Elements to Successful Rainfall Monitoring

Rain Gauge Equipment Selection for the Urban Sewer Environment

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ABSTRACT Important engineering decisions are made every day regarding sanitary sewer, combined sewer, and storm sewer systems and often involve the use of rainfall data. Although these decisions involve significant capital investment and expenditures that are required to protect life, health, and property, the integrity of rainfall measurements supporting these decisions is often overlooked. The authors have examined guidance from a variety of professional organizations in engineering, water resources, and meteorological fields and have consolidated their findings into a concise, flexible approach to obtain appropriate rainfall data to support sound engineering evaluations and decisions.

The reliability of rainfall data depends on four concurrent factors: selecting suitable rain gauge equipment, determining an appropriate density, properly siting them, and properly maintaining them once installed. Selecting appropriate rain gauge equipment is the focus of this discussion, including a methodology to set rain gauge performance expectations and find rain gauges that meet or exceed them.

KEY WORDS Rainfall Monitoring, Rain Gauge, Tipping Bucket

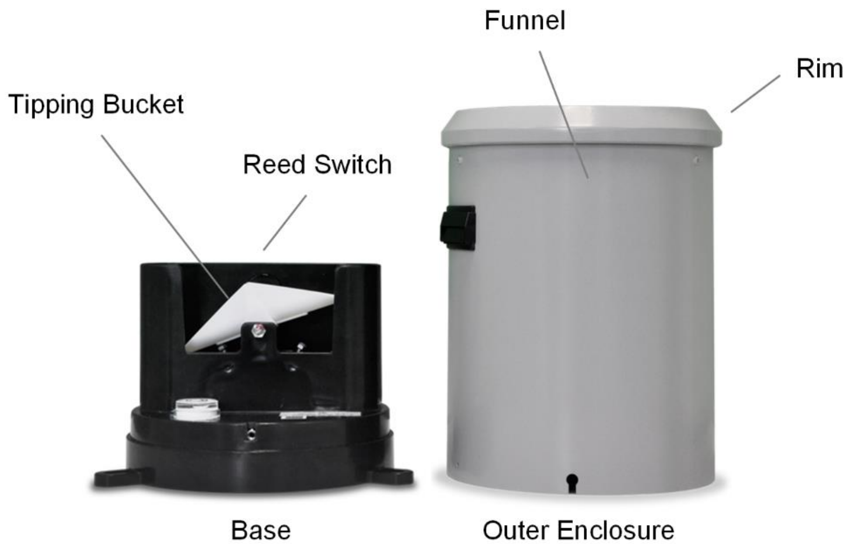
Introduction

Rain gauge equipment selection affects the accuracy and reliability of rainfall data. Accurate rainfall measurement is a critical, but often overlooked, factor needed for sewer design and evaluation, and less accurate rainfall data can have a significant, but often unnoticed, impact on sewer planning, design, and construction. Best management practices for rain gauge equipment selection are developed, discussed, and applied to demonstrate how to set rain gauge performance expectations and determine which rain gauges meet or exceed them.

Principle of Operation

Various technologies are available to measure rainfall, and each technology applies a different measurement principle. The standard tipping bucket is the most commonly used technology and operates by funneling rainfall to a bucket assembly located inside the rain gauge. The bucket assembly is divided into two equal compartments and operates like a seesaw on a playground. When one compartment has collected a known amount of rainfall, the bucket tips and empties its contents. As the first compartment tips, the second compartment is positioned under the funnel, and the time that the tip occurs is recorded by a reed switch connected to a rainfall monitor. Figure 1 shows the major components of a standard tipping bucket.

FIGURE 1: Major Components of a Standard Tipping Bucket



Standard tipping buckets have been used for many years. They are simple to install, simple to operate, and simple to maintain. However, they are known to have a characteristic systematic error. As soon as the bucket begins to tip, it must travel a small but finite distance before the time of tip is recorded and before the second compartment is in position to collect rainfall. As a result, any rainfall that falls from the funnel to the bucket during this brief period is not recorded, and the accuracy of a standard tipping bucket generally decreases as rainfall intensity increases. The magnitude of the error depends on the design, construction, and condition of the tipping bucket.[1]

A variety of other technologies have been developed over the years to reduce or eliminate this systematic error and are found in a variety of applications. One variation of the standard tipping bucket is the siphoning tipping bucket, which uses a siphon installed at the base of the funnel to regulate the rate at which rainfall is directed from the funnel to the bucket assembly. By controlling this rate, the bucket can be configured to tip preemptively, such that it accounts for the rainfall falling to the bucket during the tip. Weighing rain gauges and water level rain gauges are also available as alternatives to tipping bucket technologies. These rain gauges accumulate rainfall in a collection bucket and then measure the change in weight or depth over time.

