Rainfall Intensity Changes Over Time: *Have the Codes Kept Pace?*

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More intense rains seem to be occurring and with greater frequency in many parts of the United States. In 2016, the U.S. Environmental Protection Agency (EPA) reported that total annual precipitation has increased in the United States and worldwide at an average rate of 0.08 in. (2 mm) per decade since 1901, and during this same period, precipitation in the contiguous 48 states has increased at a rate of 0.17 in. (4 mm) per decade (**Fig. 1**).[1] The EPA went on to say, “In recent years, a higher percentage of precipitation in the United States has come in the form of intense single-day events. Nationwide, nine of the top 10 years for extreme one-day precipitation events have occurred since 1990.” Furthermore, from 1910 to 2015, “the portion of the country experiencing extreme single-day precipitation events increased at a rate of about half a percentage point per decade.”[2]

So, have the codes kept up with the changes in the frequency and intensity of rainfalls? We all refer to the building codes, at least as a starting point, when calculating the rainwater capacity of roof drains, scuppers, gutters, downspouts, and secondary drainage systems (overflow devices). Specifically, for most jurisdictions, we refer to Fig. 1106.1 of the *International Plumbing Code* (IPC),[3] which provides 100-year, 1-hour (60-minute) rainfalls for various regions of the United States, or IPC Appendix B, “Rainfall Rates for Various Cities.” The latter, which may or may not be adopted as part of the local building code, also provides rainfall rates in inches per hour for rain events having a duration of 1 hour and a return period of 100 years. Knowing the code sets minimum standards, it is possible for designers to exceed code and use more conservative rainfall intensity data—such as a 100-year, 15-minute or 100-year, 5-minute rainfall intensity—for the cities in which our projects are located. Nevertheless, the question remains: Have the plumbing codes we use in our design work kept pace with what is going on around us? Or, are the 100-year, 1-hour rainfall rates we are using outdated, resulting in the design of undersized rainwater conduction systems; risking the overflowing of gutters or, worse, the overloading of low-slope roofs if such accumulated water load time periods are not accounted for by the design?

This paper reviews U.S. rainfall intensity data reports and various plumbing codes from 1935 to the present. This review suggests that plumbing codes have remained relatively static, rarely contain current rainfall intensity data, and truly represent a minimum standard with regard to the design of roof drainage systems.

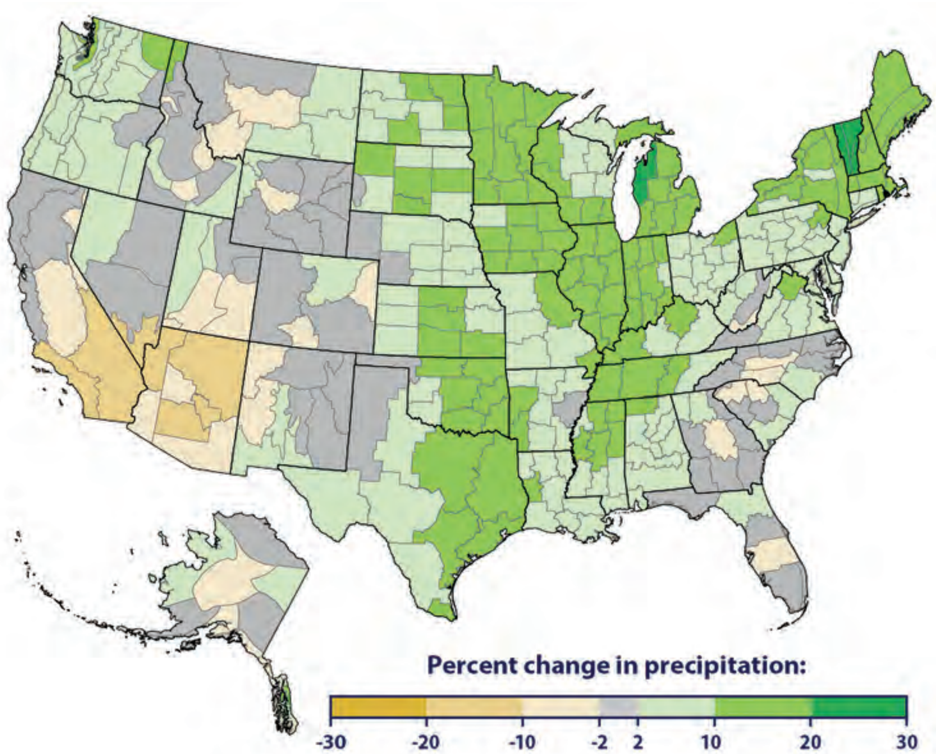


Figure 1. Percent change in precipitation in the United States, 1901–2015 (1925–2015 for Alaska). The map depicts climate divisions as defined by the National Oceanic and Atmospheric Administration. Reproduced from Reference 1.

Those interested in adding resiliency to their roof designs would therefore do well to employ more current and more conservative rainwater intensity values when calculating the size of required rainwater conduction systems for buildings.

RAINFALL BASICS

Rainwater conduction systems help protect a building, as well as interior finishes and furnishings, from water infiltration. The sizing of rainwater conduction systems requires an understanding of the amount and distribution of rain that is likely to fall on a structure during its useful life. "Raining cats and dogs," "drizzle," "Cloudy with a Chance of Meatballs," and other such colloquialisms are not quite precise enough in this case. We have to dig a little deeper.

