

# Analysis of Meter Registry Uncertainty

McKENNA L. SUMRAK,<sup>1</sup> MICHAEL C. JOHNSON,<sup>1</sup> AND STEVEN L. BARFUSS<sup>1</sup>

<sup>1</sup>Utah Water Research Laboratory, Logan, Utah

This study was conducted to quantify the effects of uncertainty on residential water meter registry testing and to demonstrate how to calculate registry uncertainty. All measurements have random and systematic errors, and understanding those errors is important to properly assess the limitations of the test. For this study, registry uncertainty calculations were computed according to the American Society of Mechanical Engineers (ASME) *Test Uncertainty Manual* (2006) for volumetric and

gravimetric scale test setups. Because of possible errors, uncertainties in the registry results may be high enough to justify passing some meters that fail and failing some meters that pass. In such cases, increasing the volume of water collected to higher than AWWA minimum standards reduces uncertainty and provides more relevant results. This study shows that uncertainties are significant and should be computed in order to accurately analyze the results.

**Keywords:** *error, meter registry, residential water meters, uncertainty*

Meter accuracy testing of residential flow meters is common practice among meter manufacturers and end users to ensure accurate registry readings that meet standards set by AWWA (2012). These standards are specific to meter size, type, and flow rate, and they establish criteria to ensure the meters perform as required, which then aids in decision-making regarding meter type selection. To correctly make a decision based on meter accuracy test results, one must understand the test itself, including the equipment used, how the test was conducted, and the test limitations. Once these factors are known and accounted for, the test data become more valuable.

Of utmost importance when analyzing the acceptability of a meter accuracy test is acknowledging areas of error and limitations in the data collected. Understanding potential errors and measurement uncertainty resulting from the testing apparatus and test methods is critical to obtaining reliable data. The testing apparatus consists of a test bench with either a volumetric or gravimetric tank to collect the water; a pipeline setup to connect the meters being tested and allow water to flow through the meters; and measuring devices to record the flow rate, weight, and temperature if a gravimetric tank is used, or the flow rate and volume if a volumetric tank is used. Some test benches are manufactured as a single piece of equipment, while others are a setup of separate pieces manually connected to form a system. Accepting the readings of the meter as well as the test bench at face value, and comparing the results with the expected outcome, does not tell the entire story about a meter's registry performance. The errors associated with the meter reading and test bench can be significant and should be established and quantified. Uncertainties in test measurements arise from the limitations of the measurement equipment, readability of the instruments,

instrument error, human error, and bias of the meter readings or bias of the measuring instruments. Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance* (AWWA 2012) regarding water meter accuracy testing also addresses these errors: operator error, repeatability error, and bias. These errors result in registry and test bench uncertainty and, when combined, provide a way to analyze the data and understand more clearly the reliability of the data obtained, and consequently provide an indication of the metrics used to gauge the meter's performance. While some of these errors are difficult to quantify and may be subjective, they should still be included in assessing the test data. The amount of uncertainty that exists within a specific method of registry investigation should be known in order to understand how certain the collected data are. While it is extremely difficult to get an exact measurement, it is possible to quantify the quality of the measurement through an uncertainty analysis. The authors suggest that before accepting a passing or failing registry result, one should first question the integrity of the method and readings used to determine the meter's registry.

## THE PROBLEM

When analyzing data from meter registry testing, uncertainties in the test method and equipment are often ignored, but these uncertainties are not negligible and should be addressed before classifying a meter as passing or failing. Assuming that human error can be taken out of test results, uncertainties may arise from the meter or the test equipment. While there are various sources of error, the main focus of error in this study is readability and reliability of the measurement equipment; however, the method used here can be applied to other possible quantifiable errors.

