5-2013

The Effect that Non-Recommended Condition Have on Residential Water Meters

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THE EFFECTS THAT NON-RECOMMENDED CONDITIONS HAVE ON RESIDENTIAL WATER METER ACCURACIES

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

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UTAH STATE UNIVERSITY
Logan, Utah

2013

ABTRACT

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Colton F. Smith, Master of Science

Utah State University, 2013

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Department: Civil Engineering

Every year, clean, readily available water becomes more and more scarce. Metering water usage is a way to make users more aware of how much water they use, which in turn will increase the desire to conserve water and to reduce their water bill.

When meters are tested in their new condition, it is normally performed under ideal laboratory conditions at constant flow rates. Then when the meters are installed in the field, they often are installed in or experience non-recommended conditions that are quite different from the ideal laboratory setting. This study investigated several non-recommended conditions that can exist in a distribution system. The conditions that were simulated were endurance (the study of accuracy as a function of meter throughput), installation (the study of accuracy as a function of upstream piping and meter mounting effects), and flow profile (the study of accuracy as a result of dynamic real world flow variances over time).

The meter types that were tested in this study were displacement piston, nutating disc, multi-jet, single-jet, fluidic oscillator, magnetic, and ultrasonic. When comparing the results between the meter types it was found that some meter types were more susceptible than others to the conditions that were simulated. Displacement piston and nutating disc meters had the best overall accuracy performance under the three non-recommended conditions that were simulated.

(48 pages)

PUBLIC ABSTRACT

Every year, clean, readily available water becomes more and more scarce. Metering water usage is a way to make users more aware of how much water they use, which in turn will increase the desire to conserve water and to reduce their water bill.

When meters are tested in their new condition, it is normally performed under ideal laboratory conditions at constant flow rates. Then when the meters are installed in the field, they often are installed in or experience non- recommended conditions that are quite different from the ideal laboratory setting. This study investigated several non-recommended conditions that can exist in a distribution system. The conditions that were simulated were endurance (the study of accuracy as a function of meter throughput), installation (the study of accuracy as a function of upstream piping and meter mounting effects), and flow profile (the study of accuracy as a result of dynamic real world flow variances over time).

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ACKNOWLEDGMENTS

I would like to thank my major professor, Steven Barfuss, for his contributions to this analysis, which include but are not limited to: guiding my research and analysis of the test results, encouraging me to expand on my ideas for development of the project, and suggesting revisions all along the way. I would also like to thank Dr. Michael Johnson for his insight and guidance on the project, as well as Dr. Kevin Heaslip for his contribution to the project.

I also want to thank my family, friends, and Utah Water Research Laboratory associates for supporting me throughout the five years that I worked on this project. I would like to especially thank my wife and daughters for their constant support and motivation to keep me going through all the tough times in school.

Colton F. Smith

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LIST OF SYMBOLS AND ABBREVIATIONS

List of Symbols

DP	Displacement or Oscillating Piston Meter Type
ND	Nutating Disc Meter Type
MJ	Multi-Jet Meter Type
SJ	Single-Jet Meter Type
FO	Fluidic Oscillator Meter Type
MA	Meter type Magnetic Meter Type
US	Meter type Ultrasonic Meter Type

List of Abbreviations

UWRL	Utah Water Research Laboratory
WRF	Water Research Foundation
NIST	National Institute of Standard and Technology
AWWA	American Water Works Association

CHAPTER 1

INTRODUCTION

With water usage increasing each year, it becomes more necessary to measure this usage accurately (Bowen et al., 1991). Some utilities require meters to be tested before they are installed in their distribution system. The meters are normally tested in their new condition in the manufacturer's facilities under ideal straight-pipe conditions, using clean water and constant flow rates. However, flow conditions in the distribution system and in the test laboratory are often very different. Unique conditions that exist within a distribution system can affect meter accuracy and some meter types are more susceptible than others.

This paper examines the effects that non-recommended conditions can have on meter accuracy by modeling typical distribution system conditions in the laboratory. The non-recommended conditions that were examined in this study were accuracy as a function of throughput (endurance), upstream piping and meter mounting conditions (installation) and variable flow conditions (flow profile). Hereafter in this document the simplified terms "endurance," "installation," and "flow profile" will be used to define the laboratory tests

A Water Research Foundation study (Barfuss et al., 2011) performed at the Utah Water Research Lab (UWRL) examined the effects of throughput on meter accuracy. Test meters were subjected to large volumes of throughput in the laboratory up to a predetermined full-life condition. To increase the statistical reliability of the results, the meters were then endurance tested beyond the predetermined full-life condition (Lankin, 2003).

When a meter is installed in a distribution system it can be affected by upstream approach conditions. Upstream flow conditions are affected by fittings and valves. The resulting distorted velocity profiles can have considerable effects on meter accuracy. A study conducted by the Letton-Hall Group (Kelner, 2003) examined the effect that piping configurations can have on the velocity profile. The metering device that measures water volumes passing through the meter assume ideal velocity conditions with maximum velocities at the centerline of the pipe (Kelner, 2003) see Figure 1. Essentially, upstream conditions can change or distort the velocity profile, which in turn can affect meter accuracy. When a mechanical meter is not installed to the manufacturer's specifications, the meter can have greater friction on moving parts. This can cause meter degradation rate to increase, reducing the life of the meter (Arregui et al., 2005).

In the 2011 Water Research Foundation (WRF) study (Barfuss et al., 2011) endurance and accuracy testing was performed at constant flow rates, as opposed to the non-recommended scenario where flow rates through the meters are always changing. This variance in flow over time is called a flow profile. In a typical home, the flow rate is always changing with toilets flushing, faucets being turned on and off, showering and outside watering. This constant change in the flow rate can affect the meter's ability to measure throughput accurately.

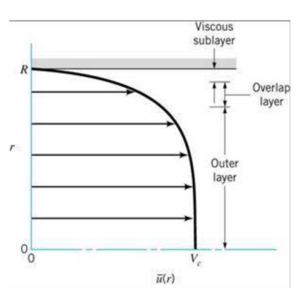

Figure 1. Ideal velocity profile (Kelner, 2003)

This paper examines the non-recommended conditions of endurance, installation conditions and flow profile to determine the effects they have on a residential meter's accuracy.

CHAPTER 2

LITERATURE REVIEW

Previous studies have identified key components of residential water meter accuracy and performance that have influenced the analysis of the conditions simulated in this study. Studies done by the WRF in 1991 and 2011 by Bowen et al. (1991) and Barfuss et al. (2011), focused on evaluating the effect of throughput on meter accuracy. The study conducted by Bowen in 1991 compared meter accuracy on meters that were endurance tested with a constant flow to meters that were endurance tested with pulsed flow. A greater sample size of meter types and sizes were used in the 2011 study which increased the statistical reliability of the results (Lankin, 2003).

Upstream conditions and meter mounting can affect meter performance. Studies conducted by Kelner (2003) and Arregui et al. (2005), examined the effects that upstream conditions and meter installation have on meter accuracy. Kelner (2003) also examined the effects that upstream conditions can have on the velocity profile. The study examined different pipe fitting configurations that would change or distort the velocity profile. This research suggests that when the velocity profile is changed or distorted from the ideal velocity profile, then meter accuracy is affected. The 2005 study performed by Arregui et al. (2005) examined the effects that mounting position and upstream conditions have on meter accuracy and he proposed possible reasons for the effects. The research suggests that when a meter is not installed according to the manufacturer's recommendations, it will create greater friction on mechanical parts, thereby decreasing a meter's accuracy and the life of the meter.

In a typical residence the flow rate varies and is not constant (Bowen et al., 1991). Varying flow rates were studied by two similar studies done by Mayer et al. (1999) and DeOreo et al. (2009). They monitored residential throughput by installing data loggers on the meters that recorded the flow rate, time and consumption. The studies used data loggers to quantify usage from faucets, showers, toilets, dishwashers, clothes washer, outdoor watering and leaks of each home that participated in the studies. The work conducted by Mayer et al. (1999) suggested that a longer data-logging period would increase the understanding of the varying flow profile. Work done by DeOreo et al. (2009) found that some data loggers recorded extended periods of throughput that were categorized as leaks. It is unclear if these events were actual leaks or if there are conditions that exist in the distribution system that caused the meters to register throughput.

CHAPTER 3

TEST PROCEDURE

Laboratory testing associated with meter throughput (endurance), installation and flow rate variability (flow profile) each involved a different testing procedure. Five meter types were tested in the installation and endurance condition tests: nutating disc (ND), displacement piston (PD), single-jet (SJ), multi-jet (MJ), and fluid oscillator (FO). The flow profile tests included the same five meter types, but also included two more meter types that have been recently released on the market: magnetic (MA) and ultrasonic (US) (see Table 1).

Table 1. Meter sample sizes by type

	In-Field Condition			
Type	Endurance	Upstream	Flow Profile	Total
Displacement Piston (DP)	15	3	6	24
Multi-Jet (MJ)	18	3	6	27
Nutating Disc (ND)	9	3	6	18
Single-Jet (SJ)	6	3	6	15
Fluidic Oscillator (FO)	3	3	6	12
Magnetic (MA)	0	0	6	6
Ultra Sonic (US)	0	0	6	6

Each type of meter measures throughput differently. ND and DP meters are volumetric-type meters that measure discrete volumes of water that enter and exit the metering chamber. The water entering the chamber causes the meter device (disc or piston) to move in the chamber. SJ and MJ meters are an inferential type meter that uses a linear relationship between the velocity of the water entering the metering chamber and the speed of the metering device (rotor or propeller). The meter registry is calibrated to the number of rotations. MA and US meters are electronic-type meters. MA metering uses Faraday's Law of Electromagnetic Induction. When water passes through a magnetic field, a voltage is created and the sensors inside the metering chamber correlate the reading to the flow rate. US technology measures the time it takes for a sound wave to propagate from one sensor to the next (transit time). The length of time it takes the signal is correlated to the flow rate.

The three non-recommended conditions upon which this research is based all have different specific testing procedures, but the procedure for accuracy testing is the same. Accuracy tests were performed during this study by using a gravimetric bench with weight tanks that were calibrated and traceable to the National Institute of Standard and Technology (NIST). Flow rates were set by using calibrated magnetic flow meters and then double-checked by timing each flow rate that was entering the weight tank. Intermediate flow rate checks were performed during the tests and the flow rate was adjusted as needed. Flow rates that were tested were based on the American Water Works Association (AWWA) standards for maximum, intermediate and minimum flow rates for meter size and type.

