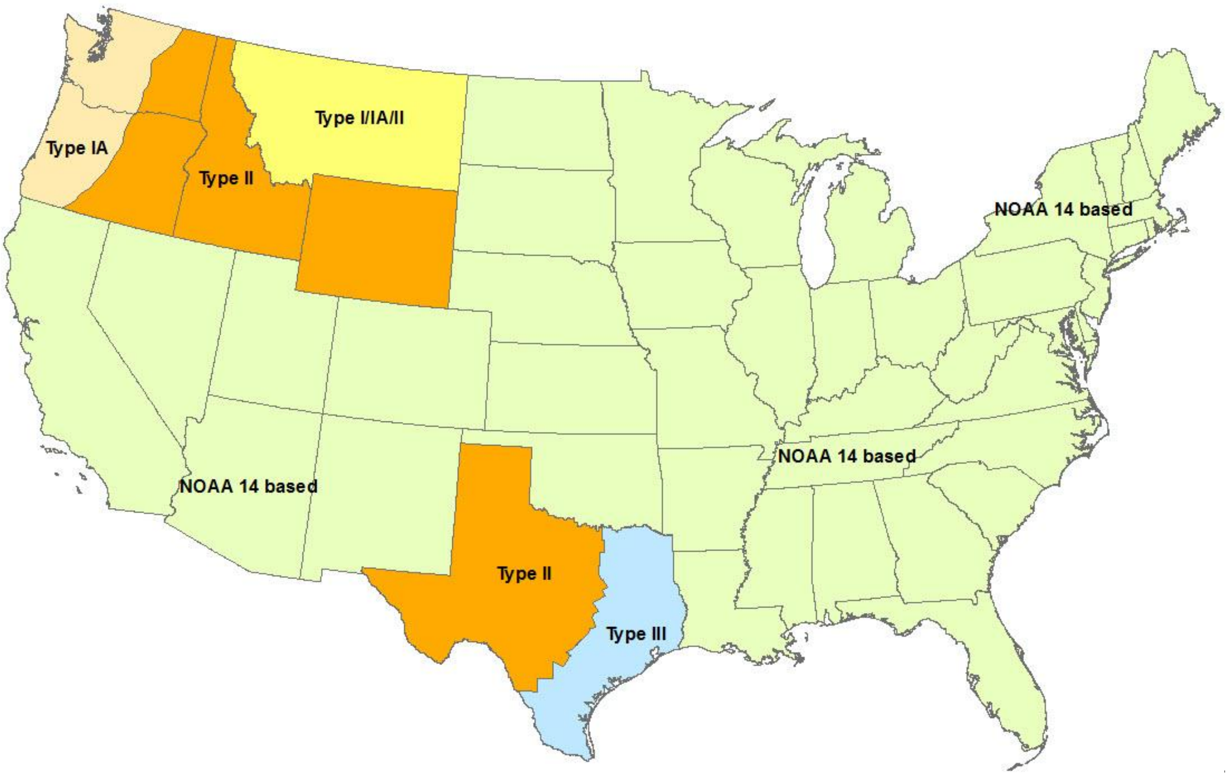


The Type I, Type IA, Type II, and Type III distributions have been applied to very large geographic regions. A map is included in TR-55 (1986). For instance, the Type II distribution has been applied to a large part of the central continental Unites States.

Figure 4-25 shows the current status of rainfall distribution regions within the 48 contiguous United States. NOAA Atlas 14 is complete for the southwest states, California, Ohio Valley and adjacent states, the Midwest, the southeast states, and the northeast states. NOAA Atlas 14 is also complete for Hawaii, Puerto Rico, US Virgin Islands, selected Pacific Islands, and Alaska, although these are not shown in Figure 4-25. Within the states where NOAA Atlas 14 is complete, the West National Technology Support Center (WNTSC), National Water Quality and Quantity Team developed updated rainfall distributions for individual states and groups of states. Documentation of these distributions is available at the NRCS WNTSC National Water Quality and Quantity Team web site http://go.usa.gov/rXYw under Technical Information. Documentation on use of NOAA Atlas 14 data and rainfall distributions in each individual state covered by NOAA Atlas 14 is available at the NRCS WNTSC National Water Quality and Quantity Team web site http://go.usa.gov/KoZ under the link to the WinTR-20 model. Appendix 4D discusses development of regional rainfall distributions based on GIS data. Regional rainfall distributions were developed for California, Nevada, Midwest states, Southeast states, Ohio Valley and neighboring states, and New York and New England states.

As the rest of the states are covered in future volumes of NOAA Atlas 14, Figure 4-25 will be revised. Montana is not assigned a single distribution because the state has a procedure to select the rainfall distribution based on the ratio of 6-hour to 24-hour rainfall depths (NRCS, 1990).

Figure 4- 25. United States map with updated synthetic rainfall distributions as of January 2016



Any rainfall distribution developed prior to release of volumes of NOAA Atlas 14 should not be used without a specific evaluation of imbedded rainfall ratios. An important feature of a NRCS synthetic design rainfall distribution is the ratio of rain falling in a shorter duration to the total storm rainfall. For example, Table 4-5 shows that in a Type II rainfall distribution, 45.4% of the 24-hour storm rainfall occurs in 1 hour. In areas covered by NOAA Atlas 14, this ratio is generally different and highly site-specific. The same concept is true for other durations such as 5, 10, 15, and 30 minutes, 2 hours, etc. To use a Type II or other legacy rainfall distribution with the updated NOAA Atlas 14 data could introduce errors by application of inaccurate rainfall intensities during the storm.

Very little documentation is available that describes the development of the Type II and other legacy rainfall distributions. Study of what is available leads to the conclusion that their use be discontinued in areas covered by NOAA Atlas 14 data. The Type II was assigned as the design storm distribution for much of the 48 contiguous United States. Using maps contained in TP-40, rainfall ratios for durations from 30 minutes to 12 hours divided by the 24-hour rainfall reveal significant variation from the ratios imbedded in the Type II storm distribution. In SCS TP-149 (1973), there are several locations (Alabama, Puerto Rico, Nebraska, and Utah) where the rainfall versus duration is plotted. These plots show differences at a station over 0.5 inches when compared to the Type II curve. There is no doubt that when these legacy rainfall distributions were developed, they were developed using the best available data, technology, and engineering judgment available at the time. With current data of improved quantity and quality, geographic information systems, and computer capabilities, a higher standard may be set with respect to developing and using updated rainfall distributions.

An important characteristic of NRCS synthetic rainfall distributions is that the maximum rainfalls for all durations from 5-minutes to 24-hours are represented accurately. The primary assumption made in the development of the rainfall distribution is that the rainfall values for all durations for a single return period occur within one 24-hour period. For example, the 25-year 5-minute, 25-year 10-minute, 25-year 15-minute up to the 25-year 24-hour rainfall occurs within the same design storm and are centrally nested within each greater storm duration listed.

(b) Precipitation – Frequency Data Ratio Analyses

The foundation of rainfall distributions as used throughout the history of NRCS is the set of ratios of the shorter durations to the 24-hour rainfall. The ratios of 5-minute through 12-hour rainfall to the 24-hour rainfall imbedded in the Type II distribution are included in table 4-6 as an example. NOAA Atlas 14 data for the desert southwest (NOAA Atlas 14, Volume 1) and Ohio Valley and neighboring states (NOAA Atlas 14, Volume 2) were analyzed with respect to ratios of shorter durations to the 24-hour rainfall values at many point locations (Merkel et al. 2006).

Appendix 4A has an example which compares the Type II distribution with the original TP-40 and Hydro-35 rainfall values. The ratios of shorter duration to the 24-hour rainfall developed with data from TP-40 and Hydro-35 are compared with ratios from the standard Type II distribution which has been used there in the past. Columbus, Ohio is the location that was evaluated.

The ratios for each duration to the 24-hour rainfall which are imbedded in the standard Type II rainfall distribution follow in table 4-6.

Table 4-6. Ratios to 24- hour rainfall for the Type II distribution

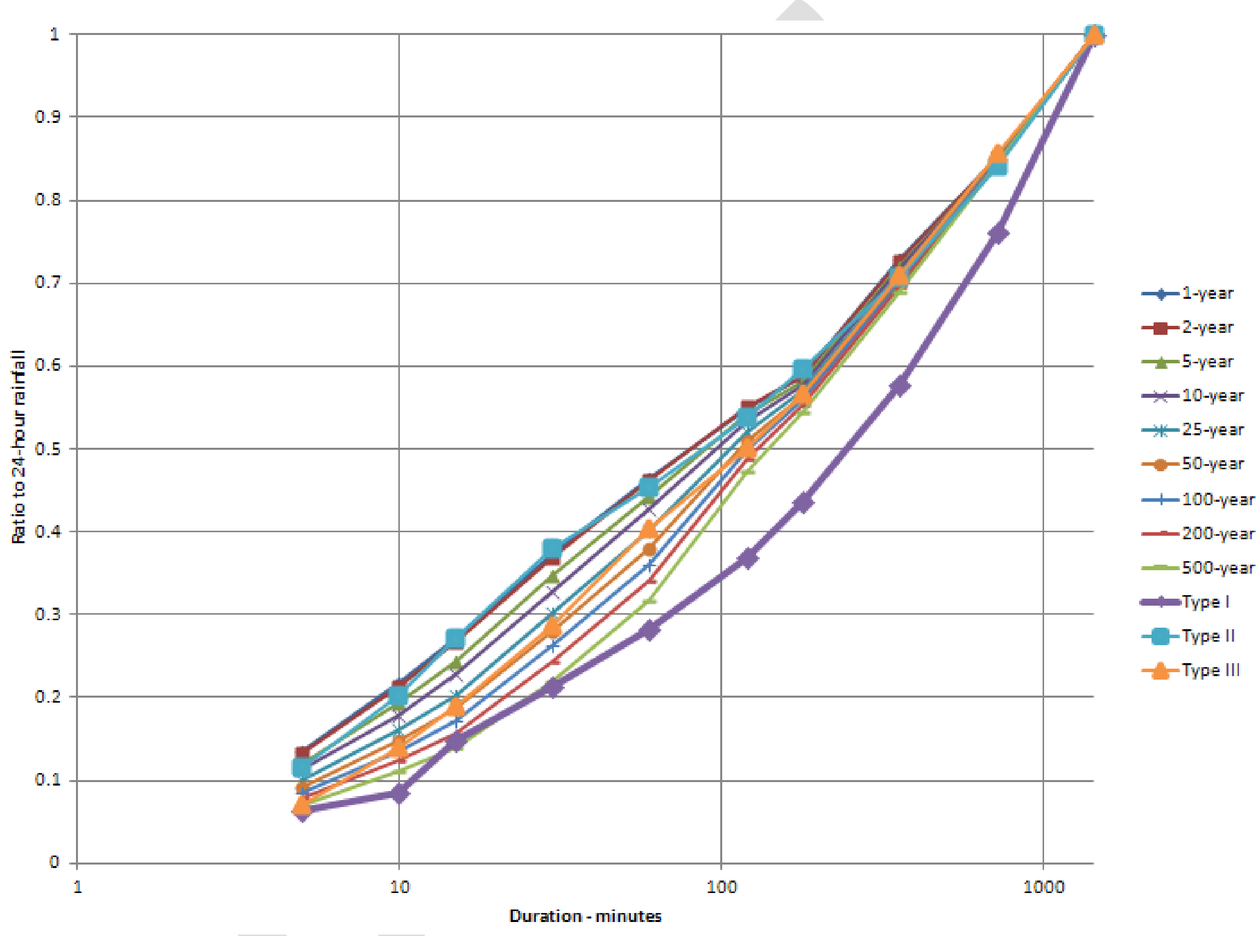
Duration	Ratio to 24-hour rainfall
5-minutes	0.114
10-minutes	0.201
15-minutes	0.270
30-minutes	0.380
1-hour	0.454
2-hours	0.538
3-hours	0.595
6-hours	0.707
12-hours	0.841
24-hours	1.00

Variability of ratios is also evident in rainfall distributions based on the NOAA Atlas 14 data. The engineer must determine how much difference between the site-specific distribution and the regional rainfall distribution is acceptable for each specific project.

To summarize the results of the analyses, the ratios of shorter duration to the 24-hour rainfall varied both spatially and by return period enough to conclude that the ratios imbedded in the standard NRCS rainfall distributions (Types I, IA, II, and III) are not consistent with ratios developed from NOAA Atlas 14 rainfall values. Rainfall distributions which cover large geographic regions may have large variation of ratios that could lead to over- or under-estimation of peak discharge when used with a hydrologic model such as WinTR-20 or WinTR-55. Over- and under-estimation refers to the difference between using the regional rainfall distribution and the site-specific rainfall distribution based on the return period being analyzed. However, a properly designed rainfall distribution such as demonstrated in Appendix 4D may be feasible if ratio limits are set and tests are made to insure the maximum range in peak discharge values is within an appropriate tolerance.

To illustrate the variation of rainfall distribution with return period and sensitivity of peak discharge, the Wilmington Airport, North Carolina station was selected. The partial duration precipitation values were downloaded and the ratios of 5-minute / 24-hour through 12-hour / 24-hour ratios were computed and plotted in Figure 4-26.

Figure 4- 26. Ratios of 5-min 24-hr through 12-hr 24-hr ratios for different distributions, data for Wilmington Airport, NC



In figure 4-26, the ratios for the 1-year through 500-year return periods are compared with the ratios imbedded within the standard Types I, II, and III rainfall distributions.

The figure shows that the Type II ratios are an approximate upper limit, which falls close to the 1-year ratios. The Type III ratios fall in the mid-range of the return periods (25-

and 50-year). The Type I ratios are an approximate lower limit for the 500-year ratios up to about 30-minute duration. The ratios show that it may be inappropriate to use a single rainfall distribution for all return periods. However, depending on the project purpose and complexity, using a single rainfall distribution to represent a design storm may be appropriate.

The ratios of shorter duration to the 24-hour duration may have a significant impact on peak discharges of hydrographs generated using the particular rainfall distribution. Considering the storms from 1-year through 100-years, the ratios for the 10-year storm shown in figure 4-26 represent the average for this location. For this example, rainfall distributions for each return period were developed based ratios of the 5-minute to 24-hour through 12-hour to 24-hour ratios. The expected difference in peak discharge based on an individual rainfall distribution for each return period versus the average for all return periods from 1-year through 100-years varies by location and by runoff curve number and time of concentration. WinTR-20 was run for a runoff curve number of 75 and times of concentration (Tc) of 0.5 and 1.0 hour. A drainage area of 0.5 square mile was used. However, when only interested in percentage difference of peak discharge, the drainage area is immaterial. The percent differences are shown in table 4-7.

Table 4- 7. Percent difference in peak discharge using individual storm rainfall distributions versus an average rainfall distribution for Wilmington NC.

Storm Return Period, years	Percent Difference Tc = 0.5 hour	Percent Difference Tc = 1.0 hour
1	14.5	9.8
2	13.0	9.4
5	5.2	4.3
10	0.0	0.0
25	-8.3	-6.2
50	-14.6	-11.6
100	-20.0	-16.2

Positive differences in table 4-7 indicate the peak discharge is greater with the individual return period rainfall distribution when compared to the average rainfall distribution. Negative differences indicate the peak discharge is less with the individual return period rainfall distribution when compared to the average rainfall distribution. The results in table 4-7 show what is expected when considering the plot of ratios in figure 4-26. Ratios for the 1-year, 2-year and 5-year storms are greater than ratios for the 10-year return period and the higher peak discharges for those storms reflect that.

Wilmington, NC is a somewhat extreme example of ratio variation by return period. Many other locations have a narrower range of variation. However, if this variation is evident anywhere, it leads to the conclusion that new rainfall distributions are needed to replace the legacy rainfall distribution types.

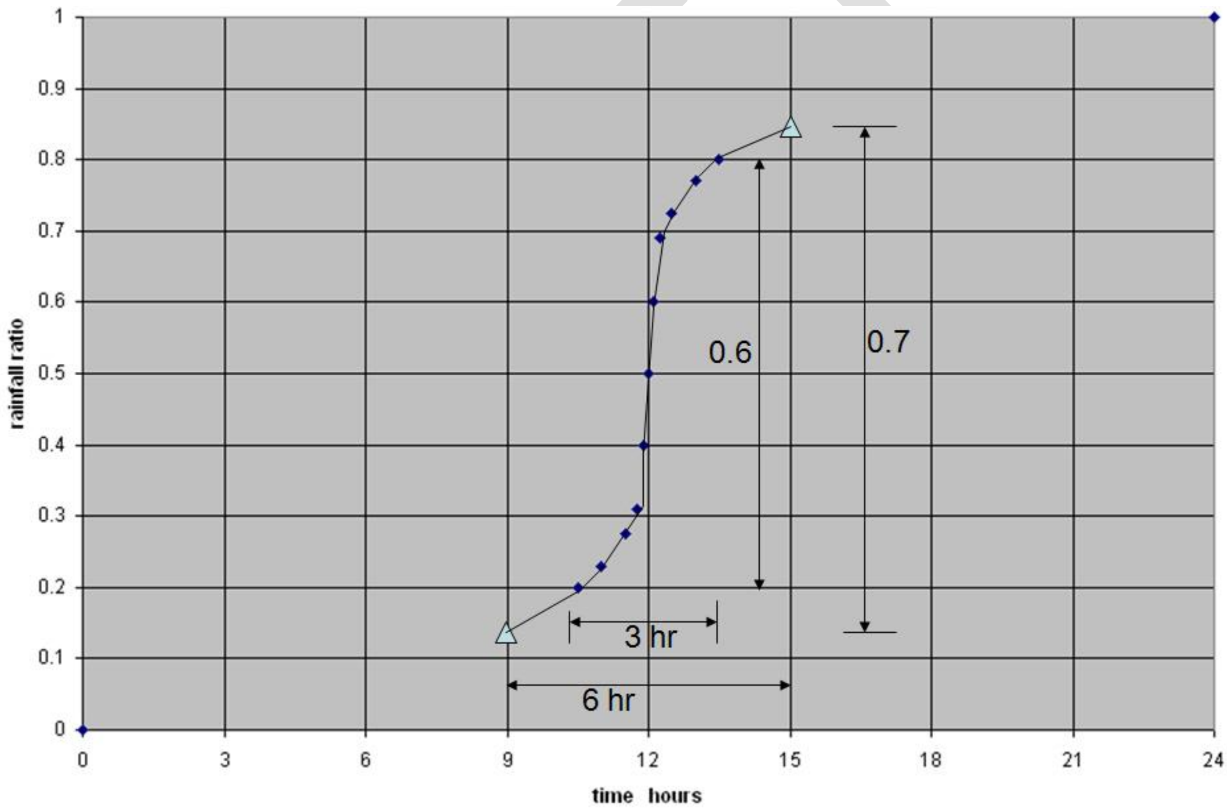
(c) Development of synthetic rainfall distributions

A procedure has been developed which will derive rainfall distributions to cover the wide range of climatic conditions from tropical to arctic that occur in the US (Merkel, 2006 and Merkel, et al, 2015).

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. It is one of the principles of hydrology that the peak discharge for a watershed is determined primarily by rain falling in a duration which equals the time of concentration (see NEH Part 630 Chapter 15). The 24-hour rainfall distribution has the maximum 5-minute rainfall occurring from 12 to 12.1 hours. The maximum 10-minute rainfall is between 11.9 and 12.1 hours, and includes the maximum 5-minute rainfall, and so on. Since the rainfall distribution is developed at a 0.1 hour (6 minute) time interval, the values at 0.1 hour time interval are interpolated from the 5, 10, 15 and 30-minute rainfall values. In this way, a single rainfall distribution for 24 hours may be used for any watershed with time of concentration less than 24 hours.

In many investigations of precipitation-frequency data from NOAA Atlas 14, a number of geographic regions have a relationship of precipitation intensity versus duration which is not smooth. When the precipitation intensity-duration relationship is not smooth, the resulting rainfall distribution is not smooth. Appendix 4B explains these situations and how the data may be smoothed in order to generate a smooth rainfall distribution. Software associated with WinTR-20 automates this data smoothing option.