To illustrate this point, the individual and combined uncertainties are examined for a  $\frac{5}{8}$ -in.  $\times$   $\frac{3}{4}$ -in. meter tested at the AWWA minimum flow of 0.25 gpm with a draft size of 10 gal (AWWA 2012). For the purposes of this example, it is assumed that the flow rate of 0.25 gpm can be precisely set. Assuming also that the test equipment is completely accurate and that there are no human errors, possible errors of the result then include the readability of the register and the accuracy of the meter itself. Since the meter accuracy is the dependent variable, only the error associated with the readability of the register is accounted for. Suppose one revolution of the meter dial is 10 gal, subdivided by gallons, with each gallon subdivided by 0.1-gal marks. If readings can be made to the nearest half mark, the meter can reasonably be read to the nearest 0.05 gal. The meter is read for an initial and a final reading, resulting in a registry reading with a maximum error of 0.1 gal (0.05 gal below the actual initial reading and 0.05 gal higher than the actual final reading). The maximum error would then be 1% (0.1 gal out of the 10-gal draft size) because of meter readability, which could cause the registry to fall outside of the AWWA standard.

Next, supposing that the meter registry is completely accurate and there are no human errors, the readability and accuracy of the equipment must be evaluated. Residential meter accuracy test benches are normally one of two equipment types—volumetric (pre-made test bench) or weight. If a test bench with a volumetric tank is used, and assuming the tank has a diameter of 1 ft and the water level in the tank can be set at 10 gal to within  $\frac{1}{16}$  in. of the 10-gal mark, the volume error may be 0.031 gal, resulting in an error of 0.31%. This error is directly related to the tank's diameter and, consequently, a larger-diameter tank would result in a larger error when reading 10 gal. If a weight tank is used and digitally displays in 0.5-lb increments, then the combination of the initial and final reading error could be as large as 0.5 lb, assuming that conventional methods of rounding are used for the starting and ending weight. The error would then be 0.6% (0.5 lb out of the 83.4 lb required to pass 10 gal).

For the combined readability uncertainty of the meter and equipment, simple addition of the two errors provides an uncertainty of 1.3 to 1.6%. However, this is not the most accurate approach. According to statistical rules, uncertainties cannot be summed but must be combined using the root-sum-square method. The American Society of Mechanical Engineers (ASME) has developed a method to accurately calculate test uncertainties that not only combines uncertainties using the root-sum-square method, but also incorporates the influence each measured parameter has on the result (ASME 2006). The uncertainties obtained using this method provide better insight into the accuracy and reliability of the data than the simple addition method. The intent of this study is to provide a means to analyze and interpret registry data and explain with confidence its value, given the equipment used to determine it.

## LITERATURE REVIEW

Uncertainty in testing is addressed in all areas in which data are collected and analyzed. Because of this, numerous studies and articles have been written on the subject, but few directly address

uncertainty in residential water meter accuracy testing. A study in Australia in 2002 on chemical measurement uncertainty was completed pursuant to the release of the ISO/IEC 17025:1999 standard, which requires chemical testing laboratories to estimate uncertainty. Those affected by the standard were concerned about how uncertainty would be estimated and the time it would take to complete this process. In answer, one of the country's national laboratories conducted a study to estimate the process of calculating uncertainty in the amount of toluene in water. The sources upon which they focused were method recovery, sample recovery, homogeneity, precision, and calibration. After all errors were determined, the root-sum-square method was used to calculate the uncertainty (Armishaw 2003). These same methods are applicable to water meter testing. By focusing on the calibration of the equipment and the precision of the testing, uncertainty can also be found in the water meter test procedure. By way of an example, a laboratory in Belgium was commissioned to analyze the process and sources of uncertainty in analytic chemistry. The laboratory found systematic errors in the method and laboratory bias and random errors in test runs and repeatability. This study differed from the one in Australia because the Belgium study focused on errors from the measurement procedure as well as the standard used, and much of the emphasis in the Belgian study was placed on documentation and referencing (Taverniers et al. 2004). This focus can also be applied to water meter testing. By documenting all methods and standards used, as well as actual data and test conditions, the uncertainty under the specific conditions can be calculated.

