

# Comparing Low-Flow Accuracy of Mechanical and Electronic Meters

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

Previous studies have identified water meter inaccuracy at low flows in mechanical metering technologies; however, little has been done to measure the inaccuracy of electronic metering technologies at low flows. This study confirms previous studies on mechanical meter accuracy and includes electronic meter

accuracy data from results of testing conducted at the Utah Water Research Laboratory. By comparing the new technologies to the commonly used mechanical metering technologies over a wide range of flows, this analysis is intended as a guide to assist meter users in choosing the meter type to accommodate their needs.

**Keywords:** *electronic meter, low flow registry, residential, water meter accuracy*

With rapid advances being made in metering technology, understanding how technologically advanced meters perform is important to those making decisions about which technology to use in their systems. There are several types of mechanical residential meters that are commonly used in municipal water systems, and in recent years a few electronic meter types have entered the market. AWWA has instituted accuracy standards for mechanical water meters to ensure that the meters are operating accurately and maintaining that accuracy over time and throughput (AWWA 2012). Yet even if a meter passes the AWWA standard, up to 100% of the flow passing through the meter can be unregistered at flow rates lower than the AWWA minimum.

As accurate water measurement has become a significant focus of this limited resource, advances have been made to improve mechanical meters and to develop electronic meters to increase measurement accuracy at low flows. Manufacturing methods and improved materials have reduced friction in mechanical meters, while electronic meters have no moving parts and are therefore typically easy to use and maintain. The lack of moving parts also decreases the likelihood of diminishing accuracy over time. Recent laboratory testing of electronic metering technologies provides valuable data that can be compared with more established and well-known mechanical meter accuracy results. A previous study sponsored by the Water Research Foundation and the US Environmental Protection Agency titled *Accuracy of In-Service Water Meters at Low and High Flow Rates* demonstrated that positive-displacement meters, nutating-disc meters in particular, excelled in performance compared with other mechanical metering technologies (Barfuss et al. 2011). Improvements in technology have made it important to confirm the performance of these meters against other mechanical meters and compare mechanical meters with electronic meters. The decision that users must make is no longer to choose only between different types of mechanical meters but first between electronic and mechanical technologies and then between the different types of mechanical and electronic meters.

## BACKGROUND

The purpose of this study was to investigate the accuracy of several meter types at low flows. Accuracy was reported at the minimum AWWA flow as well as flows considerably lower than the standard. Although there are previous studies regarding this topic, this document specifically introduces electronic meters and their registry accuracy in comparison with mechanical meters while also confirming the results of mechanical meters that are currently available.

The objective of the 2011 study by Barfuss et al. was to evaluate the accuracy of in-service flow meters with a more detailed focus on low flows while also studying the effects of age, throughput, and particulates on accuracy degradation. Barfuss et al. (2011) found that oscillating-piston and nutating-disc meters excelled in performance. In a separate study completed on new meters, Neilsen et al. (2011) revealed that at AWWA minimum, intermediate, and maximum flow rate standards, there was an observable difference in meter accuracy and registry percentages. Shields et al. (2012) focused on revenue recovery through replacing meters with more accurate meters and also found that by replacing old meters with new meters, sometimes with different types from what been originally used, flows were recorded with increased accuracy, and revenue would increase.

Other studies have been conducted on factors that affect the accuracy of meters. Arregui et al. (2005) approached how mounting position, velocity profile distortions, fatigue, partial blockage, accurate sizing, consumption patterns, and private storage tanks affect meter accuracy. Bowen et al. (1991) analyzed how the physical characteristics of a meter, such as casing material, affect accuracy; they also discussed the effect of pulse flows on endurance accuracy. Criminisi et al. (2009) focused on the effects of aging and private storage tanks similar to the 2005 study by Arregui et al. Arregui et al. (2003) also tested in-use meters to determine an optimal renewal frequency and average cost. A study by Mukheibir et al. (2012) specifically focused on



**This gravimetric test bench was used to analyze mechanical and electronic meter accuracy for this study at the Utah Water Research Laboratory in Logan, Utah.** Photo courtesy of Utah Water Research Laboratory.

non-registration meters and made recommendations on when to consider replacement of low-registration meters.

Although these studies all focus on water meter accuracy relating to various factors, their main focus is on the commonly used mechanical meters. This study is intended to add an analysis of electronic meters to the research available. Recently electronic meters have become better known and are continuing to gain popularity. During a water conservation showcase in San Francisco, Calif., Arthur Burns—a representative from a company<sup>1</sup> that manufactures electronic meters—discussed the advancements in metering technology. Burns (2011) explained the benefit of having proven and trusted technology among mechanical meters but acknowledged the disadvantage of low-flow performance limitations among those same meters. He addressed the benefits of electronic meters—no moving parts to wear out over time, no maintenance, unaffected by particles in water, better high-flow durability, and better low-flow accuracy. He also discussed the challenges for different electronic meter types, most dealing with a power requirement. He concluded that mechanical meters are still good, but there is compelling evidence to consider new technologies (Burns 2011).

