Gutter Design and Business Development for Domestic Rainwater Harvesting Systems: A Case Study

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Abstract - Rainwater harvesting is a simple and effective tool to collect and store water for domestic and institutional use. In developing countries, captured rainwater can be used to replace or supplement government-supplied or manually-transported water. A rainwater harvesting system consists of a catchment area, gutter, and storage tank. Gutters typically have a V-shaped, trapezoidal or rectangular cross-section. This work presents a case study on the design and performance analysis of three conventional and one novel, “wrapped” gutter cross-section along with the implementation of a novel gutter design in the developing world. A Team of undergraduate students performed the design and analysis and, though a service-learning experience in May 2013, investigated barriers to implementing rainwater harvesting in central Kenya. It was found that while gutters can be easily fabrication and installed using locally-available materials and skill-sets, for consumer, the potential return on investment was low and the cost of implementation was high. For producers and installers, non-uniform roof designs and conditions was a major obstacle.

Index Terms - Rainwater harvesting; Catchment; Domestic; Roof Runoff; Water; Business Model

INTRODUCTION

Within water-scarce areas, specifically those that have underdeveloped water infrastructure, rainwater collection is a creative means of sustaining water sources and improving the quality of life¹. One of the most common practices is the use of rainwater harvesting (RWH), a technique that aims to collect water running off roofs and other surfaces¹. A rainwater harvesting system normally consists of the catchment area, an attached gutter with mounting system, and a storage area². Systems vary most greatly in the cross-sectional design of their gutters. In a previous work³, we experimentally assessed the performance of four gutter cross-section designs based on their ability to intercept and convey water to a collection tank. We showed that, under heavy rainfall conditions, a cross-section that wraps around the ends of the catchment area reduces losses due to

water overshooting the gutter. But, due to leaks associated with its more complex connections, the wrap design was second best under rainfall of less than 7 inches per hour. It was asserted that using more watertight connections, the performance of the wrap design could have been improved. This work seeks to explore issues associated with in-the-field implementation of this and other RWH systems in the developing world, within a service-learning framework.

The service learning experience took place during May 2013 in Nyeri, Kenya, as part of a humanitarian engineering and social entrepreneurship program at Penn State University. A team of undergraduate students, majoring in both engineering and agricultural sciences, and under the supervision of engineering faculties, sought to understand if and how novel gutter systems could be implemented in the developing world; what barriers to entry exist for this and other gutter designs; and, where would implementation of rainwater harvesting be most beneficial to users? To answer these questions, students built multiple prototypes and installed them to typical roofs at a children and youth center in the area, gathering data to determine the costs and tradeoffs associated with rainwater harvesting.

Prior to detailing field-work activities and results, a brief overview of the laboratory work, used to determine gutter performance is given in Section I. Following this, in section II, a description of the fieldwork is provided, together with an analysis of barriers to implementing rainwater harvesting in the developing world. This work serves as both as a case study of a project-based, service-learning experience, which complemented classroom and laboratory study, to investigate broader issues associated with technological innovation.

SECTION I DESIGN CRITERIA FOR GUTTER CROSS-SECTIONS

Material Selection

Rainwater harvesting gutter systems work successfully through the interaction of three basic components: the catchment, delivery system, and storage reservoir⁴. Most critically, the interaction between the catchment and the delivery system must convey water from the roof of a home into the gutter system with minimal water lost. The total conveyance of a gutter system can be calculated using Manning's formula, shown in equation (1). This flow of water from the roof (Q) is a function of the roughness coefficient of the gutter material (n), the cross-sectional area of the gutter, (a), hydraulic radius of the gutter, (r), and the slope of the gutter following the roof, (S)².

$$Q = \frac{1}{n} a r_h^{2/3} \sqrt{S} \quad (1)$$

Equation (1) can be used to compare the conveyance of different potential gutter materials, using their roughness coefficients. Sheet metal is typically used due to its low roughness coefficient (<0.015) and the ease with which it can be shaped. Moreover, sheet metal is readily available in most of the developing world, including Kenya, where our fieldwork was conducted. For these reasons, we used galvanized sheet metal to construct the gutters described here.

Cross Section Design

While roughness dictated the materials used, cross-sectional area, a , had a greater impact on the flow capacity of a gutter system, and thus the amount of water that could be collected and stored within the storage tank. Cross-sectional area also directly impacts the performance of using a gutter to collect rooftop runoff.

