American Water Works Association

The Authoritative Resource on Safe Water[SM]

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California Energy Commission
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California Energy Commission
Dockets Unit
Docket # 12-AAER-2C
1516 Ninth Street, MS-29
Sacramento, CA 95814-5512

RE: Docket # 12-AAER-2C, Water Meters

Dear Commissioners:

The American Water Work Association (AWWA) is responding to your June 13, 2013 *Invitation to Submit Proposals, for Water Appliances*. AWWA shares the Commission's interests in power and water efficiency. As a 501(c)3 technical and educational association AWWA plays an active role in providing education and training materials for water systems on ways to promote efficient water use. AWWA's efforts to promote efficient use of water are long standing and reflect a broad array of activities in keeping with the association's statement of policy on water use efficiency.

AWWA's commitment to accurate metering and accountability is also long standing. AWWA's interest in sound meter design has led AWWA to take responsibility for establishing American National Standards Institute (ANSI) accredited standards for water meters in the United States. AWWA takes on this task through an open and transparent process to which representatives from the CEC and other interested stakeholder perspectives as well as manufacturers and users are welcome and encouraged to participate. As an ANSI accredited standard body AWWA has a responsibility to not only provide an open and balanced process, but also to regularly review and up-date meter standards.

Water meters are an essential component of a well-run water system. The design of these devices must be accurate, perform reliably under field conditions, and assure dependability while also allowing sufficient flexibility that innovation and improvement can occur. It is out of AWWA's commitment to sound meter performance criteria that the following comments are offered. It is important to recognize that:

1. Water meters are not appliances, and their operations do not result in consumption of water by consumers.

2. Water systems are interested in accurate metering of water over the full range of water flows through a water meter, including low-flow both to conserve water as a valuable resource and to ensure customer accountability for the water used.

3. **The Natural Resources Defense Council (NRDC) is represented on a task group formed as part of the ANSI/AWWA standards process to evaluate modifying current low-flow performance criteria for water meters. CEC staff is welcome to join the task group.** The ANSI accredited AWWA standards process is a technically sound and transparent process; it is the most appropriate process for setting performance standards for water meters. Where the application of water meter standards is appropriate, AWWA recommends the use of ANSI/AWWA water meter standards. For metering technologies that are not yet covered by such standards, AWWA recommends that accuracy requirements for such devices be comparable to those for existing ANSI/AWWA standards.

4. There are a number of technical considerations that must be addressed before adoption of additional, extended low-flow performance requirements beyond the minimum flow test requirements of existing ANSI/AWWA meter standards are adopted.

<u>Water Meters as Appliances</u>

Title 20 of the California Code of Regulations (Chapter 4, Article 4) provides regulations that comprehensively regulate appliances within the jurisdiction of the CEC, as granted by the Warren-Alquist Act. “Water meters” are not addressed in that Chapter, and are not appliances. The Code specifically defines “water use” with reference to the quantity of water flowing through devices including “showerheads”, “faucets”, “water closets”, and “urinals”. Accordingly, water meter accuracy standards are beyond the scope of rulemaking authority for energy- and water-efficient appliances, and the CEC does not have the jurisdiction to undertake rulemaking of water meters.

Water meters are not appliances. Their operation does not result in the specific end-use consumption of water by the consumer. Such consumption is, instead, the direct result of the operation of appliances downstream of any metering device that may be employed. The operation of water meters does not drive the use of water (or energy).

Accuracy in Metering

AWWA recognizes that the accurate metering of water improves efficiency in the operation of water utilities, and provides equity in the billing of end-users for their water consumption. Where the application of water meter standards is appropriate, the AWWA recommends the use of ANSI/AWWA water meter standards. Specific standards requirements for meter accuracies can be found in ANSI/AWWA Standards C700, C701, C702, C703, C704, C708, C710, C712 and C713. Note that these standards provide much better metrological definition (and, in most cases, tighter accuracy requirements) than what was recommended in the *California 20x2020 Water Conservation Plan* issued in February 2010. ANSI/AWWA standards represent the consensus of the water supply industry. ANSI/AWWA standards committees are composed of subject matter experts from a broad range of interests, including water utilities, manufacturers, academia, and general interest groups who are directly and materially affected by the standard. AWWA is a standards developer accredited by ANSI, which enforces AWWA's strict adherence to the ANSI principles of due process, openness, lack of dominance, and balance. Furthermore, the AWWA standards committee must consider all comments received during the mandatory 45-day public review period. ANSI promotes the development of voluntary consensus standards that are relied upon by industry, government agencies, and consumers across the United States and around the world.

ANSI/AWWA meter standards do not, at present, cover solid-state metering technologies other than fluidic oscillators. AWWA committee work is underway on standards provisions for other solid state metering technologies. This standard writing activity is based -- in part -- on reports from multiple U.S. utilities regarding their successful use of such meters. AWWA does not discourage utilities from using metering technologies beyond the scope of current AWWA standards. AWWA recommends that accuracy requirements employed, when using these technologies, be comparable to those in ANSI/AWWA meter standards.

ANSI/AWWA Standard Setting Process

NRDC and California Investor-Owned Electric Utilities (IOUs) recently proposed modifying current ANSI/AWWA meter standards – by incorporating additional, extended low-flow ('leak-detect') accuracy requirements – in order to create additional financial incentives for homeowners to correct leaks downstream of the meter. The AWWA Standards Committee on Water Meters has established a task group to address the NRDC proposal. NRDC is represented on the task group. CEC staff is welcome to join the task group. Joining the task group would provide the Commission a clear window into the voluntary standards process for water meters. It would also help the Commission obtain a complete understanding of the entire sweep of considerations important to sound water meter design.

<u>Technical Considerations</u>

There are several issues to consider when evaluating the information submitted by NRDC and by the California electric-IOUs in support of their proposed meter standards provisions:

1. The Accuracy of In-Service Water Meters at Low and High Flow Rates Study performed by Utah State University (Water Research Foundation Project #4028) was referenced, as demonstrating the fact that multiple mechanical meter technologies could comply with extended low-flow performance requirements. The Utah State University study was quite large, reflecting testing of almost 450 new meters. The study goal was to be comprehensive so it included eight types of water meter within a range of five different meter sizes and reflected production by 15 different manufacturers. The study also included almost 600 used meters of various ages, to explore the effect of age in the study. So, while there is a large amount of data collected through this one study, the information available about any one sub-group of meters must be evaluated carefully. In the judgment of professionals with expertise in evaluating water meter performance this study is a valuable contribution to the field but alone does not provide a sufficient basis for setting new meter standards.

   It is also worthwhile to note that the report was prepared in 2011 and reflects a cross-section of new water meters that were available to researchers several years prior from the participating vendors. Information is not available on a number of other product lines. Perhaps most importantly, the study authors drew a number of conclusions and recommendations, and the authors themselves did not come to the conclusion that their study alone would be sufficient basis for modifying industry standards nor did they recommend that one aspect of meter performance - efficiency at low flows - was more important than other aspects of meter design. Rather, the study authors provided a balanced appraisal of a number of factors so that water system professionals could make informed choices regarding when one meter type was more appropriate than another. The study recommendations are substantially different from the proposal by NRDC and California electric-IOUs for extended low-flow performance brought before the CEC. The NRDC/California electric-IOUs recommendations would set a performance standard for perhaps four-or-more types of mechanical-type water meters when the Utah State Study data may demonstrate compliance by, at most, one of these water meter technologies.

2. In a point raised by Badger Meter, and by CEC staff during the 31 May workshop on water appliances (see pages 126 and 127 of the transcript), a postulated increase in meter performance requirements does not directly lead to a calculable decrease in water loss through the correction of leaks. This reinforces the distinct difference between a water appliance and a water meter--only for the former can one calculate a direct water savings, based upon a change in performance. Similarly, Badger Meter has noted that the Aquacraft 2011 California study (referenced in the California electric-IOUs submittal to the CEC) includes numerous examples of existing meters already indicating on-going flows in the 'leak-detect' flow ranges covered by the NRDC and California electric-IOUs proposals (see pages 146-148 of the Aquacraft report, for examples). In these instances, the homeowners have clearly taken no steps to eliminate these leak-type flows. In the May 31, 2013 CEC workshop, Forest Kaser of Energy Solutions (author of the California electric-IOUs submittal), stated that a *Journal AWWA* article provides methodologies for calculating water savings based upon improvements in meter performance at lower flow rates. However, the *Journal AWWA* article from May 2010 (see attached), provides methodologies for calculating increases in registered volumes of flow, based upon models for residential consumption patterns and/or leak flow rate distributions, but does not provide methodologies for calculating decreases in actual water consumption/loss. The reduced losses referred to in this article relate to lost accountability or revenues, not to the physical elimination of leaks.

3. The Aquacraft study has been used to project the amount of water being lost through leaks downstream of the meter. However, the authors are careful to note that some of the 'leak-like' flows reported may actually be due to deliberate water usage, from appliances operating at very low-flow rates (see discussions on pages 26, 27, 73, and 148 of the Aquacraft report, for examples). Increased meter registration in these cases may lead to better accountability, but would not reduce leakage losses (since there are no leaks).

4. From the May 31, 2013 CEC workshop, it is clear that there would be added costs in extended low-flow accuracy performance requirements:

    a. Increased testing costs for water meters - Direct meter accuracy test times and test stand capabilities would have to be increased. For an example of specific impacts, note that the NRDC submittal to AWWA gives an additional 80-minute test flow for ¾" meters (beyond the existing three test flows listed in AWWA M-6, which represent cumulative test times of 27.33 minutes at present). Added test times would be even more onerous for 5/8" meters, for which the same types of calculations would result in an additional 160-minute test flow.

b. The risk mechanical meters would be more susceptible to damage in the field (with attendant increases in field repair and/or meter replacement costs), if their operating tolerances were to be reduced in order to meet additional accuracy requirements at extended low flows.

5. There are challenges in developing a sound cost-benefit analysis with respect to true water losses, in imposing extended low-flow accuracy requirements on water meters. For example, are leaks upstream of the meters more significant, and/or would fixing these 'upstream' leaks provide a better return on investment, versus leaks downstream of the meters?

   While limited in scope, there is on-going research being conducted by Johnson Controls, Inc. that may speak to the relative impact that could be provided by extended low-flow accuracy meter capabilities. See attached report update "*Comparing the Performance of Static Water Meters to Positive Displacement Water Meters in Residential Services*", by Craig Hannah. This study uses 'tandem' metering at 39 residences in three cities. At each site, a solid-state meter has been plumbed in series with a new mechanical meter. Testing shows that the solid-state meters have much better accuracies than the mechanical meters at leak-like flows of roughly 0.06 gpm or lower. Yet, with almost three years in service for some of the units, and less than one year in service for the other units, the 'global' advantage in registered through-put has only been 62,513 gallons (or less than 2%) for the solid state water meters (e.g., meters that do not rely on a mechanical mechanism to determine the volume of water passing through the meter). Possible explanations for this might include: (a) That the 39 study sites have minimal losses from leaks; or (b) that any leaks at these sites are actually at higher flow rates, where the mechanical meters have accuracies comparable to those of the solid state meters.

AWWA greatly appreciates the CEC seeking input from stakeholders prior to initiating a formal rulemaking. If you have any questions regarding AWWA's comments, ANSI/AWWA water meter standards, or the ANSI/AWWA standards process please contact Frank Kurtz at (303) 347-6221.

Sincerely,

Thomas W. Curtis
AWWA Deputy Executive Director

cc: Tuan Ngo, Appliances and Process Energy Office, CEC
John Nuffer, Appliances and Process Energy Office, CEC
Tim Worley, California-Nevada American Water Works Association

Attachments (2)

About the American Water Works Association

The American Water Works Association (AWWA) is an international, nonprofit, scientific and educational society dedicated to providing total water solutions assuring the effective management of water. Founded in 1881, the Association is the largest organization of water supply professionals in the world. Our membership includes more than 4,000 utilities that supply roughly 80 percent of the nation's drinking water and treat almost half of the nation's wastewater. Our 50,000-plus total membership represents the full spectrum of the water community: public water and wastewater systems, environmental advocates, scientists, academicians, and others who hold a genuine interest in water, our most important resource. AWWA unites the diverse water community to advance public health, safety, the economy, and the environment.

Attachment1. Richards, G.L., M.C. Johnson, S.L. Barfuss. *Apparent losses caused by water meter inaccuracies at ultralow flows*. Journal AWWA 102(5): 123 – 132. May 2010.

GREGORY L. RICHARDS, MICHAEL C. JOHNSON, AND STEVEN L. BARFUSS

Apparent losses caused by water meter inaccuracies at ultralow flows

TWO DIFFERENT APPROACHES TO QUANTIFYING REVENUE LOSS ARE USED TO HIGHLIGHT THE EFFECTS OF METER INACCURACY AT LOW FLOW RATES AND THEIR CONSEQUENCES FOR A UTILITY'S BOTTOM LINE.

Reduction of nonrevenue water use is currently a common goal for most water distribution systems. Nonrevenue water consists of water lost either through real losses (e.g., underground leakage) or through apparent losses (e.g., metering inaccuracies and unauthorized use). Reducing the apparent losses caused by meter inaccuracies at low flows can result in substantial short-term increases in utility revenue and lead to increasingly equitable service charges for water users in the long term.

This article describes two methods for estimating apparent losses caused by meter inaccuracies that should help municipal utilities better understand the consequences of meter accuracy at low flow rates. The authors also provide the average low-flow accuracies of several meter types, should current system information be incomplete or unavailable. These accuracy data were obtained as part of the Water Research Foundation project Accuracy of In-Service Water Meters at Low and High Flow Rates, which is investigating the accuracies of water meters at flow rates below the AWWA minimum flow rate standard. These data facilitate comparison of current in-service meters with different meter types. In light of the prospect of increased utility revenue and ability to account for water supplies, low-flow accuracy of residential water meters represents a key consideration for utilities in selecting a water meter.

VARIOUS FACTORS CONTRIBUTE TO METER ACCURACY

Because the loss of revenue attributable to apparent losses can account for between 0.5% and 5% of a utility's total revenue (AWWA, 2009a), accuracy of customer water meters may significantly influence revenues. Most water meters tend to record less water than what actually passes through the meter, which corresponds to a revenue loss for the utility. However, it is also possible for a meter to register inaccurately high volumes of water, thereby overcharging customers. The accuracy of a system's water meters ensures equitable charges for consumers as well as complete revenues for the utility.