The previously discussed studies reveal differences in meter accuracy based on a variety of factors including, but not limited to, meter size, type, manufacturer, age, water quality, and installation; however, there is a lack of electronic meter accuracy data for utility managers on which to base purchases. This study stands to fill that void. Accuracy is important, and limitations of different technologies should be addressed.

**TEST PROCEDURE**

To analyze the low-flow accuracy of the meters, laboratory results were compared with the AWWA standards for minimum flow (AWWA 2012). Minimum required flow rates and accuracy ranges are listed in Table 1. Since electronic meters have been introduced, AWWA has not released applicable standards for all types of electronic meters, so these meters were evaluated using available standards for positive-displacement, single-jet, and multi-jet meters, against which the electronic meters compete for market presence.

Six meter types were tested at various flow rates using a gravimetric test bench at the Utah Water Research Laboratory in Logan, Utah (see the photograph on this page). Flow rates comprised AWWA maximum, intermediate, and minimum flows, as well as flows lower than the AWWA minimum. Tested meter types included oscillating-piston, nutating-disc, multi-jet, single-jet, and electronic meters. Both ultrasonic and electromagnetic meters were tested during this study and will be referred to separately as EM1 and EM2 in no particular order, or combined as EM. The electronic meters were combined to preserve anonymity of manufacturers since there is only one manufacturer of each type. Among all the types of meters, two sizes were tested: 3/4 in. and 5/8 in. x 3/4 in. Table 2 lists the number of meters tested by type and size. All meters were in new condition and received under contract through various entities.

This research was a result of several studies and as such had limited sample sizes. Sample sizes were smaller for multi-jet,

**TABLE 1** AWWA accuracy standards for minimum flow rates<sup>a</sup>

Meter Type	Meter Size		Accuracy Range %	
	5/8 in. x 3/4 in. gpm	3/4 in. gpm	Lower	Upper
EM <sup>b</sup>	NA	NA	NA	NA
ND	1/4	1/2	95	101
OP	1/4	1/2	95	101
MJ	1/4	1/2	97	103
SJ	1/4	1/2	95	101.5

Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, NA—not applicable, ND—nutating disc, OP—oscillating piston, SJ—single jet

<sup>a</sup>AWWA 2012

<sup>b</sup>Ultrasonic and electromagnetic meters are combined and referred to as EM. No standards exist, so accuracy was evaluated using positive displacement, single-jet, and multi-jet standards.

**TABLE 2** Sample size by meter type

Meter Type	Meter Size		Total
	5/8 in. x 3/4 in.	3/4 in.	
EM1 <sup>a</sup>	9	3	12
EM2	9	3	12
ND	54	27	81
OP	34	21	55
MJ	12	6	18
SJ	3	3	6

Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, ND—nutating disc, OP—oscillating piston, SJ—single jet

<sup>a</sup>Ultrasonic and electromagnetic meters are referred to separately as EM1 and EM2 in no particular order.

single-jet, and both electronic meter types because additional data were not available in the studies used. To analyze the statistical quality of the smaller data sets, each was investigated for outliers. Two outliers were found in the 5/8-in. x 3/4-in. nutating-disc meter set, but because of the large sample size, they did not have a major effect. It was difficult to classify outliers in the smaller sets because the high variability could be attributed to outliers or an inaccurate type of meter. The sample sizes should be noted when analyzing the results.

Laboratory accuracy tests were conducted using certified weight tanks. Each target flow rate was set using calibrated magnetic flow meters and double-checked by timing the flow entering the weight tank. Flow rates were based on the AWWA minimum, maximum, and intermediate flow rates for each meter size with additional flows being tested below the minimum standard. These extremely low-flow tests were taken at 1/2 and 1/4 of the specified AWWA minimum flow rate.

Tables 3 and 4 show comparative performance ranking of different meter types at various flows. To illustrate precision and accuracy of the data, the absolute value of the difference between

the meter registry percentage and 100% registry for each meter was summed on the basis of meter type. The sum was then divided by the number of meters of that particular meter type to find an average difference from 100% accuracy. These numbers were then ranked so that the smallest number, representing most precise and accurate, is ranked as first. The number in parentheses is the average difference for that meter type.