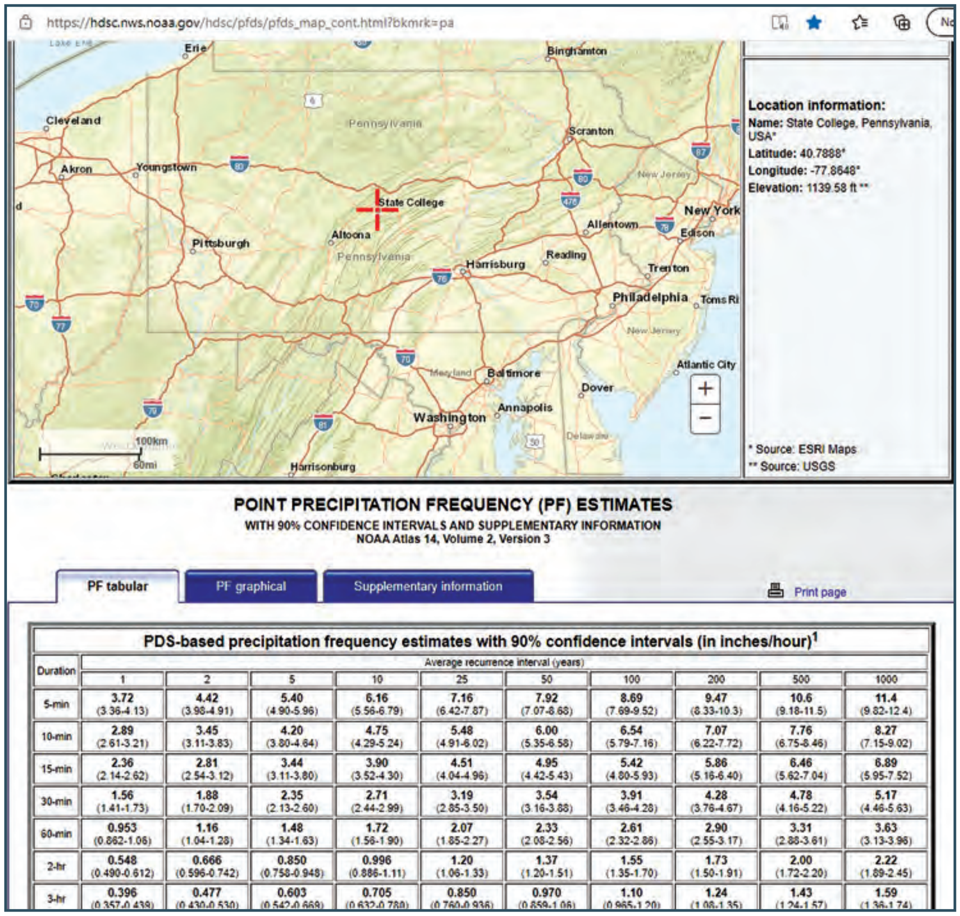
Intensity, Duration, and Frequency

The amount relative to time, or intensity, of rainfall to which a building is exposed, is often stated in inches per hour (in./hr). Rainfall intensity varies by region of the country and is dependent on two additional factors: duration and frequency.

Duration recognizes the time mode of rainfall. It measures the period over which the rainfall occurs, typically in minutes or hours. Duration is important because more-intense rainfalls can overwhelm drainage systems by depositing large amounts of rainwater over short periods of time, whereas less-intense rainfalls, which deposit less rainwater per unit of time, tend to be accommodated by drainage systems. This is true even if *total* rainfall in the less-intense event exceeds the *total* rainfall in the more-intense event, as in the examples given in the paragraph below.

Although rainfall intensity is typically given in inches per hour, the duration over which that intensity is sustained does not necessarily have to be 1 hour. Given the historic practice of reading rain gauges once a day, 24-hour durations are common. Thus, if the rainfall collected over a 24-hour period (duration) in a particular location is 1.2 in. (30 mm), the rainfall intensity is stated as a 24-hour, 0.05-in./hr (1.3-mm/hr) rainfall (1.2 in./24 hr [30 mm/24 hr]). Similarly, if the rainfall collected over a 5-minute duration is 0.75 in. (19 mm), the rainfall intensity is stated as a 5-minute, 9-in./hr (230-mm/hr) rainfall (0.75 in. × [60 min./5 min.]).

The *frequency*, or return period (also known as return interval or recurrence interval), of a rainfall refers to the likelihood that a rain event of a certain intensity, or greater, will occur within a certain time frame. Rainfall frequency is typically measured in years and, like intensity, varies by region. It can be thought of as the expected number of years between rainfalls of a given, or greater, intensity for a given location. Generally, short, intense rains occur with less frequency than longer, less-intense rains. For example, a 10-year, 5-minute rainfall with an intensity of 9 in./hr (230 mm/hr), has a return period of 10 years, which suggests that the probability of a rainfall of 9 in./hr (230 mm/hr), or greater, occurring in any one year is 1 in 10. Because rainfall data typically represent historical averages, it is possible, for example, to have more than one 10-year rainfall in a 10-year period.



POINT PRECIPITATION FREQUENCY (PF) ESTIMATES
WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 2, Version 3

PF tabular | PF graphical | Supplementary information | Print page

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

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	3.72 (3.36-4.13)	4.42 (3.98-4.91)	5.40 (4.90-5.96)	6.16 (5.56-6.79)	7.16 (6.42-7.87)	7.92 (7.07-8.68)	8.69 (7.69-9.52)	9.47 (8.33-10.3)	10.6 (9.18-11.5)	11.4 (9.82-12.4)
10-min	2.89 (2.61-3.21)	3.45 (3.11-3.83)	4.20 (3.80-4.64)	4.75 (4.29-5.24)	5.48 (4.91-6.02)	6.00 (5.35-6.58)	6.54 (5.79-7.16)	7.07 (6.22-7.72)	7.76 (6.75-8.46)	8.27 (7.15-9.02)
15-min	2.36 (2.14-2.62)	2.81 (2.54-3.12)	3.44 (3.11-3.80)	3.90 (3.52-4.30)	4.51 (4.04-4.96)	4.95 (4.42-5.43)	5.42 (4.80-5.93)	5.86 (5.16-6.40)	6.46 (5.62-7.04)	6.89 (5.95-7.52)
30-min	1.56 (1.41-1.73)	1.88 (1.70-2.09)	2.35 (2.13-2.60)	2.71 (2.44-2.99)	3.19 (2.85-3.50)	3.54 (3.16-3.88)	3.91 (3.46-4.28)	4.28 (3.76-4.67)	4.78 (4.16-5.22)	5.17 (4.46-5.63)
60-min	0.953 (0.862-1.06)	1.16 (1.04-1.28)	1.48 (1.34-1.63)	1.72 (1.56-1.90)	2.07 (1.85-2.27)	2.33 (2.08-2.56)	2.61 (2.32-2.86)	2.90 (2.55-3.17)	3.31 (2.88-3.61)	3.63 (3.13-3.96)
2-hr	0.548 (0.490-0.612)	0.666 (0.596-0.742)	0.850 (0.758-0.948)	0.996 (0.886-1.11)	1.20 (1.06-1.33)	1.37 (1.20-1.51)	1.55 (1.35-1.70)	1.73 (1.50-1.91)	2.00 (1.72-2.20)	2.22 (1.89-2.45)
3-hr	0.396 (0.357-0.439)	0.477 (0.430-0.530)	0.603 (0.542-0.669)	0.705 (0.632-0.780)	0.850 (0.760-0.936)	0.970 (0.859-1.06)	1.10 (0.965-1.20)	1.24 (1.08-1.35)	1.43 (1.24-1.57)	1.59 (1.36-1.74)

Figure 2. Screenshot of the National Oceanic and Atmospheric Administration's Precipitation Frequency Data Server[4] rainfall intensity data for State College, Pa.