While many studies focusing on uncertainty were set in the chemistry field, a study completed in Norway focused on calibration of water and flow meters. Testing was based on European standards and extremely low flow rates. Three test setups were studied: static weighing, volume tank, and reference flow meters. Errors were found through resolution, repeatability, flow medium, scale calibration, buoyancy corrections, water density, and readability. The Norwegian study provides specific random and systematic error quantities that apply to similar test setups. Using the determined error values, the root-sum-square method was applied to find the total uncertainty (Nordon 2004). The root-sum-square method is useful if a test is evaluated in detail for all possible uncertainties that may occur, but does not show a complete description regarding the source of the errors.

In 1985, ASME published a very useful article that discussed the ASME methodology used in this study (Abernethy et al. 1985). Its focus was to introduce the basis for ASME/ANSI standards regarding uncertainty. It also discussed the application of specific organization standards from the Nuclear Regulatory Commission, International Organization of Standardization, and North Atlantic Treaty Organization, among others. The study concluded that the ASME methodology quickly gained influence nationally and internationally.

## DEFINITIONS

Measurement uncertainty calculations help quantify error bounds in data collection methods and measurements. The ASME *Test Uncertainty Manual* defines different types of uncertainties

and illustrates how to calculate uncertainties of measurements and results. At present, the ASME *Test Uncertainty Manual* contains the recommended standard for making these calculations. As stated in the standard (ASME 2006),

the analysis of test measurement and result uncertainty is useful because it (a) facilitates communication regarding measurement and test results; (b) fosters an understanding of potential error sources in a measurement system and the effects of those potential error sources on test results; (c) guides the decision-making process for selecting appropriate and cost-effective measurement systems and methodologies; (d) reduces the risk of making erroneous decisions; and (e) documents uncertainty for assessing compliance with agreements.

There are two primary components of uncertainty that are accounted for in the calculation of the result and its associated uncertainty—systematic error and random error. Systematic error is defined as the portion of the total error that remains constant in repeated measurements throughout a test process. An example of systematic error (i.e., bias) is a scale that consistently reads 0.5 lb higher than the actual weight applied. Random error is defined as the portion of total error that varies randomly in repeated measurements throughout a test process. An example of random error using a scale that outputs to the nearest 0.5 lb can be illustrated as follows: assume a scale reads 100.5 lb, 100.0 lb, 99.5 lb, and 100.0 lb when a calibrated 100.0-lb weight is applied four times. There is error in the scale’s registry, but the error varies randomly with each test. Quantifying random error is possible but requires additional testing of the measuring device.

Random and systematic components of the measurement error are then combined to determine the total uncertainty. The calculation of the uncertainty incorporates the sensitivity of each parameter to determine a more accurate uncertainty interval. Sensitivity is the instantaneous rate of the change in a result because of a change in a measured parameter. This is used to give accurate weight to each parameter based on its influence on the result. Details of the calculation process are discussed in the methods section.

## SOURCES OF UNCERTAINTY

In a typical meter registry test, there are several potential sources of measurement error contributing to uncertainty. These sources include the meter, the meter register, connection hardware, weight or volumetric tank, thermometer, stopwatch, and human error. From each of these sources there are errors associated with the accuracy of the device and errors associated with reading the output of the device.

Examples of systematic errors include weight tanks that consistently read too low or too high, the readability of the outputs of devices (i.e., precision of the output value), or the stopwatch running slow. To determine systematic uncertainty, calibrations should be performed on all equipment to determine consistent inaccuracies. Examples of random errors include leaks in the connection hardware, variable readings of the weight tank that cannot be repeated, and most human error that is involved. To determine the random error of a scale, a known weight should

be placed on the scale many times, recording the reading each time. The measurements can then be used to determine an estimate of the random error of the device. Similar tests can be performed on all pieces of equipment to determine the random errors of each measured parameter of the test. In this study the authors focused on the errors associated with the readability of each device and random errors of a scale while also addressing how to incorporate all sources of error into the total uncertainty. The result is given with a 95% confidence interval.