An example calculation is shown in Figure 1, consisting of meter performance results from a single meter type. If these data ranked second at that flow rate, the table (e.g., Tables 3 and 4) would list this result under its meter type and size as, e.g., “2 (1.58).”

By comparing meter types through this method instead of averaging the registry output, meters with a large accuracy span with a fairly accurate average do not outrank meters with a small accuracy span that is slightly less accurate. Meters with a smaller accuracy span provide a higher likelihood that the meter will consistently perform well. This measure of accuracy is similar to standard deviation, but because of small, inconsistent sample sizes across meter types, using the standard deviation may not be the most applicable.

**TABLE 3** Comparative performance of new 5/8-in. x 3/4-in. meters

Meter Type	Flow Rate <sup>a</sup> gpm					
	1/16	1/8	1/4	1	2	15
EM <sup>b</sup>	1 (0.52)	1 (0.84)	1 (0.55)	1 (0.81)	1 (0.45)	3 (0.55)
ND	3 (32.22)	5 (22.5)	5 (5.10)	2 (1.15)	3 (0.52)	2 (0.46)
OP	4 (52.27)	3 (11.72)	4 (2.43)	3 (1.51)	5 (1.29)	1 (0.27)
MJ	5 (86.64)	4 (21.98)	3 (1.23)	4 (1.98)	4 (1.21)	4 (0.90)
SJ	2 (7.41)	2 (2.30)	2 (0.93)	5 (3.32)	2 (0.47)	5 (1.67)

Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, ND—nutating disc, OP—oscillating piston, SJ—single jet

<sup>a</sup>Numbers indicate meter ranking from 1 to 5 (1 being the most accurate and 5 being the least accurate) with average difference of flow registered from 100% (in parentheses). Ranking is based on difference in percentage. See Figure 1 for sample data calculation.

<sup>b</sup>Ultrasonic and electromagnetic meters are combined and referred to as EM.

**TABLE 4** Comparative performance of new 3/4-in. meters

Meter Type	Flow Rate <sup>a</sup> gpm					
	1/8	1/4	1/2	2	3	25
EM <sup>b</sup>	1 (0.86)	2 (1.44)	4 (1.68)	5 (1.67)	4 (1.39)	4 (1.22)
ND	2 (10.31)	3 (3.43)	3 (1.13)	3 (0.94)	1 (0.59)	2 (0.75)
OP	3 (21.52)	4 (3.69)	2 (0.67)	1 (0.69)	2 (0.60)	1 (0.73)
MJ	5 (46.80)	5 (7.40)	5 (2.40)	4 (1.65)	4 (1.39)	5 (1.82)
SJ	4 (29.40)	1 (0.38)	1 (0.51)	2 (0.73)	3 (1.19)	3 (0.92)

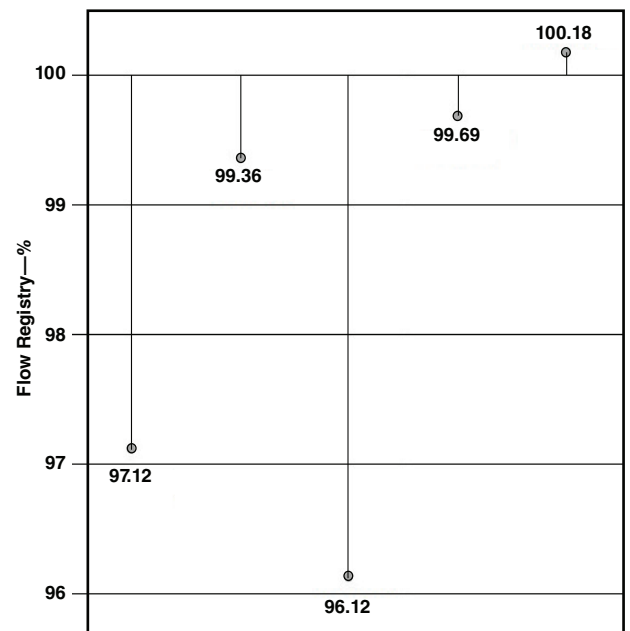
Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, ND—nutating disc, OP—oscillating piston, SJ—single jet

<sup>a</sup>Numbers indicate meter ranking from 1 to 5 (1 being the most accurate and 5 being the least accurate) with average difference of flow registered from 100% (in parentheses). Ranking is based on difference in percentage. See Figure 1 for sample data calculation.

<sup>b</sup>Ultrasonic and electromagnetic meters are combined and referred to as EM.

