Relabeling Extreme Rainfall Events so the Public Understands Their Severity

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ABSTRACT

Explaining how multiple 100-year storms can occur in less than 100 years to the public is difficult since they do not understand and refuse to accept that this can happen. Other natural disasters (e.g. earthquakes, tornadoes, hurricanes) are not rated using recurrence intervals, but use simple scales instead like the Richter scale, Fujita scale, and Saffir-Simpson scale, respectively. The public understands the ratings for these other events since they use a simple scale to rate the severity of the event, not the rarity of the event.

This paper proposes to re-rate rain storms, building on existing hydrologic science, but changing the designation from a recurrence interval to one that is more general in description, similar to the rating of other natural disasters. The new scale rates the rain event on a scale of 1 to 10 based on how severe the storm was, making it more understandable to the public.

KEYWORDS: 100-year storm, Flooding, Hydrology, Rainfall frequency, Recurrence interval, Probability, Stormwater management.

INTRODUCTION

Are stormwater professionals misleading the public by labeling extreme rain events by their recurrence interval? The current method of describing extreme rain events uses the rarity of the storm to define it. This is poorly understood by the public and can lead to confusion or worse.

What does the average person understand about the term 100-year storm? Most would say it is a rare storm, happens only once every 100 years, and it is extreme in nature and impact. They would not understand that the 100-year storm can be of various durations, intensities and total rainfall falling on a defined curve for such an event. Plus, they would not expect two 100-year storms to occur in subsequent years or worse, three years in a row.

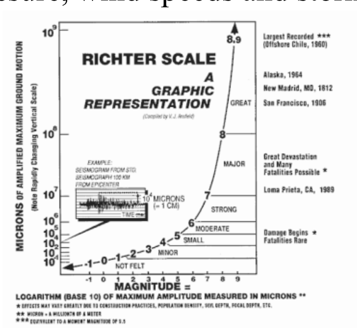
Yet, that is what has happened in the City of Brookfield, Wisconsin in the late 1990's and early 2000's. The City of Brookfield received five 100-year rain storms in a 14 year period (1997, 1998, 2008, 2009 and 2010). Each storm was different in duration, intensity and total rainfall too. This makes it much more difficult to explain to the public, and much more difficult for the public to understand and accept the explanation.

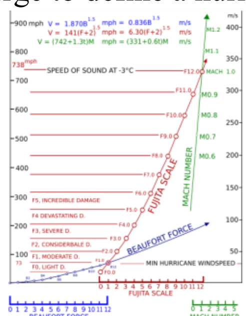
One method around this has been to use probabilities. The 100-year storm can be described as the one percent probability storm, having an equal chance of occurring any given year. This helps a little, until the public figures out that a one percent storm has a 1 in 100 chance of occurring, and therefore it's the 100-year storm. Then they think you're trying to trick them by using different terminology.

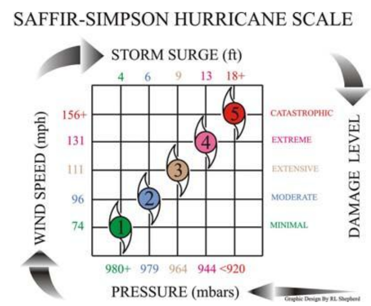
Because of this and the extreme rain events that occurred in Brookfield, the author developed an alternative rating system for rainstorms which gives the public a better understanding about the severity of the storm, without implying its rarity. This paper walks the reader through the process of developing this alternative rating system, defines the new system for rain events based on severity of the event and describes the advantages of the system for clearing up the public's muddled views on these extreme rain events.

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.







Note: Graphics above from Google images, references listed at the end of this paper.

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 event.

SEVERITY VERSUS RARITY

The public understands the ratings for these other natural weather events since the scale is simple, even though the graphic may not be. But the public is rarely shown the graph or told how the rating was determined. The rating is simple to understand, the larger the number the worse the event.

However, the current rating for rain events defines how rare the event is, not how severe it is. 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 severity of the storm, not the rarity of the storm.

