Flow measurement accuracies of in-service residential water meters

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Water utility managers generally agree that water meters, especially mechanical water meters, experience a degradation of accuracy over time. This degradation is a function of several factors, such as wear, water quality, water velocities, throughput volumes, and installation and handling. Both a thorough understanding of the factors that affect meter accuracy and the ability to pinpoint, if possible, the optimal lifespan of any particular type of water meter in a residential distribution system are desirable for improved system management. The purpose of this article was to investigate the relationship between meter accuracy degradation and factors such as age, wear, and throughput for in-service water meters pulled from utilities across the United States. The information contained in this article is intended to provide insight to water utility managers and decision-makers about meter replacement programs and schedules.

KEYWORDS: *flow measurement, meter replacement, utility operations and management, water meter*

Water meters serve many purposes for utilities, including assessing demand management, ensuring equity in billing, identifying both distribution system and customer leaks, and studying use patterns among consumers. From a utility manager's perspective, water meter accuracy is of utmost importance because it allows utilities to bill customers fairly and accurately and provides accurate data for utility management purposes. Although water meters are a critical tool in the hands of utility managers, the benefit of having such a tool decreases if accuracy degradation occurs. The potential revenue loss for a distribution system that has a large number of meters that underregister the actual throughput can be significant. If only for this reason, water meter accuracy will remain a high priority for utility managers.

As with any mechanical device, water meters are subject to wear. Wear contributes to meter accuracy degradation, meaning that the water meters become less efficient for measuring flow and will generally underregister the actual throughput. Compounding this issue is the variability among different water utilities with respect to meter type, water quality, and use patterns—not to mention the variability in use patterns among individual consumers. Every water distribution system presents a unique set of circumstances and variables that will directly affect the issue of water meter accuracy, yet it is clear that there is often revenue loss associated with water meter inaccuracies (Richards et al, 2010).

AWWA FLOW ACCURACY STANDARDS

To ensure that water is being accurately accounted for, meters should be selected, purchased, installed, operated, and maintained according to industry standards. Guidelines for such actions are given by AWWA (2012), which also has standards in place for residential water meter performance. AWWA recommends the use of periodic bench-testing of meters to identify groups of meters that have accuracy degradation problems (AWWA, 2012). Whether a water utility tests its own water meters or has another entity conduct the tests depends on several factors, such as facilities, time, and manpower available.

To meet the AWWA flow accuracy standard, a meter should register within a certain range at a given flow rate set by the standard. Accordingly, AWWA has established accuracy standards as a function of meter type and for minimum and normal ranges of operation. AWWA's Manual of Water Supply Practices, M6, *Water Meters—Selection, Installation, Testing, and Maintenance* indicates that testing should be performed at maximum, intermediate or transitional, and minimum flow rates (AWWA, 2012). For each meter type and flow rate, the water meter must register a certain percentage of flow relative to the actual flow in order to meet the accuracy standard. For water audit procedures, AWWA (2009) also recommends that a minimum of 50 residential meters as well as larger meters, which typically represent nonresidential users, be tested. This study focused only on AWWA standard flow rates, not on flow rates that are below AWWA standards.

It is important to understand the different characteristics and limitations of various meter types. Most in-service water meters have moving parts that affect accuracy depending on flow rates, water velocities, and water quality. Debris found in water distribution systems is a common concern because it can have a significant effect on certain types of meters. Debris most typically found in a distribution system includes sand, gravel, or pipe shavings from drilling and tapping operations. In addition, the water quality in some cases can be such that a nearly constant quantity of particulate matter is passing through meters in a distribution system. A thorough understanding of the differences between meter types gives utilities an advantage in finding the meter type that best suits users' needs so that the utilities can effectively manage their distribution systems.

The AWWA test requirements for new and rebuilt cold-water meters for the meters investigated in this study are shown in Table 1. For the meter to meet the accuracy requirement, it must register within the bounds listed relative to the actual volume of water put through the meter at the prescribed flow rate. The three meter types used for this study—oscillating piston (OP), nutating disc (ND), and multijet (MJ)—were pulled from service and provided by participating utilities. The size and distribution of meter types received at the laboratory were largely dependent on the utilities that offered to participate in this project and the types of meters these utilities had within their systems.

OBJECTIVE

Many utilities have attempted to develop programs for water meter operation, maintenance, and replacement. Accounting for all water in a distribution system is a primary objective for all water utilities, and one of the most difficult questions utility managers face is when water meters should be replaced. These managers and their suppliers often have to balance the potential loss of revenue from meter accuracy degradation with the cost of replacing meters. From a purely economic standpoint, it makes sense to replace a water meter when the loss in revenue from accuracy degradation exceeds the cost to replace the meter. When that point occurs, however, is typically unknown without testing the meter.