Figure 4-27. Construction of rainfall distribution from precipitation versus duration data



In figure 4-27 above, the ratio of 3-hour to 24-hour rainfall is 0.6. The 3-hour duration is centered on 12 hours, so the 3-hour period will start at 10.5 hours and end at 13.5 hours. The ratio value of 0.6 is centered at 0.5 so the cumulative rain ratio for the 3-hour duration begins at 0.2 and ends at 0.8. The ratio of 6-hour to 24-hour rainfall is 0.7. The 6-hour duration is centered on 12 hours, so the 6 hour period will start at 9 hours and end at 15 hours. The ratio value of 0.7 is centered at 0.5 so the cumulative rain ratio for the 6-hour duration begins at 0.15 and ends at 0.85. All durations from 1-hour to 12-hours are treated similarly as the 3-hour and 6-hour explained above. Since the rainfall table is developed at a 0.1-hour time interval, cumulative rainfall ratios from 11.6 hours to 12.4 hours are interpolated based on ratios of 5 minute, 10 minute, 15 minute, and 30 minute to 24-hour rainfall. A curve is fit to pass through the ratio points developed from the procedure described above to make a smooth cumulative rainfall distribution which gradually increases in rainfall intensity from zero to 12 hours and gradually decreases in rainfall intensity from 12 hours to 24 hours. Appendix 4C describes the procedure in detail.

Since the 24-hour design rainfall distribution is built to include the maximum rainfall distribution for any shorter duration, the rainfall distribution for any duration may be extracted from it. An example follows.

Example 4-5. Extract a 6-hour rainfall distribution from the 24-hour rainfall distribution at a location in Bradford County, Florida, using data from NOAA Atlas 14. The table of 24-hour cumulative rainfalls at an increment of 0.5 hour is in table 4-8 columns 1 and 2. A time increment of 0.5 hour is used to shorten the example and still demonstrate the concepts. The maximum 6 hours of the 24-hour rainfall distribution is from 12 hours plus and minus 3 hours or from 9 hours to 15 hours. The cumulative value at 9 hours is 0.1108 and at 15 hours is 0.8892 and the difference is 0.7784. Values in column 3 are values in column 2 with 0.1108 (value at 9 hours) subtracted from each. Values in column 4 are the cumulative values of time for the 6-hour rainfall distribution (beginning at 0.0 and ending at 6.0 hours). The values in column 5 are the values in column 3 divided by 0.7784 (difference between 9 and 15 hours). Thus, columns 4 and 5 represent the 6-hour rainfall distribution. The 6-hour rainfall distribution starts at a cumulative value of 0.0 and ends at a cumulative value of 1.0.

Table 4-8. 6-hour rainfall distribution extracted from a 24-hour rainfall distribution.

Time hr	Cumulative 24-hr rainfall ratio	Unadjusted cumulative 6-hr rainfall ratio	6-hr distribution Time hr	6-hr distribution Cumulative rainfall ratio
(1)	(2)	(3)	(4)	(5)
0	0.0000			
0.5	0.0031			
1	0.0064			
1.5	0.0100			
2	0.0139			
2.5	0.0180			
3	0.0224			
3.5	0.0271			
4	0.0320			
4.5	0.0372			
5	0.0427			
5.5	0.0484			
6	0.0544			
6.5	0.0612			
7	0.0690			
7.5	0.0778			
8	0.0878			
8.5	0.0988			
9	0.1108	0.0000	0	0.0000
9.5	0.1259	0.0151	0.5	0.0194
10	0.1454	0.0346	1	0.0445
10.5	0.1693	0.0585	1.5	0.0751
11	0.2057	0.0949	2	0.1219
11.5	0.2712	0.1604	2.5	0.2061
12	0.4763	0.3655	3	0.4696
12.5	0.7288	0.6180	3.5	0.7939
13	0.7943	0.6835	4	0.8781
13.5	0.8307	0.7199	4.5	0.9249
14	0.8546	0.7438	5	0.9555
14.5	0.8741	0.7633	5.5	0.9806
15	0.8892	0.7784	6	1.0000
15.5	0.9013			
16	0.9122			
16.5	0.9222			
17	0.9310			
17.5	0.9388			
18	0.9456			
18.5	0.9516			

19	0.9573			
19.5	0.9628			
20	0.9680			
20.5	0.9729			
21	0.9776			
21.5	0.9820			
22	0.9861			
22.5	0.9900			
23	0.9936			
23.5	0.9969			
24	1.0000			

Why does NRCS use primarily the 24-hour rainfall distribution? When NRCS originally developed hydrologic procedures in the 1950's, most rain gages recorded daily (24-hour) rainfall. Very few recorded hourly and sub-hourly values and there was much more confidence in the daily records and associated rainfall frequency analyses. Hourly and sub-hourly measurements were used to distribute the rainfall within the 24-hour duration storm. With only two original rainfall distributions, the Type I and Type II (TP-149), tables and graphs for hydrologic analyses could be developed easily. Users of the hydrologic procedures needed only a 24-hour rainfall value along with basic watershed data to complete a hydrologic analysis.

Rainfall and runoff data used to develop runoff curve numbers are a combination of storm event rainfall and runoff and daily rainfall and runoff. The word "daily" is interpreted as being 24 hours. In NRCS hydrologic procedures, the curve number is applied to estimate the 24-hour runoff volume based on the 24-hour rainfall. The 24-hour rainfall distribution includes the maximum rainfall distribution for all shorter durations. By using rainfall values for all durations from 5 minutes to 24 hours to develop the rainfall distribution and nesting the durations, a maximized rainfall distribution results. This will insure that the maximum rainfall intensity is applied to a watershed with any time of concentration less than 24 hours. In modernizing NRCS hydrologic procedures, the number of rainfall distributions has increased greatly, though standard use of the 24-hour duration is continued. Development of the rainfall distribution is automated in WinTR-20 allowing for use of both regional and site-specific rainfall distributions.

(d) Development of a rainfall distribution for an historical storm

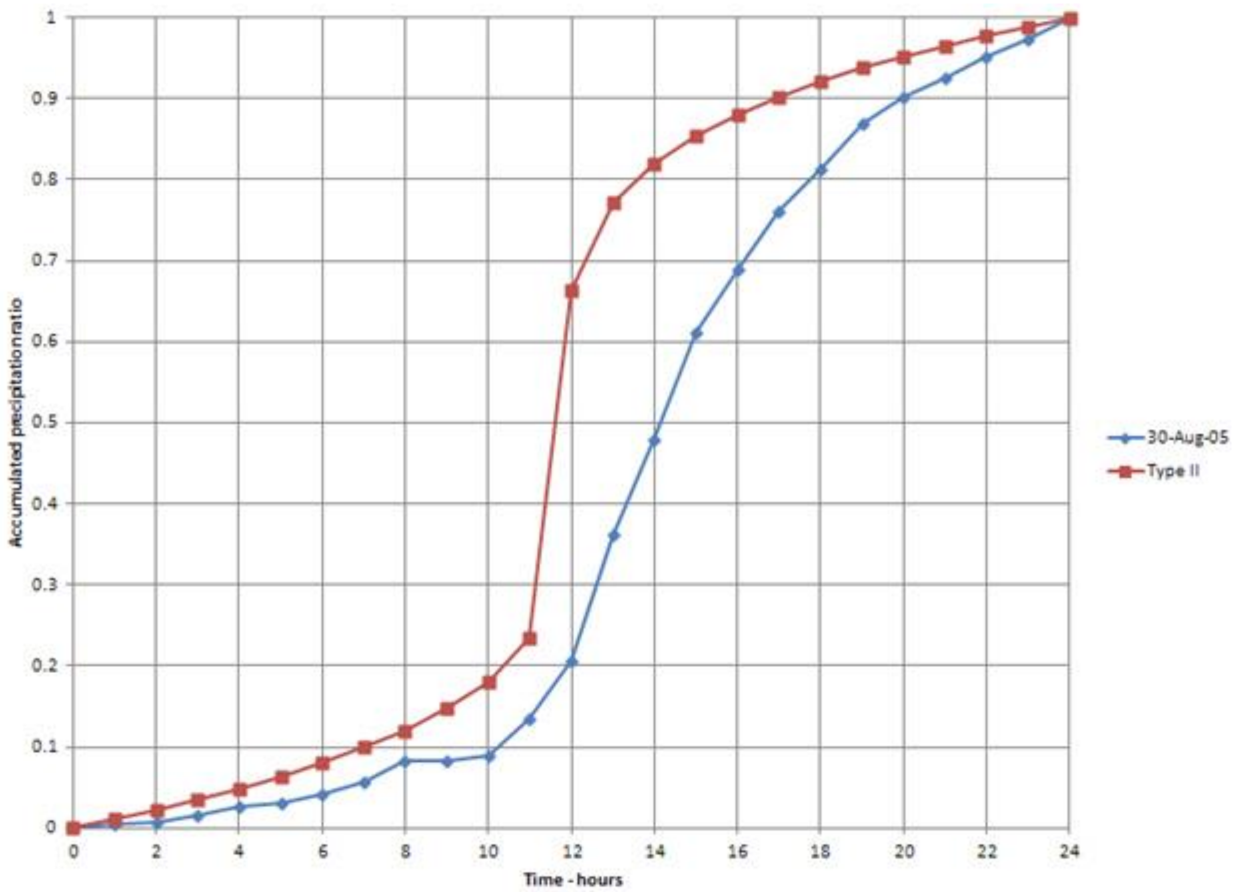
One purpose for developing a rainfall distribution for an historical storm is to run a hydrologic model such as WinTR-20 or WinTR-55 for a watershed to validate the model data or conduct a storm assessment comparing the model results to actual flood data such as a peak discharge, flood hydrograph, or high water marks. This example uses the storm of August 30, 2005 at Columbus, Ohio. From records of the National Weather Service, the actual time and hourly precipitation data are shown in columns 1 and 3 of table 4-9.

Table 4-9. Hourly rainfall data and distribution at Columbus Ohio, August 30, 2005

Actual time, hours (1)	Time from beginning of storm, hours (2)	Hourly precipitation, inches (3)	Accumulated precipitation, inches (4)	Accumulated ratio (Col.3/Col.4) (5)	Type II storm ratio (6)
4 AM	0	0	0	0	0
5	1	0.01	0.01	0.004	0.011
6	2	0.01	0.02	0.007	0.022
7	3	0.02	0.04	0.015	0.035
8	4	0.03	0.07	0.026	0.048
9	5	0.01	0.08	0.030	0.063
10	6	0.03	0.11	0.041	0.080
11	7	0.04	0.15	0.056	0.099
12 Noon	8	0.07	0.22	0.082	0.120
1	9	0.0	0.22	0.082	0.147
2	10	0.02	0.24	0.090	0.181
3	11	0.12	0.36	0.135	0.235
4	12	0.19	0.55	0.206	0.663
5	13	0.42	0.97	0.363	0.772
6	14	0.31	1.28	0.479	0.820
7	15	0.35	1.63	0.610	0.854
8	16	0.21	1.84	0.689	0.880
9	17	0.19	2.03	0.760	0.902
10	18	0.14	2.17	0.813	0.921
11	19	0.15	2.32	0.869	0.938
12 Midnight	20	0.09	2.41	0.903	0.952
1	21	0.06	2.47	0.925	0.965
2	22	0.07	2.54	0.951	0.977
3	23	0.06	2.6	0.974	0.989
4	24	0.07	2.67	1.000	1.000

The hourly values are accumulated from the beginning to the end of the storm in column 4 of table 4-9. The ratios of the accumulated precipitation to the total storm precipitation are shown in column 5. For comparison, the ratios for the Type II storm distribution are shown in column 6. The cumulative rain ratios for the actual storm event and the Type II are shown in figure 4-28. The storm of August 30, 2005 has the same general shape as the Type II distribution, starting with low rainfall intensity at the beginning of the storm, higher intensity in the middle and lower intensity near the end. Actual storm distributions which may be front-loaded or an end-loaded may plot anywhere within a graph similar to figure 4-28. Even though the Type II is a hypothetical storm, actual storms may approach the Type II storm distribution with respect to general shape and maximum rainfall intensity.

Figure 4- 28. Actual storm accumulated precipitation and the Type II distribution



630.0404 Uses of Precipitation Depth and Distribution

Average storm rainfall is sometimes used in hydrologic models such as WinTR-20 and WinTR-55 to estimate the peak discharge for a particular storm event. Another possible application is to use average watershed rainfall along with measured runoff volume to determine a calibrated watershed runoff curve number for a particular storm event. An estimation of mean annual precipitation may be needed for other purposes such as application of USGS peak discharge equations when the mean annual precipitation is a regression variable or relating the mean annual precipitation value to other hydrologic data such as volume of runoff.

The WinTR-20 hydrologic model could be used to analyze the effects of the 25-year 24-hour and other storms on a watershed. The EFH2 program has the limitation of using only a single watershed and WinTR-55, though it may analyze a watershed with subareas, has the limitation of using a uniform rainfall over the entire watershed.

An actual storm distribution may be used in WinTR-20 or WinTR-55 to estimate peak discharges and hydrographs for a watershed impacted by a particular storm event in order to assess damages as a result of this storm or to calibrate other data. Calibration involves verifying the proper assignment of the various hydrologic model input parameters such as watershed area, runoff curve number, time of concentration, and dimensionless unit hydrograph peak rate factor. Once a hydrologic model is calibrated, hypothetical, synthetic, and/or design rainfall depths and distributions may be analyzed with the hydrologic model to estimate impacts of flood events. This can be done with confidence based on comparing the hydrologic model results to actual rainfall and runoff gages for multiple storms.

NRCS models such as WinTR-20, WinTR-55, SITES, and EFH-2 are designed to use standardized rainfall distributions. A custom rainfall distribution may be used instead of one of the standard rainfall distributions in WinTR-20, WinTR-55, and SITES. This custom rainfall distribution may be based on an historical or actual storm event or based on NOAA Atlas 14 data at the project location.

630.0405 References

Arkell, R.E., and F. Richards. 1986. Short duration rainfall relations for the western United States, Conference on Climate and Water Management-A Critical Era and Conference on the Human Consequences of 1985's Climate, August 4-7, pp 136-141. Asheville, NC.

Brakensiek, D.L., H.B. Osborn, W.J. Rawls, coordinators. 1979. Field manual for research in agricultural hydrology. USDA, Agriculture Handbook 224.

Bras, R.L., I. Rodriguez-Iturbe. 1985. Random functions and hydrology. Addison Wesley, Reading, MA.

Chow, Ven Te, editor-in-chief. 1964. Handbook of applied hydrology: A compendium of water resource technology. McGraw-Hill, New York.

Citizen Weather Observer Program website http://www.wxqa.com/resources.html has a number of references for weather observers' use.

Cronshey, R. G. and D. E. Woodward. 1989. Derivation of the Type III rainfall distribution, paper presented at the International Conference on Channel Flow and Catchment Runoff. Charlottesville, VA, International Association for Hydraulic Research.

Cronshey, R. G.1982. Synthetic Rainfall Time Distributions in Statistical Analysis of Rainfall and Runoff, part of the Proceedings of the International Symposium on Rainfall-Runoff Modeling, May 18-21 at Mississippi State University, Mississippi. Water Resources Publications, Littleton, CO.

Environmental Systems Research Institute. 2012. ArcGIS ArcMAP 10.1.

Hiatt, W.E. 1953. The analysis of precipitation data, in Subsurface facilities of water management and patterns of supply-type area studies. Edited by U.S. House of Representatives, Interior and Insular Affairs Committee, vol. IV, The physical and economic foundation of natural resources series, pp. 186-206.

J. Holton. 2004. An Introduction to Dynamic Meteorology, 4th Edition. Academic Press, Burlington, MA.

Huff, F.A., and J.C. Neill. 1957. Rainfall relations on small areas in Illinois. Bul. 44, IL State Water Survey, Urbana, IL.

Kurtyka, J.C. 1953. Precipitation measurement study. Report of investigation no. 20, IL State Water Survey Division, Urbana, IL.

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1982. Hydrology for engineers. McGraw-Hill Book Co., New York, NY.

Maidment, D.R. 1993. Editor-in-chief, Handbook of Hydrology, McGraw-Hill. . New York, N.Y.

McCuen, R.H., and W.M. Snyder.1986. Hydrologic modeling, statistical methods and applications. Prentice-Hall, Englewood Cliffs, NJ.

Merkel, W. H., Moody, H.F., Quan, Q.D., 2006. United States Department of Agriculture, Natural Resources Conservation Service. 2006. Rainfall Distribution for States

Covered by NOAA Atlas 14 Volumes 1 and 2, NRCS internal publication (available upon request).

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

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

Mockus, V. 1957. Use of storm and watershed characteristics in synthetic hydrograph analysis and application. Paper presented at the American Geophysical Union, annual meeting of the Pacific Southwest Region, Sacramento, CA.

Rallison, R.E., and N. Miller. 1982. Past, present, and future SCS runoff procedure, in Rainfall-runoff relationship, part of the proceedings of the International Symposium on Rainfall-Runoff Modeling, May 18-21 at Mississippi State University, Mississippi. Water Resources Publications, Littleton, Co.

Singh, V.P., and P.K. Chowdhury. 1986. Comparing methods of estimating mean areal rainfall. Water Resources. Bul., vol. 22, no. 2, pp. 275-282.

Oregon State University. 2012. Parameter-elevation Regressions on Independent Slopes Model (PRISM). Prism Climate Group. Website at http://www.prism.oregonstate.edu/

U.S. Department of Agriculture, Division of Drainage, Bureau of Agricultural Engineering. 1935. Rainfall Intensity-frequency data. Misc. publication No. 204. Washington, D.C.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2010. Generation of weather Elements for Multiple applications GEM). Website at http://www.wcc.nrcs.usda.gov/climate/gem.html

U.S. Department of Agriculture, Natural Resources Conservation Service. 2004. National Engineering Handbook, Part 630, Chapter 10, Estimation of Direct Runoff from Storm Rainfall. Washington, DC.

United States Department of Agriculture, Natural Resources Conservation Service. 2005. Earth dams and reservoirs, TR-60.

U. S. Department of Agriculture, Soil Conservation Service. 1975. WTSC Technical Note – Hydrology – PO-6 (rev. 2).Use of National Weather Service Revised Precipitation-Frequency Maps and Estimation of 10-Day Precipitation Values.

U.S. Department of Agriculture, Natural Resources Conservation Service 1993. Engineering Field Handbook Chapter 2. 1993. Estimating Runoff.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2007. National Engineering Handbook, Part 630, Chapter 16, Hydrographs.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2009. Technical Note 3, Rainfall Frequency for Selected Pacific Islands.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2012. National Engineering Handbook, Part 630, Chapter 18, Selected Statistical Methods. Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2012. Field Office Technical Guide (FOTG). Washington, DC. Website at http://efotg.sc.egov.usda.gov/efotg_locator.aspx

U.S. Department of Agriculture, Natural Resources Conservation Service, 2010. WinTR–20 computer program for project formulation hydrology, ver. 1.5, Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2009a. Small watershed hydrology WinTR–55 user guide. Washington D.C.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2005. SITES water resources site analysis computer program user guide. Washington, DC.

U.S. Department of Agriculture, Soil Conservation Service. 1972. National Engineering Handbook, Part 630, Chapter 21, Design Hydrographs. Washington, DC.

U.S. Department of Agriculture, Soil Conservation Service. 1973. A method for estimating volume and runoff in small watersheds, TP-149.

U. S. Department of Agriculture, Soil Conservation Service. 1990, Montana Supplement to Engineering Field Handbook Chapter 2.

U.S. Department of Commerce, Environmental Science Services Administration, Weather Bureau. 1966. Meteorological Conditions for the Probable Maximum Flood on the Yukon River above Rampart, Alaska. Hydrometeorological Report No. 42. Washington, D.C.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, Northeast Regional Climate Center (NRCC). 2012. Extreme Precipitation in New York and New England (http://precip.eas.cornell.edu/).