## METHODS

The ASME method for calculating error and uncertainty is detailed in the *Test Uncertainty Manual* (ASME 2006). To follow is a summary of the step-by-step process:

1. Establish the governing equation for accuracy testing.
2. Record parameter measurements of the test and calculate the result.
3. Determine random and systematic errors associated with each parameter.
4. Calculate the sensitivity coefficient for each parameter.
5. Calculate the total random and systematic errors separately.
6. Calculate the total uncertainty of the test at the 95% confidence interval by root-sum-squaring the random and systematic uncertainties.

Determining values for the random and systematic errors can be difficult and may require testing on each piece of equipment or may require making reasonable estimates. Sensitivity coefficients are calculated by taking the partial derivative of the governing equation with respect to each parameter. For example, the sensitivity coefficient for a parameter is

$$\theta_p = \frac{\partial R}{\partial p} \quad (1)$$

where  $\theta_p$  is the sensitivity coefficient of parameter  $p$ ,  $R$  is the governing equation to obtain the result, and  $p$  is the measured parameter.

To calculate the total of the systematic or random error, the root-sum-square method is used: each parameter error is multiplied by its sensitivity coefficient and squared, and the square root is taken of the sum of individual parameter uncertainties. Equations for total random and systematic uncertainties are provided in Eqs 2 and 3, respectively.

$$s_R = \left[ \sum_{i=1}^I (\theta_i s_{x_i})^2 \right]^{1/2} \quad (2)$$

where  $s_R$  is the random uncertainty of a test,  $\theta_i$  is the sensitivity coefficient of the  $i$ th parameter, and  $s_{x_i}$  is the random error of the  $i$ th parameter for a sample of the population.

$$b_R = \left[ \sum_{i=1}^I (\theta_i b_{x_i})^2 \right]^{1/2} \quad (3)$$

where  $b_R$  is the systematic uncertainty of a test, and  $b_{x_i}$  is the systematic error of the  $i$ th parameter for a sample of the population.

To find the total uncertainty of the test, the root-sum-square method must be applied to the total random and total systematic errors as shown in Eq 4, then multiplied by 2 to obtain a 95%

confidence interval bounding the result. The combination of these uncertainties provides the absolute uncertainty of the test. To find the relative uncertainty, the calculated uncertainty is divided by the result. However, in meter testing, the results are already percentages, so the relative uncertainty is unnecessary. The uncertainty at 95% confidence is given by

$$U_{R95} = 2(s_R^2 + b_R^2)^{1/2} \quad (4)$$

where  $U_{R95}$  is the total uncertainty with 95% confidence,  $s_R$  is the random error of a test, and  $b_R$  is the systematic error of a test.

**EXAMPLE CALCULATION USING A GRAVIMETRIC TEST BENCH**

A meter accuracy test is conducted on residential water meters using a gravimetric test bench, weight tank, and thermometer. Determine the uncertainty associated with the meter and bench readability and scale accuracy with 95% confidence.

Step 1: Establish the governing equation. The registry accuracy is calculated by

$$R = \frac{(R_f - R_i)\gamma}{(W_f - W_i)} \quad (5)$$

where  $R$  is the registry relative to standard,  $R_f$  is the final register reading,  $R_i$  is the initial register reading,  $\gamma$  is the specific weight of water (function of water temperature),  $W_f$  is the final weight,  $W_i$  is the initial weight, and  $T$  is temperature.

Step 2: Record the parameter measurements of the test and calculate the result. The test is run at 0.25 gpm, and data collection indicates that  $R_i = 0$  gal,  $W_i = 0$  lb,  $R_f = 19.3$  gal,  $W_f = 166.8$  lb, and  $T = 55.7^\circ\text{F}$ .