For a complete definition of rainfall at a particular location, all three parameters—intensity, duration, and frequency—should be specified. The relationship among the three parameters can be summarized as follows:

- For a given return period, whether 1 year, 10 years, or 500 years, the longer the duration of a rain event, the lower its intensity (that is, the fewer inches of rain that will fall within a given period of time, whether that be 5 minutes, 15 minutes, 1 hour, or 24 hours). Conversely, the shorter the duration, the higher the intensity.
- The shorter the return period, the less intense the rain events will be for any given duration. The converse is true as well; the longer the return period, the more intense the rain event is likely to be for any given duration.
- Lastly, high-intensity rain events, wherein a large amount of precipitation falls within a short period of time, occur with less frequency than low- and moderate-intensity rain events. For example, in Philadelphia, 5-minute rainfall with a return period of 100 years has an intensity of 8.17 in./hr (207 mm/hr), whereas a 60-minute rainfall with a return period of 10 years has an intensity of 2.05 in./hr (52 mm/hr).[4]

Relatively recent rainfall data for almost any city in the United States can be obtained online from the National Weather Service's National Oceanic and Atmospheric Administration (NOAA), Precipitation Frequency Data Server (PFDS)[4] by simply clicking on a map (**Fig. 2**). Rainfall depth (in inches) and intensity

Year Published	Author	Title	Reference(s)
1935	Yarnell, D.L./US Department of Agriculture	*Rainfall Intensity-Frequency Data*	6
1949	US Department of Commerce and Housing, and Home Finance Agency	*Uniform Plumbing Code* (UPC)	10
1955	American Society of Mechanical Engineers	*American Standard National Plumbing Code* (NPC)	11
1961	Hershfield, D. M./US Department of Commerce	*Technical Paper No. 40*, "Rainfall Frequency Atlas of the United States"	8
1975	National Association of Plumbing-Heating-Cooling Contractors	*National Standard Plumbing Code* (NSPC)	16
1987	National Association of Plumbing-Heating-Cooling Contractors	NSPC	9
1996	National Association of Plumbing-Heating-Cooling Contractors	NSPC	18
1995–2021	International Code Council	*International Plumbing Code* (IPC)	3 (2021 ed.), 12–14 (2012, 2015, 2018 ed.), 19 (1995 ed.)
2021 (see endnote 4)	National Oceanic and Atmospheric Administration	National Weather Service Precipitation Frequency Data Server (PFDS)	4

Table 1. Publications and plumbing codes consulted

(in inches per hour) are given for durations ranging from 5 minutes to 60 days and return periods ranging from 1 year to 1000 years.

For the purpose of roof system design, where the focus is typically on the sizing of gutters, downspouts, roof drains, scuppers, secondary drainage systems, and related stormwater piping, relatively short durations (typically between 5 minutes and 1 hour) and a single frequency (typically 100 years) are relied upon. This practice is primarily code driven. For example, the *International Building Code*[5] requires that roofs be designed to accommodate rain loads based on a 100-year, 60-minute rainfall. Similarly, the IPC requires that the size of conductors, leaders, and storm drains be determined as a function of the 100-year, 60-minute rainfall rate for a building's location. (Longer return periods are commonly used in other fields, such as in the design of hydrologic, hydraulic, and water resource systems.)

A LOOK AT THE HISTORICAL DATA

Table 1 lists the publications and plumbing codes reviewed for this paper. By comparing these documents, we can better understand the adequacy of today's building codes regarding rainfall intensity.

Yarnell

Yarnell's *Rainfall Intensity-Frequency Data*[6] is one of the earliest comprehensive studies of rainfall data in the United States. Published in 1935 by the U.S. Department of Agriculture, it encompasses rainfall data from 206 weather stations located across the United States for the period 1900–1933.[7] **Figures 3** and **4** reproduce two of the more than 50 rainfall maps published in Yarnell's study.

Technical Paper No. 40

Published in 1961 by the U.S. Department of Commerce, *Technical Paper No. 40*, "Rainfall

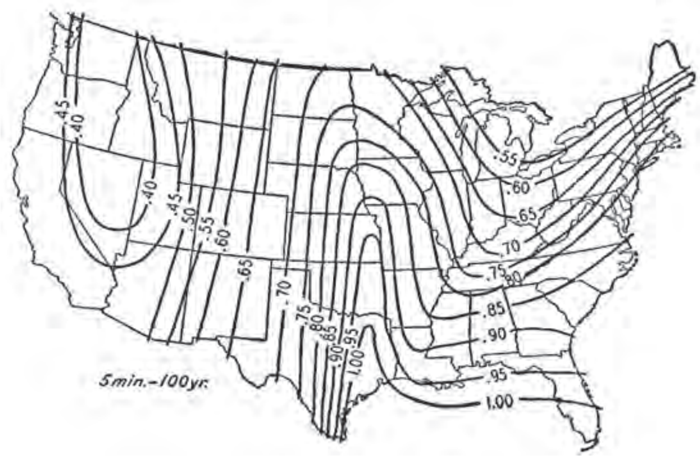


Figure 3. Five-minute rainfall, in inches, to be expected once in 100 years, as of the year 1935. Note that the data are given in inches (depth). To determine the rainfall intensity in inches per hour, multiply the depth given by each isohyet by 12. Reprinted from Yarnell.[6(p.31)]

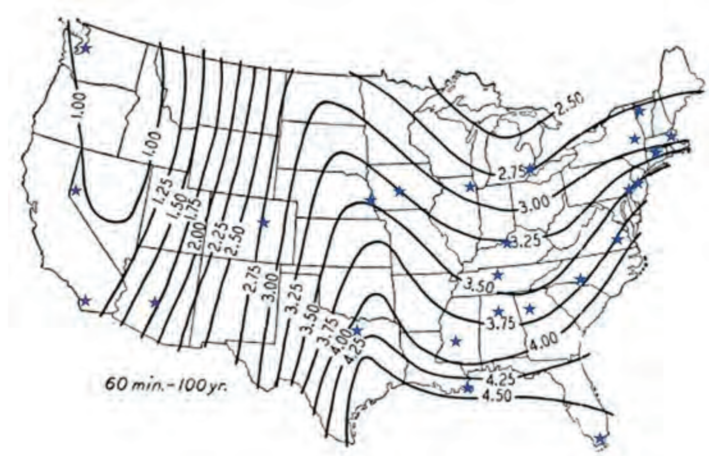


Figure 4. Sixty-minute rainfall, in inches, to be expected once in 100 years, as of the year 1935. Because the duration is 60 minutes, the map also shows rainfall intensities in inches per hour. Stars represent the locations of the cities listed in Tables 3, 5, and 6. Figure: Adapted from Yarnell.[6(p.43)]

Figure 5. Maximum projected roof area for drain pipes of various sizes and slopes. A rainfall intensity of 4 in./hr is assumed. The return period is not stated. Reprinted from 1949 UPC[10(p.49)]. Note: 1 in. = 25.4 mm.