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. NOAA Atlas 2. 1973. Precipitation Atlas of the Western United States: Vol. 1, Montana, Vol. 2, Wyoming, Vol. 3, Colorado Vol. 5, Idaho Vol. 9, Washington, Vol. 10, Oregon. Washington, D.C.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1977. Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States, NOAA Technical Memorandum NWS HYDRO-35. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1979. Interduration Precipitation Relations for Storms – Southeast States. NOAA Technical Memorandum Hydrometeorological Report No. 21. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1980. Comparison of Generalized estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls. NOAA Technical Memorandum Hydrometeorological Report No. 25. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1984. Probable Maximum Precipitation Maximum

Precipitation for the Upper Deerfield Drainage Massachusetts/Vermont. NOAA Technical Memorandum NWS Hydro 39. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1985. Probable Maximum Precipitation Estimates for the Drainage above Dewey Dam, Johns Creek, Kentucky. Technical Memorandum NWS Hydro 41. Silver Spring, MD.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1989. Cooperative station observations. Observing Handbook. No. 2.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1995a. Relationship between Storm and Antecedent Precipitation over Kansas, Oklahoma, and Eastern Colorado. NOAA Technical Memorandum Hydrometeorological Report No. 45. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1995b. A Climatic Analysis of Orographic Precipitation over the Big Horn Mountains. NOAA Technical Memorandum Hydrometeorological Report No. 46. Silver Spring, MD.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, NOAA Atlas 14, Volumes 1 through 7. 2004-2012. Located at http://hdsc.nws.noaa.gov/hdsc/pfds/.

NOAA Atlas 14 Precipitation-Frequency Atlas of the United States. 2004, rev 2006. Volume 1 Version 4.0: Semiarid Southwest.

NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, 2004, rev 2006. 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.

NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, 2006. Volume 3, Version 4.0 Puerto Rico and the U.S. Virgin Islands .

NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, 2009, rev. 2011. Volume 4 Version 3: Hawaiian Islands .

NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, 2009, rev. 2011. Volume 5 Version 3.0: Selected Pacific Islands .

NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, 2011. Volume 6 Version 2.0 California.

NOAA Atlas 14 Precipitation-Frequency Atlas of the United States. 2012. Volume 7 Version 1.0 Alaska.

NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. 2013, Volume 8 Version 2.0 Midwestern States.

NOAA Atlas 14, Precipitation-Frequency Atlas of the United States. 2013, Volume 9 Version 2.0 Southeastern States.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service Forecast Office, Northern Indiana. 2010. NOAA 8 Inch Non-Recording Standard Rain Gage. http://www.crh.noaa.gov/iwx/program_areas/coop/8inch.php

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of the Federal Coordinator of Meteorology. 1995. Federal Meteorological Handbook No. 1 - Surface Weather Observations and Reports. Washington, D.C.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Army, Corps of Engineers. 1973. Probable Maximum Precipitation and Snowmelt Criteria for Red River of the North above Pembina, and Souris River above Minot, North Dakota. United States Weather Bureau Hydrometeorological Report No. 48. Washington, D.C.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Army, Corps of Engineers. '1978. Probable Maximum

Precipitation Estimates, United States East of the 105th Meridian, NOAA Hydrometeorology Report No. 51. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, U.S. Department of the Army, Corps of Engineers. 1981. Meteorology of Important Rainstorms in the Colorado River and Great Basin Drainages. Hydrometeorological Report No. 50. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Army, Corps of Engineers. 1982. Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian, NOAA Hydrometeorology Report No. 52. Washington, D.C.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Army, Corps of Engineers. 1983. Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska, NOAA Hydrometeorological Report No. 54. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Army, Corps of Engineers. reprint 1984. Probable Maximum Precipitation Estimates, Colorado River and Great Basin drainages, United States Weather Bureau Hydrometeorological Report No. 49. Silver Spring, MD.

U.S. Department of Commerce, National Weather Service and U.S. Department of the Army, Corps of Engineers. 1998. Probable Maximum Precipitation in California, Calculation Procedure. United States Weather Bureau Hydrometeorological Report No. 58, Report. Silver Spring, MD.

U.S. Department of Commerce, National Weather Service and U.S. Department of the Army, Corps of Engineers. 1998. Probable Maximum Precipitation in California, Calculation Procedure. Hydrometeorological Report No. 58, Plates I and II, Procedure. Silver Spring, MD.

U.S. Department of Commerce, National Weather Service and U.S. Department of the Army, Corps of Engineers. 1998. Probable Maximum Precipitation in California, Calculation Procedure. Hydrometeorological Report No. 58, Shapefiles. Silver Spring, MD.

U.S. Department of Commerce, National Weather Service and U.S. Department of the Army, Corps of Engineers. 1998. Probable Maximum Precipitation in California, Report. United States Weather Bureau Hydrometeorological Report No. 59, Plates I and II. Silver Spring, MD.

U.S. Department of Commerce, National Weather Service and U.S. Department of the Army, Corps of Engineers. 1998. Probable Maximum Precipitation in California, Calculation Procedure. United States Weather Bureau Hydrometeorological Report No. 59, Shapefiles. Silver Spring, MD.

U.S. Department of Commerce, National Weather Service and U.S. Department of the Army, Corps of Engineers. 1999. Probable Maximum Precipitation in California, Report. United States Weather Bureau Hydrometeorological Report No. 59, Report. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Army, Corps of Engineers, and U.S. Department of Interior, Bureau of Reclamation. 1988. Probable Maximum Precipitation Estimates -United States Between the Continental Divide and the 103rd Meridian, NOAA Hydrometeorological Report No. 55A. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Army, Corps of Engineers, and U.S. Department of Interior, Bureau of Reclamation. 1988. Probable Maximum Precipitation Estimates -United States Between the Continental Divide and the 103rd Meridian, NOAA Hydrometeorological Report No. 55A, Plates I-III. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, U.S. Department of the Army, Corps of Engineers, and U.S. Department of Interior, Bureau of Reclamation. 1988. Probable Maximum Precipitation Estimates -United States Between the Continental Divide and the 103rd Meridian, NOAA Hydrometeorological Report No. 55A, Plates IV-VI. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, U.S. Department of the Army, Corps of Engineers, and U.S. Department of Interior, Bureau of Reclamation. 1994. Probable Maximum Precipitation - Pacific Northwest States. Columbia River (including portions of Canada), Snake River and Pacific Coastal Drainages. Hydrometeorological Report No. 57, Report, Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, U.S. Department of the Army, Corps of Engineers, and U.S. Department of Interior, Bureau of Reclamation. 1994. Probable Maximum Precipitation - Pacific Northwest States. Columbia River (including portions of Canada), Snake River and Pacific Coastal Drainages. Hydrometeorological Report No. 57, Maps. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Tennessee Valley Authority. 1973. Meteorological Criteria for Extreme Floods for Four Basins in the Tennessee and Cumberland River Watersheds. Hydrometeorological Report No. 47, Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and Tennessee Valley Authority. 1986. Probable Maximum and TVA Precipitation Estimates with Areal Distribution for Tennessee River Drainages Less Than 3,000 Mi^2 in Area. United States Weather Bureau Hydrometeorological Report No. 56. Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1979. Interduration Precipitation Relations for Storms – Southeast States. NOAA Technical Report NWS No. 21, 72 p, Silver Spring, MD.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. 1981 .Interduration Precipitation Relations for Storms – Western United States. NOAA Technical Report NWS 27, 159 p, Silver Spring, MD.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration, the tipping bucket rain gauge, http://www.nws.noaa.gov/asos/tipbuck.htm , 1995.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Nuclear Regulatory Commission. 1980. Seasonal Variation of 10-Square-Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. United States Weather Bureau Hydrometeorological Report No. 53. Silver Spring, MD.

U.S. Department of Commerce, U. S. Weather Bureau. 1961. Rainfall Frequency Atlas of the United States, Technical Paper No. 40. Washington, D.C.

U.S. Department of Commerce, U. S. Weather Bureau. 1961. Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands, United States Weather Bureau, Technical Paper 42. Washington, D.C.

U.S. Department of Commerce, U. S. Weather Bureau. 1963. Probable Maximum Precipitation in the Hawaiian Islands, United States Weather Bureau Hydrometeorological Report No. 39. Washington, D. C.

U.S. Department of Commerce, U. S. Weather Bureau. 1963. Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska, United States Weather Bureau, Technical Paper No. 47, Washington, D.C.

U.S. Department of Commerce, U. S. Weather Bureau. 1964. Two- to Ten-Day Precipitation for Return Periods of 2 to 100 years in the Contiguous United States, United States Weather Bureau, Technical Paper No. 49. Washington, D.C. Includes the 48 contiguous states.

U.S. Department of Commerce, U. S. Weather Bureau. 1965. Probable Maximum and TVA Precipitation over the Tennessee River Basin above Chattanooga. United States Weather Bureau Hydrometeorological Report No. 41. Washington, D. C.

US Department of Interior, US Geological Survey, 1942. Floods of March 1938 in Southern California, Water Supply Paper 844. Washington, D.C.

Vasquez, T. 1998. International Weather Watchers observer handbook, Weather Graphics Technologies. Washington, D.C.

Wei, T.C., and J.L. McGuinness. 1978. Reciprocal distance squared methods, a computer technique for estimating area precipitation. ARS-NC-8, U.S. Agric. Research Serv., North Central Region, Coshocton, OH.

Woodward, D. E. 1974. Discussion of Estimation of Rainfall Erosion Index by J.K.H. Ateshian, Journal of Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 100. No IR3, pp.245-247.

Appendix 4A. Precipitation-frequency data and distribution for Columbus, Ohio

This appendix explains and shows through tables and calculations how to compare rainfall magnitude and rainfall distribution from an older rainfall atlas (such as TP-40 or NOAA Atlas 2) with data from NOAA Atlas 14 for a particular location. This appendix is referenced in section 630.0403, Temporal distribution of rainfall.

This example, using the data for Columbus, Ohio, is included to illustrate an example of the comparison between old and new rainfall-frequency data and rainfall distributions.

Comparing rainfall distribution based on Hydro-35 and TP-40 to the Type II

Table 4A-1 lists the partial duration precipitation values in inches for Columbus, Ohio derived from maps in Hydro-35 (NOAA, 1977) by frequency. Hydro-35 includes only data from 5-minutes through 60-minutes.

Table 4A-1. Precipitation-frequency for Columbus Ohio, Hydro-35

Duration min	2-yr in	5-yr in	10-yr in	25-yr in	50-yr in	100-yr in
5	0.43	0.49	0.55	0.63	0.69	0.75
10	0.66	0.79	0.89	1.03	1.15	1.26
15	0.82	1.00	1.13	1.32	1.46	1.61
30	1.06	1.33	1.52	1.79	2.01	2.22
60	1.30	1.67	1.92	2.29	2.57	2.85

Table 4A-2 lists the partial duration precipitation values in inches for Columbus, Ohio derived from maps in TP-40 (NWS, 1961) by frequency. TP-40 includes data only from 0.5-hour through 24-hours.

Table 4A-2. Precipitation-frequency for Columbus, Ohio, TP-40

Duration hr	2-yr in	5-yr in	10-yr in	25-yr in	50-yr in	100-yr in
0.5	1.02	1.28	1.48	1.7	1.9	2.1
1	1.26	1.6	1.8	2.15	2.4	2.7
2	1.52	1.9	2.25	2.5	2.85	3.1
3	1.65	2	2.4	2.8	3	3.4
6	1.95	2.45	2.9	3.25	3.7	3.9
12	2.35	2.9	3.35	3.75	4	4.75
24	2.6	3.3	3.8	4.3	4.7	5

Ratios of shorter duration to the 24-hour rainfall are shown in table 4A-3. For example, the ratio for the 10-year 1-hr rainfall is 1.8 inches divided by 3.8 inches (both values from table 4A-2) or 0.474.

There is overlap of data between tables 4A-1 and 4A-2 for 30-minutes and 60-minutes (0.5 hr and 1-hr). TP-40 values for 0.5-hr and 1-hr are used to compute ratios in table 4A-3 because the plot of ratio versus duration is smoother as shown in figure 4A-1. If Hydro-35 ratios had been used, there would be a sharp change of slope in the curves between 1-hour and 2-hours.

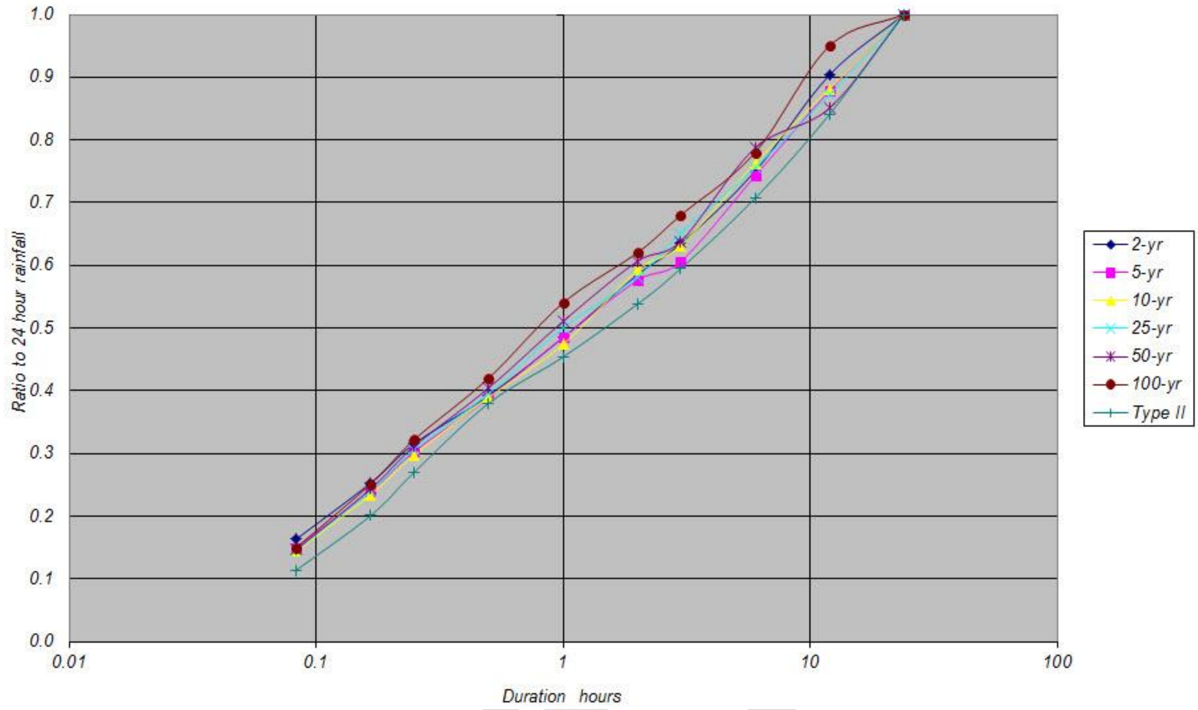
Table 4A-3. Ratio of shorter duration to 24-hour precipitation for Columbus, Ohio 1/ (Hydro-35 and TP-40)

Duration min or hr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5-min Hydro-35[1]	0.165	0.148	0.145	0.147	0.147	0.150
10-min Hydro-35[1]	0.254	0.239	0.234	0.240	0.245	0.252
15-min Hydro-35[1]	0.315	0.303	0.297	0.307	0.311	0.322
30-min TP-40	0.392	0.388	0.389	0.395	0.404	0.420
1-hr TP-40	0.485	0.485	0.474	0.500	0.511	0.540
2-hr TP-40	0.585	0.576	0.592	0.581	0.606	0.620
3-hr TP-40	0.635	0.606	0.632	0.651	0.638	0.680
6-hr TP-40	0.750	0.742	0.763	0.756	0.787	0.780
12-hr TP-40	0.904	0.879	0.882	0.872	0.851	0.950
24-hr TP-40	1.000	1.000	1.000	1.000	1.000	1.000

1/Ratios equal 5- to 15-min values from Table 4A-1 over 24-hr values from Table 4A-2 and 30-min-to 24-hr values from Table 4A-2 over 24-hr values from Table 4A-2.

Figure 4A-1 is a plot of the values in table 4A-3. The plotted curves show significant variation of ratios among return periods which are equal or greater than the ratios of the Type II rainfall distribution.

Figure 4A-1. Plot of ratios of shorter duration to the 24-hour precipitation for Columbus, Ohio



The Hydro-35 ratio is plotted for 5-minute to 15-minute. The TP-40 ratio is plotted for 30-minute to 24-hour durations.

Just as a rainfall distribution may be built based on ratios of 5-minute to 24-hour rainfall through 12-hour to 24-hour rainfall, ratios of these shorter durations to the 24-hour may be extracted from an existing rainfall distribution. Column 3 of table 4A-4 includes ratios of shorter duration to the 24-hour total extracted from the Type II rainfall distribution.

Table 4A- 4. Comparison of ratios for Columbus, Ohio (Hydro-35 and TP-40) and the Type II ratio for all durations

Duration min or hr (1)	Columbus, Ohio Average Ratio[1]/ (2)	Type II Ratio (3)	Average percent difference in Ratio[2]/ (4)	Largest percent difference for any return period[3]/ (5)
5-min Hydro-35	0.150	0.114	31.58	44.74
10-min Hydro-35	0.244	0.201	21.39	26.37
15-min Hydro-35	0.309	0.270	14.44	19.26
30-min TP-40	0.398	0.380	4.74	10.53
1-hr TP-40	0.499	0.454	9.91	18.9
2-hr TP-40	0.593	0.538	10.22	15.24
3-hr TP-40	0.640	0.595	7.56	14.29
6-hr TP-40	0.763	0.707	7.92	11.32
12-hr TP-40	0.890	0.841	5.83	12.96
24-hr TP-40	1.000	1.000	0.00	0.00

1/ col. 2 = average of all frequencies for each duration, Table 4A-3

2/ col. 4 = [(col 2-col 3)/col 3] x 100

3/ col. 5 = [(largest ratio for duration in Table 4A-3-col 3)/col 3] x 100

These analyses compare the Type II distribution to Hydro-35 and TP-40 data. A rainfall distribution developed from Hydro-35 and TP-40 for Columbus, Ohio would produce higher peak discharges than the Type II because the ratios for durations from 5-minutes to 12-hours are higher for Hydro-35 and TP-40 data. Based on the ratios in table 4A-4, the percentage increase in peak discharge differs for the various return periods.

Comparing rainfall distribution based on NOAA Atlas 14 to the Type II

Table 4A-5 shows partial duration data downloaded from the NOAA/NWS website for NOAA Atlas 14 for Columbus, Ohio at the WSO Airport (latitude 39.9914 N and longitude 82.8808 W). Partial duration data were downloaded because NRCS typically uses that for design of engineering projects.