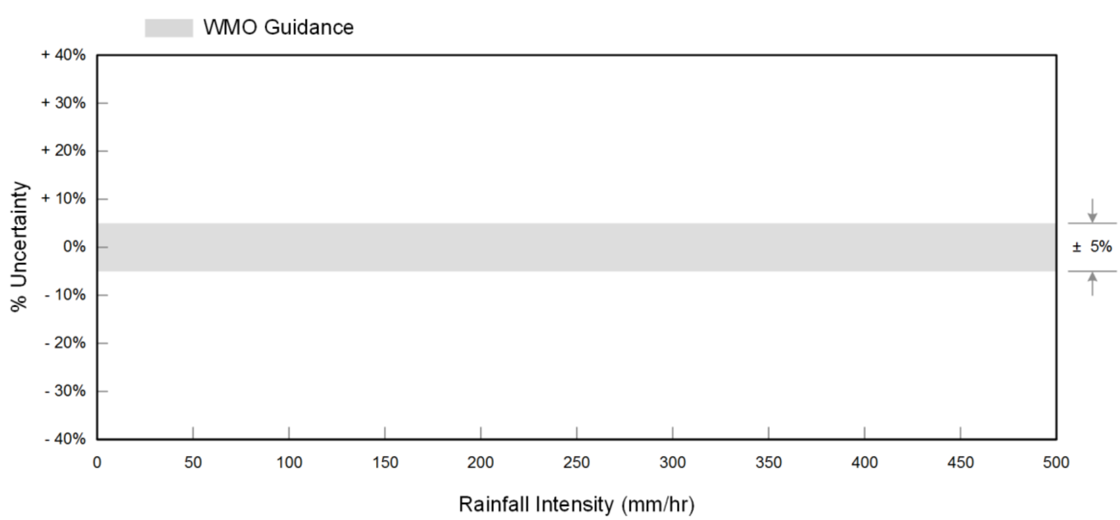
The accuracies of various rain gauge technologies as a function of rainfall intensity have been studied and evaluated by a variety of researchers.[2] As previously noted, standard tipping buckets exhibit a decrease in accuracy as rainfall intensity increases. Siphoning tipping buckets show improvement over standard tipping buckets and have accuracies that are much less sensitive to rainfall intensity. Weighing rain gauges are considered the most accurate rainfall measurement technology, and for this reason they are often used as reference rain gauges or for research purposes. Although similar in principal to weighing rain gauges, water level rain gauges are generally reported to be less accurate than weighing rain gauges.[2]

Performance Expectation

Knowing the performance characteristics of various rain gauges can help determine which ones are technically suited for a given application. Selecting rain gauge equipment suitable to support sewer system design and evaluation requires that two questions be asked and answered: (1) what accuracy is required and (2) over what rainfall intensity range? The answers to these two questions define a performance envelope within which a rain gauge is expected to operate.

The first question has been answered by the World Meteorological Organization (WMO), which recommends measurement uncertainties within ±5% for rainfall intensity.[1] This guidance is illustrated in Figure 2.

FIGURE 2: World Meteorological Organization Rain Gauge Accuracy Recommendation



The second question is answered based on local rainfall characteristics and the design storm of interest. Rainfall characteristics vary around the world, and local rainfall intensity-duration-frequency (IDF) data reveal the rainfall intensities that are expected in a given community. Design storms of interest also vary, depending on the application, and knowing the return frequency of interest refines the required working range. This methodology is demonstrated in the following example.

EXAMPLE

A rain gauge network is needed to provide rainfall data in Washington, D.C. What is the required working range for this rain gauge network for various return frequencies?

Solution

Rainfall IDF data in the United States are obtained from the National Oceanic and Atmospheric Administration (NOAA).[3-18] Rainfall intensities associated with various return frequencies in Washington, D.C. are shown below.