By compiling various data regarding flow rates and capacities of several gutter designs^{2,5}, three gutter designs, V-Shaped, Square, and Trapezoidal, were chosen for further examination. Through the use of a rainwater simulator, we were able to determine the best gutter design for varying rain intensities³. Along with V-Shaped, Trapezoidal, and Square gutters, a “wrap” design was implemented during the second round of test trials. All cross-sections are shown in FIGURE 1, copied, with permission, from Zankowski, et al., 2013.

FIGURE 1

CROSS SECTIONS (FROM LEFT TO RIGHT) OF V-SHAPED, SQUARE, TRAPEZOIDAL, AND WRAP GUTTER DESIGN, WITH DASHED LINES REPRESENTING EXTENSION OF ROOF

Methodology

In order to compare cross-sections, each cross-section prototype was installed onto a test roof and placed under a rainwater simulator modeled after that described by Miller and Fennessey⁶. Experiments were conducted to measure conveyance, conductance and interception characteristics of the four different gutter designs. Interception refers to the act of water flowing off the roof being caught by the gutter. Gutters were tested under rainfall intensities of 1 inch (2.54 cm) per hour, 3 inches (7.62 cm) per hour, 7 inches (17.78 cm) per hour, and 9 inches (22.86 cm) per hour, to replicate the variable rainfall of Nyeri, Kenya, where fieldwork took⁷. Each experiment lasted 2 minutes, used to replicate the first wave of intense downpour during a storm⁸. Rainfall caught within the gutters flowed into a cylinder, which was compared to the amount of rain which fell onto the roof, or catchment area. Overshoot and percentage of rainfall caught could be calculated in this way. Under 1 inch per hour, gutters were subjected to 0.5 gallons (1.9 L) of water, 1.5 gallons (5.7 L) under 3 inches per hour, 3.5 gallons (13.2 L) under 7 inches per hour, and 4.5 gallons (17 L) under 9 inches per hour. A 5 foot (1.5 m) high test roof, with a catchment area of 24 ft² (2.16 m²) and an angle of 15 degrees (FIGURE. 2), was used to mimic rooftops within Kenya. The V-Shaped, Square and Trapezoidal cross-sections were hung from the jig, while the wrap-design was attached directly to the roof. Further experimental details are discussed in the authors' previous work³.

FIGURE 2
 FRONT IMAGE OF TEST JIG

To compare the cross-sections, overflow, overshoot, the volume of standing water left in the gutters, volume caught, and rate of draining were taken into account. Standing water refers to water remaining inside the gutter after the rainfall. The amount of standing water was influenced by the gutter's longitudinal slope along the side of the building, as well as the length of the building. To create a slope along the building, the distance from the roof to the bottom of the gutter's cross-section increased from one end of the gutter towards the downspout; longer buildings thus would require flatter slopes. Volume caught refers to water, which fell onto the roof, which was collected by the downspout during the rainfall, while rate of draining was measured by the amount of time that has passed between the end of the rainwater simulation and the cessation of water flow through the gutter. Data points in each category were weighted so as to be comparable. TABLE I shows the weights assigned to each category, adding up to 1, to assess total gutter performance. Weights were subjectively determined by the authors based on the perceived importance of those criteria for the Kenyan context³. For full explanation of weighted points and reciprocal evaluation, please see Appendix 1

TABLE I
 SCORING MATRIX FOR GUTTER PERFORMANCE

Design Criteria	Weight
Standing Water	0.125
Overflow	0.250
Overshoot	0.250
Caught vs. Lost	0.250
Rate of Draining	0.125
Total Score	1.000

Results

Laboratory data were collected for each cross-sectional design under 1 inch, 3 inches, 7 inches, and 9 inches per hour. Within a typical year in Kenya, rainfall intensity is 1 inch per hour or less⁹. Thus for the remainder of the paper, data collected at a rainfall intensity of 1 inch per hour are used in evaluating performance and economy. Weighted performance data for this intensity, including overflow, drainage, standing water, overshoot and total rain caught, can be found in TABLE II. To be clear, these are not raw data, but weighted (dimensionless) values based on the weights assigned in TABLE I. Raw data are available in the authors' previous work³.

