

Rethinking Gutter Design for Steep-Sloped Roofing

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Photo 1 – This photo illustrates one of the roof conditions observed by the authors in which the configuration of valleys and dormers directed roof water to discrete sections of gutters. Though the gutters were sized appropriately for the local rainfall intensity and roof area, frequent gutter overtopping was reported.



ABSTRACT

There are currently two methods for calculating gutter sizes for use with steep-sloped roofing. The methods offered by both the International Code Council (ICC) and the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) can trace their roots to a paper entitled "Flow in Roof Gutters" by K. Hilding Beij, published in 1934. A recent forensic study near Charleston, SC, identified roof areas where gutters, though properly sized per the ICC method, were routinely overtopped by roof drainage during moderate rain events.

A review of the Beij paper revealed that the author advised about limitations in his method that are not mentioned by ICC or SMACNA. Current design practices can result in roofs that have drainage characteristics beyond the scope of the method devised by Beij.

To better understand the overtopping issues associated with the Beij method, the authors developed an experiment to mea-

sure flow rates from roof areas into gutters. Alternative gutter calculation methods are proposed that account for some of the limitations recognized by Beij.

INTRODUCTION

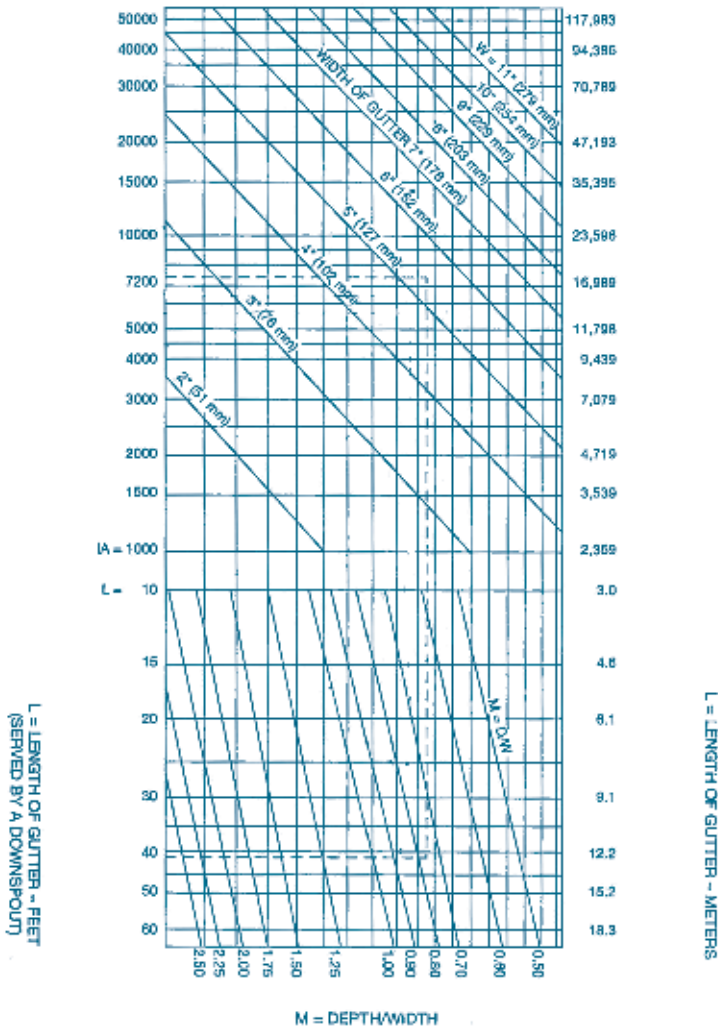
The roof is often the largest and arguably most important weatherproofing element on a building. It is typically the first surface to intercept rain and other forms of precipitation that fall from the sky. Once rain falls on a roof, its journey toward the ground is not over. Water on the roof must be conveyed to the ground in a manner that protects the walls, fenestration, and foundation. For steep-sloped roofs and some low-sloped roofs, gutters and leaders are the common solution. In order for gutters to perform this function, they must be properly sized and selected based on roof area and geographical climate.