Diameter of pipe (inches)	⅛ inch fall per foot	¼ inch fall per foot	½ inch fall per foot
1	2	3	4
	Square feet	*Square feet*	*Square feet*
2	------	350	500
3	750	1,050	1,500
4	1,550	2,150	3,100
5	2,700	3,600	5,400
6	4,200	6,000	8,400
8	8,700	11,900	17,400
10	15,200	19,600	30,400
12	24,700	31,800	49,400

Frequency Atlas of the United States"[8] made use of data from the same 206 weather stations as Yarnell's study, plus more than 6000 additional weather stations located across the United States. The average length of record for the weather stations ranged from 14 to 48 years. *Technical Paper No. 40* contains 49 county-delineated maps of the United States, for durations ranging from 30 minutes to 24 hours and return periods of 1 year to 100 years. The paper does not provide data for rainfalls of less than 30-minute duration. In need of such information, the authors of the 1987 *National Standard Plumbing Code* (NSPC)[9] converted the reported data via a series of multipliers.

Comparing the data provided in *Technical Paper No. 40* for the eastern half of the country to that in Yarnell, rainfall depths are very similar, rarely varying by more than 10%. For the mountainous regions of the western half of the country, however, rainfall rates are generally higher, sometimes by a factor of 3, due to the expanded collection of data in these regions in the years since Yarnell published his report.

1949 UPC and 1955 NPC

Neither the 1949 *Uniform Plumbing Code* (UPC)[10] nor the 1955 *American Standard National Plumbing Code* (NPC)[11] provides rainfall data by location via maps or tables. Rather, they provide a table indicating the maximum allowable projected roof area to be drained by pipes of various diameters and slopes given an assumed rainfall intensity of 4.0 in./hr (100 mm/hr). **Figure 5** reproduces the information provided in the 1949 UPC.

Notes accompanying the tables in both codes state:[10(p.49), 11(p.107)]

> If in any state, city, or other political subdivision, the maximum rate of rainfall is more or less than 4 inches per hour, then the above figures for roof area must be adjusted proportionally by multiplying the figure by 4 and dividing by the maximum rate of rainfall in inches per hour.

For example, if a 4-in.-diameter (100-mm) leader with a slope of ½ in./ft (42 mm/m) can accommodate up to 3100 ft² (290 m²) of roof area at a rainfall rate of 4 in./hr (100 mm/hr)

	⅛-in. Slope			¼-in. Slope			½-in. Slope		
	Maximum Projected Roof Area (ft²)								
Pipe Diameter (in.)	1949 UPC	1955 NPC*	2015–2021 IPC†	1949 UPC	1955 NPC*	2015–2021 IPC†	1949 UPC	1955 NPC*	2015–2021 IPC†
3	750	822	1323	1050	1160	1901	1500	1644	2671
4	1550	1880	2767	2150	2650	3922	3100	3760	5558
5	2700	3340	3970	3600	4720	5631	5400	6680	7965
6	4200	5350	8278	6000	7550	11,718	8400	10,700	16,579
8	8700	11,500	17,181	11,900	16,300	24,303	17,400	23,000	34,385
10	15,200	20,700	31,546	19,600	29,200	44,636	30,400	41,400	63,116
12	24,700	33,300	50,363	31,800	47,000	71,225	49,400	66,600	100,750
15	n/a	59,500	85,326	n/a	84,000	120,698	n/a	119,000	170,675

Note: n/a = not available. 1 in. = 25.4 mm; 1 ft = 0.3048 m.

* Maximum projected roof areas contained in the 2012 IPC are identical to those in the 1955 NPC.

† Original data were presented as capacity of the storm piping in gallons per minute and have been converted to capacity of the piping to accommodate a maximum projected roof area A, using the equation $A = 96.25 \times Q/I$, where Q = the flow (discharge) rate of a horizontal pipe of certain diameter and slope, in gallons per minute (GPM), and I = rainfall intensity in inches per hour. In this case, I was set at 4 in./hr to match the assumed rainfall intensity in the 1949 and 1955 plumbing codes.

Table 2. Maximum projected roof area for drain pipes at various slopes, with rainfall intensity of 4 in./hr.

(**Fig. 5**), and the actual rate for the building location is 6 in./hr (150 mm/hr), one would multiply 3100 by 4 and then divide the product by 6 to derive a maximum projected roof area of 2067 ft² (192 m²).

Interestingly, neither code provides a reference regarding where to find alternative rainfall intensities. Based on Yarnell's report, which was the most current publication containing rainfall data at the time the two codes were published, only a relatively small area of the United States, encompassing portions of Texas, Louisiana, Alabama, Mississippi, Florida, Oklahoma, Arkansas, Georgia, North Carolina, and South Carolina (see **Fig. 4**), was known to have a rainfall intensity greater than 4.0 in./hr (100 mm/hr), assuming a return period of 100 years. Still, the guidance contained in the codes appears to fall short, leaving many designers to potentially either over- or under-design required roof drains and conductor pipes.

How do the maximum projected roof areas able to be accommodated by drain pipes of various sizes and slopes contained in the 1949 UPC and 1955 NPC compare to those in the IPC? First, it is important to note that in the 1995–2012 editions of the IPC, maximum projected roof areas for various pipes sizes are based not only on the slope of the pipe (⅛:12, ¼:12, and ½:12), but also on rainfall intensity for a 100-year, 60-minute rain event. Interestingly, for a rainfall intensity of 4 in./hr (100 mm/hr), the maximum projected roof areas contained in Table 1106.3, "Size of Horizontal Storm Drainage Piping," of the 2012 IPC[12] exactly match those in the 1955 NPC (see **Table 2** for 1955 NPC data in this regard).

Beyond 2012, that is, for the 2015,[13] 2018,[14] and 2021 editions of the IPC, direct comparison to the 1949 UPC and 1955 NPC is more involved because the IPC no longer bases pipe sizing on projected roof area; instead, pipe sizing is based on flow capacity in gallons per minute (GPM). Starting with the 2015 IPC, Table 1106.3 was removed from the code and replaced with Table 1106.2, "Storm Drain Pipe Sizing, Capacity (GPM)." Table 1106.2 indicates that a 4-in.-diameter (100-mm) drain pipe sloping at ½ in./ft (42 mm/m) can accommodate a flow of 231 gal./min. (874 L/min.). Since flow (or discharge) rates in GPM cannot be used directly in designing roof drainage, it is necessary to convert the flow rate of the drain pipe to its drainage capacity in square feet of roof area (similar to the way this information used to be presented in the IPC prior to 2015). The appropriate equation for making this conversion is shown in **Equation 1**.[15]

$$A = 96.25Q/I$$

where

A = maximum projected roof area that can be drained

Q = the flow (discharge) rate of a horizontal pipe of certain diameter and slope, in gal/min.

I = rainfall intensity in inches per hour

Equation 1

Thus, the maximum projected roof area A that can be accommodated by a 4-in.-diameter (100-mm) pipe sloped at ½ in./ft (42 mm/m) at a rainfall intensity I of 4 in./hr (100 mm/hr) is 5558 ft² (516 m²) (96.25 × 231 gal./min. /4.0 in./hr). This is far greater than the maximum projected roof area contained in the 1949 UPC and 1955 NPC (see Table 2). In fact, the maximum projected roof area is up across the board for each pipe size/slope and each successive plumbing code (Table 2). For example, let us consider the 4-in. pipe diameter, which is one of the more common drain pipe sizes used in association with low-slope roofs: At a slope of ½ in./ft (42 mm/m), the maximum projected roof area increased by 21% from the 1949 UPC to the 1955 UPC, and by 48% from the 1955 UPC to the 2015 IPC.