Table 4A- 5. NOAA Atlas 14 partial duration series (PDS) precipitation-frequency data for Columbus, Ohio

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]									
Duration	Average recurrence interval (years)								
	1	2	5	10	25	50	100	200	500
5-min	0.353 (0.322-0.387)	0.421 (0.384-0.462)	0.504 (0.459-0.553)	0.569 (0.517-0.623)	0.652 (0.589-0.713)	0.715 (0.644-0.780)	0.778 (0.696-0.848)	0.842 (0.749-0.918)	0.927 (0.818-1.01)
10-min	0.548 (0.500-0.602)	0.657 (0.600-0.721)	0.784 (0.713-0.860)	0.879 (0.799-0.961)	0.997 (0.900-1.09)	1.09 (0.976-1.18)	1.17 (1.05-1.28)	1.26 (1.12-1.37)	1.36 (1.20-1.49)
15-min	0.672 (0.613-0.738)	0.803 (0.733-0.882)	0.962 (0.875-1.06)	1.08 (0.983-1.18)	1.23 (1.11-1.35)	1.34 (1.21-1.46)	1.46 (1.30-1.59)	1.56 (1.39-1.70)	1.70 (1.50-1.85)
30-min	0.889 (0.811-0.976)	1.08 (0.981-1.18)	1.32 (1.20-1.45)	1.50 (1.36-1.64)	1.74 (1.57-1.90)	1.92 (1.73-2.09)	2.10 (1.88-2.29)	2.28 (2.03-2.49)	2.52 (2.22-2.75)
60-min	1.09 (0.990-1.19)	1.32 (1.20-1.45)	1.65 (1.50-1.81)	1.91 (1.74-2.09)	2.26 (2.04-2.47)	2.53 (2.28-2.76)	2.81 (2.51-3.06)	3.10 (2.75-3.38)	3.49 (3.08-3.80)
2-hr	1.27 (1.16-1.39)	1.54 (1.41-1.68)	1.93 (1.76-2.11)	2.24 (2.04-2.45)	2.67 (2.42-2.92)	3.02 (2.72-3.30)	3.39 (3.03-3.69)	3.77 (3.35-4.10)	4.30 (3.79-4.67)
3-hr	1.35 (1.23-1.48)	1.63 (1.49-1.78)	2.04 (1.86-2.23)	2.37 (2.16-2.58)	2.84 (2.57-3.09)	3.21 (2.90-3.49)	3.61 (3.24-3.92)	4.03 (3.59-4.37)	4.62 (4.07-5.01)
6-hr	1.61 (1.48-1.76)	1.94 (1.78-2.12)	2.41 (2.20-2.63)	2.80 (2.56-3.05)	3.36 (3.05-3.65)	3.83 (3.45-4.15)	4.33 (3.88-4.68)	4.86 (4.32-5.24)	5.62 (4.93-6.07)
12-hr	1.89 (1.73-2.07)	2.26 (2.07-2.48)	2.80 (2.56-3.07)	3.25 (2.96-3.56)	3.90 (3.54-4.25)	4.44 (4.00-4.83)	5.03 (4.49-5.45)	5.65 (5.01-6.11)	6.55 (5.72-7.09)
24-hr	2.20 (2.04-2.37)	2.62 (2.44-2.84)	3.23 (3.00-3.49)	3.73 (3.46-4.02)	4.44 (4.09-4.79)	5.03 (4.61-5.42)	5.65 (5.15-6.09)	6.30 (5.71-6.80)	7.23 (6.48-7.81)

The 90% confidence limits are shown in parentheses for each duration and frequency in the table. The probability is 90% that the actual value will fall within that range.

Table 4A-6 lists ratios of shorter duration to the 24-hour duration rainfall based on values from Table 4A-5 above. For example, the ratio of 2-year 5-minute to 2-year 24-hour rainfall is 0.421 / 2.62 or 0.161.

Table 4A- 6. Ratio of shorter duration to 24-hour precipitation for Columbus, Ohio (based on NOAA Atlas 14 data)

Duration min or hr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5-min	0.161	0.156	0.153	0.147	0.142	0.138
10-min	0.251	0.243	0.236	0.225	0.217	0.207
15-min	0.306	0.298	0.290	0.277	0.266	0.259
30-min	0.412	0.409	0.402	0.392	0.382	0.372
1-hr	0.504	0.511	0.512	0.509	0.503	0.498
2-hr	0.588	0.598	0.601	0.601	0.600	0.601
3-hr	0.622	0.632	0.635	0.640	0.638	0.640
6-hr	0.740	0.746	0.751	0.757	0.761	0.768
12-hr	0.863	0.867	0.871	0.878	0.883	0.892
24-hr	1.000	1.000	1.000	1.000	1.000	1.000

Ratios for 5-minute through 30-minutes decrease from the 2-year to 100-year values. Ratios for the 1-hour through 3-hour durations are relatively constant. Ratios for 6-hour and 12-hour durations increase from the 2-year to 100-year values. This leads to slightly different rainfall distributions for each of the return periods.

Figure 4A-2. Plot of NOAA Atlas 14 ratios of shorter duration to the 24-hour precipitation for Columbus, Ohio

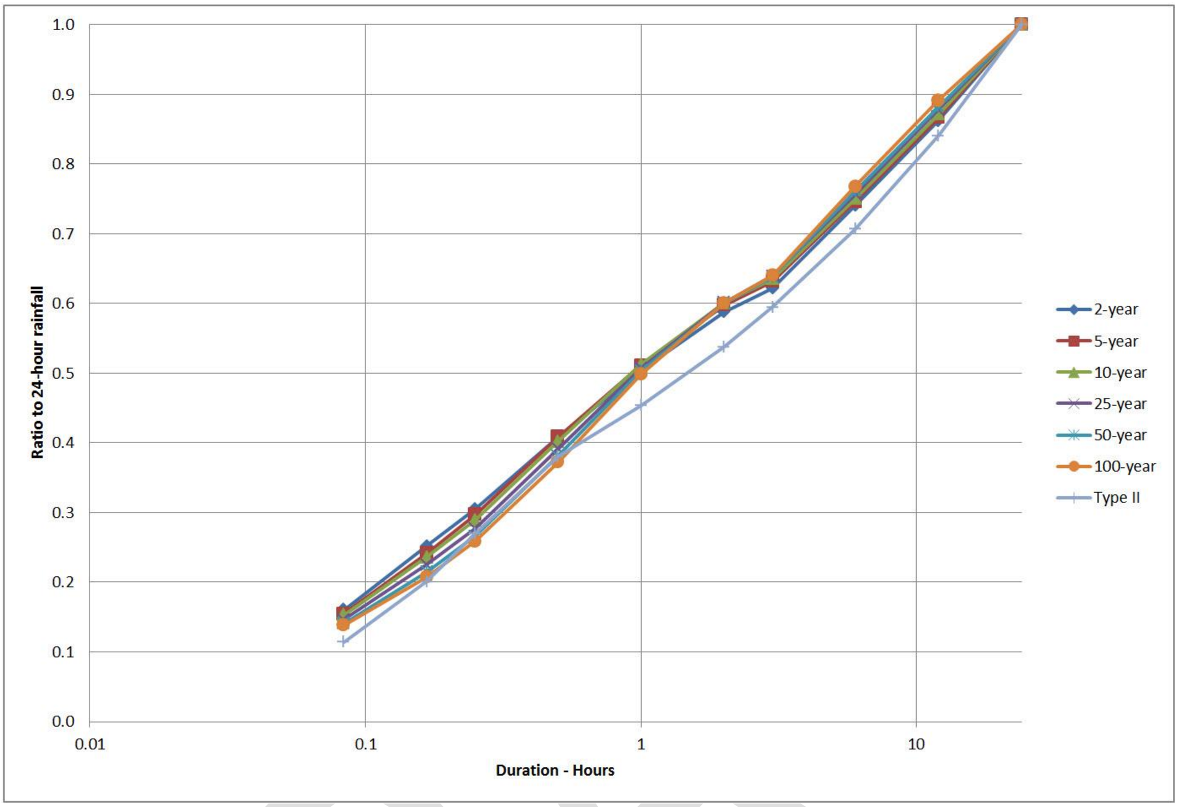


Table 4A- 7. Comparison of ratios for Columbus, Ohio (NOAA Atlas 14) and the Type II ratio for all durations

Duration min or hr (1)	Columbus, Ohio Average Ratio of NOAA Atlas 14 data1/ (2)	Type II Ratio (3)	Average percent difference in Ratio2/ (4)	Largest percent difference for any return period3/ (5)
5-min	0.149	0.114	31.02	40.95
10-min	0.230	0.201	14.25	24.76
15-min	0.283	0.270	4.70	13.51
30-min	0.395	0.380	3.90	7.54
1-hr	0.506	0.454	11.56	12.86
2-hr	0.598	0.538	11.17	11.72
3-hr	0.634	0.595	6.64	7.57
6-hr	0.754	0.707	6.63	8.59
12-hr	0.876	0.841	4.12	6.05
24-hr	1.000	1.000	0.00	0.00

1/ col. 2 = average of all frequencies for each duration, Table 4A-6

2/ col. 4 = [(col 2-col 3)/col 3] x 100

3/ col. 5 = [(largest ratio for duration in Table 4A-6-col 3)/col 3] x 100

These analyses compare the Type II distribution to NOAA Atlas 14 data. A rainfall distribution developed from NOAA Atlas 14 data for Columbus, Ohio would produce higher peak discharges than the Type II because the ratios for durations from 5-minutes to 12-hours are higher for NOAA Atlas 14 data. Based on the ratios in table 4A-7, the percentage increase in peak discharge differs for the various return periods and time of concentration.

Comparing rainfall data of NOAA Atlas 14 with Hydro-35 and TP-40

Table 4A-8 shows the comparison of NOAA Atlas 14 data and Hydro-35 and TP-40 for Columbus Ohio.

Table 4A- 8. Difference between NOAA Atlas 14 and Hydro-35 / TP-40 rainfall for Columbus, Ohio

Duration min or hr	2-yr Difference in	5-yr Difference in	10-yr Difference in	25-yr Difference in	50-yr Difference in	100-yr Difference in
5-min Hydro-35	-0.01	0.01	0.02	0.02	0.02	0.03
10-min	0.00	0.00	-0.01	-0.03	-0.06	-0.09
15-min	-0.02	-0.04	-0.05	-0.09	-0.12	-0.15
30-min TP-40	0.06	0.04	0.02	0.04	0.02	0.00
1-hr	0.06	0.05	0.11	0.11	0.13	0.11
2-hr	0.02	0.03	-0.01	0.17	0.17	0.29
3-hr	-0.02	0.04	-0.03	0.04	0.21	0.21
6-hr	-0.01	-0.04	-0.10	0.11	0.13	0.43
12-hr	-0.09	-0.10	-0.10	0.15	0.44	0.28
24-hr	0.02	-0.07	-0.07	0.14	0.33	0.65

Table 4A-7 uses values of Hydro-35 for the 5-minute through 15-minute of table 4A-1 and TP-40 rainfalls for 30-minute through 24-hour from table 4A-2, respectively, subtracted from the NOAA Atlas 14 rainfall values in table 4A-5. In other words, a positive difference means that NOAA Atlas 14 rainfall is higher. The differences for 2-year to 10-year are relatively small. NOAA Atlas 14 has larger precipitation for the 25-year to 100-year 1-hour to 24-hour durations.

Summary

Precipitation-frequency data and storm distribution are important components of the NRCS hydrologic modeling procedures. Different assumptions and procedures were used in preparation of precipitation-frequency atlases TP-40 and NOAA Atlas 14 by the National Weather Service and in preparation of storm distributions Type II and those based on NOAA Atlas 14 data. Understanding these differences will provide more background on why hydrologic results could be different when changing from TP-40 and the Type I, IA, II, or III storm distribution to NOAA Atlas 14 data and a locally-derived storm distribution. With many more years of data, better quality control, and more short duration measurements, much more confidence can be placed in the NOAA Atlas 14 precipitation-frequency estimates and storm distributions based on the estimates.

Appendix 4B. Smoothing precipitation values from NOAA Atlas 14 data

Background

For a location with "smooth data" the incremental intensity for durations from 5 minutes through 24 hours plots as a line with either one or two straight line segments on a log-log graph. Incremental intensity is defined in section Data Smoothing Technique below.

Using a 24-hour design storm distribution is standard practice in WinTR-20, WinTR-55, and Engineering Field Handbook, Chapter 2 Estimating Runoff and Peak Discharge (EFH2. In order to best reflect the updated NOAA Atlas 14 partial duration precipitation frequency data, a site-specific distribution may be developed based on the updated NOAA Atlas 14 data. These data are downloaded from the NOAA Atlas 14 web site as a comma separated value (csv) file.

Investigations showed that developing regional storm distributions to replace the prior standard NRCS storm distributions (Type I, Type IA, Type II, and Type III) is - feasible in states covered by NOAA Atlas 14 (NRCS, July 2006, Merkel, Moody, Quan, Rainfall Distribution for States Covered by NOAA Atlas 14 Volumes 1 and 2, NRCS internal publication).

The primary assumption of NRCS storm distributions is that the maximum precipitation of all storm durations from 5-minutes to 24-hours occurs within the design storm, so that all precipitation intensities are represented in a single storm distribution. This allows the design storm distribution to be used for watersheds with times of concentration from 5-minutes to 24-hours. Otherwise, the engineer would have to develop or select a design storm distribution with a duration equal to the time of concentration that is unique to the watershed being analyzed.

The basic data used to develop the rainfall distribution are the 5-minute through 24-hour precipitation for a particular return period such as 25-year.

Each duration in NOAA Atlas 14 was analyzed separately. For example, the maximum 60-minute value for each year was extracted and analyzed for precipitation-frequency. The specific techniques to derive mean, standard deviation, skew, and apply a probability distribution to the data are described in each volume of NOAA Atlas 14, respectively. Then the maximum 2-hour value for each year was extracted and analyzed for precipitation-frequency. This duration also had a mean, standard deviation and skew. The maximum 3-hour, 6-hour, 12-hour, 24-hour etc. were extracted from the data and analyzed separately; each with a calculated mean, standard deviation, and skew. No attempt was made to smooth these data across the series of durations for each return period. With all the limitations of the data being analyzed and the possibility of high or low values which could affect the skew, the curves for each duration could converge, diverge, or remain relatively parallel. If data are not smoothed, there is a possibility that the resulting storm distribution will not be smooth. This can potentially cause irregularities in a hydrograph developed from the storm distribution such as bumps, sharp rises and drops, and misplaced gradual increases or decreases in discharge.

Data Smoothing Technique

Several mathematical techniques were investigated to determine a computationally efficient, accurate, practical, stable, and robust procedure. 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 defined as 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 and has the units of 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. Examples of these non-smoothed plots follow in figures 4B-1, 4B-2, and 4B-3.

Figure 4B-1. Plot for Sun City, CA not smooth between 10 minutes and 6 hours

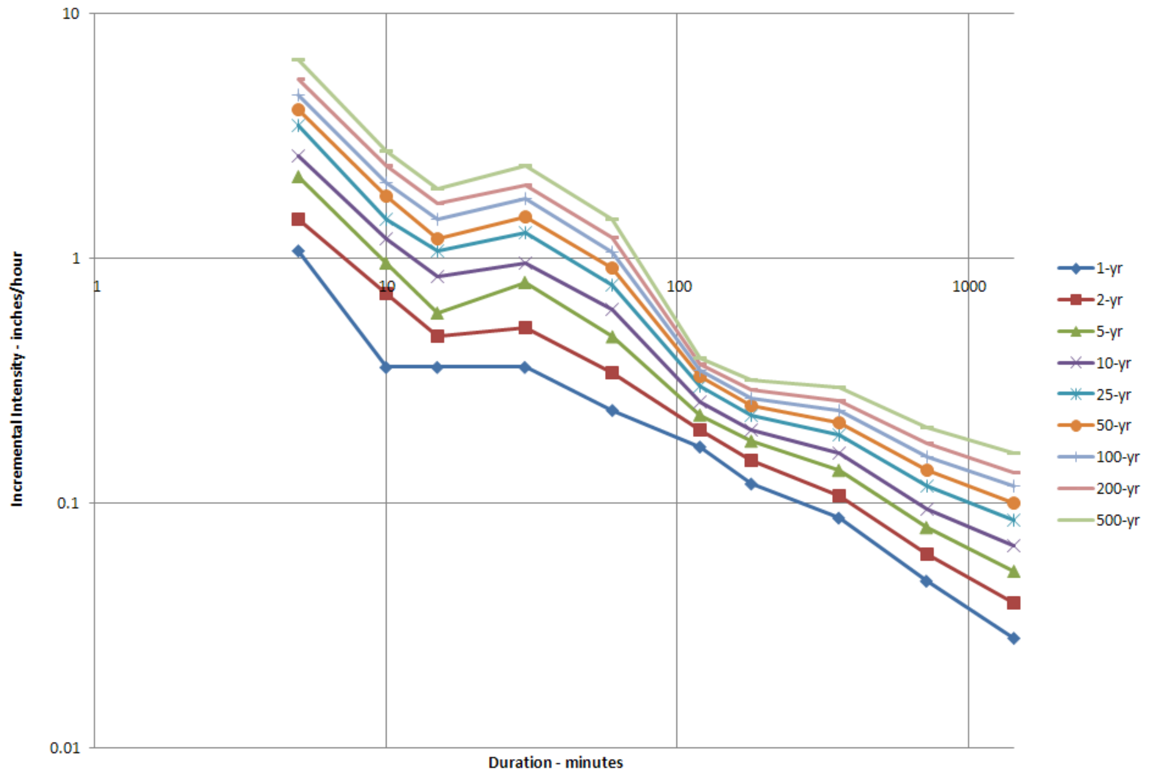


Figure 4B-2. Curve with irregularities at 15 minutes and 3 hours for Mercer County, NJ

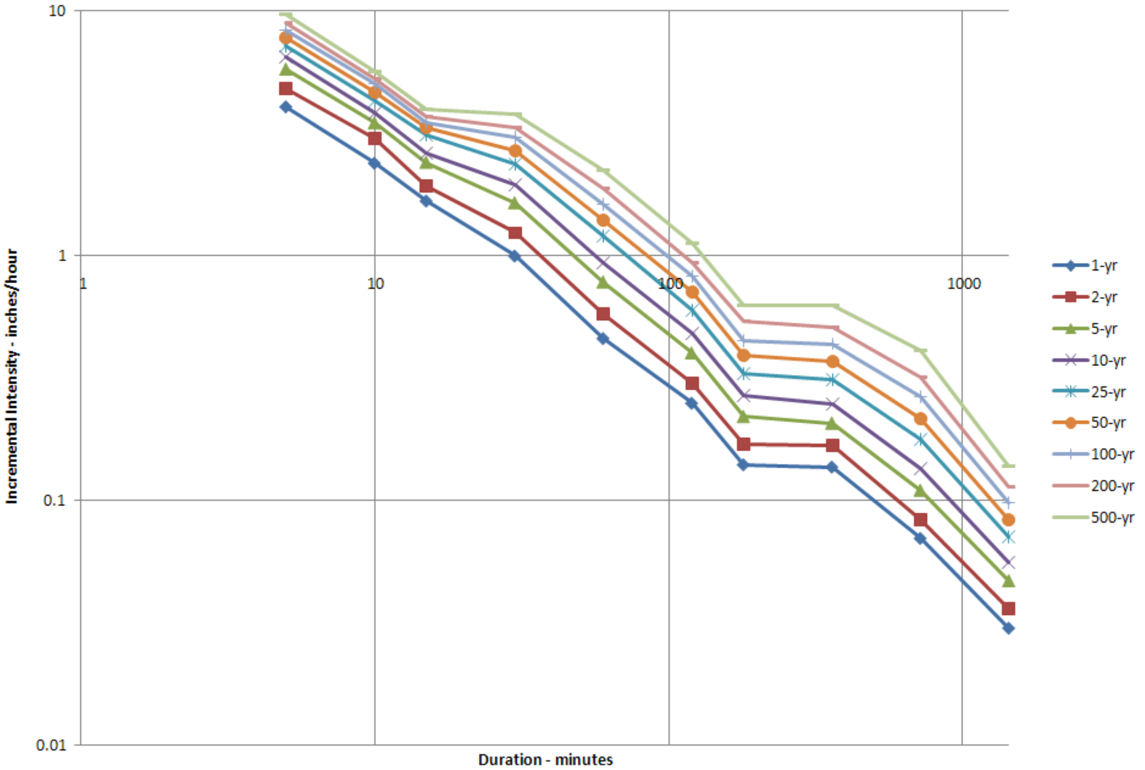
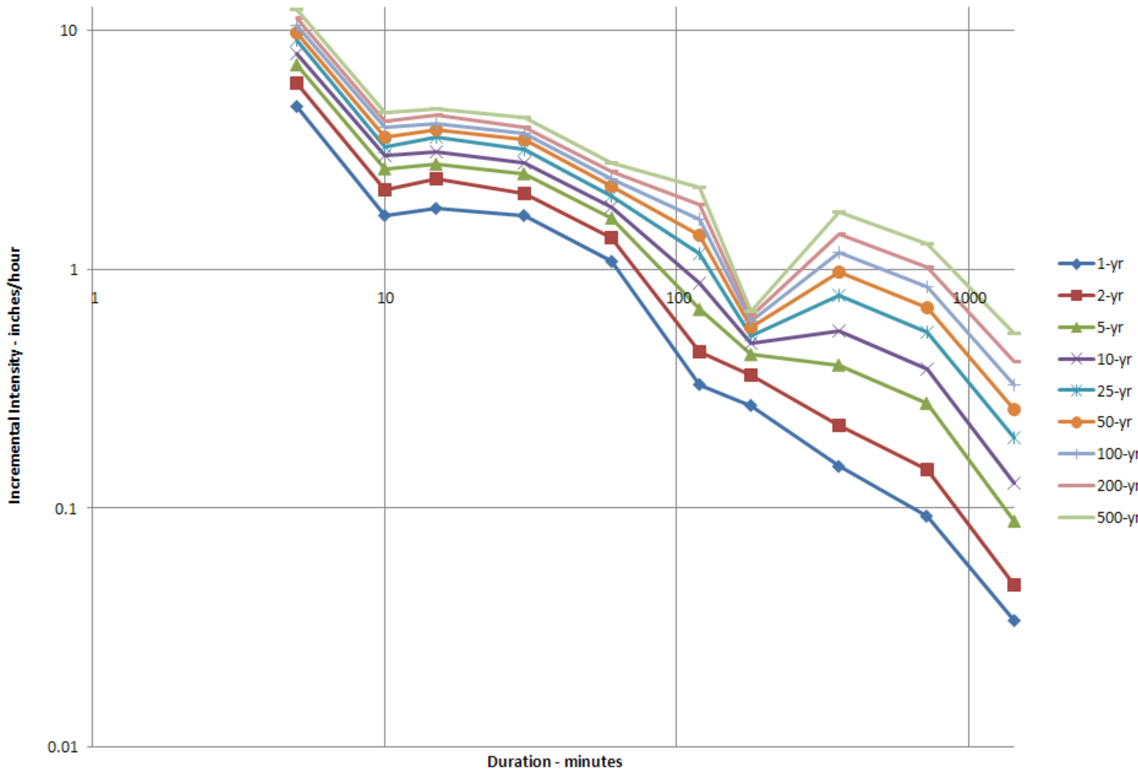


Figure 4B-3. A very irregular plot of incremental intensity for Bethlehem Upper Works, US Virgin Islands



Three examples of the smoothing procedure follow, shown by figures 4B-4, 4B-5, and 4B-6. 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 computed such that the squared difference between the smoothed 5-minute, 10-minute, 15-minute, 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 (or 1440 minutes) value. This line is computed 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. The smoothing algorithm is available in the WinTR-20 system. Three examples follow, shown by figures 4B-4, 4B-5, and 4B-6.

