Relabeling Extreme Rainfall Events so the Public Understands Their Severity

By
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Abstract

Why are rain events labeled based on recurrence intervals? The public does not understand how the 100-year rain event can occur more than once in 100 years. In addition, two 100-year events may occur that are completely different in duration and intensity, but are both called the 100-year event. This is confusing to the public and leads to problems for engineers explaining how this could happen.

Other natural disasters (e.g. earthquakes, tornadoes, hurricanes) are rated using scales based on other factors than recurrence intervals or probability of these events occurring. The public understands the ratings for these other natural weather events since they use a simple scale to rate the severity of the event, not the rarity of the event.

This paper proposes that the industry rerate rainstorms, building on existing science, but changing the designation from a recurrence interval standard to one that is more general in description and more understandable to the public, similar to the rating of other natural disasters.

Subject Headings:
1. Floods
2. Hydrology
3. Municipal government
4. Natural disasters
5. Probability
6. Rainfall
7. Rainfall frequency
8. Stormwater management

Frustration – It Happened Again

The 100-year storm. How many times must I tell a resident in my career that the City has experienced yet another 100-year storm? It has now happened five times in Brookfield in the past 23 years, since 1986. It happened twice in back-to-back years (1997 & 1998 and 2008 & 2009). Residents do not understand this, and it can be difficult explaining it in terms they can understand.

Many of us have been there. Intense rainfall events occur again, resulting in widespread flooding … again. Then we have the audacity to tell the residents that this rainstorm, which overwhelmed our storm sewer system, did so because it was the 100-year rain event. The residents explode. They do not believe us. The City already had a 100-year event last year and three more prior to that. The 100-year rain event should not occur five times in 23 years. It is hard not to agree with them.

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Engineers understand the methodology used to develop recurrence intervals and the probability of rain events, given the historic rains that occur in an area. But as a practitioner, this understanding and our explanation of it to residents does not help people understand the severity and magnitude of these events or the statistical probability of these events happening every year. Residents think the engineers are either dumb or lying about the event, thus destroying the credibility of civil engineers everywhere.

Why do we as a profession label these events based on their recurrence interval? Some in the industry have changed their approach to this and are using probability of rain event instead. But the public is not easily fooled. They can easily figure out that a one percent storm has a 1 in 100 chance of occurring, and therefore it's the 100-year storm.

This paper offers an alternative rating system for rainstorms. The proposed system does not apply to rainfall discharges, runoff, floods, or floodplains, since they do not influence the storm. Instead, the intensity and duration of the storm affects these factors.

Other Types of Natural Disasters Defined Differently

Other professionals label natural disasters in other ways. Seismologists use the Richter scale to rate earthquakes, basing the rating on a measure of the amount of energy released as the strength and duration of the earthquakes seismic waves. The Fujita scale (or F-scale), now the Enhanced Fujita scale (since 2007) uses the intensity and area affected / damage created by tornadoes to rate them. Meteorologists use the Saffir-Simpson scale to rate hurricanes using barometric pressure, wind speeds and storm surge to define a hurricane's intensity into categories.

These professionals do not estimate recurrence intervals for these events or predict probability of these events occurring. They use a simple scale to describe the severity of the event. The public understands that for earthquakes, tornadoes and hurricanes, the higher the number the worse the storm.

Severity versus Rarity

The public identifies with the ratings for these other natural weather events since their main concern is how severe the event may be. However, the current rating for rain events defines how rare the event is, not how severe it is. It is not uncommon for severe storms to hit an area more than once in a decade and sometimes two years in a row, as has been the case in Brookfield. Defining the storm by its severity impresses on the public that these are huge events and people should do what they can to minimize the storm's impact to their property. Defining the storms by their frequency unfortunately misleads the public into thinking that once it happens, it will be a long time until it happens again.

It is inappropriate to continue to foster this notion among the public that these storms are rare. The profession needs a different method of describing these storms to the public to reinforce the concept of severity of the storm, not rarity of the storm.