There are no comprehensive studies to date that define the exact age or amount of throughput when water meter accuracy is degraded to a point that replacing it becomes economically beneficial—primarily because water meter accuracy degradation is a function of many variables. Factors such as wear, deterioration, buildup of deposits, water quality, water velocities, amount of throughput, environmental issues, and effects resulting from handling and installation are all potential contributors to meter accuracy degradation.

Information regarding the relationship between these factors and meter accuracy would be of great value to utility managers. Managers are left to make broad and perhaps inaccurate assumptions for when meters should be replaced. Although common sense dictates that water meters will become less accurate with time, decisions regarding meter replacement often have high economic effects on a utility. Utilities are certainly interested in meter performance data that could help them base their decision on more sound analyses. This is especially true for utilities that are unable to afford expensive technologies or conduct their own meter-testing programs.

The purpose of this study was to investigate the relationship between meter accuracy degradation and multiple factors such as age, wear, and throughput for in-service water meters pulled from several utilities across the United States. The results from this research illustrate the accuracy of several types of pulled meters commonly available in water distribution systems in relation to the corresponding published AWWA standard. During the project, in-depth meter inspections, in which each meter was disassembled and thoroughly inspected, were expected to aid in determining correlations between meter accuracy and mechanical wear patterns for meter types from the sampled pulled meters. The results from this study are intended to provide insight to water utility managers and decision-makers with regard to making decisions for meter replacement.

TABLE 1 AWWA test requirements for cold-water meters (AWWA, 2012)

Type	Flow per Meter Size—*gpm*					Accuracy Range—%	
	5⁄8 × 3⁄4 in.	3⁄4 in.	1 in.	1½ in.	2 in.	Upper	Lower
Maximum							
OP	15	25	40	50	100	101.5	98.5
ND	15	25	40	50	100	101.5	98.5
MJ	15	25	35	70	100	101.5	98.5
Intermediate							
OP	2	3	4	8	15	101.5	98.5
ND	2	3	4	8	15	101.5	98.5
MJ	1	2	3	5	8	101.5	98.5
Minimum							
OP	¼	½	¾	1½	2	101	95
ND	¼	½	¾	1½	2	101	95
MJ	1¼	½	¾	1½	2	103	97

MJ—miltijet, ND—nutating disc, OP—oscillating piston

TABLE 2 Summary of donated meters

Meter Type	Quantity	Percentage of Total
OP	344	58
ND	211	35
MJ	40	7
Total	595	100

MJ—multijet, ND—nutating disc, OP—oscillating piston

TABLE 3 Summary of meter size and type for tested meters

Meter Size—*in.*	Meter Type	Quantity
⅝ × ¾	OP	271
⅝ × ¾	ND	89
⅝ × ¾	MJ	22
¾	OP	36
¾	ND	35
¾	MJ	1
1	OP	31
1	ND	71
1½	OP	4
1½	ND	6
2	OP	1
2	ND	6

MJ—multijet, ND—nutating disc, OP—oscillating piston

RESEARCH APPROACH

A total of 595 meters were pulled from their field installations and were performance-tested with the objective of determining the accuaracy of meters that had been in service for various periods. The testing was conducted to study the relationship between meter accuracy and factors such as age, wear, and throughput after years of service in varied conditions. Multiple utilities from across the United States were contacted and invited to participate in the study, and each sent randomly selected meters to the Utah Water Research Laboratory for testing in accordance with its own meter replacement programs. Specific instructions regarding pulling, packaging, and shipping each meter were provided to each utility to ensure that the meters would arrive in the same condition as when they were in service. The purpose for using the support of multiple utilities was to capture a range of water quality and operational variances for meters that were sent to the laboratory.

TABLE 4 Manufacturers represented

Manufacturer	Meter Type
ABB	OP
Badger Meter	ND
Hays Fluid Controls	MJ
Hersey Meters Co.	MD
Invensys	OP
Master Meter	MJ
Neptune Technology Group	ND
Precision Meters	MJ
Rockwell	OP
Sensus	OP
Trident	ND
Worthington-Gamon	ND

MJ—multijet, ND—nutating disc, OP—oscillating piston

TABLE 5 Square of the correlation coefficient, *R*, for linear regressions

Meter Type	Figure	R^2 from Linear Regressions		
		¼ gpm	2 gpm	15 gpm
OP	1	0.2261	0.002	5×10^{-6}
	2	0.0149	0.0084	0.0079
ND	3	0.0371	0.0133	0.0035
	4	0.1985	0.0514	0.0186
MJ	5	0.0125	0.0101	0.1886