Because the flow rate through a pipe Q is in the numerator of Eq. (1) and rainfall intensity I is the denominator, the data suggest that Table 1106.2 in the 2015, 2018, and 2021 editions of the IPC reflect increased flow rates through drainage pipes, reduced rainfall intensities, or some combination of the two. If reduced rainfall intensities are the primary explanatory factor, this would seem to be a move in the wrong direction.

1975, 1987, and 1996 NSPC

Appendix A of the 1975 National Standard Plumbing Code (NSPC)[16] provides rainfall intensities in inches per hour in tabular format for various U.S. cities based on a 10-year, 5-minute rainfall. A footnote for the table indicates that the data provided are derived from *Technical Paper No. 25*, "Rainfall Intensity-Duration-Frequency Curves,"[17] published by the U.S. Department of Commerce, Weather Bureau, in 1955.

Appendix A of the 1987 NSPC[9] provides a map of the United States indicating rainfall intensities in inches per hour based on a 10-year, 15-minute rainfall. Guidance accompanying the rainfall map suggests increasing the values shown by 20% to obtain rainfall intensities for a 100-year return period.

Appendix A of the 1996 NSPC,[18] like the 1975 NSPC, provides rainfall intensities in inches per hour in tabular format for various U.S. cities, but instead of being based on a 10-year, 5-minute rainfall, the 1996 appendix provides two different rainfall intensities for each city: a 100-year, 60-minute rainfall to be used in the sizing of primary roof drainage systems, and a 100-year, 15-minute rainfall for use in sizing secondary drainage systems. These rainfall data were derived from *Technical Paper No. 40*, published in 1961.

1995–2021 IPC

Figure 1106.1 in the 2021 IPC (Figure 1107.1 in the 1995 IPC[19]) provides rainfall rates for all 50 states in inches, based on a rainfall of 60-minute duration and a return period of 100 years. Five regional maps (eastern US, central US, western US, Alaska, and Hawaii) delineated by county are provided. Appendix B of the IPC provides rainfall rates for various U.S. cities in tabular format. The stated source of the rainfall data is NOAA, and the data are unchanged over the 26-year period from 1995 to 2021, except for corrections of typographical errors and omissions.

The isohyets in the IPC maps have shifted relative to those presented by Yarnell in 1935 (**Fig. 6**). If there are any trends, it is that the isohyets in the 2021 IPC generally start out further south (except for those representing rainfalls of 4.0 and 4.25 in. [100 and 113 mm]) and are more convoluted compared to those contained in Yarnell. These differences may have to do, at least in part, with the greater number of weather stations and greater amount of historical data reflected in the IPC maps.

Figure 6. Yarnell's 100-year, 60-minute isohyets[6] (shown in red; locations are approximate) overlaid on the 2021 International Plumbing Code[3] Figure 1106.1, "100-Year, 1-Hour Rainfall Map of the Eastern United States." The isohyets have become more convoluted and generally shifted to the south over time.

CODE COMPARISONS

Historically, rainfall data referenced in the plumbing codes promulgated in the United States have been outdated and inconsistent with regard to duration and return period of rainfalls serving as the basis for the sizing of rainwater conduction systems. And, while 100-year, 60-minute rainfall intensity data have remained fairly consistent over time on an overall basis, more recent rainfall data for some cities far exceed the data contained in the IPC and earlier codes. Further, when the data for more-intense rainfalls are examined, the trend is clear: recent rainfall intensities for shorter-duration rainfall events have increased for a majority of cities examined, and they far exceed the rainfall intensity data in the IPC.

Table 3 presents stipulated rainfall intensity data given in the various U.S. plumbing codes discussed previously. Interestingly, the 1975, 1987, 1996, 2018, and 2021 codes all make use of rainfall data that were at least 20 years old. The IPC states that the rainfall data presented derive from NOAA data. Rainfall data appear to be updated periodically (although not necessarily consistently across all regions) by NOAA and available online. As such, there would seem to be no technical reason not to update the rainfall data in the IPC on the same triennial cycle the ICC updates all of its model codes.

With two exceptions (Miami, Fla., and Seattle, Wash.), code-stipulated rainfall intensities decreased from the 1975 to the 1987 NSPC, as would be expected since the rainfall duration in the codes increased from 5 minutes to 15 minutes. Likewise, rainfall intensities decreased from the 1987 to the 1996 NSPC; again, this is as would be expected, since both the rainfall duration and return period increased.

	Code/Rainfall Intensity (in./hr) for Stipulated Duration and Return Period					
	1949 UPC	1955 NPC	1975 NSPC*	1987 NSPC†	1996 NSPC‡	1995–2021 IPC
City	Unknown Unknown	Unknown Unknown	10 Year, 5 Min.	10 Year, 15 Min.	100 Yr., 60 Min.	100 Yr., 60 Min.
Birmingham, AL	4.0	4.0	7.0	6.0	3.7	3.8
Phoenix, AZ	4.0	4.0	4.3	4.0	2.2	2.5
Los Angeles, CA	4.0	4.0	3.6	3.0	2.0	2.1
Denver, CO	4.0	4.0	5.7	4.0	2.2	2.4
Hartford, CT	4.0	4.0	6.2	4.0	2.8	2.7
Miami, FL	4.0**	4.0**	7.5	9.0	4.5	4.7
Atlanta, GA	4.0	4.0	7.7	6.0	3.5	3.7
Chicago, IL	4.0	4.0	7.0	5.0	2.7	3.0
Des Moines, IA	4.0	4.0	6.4	6.0	3.4	3.4
Louisville, KY	4.0	4.0	7.0	5.0	2.8	3.2
New Orleans, LA	4.0**	4.0**	8.2	8.0	4.5	4.8
Boston, MA	4.0	4.0	5.5	5.0	2.7	2.5
Detroit, MI	4.0	4.0	6.4	4.0	2.5	2.7
Jackson/ Vicksburg, MS	4.0	4.0	7.5	6.0	3.8	4.1
Omaha, NE	4.0	4.0	7.0	6.0	3.6	3.8
Reno, NV	4.0	4.0	3.2	3.0	1.2	1.1
Trenton, NJ	4.0	4.0	6.4	5.0	3.2	3.1
Albany, NY	4.0	4.0	6.0	4.0	2.5	2.5
Charlotte, NC	4.0	4.0	7.0	6.0	3.4	3.7
Philadelphia, PA	4.0	4.0	6.5	5.0	3.2	3.1
Charleston, SC	4.0**	4.0**	7.0	7.0	4.1	4.3
Nashville, TN	4.0	4.0	7.2	5.0	3.0	3.3
Dallas, TX	4.0**	4.0**	7.2	7.0	4.2	4.0
Burlington, VT	4.0	4.0	5.4	4.0	2.3	2.1
Richmond, VA	4.0	4.0	7.2	6.0	4.0	3.3
Seattle, WA	4.0	4.0	2.2	3.0	1.0	1.4

Note: 1 in. = 25.4 mm.