Figure 4B-4. 25-year incremental intensity plot for original and smoothed data for Mercer County, NJ.,

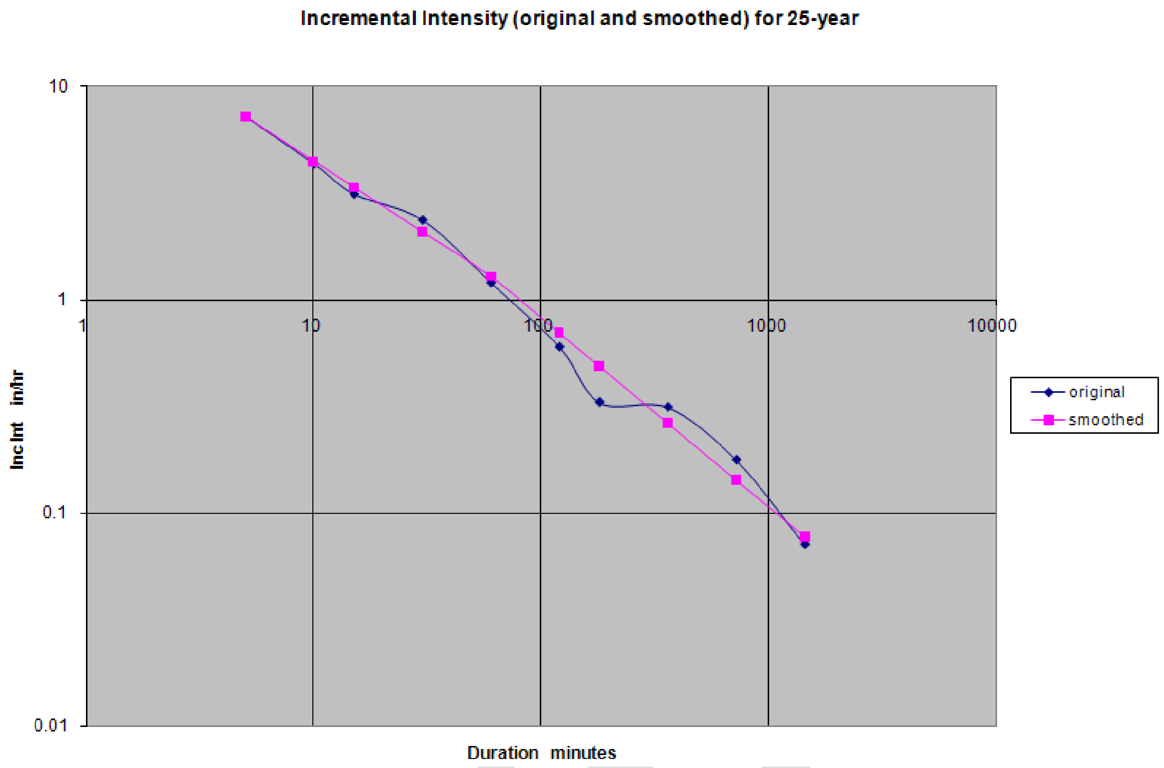


Figure 4B-5. 25-year incremental intensity plot for original and smoothed data for Phoenix, AZ

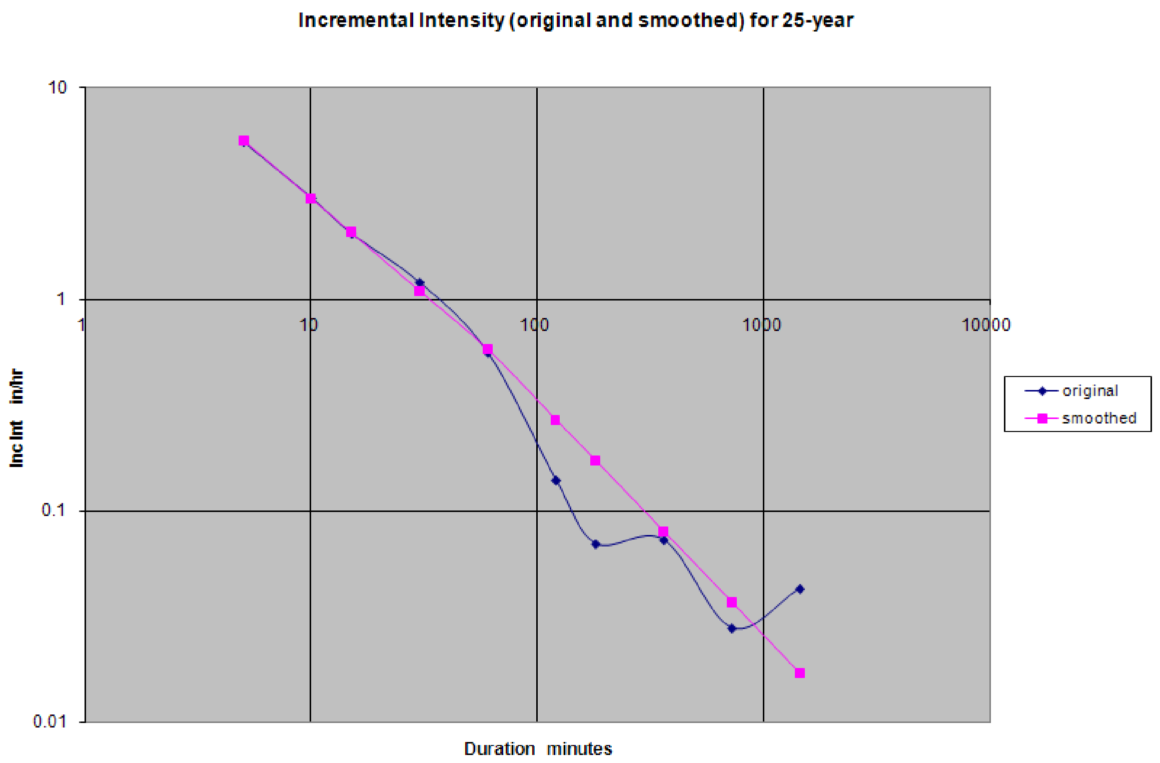
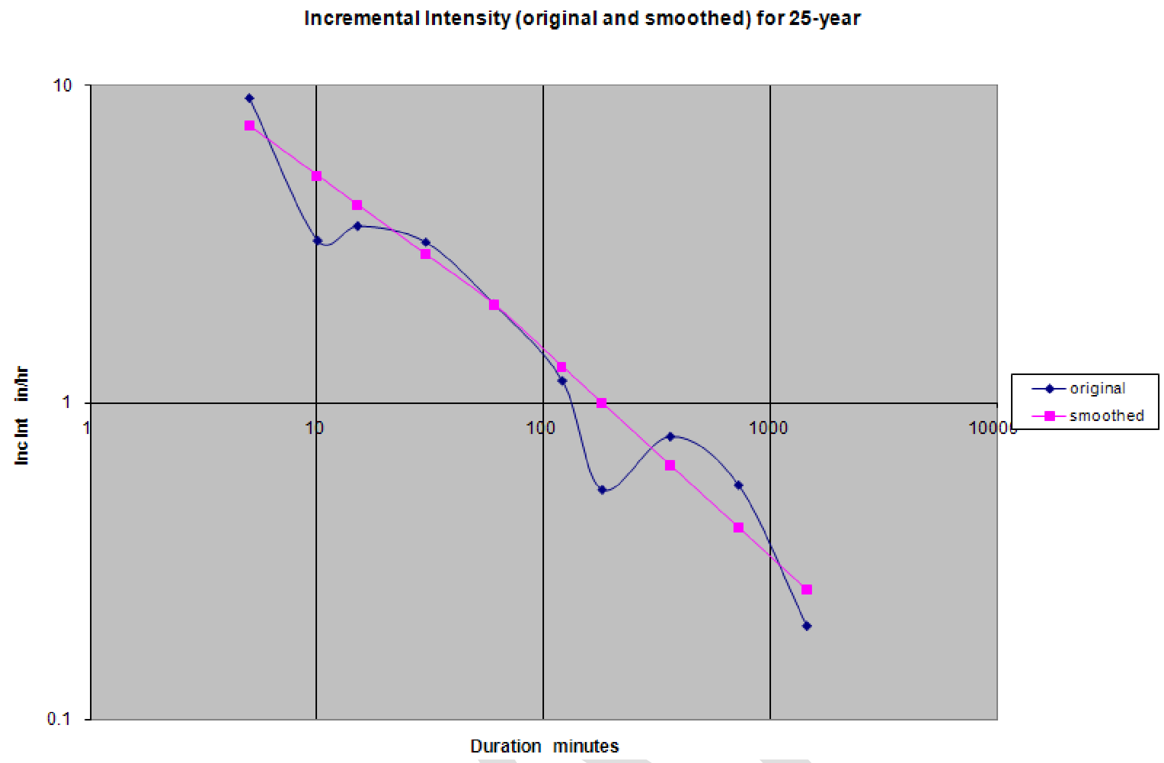
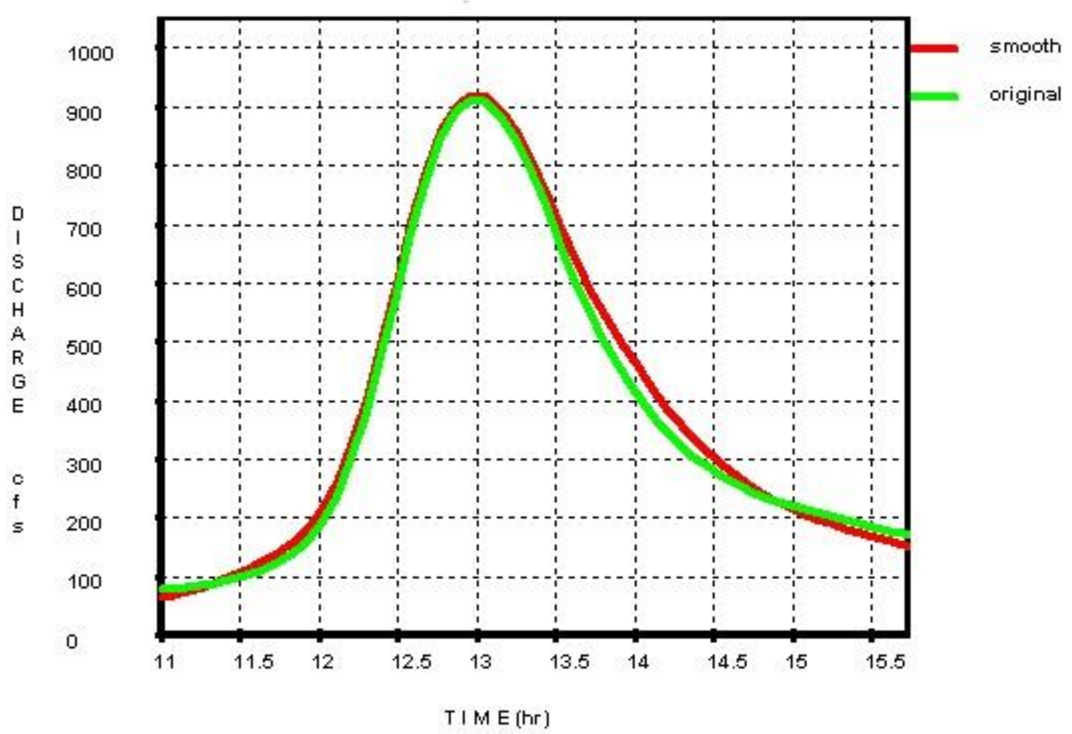


Figure 4B-6. 25-year incremental intensity plot for original and smoothed data for Bethlehem Upper Works, US Virgin Islands



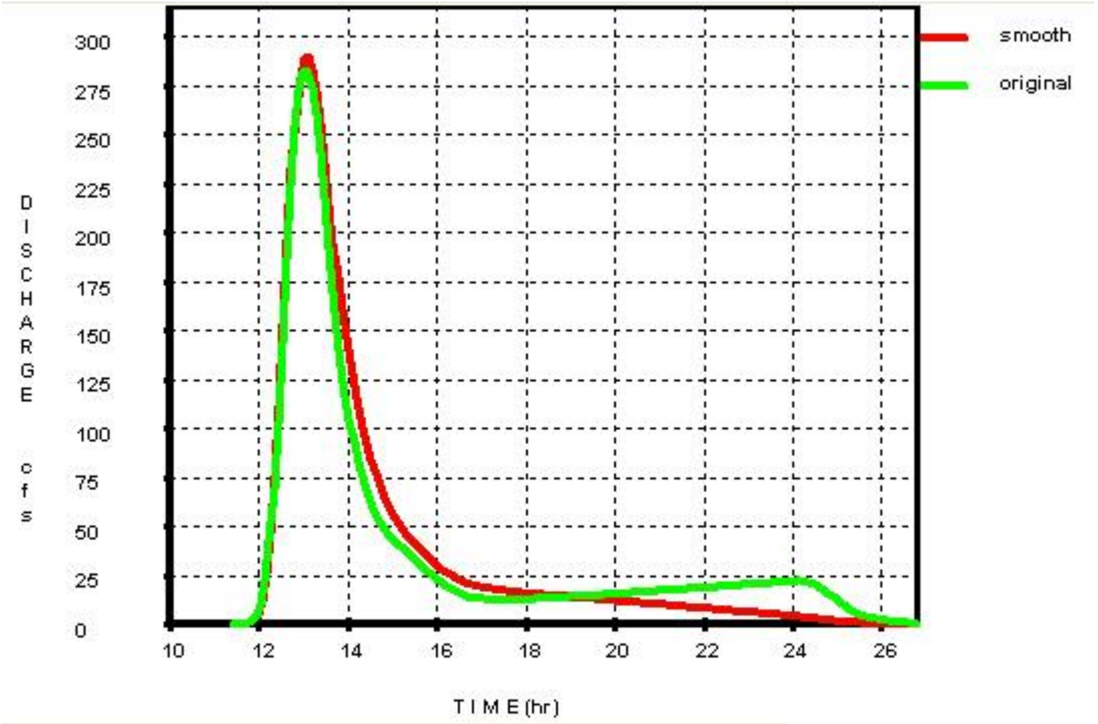
The plot of 25-year storm hydrographs is based on original non-smoothed data (original) and smoothed data (smooth) for the three examples follow in figures 4B-7, 4B-8, and 4B-9.

Figure 4B-7. 25-year hydrograph plots for Mercer Co., NJ



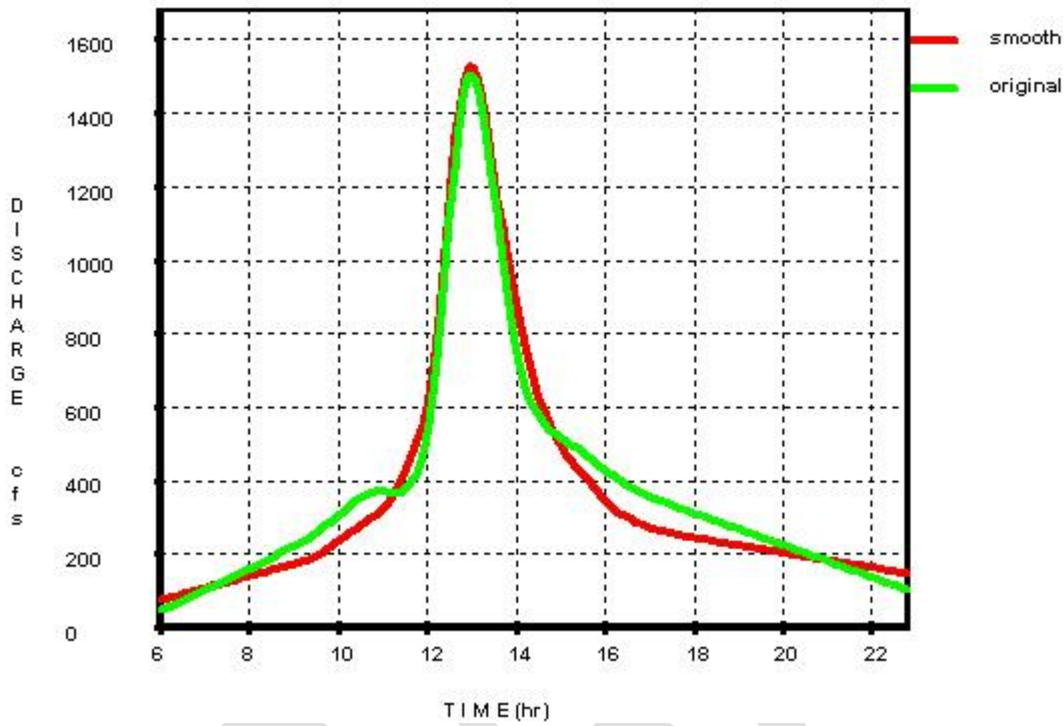
The green hydrograph (original) in figure 4B-7 is based on the original data. The red hydrograph (smooth) is based on the smoothed data. In this case, the peak discharge is practically the same and the hydrograph shape is very similar.

Figure 4B-8. 25-year hydrograph plots for Phoenix, AZ



In figure 4B-8, the green hydrograph (original) is based on the original data. The red hydrograph (smooth) is based on the smoothed data. In this case, the two are somewhat different. Between about 18 and 24 hours, the hydrograph based on the original data increases slightly to 24 hours.

Figure 4B-9. 25-year hydrograph plots for Bethlehem Upper Works, US Virgin Islands



In figure 4B-9 the green hydrograph (original) is based on the original data. The red hydrograph (smooth) is based on the smoothed data. In this case, the two are visibly different. At about 11 hours, there is a slight dip in the hydrograph based on the original data. This has been eliminated in the hydrograph based on the smoothed NOAA Atlas 14 data.

In WinTR-20, the user has the option to develop storm distributions based on the original precipitation-frequency data (NOAA Atlas 14 data) or smoothed data. A summary file is developed if the user chooses to smooth the data. This file contains the original precipitation data, the smoothed data, incremental intensity for both, and difference between the original data and the smoothed data. The name of the file is the same as the NOAA Atlas 14 csv file except the extension is changed to .dff to represent the difference. Part of an example file is included in Table 4B-1.