MJ—multijet, ND—nutating disc, OP—oscillating piston

The meter types pulled and tested—OP, ND, and MJ—represent the majority of meters in service in the United States during the past 10–20 years and were voluntarily and randomly provided by participating utilities. It was estimated by the authors and through discussions with manufacturers (Koch, 2006) that approximately 85% of meters in service before 2006 were positive-displacement meters and approximately 15% were MJ meters. Table 2 shows the quantity of each meter type that was pulled and shipped to the laboratory from each utility. In some cases, the pulled meter leaked, failed to register, or was not functional. In such cases, disassembling the meter usually indicated why the meter failed, and the meter was set aside without further testing. Twenty-two of the 595 meters were not tested. Table 3 shows the distribution of meter size and type for the remaining 573 meters that were tested. Table 4 shows the 12 manufacturers that were represented among the pulled meters. Several of the manufacturers shown in Table 4 no longer provide the listed meter, and some manufacturers have changed ownership or no

FIGURE 1 Service time versus registry ⅝- × ¾-in. piston meters (Barfuss et al, 2011)

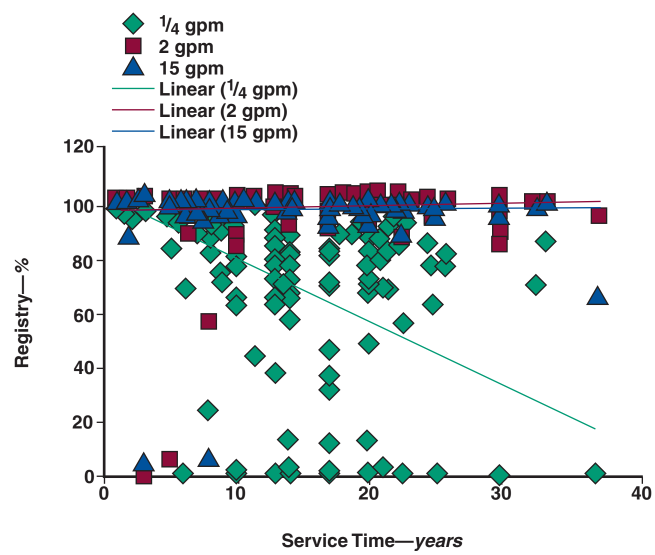


FIGURE 2 Throughput versus registry 5/8- × 3/4-in. piston meters (Barfuss et al, 2011)

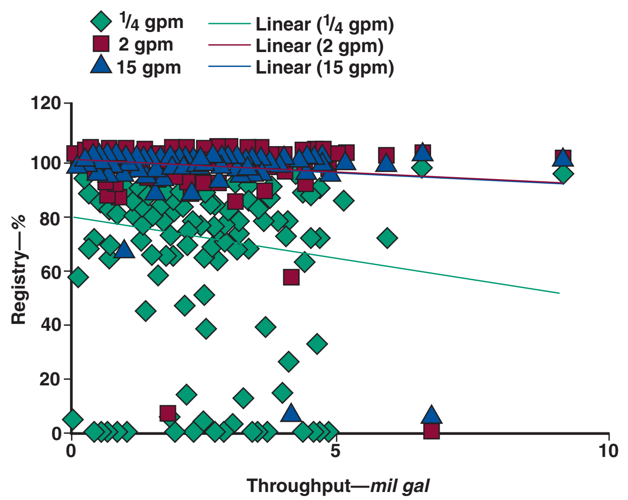
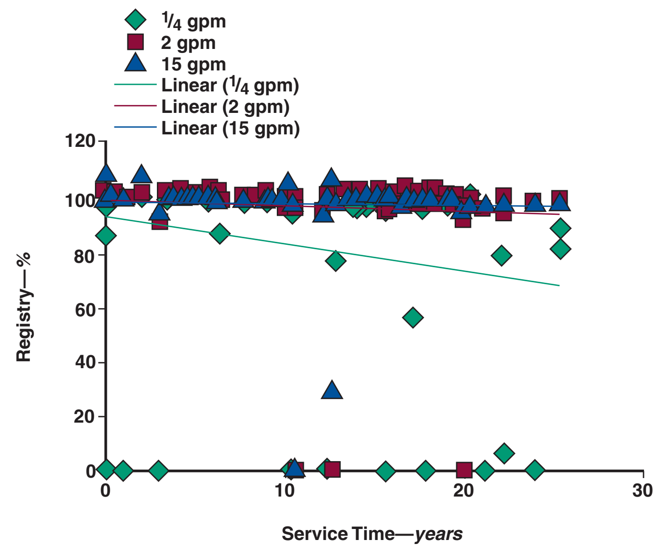


FIGURE 3 Service time versus registry 5/8- × 3/4-in. nutating disc meters (Barfuss et al, 2011)



longer manufacture meters. The 573 meters were tested for minimum, intermediate, and maximum flow rates per AWWA's Test Requirements for Cold-Water Meters (AWWA, 2012).