TABLE II
WEIGHTED GUTTER PERFORMANCE UNDER 1 INCH OF RAINFALL PER HOUR

Raining intensity	Overflow	Draining Rate	Standing water	Overshoot	Rain Caught
V Shape	1	1.72	4.29	1.24	1.05
Wrap	1	1	4.29	1.68	1.11
Trapezoid	1	1.66	1	2.8	1.18
Square	1	1.54	1.58	1	1

While overflow was not observed in any instance, overshoot was a common problem. Overshoot of the gutter increased with rainfall intensity. Though the wrap design (shown in FIGURE. 3) did surround the edge of the roof, gaps between the gutter and the roof caused leakage. This water loss was attributed to overshoot, since it was a measure of the gutter's ability to intercept the water flowing from the roof. Watertight connections would significantly enhance the gutter's overshoot performance.

FIGURE 3
CROSS-SECTIONAL VIEW OF WRAP DESIGN, IN LAB

The weighted performance data, presented in TABLE II allows comparison of each gutter across our design criteria. A sum of performance values across all criteria was used to compare overall performance of gutter cross-sections under different rainfall intensities. Final results

comparing performance of gutter cross-sections for different rainfall intensities are shown in TABLE III.

TABLE III
BEST-FIT GUTTERS FOR PARTICULAR RAINFALL INTENSITIES

Rainfall Intensity	Square	V-Shape	Trapezoidal	Wrap
1 in/hr			X	
3 in/hr			X	
7 in/hr				X
9 in/hr				X

Though a trapezoidal gutter cross-section was determined to be the best fit for rainfall conditions at, or below, 3 inches per hour, the wrap design was chosen for field-testing in Kenya for two reasons. One, the wrap design's underperformance with respect to overshoot was viewed as improvable with watertight connectivity. Two, although rare, rainfall intensity above 3 inches per hour does occur and results in a significant rainfall that can be captured⁹. Field research was focused on determining the feasibility of using this design on non-uniform roofs in the Kenyan context and the feasibility of implementing a more complex, though more efficient, gutter design.

SECTION II

COST-BENEFIT ANALYSIS AND ECONOMIC IMPLICATIONS

During May 2013, fieldwork was done in Kenya to test both the feasibility of local construction of the rainwater harvesting system (RWH), as well as to investigate the economics of rainwater harvesting in Nyeri, Kenya. Due to limited time and resources, only the wrap design was field tested in Nyeri. This section will discuss the barriers to adoption of RWH technologies within Kenya, with particular emphasis on feasibility of a cost-efficient system, the value proposition to both producer and consumer, and the scalability of such a RWH business venture. Barriers to entry were found specifically with regard to return on investment due to higher installation costs, compared to locally available options, as well as the availability of government supplied water. These issues are discussed through the use of an efficiency analysis, with regard to water caught over time, and a cost analysis, taking given efficiencies and the time until the gutter system become profitable.

Cost and efficiency analysis

Efficiency analysis

Rainwater harvesting systems tend to be sold by the foot, or meter, within the Nyeri market, as is common within the developing world context. In order for a rainwater harvesting system to be cost-effective, the system must cost less than, or equal to, the cost of water, over its lifetime. Thus, determination of cost-effectiveness requires knowledge of average rainfall, material cost and calculation of gutter efficiency.

First, the efficiency of the gutter, with regard to price, can be calculated using raw material costs as found in Nyeri. The efficiencies of each gutter can be determined through Equation (2).

$$Efficiency = \frac{Rain\ Caught}{Rain\ Caught + Overshoot + Overflow} \quad (2)$$

TABLE IV compares the efficiency of four gutter designs assuming a rainfall of 1 inch per hour, and a 400 ft² (37 m²) roof. This roof area is comparable to ones found in small schools, strip malls, and similar structures in Kenya. For example, the manager of the Children and Youth Empowerment Center (CYEC) in Nyeri, Kenya, estimated that nearly 2000 gallons (7570 L) of water was purchased by the center from the government each month. Based on this, the hours of rainfall needed was calculated using Equation (3), with M representing the number of hours of rainfall needed in order to match the 2,000 gallons used per month. At a rainfall intensity of 1 inch per hour, 33.3 cubic feet, or 249.33 gallons fall on the roof each hour. The hours of rainfall necessary, per month, to meet the total consumption needs of the CYEC are given in TABLE IV.

$$2000\ gallons / (249.33 * Efficiency) = M\ Hours \quad (3)$$

TABLE IV
HOURS OF RAINFALL PER MONTH NEEDED, AT A RAINFALL INTENSITY OF 1 INCH PER HOUR, TO COLLECT 2000 GALLONS BASED ON EFFICIENCY

	Efficiency	Hours of continuous rainfall to reach 2000 gallons
V Shape	0.82	10.10
Trapezoidal	0.92	9.00
Square	0.78	10.62
Wrap	0.87	9.52

Based on the values in TABLE IV, the ranges of rain needed for each system to store enough water to replace that purchased from the government is between 9.00 and 10.62 inches. While seemingly small, the wettest month of the year, April, only produces 7.7 inches of rain on average⁹. It is therefore impossible to collect sufficient rain to meet monthly needs. Hence, harvested rainwater is unlikely to replace purchased water. A rainwater harvesting system may however be used as a supplemental water delivery system, and can save money over time by decreasing the need to rely on purchased water.