In the following table for NOAA Atlas 14 data at Bethlehem Upper Works in US Virgin Islands, the incremental intensity increases from 10 to 15 minutes and from 3 to 6 hours. Since the incremental intensity should decrease from 5 minutes to 24 hours, this is an example where data smoothing is recommended.

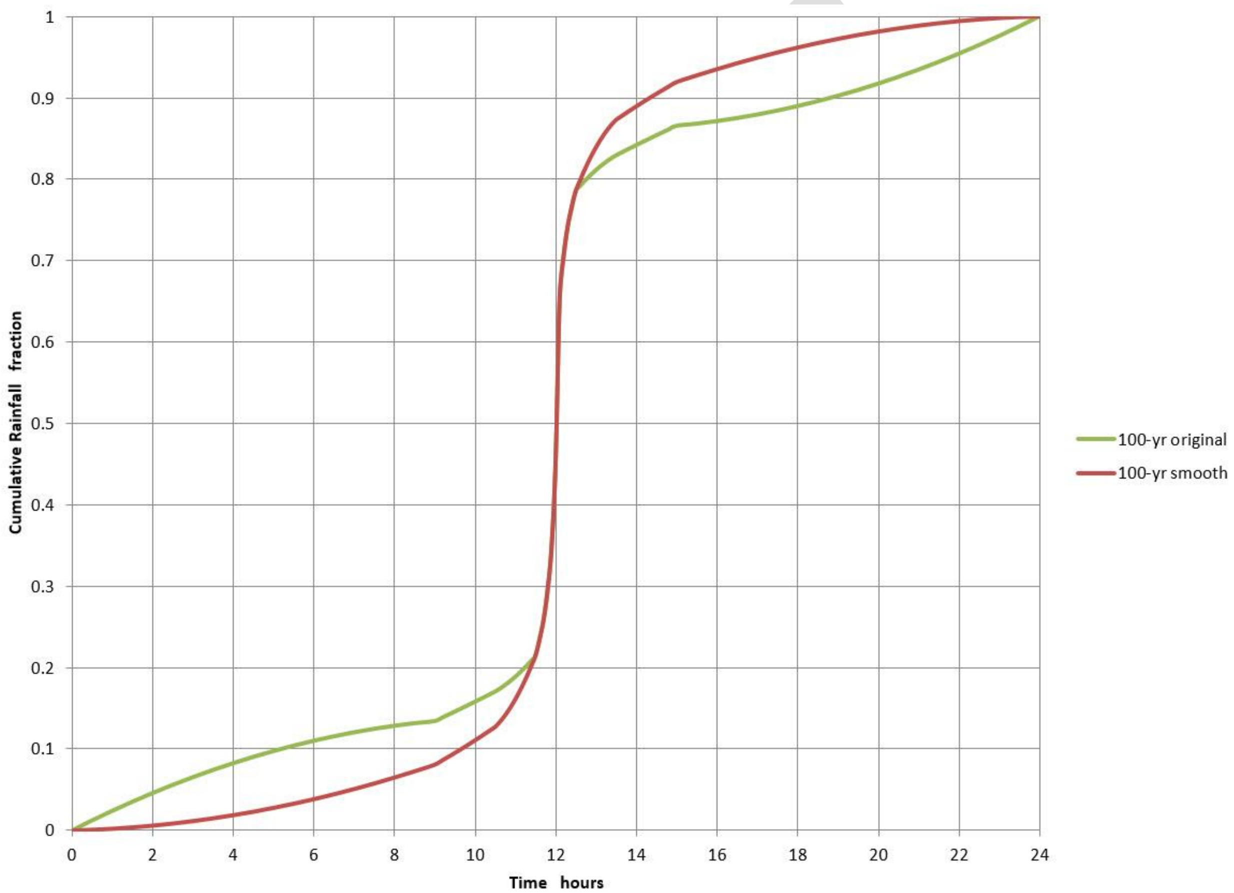
Table 4B-1. Table showing intensity reversals

Data Smoothing Information 25 Year										
Duration	5-min	10-min	15-min	30-min	60-min	2-hr	3-hr	6-hr	12-hr	24-hr
Precip	0.76	1.03	1.33	2.13	3.15	4.32	4.85	7.19	10.48	12.84
Inc_Int	9.120	3.240	3.600	3.200	2.040	1.170	0.530	0.780	0.548	0.197
Sm_Precip	0.62	1.05	1.40	2.13	3.15	4.45	5.44	7.34	9.76	12.84
Sm_Inc_Int	7.440	5.185	4.198	2.926	2.039	1.297	0.995	0.633	0.403	0.256
Precip_dif	-0.140	0.022	0.072	0.003	0.000	0.127	0.592	0.152	-0.722	0.000
Data Smoothing Information 50 Year										
Duration	5-min	10-min	15-min	30-min	60-min	2-hr	3-hr	6-hr	12-hr	24-hr
Precip	0.82	1.12	1.44	2.31	3.42	4.81	5.38	8.30	12.44	15.54
Inc_Int	9.840	3.600	3.840	3.480	2.220	1.390	0.570	0.937	0.690	0.258
Sm_Precip	0.67	1.14	1.52	2.31	3.42	4.90	6.06	8.37	11.45	15.54
Sm_Inc_Int	8.040	5.616	4.553	3.180	2.221	1.475	1.161	0.0771	0.512	0.340
Precip_dif	-0.150	0.018	0.077	0.002	0.000	0.085	0.677	0.071	-0.994	0.000

The first line in the table (Duration) lists the precipitation durations. The second line in the table (Precip) lists the original NOAA Atlas 14 precipitation data in inches. The third line (Inc_Int) is the incremental intensity for the original NOAA Atlas 14 precipitation data in units of inches per hour. The fourth line (Sm_Precip) is the smoothed precipitation values in inches (notice the 60-min and 24-hour values are unchanged). The fifth line

(Sm_Inc_Int) is the incremental intensity for the smoothed precipitation data in units of inches per hour. The sixth line (Precip_diff) is the difference between the NOAA Atlas 14 precipitation and the smoothed values in inches. Figure 4B-10 shows the rainfall distributions developed for the Phoenix AP, AZ based on the original and smoothed data.

Figure 4B-10. Smooth and original 100-year rainfall distribution for Phoenix Airport



The rainfall distribution based on original data has several sharp breaks in slope at about 9, 11.5, 12.5, and 15 hours which will cause irregularities in the computed hydrograph.

Examples of smoothing NOAA Atlas 14 data

An example of impacts of smoothing data across durations is shown for St. George, Utah. Part of the NOAA Atlas 14 partial duration data are shown in Table 4B-2. Annual maximum precipitation for each duration is tabulated for the period of record. Maximum precipitation for each duration could happen on any day of the year and often, the maxima for various durations were not from the same storm event. For example, the maximum 5-minute precipitation and maximum 24-hour precipitation of the year may not be from the same storm event. When placing these durations into a maximized and centered design storm distribution, irregularities may occur.

Table 4B-2. NOAA Atlas 14 partial duration data for St. George, Utah

1

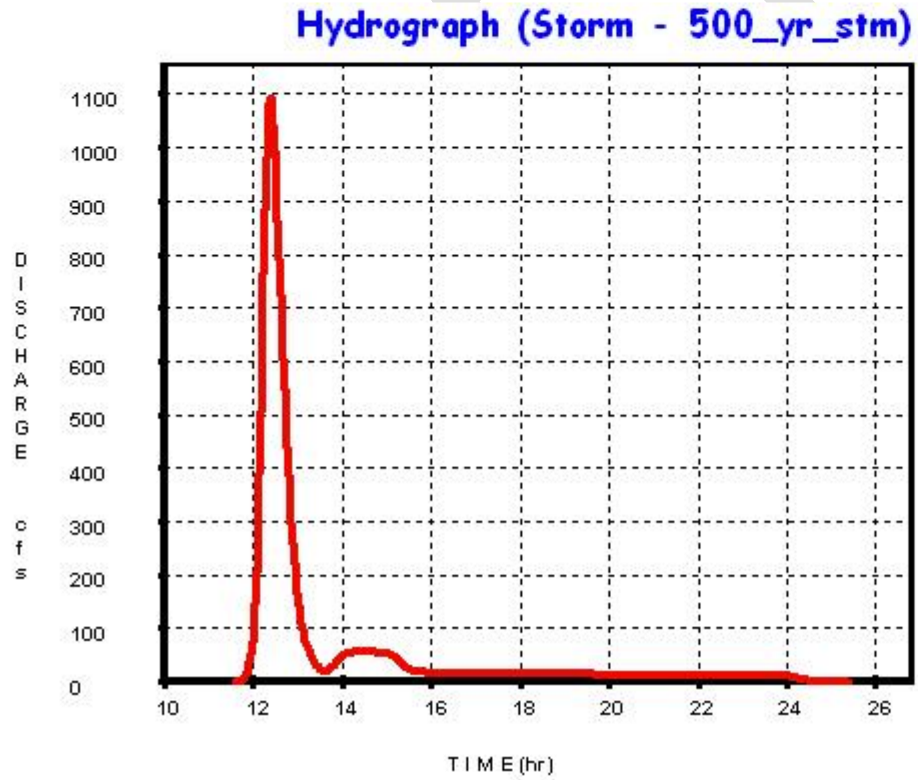
PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

	Average recurrence interval (years)								
Duration	**1**	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**
5-min:	**0.128** (0.111-0.148)	**0.163** (0.144-0.190)	**0.219** (0.190-0.251)	**0.266** (0.230-0.308)	**0.341** (0.291-0.392)	**0.405** (0.341-0.466)	**0.479** (0.394-0.555)	**0.561** (0.448-0.652)	**0.688** (0.526-0.816)
10-min:	**0.195** (0.169-0.225)	**0.249** (0.219-0.289)	**0.333** (0.289-0.382)	**0.405** (0.351-0.469)	**0.52** (0.443-0.596)	**0.617** (0.518-0.709)	**0.73** (0.599-0.844)	**0.855** (0.682-0.993)	**1.05** (0.805-1.24)
15-min:	**0.241** (0.209-0.279)	**0.309** (0.272-0.358)	**0.413** (0.359-0.474)	**0.502** (0.435-0.582)	**0.644** (0.550-0.739)	**0.765** (0.643-0.879)	**0.905** (0.743-1.05)	**1.06** (0.846-1.23)	**1.3** (0.993-1.54)
30-min:	**0.325** (0.282-0.376)	**0.416** (0.366-0.483)	**0.556** (0.483-0.638)	**0.676** (0.585-0.783)	**0.868** (0.740-0.995)	**1.03** (0.865-1.18)	**1.22** (1.00-1.41)	**1.43** (1.14-1.66)	**1.75** (1.34-2.08)
60-min:	**0.402** (0.349-0.465)	**0.514** (0.453-0.597)	**0.688** (0.598-0.790)	**0.837** (0.725-0.969)	**1.07** (0.916-1.23)	**1.27** (1.07-1.47)	**1.51** (1.24-1.75)	**1.77** (1.41-2.05)	**2.16** (1.66-2.57)
2-hr:	**0.489** (0.437-0.553)	**0.602** (0.542-0.687)	**0.779** (0.700-0.882)	**0.935** (0.834-1.06)	**1.18** (1.04-1.33)	**1.38** (1.19-1.55)	**1.6** (1.35-1.82)	**1.86** (1.53-2.13)	**2.24** (1.78-2.61)
3-hr:	**0.541** (0.488-0.605)	**0.67** (0.610-0.755)	**0.853** (0.774-0.955)	**1.01** (0.909-1.12)	**1.24** (1.11-1.39)	**1.43** (1.26-1.60)	**1.64** (1.41-1.85)	**1.87** (1.58-2.16)	**2.24** (1.83-2.64)
6-hr:	**0.669** (0.606-0.745)	**0.834** (0.763-0.932)	**1.05** (0.956-1.17)	**1.23** (1.11-1.38)	**1.5** (1.34-1.67)	**1.73** (1.51-1.93)	**1.96** (1.69-2.22)	**2.22** (1.88-2.53)	**2.6** (2.13-3.01)
12-hr:	**0.809** 0.736-0.893)	**1.01** (0.919-1.12)	**1.26** (1.14-1.39)	**1.48** (1.33-1.63)	**1.76** (1.58-1.95)	**1.98** (1.75-2.21)	**2.22** (1.93-2.49)	**2.46** (2.12-2.79)	**2.8** (2.35-3.20)
24-hr:	**0.933** (0.87-0.994)	**1.16** (1.09-1.24)	**1.46** (1.37-1.55)	**1.69** (1.58-1.80)	**2.01** (1.87-2.14)	**2.26** (2.09-2.40)	**2.51** (2.31-2.67)	**2.76** (2.54-2.95)	**3.110** (2.82-3.33)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

For the data in table 4B-2, an irregularity occurs between the 2-hour and 3-hour durations from the 10-year to 500-year return periods. Considering the 50-year return period, the additional precipitation between 2-hours and 3-hours is 0.05 inches (an intensity of only 0.05 inches/hour). The additional precipitation from 3-hours to 6-hours is 0.30 inches (an intensity of 0.10 inches/hour). The precipitation intensity for all other durations generally decreases as the duration increases. The precipitation-frequency for each duration is based on actual measurements. The major problem is that when setting up a maximized design storm distribution, when this type of intensity reversal occurs, the hydrograph generated by the storm distribution has an irregular shape, mostly evident in dips in the hydrograph before and after the peak. The plot of a hydrograph using the St. George data for a 500-year return period is shown in figure 4B-11.

Figure 4B-11. Hydrograph based on St. George, Utah original rainfall data



The hydrograph rises slightly between 13.0 and 15.0 hours. Using the zoom feature makes this more obvious; see figure 4B-12.

Figure 4B-12. Detail of the Hydrograph based on St. George, Utah original rainfall data between 13.0 and 15.0 hours using Zoom feature

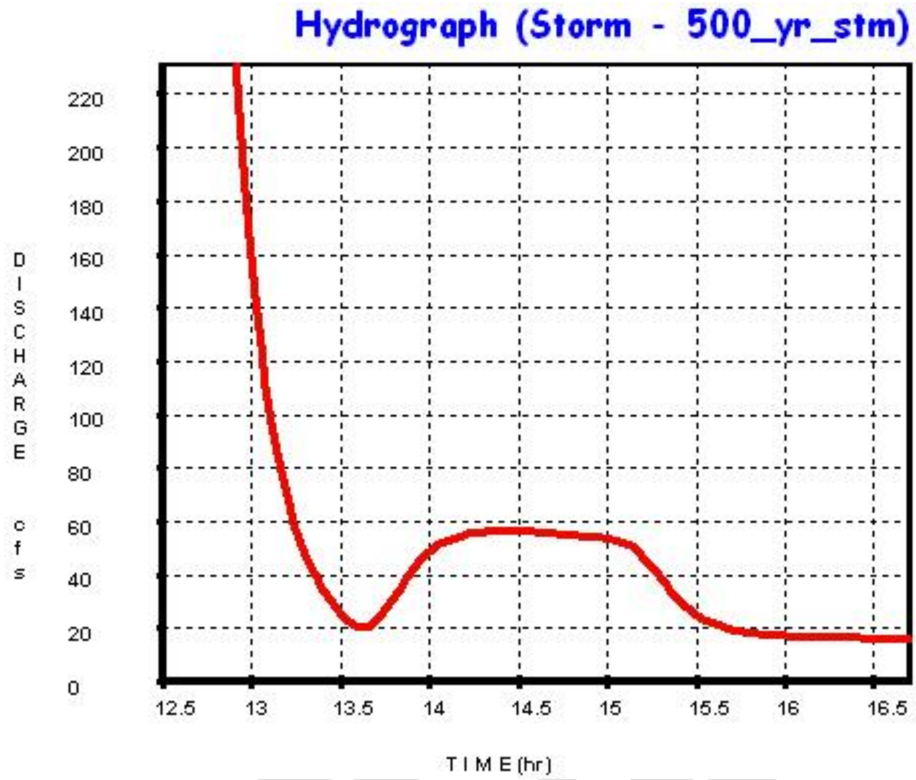
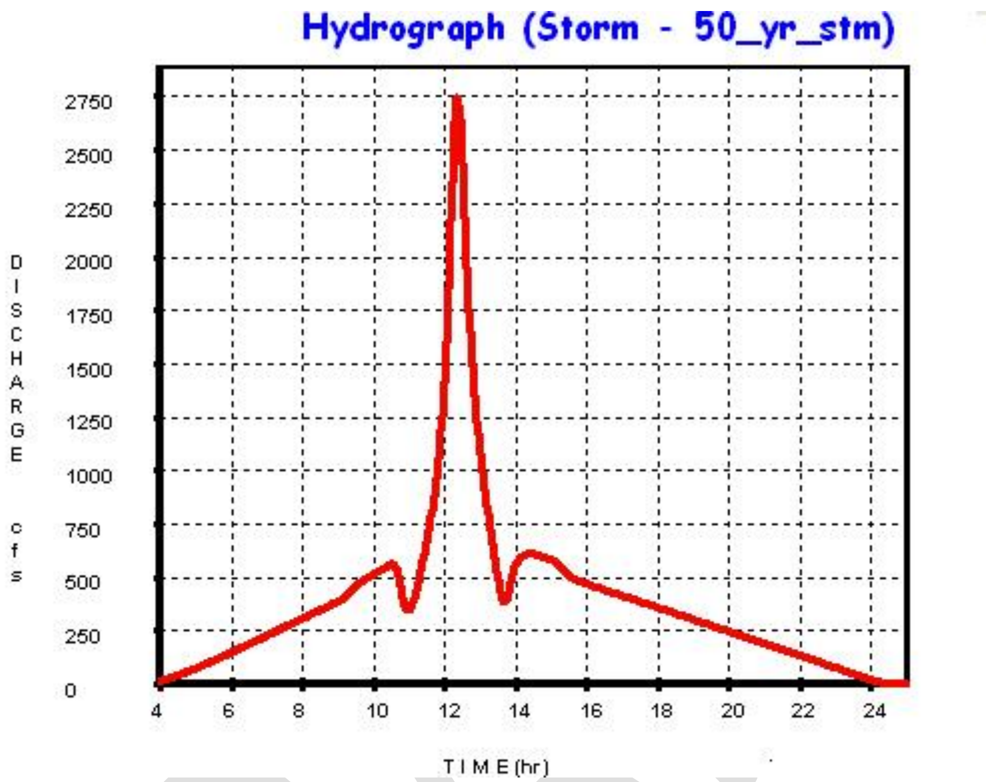


Figure 4B-13 shows a hydrograph generated for a hypothetical watershed in the US Virgin Islands using original data at Upper Bethlehem Works.

Figure 4B-13. Hydrograph with original unsmoothed data



Conclusion and Summary

The technique for smoothing NOAA Atlas 14 precipitation data is described and demonstrated in this appendix. Impacts of smoothing data have been demonstrated for a hydrologic model of a watershed treated as a single unit (not divided into sub-watershed or sub-areas). If a hydrologic model were set up with a number of sub-areas, channel reaches, reservoirs, and diversions, the shape of hydrographs is important because they are added, routed, split, etc. If data are not smoothed, the irregularly shaped hydrographs may cause unexpected results.

In testing where these irregularities occur, the states covered by NOAA Atlas 14 Volume 1 (semi-arid southwest), Volume 3 (Puerto Rico and US Virgin Islands), Volume 4 (Hawaiian Islands), Volume 5 (Pacific Islands), Volume 6 (California), and Alaska (Volume 7) show the most need for the data to be smoothed in order to produce relatively smooth hydrographs. States in the Ohio River Basin, Midwest, and Southeast (Volumes, 2, 8, and 9), show a lesser degree of this irregularity of precipitation intensity.

As a general guideline, smoothing the data when applying the WinTR-20 hydrologic model is recommended. Regional rainfall distributions developed for CA, NV, midwest/southeast states, Ohio Valley and neighboring states, and others are based on smooth NOAA Atlas 14 data.