Recently, the authors were retained to investigate frequent gutter overtopping at a multifamily residential community near Charleston, SC. Gutter overtopping occurs

when the flow from a roof is not retained within the gutter trough, even when the gutter is free of debris and has adequate drainage to a downspout. The momentum of the flow into the gutter carries the water up and beyond the outboard leg of the gutter. The initial hypothesis was that the gutters were sized incorrectly; and indeed, some instances of undersized gutters were identified. However, many areas of the roofs experienced gutter overtopping even when the gutters were appropriately sized per the ICC method. In Charleston, the ICC method is part of the adopted building codes and is, therefore, the governing standard.

Surveys were completed to identify the locations where gutter overtopping was prevalent in the subject community. Overtoppings were common among certain building styles that incorporated large valleys and/or gable dormers (see *Photo 1*). It became obvious that roof configuration could be a critical aspect of gutter design that was not included in the available design methodologies.

**CHART 1-1
WIDTH OF RECTANGULAR GUTTERS FOR GIVEN ROOF AREAS
AND RAINFALL INTENSITIES**



$IA = \text{RAINFALL INTENSITY} \times \text{AREA}$ (AREA FROM TABLE 1-1 THAT RELATES TO L)

Figure 1 – SMACNA Chart 1-1. Note that this is actually an assembly of Beij's Figures 10 and 11 from RP644 (see Figure 2).

Design Methodologies

There are three methods commonly used by designers for sizing gutters, published in the "International Plumbing Code" by ICC, the *Architectural Sheet Metal Manual (ASMM)* by SMACNA, and *Architectural Graphic Standards* by the American Institute of Architects (AIA). SMACNA and AIA use an identical set of charts for selecting gutters, differing only in the approach to selecting the local rainfall intensity. Hereafter, only the ICC and SMACNA methods will be compared, and the reader can assume that the SMACNA results are approximately equal to the results that would be derived from the AIA method.

Each of these methods uses tables or charts to define local rainfall intensities. This information is combined with the horizontally projected roof area to select a gutter size. Depending on the method, coefficients are used to account for gutter slope and roof slope. The most obvious difference between the ICC method and the SMACNA method is the discrepancy between the rainfall intensity data. In the 2006 International

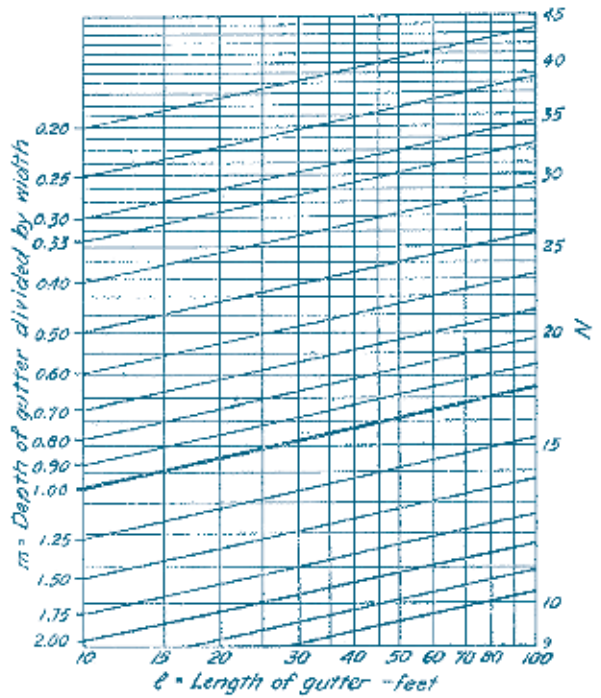


FIGURE 10.—Graph for determining the size of a level rectangular gutter when the roof area and the rainfall intensity are known. To be used in conjunction with the graph in figure 11.