An Alternate Rating System Proposed

The industry should reevaluate how we rate these rainstorms and change our designation from the recurrence interval and probability standard to one that is more general in description and more understandable to the public, similar to how we rate the other natural disasters. Before you think this is throwing out the baby with the bath water keep on reading. This new system can use existing science that is already in place. We can modify what we call these events without necessarily changing the science behind it.

Specifically the storms could be rated based on rainfall intensities and total rainfall accumulation. This builds on and uses the data and science already established for recurrence interval storms. So the analysis of these rainfall events and design of infrastructure does not need to change. Essentially this proposal is to add a public user interface on the engineering and statistical analysis performed behind the scenes, not unlike adding a graphical user interface to an engineering or hydrologic model. The computer model does not change, but it is easier for the user to perform data entry into and understand output from the model.

The proposed rating system identifies categories of storms, based on rainfall intensities and total rainfall accumulation and identifies the recurrence interval storm event associated with each rating. Essentially the category rating is the exponent (called a G-factor) applied to the number two to identify the recurrence interval for that rain event. This can be defined by the formula:

$$\mathbf{RI = 2^{(G-1)}}$$

Where: RI = Recurrence Interval of Rain Event, and
G = the Category of the Storm

For example, to rate a 2-year storm using the equation above, one must solve for G. When RI = 2, the exponent must be 1. To get an exponent of 1, the G-factor must be 2 (2 -1 = 1). A G-factor of 5 defines a 16-year event since 2 to the power of (5-1) results in an answer of 16.

Table 1 shows recurrence intervals placed into each category of storm.

Table 1 – Categorizing Rain Storms Based on Rainfall Intensity and Total Rainfall

Category of Storm	Identified Recurrence Interval Rain Storm
G - 1	< 2 year storm
G - 2	2 to 4 year storm
G - 3	4 to 8 year storm
G - 4	8 to 16 year storm
G - 5	16 to 32 year storm
G - 6	32 to 64 year storm
G - 7	64 to 128 year storm
G - 8	128 to 256 year storm
G - 9	> 256 year storm

There is no reason to stop the rating of storms at G-9. The above is just an example of how this would work.

To look at it another way, the 10-year storm has a G-factor of 4.32 (2 to the power of 3.32) and would therefore fall within Category G-4. The 100-year storm has a G-factor of 7.64, thus it would be considered a Category G-7 storm. Table 2 depicts the actual G-factor for commonly defined recurrence interval storms.

Table 2 – Identifying G-Factors for Specific Recurrence Interval Storms

Recurrence Interval Rain Storm	G-factor	Category of Storm
2 year storm	2	G - 2
5 year storm	3.32	G - 3
10 year storm	4.32	G - 4
25 year storm	5.64	G - 5
50 year storm	6.64	G - 6
100 year storm	7.64	G - 7

<u>Adjustment for Duration of Storm</u>

Different rain events have different effects on runoff and flooding. When two very dissimilar events are both called the 100-year storm, the public gets confused. Short duration 100-year storms may result in culvert and roadside washouts, while long duration 100-year storms can result in widespread flooding.

To account for these differences there should be an adjustment factor to address this issue in the rating system. This can be done by considering the relationship of total rainfall by recurrence interval of a given duration to the 24 hour duration storm. This ratio can then be used as an adjustment to the selected category storm. Table 3 shows the rainfall depth in inches for Southeastern Wisconsin.

Table 3 - Recurrence Interval and Depth of Rainfall (inches)

Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	1.31	1.60	1.84	2.20	2.50	2.82
2 hour	1.54	1.93	2.23	2.73	3.16	3.64
3 hour	1.68	2.07	2.40	2.93	3.39	3.89
6 hour	1.95	2.40	2.79	3.44	4.03	4.70
12 hour	2.24	2.74	3.17	3.89	4.53	5.25
24 hour	2.57	3.14	3.62	4.41	5.11	5.88
2 day	3.04	3.71	4.20	4.94	5.53	6.13
3 day	3.29	3.94	4.40	5.09	5.63	6.17
5 day	3.77	4.42	4.84	5.43	5.86	6.26
10 day	4.68	5.42	5.89	6.55	7.03	7.46