* Rainfall intensity data in the code were derived from *Technical Paper No. 25*.[17]

† Rainfall intensity data in the code were derived from *Technical Paper No. 40*,[8] Chart 4, "10-year, 30-minute rainfall," and converted to 10-year, 15-minute rainfalls.

‡ Rainfall intensity data in the code were derived from *Technical Paper No. 40*,[8] Chart 14, "100-year, 1-hour rainfall."

** Since the rainfall in these cities is greater than 4 in./hr based on Yarnell's 100-year, 60-minute rainfall intensity map (see Fig. 4), the rainfall intensity would have had to been adjusted based on the instructions given in the code.

Table 3. Rainfall intensity for various U.S. cities as given in plumbing codes published from 1949 to 2021.

The IPC rainfall data are unchanged since 1995. Comparing the 1995–2021 IPC data to the similar-duration/return period data contained in the 1996 NSPC (that is, 60-minute/100-year rain events), the rainfall intensities in the IPC are generally higher for the 26 representative cities listed in Table 3, as well as for the 110 cities commonly listed in the two codes. Fifty-six of the cities listed in the 1995-2021 IPC had rainfall intensities greater than those given in the 1996 NSPC, whereas 33 cities had lower rainfall intensities, and 21 cities remained unchanged. Overall, the average rainfall intensity for all 110 cities increased 0.06 in./hr (1.5 mm/hr), from 2.93 in./hr (74.4 mm/hr) in the 1996 NSPC to 2.99 in./hr (75.9 mm/hr) in the 1995–2021 IPC.

Still, one has to wonder whether the rainfall intensity rates provided in the codes should not have increased even more between 1961 and 2021 (recall that the source of rainfall data in the 1996 NSPC is *Technical Paper No. 40*, published in 1961). Rainfall data currently (as of February, 2021) contained on NOAA's PFDS website[4] for the 110 cities listed in the 1996 NSPC and 1995–2021 IPC indicate an average intensity for 100-year, 60-minute rain events of approximately 2.93 in./hr (74.4 mm/hr); this average has not changed since 1961. (Note that data for several upper northwestern states were estimated by the author to be the same as that in the 2021 IPC because no current NOAA rainfall data are available for these states.) Granted, 110 cities is a very small sampling of the thousands of weather stations from which data were sampled in *Technical Paper No. 40* (source of the data for the 1996 NSPC) and those that are searchable on NOAA's website. Still, on an average, overall basis, the change in rainfall intensity for a 100-year, 60-minute rain event is likely to be small when comparing rainfall data published in 1961 and 1995 to the present. Further, for many locations, the change in rainfall intensity over these periods would be insignificant and have no impact on the sizing of rainwater conduction systems.

What is concerning, however, is that for some cities, the changes in rainfall intensity data published between 1961 and 2021 are substantial (**Table 4**). For example, the 100-year, 60-minute rainfall intensity data for Miami in the 1996 NSPC is 0.7 in./hr less than the data from NOAA's PFDS. Per Chart 1-1, "Width of Rectangular Gutters for Given Roof Areas and Rainfall Intensities," in the Sheet Metal and Air Conditioning Contractors' National Association's (SMACNA's) *Architectural Sheet Metal Manual*,[20] using the NOAA PFDS data

City	Rainfall Intensity: 100-Year, 60-Minute Rainfall, in./hr			
	1996 NSPC (based on data published in 1961, in *Technical Paper No. 40*)	1995–2021 IPC	NOAA PFDS (accessed Feb. 2021; publication dates may vary)	Maximum Difference between Previous Codes and PFDS Data
Durango, CO	1.8	1.8	2.2	0.4
Miami, FL	4.5	4.8	5.2	0.7
New Orleans, LA	4.5	4.8	5.4	0.9
Grand Rapids, MI	2.6	2.6	2.9	0.3
Minneapolis, MN	3.0	3.1	3.7	0.7

Note: 1 in. = 25.4 mm.

Table 4. Cities with substantial rainfall intensity changes, 1961–2021.

instead of the 1996 NSPC data would require an increase in gutter width from 5 to 6 in. (125 to 150 mm). Another example concerns maximum drainable roof areas in the design of low-slope roofs. The 2021 IPC indicates in Table 1106.2, "Storm Pipe Sizing," that the drainage capacity of a 6-in. (150-mm) vertical pipe is 538 gal./min. (2037 L/min.). For a rainfall intensity of 4.8 in./hr (122 mm/hr) in New Orleans, La., the maximum roof area that can be drained by this pipe is 10,788 ft^2 (1002 m^2) (as calculated using Eq. [1]). If the rainfall intensity is increased to 5.4 in./hr (137 mm/hr) using data from NOAA's PFDS, the maximum roof area that can be drained falls to 9589 ft^2 (891 m^2), a difference of 1199 ft^2 (111 m^2) or about 11%. Thus, it would seem that having accurate, reasonably current, rainfall intensity data in our plumbing codes is important to help ensure that roof drainage systems are designed to accommodate probable rain events.

The preceding review is for a 100-year, 60-minute rain event. What do the data look like for more-intense rainfalls? The trends in 10-year, 5-minute and 100-year, 5-minute intensities for the same 26 cities previously examined are clear (**Table 5**). The 10-year, 5-minute rainfall intensity for almost 70% of the cities increased between 1955 and 2021 (publication dates for the data and not necessarily the years in which the data were collected), dramatically in some cases (for example, Miami, New Orleans, or Charleston, S.C.). The same is true for the 100-year, 5-minute rainfall over the period from 1935 to 2021 (again, publication dates for the data), with the average intensity increasing by 1.0 in./hr (25 mm/hr). It would appear, then, that the intensity of shorter-duration, 5-minute, rainfall events has increased over time to a greater degree than the longer-duration, 60-minute rainfall events. (Whether this increase is due to an actual increase in rainfall intensity or more improved data acquisition/record keeping is irrelevant from the standpoint of roof drainage system design.) Because the IPC does not mention shorter-duration rain events for primary, or secondary, roof drainage systems, the increase in intensity of the shorter-duration rain events may be going unnoticed by many roof system designers and generally omitted from calculations used to determine the minimum customary sizing of roof drainage components. This is unfortunate as more-intense, shorter-duration rain events have the greatest potential to overwhelm rainwater conduction systems, especially if a component of the primary drainage system is clogged. Keep in mind, as well, that rainfall data, including those presented in this paper, typically represent historical averages and that momentary rainfalls can exceed those averages.