**FIGURE 1** Sample data set for meter performance results from a single meter type



$$\frac{|100 - 97.12| + |100 - 99.36| + |100 - 96.12| + |100 - 99.69| + |100 - 100.18|}{5} = 1.58\%$$

Source: Utah Water Research Laboratory

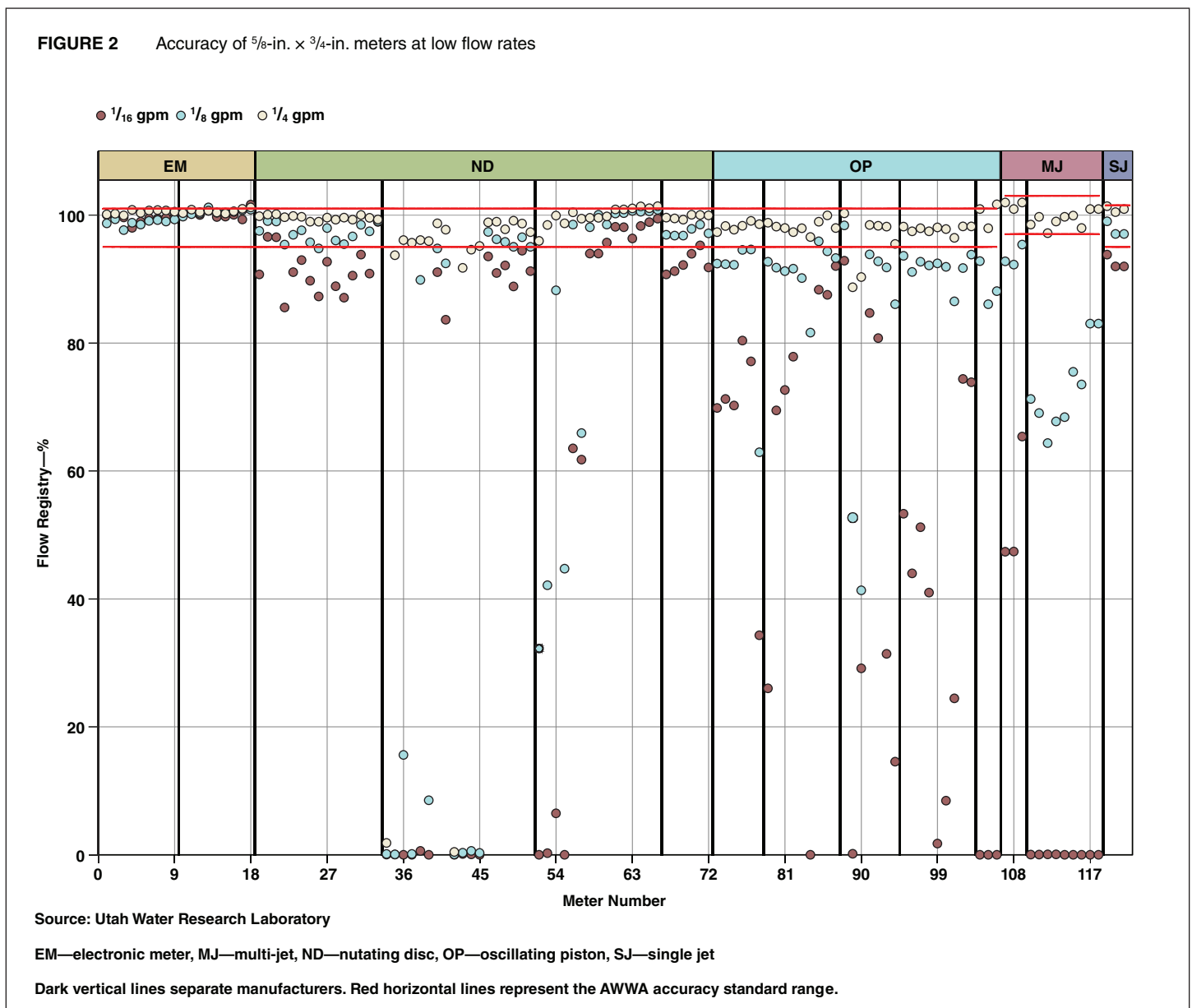
The absolute value of the difference between the meter registry percentage and 100% registry for each meter was summed on the basis of meter type. The total was then divided by the number of meters of that particular meter type to find an average difference from 100% accuracy.