Rainfall data is based on Milwaukee rainfall data for the 108-year period of 1891 to 1998.
Source: Rodgers and Potter (2000)

Using this data, a simple ratio between the total rainfall for a given duration event as compared to the 24-hour duration event becomes the duration adjustment factor. The 24-hour duration is the basis for comparison since engineers most commonly use this duration for design storms and it is the basis of the category system proposed above. The duration adjustment factor formula is:

$$\text{Duration Adjustment Factor (DAF)} = \frac{\text{Total rainfall for X-year Y hour duration storm}}{\text{Total rainfall for X-year 24 hour duration storm}}$$

The ratio of total rainfall by duration as compared to the 24-hour duration event for each storm identified in Table 3 is shown in Table 4.

Table 4 –
Recurrence Interval and Ratio of Rainfall by Duration to the 24 hour Storm

Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	51 %	51 %	51 %	50 %	49 %	48 %
2 hour	60 %	61 %	62 %	62 %	62 %	62 %
3 hour	65 %	66 %	66 %	66 %	66 %	66 %
6 hour	76 %	76 %	77 %	78 %	79 %	80 %
12 hour	87 %	87 %	88 %	88 %	89 %	89 %
24 hour	100 %	100 %	100 %	100 %	100 %	100 %
2 day	118 %	118 %	116 %	112 %	108 %	104 %
3 day	128 %	125 %	122 %	115 %	110 %	105 %
5 day	147 %	141 %	134 %	123 %	115 %	106 %
10 day	182 %	173 %	163 %	149 %	138 %	127 %

To refine the rating of the storm for duration, multiply this duration adjustment factor by the G-factor for all storms based on duration. For example, a 100-year storm is defined as a Category G-7 storm in accordance with Tables 1 and 2. For a 100-year storm that has a 1 hour duration, the duration adjustment factor is 48%. Multiplying 7 (Category G-7) by 48% results in 3.36, round to 3. Therefore, this 1 hour duration 100-year storm would be defined as a Category G-3 storm.

Calculate a longer duration storm the same way. For example, Table 1 rates a 10-year storm as a Category G-4 storm. If the duration was for 5 days, then the duration adjustment factor for this storm is 134%. Apply this to the G-4 storm makes this a Category G-5 storm event (4 x 134% = 5.36, round to 5).

Using Table 1 to rate the category of storms, apply the duration adjustment factor to each storm. This refinement of the storms shown in Table 1 is shown in Table 5.

Table 5 – Duration Adjusted Category Storms (G-factor)

	Recurrence Interval					
Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	1	2	2	2	3	3
2 hour	1	2	2	3	4	4
3 hour	1	2	3	3	4	5
6 hour	2	2	3	4	5	6
12 hour	2	3	4	4	5	6
24 hour	2	3	4	5	6	7
2 day	2	4	5	6	6	7
3 day	3	4	5	6	7	7
5 day	3	4	5	6	7	7
10 day	4	5	7	7	8	9

At first glance, this rating of storms looks reasonable. The larger and longer duration storms rate the highest on this scale and smaller storms with lower durations ranks lowest. But when one overlays the G-factor rating against the actual total rainfall for each storm by duration, there is an inconsistency that shows up that requires an additional modification to the system.

Substituting the total rainfall for the Milwaukee area from Table 3 into the respective cells in Table 5 shows that three storms have similar rainfall totals over different durations, shown by the bold and italicized numbers in Table 6. Unfortunately, this system rates them all the same (G-7) as represented by the color red in the table.

Table 6 – Duration Adjusted Category Storms with Total Rainfall (inches)

	Recurrence Interval					
Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	1.31	1.60	1.84	2.20	2.50	2.82
2 hour	1.54	1.93	2.23	2.73	3.16	3.64
3 hour	1.68	2.07	2.40	2.93	3.39	3.89
6 hour	1.95	2.40	2.79	3.44	4.03	4.70
12 hour	2.24	2.74	3.17	3.89	4.53	5.25
24 hour	2.57	3.14	3.62	4.41	5.11	***5.88***
2 day	3.04	3.71	4.20	4.94	5.53	6.13
3 day	3.29	3.94	4.40	5.09	5.63	6.17
5 day	3.77	4.42	4.84	5.43	***5.86***	6.26
10 day	4.68	5.42	***5.89***	6.55	7.03	7.46

The same amount of rain in a shorter duration cannot rate the same as a longer duration event with the same total. This will continue to confuse the public, as it does not make sense. It must rate higher on this scale. To accomplish this, we must adjust the rating using an intensity adjustment factor.