RESULTS AND DISCUSSION

Figures 1–5 show the results of the pulled meter accuracy testing for the ⅝- × ¾-in. meters. The data are plotted as percent registry against time of service, throughput, and problem index. The time of service is the number of years that the meter was in service before being pulled as reported by the utility that donated the meter. The throughput is the meter reading on arrival at the Utah Water Research Laboratory. The service times for the MJ meters sent to the Utah Water Research Laboratory were not precisely known by the utilities that sent them; therefore, no plot for percent registry against service time is given for these meters.

The ⅝- × ¾-in. meter size represented approximately two thirds of the total number of meters provided to the laboratory. For each plot, three linear regressions are shown for the AWWA minimum, intermediate, and maximum flow rates. Table 5 shows the coefficient of determination, R^2, for each linear regression in Figures 1–5. The regressions do not show any considerable correlation between registry and service time or throughput. Typically, for a correlation to exist, the R^2 value from the regression should be greater than 0.7 (Navidi, 2008). Similarly, the tests of the other meter sizes indicated no correlation between registry and service time or throughput (for those reasons, no data are presented), although the larger-sized meters constituted smaller sample sizes. The possibility of nonlinear relationships was considered, but because there were no discernible trends identified in the figures, the authors determined it was not practical to attempt to apply nonlinear relationships to the data.

The accuracy performance of the pulled meters (Figures 1–5) is similar to the performance of newly purchased meters that were laboratory-tested to full life of throughput during a different phase of this research (Neilsen et al, 2011). For example, a lower percentage of ND meters met the AWWA accuracy testing requirements for the intermediate flow rate than the low and high flow rates. In addition, MJ meters generally performed noticeably less well for the low flow rate than for the intermediate and high flow rates. These trends are true for the pulled meters tested for this study as well as for the newly purchased meters that were tested previously (Neilsen et al, 2011). For meters that failed to register flow, disassembling the meter and investigating usually revealed the problem (e.g., broken components, severe wear, deterioration, scarring, buildup of deposits). These are the meters that indicate no registry on the previous plots. Although these data points show the full distribution of registry among all meters tested for this study, these data points were not used in the regressions provided.

In general, a low percentage of the OP meters met the AWWA accuracy requirement for the low flow of ¼ gpm. In addition, a lower percentage of the OP meters met the accuracy standards for the intermediate flow rate of 2 gpm than for the high flow rate of 15 gpm. This is consistent with previously published data for new ⅝- × ¾-in. piston meters (Neilsen et al, 2011; Richards et al, 2010).

CONCLUSIONS

Current AWWA recommendations suggest the need to implement a planned meter replacement program over a set number of years (AWWA, 2012). For the pulled meters in this study, some failed to meet AWWA flow accuracy standards after a short time in service or, in some cases, immediately after installation. This is a concern because meters are usually reported and marketed to meet the AWWA standard (Barfuss et al, 2011).

Other meters continued to meet AWWA flow accuracy standards for more than 20–30 years, which is well beyond what

FIGURE 4 Throughput versus registry 5/8- × 3/4-in. nutating disc meters (Barfuss et al, 2011)