Meter accuracy across the entire range of expected flows is important. Although the proper sizing of a water meter is essential to an accurate registration of water consumption, even properly sized meters show registration errors because of mechanical or electronic limitations. Standard meters have the best accuracy at mid- to high-range flows. It is generally understood that meter accuracy at low flow rates tends to decrease rapidly (Bowen et al, 1991; Noss et al, 1987; Tao, 1982). Because energy transfer from the water to the meter's sensing element is small at lower flows, any increase in friction can cause slowing or even the complete stop of a meter's registration (Arregui et al, 2005).

The volume of water used at these very low flow rates is larger than many water providers realize. In fact, approximately 16% of all domestic water consumption occurs at flow rates < 1 gpm (Noss et al, 1987; Hudson, 1978). Much of this volume may actually be attributable to leaks in water-using appliances such as leaky toilets and dripping faucets, or it could even result from small leaks in underground piping on the downstream side of the meter (AWWA, 2009a). Typically, these types of leaks continue for extended durations. Despite their low flow rate, these volumes of water do accumulate and correspond to substantial annual revenue losses if they are not accounted for by a meter.

Apparent losses are often attributed to faulty, improperly sized, or misread meters. Although all of these factors contribute to apparent water loss, the selection of meter type should not be overlooked, especially for larger meters (AWWA, 2009a). There are numerous types of meters including single-jet, multijet, piston, and nutating-disk meters. No standard meter will register 100% of consumption at very low flow rates, but some types have proven to operate more accurately than others. A meter's ability to register low flows accurately should be an important consideration in the selection of a meter type for either a meter replacement program or an initial installation.

Another important consideration in water meter selection is the quality of water in the distribution system because some meters are better suited for passing particulates without being damaged. Additionally, some meters are more susceptible to damage or overregistration because of air in the distribution system. For the purposes of this article, however, only meter accuracy for pristine water was considered.

PAST EFFORTS ESTABLISHED STANDARDS AND SURVEYED METER PERFORMANCE

AWWA has issued accuracy standards for most types of water meters. AWWA standards are the result of many considerations including revenue loss to a utility, overcharging of water users, and the feasibility of manufacturing an economical meter that falls within the specified accuracy range (AWWA, 1999). The standards vary according to meter design and size. For example, in order for a new or rebuilt positive displacement meter to meet the minimum flow rate accuracy standard, it must register between 95 and 101% of the actual test volume. For a multijet meter, the accuracy range is 97 to 103%. A class 1 turbine meter is required to register between 98 and 102% at the minimum flow. For repaired water meters, the minimum accuracy limit is consistently 90%.

The longer a water meter is in use, the more it degrades. This degradation typically causes a downward shift in a meter's accuracy curve. For this reason, AWWA recommends testing of in-service meters. According to association guidelines, an in-service meter that does not meet the accuracy limits shown in Table 1 should be repaired or replaced. The lower limit of 80% accuracy at minimum test flow rates is important because it essentially concludes that meters registering below this limit are losing substantial amounts of revenue for the utility.

AWWA standards do not require any degree of meter accuracy below the minimum test flow rate. However, it can be assumed that a meter functioning within the accuracy limits at that low flow rate will continue to register at least some percentage of the flow at even lower rates. The accuracy curves of most water meters do not jump abruptly from 90% registry to zero at low flows, but rather the accuracy drops off slowly to levels as low as 50% before stopping completely. The following meter test data provide a better understanding of meter accuracy below the minimum flow threshold set by AWWA.

Residential water meter performance was evaluated in a 1991 report. The report Evaluating Residential Water Meter Performance investigated the accuracy of ⅝- × ¾-in. piston and nutating-disk water meters (Bowen et al, 1991). During initial testing, the average of test results was well within AWWA accuracy standards for flow rates down to 0.25 gpm. At 0.25 gpm, the meters averaged

TABLE 1 Required accuracy limits for compliance with AWWA replacement guidelines

Meter Type (All Sizes)	Accuracy Limits as Found by Testing—%: Normal Test Flow Rates	Minimum Test Flow Rates
Displacement	96–102	80–102
Multijet	96–102	80–104
Propeller and turbine	96–103	Not applicable
Compound and fire service	95–104	Not applicable

Source: AWWA, 1999

99.3% registry of the actual test volume. At 0.125 gpm, the meters showed a slight decrease with an average registry of 94.3%. The accuracy drop continued at 0.0625 gpm with an average accuracy of 82.8%.

Although the 1991 study examined meter accuracies below the AWWA minimum flow rate standard, it did not examine the full extent of the meter accuracy curve. The accuracy of a meter below the 0.0625-gpm mark could be important in determining revenue losses caused by meter inaccuracies. Although the study contributed to an understanding of the performance of piston and nutating-disk meters, it did not address other available meter types such as the single-jet or multijet meters.

A 2003 study focused on low- and ultralow-flow meter accuracy. In 2003, the South Central Connecticut Regional Water Authority of New Haven, Conn., conducted a study on the accuracy of various types of residential meters at low and ultralow flows (Lakin, 2003). The study closely followed the objectives of this article in that it focused on the accuracy of meters at very low flow rates as well as the effect of these accuracies on revenues. Nutating-disk, piston, propeller, and fluidic oscillator meters of the ⅝-in. size were included in the study. One limitation of the study was the small number of meters tested (two of each meter model). As stated in the report, a greater number of meters as well as larger volumes and run times would ensure statistically reliable results.

All meters in the Connecticut study were tested from the AWWA minimum flow rate of 0.25 gpm down to 0.0078 gpm. The nutating-disk meters demonstrated the greatest accuracy over the range of flows that were tested. The piston- and propeller-type meters performed at accuracies > 80% for flows ≥ 0.0312 gpm. The fluidic oscillator meter's average accuracy dropped off rapidly at flows below the 0.25-gpm mark and then registered sporadic amounts at very low flows.

Many sizes and types of meters were tested as part of an ongoing Water Research Foundation project investigating the accuracy of water meters at various flow rates.

WATER RESEARCH FOUNDATION IS CURRENTLY TESTING METERS

Ongoing study has several objectives. The accuracies of water meters at flow rates below the AWWA minimum flow rate standard are being investigated at the Utah Water Research Laboratory (UWRL) in Logan as part of an ongoing project funded by the Water Research Foundation. The intent of the study is to determine whether the currently available technology for meters can accurately measure well below 0.25 gpm and above 30 gpm in both new and aged conditions. The influence of particulates on meter accuracy is also being investigated. A complete survey of meter types, brands, and models was conducted before the start of testing, and a selection of oscillating-piston, nutating-disk, multijet, single-jet, turbine, and fluidic oscillator meters was obtained (see sidebar on page 126). In all, 381 water meters of different types and sizes were included in the study (Table 2). This article presents the average new meter accuracy of each meter size and type for low flows. Additional results will be forthcoming as particulate testing is completed and additional data are available.

Steps were taken to minimize uncertainty and error. As the testing conducted by the South Central Connecticut Regional Water Authority made clear, in order for meter tests to be statistically significant, a sufficiently large sample of meters must be used. The current study included at least six meters of each tested model (for 1-in. meters and smaller). Because of budgetary constraints, only one meter of each model was tested for the 1.5-in. and 2-in. sizes. Therefore results provided for the 1.5-in. and 2-in. meters are less significant and should be considered accordingly.

For this project, the primary component of quality control was to ensure that flow measurement uncertainty was minimized during laboratory tests. To accomplish this, flow test durations and volumes were consistently regulated. In addition, multiple individuals checked meter readings and data entry. The calibration of weight tanks, timers, master meters, and thermometers was also

Summary of Selected Meter Types

The following summary of selected meter types is adapted from Neilsen et al (2009).

Multijet meters are inferential-type meters, which means that the velocity of water passing through the meter has a linear relationship with the rotational speed of the rotor. Flow is separated by an outer casing around the rotor, which causes several streams to make contact with the rotor from multiple directions. Multijet meters typically are more resistant to wear caused by particulates in the water.

Single-jet meters are also inferential type meters, and like the multijet meter, the single-jet type assumes that velocity of the water passing through the meter has a linear relationship with the rotational speed of the rotor. A single jet of water is formed, which turns the rotor accordingly. Single-jet meters typically are more resistant to wear caused by both particulates and small inline debris.

The fluidic oscillator meter is a method of measuring flow that is relatively new to AWWA Standards. Unlike most other residential meters, which use mechanical devices for flow registration, the fluidic oscillator uses a battery-powered transducer element that measures the oscillations the fluid makes as it passes through the meter. The number of oscillations is proportional to the flow.

The nutating-disk meter uses a volumetric method for measuring flow. In this type of meter, water enters the meter and rotates a disk as it passes through the metering chamber. This causes the meter shaft to make a circular pattern that rotates a magnet coupled to the meter's register. Because the nutating-disk meter relies on volumes instead of inferring a velocity, it tends to be more accurate at low flows. However, the meter is more susceptible to wear from particulates in the water.

The oscillating-piston meter also uses a volumetric method for measuring flow. Water enters the meter chamber and causes the piston to rotate around a center hub. Piston meters are also susceptible to wear and grooving caused by small particulates in the water.

The turbine meter is similar to the single-jet meter in that it is an inferential meter. However, instead of the rotor being normal to the flow, the turbine is placed with its axis parallel to the flow. Angled blades on the rotor create the rotation that corresponds to the water velocity. Turbine meters are generally resistant to debris and are commonly used in irrigation applications.

regularly inspected and tested. Obtaining a random sampling of meters was essential for a precise representation of meter accuracies. To ensure that no specially prepared meters were received from manufacturers, all meters were purchased through standard meter distributors. These and other measures helped ensure the accuracy and validity of study results.

Results found accuracy variations for meter type and size. Figure 1 summarizes the average accuracies of the different meter types and sizes. For meters of size ¾ in. and smaller, the nutating-disk meter produced the best performance at low flows. Both nutating-disk and single-jet meters demonstrated approximately the same average accuracy for 1-in. meters. Of the meters that were 1½ or 2 in. in diameter, single-jet meters tended to have the greatest accuracy at low flows.

Although these average accuracies can be helpful in selecting meter types, it should be noted that each meter model and each specific meter performed at a different level. The data provided in Figure 1 represent the averages of all meters tested of a particular size and meter type. These averages comprise many manufacturers and models, and it is important to acknowledge that meter performance changes significantly between meter models. Nutating-disk-type meters tended to have somewhat less deviation than other meter types, and the average accuracy was fairly representative of all models tested. Piston meters, on the other hand, showed much greater variability, with a standard deviation greater than 40% at certain sizes and flows. Additional information about the variability of meter accuracy between models will be included in forthcoming papers and reports. The final project report will be available through the Water Research Foundation after project completion in September 2010.

These accuracy data for new meters are intended to be useful in estimating apparent losses attributable to metering inaccuracies at low flows. However, just as meter model and type influence the average accuracy of a meter, other considerations should be recognized when these data are used. First, the accuracies presented in this article were obtained from newly purchased meters only. Typically, water meter accuracy decreases with use, especially at the lower flows of interest in this study (Arregui et al, 2005). Additionally, the presence of particulates such as sand or pipe scale in a distribution system can increase the rate of meter degradation. Given that new meters were tested in a controlled laboratory setting without particulates or other meter contaminants, these accuracies should be viewed as best-performance scenarios. Systems whose meters are subject to poor water quality or have been in service for several years could assume actual meter accuracy to be much less than the accuracies given here. The meter tests that are currently under way at the UWRL will increase understanding of how accuracy changes or degrades over time and will aid estimates of how much water is actually lost because of meter inaccuracies at low flows.

TWO APPROACHES CAN HELP UTILITIES QUANTIFY WATER LOSS

In 1999, the Residential End Uses of Water Study (REUWS) investigated residential water leaks and found that 13.7% or 21.9 gpd per residence of estimated indoor water use was wasted because of leakage (Mayer et al, 1999). However, the study also concluded that the majority of leakage occurred in a small number of homes. The median leakage rate was only 4.2 gpd per household. As stated in the report, nearly 67% of the study homes leaked 10 gpd or less, but 5.5% leaked more than 100 gpd or about 0.067 gpm. Some portion of this leakage may be registered by a meter, but as shown in the test results previously cited, meter accuracy rapidly degrades at low flows, such as those created by leaks. The amount of water lost because of inaccuracy at low flow rates can vary greatly, depending on meter type and the extent of meter aging. The amount of apparent loss attributable to residential leaks might be greater than 13.7% of indoor use because the study assumed that the water meters used to record water use were 100% accurate. All meters stop registering at some low-flow rate point, so there is inherently some amount of water consumed at low flow rates that passes unregistered through the meter.

The REUWS also made some interesting conclusions about frequency and magnitude of leaks compared with different characteristics of individual users. Households with a larger number of people tended to have an increased amount of leakage, whereas households with more people working outside the home had less leakage. Leaks were also shown to increase according to the number of toilets in the home. The amount of leakage differed according to the marginal price of water and sewer services, meaning that as users were charged more, they voluntarily became more aware of leak detection and correction in their homes (Mayer et al, 1999).

The REUWS grouped all leakage with indoor use even if it occurred outdoors, such as in an irrigation system. As a result, the actual leakage percentage of total water use (indoor and outdoor) may be less than the 13.7% cited. Actual residential leakage rates will differ depending on several factors including climate, average connection age, and average appliance age. Furthermore, because REUWS figures reflected composite data from 12 cities throughout North America (eight of which are not regularly subject to freezing temperatures), the study may not be representative of many North American water systems.

The amount of water loss attributable to a meter's inability to record the flow passing through a dripping faucet may seem minimal, but if that leak continues day and night over the course of an entire year, the volume of water lost can be substantial. For example, if a residence has an appliance that is dripping continuously at a meter threshold of 0.0078 gpm (about 78 drips per min), 11.25 gpd per fixture could be lost to leakage (AWWA, 2009b). If it is assumed that the meters do not register at this

> The accuracy of a system's water meters ensures equitable charges for consumers as well as complete revenues for the utility.