## RESULTS AND ANALYSIS

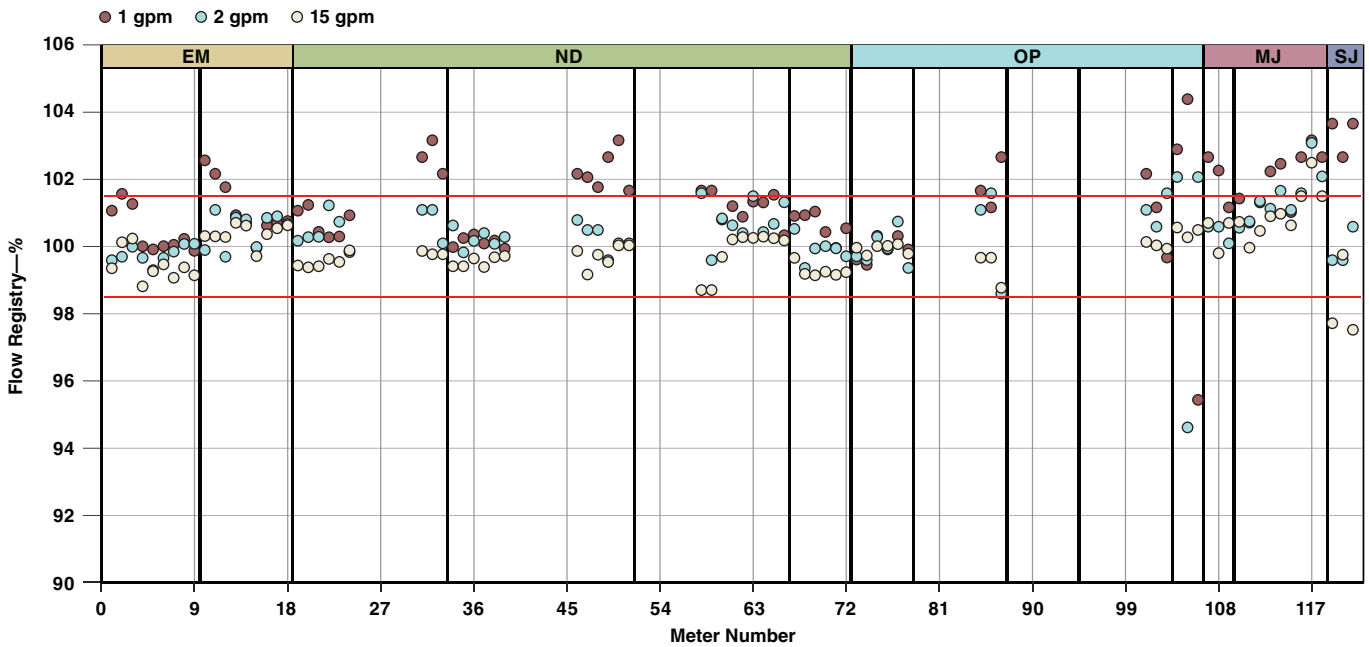
Data were taken at the Utah Water Research Laboratory in Logan, Utah. Meters are not identified by manufacturer name. Figures 2 through 5 illustrate the accuracy of the tested meters in off-the-shelf condition at different flow rates. Figures 2 and 4 show the accuracy of individual meters at three low-flow rates, and Figures 3 and 5 show the accuracy of individual meters at three intermediate-to-high flows. Each meter was tested at six flow rates. Dark vertical lines on the plots separate meters by manufacturer. For the  $\frac{5}{8}$ -in.  $\times$   $\frac{3}{4}$ -in. meters, meter types are as follows according to meter number: 1–18 are electronic, 19–72 are nutating-disc, 73–106 are oscillating-piston, 107–118 are multi-jet, and 119–121 are single-jet meters. For  $\frac{3}{4}$ -in. meters, meter types are as follows: 1–6 are electronic, 7–33 are nutating-disc, 34–54 are oscillating-piston, 55–60 are multi-jet, and 61–63 are single-jet meters. These meter types are indicated in the figures

by colored horizontal bars. For reference, red horizontal lines on the plots represent the AWWA accuracy standard range. Points inside these lines pass AWWA standards. Electronic meters were assumed to have an accuracy range similar to fluidic oscillators, which are electronic meters with published standards equal to displacement meter standards. Note that there are no data available for some meters at intermediate and high flows because one of the studies involved did not require high-flow data; as a result, only low-flow data were collected and made available.