Flow rates were calculated by recording initial and final weights that entered the weight tank to obtain a net weight. Using temperature to calculate the specific gravity of the water during the test, the volume that was passed through the meters was calculated. For each test, the actual volume of water that was measured in the weight tank was compared to the volume of water that each meter recorded to give the percent volume registered by each meter.

To evaluate the dependability of the data collected an uncertainty analysis was performed on the data that was collected. The root sum square method was used. To reduce the amount of uncertainty in recording the weights, one of two weight tanks were used for either high or low flow rates. The smaller weight tank was readable to 0.01 pounds and the larger tank was readable to 0.1 pounds. The smaller tank was used for AWWA low and intermediate flow rates while the larger tank was used for the high AWWA flow rates. Test runs for low and intermediate flow rates used a throughput of 10 gallons and high flow rates used a throughput of 100 gallons, which further reduced the amount of uncertainty during accuracy testing. The mechanical meters could be read to the nearest 0.1 gallon and the electronic meters could be read to the nearest 0.01 gallons. Temperature could be read to the nearest 0.1 degree. Meter readability had the greatest effect on the uncertainty analysis. The uncertainty on the low and intermediate AWWA flow rates for the mechanical meters was not greater than 0.51%. The uncertainty on the low and intermediate AWWA flow rates for the electronic meter was not greater than 0.06%. At the high AWWA flow rate conditions, the uncertainty for both the mechanical and electronic meters was not greater than 0.06%.

Endurance

The endurance testing of 3/4-in meters during the WRF study (Barfuss et al., 2011) using a recirculation test bench, formed the basis for this portion of the research. To reduce uneven wear on the meters from a constant flow rate, flow rates were alternated between 1/3 and 2/3 the AWWA maximum flow rate for 3/4-in meter (Barfuss et al., 2011). The flow rates were controlled using a programmable clock and solenoid valves. Meters were accuracy tested at four flow rates: 0.5, 2, 3, 25 gpm. Accuracy tests at the four flow rates were performed at every 1,000,000 gallons of throughput. Accuracy tests were also performed when the meters reached 3,000,000 gallons of throughput, which was defined as the full life condition. The accuracy tests at the 3,000,000 gallon mark were also retested before continuing with endurance testing. This portion of the testing used 3/4-inch meters.

Installation

The 5/8 x 3/4-inch meters that were selected for this portion of the study (see Table 1) were baseline accuracy tested in their new condition at the AWWA standard flow rates 0.25, 1, 2 and 15 gpm. After obtaining the baseline accuracies, to have a comparison for each condition tested, they were then tested in various installation configurations. Ten installation conditions were tested (Figures 2-11) and in each case, the meter type was accuracy tested at the four AWWA standard flow rates.

Figure 2. Flow downward with meter vertical

Figure 3. Flow upward with meter vertical

Figure 4. Meter tilted 45 degrees

Figure 5. Meter tilted 90 degrees

Figure 6. 90 degree elbow upstream of meter

Figure 7. Two 90 degree elbows in plane

Figure 8. Two 90 degree elbow out of plane

Figure 9. 1-1/4-inch to 3/4-inch bushing

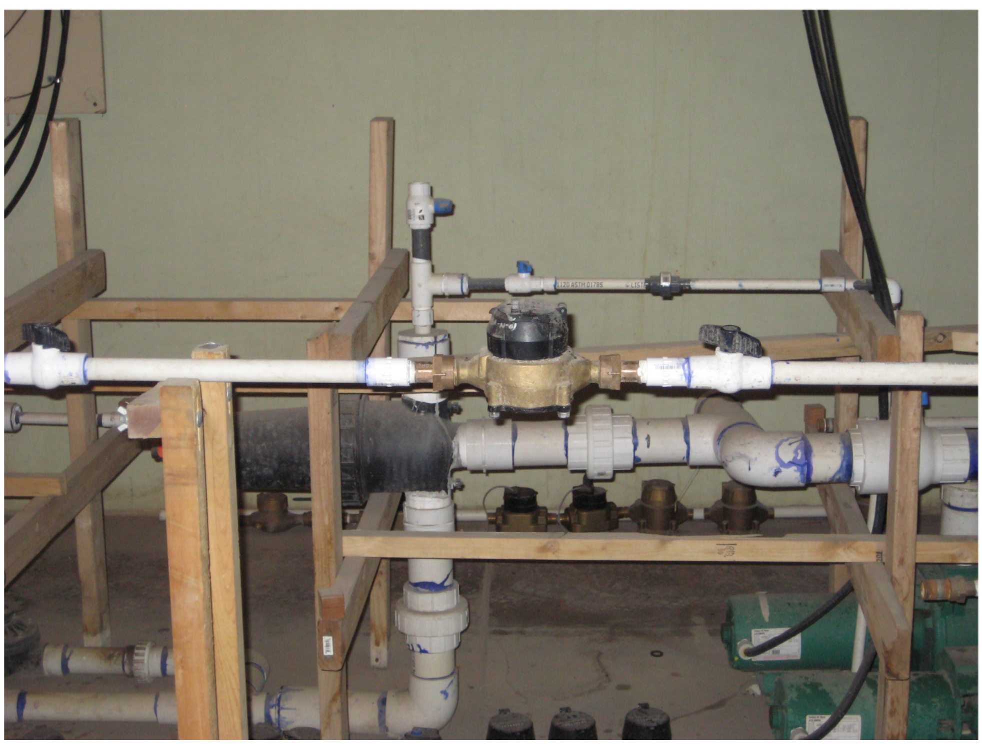

Figure 10. Partially open valve

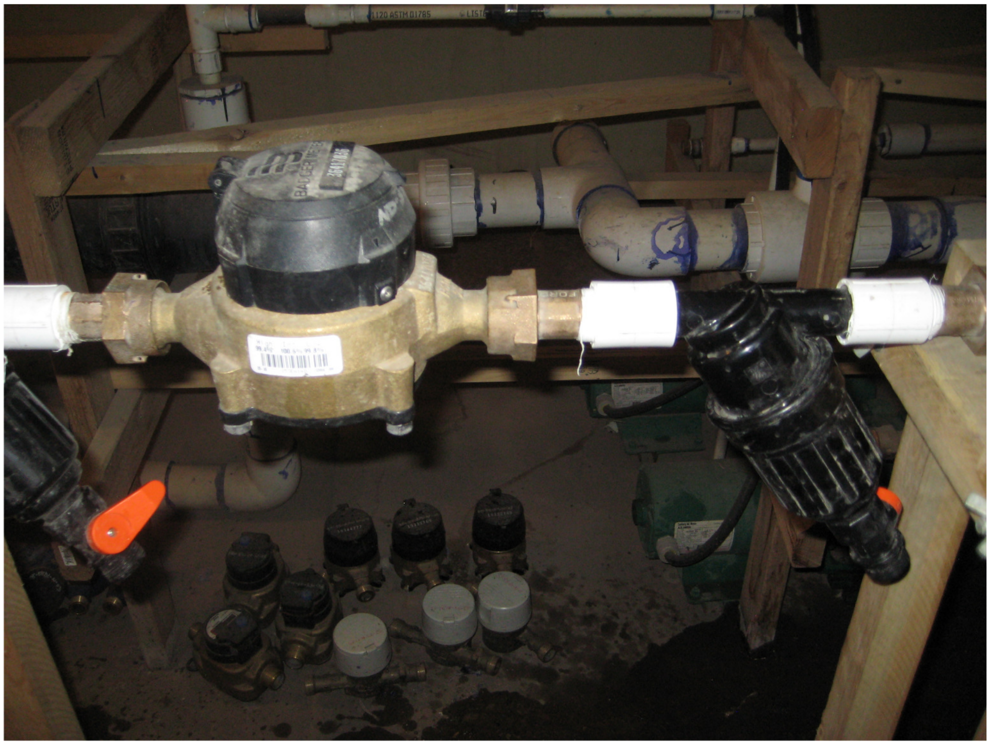

Figure 11. Filter

Flow Profile

Similar to endurance testing, the meters that were selected for this portion of the study were baseline accuracy tested in their new condition before being installed in a modified recirculating test bench. A theoretical daily household-use flow profile was created by selecting eight flow rates typical of common household water use conditions. Flow rates were controlled in the test bench using programmable solenoid valves (Figure 12). Each solenoid valve was programmed at different on and off time periods. Flow rates were set by utilizing a throttling ball valve downstream of each solenoid valve. Flow rates were measured by using the weight tank, thermometer, and stop watch. The throttling valve was adjusted as needed. The flow profile that was created was repeated every four hours.

A total volume calibration was performed to compare the theoretical volume to the volume recorded by each meter. This was accomplished by using three 50 gallon tanks, a weight scale and a stop watch. Tank one and tank two were used for filling and tank three was used to divert flow from tank one or tank two when full. The four-hour flow profile was started with tank one on the weight scale (Figure 13), and when full, flow was immediately diverted to tank three (Figure 14). The tank one weight was recorded and then removed from the scale and emptied. Tank two was placed on the scale and verified that the weight was at zero (Figure 15). Flow was then diverted from tank three to tank two. The volume of water that entered tank three in the interim period was then emptied into tank two. This process was then repeated throughout the simulated four hour cycle switching between tank one and tank two on the weight scale. In laboratory accuracy tests the flow rates remain constant, where as in a distribution system flow rates are varying which can affect meter accuracy.

The meter's initial volumes were recorded before the actual profile testing began. After initial volumes were recorded, the computerized flow profile was then started to run for a simulated six-month period. After the six month simulated flow profile had finished, a constant flow rate endurance test was then performed as a comparison to the flow profile simulation. A constant flow rate of 3 gpm was calibrated by weight tank and stop watch. The initial volumes were recorded for each meter and they were endurance tested to the same volume throughput as the flow profile. After the meters were endurance tested to the same volume of throughput, they were then accuracy tested at the four AWWA standard flow rates to ensure no degradation had occurred. The constant flow rate endurance test and flow profile endurance test were then compared to determine if flow rate variability affected registry accuracy in any way. The meters that were tested were 5/8 x 3/4-inch meters.