TABLE 2 Number of meters tested of each size and type

Meter Size—*in.*	Meter Type						
	Piston	Fluidic Oscillator	Multijet	Nutating Disk	Single Jet	Turbine	Total
⅝ × ¾	48	6	43	30	24	0	151
¾	30	6	33	18	12	6	105
1	30	0	33	18	6	6	93
1½	3	0	4	3	1	3	14
2	3	0	4	3	2	6	18
Total number of meters tested							381

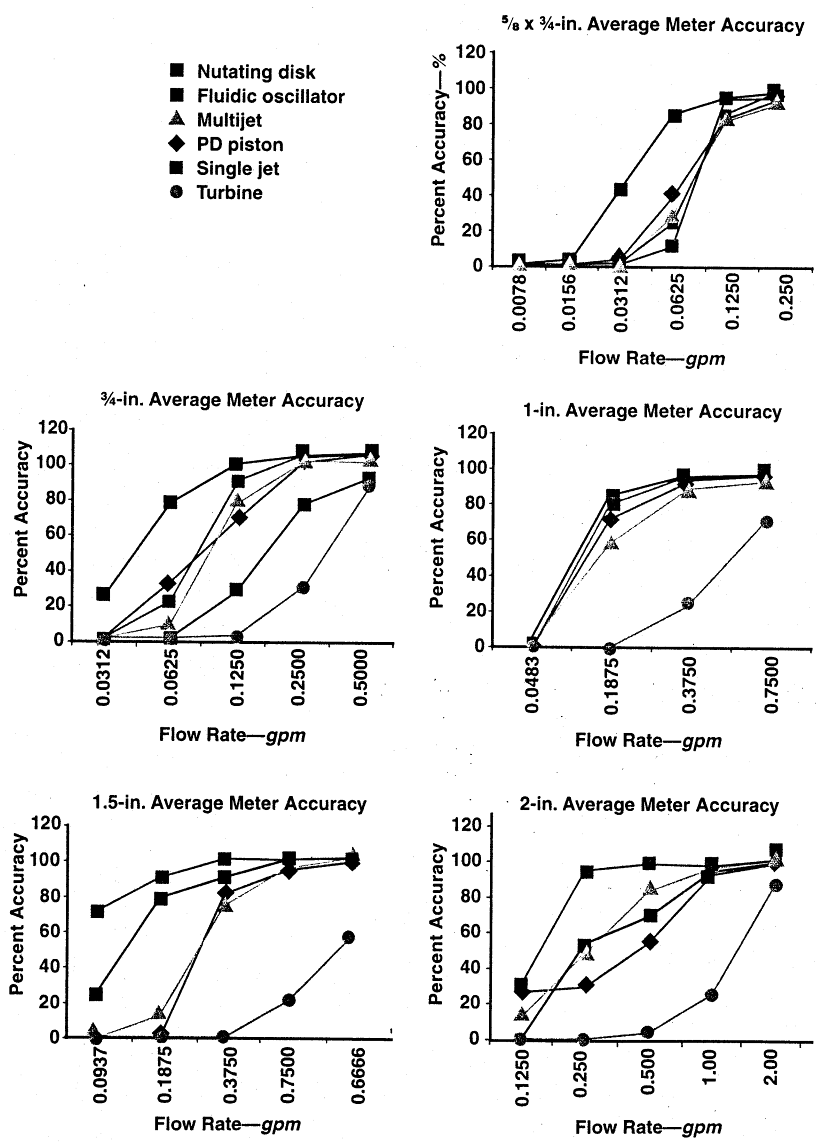
extremely low flow rate and that there are 18,000 leaks flowing at 0.0078 gpm within a city, then 202,500 gpd could be lost. This estimate should be decreased by approximately 10% to 182,250 gpd lost in light of the fact that a meter records some portion of a small continuous leak during the times that larger flows are simultaneously passing through the meter. Annually, this amounts to more than 65 mil gal of lost water and lost revenue of nearly $100,000 (assuming a water rate of $1.50 per 1,000 gal). For the purposes of this article, it is assumed that these higher-consumption flows that allow meters to simultaneously register continuous leaks occur about 10% of the time.

AWWA flow profile method of estimating water loss requires estimating the percentage of water use in different flow ranges. It is apparent that water meter accuracy and residential leakage rates can affect the extent of customer accountability for water consumption. In order to fully appreciate the effect of low-flow accuracy, however, it is necessary to estimate how much water is actually lost because of meter inaccuracy. Although there are numerous ways to estimate these apparent losses, this article addresses only two approaches.

The first approach is similar to that cited by AWWA in the water supply practice manual Water Audits and Loss Control Programs (AWWA, 2009a). This approach requires estimation of the percentage of total water use in different flow ranges as well as the average accuracy of meters in those flow ranges. The estimation of meter accuracy can be determined by testing a representative sample of in-service meters across the desired flow range. If testing is not possible, estimations can be made using manufacturer specification or the generic new meter testing data provided in this article.

Estimating the percentage of total water use in different flow ranges (i.e., the water use profile) is a more challenging problem, especially if only low flows are considered. This is in part because of a lack of public information about water use profiles. Table 3 summarizes the findings of research that compiled water use profiles from several previous studies (Noss et al, 1987). According to this information, an average of about 16% of total water use occurs at flow rates below 1 gpm. Although this percentage will vary from one utility to another, this information does validate concern over low-flow accuracy. Table 4 provides similar data compiled in a more recent study for the state of California (DeOreo et al, 2009). According to that research, about 10% of total water use occurs at flow rates below 1 gpm. In order to use the AWWA methodology to determine apparent losses, however, a flow profile at much smaller increments is necessary. Because this information is not readily available, appropriate esti-

FIGURE 1 Average accuracy of different sizes and types of meters



PD—positive displacement

These accuracy data were obtained as part of the project Accuracy of In-Service Water Meters at Low and High Flow Rates funded by the Water Research Foundation.

mates of the low-flow water use profile must be made. The authors show an example of such estimates in Table 5 using an assumption that 5% of all water consumption occurs at flow rates < 0.5 gpm. It is also necessary to know the total volume of water supplied annually for a system. With this information, Eq 1 can be used to obtain an estimate of apparent loss attributable to meter inaccuracy at low flows:

$$ME = \Sigma V_t \times F_i(1 - 0.01\ R_i) \times (1 - 0.01 \times U_i) \qquad (1)$$

in which ME is the volume of water lost to meter error, V_t is the total volume of water supplied by a system, F_i is the fraction of total consumption over a given flow range, R_i is the percentage of registry over the same flow range (i.e., 95.5%), and U_i is the percentage of time that the meter is registering other flow (i.e., 10%). The sum of this equation for all flow ranges of interest equals the meter error. Although this article focuses strictly on water loss at low flows, Eq 1 can be applied to the full range of flows that a meter would experience.

The public water system of Salt Lake City, Utah, can be used as a simplified example to illustrate this method. The system consists of approximately 92,300 connections and sells approximately 29 bil gal of water annually or about 79 mgd (SLCDPU, 2004). Although a variety of meter types and sizes are used in the system, this simplified example assumes that all meters are ¾-in. piston-type meters. With this information and the assumed meter accuracy provided in Table 5, the total amount of water lost to meter inaccuracy at flows below 0.5 gpm is estimated to be approximately 517 mil gal annually.

Many municipal water systems have had dramatic success in reducing nonrevenue water use by appropriately downsizing targeted meters.

Distribution of quantified leaks method requires estimations regarding leak distribution, meter accuracy, and flow rate. The previously cited study by the South Central Connecticut Regional Water Authority used a different approach to estimate apparent losses attributable to meter inaccuracy at low flows. This approach requires the estimation of the distribution of leaks at various flow rates as well as the accuracy of meters at these flow rates. As in the first method, several assumptions are made in this approach. First, the breakdown percentage of leaks that occur downstream of a residential meter must be estimated. Example assumptions for this distribution can be found in Table 6, which shows a largest occurring leak of 0.5 gpm and a smallest leak of 0.03 gpm. Everything below 0.03 gpm is assumed immeasurable by a ¾-in. meter and therefore an unavoidable loss.

The main assumption is that the larger the leak is, the more likely the end user will repair it. Therefore, only a small percentage of existing leaks are assumed to be 0.5 gpm, whereas the majority of leaks are assumed to correspond to smaller flow rates. Not all of these leaks occur inside a residential home; a large portion of them may occur in buried connection piping or in outdoor irrigation systems. The proportion of connections experiencing some sort of leak downstream of the meter will differ, depending on a system's average connection age and quality of construction. One final assumption is that leakage rates are

TABLE 3 Reported domestic water use profiles by percentage of total flow

Study	Year Published	Percentage of Total Flow in Flow Range: 0–0.25 gpm	0.25–0.5 gpm	0.5–1 gpm	1–2 gpm	2–4 gpm	4–6 gpm	6–10 gpm	> 10 gpm	Total Percentage of Use at Flows < 1 gpm
1	1966	4.60	5.90	(5.90)*	13.70	59.00	(59.00)*	16.80		10.50
2	1958	5.00	6.00	8.00	31.00	40.00†	10.00‡	(10.00)*		19.00
3	1964	13.00	3.40	6.80	13.30	43.00	20.50	(20.50)*		23.20
4	1942	13.60	1.80	5.00	11.80	52.40	14.70	0.70		20.40
5	1969	8.00	(8.00)*	11.00	18.00	39.00	20.00	(20.00)*	4.00	19.00
6	1970	2.59	1.55	10.23	21.93	33.50	19.70	10.50		14.37
7	1969	1.00	4.00	(4.00)*	81.00	(81.00)*	14.00	(14.00)*		5.00

Adapted from Noss et al, 1987

Blanks indicate no data.

*Use of parentheses indicates that the flow ranges are inclusive of amount in previous column.
†This percentage actually represents a flow range of 2–5 gpm.
‡This percentage actually represents a flow range of 5–10 gpm.

constant or that they are occurring continuously over the course of an entire year.

Apparent losses attributable to meter inaccuracy can be determined using Eqs 2 and 3:

$$ME = \Sigma(1 - 0.01 \times R_i) \times (1 - 0.01 \times U_i) \times V_i \quad (2)$$

$$V_i = Q_i \times L_i \times N \times F_N \quad (3)$$

in which ME is the volume of water lost to meter error, R_i is the average meter registry at a given flow rate (i.e., 95.5%), U_i is the percentage of time that the meter is registering other flow (i.e., 10%), V_i is the volume of water consumed annually at a given flow rate, Q_i is the given flow or leakage rate converted to an annual flow (i.e., 0.0625 gpm corresponds to 32,850 gal annually), L_i is the fraction of total leaks occurring at that particular flow rate as shown in Table 6, N is the number of connections served by the system, and F_N is the fraction of system connections that are assumed to have a leak downstream of the meter (i.e., 0.25 corresponds to 25% of system connections having a leak). The sum of Eq 2 for all assumed leakage flow rates equals the meter error. Because these equations rely on estimated leakage rates and amounts, this approach is not recommended for use over the entire range of flows that a meter would experience.

Using the example data in Table 6 and assuming that 25% of homes have some sort of leak, the water lost through meter inaccuracies at leakage flow rates for the Salt Lake City municipal water system is estimated at about 350 mil gal annually. This compares with an estimate of approximately 517 mil gal annually arrived at using the AWWA flow profile method of estimating water loss. The discrepancy largely results from the many uncertainties involved in estimating water use flow profiles and leak-frequency percentages. Furthermore, the estimates were based on test data for brand new meters. Again, given that meter accuracy at low flows can degrade substantially with wear, both of these estimates for water loss may be conservative. Using actual system data—such as in-service water meter accuracies or flow profile information—in these estimations will eliminate assumptions and decrease uncertainties, thereby producing increasingly reliable results.

DETERMINATION OF REVENUE LOSSES HIGHLIGHTS EFFECT OF METER ACCURACY

Because apparent losses attributable to meter inaccuracies correspond to water supplied but not paid for, their value should be calculated at the appropriate rate as charged to the customer. The valuation of these losses becomes increasingly complex if a system uses various rate systems such as increasing and decreasing block structures. Additionally, many municipalities charge sewer fees based on potable water consumption. Potential revenue increases can be found by considering all applicable aspects of the billing regulations (AWWA, 2009a; Hudson, 1978). To simplify this process, a composite rate that estimates the average rate (which could include additional charges such as sewer) can be multiplied by the volume of lost water (ME) to obtain the revenue lost per year because of meter inaccuracies at low flows. In all of these calculations, it is important to maintain consistent units or perform appropriate unit conversions.

Using a composite rate of $1.81 per 1,000 gal for the Salt Lake City system, current annual revenue losses

TABLE 4 Water use profile data obtained from 750 single-family homes in California

Flow Rate Range *gpm*	Timed Flow Through Meters %	Measured Volume Through Meters %
0–0.25	77.90	5.00
0.25–0.50	4.20	2.00
0.50–1	3.10	3.10
1–2	5.70	11.80
2–4	4.90	18.90
4–6	1.70	11.40
6–10	1.30	13.80
> 10	1.20	34.00
Total	100.00	100.00

Adapted from DeOreo et al, 2009

TABLE 5 Example data for ¾-in. meters using AWWA flow profile approach

Flow Rate Range *gpm*	Fraction of Total Consumption	Piston-type Average Meter Accuracy Over Flow Range %	Nutating-disk Average Meter Accuracy Over Flow Range %
0–0.0312	0.0050	0.050	11.00
0.0312–0.0625	0.0075	15.00	47.20
0.0625–0.1250	0.0100	46.50	83.15
0.1250–0.2500	0.0125	79.00	96.15
0.2500–0.5000	0.0150	96.85	99.40

caused by meter inaccuracies at low flow rates are estimated to be $936,000 using the flow profile approach and $633,000 using the quantified leaks approach. It is true that a large portion of this lost revenue is unrecoverable because of mechanical and electronic metering limitations. However, some of this revenue can be recovered by the application of meter-typing techniques.

Many municipal water systems have had dramatic success in reducing nonrevenue water use by appropriately downsizing targeted meters. Similarly, some systems have had success in reducing these losses in large meters by changing meter types (Hannah, 2009). The variations in low-flow accuracy of different meter types as shown in Figure 1 demonstrate the effect that meter selection can have. Actual revenue gains can be estimated by using a different meter type's accuracy in either approach as outlined in Eqs 1 through 3 and then taking the difference between the computed apparent loss or annual revenue loss and that of the existing system condition:

$$ME_{Current} - ME_{Proposed} = \text{Potential recoverable losses} \quad (4)$$

in which $ME_{Current}$ is the estimated volume of water lost to meter error under current system conditions and $ME_{Proposed}$ is the estimated volume of water that would be lost if a new type or model of meter were installed. Potential recoverable losses from the installation of a different meter type can be multiplied by a composite rate to determine recoverable revenue.