As Figure 2 illustrates, the  $\frac{5}{8}$ -in.  $\times$   $\frac{3}{4}$ -in. mechanical meters showed high variability at low flows. In addition, there was inconsistency within each meter type. Each manufacturer had a different level of variability, and in the case of  $\frac{5}{8}$ -in.  $\times$   $\frac{3}{4}$ -in. meters 52–66, a single manufacturer had inconsistent variability. At  $\frac{1}{16}$  gpm the data were extremely scattered with limited consistency among the oscillating-piston, nutating-disc, and multi-jet



**FIGURE 3** Accuracy of 5/8-in. x 3/4-in. meters at intermediate and maximum flow rates

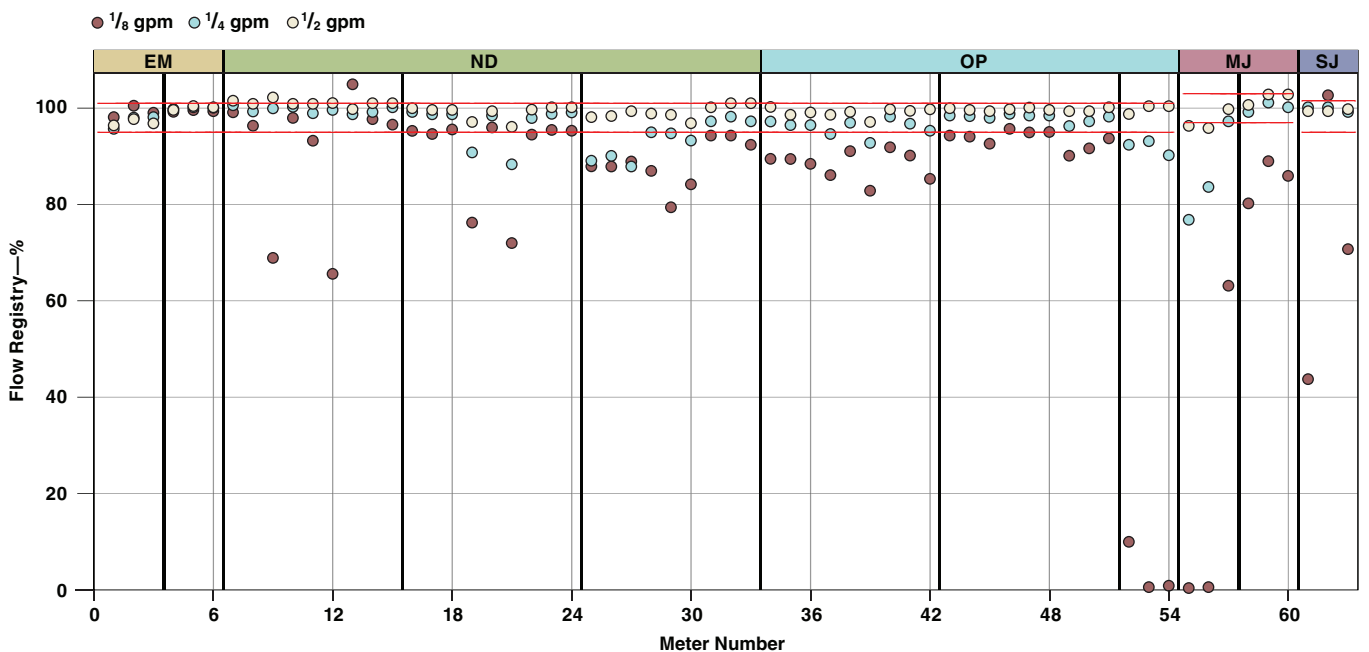


Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, ND—nutating disc, OP—oscillating piston, SJ—single jet

Dark vertical lines separate manufacturers. There are no intermediate or maximum flow data for some meters; all available data are depicted on the plot. Red horizontal lines represent the AWWA accuracy standard range.

**FIGURE 4** Accuracy of 3/4-in. meters at low flow rate



Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, ND—nutating disc, OP—oscillating piston, SJ—single jet

Dark vertical lines separate manufacturers. Red horizontal lines represent the AWWA accuracy standard range.