AN ALTERNATE RATING SYSTEM

Storm water professionals and others who use this information and communicate with the public should reevaluate how they rate these rain storms and change its 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. This new system can build upon the existing hydrologic science that has already been collected and accepted so there is no major change in background data or analysis.

The proposed rating system was first conceived after the third 100-year storm in 11 years. Essentially the author converted the recurrence interval into categories using a simple scale from 1 to 10 using the Recurrence Interval Conversion formula (equation 1) expressed below:

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

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

Solving for G yields equation 2:

$$\mathbf{G = \{1 + Log(RI)/Log(2)\}.}$$

Table 1 depicts the actual G-factor for commonly defined recurrence interval storms.

Table 1 – Identifying G-Factors for Specific Recurrence Interval Storms

Recurrence Interval Rain Storm	G-factor
2 year storm	2
5 year storm	3.32
10 year storm	4.32
25 year storm	5.64
50 year storm	6.64
100 year storm	7.64

Adjustment for Duration of Storm

However, presentation of this concept to other professionals, resulted in several comments that needed to be addressed. Most specifically, how does this deal with different rain events that have different durations and intensities and correspondingly different effects on runoff and flooding. 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 2 shows the rainfall depth in inches for Southeastern Wisconsin by recurrence interval.

Table 2 - Recurrence Interval and Depth of Rainfall (centimeters)

Storm Duration	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	3.33	4.06	4.67	5.59	6.35	7.16
2 hour	3.91	4.90	5.66	6.93	8.03	9.25
3 hour	4.27	5.26	6.10	7.44	8.61	9.88
6 hour	4.95	6.10	7.09	8.74	10.24	11.94
12 hour	5.69	6.96	8.05	9.88	11.51	13.34
24 hour	6.53	7.98	9.19	11.20	12.98	14.94

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

Note: There is also data for rainfall periods exceeding 24 hours, but it is easiest for the public to understand rain storm classifications in terms of one day duration or less rainstorms, so the rest of this data is not provided or included in this system (though it could certainly be extrapolated if needed).

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 most people think of weather in terms of one day. The Duration Adjustment Factor formula is shown by equation 3:

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

The ratio of total rainfall by duration as compared to the 24-hour duration event for each storm identified in Table 2 is shown in Table 3.

Table 3 –
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 %

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-7.64 storm in accordance with Table 1. For a 100-year storm that has a 1 hour duration, the duration adjustment factor is 48%. Multiplying 7.64 by 48% results in 3.67, round to G-4. Therefore, this 1 hour duration 100-year storm would be defined as a Category G-4 storm.

Using Table 1 to rate the category of storms, apply the duration adjustment factor from Table 3 to each storm. This refinement of the storms is shown in Table 4.

Table 4 – Duration Adjusted Category Storms (G-factor)

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

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 color scheme 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 2 into the respective cells in Table 5 shows that some storms have similar rainfall totals over different durations, shown by way of example in the bold and italicized numbers in Table 5. Unfortunately, this system rates them all the same (G-5) as represented by the color yellow in the table.

Table 5 – Duration Adjusted Category Storms with Total Rainfall (cm)

Storm Duration	Recurrence Interval					
	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	3.33	4.06	4.67	5.59	6.35	7.16
2 hour	3.91	4.90	5.66	6.93	8.03	9.25
3 hour	4.27	5.26	6.10	7.44	8.61	***9.88***
6 hour	4.95	6.10	7.09	8.74	10.24	11.94
12 hour	5.69	6.96	8.05	***9.88***	11.51	13.34
24 hour	6.53	7.98	9.19	11.20	12.98	14.94

Adjustment for Storm Intensity

Clearly the same amount of rain in a shorter duration cannot rate the same as a longer duration event with the same total rainfall. 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 the storm's intensity.

Using the rainfall data in Table 2, 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 for which the public is familiar. The Intensity Adjustment Factor formula is shown by equation 4:

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

The ratio of total rainfall by intensity as compared to the 100-year event for each storm identified in Table 2 is shown in Table 6.

Table 6 –
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 %

To adjust the rating of the rain event one last time, multiply the intensity adjustment factor in Table 6 by the refined rating of the storm in Table 5. The category storm determined from equation 2 will then change based on these two adjustment factors.