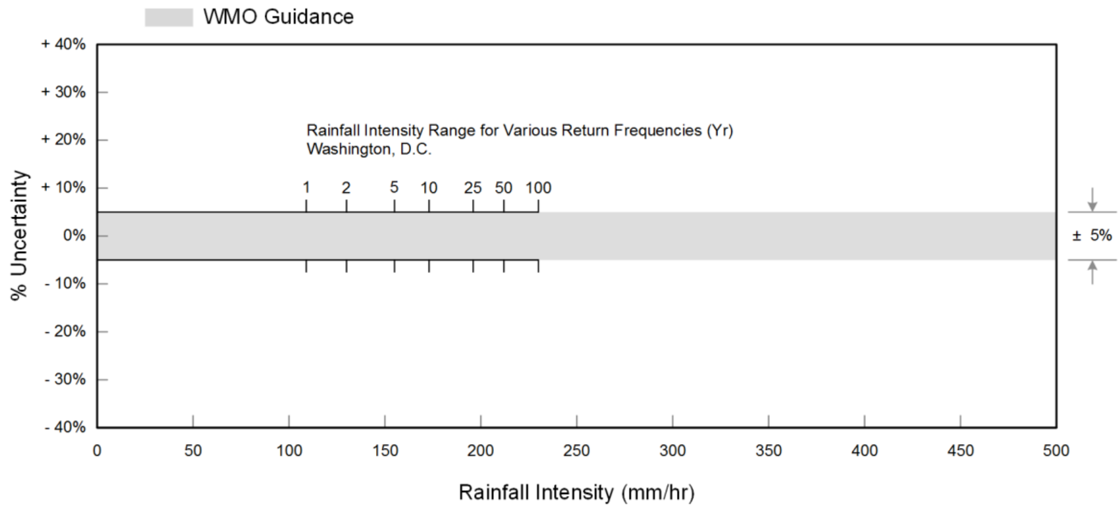
Rainfall Intensity for Various Return Frequencies

Duration	1-Yr	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr
min	mm/hr	mm/hr	mm/hr	mm/hr	mm/hr	mm/hr	mm/hr
5	108	130	154	172	195	212	229
10	86	104	123	138	155	169	182
15	72	87	104	116	131	142	153
30	49	60	74	84	97	107	117
60	31	38	47	55	65	73	81
120	18	22	28	32	38	44	49
180	13	15	20	23	28	32	36
360	8	9	12	14	17	20	22
720	5	6	7	9	11	12	14
1440	3	3	4	5	6	7	9

A design storm associated with a given return frequency is comprised of a range of rainfall intensities, where the maximum expected rainfall intensity is associated with the 5-minute duration. For example, a 2-year, 1-hour design storm in Washington, D.C. has an average rainfall intensity of 38 mm/hr. However, embedded within this design storm are the rainfall intensities associated with the 5, 10, 15, and 30-minute durations. Rain gauges, like sewers, are sized for maximum capacity, not average capacity. Therefore, the working ranges associated with the 1, 2, 5, 10, 25, 50, and 100-year return frequencies in Washington, D.C. are 0 to 108, 130, 154, 172, 195, 212, and 229 mm/hr, respectively.

The accuracy and working range define a performance envelope used to evaluate rain gauges and ensure that the right rain gauge is applied to the right application. Performance envelopes for rainfall monitoring in Washington, D.C. during 1, 2, 5, 10, 25, 50, and 100-year return frequencies are illustrated in Figure 3.

FIGURE 3: Rain Gauge Performance Envelope for Washington, D.C.



Performance Evaluation

Once a performance envelope is defined, selecting the right rain gauge equipment is a simple matter of identifying which rain gauges operate within it. Rain gauge accuracy information should be readily available from product specifications provided by the manufacturer, and sometimes supporting laboratory data are available as well. Figure 4 shows the performance specifications for a standard tipping bucket recommended and used by ADS.[19] Note that this standard tipping bucket meets WMO guidelines up to rainfall intensities of 150 mm/hr, which accommodates rainfall events with return frequencies up to nearly 5 years in Washington, D.C.