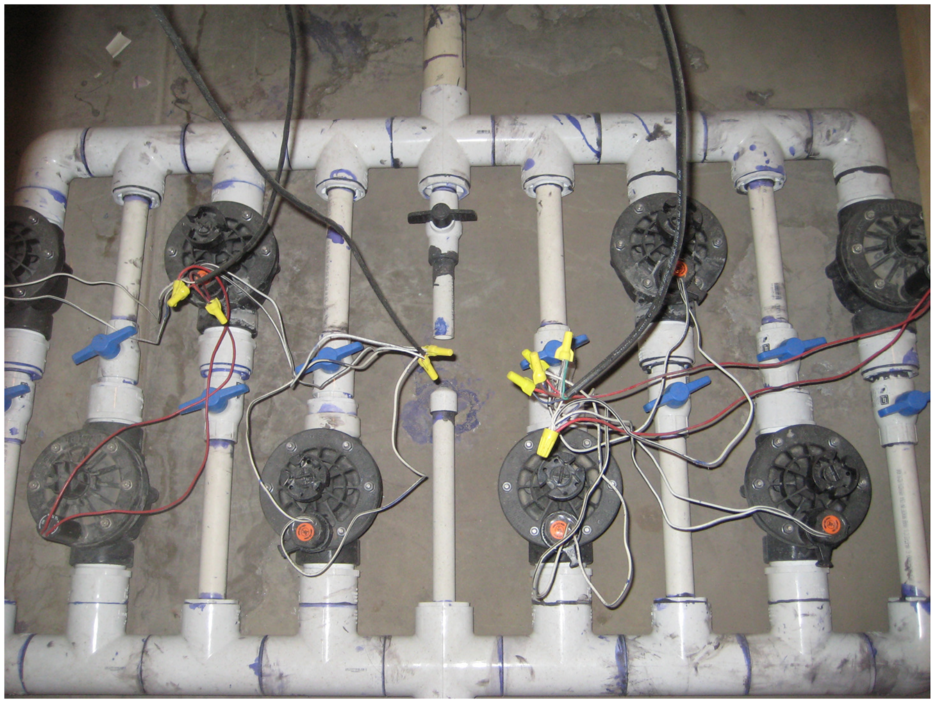

Figure 12. Solenoid bench setup

Figure 13. Fill tank on weight scale

Figure 14. Diverting flow from fill tank

Figure 15. Replace fill tank with empty tank

CHAPTER 4

LABORATORY RESULTS AND ANALYSIS

Accuracy test results are reported in this paper for each tested condition as average accuracy values. Accuracy results for each meter type were examined.to prevent any bias towards the meter manufacturers. The meter manufacturer's names have been replaced with a letter ranging from A through K. This method was used only in the endurance analysis where some meter types had multiple manufacturers. Installation and flow profile tests included only one manufacturer for each meter type. Manufacturers were selected by examining the results in the WRF study (Barfuss et al., 2011). The manufacturer with the best overall accuracy was selected.

Endurance Tests

When the WRF project (Barfuss et al., 2011) was completed and meter accuracy at the full life condition was examined, accuracy results showed that the majority of the meters were still passing the AWWA standards. This is consistent with a report given by Lankin (2003) which suggested that testing at a greater volume would increase the statistical reliability of the results.

During the analysis of the data it was observed that more meters were not passing the AWWA standard at the low flow than at the intermediate and high flow rates. So the analysis was performed on the AWWA low flow standard of 0.5 gpm for 3/4-inch meters (Figures 16-20).

From 0 gallons to 10 million gallons, the ND meter types showed the highest meter accuracy and had a passing rate of 89% at the low flow standard flow rate (Figure

17, Table 2). The results for the DP meter types were similar to the ND meters, although one manufacturer in the set pulled the average registry down (Figure 16). When that manufacturer was removed from the analysis, the ND and DP meter types are very similar in meter accuracy (Table 3). FO average meter accuracy was very consistent throughout endurance testing. But at the low flow standard, meter accuracy fell below the AWWA standard requirement (Figure 20). MJ and SJ meters showed the greatest accuracy degradation with a passing rate of 33% at the AWWA low flow standard (Table 2, Figures 18-19). The SJ meters had a manufacturer that was pulling the average meter accuracy down. When that manufacturer's data was removed from the analysis, the average registry increased from 32.9% to 65.9%. The SJ meters showed the greatest amount of meter degradation with the average registry dropping to 65%, which is well below the low flow passing standard. The SJ meters also had the greatest difference in meter accuracy between the new condition and the 10 million gallon (full life) condition, with a difference of about 33% (Table 3). Additional graphs that show individual meter accuracy by type at the four AWWA standard flow rates are shown in the Appendix (Figures 26-30).

Table 2. Percent passing AWWA low flow standard for 3/4-inch meters at 0.5 gpm after millions of gallons of throughput

Meter Type	Passing AWWA low standard by manufacturer (1,000,000 gallons)										
	0	1	2	3	4	5	6	7	8	9	10
DP	100%	100%	100%	87%	87%	93%	93%	93%	87%	80%	73%
ND	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	89%
MJ	83%	83%	89%	89%	78%	78%	61%	61%	56%	44%	33%
SJ	100%	100%	83%	83%	50%	50%	50%	33%	33%	33%	33%
FO	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

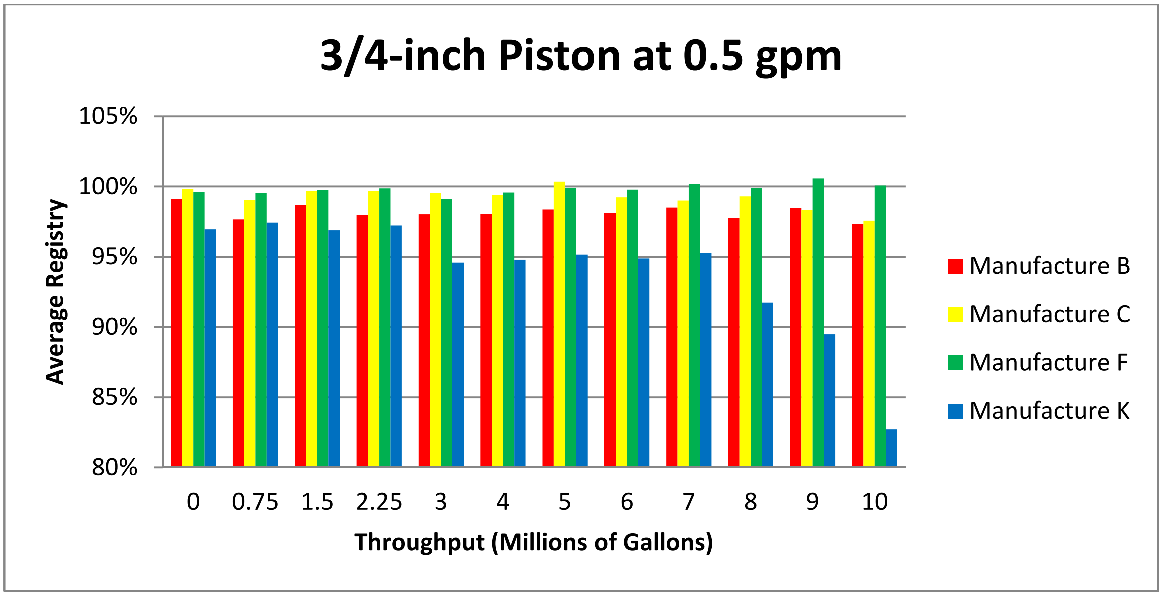

Figure 16. Average displacement piston meter accuracy after millions of gallons of throughputs by manufacturer

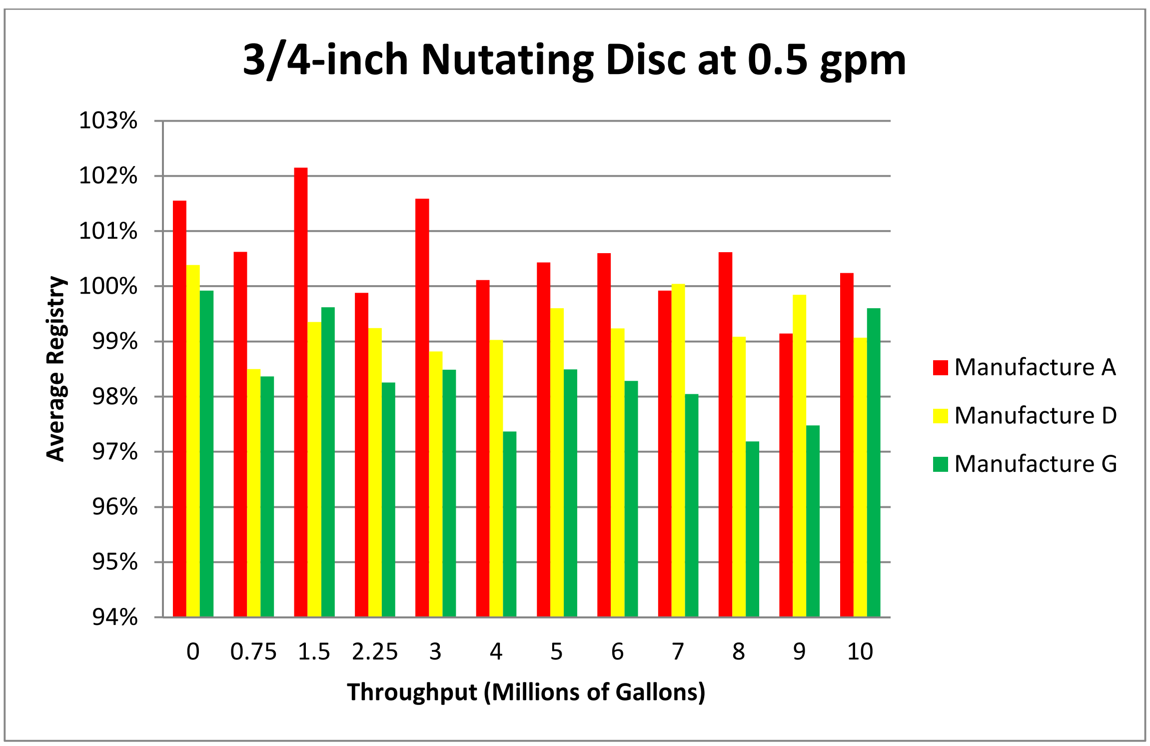

Figure 17. Average nutating disc meter accuracy after millions of gallons of throughputs by manufacturer