The effect of meter type can be illustrated by comparing what would happen if Salt Lake City's municipal water system used 100% nutating-disk meters versus 100% piston meters. If nutating-disk meters were installed, the flow profile method estimates $ME_{Proposed}$ (the amount of water loss attributable to meter error at low flows) to be 278 mil gal annually whereas the leak frequency method estimates that value to be 148 mil gal annually. Under the AWWA flow profile approach, the change in meter type results in an apparent loss reduction of almost 239 mil gal or a revenue recovery of approximately $430,000 annually. The leak frequency method is somewhat more conservative in this case, estimating an apparent loss reduction of 202 mil gal, which corresponds to an increase in annual revenue of approximately $365,000. It is important to note that assumed accuracies and population parameters strongly influenced these estimations, and one method should not be considered more or less conservative for all cases.

TABLE 6 Example data for ¾-in. meters using South Central Connecticut Regional Water Authority leak frequency approach

Leak Flow Rate *gpm*	Fraction of Total Leaks	Piston-type Average Meter Accuracy Over Flow Range %	Nutating-disk Average Meter Accuracy Over Flow Range %
0.0312	0.30	0.10	22.00
0.0625	0.25	29.90	72.40
0.1250	0.20	63.15	93.90
0.2500	0.15	94.80	98.40
0.5000	0.10	98.90	100.40

Although the revenue savings per connection may not economically justify implementation of a residential meter replacement program founded entirely on meter typing and low-flow accuracies, the effect of meter typing should be considered nonetheless. If the type of meter currently used by a system is found to be inappropriate or even less ideal than another, then a reasonable approach may be a gradual transition to the new meter type as meters are routinely replaced or new system connections are made. The initial benefits may seem small, but as shown by the example, a small increase in low-flow accuracy over a large number of connections can make a substantial difference. Additionally, increased meter accuracy will allow for more equitable billing of the consumers. Obviously, other factors such as a meter's durability against particulates or maintained accuracy at higher flow rates over time may hold greater sway in the selection of a meter type appropriate for a system, but low-flow accuracy should still be an important consideration in the decision process.

Reduction of apparent losses caused by meter inaccuracies at low flows can result in substantial increases in revenue for a utility.

CONCLUSION

Reduction of apparent losses caused by meter inaccuracies at low flows can result in substantial increases in revenue for a utility. Correct meter sizing and meter reading are essential to the accuracy of meters over an entire flow range, but meter type is also important, especially when considering low-flow accuracy in which performance varies. Given that about 16% of all domestic water consumption occurs at flow rates < 1 gpm, proper meter typing can significantly decrease underregistration of low flows.

To provide municipal utilities with a better understanding of the effect of meter accuracy at low flow rates, this article outlined two methods to estimate apparent losses attributable to meter inaccuracies. With available system information (including average in-service water meter accuracies and flow profile data), these methods can be applied to determine potentially recoverable revenue. For cases in which current system information is incomplete or unavailable, the authors provided average low-flow accuracies for several meter types. These data, obtained as part of a Water Research Foundation project, facilitate comparison of current in-service meters with different meter types. However, the data reflect new meter accuracy and have been applied to multiple manufacturers who produce the same type of meter; performance of individual meters may vary among manufacturers from the aggregate data provided. Additional data on the performance of these meter types with extended use will be forthcoming.

As demonstrated in a simplified case study of the Salt Lake City municipal water system, selection of different meter types or models can effectively increase revenues. Although the revenue savings per connection may not economically justify implementation of a residential meter replacement program founded entirely on meter type and low-flow accuracies, these potential savings do demonstrate the significant effect of meter type. Other factors, such as a meter's durability against sand particulates or maintained accuracy at higher flow rates over time, are key considerations in meter type selection. Similarly, the increased revenue and ability to account for water supplies make the low-flow accuracy of residential water meters an essential factor in selecting a water meter.

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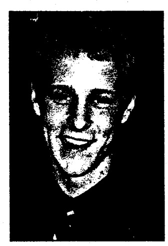

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Attachment 2. Hannah, Craig. *Comparing the Performance of Static Water Meters to Positive Displacement Water Meters in Residential Services*, April 2013.

Comparing the Performance of Static Water Meters to Positive Displacement Water Meters in Residential Services

Craig Hannah, P.E.
Johnson Controls, Inc.

Agenda

- Purpose
- Procedure
- Experiment
  - Glendale, CA – Badger
  - Salisbury, NC – Badger
  - Olathe, KS – Sensus
- Results
- Questions?

Static Metering Technology

- Electromagnetic meter (“magmeter”) and transit-time ultrasonic meters are proven technologies
  - High accuracy
  - Very reliable

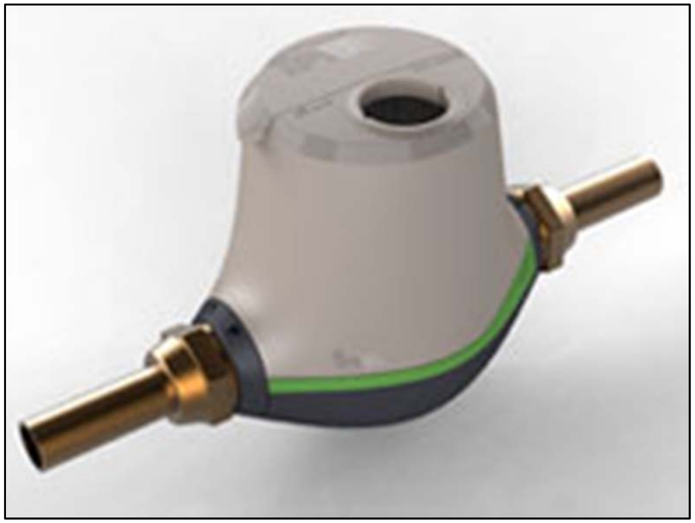
- Previously impractical for small water meters because of need for a constant power supply

- Now practical for small water meters because of recent improvements in battery technology
  - Fluidic Oscillation: Elster-AMCO SM700
  - Electromagnetic meter: Sensus iPERL series
  - Transit-time ultrasonic meter: Badger E-Series
  - 20-Year battery warranty

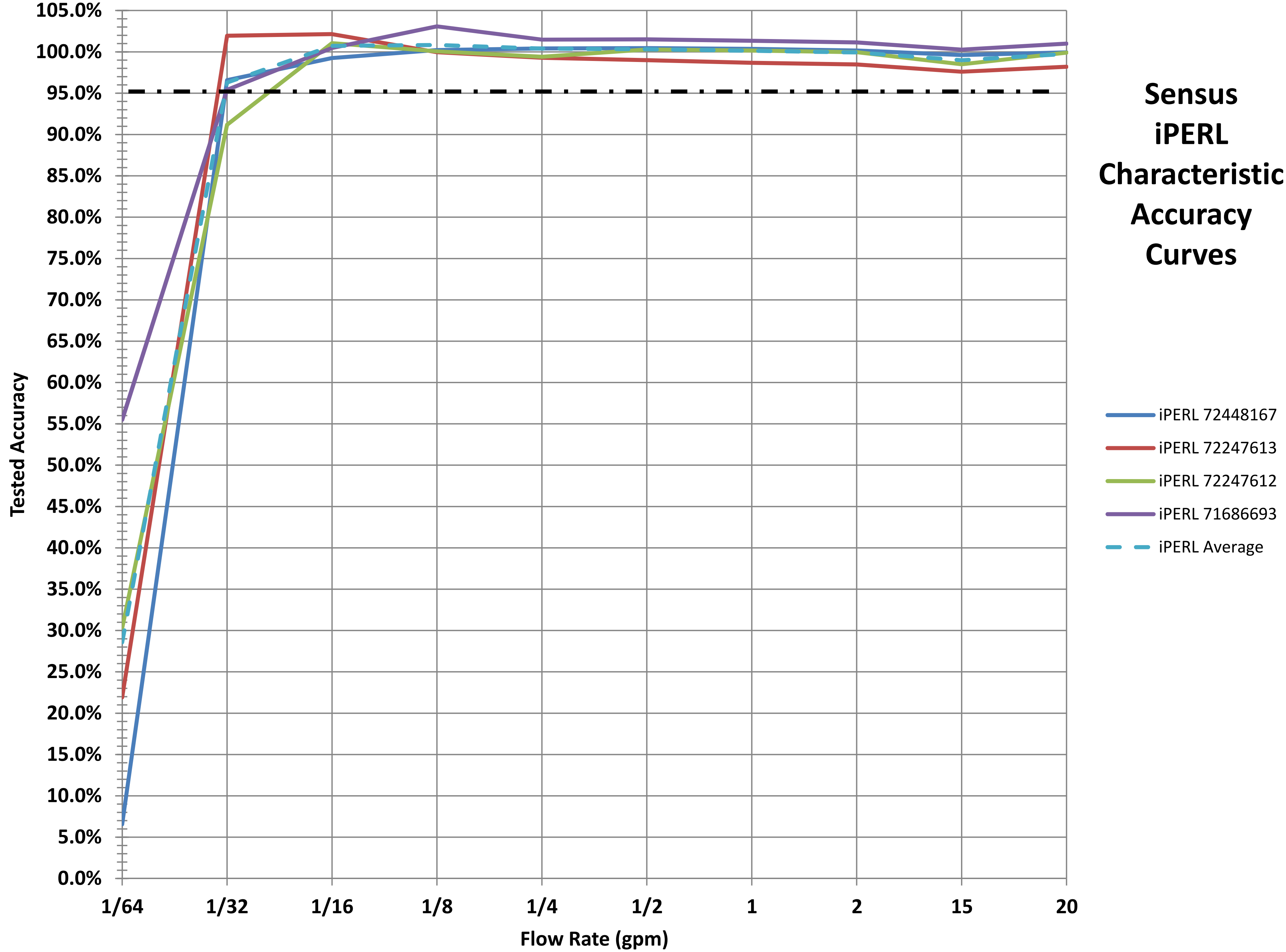
Sensus iPERL

Electromagnetic Meter Technology

NORMAL OPERATING FLOW RANGE (100%±1.5% of actual throughput)	5/8" (DN 15mm) size: 0.11 to 25 gpm (0.02 m^3h to 5.7 m^3h) 3/4" (DN 20mm) size: 0.11 to 35 gpm (0.02 m^3h to 8.0 m^3h) 1" (DN 25mm) size: 0.4 to 55 gpm (0.09 m^3h to 12.5 m^3h)
LOW FLOW REGISTRATION (95%-101.5%)	5/8" (DN 15mm) size: 0.03 gpm (0.007 m^3h) 3/4" (DN 20mm) size: 0.03 gpm (0.007 m^3h) 1" (DN 25mm) size: 0.11 gpm (0.025 m^3h)
MAXIMUM PRESSURE LOSS	5/8" (DN 15mm) size: 4 psi at 15 gpm (0.3 bar at 3.4 m^3h) 3/4" (DN 20mm) size: 2 psi at 15 gpm (0.1 bar at 3.4 m^3h) 1" (DN 25mm) size: 2 psi at 25 gpm (0.1 bar at 5.7 m^3h)



For 0.625" and 0.75" water meters, there is a 95% or better accuracy at 1/33rd gpm (0.03 gpm or 0.007 m^3h).



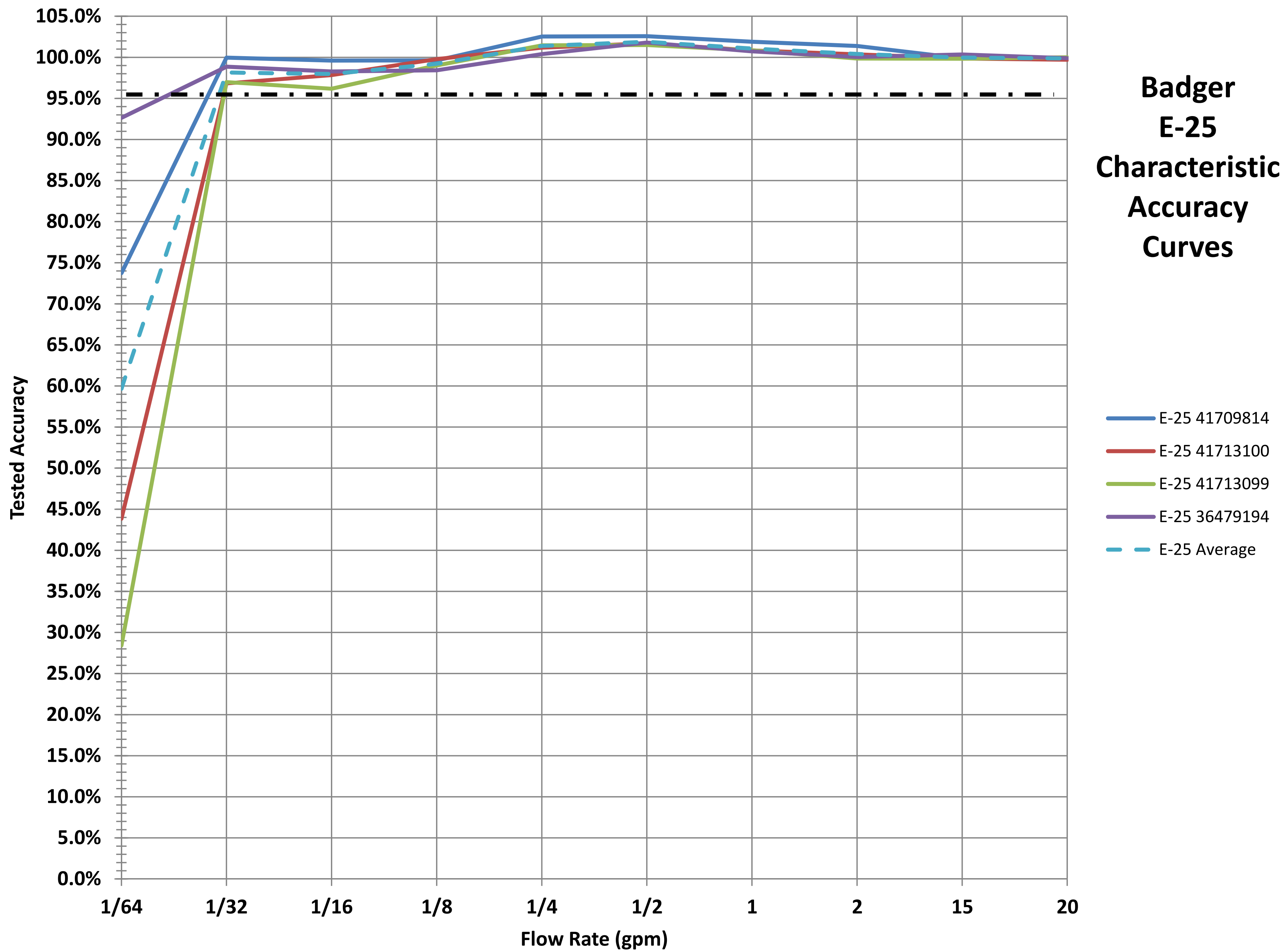
Sensus
iPERL
Characteristic
Accuracy
Curves
Tested Accuracy
Flow Rate (gpm)
105.0%
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
55.0%
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
1/64
1/32
1/16
1/8
1/4
1/2
1
2
15
20
iPERL 72448167
iPERL 72247613
iPERL 72247612
iPERL 71686693
iPERL Average