FIGURE 4: Performance Characteristics of a Standard Tipping Bucket

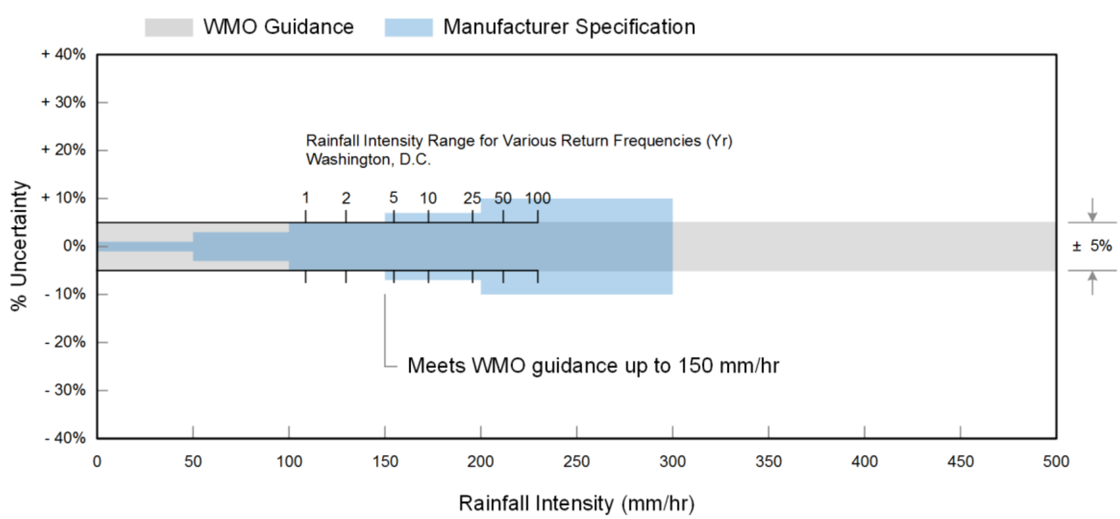
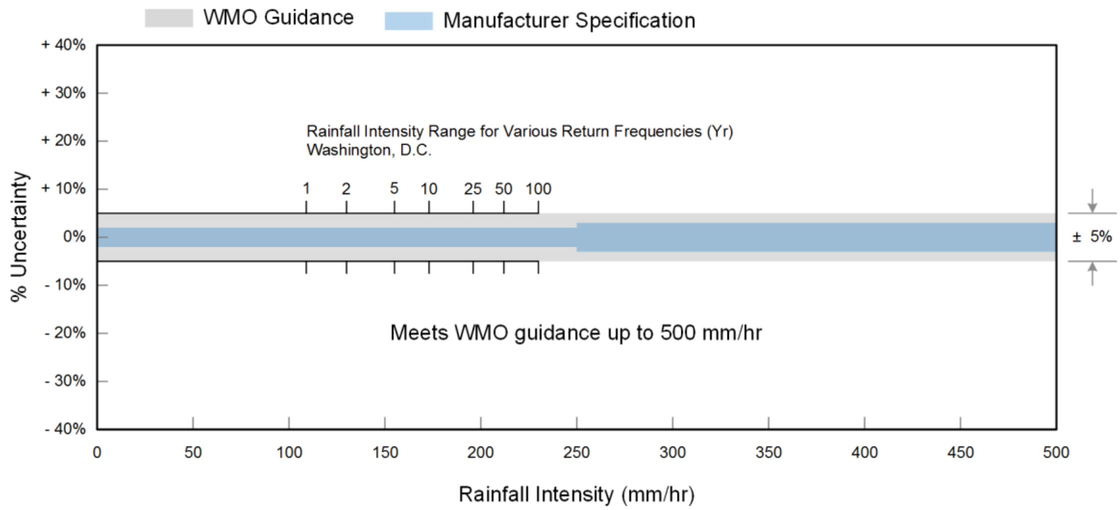