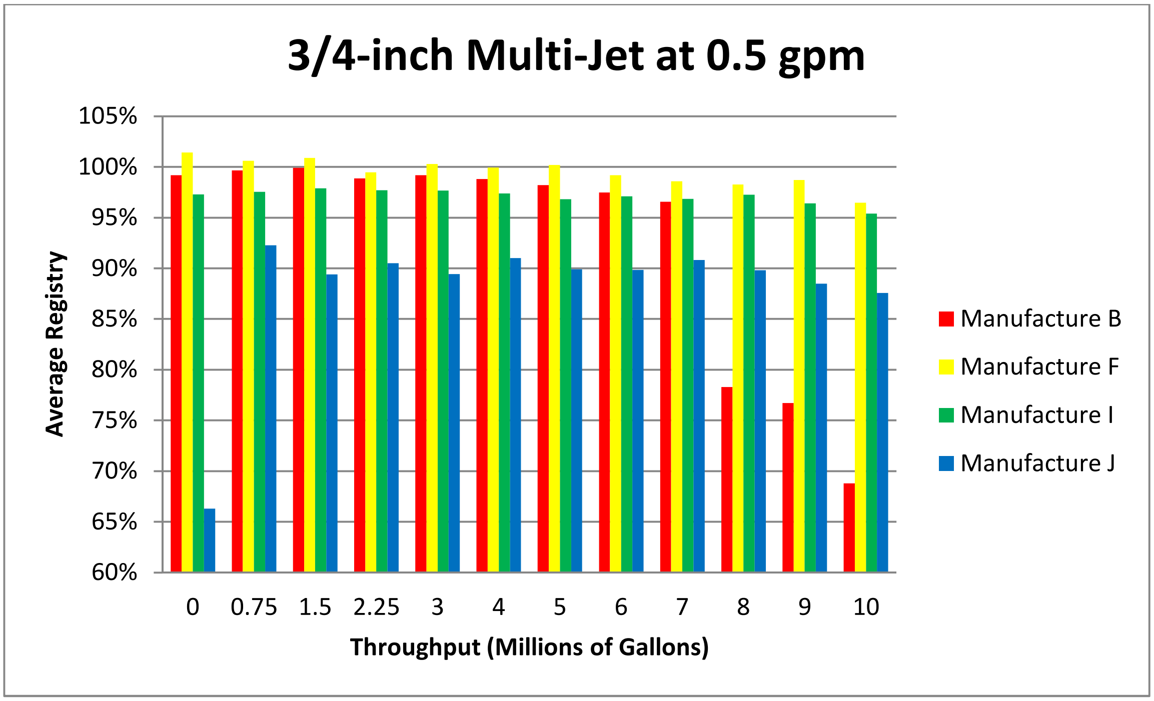

Figure 18. Average multi-jet meter accuracy after millions of gallons of throughputs by manufacturer

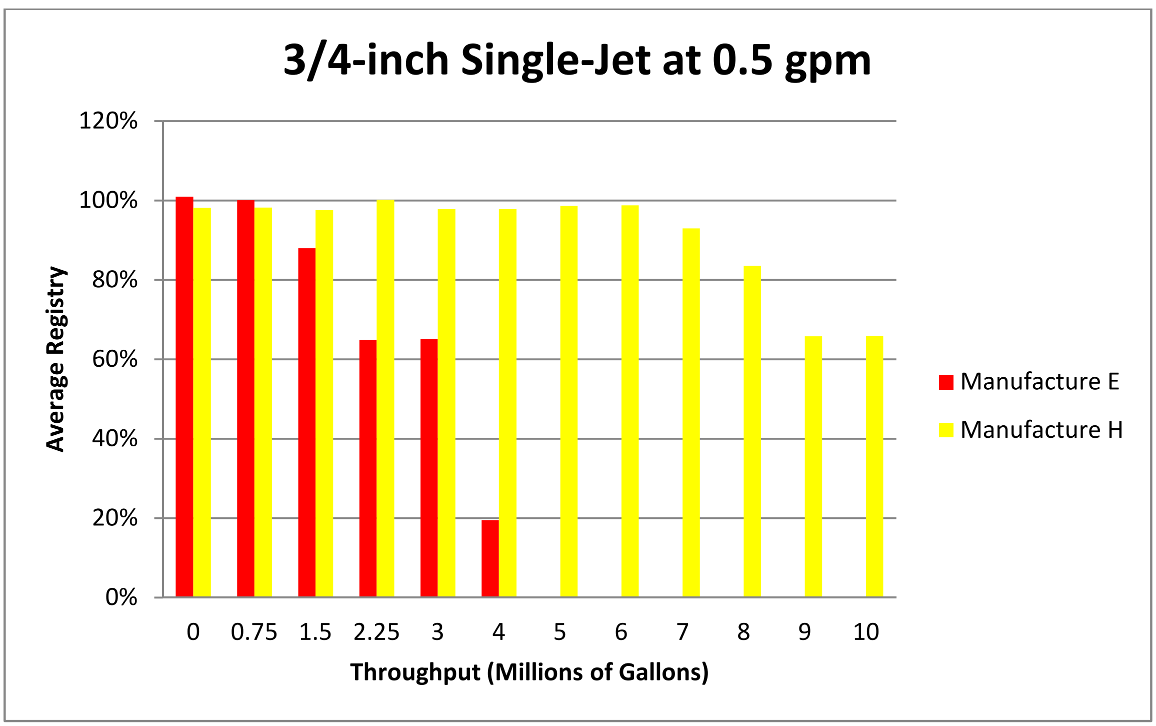

Figure 19. Average single-jet meter accuracy after millions of gallons of throughputs by manufacturer

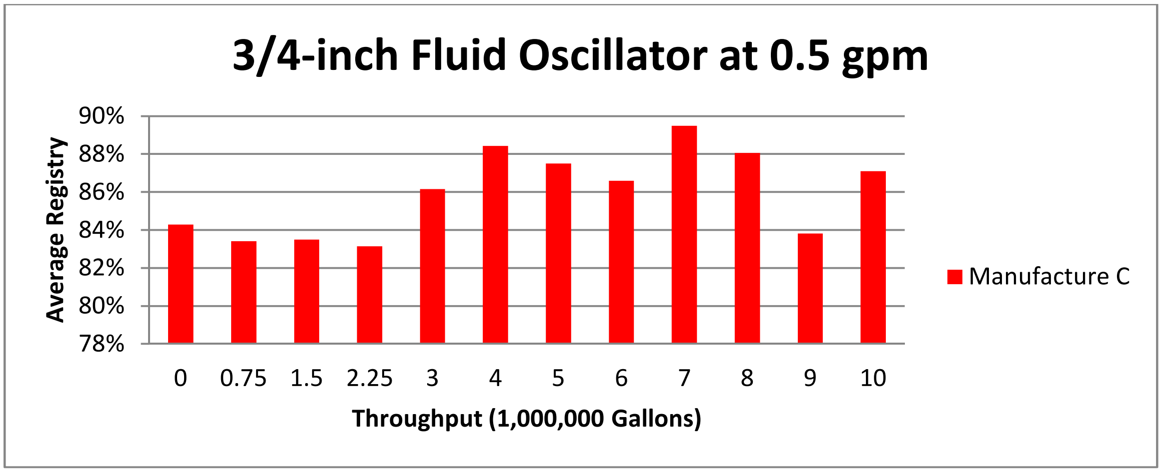

Figure 20. Average fluid oscillator meter accuracy after millions of gallons of throughputs by manufacturer

Table 3. 5/8x3/4-inch meter size comparison of meters in new condition to accuracy at 5 and 10 million gallons (MG)

		Percent Difference from New Condition		
Endurance	Type	Low	Intermediate	High
	DP*			
New Condition		99.41%	100.80%	99.57%
5 MG		99.24%	100.42%	99.19%
10 MG		98.07%	100.94%	99.06%
Percent Difference				
5MG		0.17%	0.38%	0.38%
10MG		1.34%	-0.14%	0.50%
	ND			
New Condition		100.62%	101.57%	99.36%
5 MG		99.51%	100.99%	99.57%
10 MG		99.64%	100.26%	99.84%
Percent Difference				
5MG		1.11%	0.58%	-0.20%
10MG		0.98%	1.32%	-0.48%
	MJ			
New Condition		99.67%	100.57%	98.54%
5 MG		98.30%	99.75%	98.41%
10 MG		86.29%	94.78%	94.50%
Percent Difference				
5MG		1.36%	0.82%	0.13%
10MG		13.37%	5.79%	4.04%
	SJ*			
New Condition		99.53%	101.68%	99.98%
5 MG		98.56%	99.75%	99.56%
10 MG		65.85%	66.04%	66.71%
Percent Difference				
5MG		0.97%	1.93%	0.43%
10MG		33.68%	35.63%	33.27%
	FO			
New Condition		84.29%	99.15%	99.12%
5 MG		87.50%	100.51%	99.30%
10 MG		87.10%	100.79%	99.88%
Percent Difference		-3.22%	-1.36%	-0.18%
		-2.81%	-1.64%	-0.77%

* Indicates that a manufacturer was removed due to pulling the average down

Installation Tests

Meter installation can affect meter accuracy if not installed to the manufacturer's specification. Poor installations can cause friction on moving parts and increase the degradation rate of the meter to increase (Arregui et al., 2009). The installation of the meter can have the same effect on meter accuracy by distorting the ideal velocity flow profile and causing the meter accuracy to increase or decrease (Kelner, 2003).

Meter accuracy as affected by installation conditions showed that overall, most installation conditions had little effect on meter accuracy (Figures 11-14). Installation conditions were found to affect meter accuracy the greatest at the lower flow rates and therefore meter accuracy was examined at the AWWA low flow standard of 0.25 gpm for 5/8 x 3/4-inch meters.

The meter type that was affected the most by the installation conditions was the MJ meter. The installation conditions that affected the MJ were: flow downward with meter vertical (Figure 7), flow upward with meter vertical (Figure 8), the meter tilted 45 degrees (Figure 9) and 90 degrees (Figure 10 and 14). Meter accuracy dropped to an average value of 45.2%, with a percent difference from the new condition of 56.6%. This is the highest of all the meter types (Table 4). DP, ND and SJ meters did not show any significant change in accuracy during the installation condition tests. Percent difference from new condition was generally within ± 5% for these meters. The graphs do show some variability in the accuracies, but meters were still passing the AWWA standards (Figures 21-24).

Plans to test additional conditions were abandoned due to time and budget restraints. It was also desired to examine the effects of pressure surges and vibrations. It was noted in the WRF study (Barfuss et al., 2011) that some meter types were susceptible to registering flow when surges or transients were present in the system even when no flow in the pipe was observed. The study performed by DeOreo et al. (2009) likewise noted that at times the data loggers recorded long periods of continuous flow that indicate a possible leak. It suggests that it could also be a condition that exists in the distribution system that causes the meter to register. This could be created by pressure surges, transients and vibrations which are occurring within the distribution system. These conditions need further testing and evaluation.