Cost analysis

Consumers want to buy the least expensive and most durable product for their home or business. Within the developing world context, cost is a primary driving factor. TABLE V compares the prices of different gutters per 6-foot sections, based on raw materials and tools needed. In calculating the values shown in TABLE V, it was assumed that the gutters are attached to a 20 ft x 20 ft roof, typical of large institutions surveyed in Nyeri, Kenya, requiring 80 feet of gutter. It may be noted that 80 ft is an over estimate, as many institutions use a gable or skillion roof rather than a pyramid-shaped roof. It was also assumed that 650 Kenyan shillings (KES) will be spent for a tank--this figure is based on a survey of shop owners within the market of Nyeri, Kenya.

The cost of a full 80-foot system can be estimated by calculating the cost of 80 feet of gutter and then adding the cost of the tank. These prices were used to determine how many hours of rainfall, at a relatively strong rainfall intensity of 1 inch per hour⁹, would be needed to recoup the capital costs (i.e. return on investment). Payback periods can be seen in TABLE V.

TABLE V
 RETURN ON INVESTMENT EXPRESSED IN HOURS

Gutter Type	Price per 6 feet (KES)	Price per system (KES)	Hours of rain until Break Even
Trapezoid	657.33	9414.4	38.99
V Shape	429	6370.0	28.68
Wrap	570	8250.0	43.81
Square	450	6650.0	31.66

Assuming that water costs 2,000 KES per month for an average local institution, it would take over a day of continuous rainfall or more than 28 inches of rain for the gutter systems to make back their investment in full. Even when spread out over the course of a month, it is highly unlikely that sufficient rainfall events would occur in an arid or semi-arid environment, particularly in the dry season. Simply put, there are cheaper options available to obtain clean water other than a RWH system.

Barriers to Entry

Standardization Barrier

One of the fundamental objectives of this rainwater harvesting project was to standardize gutter design and installation. However, our fieldwork demonstrated that this approach is inherently problematic. In Nyeri, Kenya, and much of the developing world, roofs are not standardized (FIGURE. 4), and thus anything attached to them has to be altered to account for unique roof designs.

FIGURE 4

CLOSE-UP OF A RUSTED AND NON-UNIFORM ROOF IN NYERI, KENYA

For one, materials used to make roofs vary considerably. In cities, most rooftops are constructed with corrugated metal sheet in flat, skillion (or lean-to), and hipped shapes. In rural areas, where people do not have access to sheet metal, rooftops are constructed with lumber, leaves, straw, and newspaper. Practically, metal-gutter-based rainwater harvesting systems can only be attached on the skillion or fascia board and hipped roofs made of sheet metal. This implies that rural areas, where the need for water is greatest, cannot be supplied easily. Secondly, there is no standard for the slope of the roof and the distance between the edge of the roof and the wall. Since our wrap design is dependent on the slope of the roof and the distance between the edge of the roof and the wall, customizing the gutter design is crucial and inevitable. Thus, mass manufacturing, which can drastically reduce overhead costs cannot be easily employed. Moreover, lack of maintenance is a common problem in both rural and urban areas, contributing to rusted and fragile roofs that are not strong enough to attach gutter systems.

Value proposition challenges

To justify the expense of the gutter, its primary purpose of collecting and storing rainwater has to be the main goal of the consumer. Within the parts of Kenya in which government water delivery is available, there is no need to collect rainwater for domestic use. Government-supplied water is also widely available in the more developed areas, which coincide with areas that receive periods of heavy rainfall and have many available bodies of water. Bodies of water, including streams, rivers, and lakes, are used when there is a need for more water than what the government is providing through taps. Thus, the need for an additional water source is nonexistent. Informal interviews with locals indicated that these regions tend to use gutters to keep water from running down exterior building walls to prevent them from decaying. In this instance, a wrap design would provide the most benefit, since, when installed correctly, no gaps occur between the gutter and the wall of the building, allowing minimal water to escape.