INDUSTRY STANDARDS

Given the increase in intensity for shorter-duration rainfall events, it is interesting to note that two well-known flashing and sheet metal design guides have long made the sizing of rainwater conduction systems a function

City	Publication Year and Source/Rainfall Intensity (in./hr) for Stipulated Duration and Return Period			
	1975 NSPC (based on data published in 1955, in *Technical Paper No. 25*)	NOAA PFDS (accessed Feb. 2021; publication dates may vary)	1935 YARNELL	NOAA PFDS (accessed Feb. 2021; publication dates may vary)
	10 Year, 5 Min.	10 Year, 5 Min.	100 Year, 5 Min.	100 Year, 5 Min.
Birmingham, AL	7.0	8.27	10.8	12.20
Phoenix, AZ	4.3	4.52	6.0	7.19
Los Angeles, CA	3.6	3.43	6.0	5.45
Denver, CO	5.7	5.36	8.4	9.55
Hartford, CT	6.2	7.49	9.6	11.40
Miami, FL	7.5	11.0	12.0	15.70
Atlanta, GA	7.7	7.74	10.2	11.60
Chicago, IL	7.0	7.36	8.4	10.20
Des Moines, IA	6.4	7.94	10.8	12.50
Louisville, KY	7.0	6.85	8.4	9.22
New Orleans, LA	8.2	10.50	11.4	15.40
Boston, MA	5.5	6.89	9.6	10.90
Detroit, MI	6.4	6.52	7.2	10.00
Jackson/Vicksburg, MS	7.5	9.02	10.8	12.80
Omaha, NE	7.0	7.56	10.8	11.80
Reno, NV	3.2	2.11	5.4	4.09
Trenton, NJ	6.4	6.52	9.6	8.56
Albany, NY	6.0	6.38	8.4	9.86
Charlotte, NC	7.0	7.24	10.2	9.04
Philadelphia, PA	6.5	6.44	9.6	8.17
Charleston, SC	7.0	9.43	10.8	12.60
Nashville, TN	7.2	6.82	9.0	8.83
Dallas, TX	7.2	8.32	12.0	12.10
Burlington, VT	5.4	6.30	7.2	9.50
Richmond, VA	7.2	7.02	10.2	9.14
Seattle, WA	2.2	not available	5.4	not available
Average	6.4*	7.08	9.3*	10.31

Note: 1 in. = 25.4 mm.

*Seattle data are excluded from average.

Table 5. Comparison of rainfall intensity data for more intense rain events, various U.S. cities, 1935–2021.

of shorter-duration rainfalls. Revere Copper's *Copper and Common Sense*[21] and SMACNA's *Architectural Sheet Metal Manual* both provide more conservative rainfall intensity data than the IPC. *Copper and Common Sense* includes three maps on page 9.B.5 (derived from Yarnell's report) depicting data for 5-year, 5-minute; 10-year, 5-minute; and 25-year, 5-minute rainfall events in inches. SMACNA's Table 1-2 provides 10-year, 5-minute and 100-year, 5-minute rainfall intensities in inches per hour for various U.S. cities (stated to be derived from National Climatic Data Center historical records). In both cases, the rainfall intensities offered far exceed those contained in the 1995–2021 editions of the IPC. This is to be expected since the IPC references only rainfalls having a duration of 60 minutes. **Table 6** compares the rainfall intensities in the Revere Copper and SMACNA publications with those in the IPC for a sampling of cities.

Using downspout sizing as an example, if we use the *Architectural Sheet Metal Manual's* 100-year, 5-minute rainfall intensity of 9.3 in./hr (236 mm/hr) for Chicago, a gable-roofed building in that city with a projected roof area of 8500 ft^2 (790 m^2) and a roof slope of 6:12, served by four downspouts, would require 6-in. (150-mm) corrugated round or 4 × 6 plain rectangular downspouts. In contrast, if the IPC's 100-year, 60-minute rainfall is employed in sizing the downspouts, 3-in. (75-mm) corrugated round or 2 × 3 plain rectangular downspouts will suffice. They would also likely become overwhelmed in a heavy rain, with the possible consequence of causing the gutters to overflow, thereby potentially causing erosion at grade or increasing the risk of rainwater infiltrating the building's foundation.

	Copper and Common Sense			*Architectural Sheet Metal Manual*		IPC
City	5 Year, 5 Min.	10 Year, 5 Min.	25 Year, 5 Min.	10 Year, 5 Min.	100 Year, 5 Min.	100 Year, 60 Min.
Chicago, IL	6.0	6.6	7.2	6.8	9.3	3.0
Dallas, TX	7.2	7.8	9.6	7.6	10.5	4.0
Denver, CO	4.8	5.4	6.6	5.7	9.1	2.4
Los Angeles, CA	3.6	4.2	4.8	4.9	6.7	2.1
Philadelphia, PA	6.0	6.6	8.4	6.8	9.4	3.1

Note: 1 in. = 25.4 mm.

Table 6. Rainfall intensity data (in./hr) for representative cities, Copper and Common Sense *and* Architectural Sheet Metal Manual *as Compared to the IPC.*

The Metal Building Manufacturers Association's (MBMA's) *Metal Roofing Systems Design Manual*,[22] another industry design guide, also recommends the use of shorter-duration rainfall events in the design of roof drainage systems. The Manual's Climatological Data Spreadsheet contains rainfall intensity data derived from NOAA's PFDS for each county in all 50 states for 5-year, 5-minute and 25-year, 5-minute rainfalls. The MBMA recommends the use of 5-year, 5-minute rainfall intensity data in the design of exterior drainage systems and 25-year, 5-minute data in the design of "interior systems" (for example, internal downspouts and built-in gutters), noting that "the risk of property loss is much higher where an interior drainage system is involved."[22(p.192)]

A note associated with SMACNA's table[20(p.1.3)] aptly states that its "design approach typically yields conservative sizing of gutters and downspouts versus code-based methods. The code represents a minimum design requirement and must be complied with[,] but where undersizing the roof drainage system presents risks[,] the building's designer should weigh the cost versus the risk." In other words, use of rainfall data contained in the plumbing code may result in an undersized roof drainage system and the owner, with advisement from a well-informed designer, should decide if this is really in their best interest. Similarly, the MBMA states that its rainfall intensity values are "actually 2 to 2.5 times more conservative than the IBC/IPC," and that "this conservatism is due to the more realistic duration of five minutes for the roof area of a building."[22(p.197)]

RECOMMENDATIONS

Rainfall intensity data is the basis on which roof drainage systems are sized. The IPC's 100-year, 60-minute rainfall intensity data are outdated. And, while this might be an issue for some cities (see Table 4), the more critical issue is that the IPC's rainfall intensity data do not recognize the reality that more-intense, shorter-duration rainfalls (5- or 10-minute downpours) have become commonplace, with the potential to overwhelm roof drainage systems and cause severe damage. With this in mind, the following are some practical suggestions for addressing the shortfalls of the rainfall data contained in the IPC:

- At minimum, compare the 100-year, 60-minute rainfall data in the IPC for the project location to the data that can be found on NOAA's PFDS website, https://hdsc.nws.noaa.gov/hdsc/pfds, and use the more conservative (higher) rainfall intensity in sizing of roof drainage systems. Section 1106.1 of the IPC[3(p.11-3)] specifically allows the use of "other rainfall rates determined from *approved* [acceptable to the code official] local weather data."
- Do not use 100-year, 60-minute rainfall intensity data as the basis of design for secondary drainage systems. Such systems are meant to be fail-safe backups. Rather, consider sizing secondary drainage as a function of 100-year, 15-minute rainfall intensities.[23]
- An even more conservative approach is to size primary roof drainage systems based on more-intense, 100-year, 15-minute or 100-year, 5-minute, rainfall data and use 100-year, 5-minute data for secondary drainage systems. This approach might be well suited for critical facilities, projects in the Midwest and Northeast regions of the United States (where the trend is toward increased precipitation; reference Fig. 1), projects in cities with a record of intense rainfalls (for example, Miami; New Orleans; Charleston, S.C.; Jackson, Miss.; reference Table 5), as well as for those adopting resilient design strategies.
- Where cost may be an issue, consider incorporating more-conservative approaches to the sizing of rainwater conduction systems as an alternative in bid documents, thereby allowing the owner to select the cost/risk trade-off that best meets their needs. Cost

Where cost may be an issue, consider incorporating more-conservative approaches to the sizing of rainwater conduction systems as an alternative in bid documents, thereby allowing the owner to select the cost/risk trade-off that best meets their needs.

may not be an issue when upsizing a few aluminum downspouts from 3-in. (75-mm) diameter to 4-in. (100-mm) diameter, but may when, for example, designing replacement built-in gutter liners, where the addition of downspouts requires re-sloping of gutter troughs.

REFERENCES

1. *Climate Change Indicators: Weather and Climate.* Washington, D.C.: U.S. Environmental Protection Agency, 2016. <https://www.epa.gov/climate-indicators/weather-climate/>. Accessed Feb. 1, 2021, 2:16 p.m. A PDF with similar information can be found here: U.S. Environmental Protection Agency. *Climate Change Indicators in the United States*, 4th ed. EPA 430-R-16-004. 2016. https://www.epa.gov/sites/production/files/2021-02/documents/climate_indicators_2016.pdf.
2. Taking a step back, and notwithstanding the causes of global warming, the fact is as temperatures rise, the rate of evaporation from the oceans increases. At the same time, as the atmosphere warms, it can hold more moisture. Combined, these two factors contribute to more rain concentrated in fewer, but more-intense events.
3. International Code Council (ICC). *International Plumbing Code*, 2021 ed. Country Club Hills, IL: ICC, 2020.
4. National Oceanic and Atmospheric Administration (NOAA). National Weather Service Precipitation Frequency Data Server. Accessed February 3, 2021. https://hdsc.nws.noaa.gov/hdsc/pfds. Rainfall data contained on this website appear to be the most current data available to the public. Note, however, that the data are sourced from NOAA's Atlas No. 14, some volumes of which were published between 2006 and 2018, or earlier. Thus, even NOAA's PFDS data may not be all that current.
5. ICC. *International Building Code*. Country Club Hills, IL: ICC, 2018.
6. Yarnell, D. L. *Rainfall Intensity-Frequency Data*. Miscellaneous Publication No. 204. Washington, DC: U.S. Department of Agriculture, 1935. https://naldc.nal.usda.gov/download/CAT87205951/PDF.
7. Not all 206 weather stations were in operation for the full 33-year period. Rather, periods of data collection vary between 20 years, 24.5 years, and 33 years, resulting in an average period of record of 29.5 years.
8. Hershfield, D. M. "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years." U.S. Department of Commerce Weather Bureau *Technical Paper No. 40*. Washington, DC: U.S. Department of Commerce, 1961. https://www.weather.gov/media/owp/oh/hdsc/docs/TechnicalPaper_No40.pdf.
9. National Association of Plumbing-Heating-Cooling Contractors (NAPHCC). *National Standard Plumbing Code*. Falls Church, VA: NAPHCC, 1987.
10. Uniform Plumbing Code Committee. *Uniform Plumbing Code: Report of the Uniform Plumbing Code Committee*. Washington, DC: U.S. Department of Commerce and Housing and Home Finance Agency (jointly), 1949.
11. American Society of Mechanical Engineers (ASME). *American Standard National Plumbing Code: Minimum Requirements for Plumbing*. New York: ASME, 1955.
12. ICC. *International Plumbing Code*, 2012 ed. Country Club Hills, IL: ICC, 2011.
13. ICC. *International Plumbing Code*, 2015 ed. Country Club Hills, IL: ICC, 2014.
14. ICC. *International Plumbing Code*, 2018 ed. Country Club Hills, IL: ICC, 2017.
15. Patterson, S.; M. Mehta; and J. R. Wagner. *Roof Drainage*. Raleigh, NC: Roof Consultants Institute Foundation, 2003, p. 45. This equation can also be derived from eq. (11.1) in the 2021 IPC, which states: $Q = I \times A \times 0.0104$.
16. NAPHCC. *National Standard Plumbing Code*. Washington, DC: NAPHCC, 1975.
17. U.S. Department of Commerce Weather Bureau. "Rainfall Intensity-Duration-Frequency Curves for Selected Stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico." U.S. Department of Commerce, Weather Bureau, *Technical Paper No. 25*. Washington, DC: U.S. Department of Commerce, 1955. https://www.weather.gov/media/owp/oh/hdsc/docs/TP25.pdf.
18. NAPHCC. *National Standard Plumbing Code*. Falls Church, VA: NAPHCC, 1996.
19. ICC. *International Plumbing Code*, 1995 ed. Country Club Hills, IL: ICC, 1994.
20. Sheet Metal and Air Conditioning Contractor's National Association. *Architectural Sheet Metal Manual*, 7th ed. Chantilly, VA: Sheet Metal and Air Conditioning Contractor's National Association, 2012.
21. Revere Copper Products. *Copper and Common Sense*, 8th ed. Rome, NY: Revere Copper Products, 2005.
22. Metal Building Manufacturers Association. *Metal Roofing Systems Design Manual*, 2nd ed. Cleveland, OH: Metal Building Manufacturers Association, 2012.
23. FM Global's Data Sheet 1-54, recommends using two-times the 100-year, 60-minute rainfall intensity for the design of secondary roof drainage systems. The Data Sheet, however, goes on to state: "Alternatively, the use of the 100-year, 15-minute rainfall intensity is acceptable if it is from a nationally recognized source (e.g., a national weather service)." (Source: FM Global. Property Loss Prevention Data Sheet 1-54: *Roof Loads and Drainage*, April, 2021, Section 2.5.4.1.C.2).

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