Using the rainfall data in Table 3, a simple ratio between the total rainfall for a given duration event divided by the total rainfall for the 100-year storm of the same duration becomes the intensity adjustment factor. The 100-year event is the basis for this adjustment since this is typically the most common extreme event considered for design storms. The intensity adjustment factor formula is:

$$\text{Intensity Adjustment Factor (IAF)} = \frac{\text{Total rainfall for X-year Y hour duration storm}}{\text{Total rainfall for 100-year Y hour duration storm}}$$

The ratio of total rainfall by intensity as compared to the 100-year event for each storm identified in Table 3 is shown in Table 7.

Table 7 –
Recurrence Interval and Ratio of Rainfall by Intensity to the 100-year Storm

Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	46 %	57 %	65 %	78 %	89 %	100 %
2 hour	42 %	53 %	61 %	75 %	87 %	100 %
3 hour	43 %	53 %	62 %	75 %	87 %	100 %
6 hour	41 %	51 %	59 %	73 %	86 %	100 %
12 hour	43 %	52 %	60 %	74 %	86 %	100 %
24 hour	44 %	53 %	62 %	75 %	87 %	100 %
2 day	50 %	61 %	69 %	81 %	90 %	100 %
3 day	53 %	54 %	71 %	82 %	91 %	100 %
5 day	60 %	71 %	77 %	87 %	94 %	100 %
10 day	63 %	73 %	79 %	88 %	94 %	100 %

To adjust the rating of the rain event one last time, multiply the intensity adjustment factor to the refined rating of the storm. The category storm determined from the original formula identified above will then change based on these two adjustment factors. The adjustment formula is:

G x (DAF) x (IAF)

Where:
G = the Category of the Storm
DAF = Duration adjustment factor, where:

$$\text{DAF} = \frac{\text{Total rainfall for X-year Y hour duration storm}}{\text{Total rainfall for X-year 24 hour duration storm}}$$

IAF = Intensity adjustment factor, where:

$$\text{IAF} = \frac{\text{Total rainfall for X-year Y hour duration storm}}{\text{Total rainfall for 100-year Y hour duration storm}}$$

For example, a 10-year storm is a Category G-4 storm in accordance with Tables 1 and 2. For a 10-year storm that has a 10 day duration, the duration adjustment factor is 163% from Table 4. The intensity adjustment factor is 79%. Using the adjustment formula yields:

4 x 163% x 79% = 5.15, round to 5.

Therefore, this 10 day duration 10-year storm would be defined as a Category G-5 storm, not the G-7 as rated using solely the duration adjustment factor.

Using Table 1 to rate the category of storms and then applying the adjustment factors for duration and intensity to each storm yields the category ratings for the rain events as shown in Table 8.

Table 8 – Fully Adjusted Category Storms (G-factor)

	Recurrence Interval					
Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	0	1	1	2	3	3
2 hour	1	1	2	2	3	4
3 hour	1	1	2	3	3	5
6 hour	1	1	2	3	4	6
12 hour	1	1	2	3	5	6
24 hour	1	2	2	4	5	7
2 day	1	2	3	5	6	7
3 day	1	2	3	5	6	7
5 day	2	3	4	5	6	7
10 day	2	4	5	7	8	9

Checking the results of this revised table to see if there are storms rated the same that should not results in a reasonable rating for each storm. The three storms (using total rainfall) that all rated the same despite differing durations are shown in Table 9.