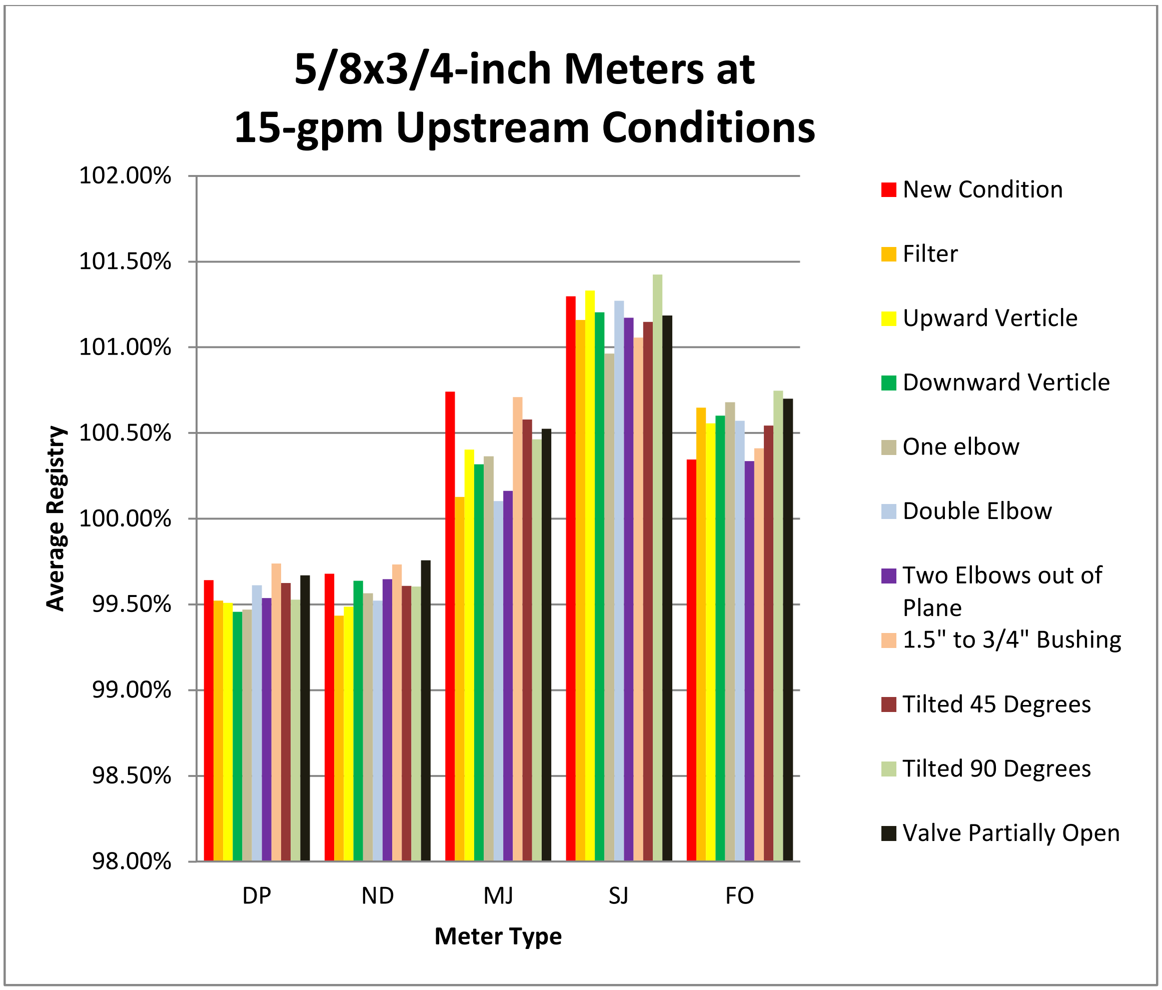

Figure 21. 15 gpm installation conditions

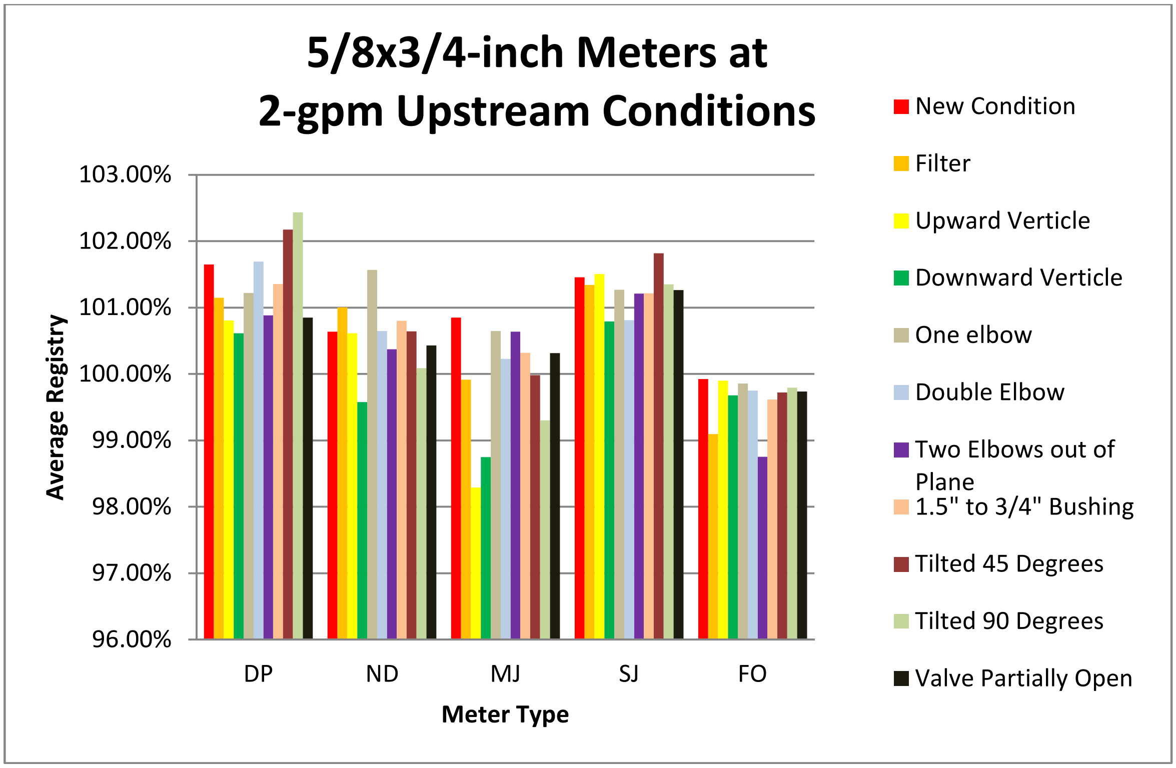

Figure 22. 2 gpm installation conditions

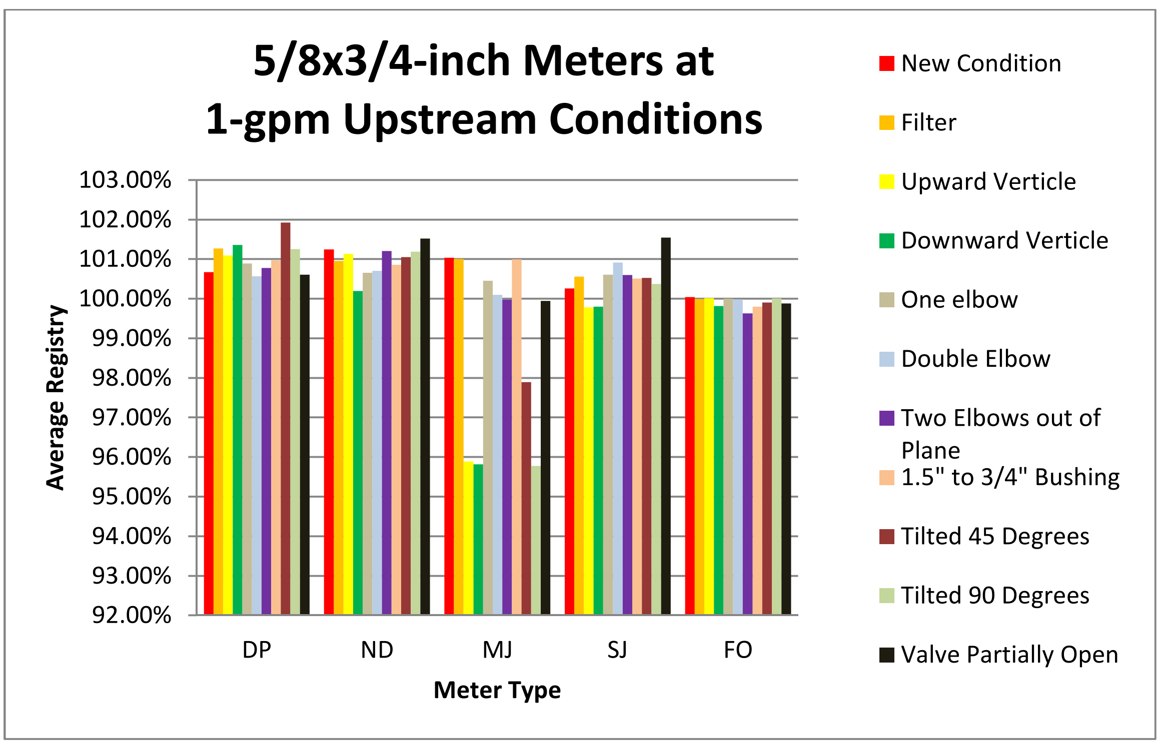

Figure 23. 1 gpm installation conditions

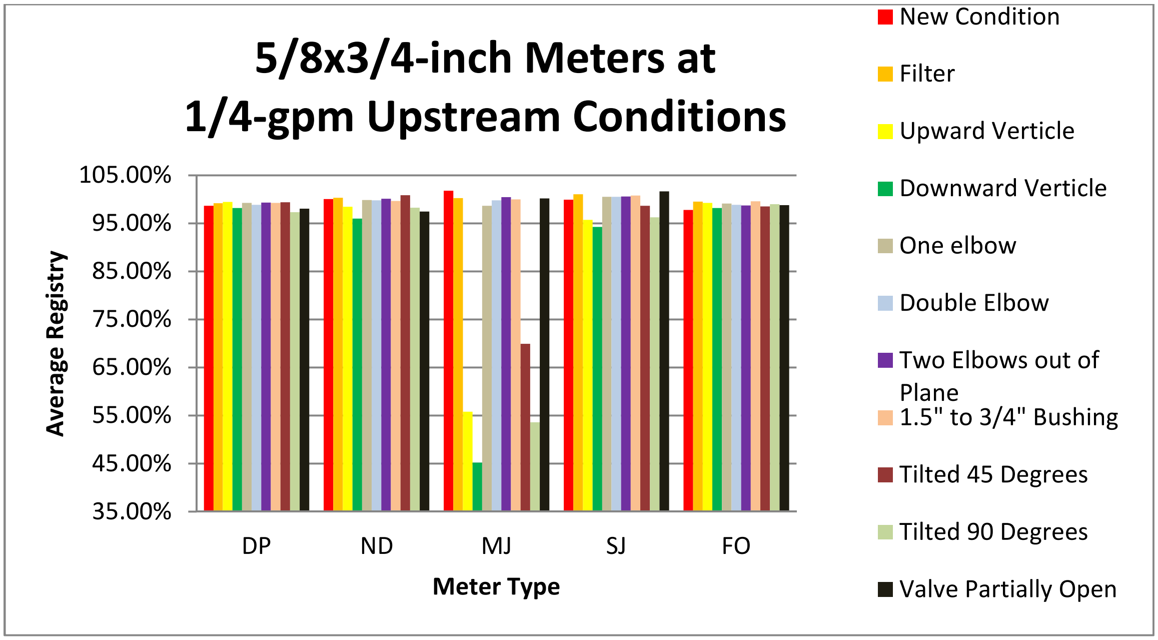

Figure 24. 0.25 gpm installation conditions

Table 4. 5/8 x 3/4-inch meter size comparison of meters in new condition to meters installed conditions

		Percent Difference from New Condition		
Installation	Type	Low	Intermediate	High
	DP			
New Condition		98.68%	100.67%	99.64%
Downward Vertical		98.21%	101.36%	99.46%
Two Elbows out of Plane		99.30%	100.78%	99.54%
Percent Difference				
Downward Vertical		0.47%	-0.69%	0.18%
Two Elbows out of Plane		-0.62%	-0.11%	0.10%
	ND			
New Condition		100.03%	101.24%	99.68%
Downward Vertical		96.01%	100.20%	99.64%
Two Elbows out of Plane		100.11%	101.20%	99.65%
Percent Difference				
Downward Vertical		4.02%	1.05%	0.04%
Two Elbows out of Plane		-0.08%	0.04%	0.03%
	MJ			
New Condition		101.80%	100.85%	100.74%
Downward Vertical		45.20%	98.75%	100.32%
Two Elbows out of Plane		100.45%	100.64%	100.16%
Percent Difference				
Downward Vertical		56.61%	2.10%	0.42%
Two Elbows out of Plane		1.36%	0.21%	0.58%
	SJ			
New Condition		99.91%	101.46%	101.30%
Downward Vertical		94.24%	100.79%	101.20%
Two Elbows out of Plane		100.58%	101.21%	101.17%
Percent Difference				
Downward Vertical		5.67%	0.67%	0.09%
Two Elbows out of Plane		-0.67%	0.25%	0.12%
	FO			
New Condition		97.82%	100.04%	100.35%
Downward Vertical		98.18%	99.82%	100.60%
Two Elbows out of Plane		98.72%	99.63%	100.34%
Percent Difference				
Downward Vertical		-0.36%	0.22%	-0.26%
Two Elbows out of Plane		-0.90%	0.41%	0.01%

Flow Profile Tests

Meters installed in the field are normally not subject to constant flow rates. In a household for example, the flow rate is always changing as every fixture in the house turns on and off. A meter's ability to measure water consumption is strongly dependent on the flow rate range of the consumer (Arregui et al., 2005).

A typical home has many fixtures that are used multiple times throughout a given day. Examples of typical fixtures are faucets, toilets, showers, clothes washers, and dishwashers, as well as outdoor watering. Each fixture when turned on has a flow rate at which it uses water.

To establish an accurate household profile, typical flow rates were used as provided in a report done by Neibauer and Waskom (2010). These values were then adjusted slightly for limitations in the testing bench setup. For example, at the peak flow rate in the flow profile, when multiple fixtures were going to be on at the same time, it was not possible to reach the maximum flow required, so flow rates were adjusted to meet these limitations in the testing bench (Table 5). A study done by Mayer et al. (1999) suggested an extended testing period to increase understanding in end user usage of water. For this study, a 6-month simulation was set up by compressing a single day of water use into an actual 4-hour period so that the simulation could be repeated six times each test day (Figure 31). The simulation was programmed to run two cycles a day, where a cycle consisted of two consecutive 4-hour cycles with a 4-hour period at zero flow. Zero flow conditions were established to model the times during the day and night when no water is being used in the home.

Table 5. Target and actual flow rate in flow profile testing

	Fixture Flow Rates (gpm)							
	Sink 1	Sink 2	Shower 1	Shower 2	Toilet	Laundry	Dishwasher	Sprinklers
Target	1.50	1.50	2.20	2.20	1.85	0.50	0.85	5.80
Actual	1.54	1.57	2.13	2.30	1.86	0.48	0.89	5.85