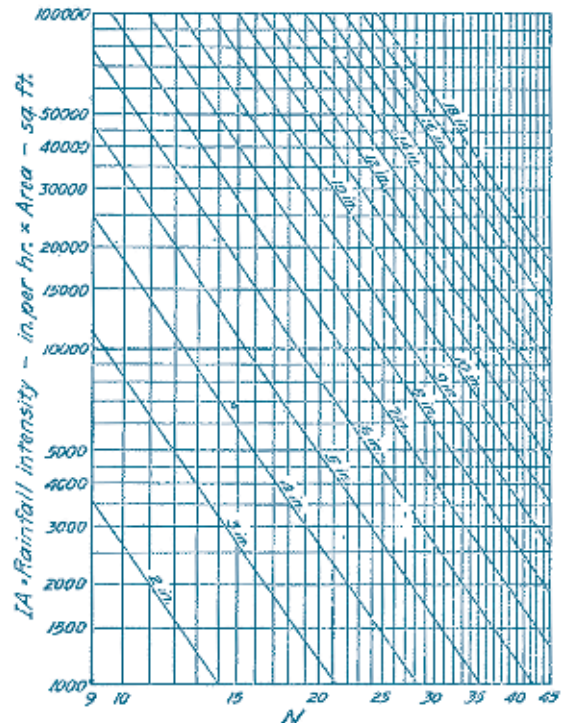


FIGURE 11.—Graph for determining the size of a level rectangular gutter when the roof area and the rainfall intensity are known. To be used in conjunction with the graph in figure 10.

Figure 2 – Figures 10 and 11 from RP644, "Flow in Roof Gutters."



Photo 2 – Overview of the test stand showing the water distribution manifold along the ridge and the 5K Ogee gutter along the eave.

Plumbing Code (2006 IPC), the 100-year, one-hour rainfall intensity for Charleston is 4.25 in. (per Figure 1106.1). SMACNA's ASMM, 5th Edition, lists a ten-year, five-minute intensity of 7.2 in./hour and a 100-year, five-minute intensity of 9.4 in./hour. SMACNA cites U.S. Weather Bureau records (through 1978) as the source of its rainfall data, while ICC cites the National Weather Service and the National Oceanic and Atmospheric Administration. The authors have not been able to identify the reason for the rainfall data discrepancy. The result, however, is that gutters designed per the SMACNA method are usually equal to or larger in size than would be required by ICC.



Photo 3 – Water supply was provided from a reservoir by an engine-driven pump.

Nevertheless, both methods trace their roots to U.S. Bureau of Standards Research Paper RP644, "Flow in Roof Gutters," by K. Hilding Beij, which was published in the *Bureau of Standards Journal of Research*, Vol. 12, in February 1934. Beij's stated purpose was "to provide a more rational method" for the design of gutters, since the method "heretofore has been solely a matter of judgment based on experience."

He set about measuring flow rates and flow depths for a variety of gutter configurations. Using the data he collected, he applied dimensional analysis (now a cornerstone of fluid mechanics) to develop empirical formulae for the design of gutters. The end of the report suggests that work was

under way to develop analytical models for gutter performance; the authors have been unable to find this work published.

Nevertheless, Beij reduced his empirical relationships for level gutters to a series of charts. The carefully hand-drawn charts that appear in RP644 are immediately recognizable to users of the SMACNA method (see *Figures 1 and 2* herein).

The charts in *Figure 2* assume that gutters are fixed along the eaves of rectangular roof sections. Beij, aware that not all roofs are rectangular in plan, makes an allowance in his method to base the gutter selection on a rectangle that encloses the plan of a subject roof section. This is possible, he warned, "provided that the inflow is

nearly uniformly distributed along the gutter." Neither SMACNA nor ICC includes this limitation in its published methodologies.

Experimentation

An experiment was devised by the authors to assess the effects of channeling roof water to a discrete section of gutter. A shed roof, 10 ft. by 10 ft. in area and pitched at 8/12, was constructed, and a manifold was installed along the upper edge of the roof to provide approximately uniform flow across the roof surface (see *Photo 2*). A Tsunami 137-gallon-per-minute (gpm) engine-driven pump provided flow from a reservoir, while an in-line valve was used to adjust the flow rate to the manifold (*Photo*

Photo 4 – View of well-distributed flow across the roof surface into the gutter. A photograph of the digital flowmeter reading is inset.



Photo 5 – When the flow rate to the manifold was adjusted to 45.0 gpm, the gutter was completely filled without overflowing. The flow rate per unit length of the gutter was 4.3 gpm/ft.



3). A new, factory-calibrated Great Plains Industries (GPI) digital flow meter was installed at the inlet to the manifold to assess the flow rate. A 5K ogee-shaped gutter, 10 ft., 7 in. long, was installed along the eave with a 1/8-in./ft. slope toward the leader. The gutter extended several inches beyond each side of the roof to ensure that all roof water was captured.

Initially, the water flow rate was adjusted such that the gutter was filled completely without overtopping. The measured flow rate was 45.0 gpm. The flow rate per unit length of gutter was 4.3 gpm/ft. (Photos 4 and 5).