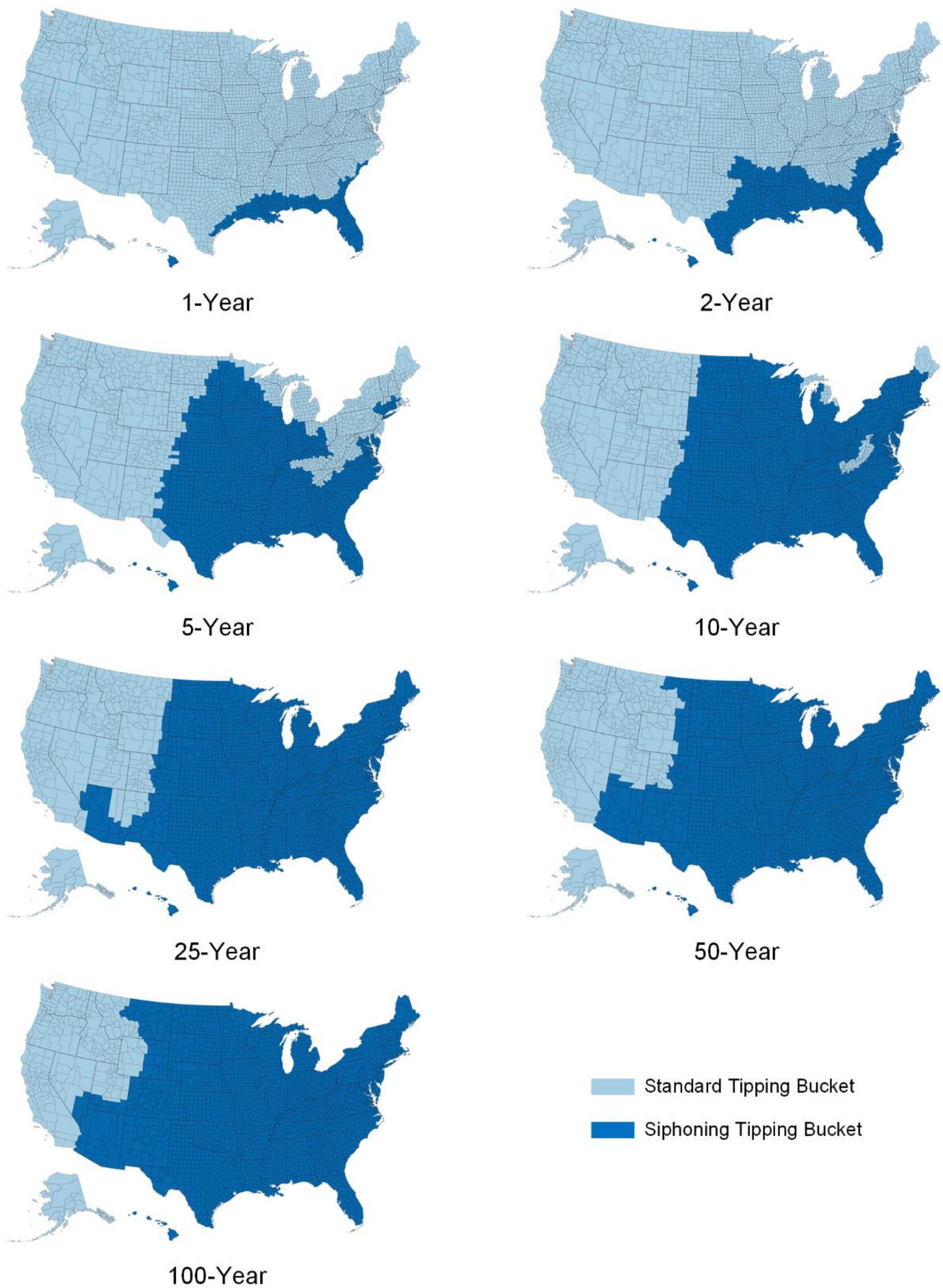
Figure 5 shows the performance specifications for a siphoning tipping bucket recommended and used by ADS.[20] Note that this siphoning tipping bucket meets WMO guidelines up to rainfall intensities of 500 mm/hr, which accommodates rainfall events with return frequencies up to 100 years and beyond in Washington, D.C.

FIGURE 5: Performance Characteristics of a Siphoning Tipping Bucket



Based on the performance characteristics of the standard tipping bucket and siphoning tipping bucket shown in Figure 4 and Figure 5, performance evaluations were made across the United States to determine where a standard tipping bucket or a siphoning tipping bucket is recommended based on local rainfall IDF data at various design storms of interest.[3-18] The results are shown in Figure 6 and provide general guidance on where standard tipping buckets and siphoning tipping buckets are recommended and under what conditions.

FIGURE 6: Standard Tipping Bucket vs. Siphoning Tipping Bucket at Various Return Frequencies



Conclusion

Selecting rain gauge equipment suitable to support sewer system design and evaluation requires that two questions be asked and answered: (1) what accuracy is required and (2) over what rainfall intensity range? The answers to these two questions define a performance envelope within which a rain gauge is expected to operate. The first question is answered by the WMO, which recommends measurement uncertainties within ±5% for rainfall intensity, while the second question is answered based on local rainfall characteristics and the design storm of interest. Rain gauges are then selected with performance specifications that meet the requirements of the desired performance envelope. Providing suitable rain gauge equipment improves the accuracy of rainfall data and increases the confidence in engineering decisions based on such data.

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