To conserve battery life when no flow is observed, the electronic meters have a sleep mode where they are designed to take fewer measurements. This tested condition was anticipated to have the greatest effects on the electronic meter types. However, the results after the 6-month simulation showed that all the meter types were affected.

The meter types that were least affected with varying and constant flow rates were DP, ND and MA-type meters. These had the least amount of difference between the meter with the lowest accuracy to the highest accuracy of ± 0.5% (Figure 15, Tables 6-7). The meter types that were affected the most were the SJ, MJ, FO and US-type meters. These had the greatest amount of difference from the minimum and maximum meter accuracy of ± 1% (Figure 15, Tables 6-7). Though the table and graphs show that there is some amount of error in meter accuracy, all of the results are within the AWWA standards. Comparing the flow profile meter accuracy to the new condition accuracies, FO meter type has the greatest difference of ±4% (Table 9).

Values in Table 6 can be used to project how much throughput each meter would measure at a given throughput. Evaluating the full life condition for the flow profile meters at 2 MG it was found that some meters under-registered and some over-registered (Table 8). SJ meters have the lowest under registry at 64,000 gallons and FO have the highest over registry at 63,000 gallons (Table 8). These results provide a clear understanding of how our meter accuracy over long periods of time affects the cash registers in a utility.

At the beginning of the flow profile testing it was observed that during the zero flow periods, many of the meters were measuring a small amount of flow. Close inspection determined that there was in fact no flow passing through the meters and that all of the flow was being bypassed through the running pump. This interesting phenomena was removed by programming the pump to shut off rather than utilizing a bypass during the zero flow period. As mentioned previously, this is one of the examples where further research may be helpful when pressure surges, negative pressures and vibration exist in a system causing a meter to register flow when there is none. The observation in the flow profile further warrants the need for additional testing in this area because in the field these conditions can and do exist.

Table 6. Max, min and average percent error with varying flow for 5/8x3/4-inch meters

	Pecent Error		
Meter Type	Minimum	Maximum	Average
SJ	-2.24%	0.56%	-1.09%
MA	-0.89%	-0.16%	-0.52%
DP	-0.24%	0.04%	-0.10%
US	-0.06%	2.53%	0.94%
ND	-0.04%	0.43%	0.21%
FO	-1.17%	1.19%	0.41%
MJ	-0.82%	0.78%	-0.14%

Table 7. Max, min and average percent error with constant flow for 5/8x3/4-inch meters

	Pecent Error		
Meter Type	Minimum	Maximum	Average
SJ	-3.22%	-0.78%	-1.95%
MA	-1.11%	-0.36%	-0.75%
DP	0.28%	0.53%	0.38%
US	-1.49%	1.69%	0.23%
ND	0.12%	0.76%	0.43%
FO	0.90%	3.16%	2.23%
MJ	-1.38%	0.12%	-0.69%

Table 8. Varying flow projected under and over registry at 2 million gallons of throughput

	Varying Flow with 2 Million Gallons of Throughput		
Meter Type	Min	Max	Average
SJ	-44868	11295	-21873
MA	-17778	-3194	-10320
DP	-4719	782	-1950
US	-1206	50577	18836
ND	-738	8673	4204
FO	-23367	23732	8215
MJ	-16340	15593	-2886

Table 9. Constant flow projected under and over registry at 2 million gallons of throughput

	Constant Flow with 2 Million Gallons of Throughput		
Meter Type	Min	Max	Average
SJ	-64363	-15687	-39010
MA	-22158	-7140	-14911
DP	5544	10695	7677
US	-29833	33792	4516
ND	2402	15210	8597
FO	17917	63176	44658
MJ	-27595	2439	-13824

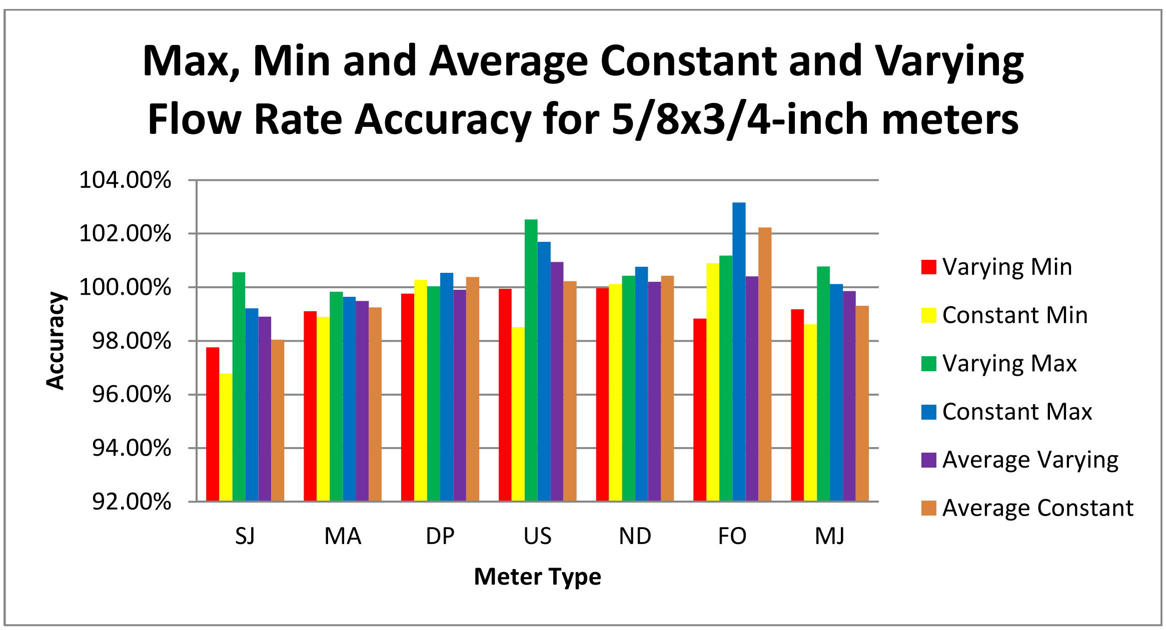

Figure 25. Maximum, minimum and average constant and varying flow rate accuracies