The specific weight is found to be 8.34 lb/gal based on the temperature reading. Using the governing equation previously given,

$$R = \frac{(19.3 - 0) \times 8.34}{(166.8 - 0)} = 96.5\%$$

Step 3: Determine random and systematic errors associated with each parameter. Systematic errors are determined on the basis of the output of each piece of equipment used to obtain data.

A meter register is pictured in Figure 1. As depicted, one revolution is equivalent to 10 gal, and each numerical indicator is equivalent to 1 gal, with each gallon divided into 0.1-gal increments. Assuming the person reading the register can reasonably read to the nearest 0.05 gal, the systematic error for the initial and final registry readings because of readability are each 0.05 gal.

The weight tank used is placed on a scale with a digital output that displays to 0.05 lb, indicating that the display is within 0.025 lb of the actual value. This implies that because of readability, the systematic error of the initial and final weights are each  $\pm 0.025$  lb.

The thermometer has a digital output that displays to  $1/10$  of a degree. Using a programmed equation, the specific weight can be calculated to within 0.00008 lb/gal based on the accuracy of the thermometer value. The systematic error is estimated to be 0.00008 lb/gal.

Random errors are determined through equipment testing. The test is designed to determine the uncertainty of the meter; extraneous random errors are difficult to calculate, so only random errors associated with the scale will be determined. To test for these random errors, a 50-lb calibrated weight was placed on a 500-lb scale 20 times, recording the weight each time. An estimate of the random error for the scale was calculated to be 0.07 lb.

Step 4: Calculate the sensitivity coefficient for each parameter (Table 1). Using Eq 1, the sensitivity coefficients are calculated for  $R_i$ ,  $R_f$ ,  $\gamma$ ,  $W_i$ , and  $W_f$ .

Step 5: Calculate the total random and systematic uncertainties separately. Using Eqs 2 and 3, the total random uncertainty,  $s_R$ , and the systematic uncertainty,  $b_R$ , are calculated as follows:

**FIGURE 1** Meter register



Source: El Paso Water Utilities 2015

**TABLE 1** Sensitivity coefficient calculations for each parameter

Parameter	Calculations	Sensitivity Coefficient, $\theta$
$R_i$	$\theta_{R_i} = \frac{\partial R}{\partial R_i} = \frac{-\gamma}{(W_f - W_i)} = \frac{-8.34}{(166.8 - 0)}$	-0.05/gal
$R_f$	$\theta_{R_f} = \frac{\partial R}{\partial R_f} = \frac{\gamma}{(W_f - W_i)} = \frac{8.34}{(166.8 - 0)}$	0.05/gal
$\gamma$	$\theta_\gamma = \frac{\partial R}{\partial \gamma} = \frac{(R_f - R_i)}{(W_f - W_i)} = \frac{(19.3 - 0)}{(166.8 - 0)}$	0.116 gal/lb
$W_i$	$\theta_{W_i} = \frac{\partial R}{\partial W_i} = \frac{-(R_f - R_i)\gamma}{(W_f - W_i)^2} = \frac{-(19.3 - 0) \times 8.34}{(166.8 - 0)^2}$	-0.00579/lb
$W_f$	$\theta_{W_f} = \frac{\partial R}{\partial W_f} = \frac{(R_f - R_i)\gamma}{(W_f - W_i)^2} = \frac{(19.3 - 0) \times 8.34}{(166.8 - 0)^2}$	0.00579/lb

Calculations were made by taking the partial derivative of Eq 5 with respect to each parameter.