The adjusted Recurrence Interval Conversion formula (equation 5) becomes:

$$\mathbf{G_{ADJ} = \{1 + Log(RI)/Log(2)\} \times (DAF) \times (IAF)}$$

Where:
G_{ADJ} = Adjusted Category of Storm
RI = Recurrence Interval
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 50-year storm is a Category G-6.64 storm in accordance Table 1. For a 50-year storm with a 12 hour duration, the duration adjustment factor is 89% from Table 3. The intensity adjustment factor is 86%. Using the adjustment formula yields:

$$6.64 \times 89\% \times 86\% = 5.08, \text{ round to } 5.$$

So the previously categorized storm changes from a 6 to a 5 given the duration of the event.

Applying the adjusted Recurrence Interval Conversion formula (equation 5) yields the category ratings for the rain events as shown in Table 7.

Table 7 – Fully Adjusted Category Storms (G-factor)

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

Checking the results of this revised table to see if there are storms rated the same that should not be shows that this formula provides a reasonable rating for each storm as shown in Table 8.

Table 8 – Fully Adjusted Category Storms with Total Rainfall (centimeters)

Storm Duration	Recurrence Interval					
	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	3.33	4.06	4.67	5.59	6.35	7.16
2 hour	3.91	4.90	5.66	6.93	8.03	9.25
3 hour	4.27	5.26	6.10	7.44	8.61	9.88
6 hour	4.95	6.10	7.09	8.74	10.24	11.94
12 hour	5.69	6.96	8.05	9.88	11.51	13.34
24 hour	6.53	7.98	9.19	11.20	12.98	14.94

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. This is a result of rounding of the actual adjusted G-factor. However, for those who find even this slight discrepancy unacceptable, Table 9 shows the actual adjusted but unrounded G-factor associated with each storm, thus resolving this inconsistency associated with rounding to whole numbers.

Table 9 – Specific G-factor Fully Adjusted Category Storms

Storm Duration	Recurrence Interval					
	2 year	5 year	10 year	25 year	50 year	100 year
1 hour	0.47	0.96	1.43	2.20	2.88	3.66
2 hour	0.51	1.08	1.63	2.62	3.56	4.73
3 hour	0.56	1.16	1.77	2.82	3.84	5.05
6 hour	0.63	1.30	1.98	3.22	4.49	6.11
12 hour	0.74	1.51	2.28	3.69	5.08	6.82
24 hour	0.87	1.77	2.66	4.23	5.77	7.64

Defining the Numbers

The author developed descriptions for the numbers on the G-factor scale to provide additional meaning to the public to supplement the number scale. Below in Table 10 is the Rain Storm Severity Index. This index describes the scale using simple language instead of numbers as some may find that more understandable.

Table 10 – Rain Storm Severity Index

G-Factor rating	Description of Rain Event
1 to 2	Minor
3 to 4	Moderate
5 to 6	Major
7 to 8	Extreme
9 to 10	Catastrophic

These descriptions provide a sense of severity of the storm, confirming the public's understanding with other scales that the bigger the number the more severe the storm.

Using this system for the five 100-year rain storms in Brookfield over the 14 year period would yield storms with ratings that would not give the public the impression that they were rare. This designation merely shows that they are extremely severe, near the top of the scale. They could happen again, so the public should take precautions to protect themselves against future events. A comparison of the ratings is shown in Table 11.

Table 11 – Comparison of Storm Rating Designations

Year	Total Rainfall (cm)	Duration (hours)	Old Designation	Proposed Rating System	Description of Rain Event
1997	15.2	26	100-year	G-8	Extreme
1998	28.8	8	>100-year	G-10+	Catastrophic
2008	14.7	24	100-year	G-8	Extreme
2009	12.2	3	100-year	G-7	Extreme
2010	15.7	20	100-year	G-9	Catastrophic

DOES THIS SYSTEM WORK ELSEWHERE?