Table 10. Comparison of meters in new condition to flow profile accuracy for 5/8x3/4-inch meters

Percent Difference from New Condition				
Flow Profile	Type	Low	Intermediate	High
	DP			
New Condition		98.41%	100.38%	99.54%
Varying		99.90%	99.90%	99.90%
Constant		100.38%	100.38%	100.38%
Percent Difference				
Varying		-1.49%	0.48%	-0.37%
Constant		-1.97%	0.00%	-0.85%
	ND			
New Condition		100.14%	101.09%	99.65%
Varying		100.21%	100.21%	100.21%
Constant		100.43%	100.43%	100.43%
Percent Difference				
Varying		-0.07%	0.88%	-0.56%
Constant		-0.29%	0.66%	-0.78%
	MJ			
New Condition		100.19%	99.84%	100.16%
Varying		99.86%	99.86%	99.86%
Constant		99.31%	99.31%	99.31%
Percent Difference				
Varying		0.33%	-0.01%	0.31%
Constant		0.88%	0.54%	0.85%
	SJ			
New Condition		99.64%	98.74%	101.17%
Varying		98.91%	98.91%	98.91%
Constant		98.05%	98.05%	98.05%
Percent Difference				
Varying		0.73%	-0.16%	2.27%
Constant		1.59%	0.70%	3.12%
	FO			
New Condition		97.74%	100.48%	100.34%
Varying		100.41%	100.41%	100.41%
Constant		102.23%	102.23%	102.23%
Percent Difference		-2.67%	0.07%	-0.07%
		-4.49%	-1.76%	-1.90%
	MA			
New Condition		99.66%	99.46%	99.31%
Varying		99.48%	99.48%	99.48%
Constant		99.25%	99.25%	99.25%
Percent Difference				
Varying		0.17%	-0.02%	-0.17%
Constant		0.40%	0.21%	0.06%
	US			
New Condition		100.61%	99.60%	100.33%
Varying		100.94%	100.94%	100.94%
Constant		100.23%	100.23%	100.23%
Percent Difference				
Varying		-0.33%	-1.34%	-0.61%
Constant		0.38%	-0.63%	0.11%

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Meter accuracy is becoming extremely important as usable water becomes scarce. Meters tested in their new condition are normally performed under ideal conditions, yet when the meter is installed in the field it is sometimes subjected to non-ideal conditions that exist within the distribution system. These conditions can affect meter accuracy and increase meter degradation rate. This research evaluated the accuracy results of meter tests under how meter accuracy differs under multiple conditions that can exist in a distribution system. An understanding of how meter accuracy differs under multiple conditions can help utilities choose the meter that best fits the conditions that exist in their distribution system.

Endurance testing revealed which meter types and manufacturers were more susceptible to accuracy degradation after large volumes of throughput. It was observed that one manufacturer within a meter type can bring down the average accuracy for that meter type. This was found in the DP and MJ meter types. The meters that showed the least amount of accuracy degradation during endurance testing were the DP and ND meters. These meter types had the highest accuracy after 10 MG of throughput.

Installation testing exposed the meter types that were most affected by non-ideal installation conditions as well as the way that the meter is mounted. Since there are many conditions that can exist in a distribution system only a few were chosen to be tested. MJ, ND, and SJ meter types were affected when the meter was installed vertically, but the MJ meter type was the most affected, dropping its registry accuracy to 45%. The MJ meters were also affected when the meter was mounted at either 45 or 90 degrees with the accuracy dropping to 50% at the AWWA low flow standard.

Flow profile testing also revealed the meter types that were most susceptible to varying flow rates, thereby affecting the meter's ability to register the correct volume of throughput. The meter type that registered the lowest amount of throughput volume at the conclusion of the flow profile testing was the SJ type and the meter that registered the highest amount of throughput volume was the FO type. When projecting the under- and over-registry with the data, it was calculated that the SJ would under-register approximately 64,000 gallons at a throughput of 2 million gallons and FO would over-register approximately 63,000 gallons at 2 million gallons of throughput. DP and ND meters varied the least from the actual volume that passed through the meters at approximately 10,000 and 15,000 gallons, respectively.

Looking at all of the test results as a whole, the meter types that were the most accurate at all three test conditions were the displacement meters, (DP and ND). These meters had the lowest degradation rate in the endurance testing, they were the least affected by installation, and were the closest to actual throughput with varying flow.

It is recommended that there be additional testing where vibrations and induced pressure surges are present to determine the effects these conditions have on meter accuracy. To better understand how the newer meter types like the US and the MA meters perform, additional testing is also suggested.

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APPENDIX

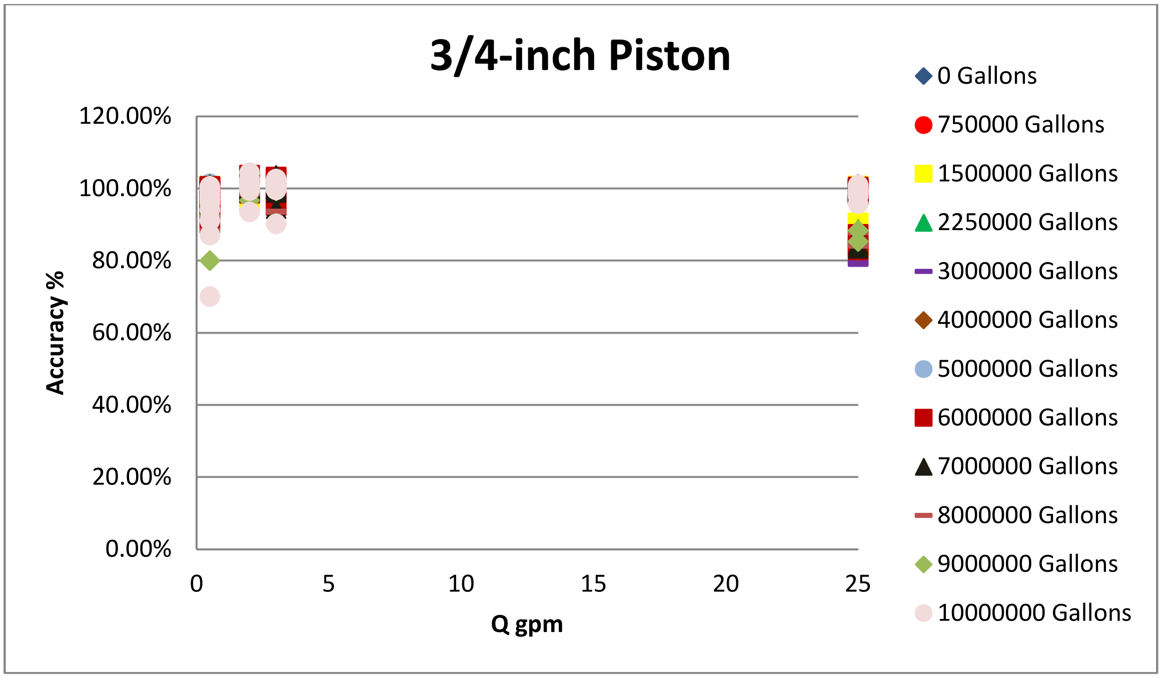

Figure 26. Endurance accuracy testing result at various level of throughput for displacement piston at 0.5, 2, 3 and 25 gpm

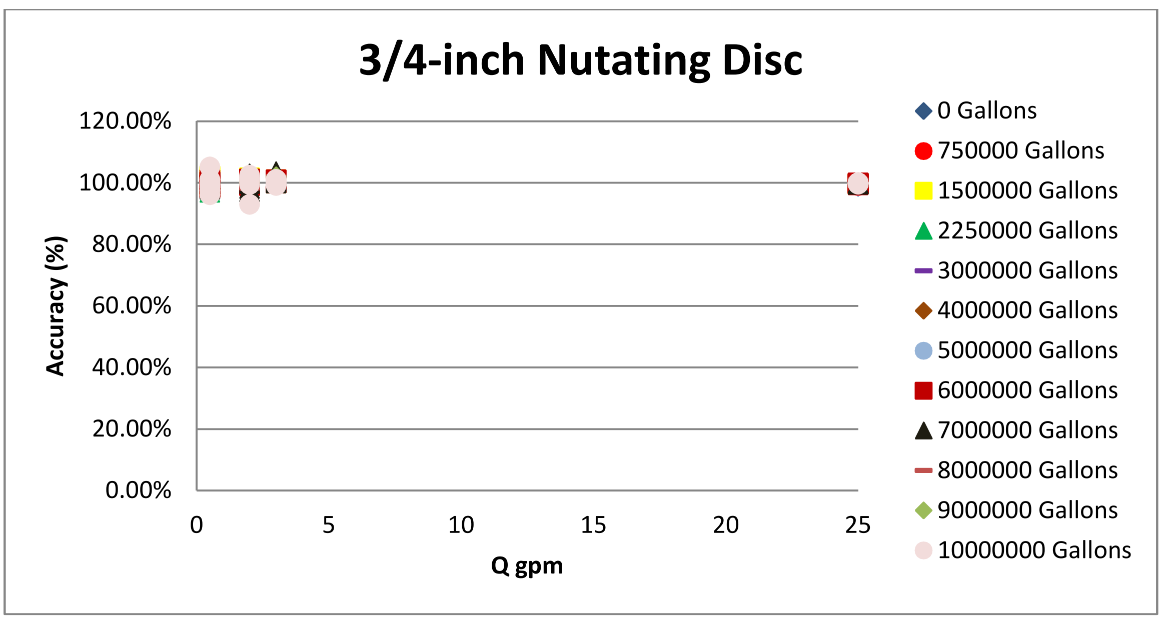

Figure 27. Endurance accuracy testing result at various level of throughput for nutating disc at 0.5, 2, 3 and 25 gpm