Table 9 – Fully Adjusted Category Storms with Total Rainfall (inches)

	Recurrence Interval					
Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	1.31	1.60	1.84	2.20	2.50	2.82
2 hour	1.54	1.93	2.23	2.73	3.16	3.64
3 hour	1.68	2.07	2.40	2.93	3.39	3.89
6 hour	1.95	**2.40**	2.79	3.44	4.03	4.70
12 hour	**2.24**	2.74	3.17	3.89	4.53	5.25
24 hour	2.57	3.14	3.62	4.41	5.11	***5.88***
2 day	3.04	3.71	4.20	4.94	5.53	6.13
3 day	3.29	3.94	4.40	5.09	5.63	6.17
5 day	3.77	4.42	4.84	5.43	***5.86***	6.26
10 day	4.68	5.42	***5.89***	6.55	7.03	7.46

The intensity adjustment factor corrected the aforementioned inconsistency. A more careful evaluation of each storm shows that there are minor inconsistencies at the smaller storms (as shown in Table 9 by numbers in bold for the smaller events). This is a result of rounding of the actual adjusted G-factor. It is not worth further modification of this system as each category has a range associated with it. However, for those who find this unacceptable, Table 10 shows the actual adjusted but unrounded G-factor associated with each storm. The actual adjusted but unrounded G-factor is less for the storm with less rain in a longer period (2-year

12 hour storm vs. 5-year 6 hour storm). This confirms that this method of adjusting the storms is correct and needs no further modification.

Table 10 – Specific G-factor Fully Adjusted Category Storms

	Recurrence Interval					
Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	0.47	0.87	1.33	1.95	2.60	3.36
2 hour	0.51	0.98	1.51	2.32	3.22	4.33
3 hour	0.56	1.05	1.64	2.50	3.47	4.63
6 hour	0.63	**1.17**	1.83	2.85	4.06	5.60
12 hour	**0.74**	1.37	2.12	3.27	4.59	6.25
24 hour	0.87	1.60	2.46	3.75	5.21	7.00
2 day	1.17	2.15	3.18	4.51	5.86	7.30
3 day	1.37	2.40	3.47	4.76	6.03	7.35
5 day	1.77	2.98	4.13	5.34	6.44	7.45
10 day	2.28	3.76	5.14	6.52	7.78	8.88

Does this System Work Elsewhere?

Engineers, meteorologists and other professionals can use this method throughout the country. A check of two significantly different geographic areas shows this is true. Las Vegas, NV is very dry and receives little precipitation and accordingly has low rainfall totals for the high recurrence interval storms (less than 4 inches of rain in its 100-year 10 day duration storm). Washington D.C. on the other hand is much wetter, receiving over 12 inches of rain in its 100-year 10 day duration storm. Precipitation data was found on the National Oceanic and Atmospheric Administration (NOAA) website for these two cities.

The proposed rating system for rainstorms categorized each of the storms in the NOAA database. The NOAA data does not include 3 day and 5 day durations but uses 4 day and 7 day durations instead. This did not appear to result in any difficulty or material change in relationships using the proposed rating system. Large and long duration storms rated highest and the ratings proceeded in a logical manner decreasing with duration and intensity. Using this system in both regions yields similar results to that for southeastern Wisconsin as far as the relationship of storms one to another.

The results of this analysis are shown in Table 11 and Table 12.

Table 11 – Category Storms for Las Vegas, NV

	Recurrence Interval					
Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	0	1	1	2	3	4
2 hour	0	1	1	2	3	5
3 hour	0	1	1	2	4	5
6 hour	1	1	2	3	4	6
12 hour	1	1	2	3	5	7
24 hour	1	2	3	4	5	7
2 day	1	2	3	4	6	7
4 day	1	2	3	5	6	8
7 day	1	2	4	5	7	9
10 day	1	2	4	6	8	9

Table 12 – Category Storms for Washington D.C.

	Recurrence Interval					
Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	0	1	1	2	2	3
2 hour	0	1	1	2	3	3
3 hour	1	1	1	2	3	4
6 hour	1	1	2	3	3	4
12 hour	1	1	2	3	4	6
24 hour	1	1	2	4	5	7
2 day	1	2	3	4	6	8
4 day	1	2	3	5	6	9
7 day	1	2	4	5	7	10
10 day	1	3	4	6	8	10

Criticism and Defense of this Proposal

Some have criticized this system for being too simplistic. That is, however, precisely the point. It should be simple for the public to understand, the bigger the number the more severe the storm, not the more rare the storm.