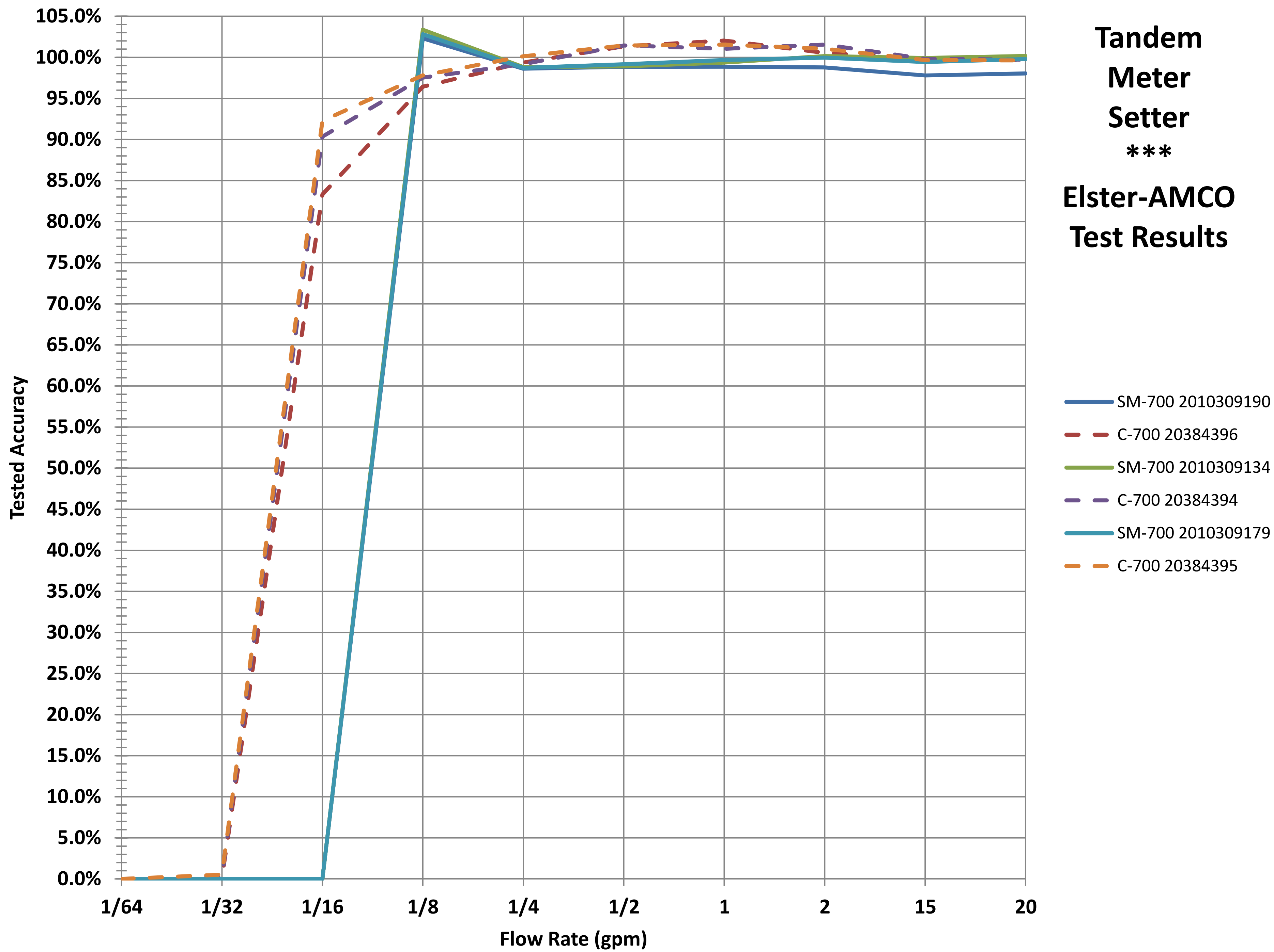
Badger Meter E-Series

Transit Time Ultrasonic Meter Technology

	Model E-25	Model E-35	Model E-55
Typical Operating Range (gpm)	0.1 – 25	0.1 - 32	0.40 – 55
Extended Low Flow Rate (gpm)	0.05	0.05	0.25
Pressure Loss at Maximum Flow	12.4 psi @ 25 gpm	8.4 psi @ 32 gpm	7.0 psi @ 55 gpm

For 0.625" and 0.75" water meters, there is a 97% or better accuracy at $1/20^{th}$ gpm (0.05 gpm or 0.011 m^3h).


Badger
E-25
Characteristic
Accuracy
Curves
Tested Accuracy
105.0%
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
55.0%
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
1/64
1/32
1/16
1/8
1/4
1/2
1
2
15
20
Flow Rate (gpm)
E-25 41709814
E-25 41713100
E-25 41713099
E-25 36479194
E-25 Average


Tandem
Meter
Setter
***
Elster-AMCO
Test Results
Tested Accuracy
105.0%
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
55.0%
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
1/64
1/32
1/16
1/8
1/4
1/2
1
2
15
20
Flow Rate (gpm)
SM-700 2010309190
C-700 20384396
SM-700 2010309134
C-700 20384394
SM-700 2010309179
C-700 20384395

Static Water Meter Research Project

Purpose

1. Determine if a typical residence would experience a noticeable increase in registration at very low flow rates with a static water meter versus a mechanical water meter.

2. Determine if a typical residence with a static water meter versus a mechanical water meter would experience a noticeable increase in registration over time because unlike a mechanical water meter, static water meters are virtually unaffected by either viscous effects or water quality issues.

3. Determine if the water and sewer revenue generated through an increase in registration offsets the higher initial cost of the static water meters.

Residential Water Use Patterns

1993 AWWA Research Foundation Study

Residential Water Use Patterns						
(Paul T. Bowen, *et al*, AWWA Research Foundation, 1993)						
Table 4.49 Usage in each flow range by city (percentage of total), p. 64						
Range	**Altamonte Springs, FL**	**Nashua, NH**	**Norman, OK**	**Portland, OR**	**Tucson, AZ**	**All Cities**
0 - 1/50 gpm	2.5	1.2	3.0	2.4	2.3	2.5
1/50 - 1/16 gpm	**2.1**	**1.6**	**1.9**	**2.3**	**3.3**	**2.3**
1/16 - 1/8 gpm	**1.7**	**0.9**	**1.4**	**2.2**	**3.6**	**2.0**
1/8 - 1/4 gpm	**2.9**	**1.0**	**1.6**	**1.6**	**2.7**	**2.0**
1/4 - 1/2 gpm	1.5	1.1	1.0	1.5	1.2	1.2
1/2 - 3/4 gpm	1.1	2.0	1.2	1.5	1.5	1.4
3/4 - 1 gpm	1.4	1.6	1.8	1.5	2.1	1.7
1 -2 gpm	12.9	16.8	15.1	15.1	11.5	14.2
2 -3 gpm	12.0	16.1	12.6	15.5	12.6	13.4
3 - 4 gpm	10.3	19.1	16.5	16.4	12.2	14.8
4 -6 gpm	30.4	26.8	28.2	25.1	29.0	28.0
6 -8 gpm	12.0	8.1	10.0	7.8	10.4	9.8
8 - 10 gpm	3.5	2.7	3.1	3.0	3.9	3.3
10 - 15 gpm	2.6	0.6	2.1	3.1	3.3	2.5
15 - 20 gpm	2.2	0.0	0.4	0.7	0.2	0.7
20 - 25 gpm	0.3	0.0	0.1	0.1	0.0	0.1
25+ gpm	0.5	0.4	0.2	0.2	0.0	0.2

Region of Potential Increase in Registration

Static Water Meter Research Project

Procedure

1. Obtain materials
   A. Olathe, KS (December 2010 – Present)
      1) New Sensus 0.625” x 0.50” SRII and iPERL 0.75S” water meters (24 each)
      2) Tandem meter setters (24)
      3) Sensus 520M dual-port SmartPoints (24)
   B. Glendale, CA (June 2012 - Present)
      1) New Badger 0.75” Model 35 and E-35 water meters (5 each)
      2) Tandem meter setters (5)
      3) Itron Water SaveSource 200W ERT endpoints (10)
   C. Salisbury, NC (September 2012 – Present)
      1) New Badger 0.625” x 0.75” Model 25 and E-25 water meters (10 each)
      2) Tandem meter setters (10)
      3) Badger Orion ME endpoints (20)
2. Utility selects “typical residences” for test sites
3. Install tandem setter assemblies and connect water meters to AMI system to obtain hourly usage data
4. Test tandem setter assemblies at the Utah Water Research Lab to confirm that tandem setter has negligible influence on accuracy
5. Obtain and analyze hourly billed usage data from each account