Appendix 4C. Development of 24-hour rainfall distribution from 5-minute through 24-hour rainfall values.

Introduction

This appendix covers the procedure to develop a 24-hour rainfall distribution from a set of rainfall data values for 5-minute through 24-hour durations. This procedure may be repeated for each return period from 1-year to 500-years. The following procedure to operate with partial duration precipitation values is incorporated into the NRCS hydrologic model WinTR-20. The data used in this appendix were downloaded for Columbus, Ohio WSO Airport in the area covered by NOAA Atlas 14, Volume 2.

Procedure

Input to this procedure consists of precipitation values for 5-, 10-, 15-, 30-, and 60-minutes and 2-, 3-, 6-, 12-, and 24-hour durations for a single recurrence interval such as the 25-year average recurrence interval. The procedure to develop the 24-hour rainfall distribution applies to both original data and smoothed data (see Appendix 4B for data smoothing technique).

Step 1: Calculate ratios of shorter duration to 24-hour precipitation. The 25-year return period original (non-smoothed) values are used in this example. Table 4C-1 includes duration, precipitation values and calculated ratios to the 24-hour value. For example, the 60-minute value is 2.25 inches, and the 24-hour value is 4.44 inches. Therefore, the ratio is 0.5068.

Table 4C- 1. Duration, precipitation, and ratio values

Duration	**5-min**	**10-min**	**15-min**	**30-min**	**60-min**	**2-hr**	**3-hr**	**6-hr**	**12-hr**	**24-hr**
Precipitation inches	0.65	1.00	1.23	1.74	2.25	2.67	2.84	3.36	3.90	4.44
Ratio to 24-hr	0.1464	0.2252	0.2770	0.3919	0.5068	0.6014	0.6396	0.7568	0.8784	1.00

Step 2: Calculate a preliminary rainfall distribution based on the ratios from table 4C-1. Table 4C-2 shows the time in clock hours, time in decimal hours, and preliminary cumulative rainfall ratios.

Table 4C- 2. Preliminary cumulative rain ratio values

Clock time	Time - hr	Preliminary Cumulative rain ratio
0:00 AM	0.0	0.0
6:00	6.0	0.0608
9:00	9.0	0.1216
10:30	10.5	0.1802
11:00	11.0	0.1993
11:30	11.5	0.2466
11:45	11.75	0.3041
11:52:30	11.875	0.3615
11:55	11.9167	0.3874
12:05 PM	12.0833	0.6126
12:07:30	12.125	0.6385
12:15	12.25	0.6959
12:30	12.5	0.7534
1:00	13.0	0.8007
1:30	13.5	0.8198
3:00	15.0	0.8784
6:00	18.0	0.9392
12:00	24.0	1.0

Since the preliminary rainfall distribution is symmetrical about 12 hours, the 12-hr/24-hr ratio is placed from 6 hours to 18 hours of the 24-hour rainfall distribution. Table 4C-1 shows the 12-hr/24-hr ratio to be 0.8784 for this example. Thus 87.84% of the rain will fall between 6 hours and 18 hours. Since the rainfall distribution is symmetrical about 12 hours, one-half of this rain will fall before 12 hours and one-half will fall after 12 hours. The cumulative rain ratio at 6 hours of the preliminary distribution is 0.5 – (12-hr/24-hr ratio)/2 or in equation form:

$$0.5 - (0.8784 / 2) = 0.0608$$

The 6-hr/24-hr ratio is placed from 9 hours to 15 hours of the 24-hour rainfall distribution. The cumulative rain ratio at 9 hours of the preliminary distribution is 0.5 – (6-hr/24-hr ratio)/2 or in equation form:

$$0.5 - (0.7568 / 2) = 0.1216$$

The 10-minute/24-hour ratio is used to calculate the cumulative rain ratio at 11.9167 hours. The cumulative rain ratio at 11.9167 hours of the preliminary distribution is 0.5 – (10-min/24-hr ratio)/2 or in equation form:

$$0.5 - (0.2252 / 2) = 0.3874$$

The 5-minute/24-hour ratio is used in step 8 below.

Table 4C-2 becomes the basis for interpolating a rainfall distribution for 24 hours at a time increment of 0.1 hour.

Step 3: Determine cumulative rain ratios for times from 0.0 to 9.0 hours.

The equation is of the form

$$\mathrm{CRR}(t) = a(t^2) + bt \qquad \text{eq. 4C-1}$$

Where

CRR(t) = cumulative rain ratio at time t hours

$$a = \frac{2}{3}\mathrm{CRR}(9) - \frac{\mathrm{CRR}(6)}{18}$$

$$b = \frac{(CRR(6) - 36a)}{6}$$

Table 4C-3. Cumulative rain ratios from 0.0 to 9.0 hours

Time hr	Cum. Rain Ratio	Time hr	Cum. Rain Ratio	Time hr	Cum. Rain Ratio
0.0	0.0000	3.1	0.0213	6.1	0.0625
0.1	0.0003	3.2	0.0223	6.2	0.0642
0.2	0.0007	3.3	0.0234	6.3	0.0660
0.3	0.0011	3.4	0.0245	6.4	0.0677
0.4	0.0015	3.5	0.0256	6.5	0.0695
0.5	0.0020	3.6	0.0268	6.6	0.0714
0.6	0.0024	3.7	0.0279	6.7	0.0732
0.7	0.0029	3.8	0.0291	6.8	0.0750
0.8	0.0034	3.9	0.0303	6.9	0.0769
0.9	0.0040	4.0	0.0315	7.0	0.0788
1.0	0.0045	4.1	0.0328	7.1	0.0808
1.1	0.0051	4.2	0.0341	7.2	0.0827
1.2	0.0057	4.3	0.0353	7.3	0.0847
1.3	0.0063	4.4	0.0367	7.4	0.0867
1.4	0.0069	4.5	0.0380	7.5	0.0887
1.5	0.0076	4.6	0.0394	7.6	0.0907
1.6	0.0083	4.7	0.0408	7.7	0.0928
1.7	0.0090	4.8	0.0422	7.8	0.0949
1.8	0.0097	4.9	0.0436	7.9	0.0970
1.9	0.0105	5.0	0.0450	8.0	0.0991
2.0	0.0113	5.1	0.0465	8.1	0.1013
2.0	0.0113	5.1	0.0465	8.1	0.1013
2.1	0.0121	5.2	0.0480	8.2	0.1034
2.2	0.0129	5.3	0.0495	8.3	0.1056
2.3	0.0137	5.4	0.0511	8.4	0.1078
2.4	0.0146	5.5	0.0526	8.5	0.1101
2.5	0.0155	5.6	0.0542	8.6	0.1123
2.6	0.0164	5.7	0.0558	8.7	0.1146
2.7	0.0173	5.8	0.0575	8.8	0.1169
2.8	0.0183	5.9	0.0591	8.9	0.1193
2.9	0.0193	6.0	0.0608	9.0	0.1216
3.0	0.0203				

Step 4: Determine cumulative rain ratios for times from 9.0 to 10.5 hours. An equation is developed such that the cumulative rainfall ratio gradually and constantly increases between 9.0 and 10.5 hours yet still matches the ratios at 9.0 and 10.5 hours in table 4C-2.

The equation is of the form

$$CRR(t) = a_2(t^2) + b_2 t \qquad \text{eq. 4C-2}$$

Where

CRR(t) = cumulative rain ratio at time t hours

$$a_2 = \frac{9}{10.5} CRR(10.5) - \frac{CRR(9)}{13.5}$$

$$b_2 = \frac{(CRR(9) - 81a_2)}{9}$$

Table 4C-4. Cumulative rain ratios from 9.0 to 10.5 hours

Time - hr	Cum Rain Ratio
9.0	0.1216
9.1	0.1252
9.2	0.1288
9.3	0.1325
9.4	0.1362
9.5	0.1399
9.6	0.1437
9.7	0.1476
9.8	0.1515
9.9	0.1554
10.0	0.1594
10.1	0.1635
10.2	0.1676
10.3	0.1717
10.4	0.1759
10.5	0.1802

Step 5: Determine cumulative rain ratios for times from 10.5 to 11.5 hours. An equation is developed such that the cumulative rainfall ratio gradually and constantly increases between 10.5 and 11.5 hours yet still matches the ratios at 10.5, 11.0, and 11.5 hours in table 4C-2.

The equation is of the form

$$\mathrm{CRR(t) = a_3(t^2) + b_3 t + c_3} \qquad \text{eq. 4C-3}$$

Where

CRR(t) = cumulative rain ratio at time t hours

a_3 =2 CRR(11.5) -2 (CRR(11) + CRR(10.5)

$$\mathrm{b_3 = CRR\ (11.5) - CRR(10.5) - 22a_3}$$

$$\mathrm{c_3 = CRR\ (11) - 121a_3 - 11b_3}$$

Table 4C-5. Cumulative rain ratios from 10.5 to 11.5 hours

Time – hr	Cum Rain Ratio
10.5	0.1802
10.6	0.1818
10.7	0.1845
10.8	0.1883
10.9	0.1932
11.0	0.1993
11.1	0.2065
11.2	0.2149
11.3	0.2243
11.4	0.2349
11.5	0.2466

Step 6: Determine cumulative rain ratios for times from 11.6 to 11.9 hours.

$$\mathrm{CRR(11.6) = CRR(11.5) + Factor(11.6)(CRR(11.75) - CRR(11.5))}$$

Where

$$\mathrm{Factor(11.6) = -0.867\ Intensity(11.5) + 0.4337}$$

and $\mathrm{Intensity(11.5) = \frac{CRR(11.5) - CRR(11.4)}{0.1}}$

The value of Factor(11.6) has a maximum value of 0.399. If the value of Factor(11.6) is greater than 0.399, it is changed to 0.399.

Intensity(11.5) = (0.2466 – 0.2349) / 0.1 = 0.117

Factor(11.6) = (-0.867 * 0.117) + 0.4337 = 0.3322

CRR(11.6) = 0.2466 + 0.3322 * (0.3041 – 0.2466) = 0.2657

$$\mathrm{CRR}(11.7) = \mathrm{CRR}(11.5) + \mathrm{Factor}(11.7)(\mathrm{CRR}(11.75) - \mathrm{CRR}(11.5))$$

Where

Factor(11.7) = -0.4917 (Intensity(11.5)) + 0.8182

The value of Factor(11.7) has a maximum value of 0.799.

Factor(11.7) = (-0.5917 * 0.117) + 0.8182 = 0.7607

CRR(11.7) = 0.2466 + 0.7067 * (0.3041 – 0.2466) = 0.2903

$$\mathrm{CRR}(11.8) = \mathrm{CRR}(11.75) + \frac{(11.8 - 11.75)}{(11.875 - 11.75)}(\mathrm{CRR}(11.875) - \mathrm{CRR}(11.75)$$

$$\mathrm{CRR}(11.8) = 0.3041 + \frac{(11.8 - 11.75)}{(11.875 - 11.75)}(0.3615 - 0.3041) = 0.3270$$

$$\mathrm{CRR}(11.9) = \mathrm{CRR}(11.875) + \frac{(11.9 - 11.875)}{(11.9167 - 11.875)}(\mathrm{CRR}(11.9167) - \mathrm{CRR}(11.875)$$

$$\mathrm{CRR}(11.9) = 0.3615 + \frac{(11.9 - 11.875)}{(11.9167 - 11.875)}(\ 0.3874 - 0.3615) = 0.3770$$

Table 4C-6. Cumulative rain ratios from 11.6 to 11.9 hours

Time - hr	**Cum Rain Ratio**
11.6	0.2657
11.7	0.2903
11.8	0.3270
11.9	0.3770

Step 7: Determine cumulative rain ratios for times from 12.1 to 24 hours. Since the rainfall distribution is symmetrical, the cumulative rain ratios from 12.1 hours to 24 hours are based on the cumulative rain ratios from 0.0 to 11.9 hours. The cumulative rain ratio at 12.1 hours is 1.0 minus the cumulative rain ratio at 11.9 hours. The cumulative rain ratio at 12.2 hours is 1.0 minus the cumulative rain ratio at 11.8 hours. This continues all the way to 24 hours (where the 24 hour cumulative rain ratio is 1.0 – 0.0 or 1.0).

Table 4C-7. Cumulative rain ratios from 12.1 to 24.0 hours

Time - hr	Cum Rain Ratio	Time - hr	Cum Rain Ratio	Time – hr	Cum Rain Ratio
12.1	0.6230	16.1	0.9030	20.1	0.9697
12.2	0.6730	16.2	0.9051	20.2	0.9709
12.3	0.7097	16.3	0.9072	20.3	0.9721
12.4	0.7343	16.4	0.9093	20.4	0.9732
12.5	0.7534	16.5	0.9113	20.5	0.9744
12.6	0.7651	16.6	0.9133	20.6	0.9755
12.7	0.7757	16.7	0.9153	20.7	0.9766
12.8	0.7851	16.8	0.9173	20.8	0.9777
12.9	0.7935	16.9	0.9192	20.9	0.9787
13.0	0.8007	17.0	0.9212	21.0	0.9797
13.1	0.8068	17.1	0.9231	21.1	0.9807
13.2	0.8117	17.2	0.9250	21.2	0.9817
13.3	0.8155	17.3	0.9268	21.3	0.9827
13.4	0.8182	17.4	0.9286	21.4	0.9836
13.5	0.8198	17.5	0.9305	21.5	0.9845
13.6	0.8241	17.6	0.9323	21.6	0.9854
13.7	0.8283	17.7	0.9340	21.7	0.9863
13.8	0.8324	17.8	0.9358	21.8	0.9871
13.9	0.8365	17.9	0.9375	21.9	0.9879
14.0	0.8406	18.0	0.9392	22.0	0.9887
14.1	0.8446	18.1	0.9409	22.1	0.9895
14.2	0.8485	18.2	0.9425	22.2	0.9903
14.3	0.8524	18.3	0.9442	22.3	0.9910
14.4	0.8563	18.4	0.9458	22.4	0.9917
14.5	0.8601	18.5	0.9474	22.5	0.9924
14.6	0.8638	18.6	0.9489	22.6	0.9931
14.7	0.8675	18.7	0.9505	22.7	0.9937
14.8	0.8712	18.8	0.9520	22.8	0.9943
14.9	0.8748	18.9	0.9535	22.9	0.9949
15.0	0.8784	19.0	0.9550	23.0	0.9955
15.1	0.8807	19.1	0.9564	23.1	0.9960
15.2	0.8831	19.2	0.9578	23.2	0.9966
15.3	0.8854	19.3	0.9592	23.3	0.9971
15.4	0.8877	19.4	0.9606	23.4	0.9976
15.5	0.8899	19.5	0.9620	23.5	0.9980
15.6	0.8922	19.6	0.9633	23.6	0.9985
15.7	0.8944	19.7	0.9647	23.7	0.9989
15.8	0.8966	19.8	0.9659	23.8	0.9993
15.9	0.8988	19.9	0.9672	23.9	0.9997
16.0	0.9009	20.0	0.9685	24.0	1.0000

Step 8: Determine cumulative rain ratio for time 12.0 hours. Since the rainfall distribution is developed at a time increment of 0.1 hour (6-minutes), the 5-minute / 24-hour and 10-minute / 24-hour ratios are used to calculate the maximum 6-minute rainfall ratio.

6-min / 24-hr ratio = 5-min / 24-hr ratio + 0.2 (10-min /24-hr ratio – 5-min /24-hr ratio)

6-min / 24-hr ratio = 0.1464 + 0.2 (0.2252 – 0.1464) = 0.16216

The 6-minute /24-hour rainfall ratio is subtracted from the cumulative rain ratio at 12.1 hours in order to define a cumulative rain ratio at 12.0 hours. By making this adjustment, the maximum 5-minute rainfall ratio is represented in the final rainfall distribution.

Ratio(12.0) = Ratio(12.1) - 6-min / 24-hr ratio

Ratio(12.0) = 0.62297 – 0.16216 = 0.46081

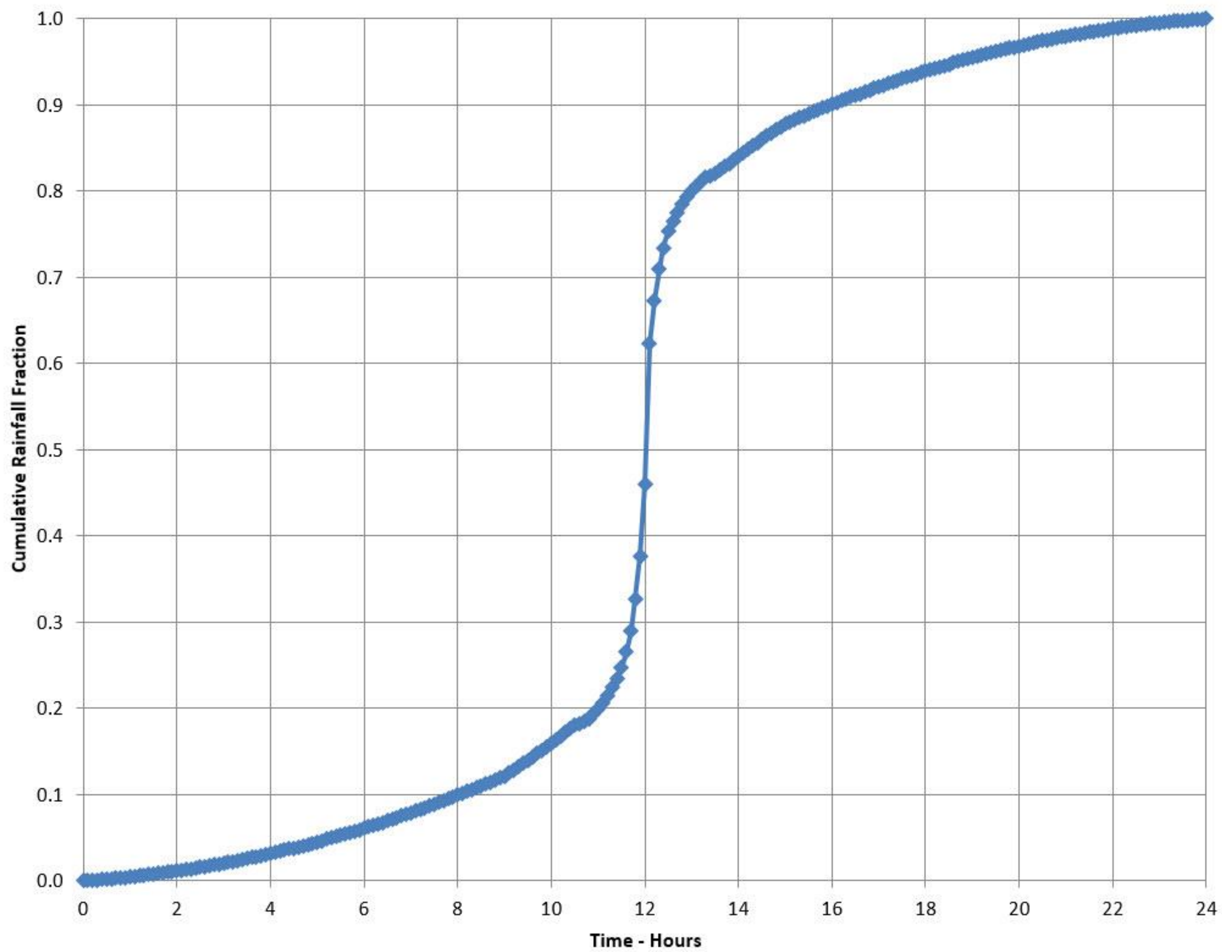
The rainfall distribution algorithm is programmed in WinTR-20. In WinTR-20, this procedure is completed for all return periods from 1-year to 500-years. Each return period will have a unique rainfall distribution.

Discussion

In Step 3, curves are used to interpolate the cumulative rain ratio at the 0.1 hour time steps. It seems logical to interpolate the ratios at these time steps linearly from the preliminary rainfall distribution in table 4C-2. If that is done, there will be irregularities in the hydrograph developed from the rainfall distribution. These irregularities include sharp changes in discharge at rainfall distribution break points (such as 6 and 9 hours) and gradual increases in discharge on the falling tail of the hydrograph. For these reasons, equations are developed such that the cumulative rainfall ratio gradually and constantly increases between 0 and 11.9 hours yet still matches the ratios in table 4C-2.