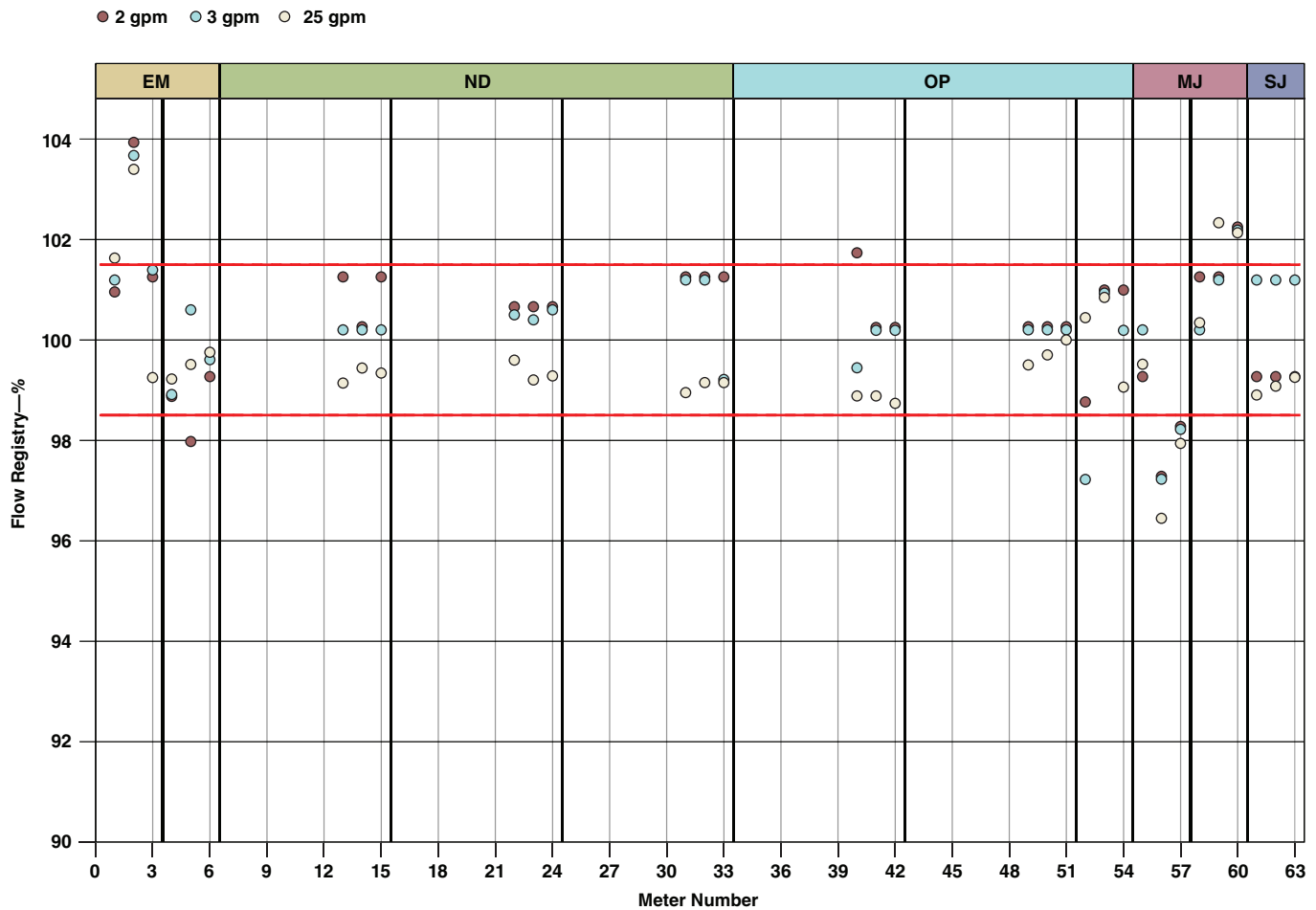
meters. As flows increased to 1/8 gpm, most meters registered above 60% of the flow. At the AWWA minimum flow standard, 13 out of the 121 meters failed to meet the standard. At intermediate flows (Figure 3), 16 out of 121 failed (electronic meters passed all standards with the exception of some failing multi-jet meter standards), and at maximum flow, three out of 121 meters failed.

The 3/4-in. meters did not have as high of variability as the 5/8-in. x 3/4-in. meters did at low flows (Figure 4). At 1/8 gpm, 58 out of 63 meters registered 60% or above. At 1/4 gpm, 62 out of 63 meters registered above 80%, and once the flow reached the AWWA minimum standard, five out of 63 meters failed to meet the standard. As higher flows were maintained, there was minimal variance in the data (Figure 5). At intermediate flows, five out of 63 meters failed, and at maximum flow, six out of 63 failed.

Although a large percentage of meters pass the AWWA standards, benefits arise from accuracy at extremely low flows. The introduction of electronic meters into this study provides a good comparison to the previously studied mechanical meters. As shown in previous studies, nutating-disc and oscillating-piston meters excel in accuracy readings from minimum standard flows to extremely low flows. This study also demonstrates high accuracy among electronic meters, comparable to or exceeding mechanical meter accuracy. Because of the similarity of these data to previous studies, it supports mechanical meter accuracy while also introducing electronic meters and providing a comparison of the differing meter technologies.