**TABLE 2** Test results at AWWA minimum, intermediate, and maximum flow rates using a scale

	$b_x^a$	$s_x^b$	Flow Rate			
			Minimum	Intermediate		Maximum
			0.25 gpm	2 gpm	2 gpm	15 gpm
$W_f$ —lb	0.025 <sup>c</sup>	0.07 <sup>d</sup>	0	0	0	0
$W_f$ —lb	0.025 <sup>c</sup>	0.07 <sup>d</sup>	85.40	85.43	170.85	893.50
$R_f$ —gal	0.05	0	0	0	0	0
$R_f$ —gal	0.05	0	10.3	10.3	20.6	107.4
$T$ —°F	0.1	0	45.9	44.1	44.1	45.6
Unit Weight—lb/gal	0.00008	0	8.34	8.34	8.34	8.34
Registry ± uncertainty			100.6% ± 1.40%	100.6% ± 1.40%	100.6% ± 0.70%	100.3% ± 0.27%

Source: AWWA 2012

<sup>a</sup>Random uncertainty

<sup>b</sup>Systematic uncertainty

<sup>c</sup>Values are for a 500-lb scale; for a 5,000-lb scale use 0.25 lb for 15 gpm run.

<sup>d</sup>Values are for a 500-lb scale; for a 5,000-lb scale use 0.7 lb for 15 gpm run.

Two 2-gpm tests were conducted with different draft sizes (volume of water run through the meters) to demonstrate that running the exact same test for a longer period of time (collecting more water) will reduce uncertainty.

$$s_R = [(-0.00579 \times 0.07)^2 + (0.00579 \times 0.07)^2]^{1/2} \times 100$$

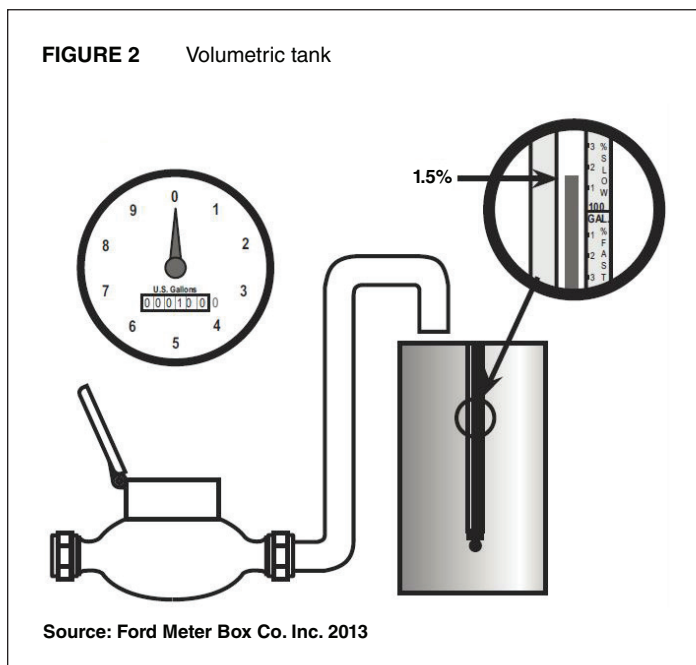
$$s_R = 0.057\%$$

$$b_R = [(-0.05 \times 0.05)^2 + (0.05 \times 0.05)^2 + (0.116 \times 0.00008)^2 + (-0.00579 \times 0.025)^2 + (0.00579 \times 0.025)^2]^{1/2} \times 100$$

$$b_R = 0.354\%$$

Step 6: Calculate the total uncertainty of the result with a 95% confidence interval. Using Eq 4, the total uncertainty with 95% confidence is calculated as follows:

$$U_{R95} = 2(0.057^2 + 0.354^2)^{1/2} = 0.72\%$$



The result of the test is now stated more accurately as 96.5% ± 0.72% and implies that one can be 95% confident that the actual result lies between 96.5% ± 0.72%. This encompasses the errors associated with readability of the equipment and aids in better analysis of the result. Note that other errors are likely associated with this test that are not addressed in this example, but if included would provide a complete analysis. Random errors for this example are nearly negligible.