The rainfall distribution developed in steps 1 through 8 is plotted in figure 4C-1.

Figure 4C-1. Rainfall distribution developed in example in Appendix C



Summary

The NRCS procedure for developing a storm distribution based on precipitation values at durations from 5 minutes to 24 hours is documented in this Appendix. The procedure is implemented in the WinTR-20 computer program and is also available in a spreadsheet available from the National Water Quality and Quantity Team West National Technology Support Center web site page http://go.usa.gov/rXYw under Technical Information. By documenting the assumptions and procedure, the procedure becomes more transparent and understandable. In future years when more research is available on storm structure, hydraulic engineers will be able to make improvements to the procedure.

Appendix 4D. Determining a design rainfall distribution for a region based on GIS data.

Introduction

This appendix describes development of four regional standardized rainfall distributions for the Ohio Valley and neighboring states in the NOAA Atlas 14 Volume 2 area. Other NRCS technical literature, including software user guides, training materials, and state supplements describe use of these rainfall distributions.

Use of a regional rainfall distribution may produce different peak discharges than if the site-specific rainfall distribution is used. This is because the ratios of shorter duration such as 60-minutes to 24-hour rainfall vary across the region. Also, if the regional rainfall distribution is based on a single storm, such as the 25-year, a site-specific 100-year rainfall distribution may be different and produce different peak discharges. For this reason, the regional rainfall distributions were tested against site-specific distributions and differences in results were evaluated.

This appendix is written for an intermediate or advanced GIS user. Anyone with little GIS experience could find this material difficult to understand. If this is the case, ask a more experienced GIS user for an explanation.

Even though the recommended method for developing a rainfall distribution is on a site-by-site basis with a unique distribution for each return period, sometimes a rainfall distribution covering a geographic area is desirable. For small-scale NRCS hydrologic projects, the Engineering Field Handbook Chapter 2 (EFH-2) and WinTR-55 computer programs are used. These software programs are not capable of developing site-specific rainfall distributions and must rely on pre-developed rainfall distributions. For this reason, regional rainfall distributions were developed. In some localities, maps of ratios of shorter duration to the 24-hour rainfall based on GIS layers from NOAA Atlas 14 show high and/or low “bulls eyes” which do not appear logical considering local meteorological conditions. These may be influenced by the results of the statistical analysis of a single rain gage. By developing a regional rainfall distribution, these high and low ratio areas are smoothed out and result in a single more representative rainfall distribution.

Procedure

Step 1. Prepare GIS data layers to include a base map or shapefile of state/county boundaries and rainfall data at durations from 5-minutes to 24-hours for the return periods of interest. The NOAA Atlas 14 data layers may be prepared using instructions available from the National Water Quality and Quantity Team West National Technology Support Center web site http://go.usa.gov/KoZ under WinTR-20.

Step 2. Develop ratios of the 5-minute / 24-hour, 10-minute/24-hour, etc., up to the 12-hour / 24-hour duration for return periods of interest using GIS grid layers for the project area. If using ESRI (Environmental Systems Research Institute, 2012) GIS software, use the Spatial Analyst Math commands.

Step 3. Decide which return period is the most important on which to base the regional rainfall distribution. The primary consideration in making this decision is what the rainfall distribution will be used for. In the case of NRCS regional rainfall distributions, they will be used primarily to design projects based on the 25-year return period 24-hour rainfall. It will also be used to a lesser degree for design of projects with 10-year and 50-year 24-hour rainfalls. An analysis of ratios of shorter duration to the 24-hour rainfall will show how different the rainfall distributions could be between selected return periods. For example, in many locations, the ratios for all return periods are very similar which would result in very similar rainfall distributions. However if the ratios are significantly different, then different rainfall distributions would be developed (such as the case in Wilmington, NC shown in section 630.0403 (c) Precipitation – Frequency Data Ratio Analyses.

Step 4. Depending on the purpose of the study, either decide on the region for which to develop a single rainfall distribution or decide how many rainfall distributions are desired within a certain geographic area. For example, perhaps an average rainfall distribution is desired for a single state. Another example could be to develop a number of rainfall distribution regions for a given state or group of states. Depending on this decision, different procedures are used from this point. Go to Step 4A or Step 4B.

Step 4A. If an average rainfall distribution is desired for a single state, use the ESRI Spatial Analyst commands to determine the zonal statistics for areas within the state boundary. The zonal statistics command will produce the mean, maximum, minimum, and range of the ratios for each duration within the selected return period (such as 25-year). Once these means are computed, compile the mean ratios for 5-minutes through 12-hours and build a rainfall distribution based on principles described in this chapter. These principles may include smoothing the ratios before building the rainfall distribution.

Step 4B. For the second project type, dividing a geographic area into a number of rainfall distribution regions, first decide on the most important duration ratio on which to base the boundaries of the rainfall regions, such as the 60-minute/24-hour ratio. Analyze the selected ratio map and determine the maximum and minimum ratios. Then divide the range of ratios into an appropriate number of regions. For example, if the range of 60-minute/24-hour ratio is from 0.3 to 0.5, a logical procedure would be to break the area up into four rainfall distribution regions based on ratios from 0.3 to 0.35, 0.35 to 0.4, 0.4, to 0.45, and 0.45 to 0.5. To do this analysis using ESRI tools, use the Spatial Analyst Reclassify command and set the limits of each class to the desired intervals such as region 1 with ratios less than 0.35, region 2 with ratios between 0.35 and 0.4, region 3 with ratios between 0.4 and 0.45, and region 4 with ratios greater than 0.45. Convert this reclassified GIS layer into a polygon shapefile where the boundaries follow the four rainfall distribution regions. If the boundaries are satisfactory, proceed to the next step. If the boundaries are not reasonable, reset the number of regions and/or the ratio limits for each region and reclassify again.

This analysis will define the regional boundaries only. To build a rainfall distribution for each of these regions, ratios of 5-minute/24-hour up to the 12-hour/24-hour ratio are required. If using ESRI GIS software, use the Spatial Analyst Zonal Statistics as a Table command. Use this command for each duration ratio and the regional distribution map (shapefile) to determine the mean ratio for each duration within each region.

Once the ratios for each duration have been computed, the ratios may be smoothed and a rainfall distribution developed based on principles outlined in this chapter.

Example application

The second project type is to divide a geographic area into a number of rainfall distribution regions. This approach was used to develop four rainfall distribution regions for the states covered by NOAA Atlas 14 Volume 2, Ohio Valley and neighboring states.

The intended purpose of the rainfall distributions was to use them in the Engineering Field Handbook Chapter 2, Estimating Runoff, and Peak Discharges (EFH2) computer program. The 25-year frequency was used as the basis for the rainfall distribution because many conservation practices are designed for the 25-year return period storm.

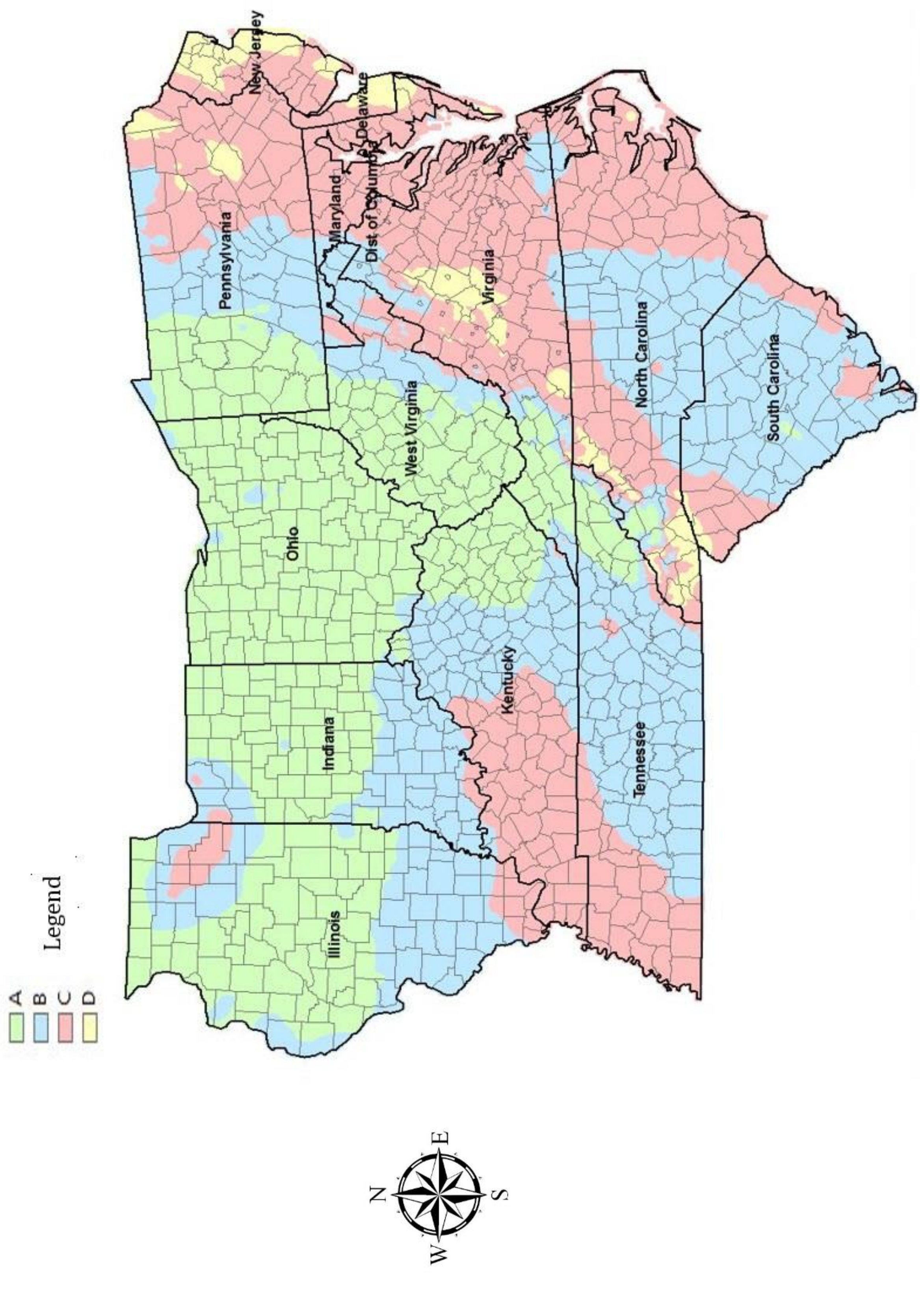
The 25-year rainfall distribution is midway between the 1-year and 100-year rainfall distributions. The 10-year and 50-year rainfall distributions are generally close enough to the 25-year rainfall distribution that minor differences in the rainfall distribution and peak discharge will result.

The GIS data for the 5-minute through 24-hour durations were downloaded from the NOAA Atlas 14 web site and prepared using ESRI software. A base map of states and counties was prepared in the same GIS map projection. Ratios of 5-minute / 24-hour, 10-minute / 24-hour, etc. ratios were determined using ESRI Spatial Analyst commands.

The 60-minute / 24-hour ratio was used to determine the boundaries of the rainfall distribution regions. This was selected because the 5-minute through 30-minute rainfall values are determined based on a percentage of the 60-minute rainfall. Therefore, the boundaries developed using the 60-minute ratio should be generally consistent with the boundaries developed by using any duration between 5-minutes and 30-minutes. Many watersheds where EFH2-2 is applied have a time of concentration less than 60-minutes.

The 60-minute / 24-hour ratio ranged from 0.28 to 0.58 and was reclassified into 4 regions with ratios of 60-minute / 24-hour of less than 0.38, 0.38 to 0.43, 0.43 to 0.48, and greater than 0.48. This analysis produced the map in figure 4D-1. The number of rainfall distribution regions and ratio limits for each one is a subjective decision that includes consideration of several factors. Perhaps the major factor is the difference in peak discharge when changing from one distribution region to another. Once a set of distribution regions and rainfall distributions are organized, tests can be run to determine this difference. For example, if the peak discharge for region A is 100 cfs, Region B is 90 cfs, Region C is 80 cfs, and Region D is 70 cfs, the potential error is plus or minus 5 cfs. After converting this to a percentage difference, judge whether this is a reasonable percentage tolerance for hydrologic design. A second consideration is the relative size of rainfall distribution regions. It may not be reasonable to have one distribution region much larger or smaller than another. A third consideration is the absolute limit of the ratios. For example, if the ratio range for the most intense and least intense rainfall distribution is large, then the potential error in discharge may exceed the desired tolerance.

Figure 4D- 1. NOAA Atlas 14 Volume 2 region, rainfall distribution regions



Region A has 60-minute 24-hour ratios greater than 0.48, Region B has ratios between 0.43 and 0.48, Region C has ratios between 0.38 and 0.43, and Region D has ratios less than 0.38.

The next step was to determine the mean ratio of 5-minutes /24-hour ratio to 12-hour / 24-hour in each of the four regions.

The following table was developed using ESRI Spatial Analyst commands.

Table 4D- 1. Mean ratios for four rainfall distribution regions NOAA Atlas 14, Ohio Valley and neighboring states.

Duration ratio	Region A	Region B	Region C	Region D
5-min / 24-hr	0.143	0.121	0.105	0.094
10-min / 24-hr	0.219	0.189	0.166	0.149
15-min / 24-hr	0.272	0.237	0.210	0.188
30-min / 24-hr	0.386	0.344	0.308	0.276
60-min / 24-hr	0.502	0.453	0.409	0.366
120-min / 24-hr	0.594	0.543	0.500	0.454
3-hr / 24-hr	0.635	0.585	0.545	0.501
6-hr / 24-hr	0.749	0.705	0.672	0.636
12-hr / 24-hr	0.864	0.840	0.823	0.805

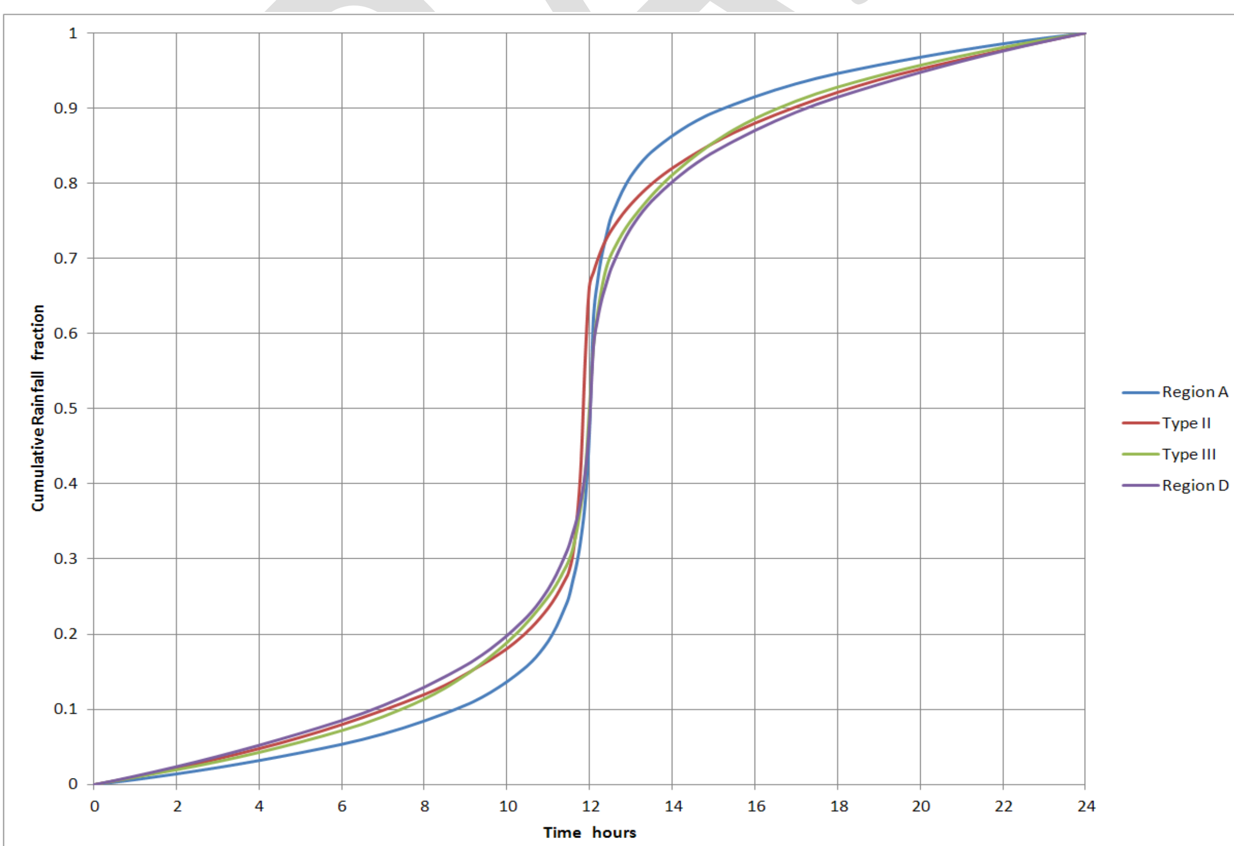
Region A has the most intense rainfall distribution because ratios in table 4D-1 are higher. Region D has the least intense rainfall distribution.

WinTR-20 both smooths the rainfall data and develops a rainfall distribution with ratio data such as contained in table 4D-1. In order to do this, a NOAA Atlas 14 text file at any random location can be edited to include one column in table 4D-1.

Since the data are non-dimensional, they may be multiplied by 10 (or any other number) and entered in the NOAA Atlas 14 text file. The number 10 is practical because the 5-min / 24-hr ratio of 0.143 becomes 1.43 and the ratio for the 24-hour rainfall becomes 10.00. The ratios are treated as rainfall in units of inches.

The WinTR-20 NOAA Atlas 14 smoothing output file shows to what degree the original ratios are non-smooth. WinTR-20 develops a 24-hour rainfall distribution at a time interval of 0.1 hours. The rainfall distributions for Region A (most intense rainfall distribution) and Region D (least intense rainfall distribution) are plotted for comparison against the Type II and Type III in figure 4D-3. The Region A distribution is slightly more intense than the Type II and the Region D distribution is slightly less intense than the Type III.

Figure 4D- 2. Plot of NOAA Atlas 14 Regions A and D rainfall distributions compared to Type II and Type III.



Discussion

These rainfall distributions based on the 25-year return period are the default rainfall distributions, which may be selected and used in WinTR-55. A different rainfall distribution, based on the 100-year storm for example, may be used in WinTR-55 by entering it as an historical storm distribution table.

The rainfall distribution may be used to compute peak discharges in both WinTR-20 and WinTR-55. To derive peak discharge curves for use in EFH2-2, WinTR-20 was run for a range of I_a/P (initial abstraction divided by precipitation) ratios and time of concentration.

There are several options to consider when defining the use of maps such as shown in figures 4D-1 and 4D-2. One is to publish the maps as is and request the user to determine which rainfall distribution to use based on the project location. The maps were generated by GIS so specific boundary lines are defined. If a user has access to GIS, the process of determining where the project is situated is relatively simple. Another possible use is to define rainfall distributions along county boundaries. In this case, when a county has two or more rainfall distributions a decision needs to be made which distribution to use. Generally, the dominant one or the most conservative one is selected. However, this could cause some parts of a county to have a larger potential error in peak discharge.

For ease in implementation, it may be helpful to ignore small pockets of different regional distributions that appear. In addition to that, in some regions, NOAA Atlas 14 data have “bull’s eyes” which are caused by either high or low precipitation frequency results at individual rain gages with respect to surrounding rain gages. It becomes difficult to specify exactly where these isolated boundaries are by visible physical attributes on the land (roads, rivers, mountains, county boundaries, etc.). If this is the case, the potential maximum and minimum difference in peak discharge may be determined by setting up tests in hydrologic computer models. For example, different rainfall distributions may be used in hydrologic computer models for various watershed sizes and rainfall depths and results compared.