In other contexts, such as Northern regions of Kenya, where water is scarcer, drought is a common occurrence. Schools and households in Kenya struggle to continually have enough water to keep their facilities running. Throughout Kenya, while there are 55 water service providers, only 7 of them offer continual service, including Nyeri, where our research took place¹⁰. For the areas under the other 48 water service providers, rainwater harvesting would be beneficial. However, medium and large institutions require much larger amounts of water than

what can be provided by domestic rainwater systems. In order to meet 2000 gallons of water needed based on the previous assumption, massive catchment systems would have to be installed. Unfortunately, such massive systems require the institution to have access to significant financial capital and long-term maintenance.

While not all areas of Kenya have access to government-supplied water, those that do not tend to be in arid areas that have less than 14 inches of rain over the year¹¹. In these regions, water bodies are the primary sources of water. Though residents may need to travel long distances to get to these bodies of water, there is a lack of other employment; so wasted time does not mean wasted money. Thus, the rainwater harvesting system can save time for local people, but they do not see the value, and the value proposition fails. While there is a need for an additional water source within the area, domestic rainwater harvesting does not provide the right answer, since there is little rainwater to be harvested.

The value proposition for the entrepreneur is fundamentally connected to the value created by the product for potential customers. Within the central Kenyan market, customers we interviewed did not find inherent value in installing rainwater harvesting systems on their roofs. The value of the product is hard to justify. At the same time, due to the non-uniformity of each roof, each gutter needs to be customized based on the slope of the roof and the distance between the edge of the roof and the wall. This leads to higher costs and makes the product even less marketable. Thus, mass manufacturing is not possible and the installation process would need to be customized to every roof, requiring a trained cohort of workers. In essence, a business that installs domestic rainwater harvesting systems is not a lucrative venture under current conditions and municipal water costs.

CONCLUDING REMARKS

Initially, the student team set out to design an efficient domestic rainwater harvesting systems to address the need for affordable, reliable and sustainable water sources in developing countries likes Kenya. Towards this end, a three-tiered approach was used. First, a laboratory analysis of the performance of four gutter cross-sections was conducted to assess the performance of three conventional and one novel gutter designs under rainfall between 1 and 9 inches per hour. Next, an analysis of the costs, benefits and challenges to implementations of a rainwater harvesting system, based on fieldwork in central Kenya, was conducted. Finally, economic and laboratory results were compared to determine the value and feasibility of a rainwater harvesting venture in Kenya.

While the ability to procure material, fabricate and install gutter systems was easily validated in Nyeri, Kenya, economic barriers and value proposition challenges emerged as main obstacles. A key challenge is the cost of the rainwater harvesting system. In areas where rainfall intensities are sufficient to enable consumers to collect enough water to meet their needs, inexpensive (utility-supplied) or free (manually-transported) water is available. Furthermore, conversations with consumers revealed that they purchased gutters to protect exterior walls from water damage, not for rainwater harvesting. Coincidentally, the communities in need of sustainable and reliable water delivery lacked access to capital and were not capable of recouping their capital costs in a short term due to the lack of rain in their area. While the laboratory results behind our design holds strong, it does not serve as a viable platform for a successful business.

Potentially, one can still implement the proposed wrap design in a different context, with a unique entrepreneurial approach, to help alleviate water scarcity. Non-profits can use the design

to enhance the efficiency of the rainwater harvesting system donated to help local communities. For-profit businesses can implement the design in urban areas, where people have more disposable income to invest in a rainwater harvesting system.

Ultimately, however, this work serves as a case study that illuminates the challenges associated with implementation of rainwater harvesting systems in the developing world. Though it may be argued that some implementation challenges, such as inconsistent roof designs, should have been obvious to the student team without fieldwork, the fieldwork proved to be the critical factor in understanding the complexities of applying engineering solutions in the developing world. Informal interviews with locals allowed generation of realistic pricing and water consumption data. First-hand experience installing gutters allowed students to understand the difficulties associated with installation of a gutter on rusty, non-uniform roof. Soliciting the views of local vendors, homeowners and managers of institutions allowed students to better appreciate that though the design may work, individuals will not purchase an item they don't see as cost efficient or beneficial. Through this service learning experience, students were able to better appreciate engineering design and its real-world considerations, as well as the broader impacts.