It is believed that storm water professionals and others can use this method throughout the country based on a limited check of different areas. Las Vegas receives little precipitation with low rainfall totals for the high recurrence interval storms (less than 7.2 centimeters of rain in its 100-year 24 hour duration storm). Washington D.C. is much wetter, receiving over 21 centimeters of rain in its 100-year 24 hour duration storm. Precipitation data was found on the National Oceanic and Atmospheric Administration (NOAA) website (Hydrometeorological Design Studies Center - HDSC) for these two cities. The proposed rating system for rainstorms applied to these two locations provides the results shown in Tables 12 and 13 below.

Table 12 – Category Storms for Las Vegas, Nevada

Storm Duration	Recurrence Interval					
	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	3	4	5
3 hour	0	1	2	3	4	6
6 hour	1	1	2	3	5	7
12 hour	1	1	2	4	5	7
24 hour	1	2	3	4	6	8

Table 13 – Category Storms for Washington D.C.

Storm Duration	Recurrence Interval					
	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	4
3 hour	1	1	2	2	3	4
6 hour	1	1	2	3	4	5
12 hour	1	1	2	3	5	6
24 hour	1	2	3	4	6	8

The results of this analysis of these two cities look similar to the table developed for southeastern Wisconsin. More severe storms with longer durations and higher recurrence intervals are rated higher than those with shorter durations or lower recurrence intervals. These two examples are typical of other areas throughout the country as well.

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.

Another criticism is that it is inherently difficult 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. However, this is also true of the current system, so this proposed change is no worse than the use of recurrence intervals in this regard.

The G-factor scale does not have a continuous curve of events like that for the recurrence interval system. However, if the durations of the event are shorter or longer than those shown in the tables 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. Certainly more refinement could be made for those who have the interest.

Some have suggested including an adjustment factor for things like antecedent moisture condition. This, they argue, would account for 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 rain 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. Similarly, hurricanes have different affects in the United States where building codes are much stricter than those in the Caribbean, for example; yet the rating is not changed based on its impact. It is true that the enhanced Fujita scale does take into account impact on property, but an EF 5 that hits a farm field has the same characteristics of an EF 5 that hits a small city – though the damage is different.

Things that affect runoff from major storms include slope, soil type, topography, snow cover and land cover with impervious surfaces, etc., some of which can change block by block. These are factors that engineers and hydrologists use to determine runoff, but do not enter into the rating for the rain storm as they are more akin to the aforementioned construction variables that affect impacts from earthquakes. Accordingly, this proposed method does not include these types of modifications.

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 the total rainfall from a 2-year storm is almost 50% of the total rainfall from a 100-year event for a given duration. Many wrongly assume that the 2-year event has 2% of the rain that a 100-year storm has. They also believe that the 50-year event has 50% of the rain as a 100-year event. That is not the case; it is closer to 87%. Using this proposed method it is more clearly understood that the Category G-6 storm is almost as severe as the Category G-7 storm, being only one number away, and does not mislead the public to think otherwise.

The recurrence interval method of rating storms leads to common misperceptions regarding floodplains and their association with the rainfall events with similar sounding names. 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.

CONCLUSION

Storm water professionals should consider modifying the 100-year storm rating system to get the public to take positive steps to protect themselves during these major rain events.

The current system for rating extreme rain events is too hard to explain and confusing to the public. The current system does not serve the public well by calling these storms something that the public perceives they are not and that they do not understand. Too much work has gone into defining these complex natural events only to see it rejected by the public.

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 bigger the storm. Changing the rating of these storms is imperative for public acceptance. This will require the cooperation of storm water professionals, public works directors, civil engineers, meteorologists, hydrologists, and those in academia.

Does this concept make sense? Is it worth trying to change? Can it work better than the current system?

The author answers with a resounding yes! Anyone else with me?

ACKNOWLEDGEMENTS

The author would like to express gratitude to the engineers, floodplain managers, hydrologists, and practitioners who reviewed early versions of this paper proposing a change in the rating of the extreme rains. Their comments, questions and encouragement were instrumental in modifying this method and addressing issues that improved the overall concept. Specific thanks go to: Theresa Caven, Rick Eilertsen, Dave Fowler, Mike Hahn, Victor Hom, Larry Larson, Mike Lemens, Tom Simmons, and Janet Thigpen

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