**EXAMPLE CALCULATION USING A SCALE**

Table 2 provides data from a meter registry test conducted at minimum, intermediate, and maximum flow rates according to AWWA standards (2012) using a scale. Uncertainty is largely affected by draft size and flow rate. As is seen in the 2-gpm tests, increasing the draft size significantly reduces the uncertainty. A large portion of uncertainty is avoided by increasing the collection size because the readability errors are constant, making their absolute relativity decrease. Most testing is conducted using the AWWA minimum standards, but exceeding those standards should be considered to minimize error.

**EXAMPLE CALCULATION USING A VOLUMETRIC TANK**

If a standard volumetric test bench is used to test a single meter, there is opportunity for error in reading the meter and the tank. Volumetric tanks have notches for every 1 gal or 1 ft<sup>3</sup>, but the notches in between only estimate the percent different from the intended volume, not the actual volume (Figure 2). These percent-different notches can only be used when testing a single meter, which is not commonly the case. Assume that the test operator is not always able to stop the test precisely at a tick mark, such that the height difference, *b*, between the water line and the tick mark is measured, then multiplied by the area of the tank to find the additional volume collected over the tick mark indication. Table 3 provides data for the same meter used in Table 2 at AWWA minimum, intermediate, and

**TABLE 3** Test results at AWWA minimum, intermediate, and maximum flow rates using a volumetric tank

	$b_x^a$	$s_x^b$	Flow Rate			
			Minimum	Intermediate		Maximum
			0.25 gpm	2 gpm	2 gpm	15 gpm
$h$ —in.	0.03125	0	1	1	0.25	3
$R_f$ —gal	0.05	0	0	0	0	0
$R_i$ —gal	0.05	0	10.3	10.3	20.6	107.4
Tank Diameter—in.			9	9	26	26
Registry ± uncertainty			100% ± 1.41%	100% ± 1.41%	100% ± 0.70%	100% ± 0.14%

Source: AWWA 2012

<sup>a</sup>Random uncertainty  
<sup>b</sup>Systematic uncertainty

Two 2-gpm tests were conducted with different draft sizes (volume of water run through the meters) to demonstrate that running the identical test for a longer period (collecting more water) will reduce uncertainty.

maximum flow rates, but uses a volumetric tank. The individual steps to complete the calculation are similar to those done using the gravimetric tank, however the partial derivatives of the governing equation must be obtained to determine different sensitivity coefficients.

Assuming each test began with the tank completely empty, the accuracy is calculated as follows:

$$R = \frac{R_f - R_i}{n + \left(\frac{h}{12} \times A\right) \times 7.48} \quad (6)$$

where  $R$  is the result (%),  $R_f$  is the final meter registry (gal),  $R_i$  is the initial meter registry (gal),  $n$  is the target notch value (gal),  $h$  is the height above the target notch (in.), and  $A$  is the area of the volumetric tank (ft<sup>2</sup>). Note that 7.48 is a conversion factor from ft<sup>3</sup> to gal.

The uncertainties are based on the readability of the equipment. As before, the meter can be read to 0.05 gal. The height is assumed to be measured with a measuring tool (e.g., tape measure, ruler) accurate to 1/32 in.

However, assuming the test operator is able to stop the test exactly on the tick mark, the error arising from the measured  $h$  value would be eliminated. In this case, the accuracy of the tank reading with meniscus effects must be accounted for. To find the potential error from reading the sight tube, the tank was filled to the 3-ft<sup>3</sup> mark, then additional water was slowly added until there was a visible increase in the water surface. The amount of water added before an increase was visible was roughly 0.009 ft<sup>3</sup>. If the same meter were tested as mentioned previously, and the test were stopped when the tank read 3 ft<sup>3</sup>, assuming the meter was perfectly accurate, the result would be 100% ± 0.67% because of meter registry readability and inaccuracy of the tank reading.