ACKNOWLEDGMENTS

We would like to acknowledge Dr. James Hamlett for generously allowing us to use his rainwater simulator and assisting us in data collection and analysis. Thank you to Chiyan Poon and Emily Passauer, who helped in data collection. We would also like to thank Tara Sulewski, Liz Kisenwether, Susan Beyerle, Andras Gordon and Irene Mena for mentoring several freshmen design teams that collectively inspired our team to explore various gutter designs and installation methods. Lastly, thank you to those that made our fieldwork possible through scholarship and awards, particularly Penn State's Undergraduate Research Exhibition judges, who awarded us the Gerard A. Hauser award, contributing to our research funds.

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APPENDIX

Methodology of rainfall simulation, from *Gutter Design and Selection for Roof Rainwater Catchment*³

METHODOLOGY

Experiments were conducted on a rainwater simulator that was modeled after the simulator described by Miller and Fennessey.⁶ The simulator was used to test conveyance, conductance and interception characteristics of the four different gutter designs (FIGURE. 1). Rainfall intensities were described as “light”, “moderate”, “heavy”, and “violent”, with rainfalls of 1 inch per hour, 3 inches per hour, 7 inches per hour, and 9 inches per hour, respectively. Note that use of these descriptors of rainfall intensities are only intended to be descriptive for the purposes of this paper and not standardized as in Still and Thomas.² The duration of each experiment was 2 minutes. Such a short experimentation time was used to mimic the first wave of intense downpour during a storm.⁸ This normally occurs within the first 5 minutes, but due to time constraints, 2 minutes was used. During this time, rainfall was captured in a calibrated graduated cylinder. Rainfall intensity was determined by dividing the total amount captured in the cylinder by the duration of the experiment (1/30) hours. It may be noted that increasing the duration of the experiment from 2 to 3 minutes did not affect the gutter performance results.

A 5 foot high test roof (Fig. 2), angled at 30 degrees, and with a 4 ft by 6 ft corrugated metal sheet secured on top was used to simulate a roof catchment. The total catchment area was 24 ft². The ‘V’ Shaped, Square and Trapezoidal gutters were suspended from the roof catchment using steel wire hung from an iron rod. The wrap gutter, however, was attached using nuts and bolts every 1.2 meters. During the light, moderate, heavy, and violent rainfalls, each gutter was subjected to 1.89L, 5.66L, 13.21L, and 16.99 L of water over 2 minute duration of each experiment, respectively. This volume was calculated based on roof area, roof angle and rainfall intensity.

FIGURE 5
 FRONT IMAGE OF TEST JIG

Collected data reflected the amount of water lost through overflow, rate of water drainage, amount of standing water remaining in the gutter, amount of water lost via overshoot and the total amount of rain caught by the gutters. Overflow was defined as the volume of water that exceeded the volume of the gutter, and spill out of the gutter, measured by the liters of water collected from the gutter's downstream. Rate of drainage was defined as the elapsed time after rainfall had stopped and the flow from the gutter stopped. Standing water was the volume of water remaining in the gutter after all flow had ceased, measured in milliliter. These measured values characterized the conveyance of each gutter system. Once raw data were collected for each gutter and rainfall intensity, they were ranked against each other and then multiplied by their weighted rates shown in Table VI. Weights in Table VI were determined based on our assessment of criteria important for success of a gutter system in and around Nairobi, Kenya. Readers are encouraged to design their own scoring matrix based on their specific context.

TABLE VI
 SCORING MATRIX FOR GUTTER EFFICIENCY.

Design Criteria	Weight
Standing Water	0.125
Overflow	0.250
Overshoot	0.250
Caught vs. Lost	0.250
Rate of Draining	0.125
Total Score	1.000

Ranking was accomplished by normalizing the reciprocals within a given data set (e.g. overflow, rate of draining, etc.), with 1 being equal to the smallest reciprocal. For instance, if A, B, C and D are measured, scalar values of some property, each respective reciprocal was scaled such that

$$c \times \min\{1/A, 1/B, 1/C, 1/D\}=1$$

Next, the scaled quantities, $\{c/A, c/B, c/C, c/D\}$, where c is the scaling coefficient, were multiplied by the weight for the measured data set, given in Table VI. The resulting data was termed weighted data.

Radar plots juxtaposed weighted data for each gutter design. This allowed determination of the best gutter for each rainfall intensity. Note that the scoring matrix shown in Table VI is subjective and based on the importance of each criteria within the context in which the RWH system is expected to be used. Additionally, it should be noted that experiments were conducted under laboratory conditions, where environmental factors such as wind, rusting and roof deformation were not accounted for. These factors may ultimately prove important in real-world implementation.