There is also an inherent difficulty with trying to categorize all variety of storms into this simplistic system given the variety of rainfall events, the changes in rainfall intensity that occur during a rainfall event, and the subjective method of defining the duration of the rainfall event to identify the category above. There is not a continuous curve of events by recurrence interval. However, if the durations of the event are shorter or longer than those shown in the rating system above, projections or interpolations can be made to rate the storm into the associated category. This should be sufficiently accurate to present to the public.

This proposal introduces a more appropriate scaling factor to the storm rating system by defining these in categories that increase numerically by one. Many people are surprised to hear that a 2-year storm drops almost 50% of the rain dropped by a 100-year event. Many wrongly assume that the 2-year event has 2% of the rain that a 100-year storm has and that the

50-year event has 50% of the rain as a 100-year event. That is not the case. Using this proposed method it is more clearly understood that the Category G-6 storm (50-year storm) is almost as severe as the Category G-7 storm (100-year storm).

Some have suggested including an adjustment factor for antecedent moisture conditions. This would take into account the increased runoff from the rain events that occur during periods of saturated soil conditions. However, that would make this a rating of the runoff from the storm and not the storm itself. Other rating systems rate the natural disaster or weather event, not necessarily the impact of the event. Impacts from earthquakes are different depending on soil conditions; stiff clays respond differently than sands and silt (e.g. liquefaction). Other factors that affect the impact of an earthquake include the type of construction materials and the building code standards used during construction. However, these things do not change the Richter scale number of the earthquake itself.

Things that affect runoff from major storms include slope, soil type, topography, snow cover and land cover with impervious surfaces. These are factors that engineers need to consider for determining runoff, but do not enter into the rating for the storm as they are more akin to the aforementioned construction variables that earthquakes affect, rather than defining the storm itself. Accordingly, this proposed method does not include these types of modifications. This is not to say that these things are unimportant or should be ignored. It is critical to inform residents about the effects of these types of storms and in doing so one can consider these things. However, including them somehow into the rating of the storm itself is confusing and introduces too many factors that change not only city to city, but also block by block. That becomes unworkable.

The recurrence interval method of rating storms leads to common misperceptions regarding floodplains and their association with the associated rainfall event. The public mistakenly believes the 100-year floodplain fills only when there is a 100-year storm and the 100-year storm will always fill the 100-year floodplain. Not necessarily so, yet try to explain that to a crowd of angry residents who already experienced the 100-year flood twice in as many years.

So not only should we consider modifying the 100-year storm rating system, but that could lead to a relabeling of the 100-year floodplain, which will have a positive impact on how the public perceives and understands the flood risk inherent to their property. If this is what it takes to get the public to take positive steps to protect themselves during these major rain events then that is a step in the right direction and could have lasting and significant impacts throughout areas that are prone to or more likely to flood.

Can the Rating of these Storms Really Change?

It may take years to adjust to a new rating system. Certainly we will need members of academia to support this or refine it themselves as a research project. There is a lot of literature that will need to adjust their descriptions of these storms. Plus, there will be those who resist change for sake of maintaining the status quo.

Conclusion

The current system for rating extreme rain events does not work for relation of the event to the public. It is too hard to explain and confusing to the public. Engineers do not serve the public well by calling these storms something that the public perceives they are not and that they do not understand. Civil engineers work too hard to define these complex natural events only to see their credibility destroyed at public meetings and in the minds of those they serve.

A revised method, building on the existing science that is already in place but using a similar method as used for rating other natural disasters, will work better. The method proposed in this paper develops a simple scale that the public understands, the bigger the number, the worse the storm. Civil engineers need to change the rating of these storms and do so before the next big storm arrives. We will need to work together to achieve this positive change.

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Notation

DAF = Duration Adjustment Factor
G = exponent used to convert recurrence intervals to the Grisa scale (category of rain event)
IAF = Intensity Adjustment Factor
RI = Recurrence Interval

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