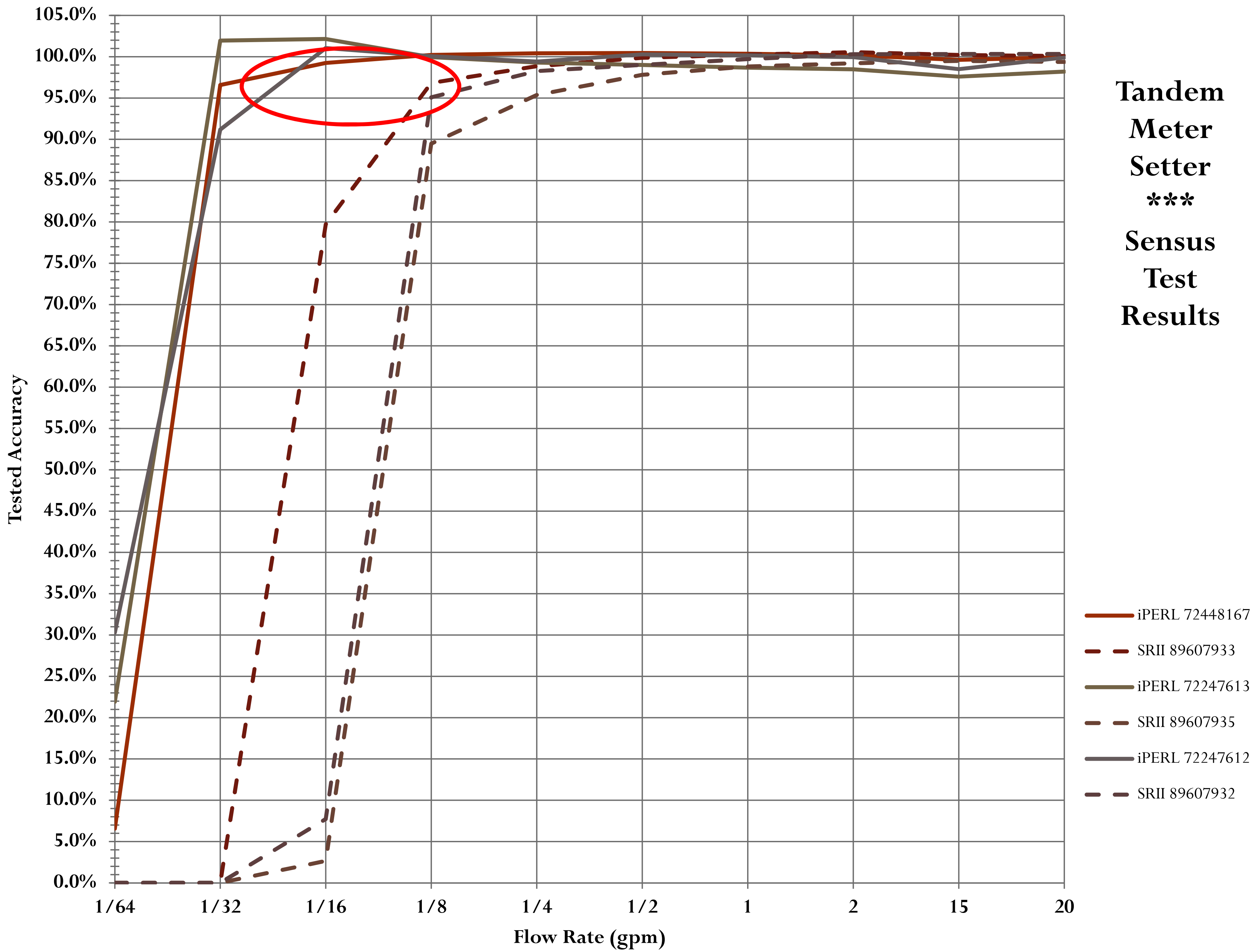
Tandem Meter Setter Assembly

Sensus iPERL and SRII

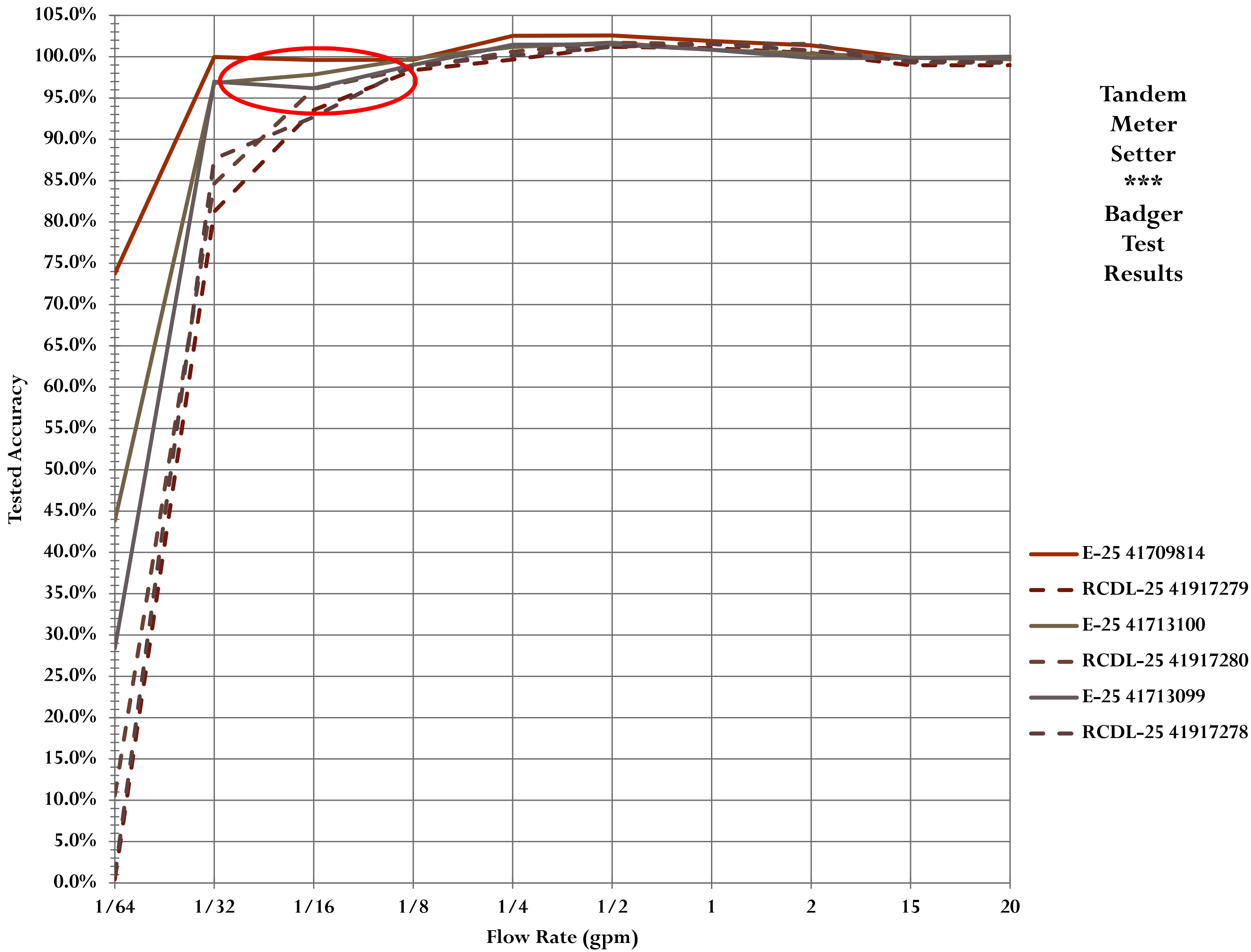
Olathe, KS

Badger E-35 and M-35

Glendale, CA



Tandem
Meter
Setter
***
Sensus
Test
Results
Tested Accuracy
105.0%
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
55.0%
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
1/64
1/32
1/16
1/8
1/4
1/2
1
2
15
20
Flow Rate (gpm)
iPERL 72448167
SRII 89607933
iPERL 72247613
SRII 89607935
iPERL 72247612
SRII 89607932


Tested Accuracy
105.0%
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
55.0%
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
1/64
1/32
1/16
1/8
1/4
1/2
1
2
15
20
Flow Rate (gpm)
Tandem Meter Setter
***
Badger Test Results
E-25 41709814
RCDL-25 41917279
E-25 41713100
RCDL-25 41917280
E-25 41713099
RCDL-25 41917278

City of Glendale, CA

Badger E-35 and M-35 Meters

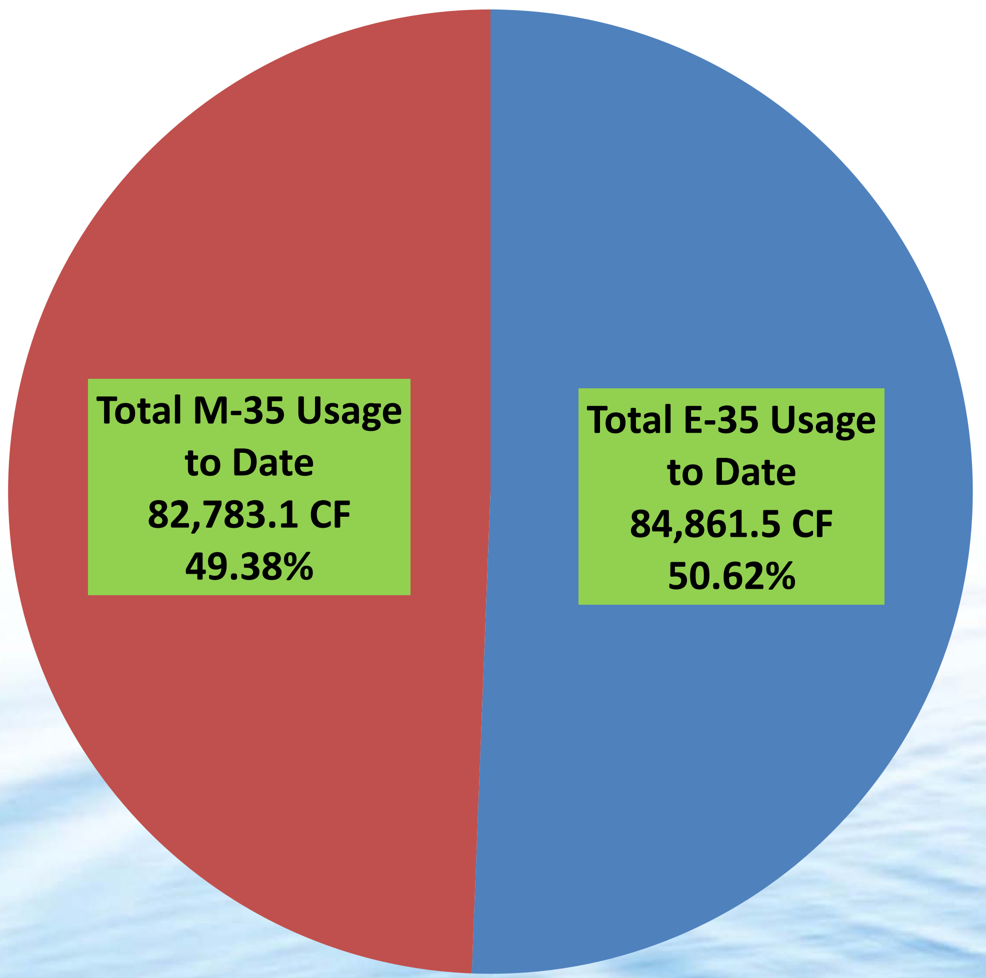
Transit Time Ultrasonic *versus* Nutating Disk Positive Displacement 0.75” Meters

City of Glendale, CA – Total Usage

Badger E-35 and M-35 Meters

Glendale, CA - Monthly Usage

June 2012 - March 2013



E-35 vs M-35

- 2,078.4 more ft^3
- 15,547.5 more gallons
- 2.45% difference

City of Glendale, CA – Monthly Usage

Badger E-35 Usage Less M-35 Usage

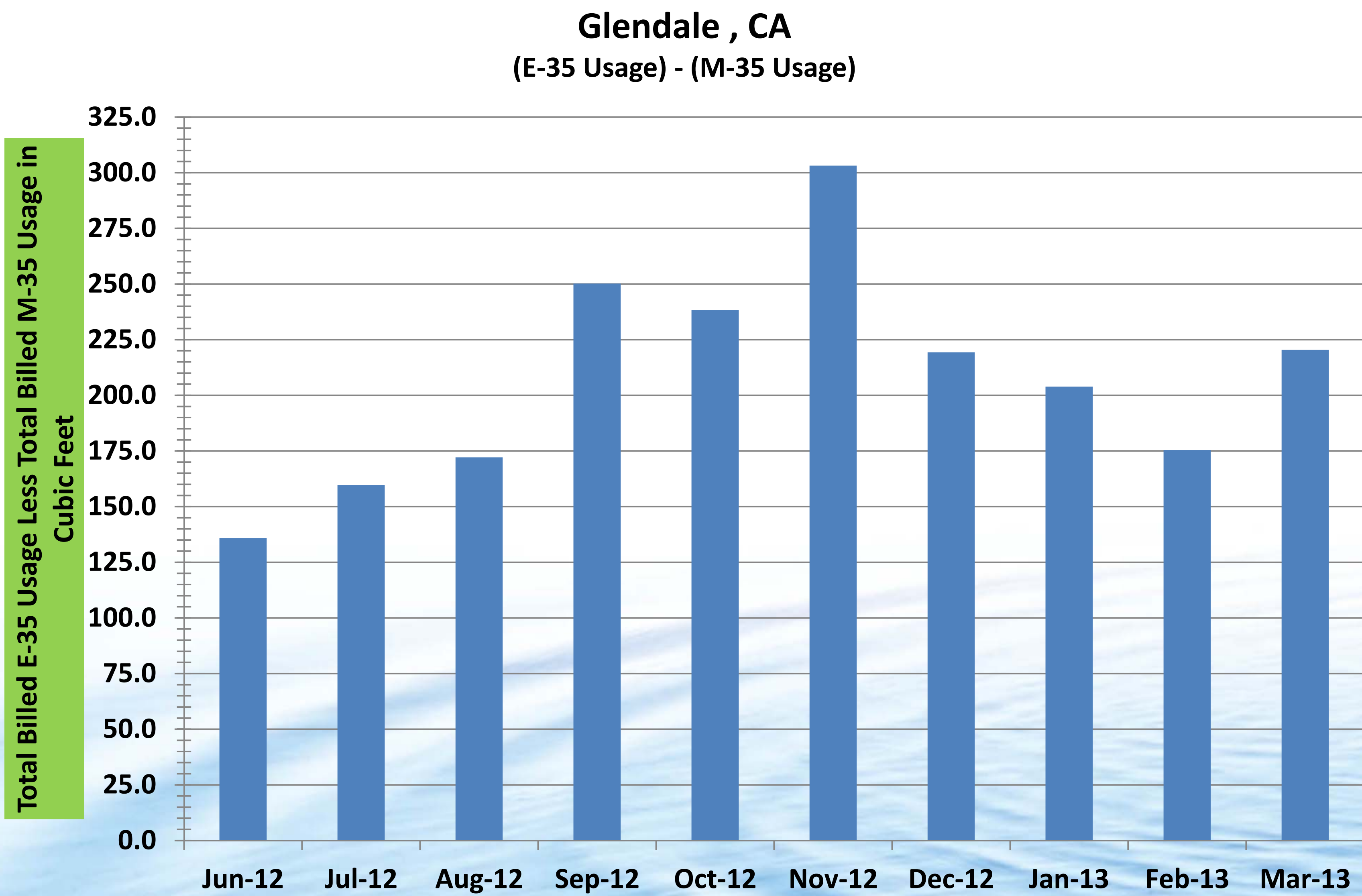
(E-35 Usage) - (M-35 Usage)											
	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Total
Vassar	45.9	1.3	4.8	7.7	-30.7	6.0	1.0	1.0	5.8	11.3	54.1
Downing	72.7	89.8	91.6	100.6	92.2	97.3	39.4	45.6	53.6	41.0	723.8
First	9.0	29.3	27.7	37.4	30.8	14.7	6.9	13.1	11.4	23.6	203.9
Zook	1.3	2.3	18.8	22.9	26.0	19.0	17.1	10.6	12.9	19.8	150.7
Cedar	7.0	37.0	29.2	81.6	120.0	166.2	154.9	133.6	91.7	124.7	945.9
Total	**135.9**	**159.7**	**172.1**	**250.2**	**238.3**	**303.2**	**219.3**	**203.9**	**175.4**	**220.4**	**2,078.4**

% Difference (E-35 Usage::M-35 Usage)											
	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Average
Vassar	12.36%	0.44%	1.19%	0.90%	-3.89%	0.79%	0.16%	0.14%	0.92%	1.49%	1.45%
Downing	2.66%	2.84%	2.77%	2.46%	2.40%	5.34%	5.32%	5.27%	6.00%	3.13%	3.82%
First	0.98%	1.55%	1.60%	2.88%	4.04%	1.91%	1.32%	1.59%	1.60%	2.73%	2.02%
Zook	0.09%	0.18%	1.38%	1.64%	2.31%	1.57%	1.47%	1.15%	1.44%	1.77%	1.30%
Cedar	0.47%	1.21%	0.85%	2.39%	3.25%	4.24%	4.08%	3.55%	2.65%	3.35%	2.60%
Total	**1.98%**	**1.65%**	**1.68%**	**2.26%**	**2.34%**	**3.57%**	**3.21%**	**2.88%**	**2.66%**	**2.84%**	