The difficulty with volumetric test bench uncertainty is that much of the possible error resides in the accuracy of the equipment. It is important to consider how the bench operates. Because the tank is not marked with a measurement stick, but rather

individual marks on gallon measurements, it is the test operator's duty to stop the test exactly when the water reaches the specified mark. However, this is difficult to achieve and creates the need for a differential height measurement to be used to calculate the actual volume collected.

This example included only the uncertainty associated with the smallest flow rate and collected volume. Generally, the largest uncertainties will be linked to the smallest volumes registered in any meter test. To reduce the uncertainty of a low-flow test, a higher volume than standards indicate should be collected. The test operator should identify the desired uncertainty bounds and design the test to achieve those bounds by increasing the throughput. Note that the result and its associated uncertainty are meter and registry dependent. Analysis of all test data should be completed to generate an understanding of the uncertainty of the registry results across the range of flows and volumes measured for the registry tests.

### CONSEQUENCES OF IGNORING UNCERTAINTY

Perhaps the most significant concern when analyzing data from meter accuracy testing is determining what the data indicate so as to know how it should be used. AWWA standards provide end users with a means of evaluating meters to determine what to purchase and install. Consider a meter that was determined to be 101.3% accurate at minimum flows through accuracy testing. AWWA standards state that to qualify as passing, accuracy must be within 95% to 101%. So, the meter would be considered failing. But if uncertainties are included, and the total uncertainty is calculated as 0.72%, the meter might be considered passing. If uncertainty is ignored, meters may be inaccurately described as failing when in fact they pass the standard; similarly, meters may be classified as passing when they actually fail the standard. There is a registry range in which meters are borderline pass/fail that should be considered in the registry evaluation when assigning a pass/fail status to a meter as a result of meter and bench-combined uncertainty. In other words, just how certain are the results? By understanding the limitations of each test and developing a test that results in acceptable uncertainty bounds, the results are more

valuable and help the user and manufacturer to better evaluate each meter.

## CONCLUSION

To more fully comprehend the data from meter accuracy testing and to properly classify meters as failing or passing the standard, measurement uncertainty should be understood and incorporated into the data analysis. While some errors can be difficult to determine, the readability of the equipment used for a meter accuracy test is often a significant contributor to measurement uncertainty and can change the outcome of the tested meters. Accounting for or eliminating the source of additional errors will only serve to enhance the value of the collected data. Manufacturers usually conduct their own accuracy testing while also occasionally sending some meters to a laboratory to be tested to ensure the validity of both test setups. However, the results are not published. It is useful for manufacturers and end users to work together to demonstrate meter performance and understand the limitations of the test that dictates how the meter is anticipated to perform. Testing can then be evaluated on the basis of the comparison of the predicted performance versus the actual performance. Assessing uncertainty before starting any test program will help users understand the limitations of the proposed test and identify ways to reduce the uncertainty of the test result. For example, collecting 20 or 30 gal rather than 10 gal for a low-flow test or testing meters with registers capable of more precise readings will reduce the uncertainty of the test result. The result will be a test with acceptable uncertainty bounds that both the manufacturer and end user will understand.

## ABOUT THE AUTHORS



*McKenna L. Sumrak recently graduated from Utah State University in Logan, where she earned bachelor's degrees in civil engineering and economics. Sumrak previously worked as a research assistant at the Utah Water Research Laboratory, Logan, Utah, addressing water rights,*

*hydraulics of large dams, water meter registry, and residential flow meter testing uncertainty. She is a civil engineer at Franson Civil Engineers, American Fork, Utah, where she works with irrigation companies and municipalities designing pipeline systems. Michael C. Johnson (to whom correspondence may be addressed) is a research associate professor at the Utah Water Research Laboratory, 8200 Old Main Hill, Logan, UT 84322 USA; [michael.johnson@usu.edu](mailto:michael.johnson@usu.edu). Steven L. Barfuss is a research associate professor at the Utah Water Research Laboratory.*

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