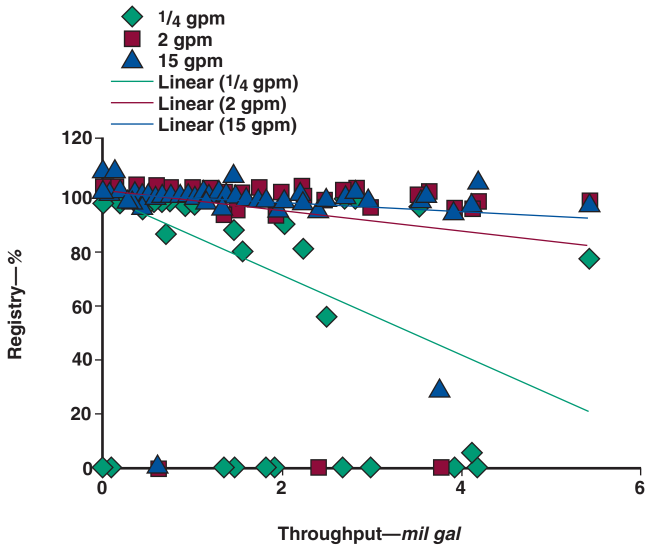
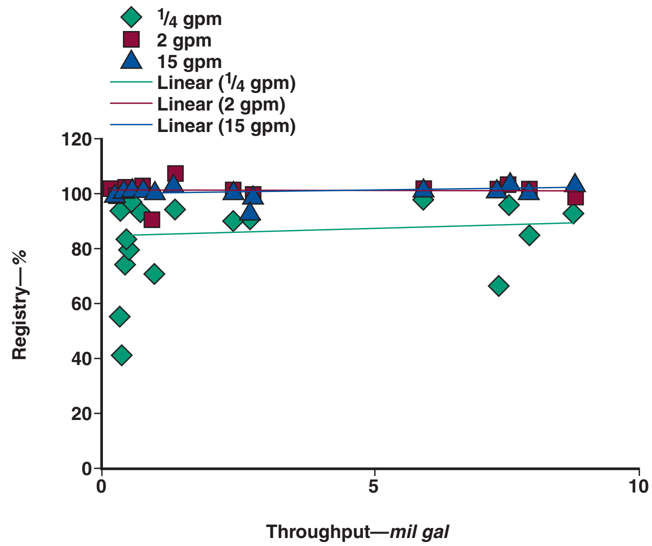


FIGURE 5 Throughput versus registry 5/8- × 3/4-in. multijet meters (Barfuss et al, 2011)



many believe to be a meter's expected life. Although service time is certainly a principal factor when considering meter replacement, these results indicate that other factors are also important and that a meter replacement program based solely on time may end up replacing some meters prematurely. Essentially, if the meters are still meeting accuracy standards, the utility is able to save money by allowing the meters to remain in service longer.

As noted previously, the regressions do not show significant correlation between registry and service time or throughput. The R^2 values for each regression are all close to zero, indicating a weak relationship between meter registry and the independent variable used for the types and sizes of pulled meters that were tested. In addition, the random nature of the data is a clear indication of the complexity of other potential factors previously addressed that may be at play in meter accuracy degradation over time.

Diligent observation of water use records may help in pinpointing individual meters that are underregistering flow. For example, if a meter's registry drops significantly for the same month during the following year, that is an indication of a potential meter accuracy problem. Yet this approach is only helpful if the actual water consumption habits and patterns downstream of said meter remain unchanged. Unfortunately, this is highly subjective and difficult to quantify. Seeking out meters that operate largely under low-flow conditions may prove valuable for some utility managers.

Establishing a meter-testing program is somewhat difficult for water utility managers because it necessitates additional manpower and cost to test meters. Yet the results of this study reinforce the need for individual utilities to understand the relationship between water meter accuracy degradation and other characteristics and factors that are unique to each utility, water meter, and that meter's longevity in a distribution system. Utilities are encouraged to develop and implement a meter-testing program in which a subset of meters within their utility can be monitored in real time for accuracy degradation. Accurate meter testing at regular intervals, in conjunction with annual water audits, will provide the necessary data to quantify degradation issues, thereby assisting in the meter-replacement decision process. The results from this research indicate that meter-replacement programs will be more effective at mitigating accuracy degradation if all factors are considered, instead of just selecting a "replacement age" for meters in a water distribution system.

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PEER REVIEW

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REFERENCES

AWWA, 2012 (5th ed.). Manual of Water Supply Practices, M6. *Water Meters—Selection, Installation, Testing, and Maintenance.* Denver.

AWWA, 2009 (3rd ed.). Manual of Water Supply Practices, M36. Water Audits and Loss Control Programs. Denver.

Barfuss, S.L.; Johnson, M.C.; & Nielsen, M.A., 2011. Accuracy of In-Service Water Meters at Low and High Flow Rates. Report Number 4028. Water Res. Fdn., Denver.

Koch, R., 2006. Personal communication.

Navidi, W., 2008. *Statistics for Engineers and Scientists.* McGraw-Hill, New York.

Neilsen, M.A.; Barfuss, S.L.; & Johnson, M.C., 2011. Off-the-Shelf Accuracies of Residential Water Meters. *Journal AWWA,* 103:9:48.

Richards, G.L.; Johnson, M.C.; & Barfuss, S.L., 2010. Apparent Losses Caused by Water Meter Inaccuracies at Ultra Low Flows. *Journal AWWA,* 102:5:123.