*Vassar service had a leak that was repaired in late June 2012

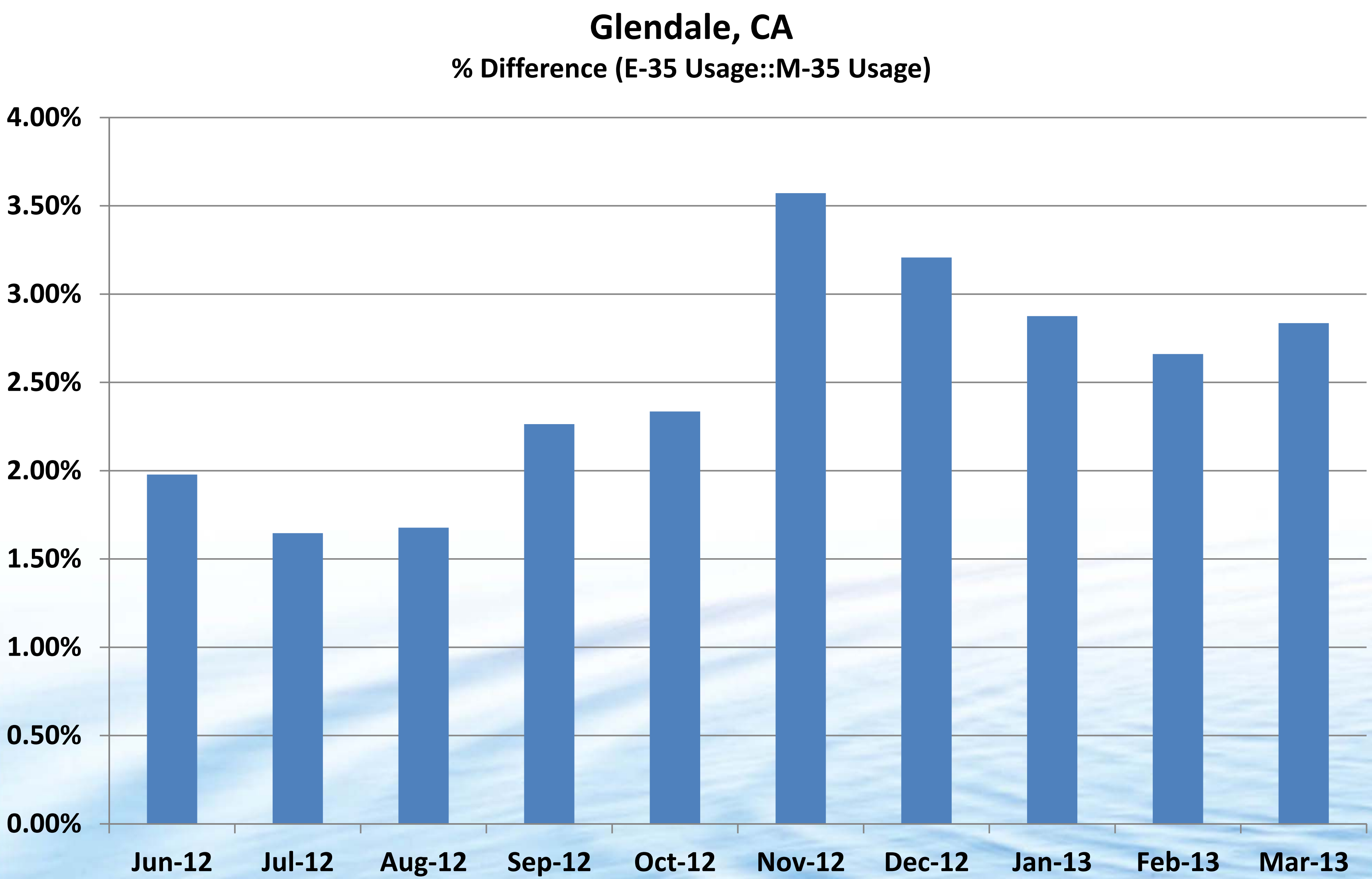
City of Glendale, CA – Monthly Usage

Badger E-35 Usage Less M-35 Usage



City of Glendale, CA – Monthly Usage

% Difference Badger E-35 to M-35 Usage



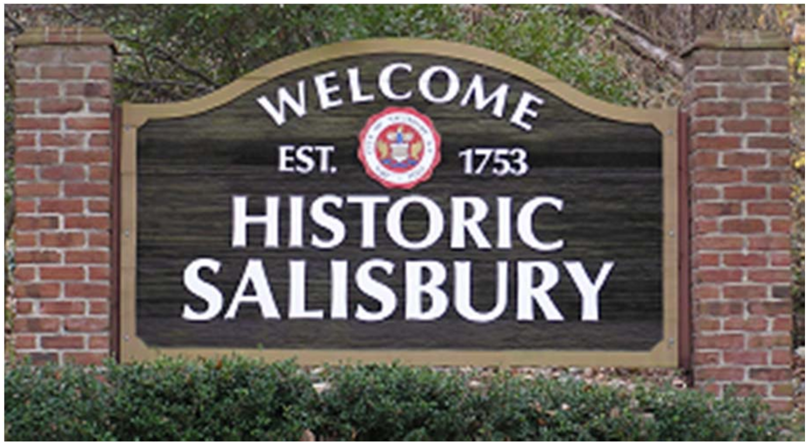
Glendale, CA – Results to Date

Conclusions

- **While the E-35 meters have registered more usage than the M-35 meters at all services except for one service in one month, there is usually slightly more than a 2% difference in billed usage between the E-35 and M-35 meters in any given month.**

- **The difference in registration between a static meter and a positive displacement meter appears to be more noticeable in a 0.75" meter than in either a 0.625" x 0.5" or a 0.625" x 0.75" meter.**

- **The transit time ultrasonic water meter appears to be very comparable in performance to a relatively *new* nutating disk positive displacement water meter (10 months of service).** ***This may change in time, however, as viscous effects and water quality issues adversely affect the accuracy of the positive displacement meters***.



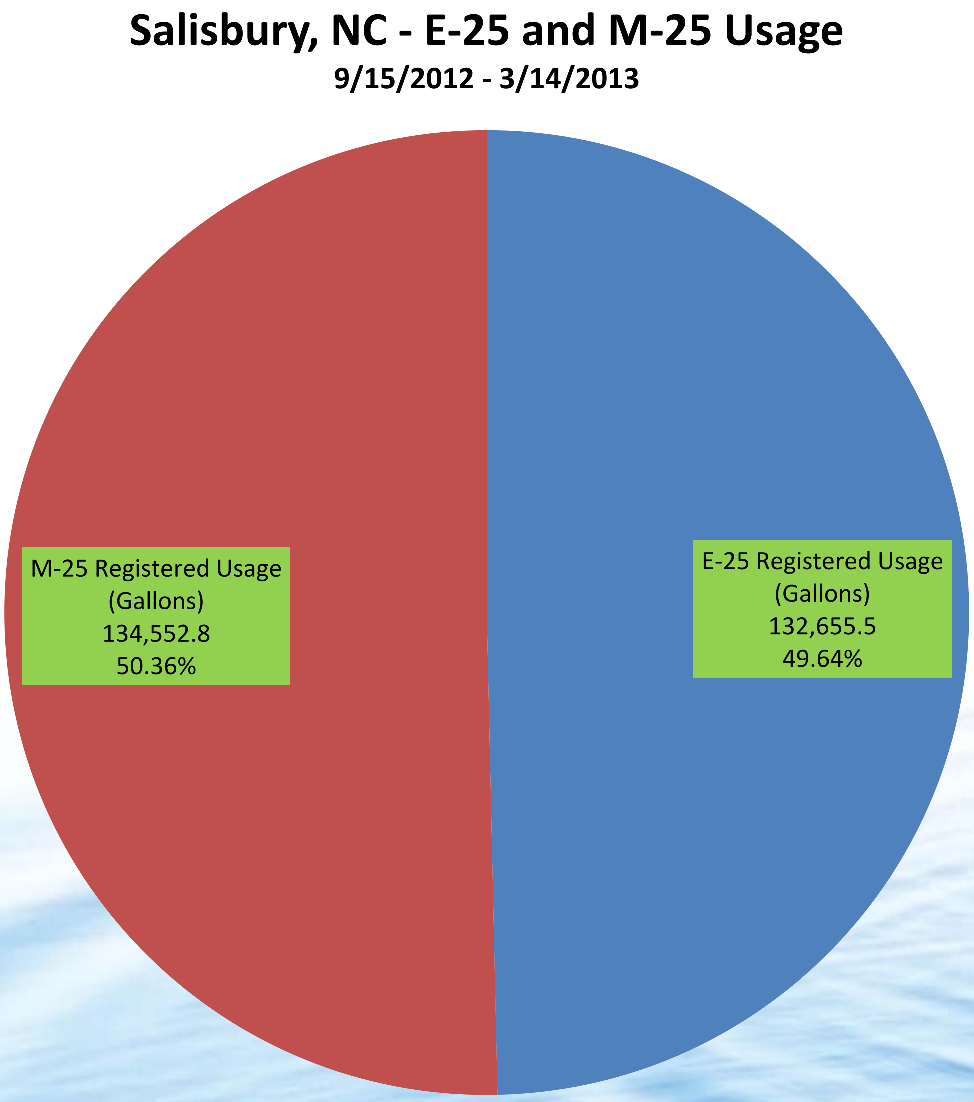
City of Salisbury, NC

Badger E-25 and M-25 Meters

Transit Time Ultrasonic *versus* Nutating Disk Positive Displacement 0.625" x 0.75" Meters

City of Salisbury, NC – Total Usage

Badger E-25 and M-25 Meters



E-25 vs M-25

-253.6 fewer ft^3

-1,897 fewer gallons

-1.41% difference

City of Salisbury, NC – Monthly Usage

Badger E-25 Less M-25 Usage (gallons)

Service Address	9/15/2012 - 10/14/2012	10/15/2012 - 11/14/2012	11/15/2012 - 12/14/2012	12/15/2012 - 1/14/2013	1/15/2013 - 2/14/2013	2/15/2013 - 3/14/2013	Total
1311	-48.8	-72.7	-79.4	-89.7	-78.7	-57.3	**-426.6**
1312	-29.3	-34.5	-41.9	-40.8	-12.9	-5.7	**-165.1**
1314	-13.1	-13.6	-15.5	-17.8	-20.5	-17.9	**-98.4**
1316	-16.7	-19.3	-19.8	-28.7	-31.9	-24.9	**-141.3**
1320	-0.6	-13.8	-27.0	-23.4	-19.2	-11.6	**-95.6**
1331	-113.4	-116.7	-183.8	-159.1	-122.7	-121.8	**-817.5**
1327	-46.4	-21.4	-13.3	**33.7**	**71.5**	**54.0**	**78.1**
1323	-7.4	-9.7	-10.7	-12.8	-3.7	-6.3	**-50.6**
1317	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
1330	-35.9	-32.9	-45.1	-66.4	N/A	N/A	**-180.4**
Total	**-311.6**	**-334.6**	**-436.5**	**-405.1**	**-218.1**	**-191.5**	**-1,897.4**

City of Salisbury, NC – Monthly Usage

% Difference Badger E-25::M-25 Usage

Service Address	9/15/2012 - 10/14/2012	10/15/2012 - 11/14/2012	11/15/2012 - 12/14/2012	12/15/2012 - 1/14/2013	1/15/2013 - 2/14/2013	2/15/2013 - 3/14/2013	Average
1311	-0.79%	-1.24%	-1.37%	-1.39%	-1.56%	-1.44%	-1.30%
1312	-1.82%	-1.91%	-2.22%	-2.53%	-2.60%	-2.67%	-2.29%
1314	-1.42%	-1.47%	-1.65%	-1.74%	-1.93%	-1.84%	-1.67%
1316	-1.12%	-1.22%	-1.32%	-1.89%	-2.02%	-1.99%	-1.59%
1320	-0.04%	-1.00%	-1.82%	-1.65%	-1.47%	-0.96%	-1.16%
1331	-2.15%	-2.50%	-3.89%	-2.85%	-2.46%	-2.76%	-2.77%
1327	-1.75%	-0.68%	-0.42%	**1.17%**	**2.11%**	**1.83%**	**0.38%**
1323	-0.63%	-0.79%	-0.97%	-1.03%	-0.33%	-0.61%	-0.73%
1317	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1330	-1.11%	-0.97%	-1.28%	-1.73%	N/A	N/A	-1.27%
Average	-1.30%	-1.40%	-1.81%	-1.59%	-1.15%	-1.20%	**-1.43%**

Salisbury, NC – Results to Date

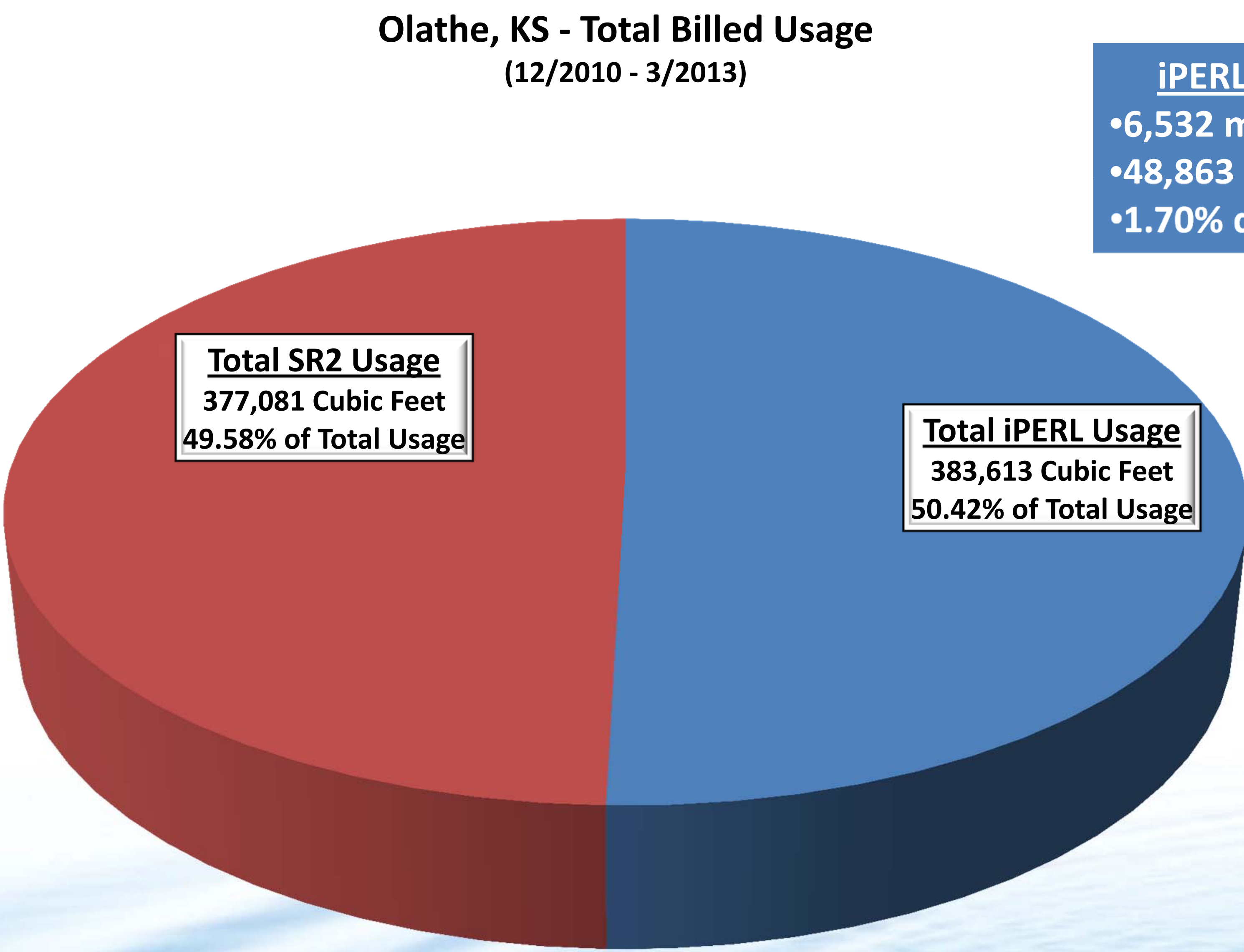
Conclusions

- **While the M-25 meters have registered more usage than the E-25 meters at all services except for one service during the past three months, there is usually less than a 2% difference in billed usage between the E-25 and M-25 meters.**
- **The transit time ultrasonic water meter appears to be very comparable in performance to a relatively *new* nutating disk positive displacement water meter (6 months of service). *This may change in time, however, as viscous effects and water quality issues adversely affect the accuracy of the positive displacement meters*.**