Then diverters were installed (Photo 6) to approximate the roof configuration between the two dormers shown in Photo 1. The throat of the diverted section was 18 in. wide and 30 in. upslope of the eave. Severe overtopping occurred when the flow rate was set to 45.0 gpm. An important observation was that the flow below the throat did not spread across the roof; rather, the width of the flow was within the



Photo 6 – Overview of the roof configuration with the diverters installed to simulate the presence of dormers. Note that the flow below the throat does not spread beyond the width of the throat.



Photo 7 – The flow rate was reduced from 45.0 gpm to 20.2 gpm. Nevertheless, water still overtopped the gutter.



Photo 8 – At 8.9 gpm, the momentum of the flow was sufficiently low for the water to be retained by the gutter.

width of the throat. The flow rate was gradually reduced until no overtopping was observed. With the diverters installed, all of the roof water was retained by the gutter at a flow rate of 8.9 gpm.

At 8.9 gpm, the flow per unit length through the 18-in.-wide throat of the diverters was 5.9 gpm/ft. The total flow rate through the throat was only 19.8% of the maximum flow rate for the entire gutter. Interestingly, the flow rate per unit length entering the gutter increased 37.2% as compared to the distributed flow case. This condition appears to be related to the fact that half of the gutter was upstream of the point where roof water entered the gutter. As a

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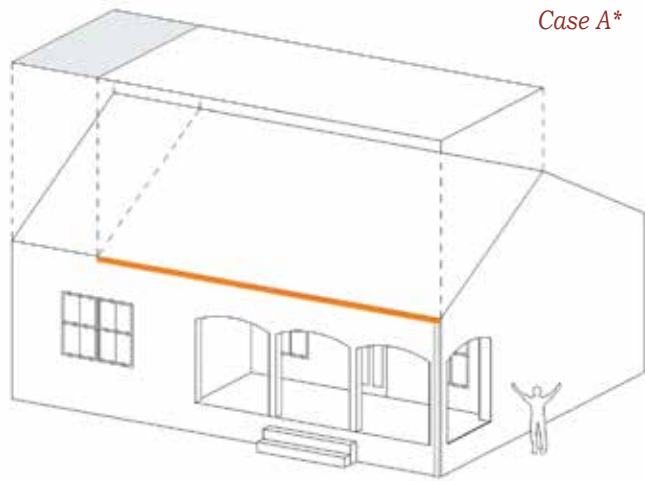
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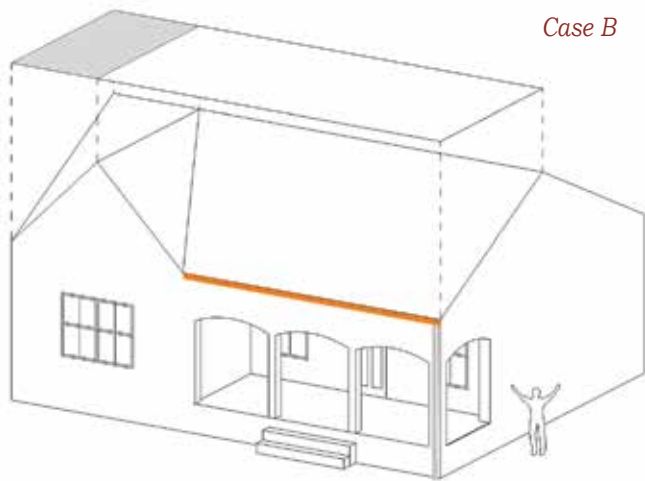
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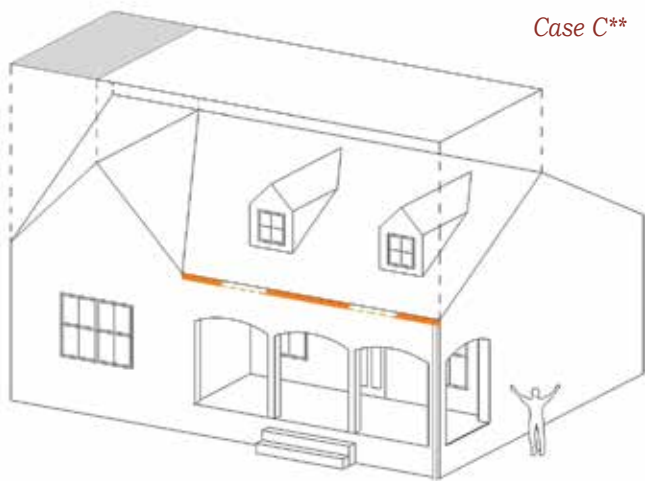
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Case A*



Case B



Case C**

*End of roof removed to make the projected roof areas consistent among the three cases.