In addition to meter size and type, some meter manufacturers were more accurate than others in producing the same type of meter. Accuracy is defined by the AWWA minimum flow standard stated in Table 1. Table 5 illustrates the percentage of passing

**FIGURE 5** Accuracy of 3/4-in. meters at intermediate and maximum flow rates



Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, ND—nutating disc, OP—oscillating piston, SJ—single jet

Dark vertical lines separate manufacturers. There are no intermediate or maximum flow data for some meters; all available data are depicted on the plot. Red horizontal lines represent the AWWA accuracy standard range.

meters by manufacturer. Electronic meters were analyzed using multi-jet, single-jet, and displacement meter standards because no related standards have been published; they were considered passing on the basis of displacement and fluidic oscillator standards. One electronic meter failed the AWWA minimum flow standard for nutating disc and oscillating piston but passed the standard for single jet and multi-jet. It was classified as “failing” for Table 5. Each set of meters within a specific meter type is produced by a different manufacturer; one manufacturer may be represented by multiple sets of meters in Table 5. Each row in Table 5 indicates a separate manufacturer.

**CONCLUSIONS**

Meters are one the most important components of water distribution systems because they quantify the flow rates through water system networks and the volume of water used. With various types of meters, users need to find a meter design that best fits their needs while providing the greatest accuracy, durability, and other

associated benefits to their respective systems. While considerations should at least include but not be limited to accuracy, durability, water quality, cost, reliability, and meter life, this study was limited to accuracy. Although previous studies have investigated the accuracy of mechanical meters, electronic meters have become more common in practice, and data are needed to compare their functionality with mechanical meters.

This study confirms the results of previous studies regarding mechanical meters. As Table 5 illustrates, accuracy of the meters is dependent on manufacturer, and as Figures 2–5 illustrate, accuracy is also dependent on meter size and type. The introduction of electronic meters in this study provides a comparison to the mechanical meters. Although no official standards have been issued by AWWA for ultrasonic and electromagnetic metering technologies (defined as “electronic meters” for this study), it is assumed that electronic meters should be able to meet standards similar to the multi-jet, single-jet, or displacement meters of the same size. The fluidic oscillator is also considered an electronic metering technology but was not included as part of this study.

One of the major differences between mechanical and electronic meters is the use of moving parts that create friction. By reducing friction, more accurate readings should occur over the life of the meter; however, with the newer electronic technologies, meter longevity is yet to be determined. Another difference is based on the amount and type of maintenance needed—for electronic metering technologies, it is assumed to be negligible. However, electronic meters provide a challenge by requiring power, usually through batteries that have yet to be time-tested, although manufacturers indicate considerable battery life. It is known that some mechanical meters have been in service for over 30 years and were found to register to the AWWA standard in some instances (Barfuss et al. 2011).

It is anticipated that the results of this study will provide useful information to those responsible for selecting meters to be installed in their systems. The results of this study show that there are excellent technologies to choose from and benefits associated with the various types of meters investigated.

**TABLE 5** Percentage of new meters passing AWWA low-flow standard by manufacturer

Meter Size	Meter Type	Meter Number	Passing AWWA Minimum Flow Standard <sup>a</sup> %
5/8 in. x 3/4 in.	EM <sup>b</sup>	1–9	100
		10–18	88.9
	ND	19–33	100
		34–51	72.2
		52–66	73.3
		67–72	100
	OP	73–78	100
		79–87	100
		88–94	71.4
		95–103	100
		104–106	66.7
MJ	107–109	100	
	110–118	100	
3/4 in.	SJ	119–121	100
	EM	1–3	100
		4–6	100
	ND	7–15	66.7
		16–24	100
		25–33	100
	OP	34–42	100
		43–51	100
		52–54	100
	MJ	55–57	33.3
		58–60	100
SJ	61–63	100	

Source: Utah Water Research Laboratory

EM—electronic meter, MJ—multi-jet, ND—nutating disc, OP—oscillating piston, SJ—single jet

<sup>a</sup>AWWA 2012

<sup>b</sup>Ultrasonic and electromagnetic meters are combined and referred to as EM and evaluated using all standards because there is no AWWA standard for EM. One EM failed multi-jet standards.

Each set of meters within a specific meter type is produced by a different manufacturer; one manufacturer may be represented by multiple sets of meters. Each row indicates a separate manufacturer.

**ENDNOTE**

<sup>1</sup>Sensus USA, Raleigh, N.C.

**ABOUT THE AUTHORS**



*McKenna L. Sumrak is pursuing bachelor of science degrees in civil engineering and economics at Utah State University in Logan, Utah. She is a research assistant at the Utah Water Research Laboratory in Logan. Sumrak has worked on water rights, hydraulics of large dams, water meter registry, and residential flow meter testing*

*uncertainty. Michael C. Johnson (to whom correspondence may be addressed) is a research associate professor with the Utah Water Research Laboratory, 8200 Old Main Hill, Logan, Utah 84322 USA; michael.johnson@usu.edu. Steven L. Barfuss is a research associate professor at the Utah Water Research Laboratory.*

## PEER REVIEW

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