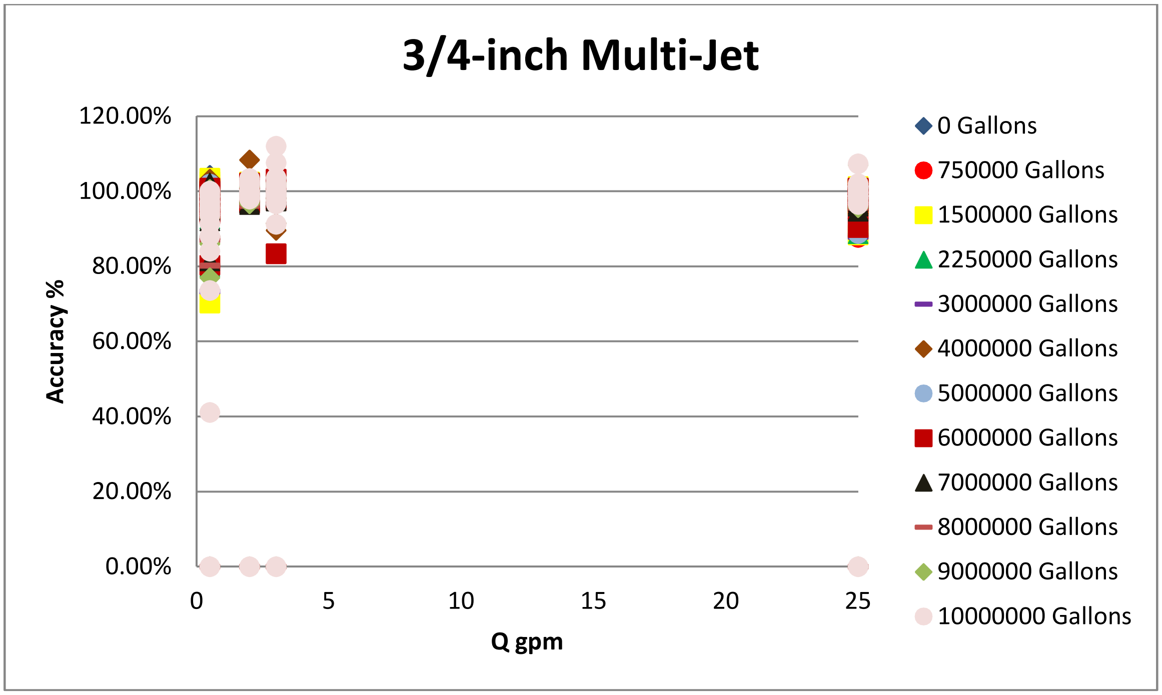

Figure 28. Endurance accuracy testing result at various levels of throughput for multi-jet at 0.5, 2, 3 and 25 gpm

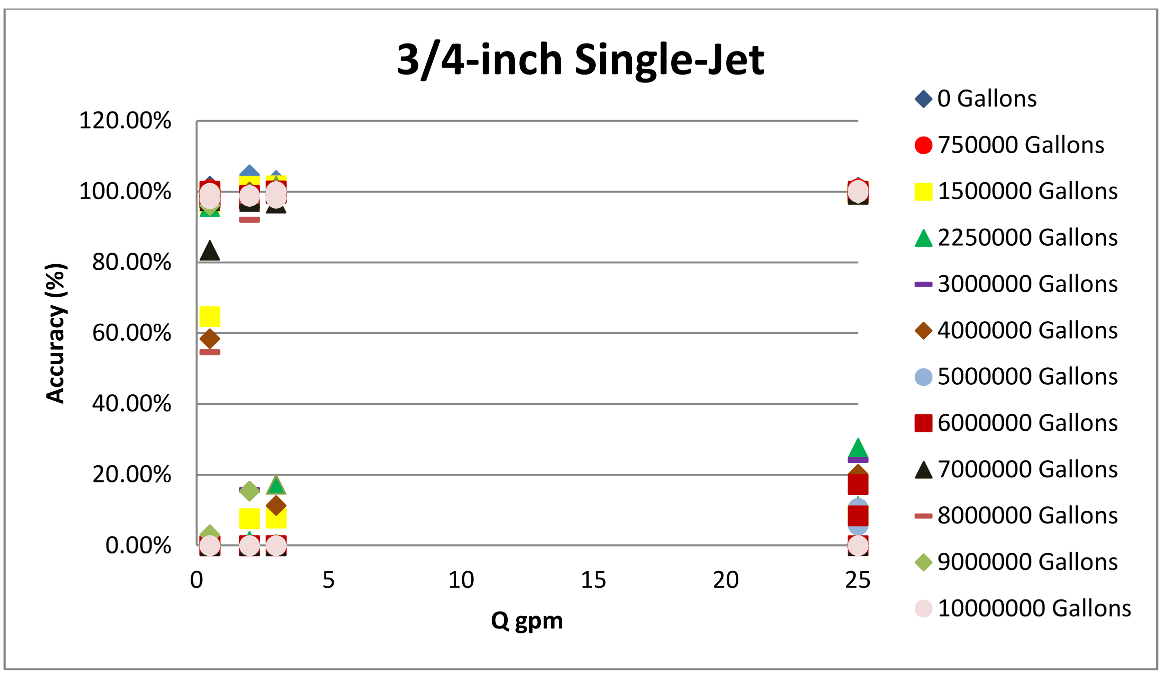

Figure 29. Endurance accuracy testing result at various levels of throughput for single-jet at 0.5, 2, 3 and 25 gpm

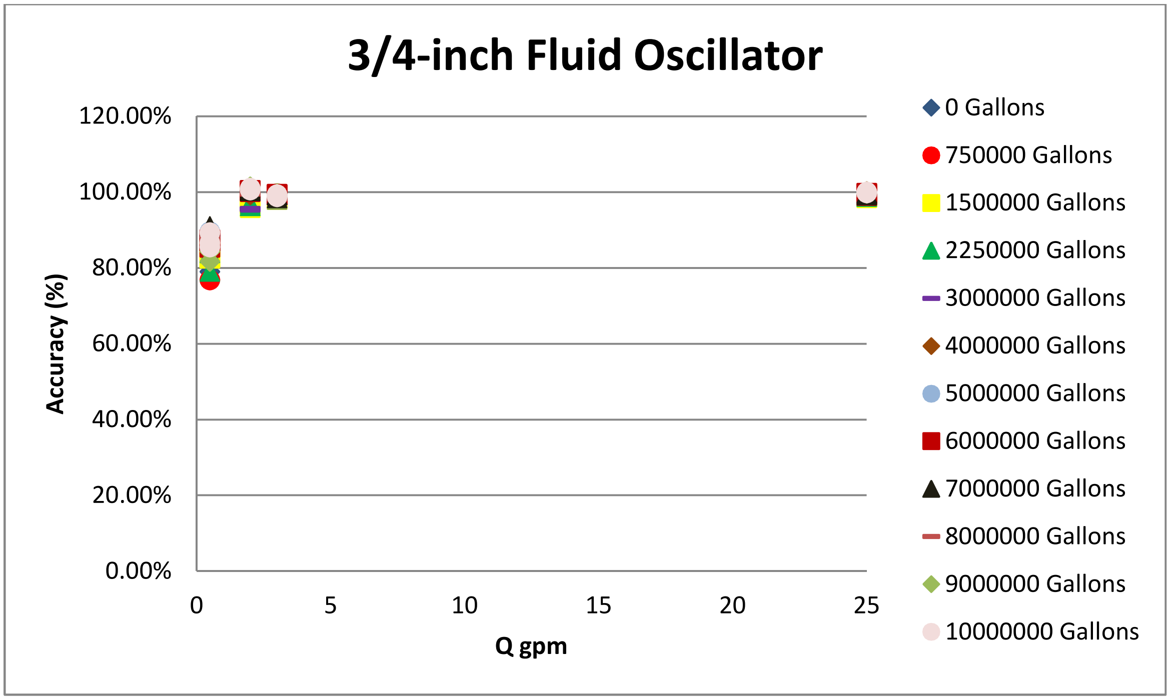

Figure 30. Endurance accuracy testing result at various levels of throughput for fluid oscillator at 0.5, 2, 3 and 25 gpm

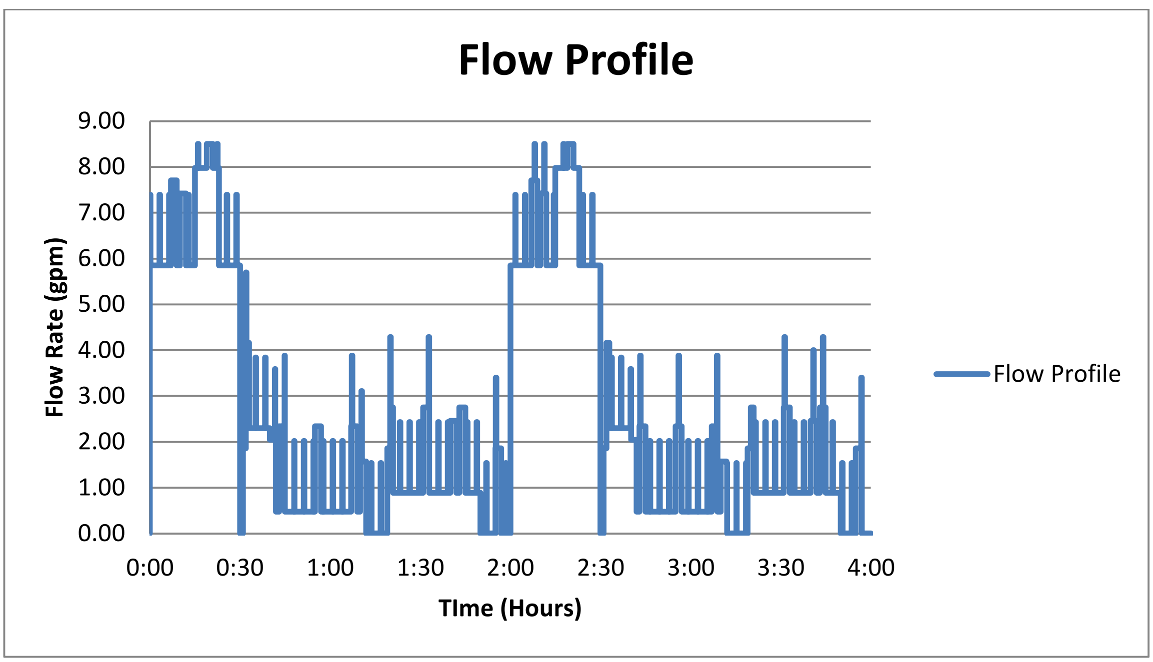

Figure 31. 4-Hour flow profile