**Gutter is continuous across the eave. Only the portions of the gutter that intercept flow are highlighted.

Figure 3 – Cases A, B, and C. Notice the horizontally projected roof areas do not change.

result, a portion of the roof water was able to flow toward the closed end until the flow momentum could be dissipated.

Analysis

Three prototypical roof areas were devised for comparative analysis. To facilitate simple graphic depiction, the design was based on a small, ranch-style residence. In Case A, the roof consists of a single gable with two rectangular roof areas that meet at a central ridge. For Case B, an intersecting gable was added to the front elevation. The addition of this roof did not increase the horizontally projected area of the roof. Finally, in Case C, two gable dormers were added. Once again, the horizontally projected roof area did not increase. The three configurations are shown in Figure 3A-C. The areas of the shaded and unshaded rectangles represent the entire horizontally projected roof areas.

Using the rainfall intensity values for Charleston, SC, the volumetric rainfall rate was calculated for the roof areas in each case. To make the analysis consistent, a small rectangle was deducted from the tributary roof area on Case A. An identical tributary area is automatically excluded in the calculations for Cases B and C due to the presence of the ridge and valley on the large intersecting gable; rainfall on these roof areas would not drain to the gutter along the front elevation eave. The formula for this calculation is derived from the continuity formulation of the conservation of mass requirement. The formula is as follows:

$$Q = 1.04 \times 10^{-2} (IA)$$

Where:

Q is the volume of water intercepted by the roof per unit time in gpm.

I is the rainfall intensity in inches per hour (in./hr.).

A is the horizontally projected roof area in square feet (ft²).

Note: The coefficient converts the units to gpm.

In addition, the maximum flow rate per unit length of gutter was also calculated for each case (Q/L in gpm/ft. where L is the total length of the gutter). For Cases B and C, all of the water to the right of the intersecting gable's ridge was assumed to enter the gutter along the eave. The results of the calculations are presented in Table 1.

The reader will note that the Q/L value is identical for Cases B and C; however, this does not represent real conditions due to the presence of the gable dormers. Therefore, in Case C, roof water was assumed to enter the gutter in three discrete locations with no significant roof water entering the gutter downslope of either gable dormer (see Figure 4).

The channeled flow rate (q) from the tributary areas between the gable and the dormers has the same effect on the local gutter lengths exposed to flow from the roof as increased rainfall intensity. The authors propose to assess this effect using a calculated equivalent

	Q (gpm)	L (ft.)	Q/L (gpm/ft.)
Case A	22.6	32	0.71
Case B	22.6	24	0.94
Case C	22.6	24	0.94

Table 1 – Maximum flow rates per unit length of gutter (Q/L).

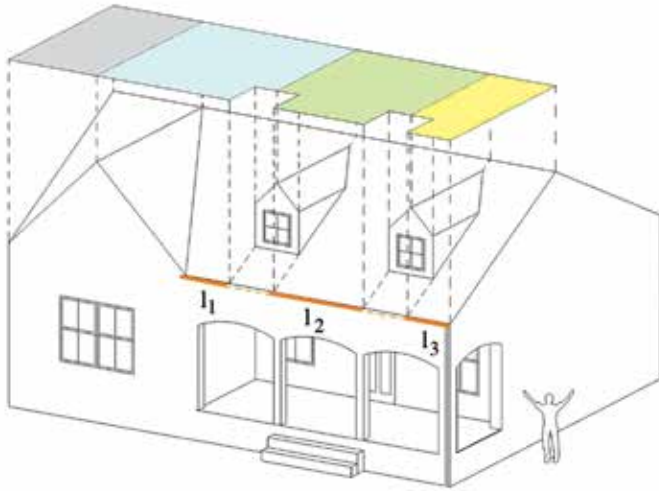


Figure 4 – Case C, highlighting the three tributary roof areas that direct water to three discrete sections of gutter.

lent rainfall intensity factor (I_{eq}).

The procedural steps for this method could be as follows:

1. Calculate all qs based on the local rainfall intensity (I) and the tributary areas (A_t) of the subject roof.
2. Determine maximum q/l for the roof, where l is the throat width.
3. Use the maximum q/l and the entire gutter length (L) to calculate the maximum equivalent flow rate as

$$Q_{eq} = \frac{q}{l} \times L$$

4. Determine the equivalent rainfall intensity as

$$I_{eq} = \frac{Q_{eq}}{1.04 \times 10^{-2} A}$$

5. Using I_{eq} , determine the gutter size using the published, existing methodologies.

For example, consider the Case C house. In Table 2, we use the maximum local volumetric flow rate (q) to derive the maximum overall volumetric flow rate for the roof, and then the equivalent maximum rainfall intensity (I_{eq}).

Using the I_{eq} derived in

	Roof Area 1		Roof Area 2	Roof Area 3
	ICC	SMACNA	ICC	ICC
A_t	216 sq. ft.	250 sq. ft.	179 sq. ft.	87 sq. ft.
I	4.25 in./hr.	9.4 in./hr.	4.25 in./hr.	4.25 in./hr.
q	9.6 gpm	24.4 gpm	7.91 gpm	3.85 gpm
l	4 ft.	4 ft.	8 ft.	4 ft.
q/l	2.44 gpm/ft.	6.11 gpm/ft.	0.99 gpm/ft.	0.96 gpm/ft.
$Q_{eq} = (q/l) \times L$	57.2 gpm	146.6 gpm		
$I_{eq} = Q_{eq}/(1.04 \times 10^{-2} A_{HP})$	10.7 in./hr.	23.9 in./hr.		

Table 2 – Calculations for Case C, showing the Equivalent Intensity (I_{eq}) for the area of the roof with the highest flow rate per length of gutter (q/l). Under Roof Area 1, the SMACNA tributary area is increased by a factor dictated by SMACNA, to account for slope.

Table 2, we compared the gutter sizes for Case C based on the prescribed rainfall intensities versus the calculated equivalent rainfall intensities. See Table 3.

CONCLUSIONS

Based on field observations, testing, and analysis, it is clear that the currently published methods for selecting gutter sizes do not

account for the configuration of the roof. Readily foreseeable roof configurations, such as intersection gables or dormers, can render gutters ineffective, even when they are designed according to recognized building codes and standards.

The existing gutter sizing methodologies are based on Beij's research from 1934. Though Beij specifically limited the applicability of his method to rectangular roof sections, building codes and standards neither warn of this limitation nor provide a method

to assess drainage on nonrectangular roof sections.

First, the building codes and standards should include language to notify designers that roof configuration must be considered in the selection of gutters. The charts and tables they provide should likely include sufficient safety factors to accommodate the presence of some deviations from rectangular roof sections. Additional research is needed to assess the relationship between the available excess capacity in existing gutter designs, compared to the degree to which a roof is not rectangular in area. In essence, a threshold must be established so that designers can know when the existing methods are no longer valid and additional analysis is needed.

Secondly, the building codes and standards should include methodologies for additional analysis. The authors have considered a possible solution. This technique, which could be called the "Equivalent Intensity Method," requires that the designer use an iterative solution to select gutters.


SUMMARY

In summary, the existing published methodologies for selecting roof gutter sizes for buildings have limitations. Some roof configurations result in the channeling of flow toward discrete sections of gutters. These

	SMACNA	SMACNA _{eq}	ICC	ICC _{eq}
I	9.4 in./hr.*	23.9 in./hr.	4.25 in./hr.	10.7 in./hr.
Gutter Size	5 in.	7 in.	5-in. diameter	N/A**

*Based on SMACNA's 100-year rainfall data. **ICC does not provide rainfall data greater than 6 in. per hour.

Table 3 – ICC and SMACNA gutter sizes based on prescribed rainfall intensity versus calculated equivalent rainfall intensity (I_{eq}).

gutters are prone to localized overtopping during periods of heavy rain. The authors have proposed a technique that could become an amendment to the current building codes and industry standards to allow for more appropriate sizing of gutters for roofs with nonrectangular roof sections. 

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