City of Olathe, KS

Sensus iPERL and SRII Meters

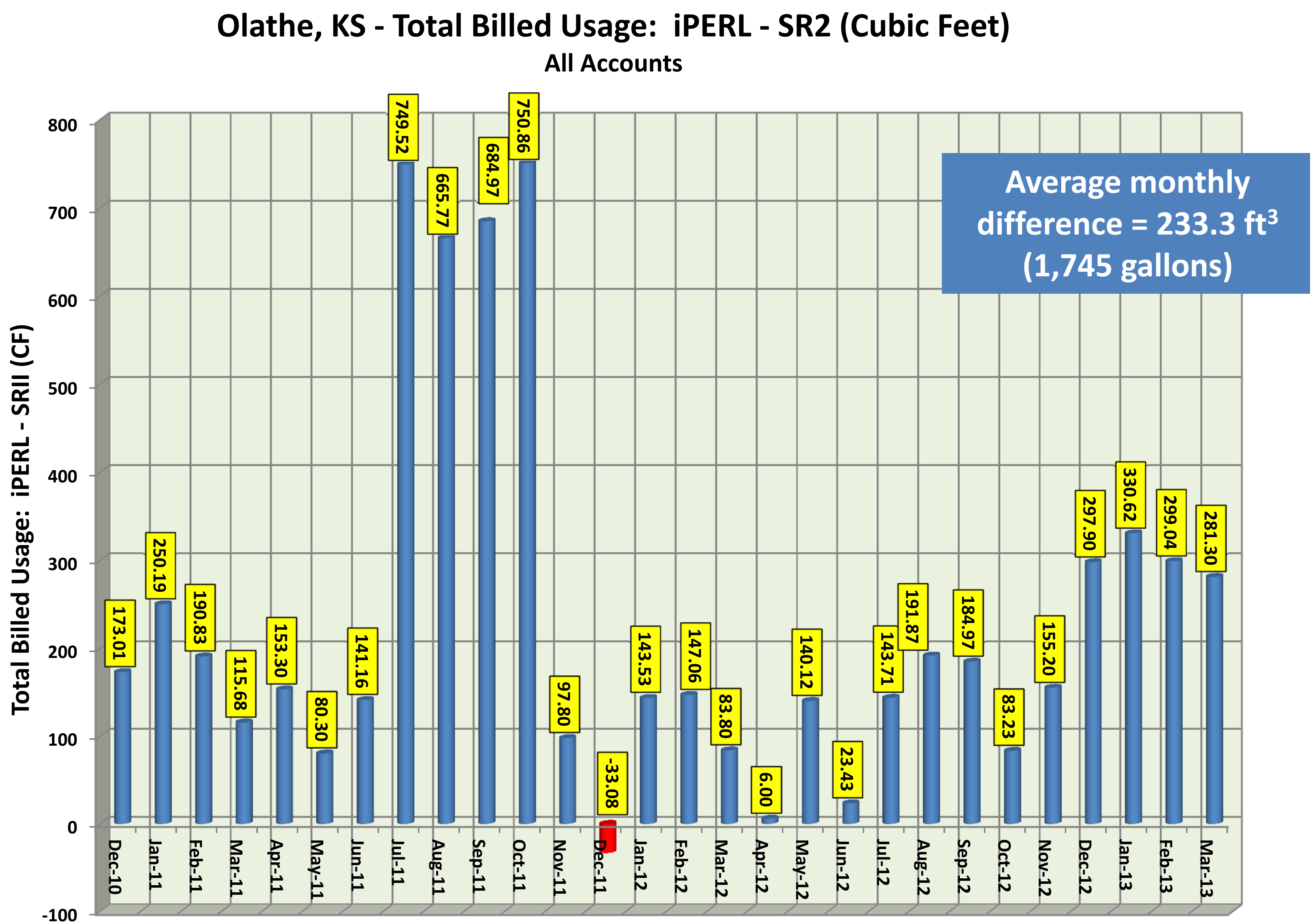
Electromagnetic ("Mag")*versus* Oscillating Piston Positive Displacement 0.625" x 0.5" Meters



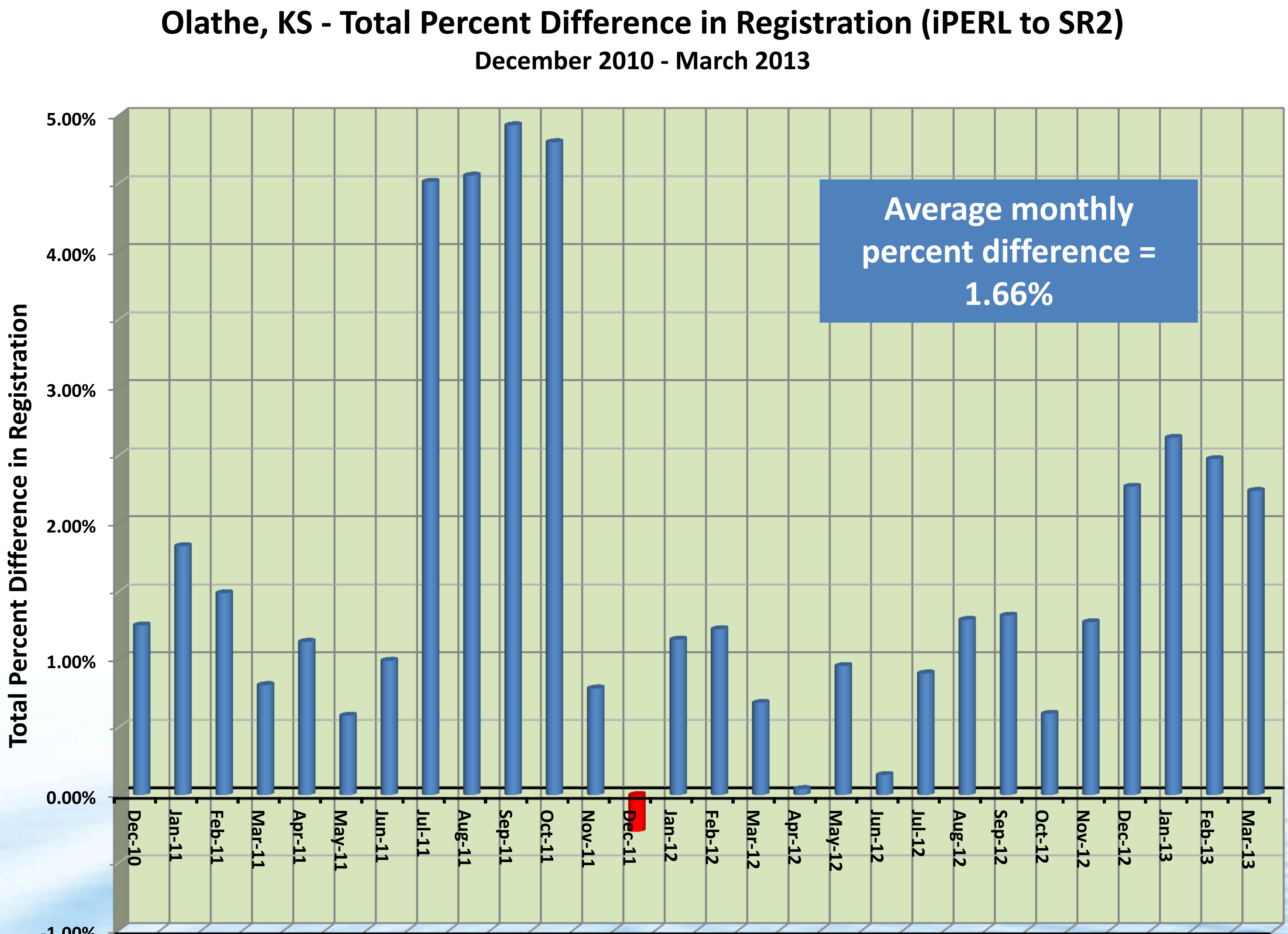
iPERL vs SR2

- 6,532 more ft^3
- 48,863 more gal
- 1.70% difference

- Account "J" excluded from June 2011 through February 2013 totals due to missing SRII usage data; Account "A" excluded from January 2012 through March 2012 totals due to missing iPERL data.



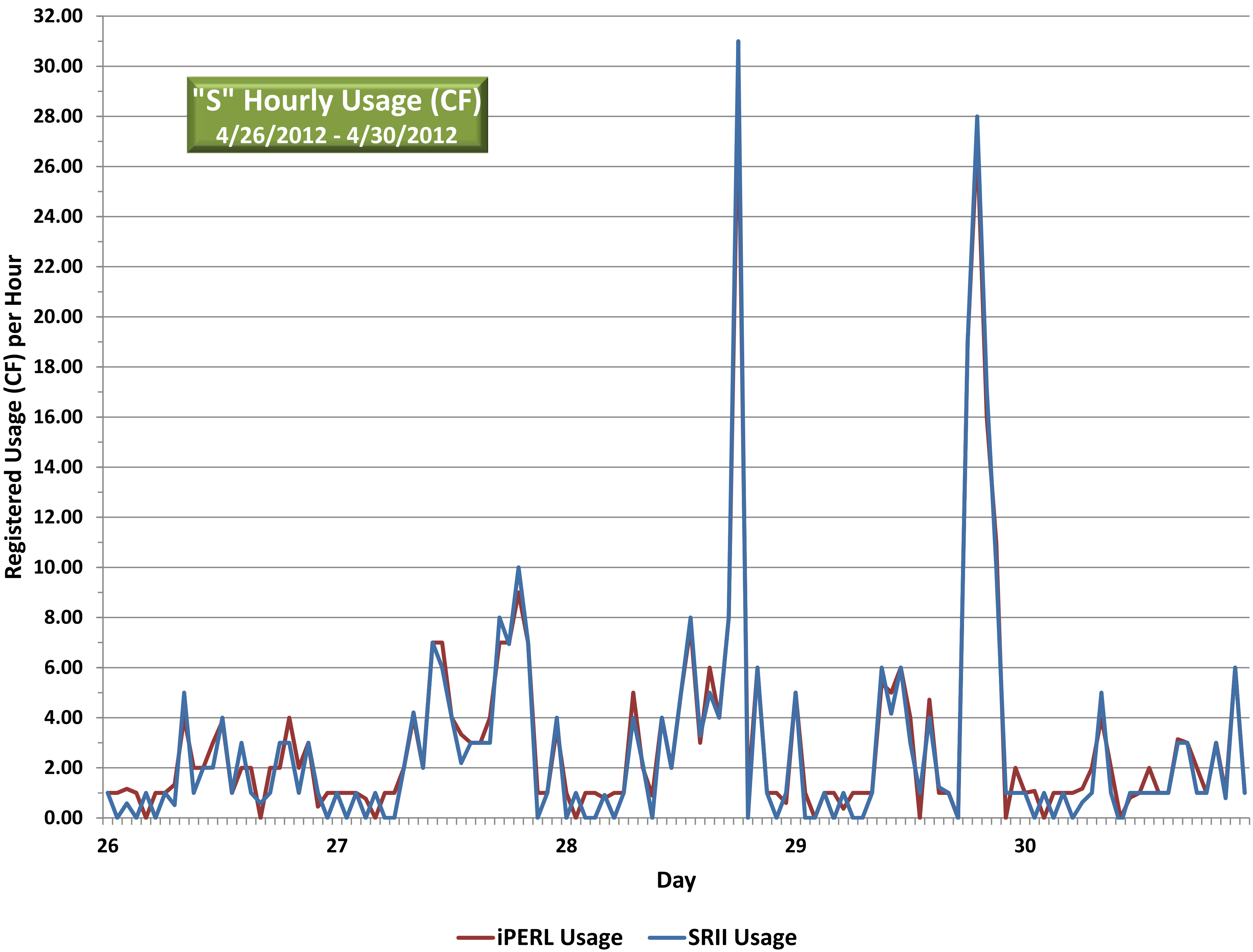
Olathe, KS - Total Billed Usage: iPERL - SR2 (Cubic Feet)
All Accounts
Total Billed Usage: iPERL - SRII (CF)
800
700
600
500
400
300
200
100
0
-100
Dec-10 173.01
Jan-11 250.19
Feb-11 190.83
Mar-11 115.68
Apr-11 153.30
May-11 80.30
Jun-11 141.16
Jul-11 749.52
Aug-11 665.77
Sep-11 684.97
Oct-11 750.86
Nov-11 97.80
Dec-11 -33.08
Jan-12 143.53
Feb-12 147.06
Mar-12 83.80
Apr-12 6.00
May-12 140.12
Jun-12 23.43
Jul-12 143.71
Aug-12 191.87
Sep-12 184.97
Oct-12 83.23
Nov-12 155.20
Dec-12 297.90
Jan-13 330.62
Feb-13 299.04
Mar-13 281.30
Average monthly difference = 233.3 ft³ (1,745 gallons)


Olathe, KS - Total Percent Difference in Registration (iPERL to SR2)
December 2010 - March 2013
Total Percent Difference in Registration
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
-1.00%
Average monthly percent difference = 1.66%
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11
Jan-12
Feb-12
Mar-12
Apr-12
May-12
Jun-12
Jul-12
Aug-12
Sep-12
Oct-12
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13

Olathe, KS
Results to Date
(12/2010 – 03/2013)

Account**	Average % Difference iPERL Usage to SRII Usage	Remarks
U	6.74%	iPERL Usage > SR II Usage
S	6.56%	
G	2.46%	
L	2.17%	
P	1.34%	iPERL Usage ≈ SR II Usage
H	0.65%	
I	0.18%	
T	-0.05%	
F	-0.15%	
M	-0.44%	
R	-0.79%	
O	-0.81%	
Q	-0.96%	
E	-1.01%	
C	-1.16%	
N	-1.39%	
B	-2.20%	SR II Usage > iPERL Usage
A	-2.25%	
V	-2.51%	
K	-6.14%	
D	-6.80%	

- **The iPERL meters register significantly more usage than do the SRII meters at 4 out of 21 accounts.**
- **The SRII meters register significantly more usage than do the iPERL meters at 5 out of 21 accounts.**
- **There is less than 2% difference in registered usage at the other 12 accounts.**
- **Account "J" excluded because of no SRII data since 6/2011. Accounts "W" and "X" excluded because they are now vacant.**


"S" Hourly Usage (CF)
4/26/2012 - 4/30/2012
Registered Usage (CF) per Hour
32.00
30.00
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
26
27
28
29
30
Day
iPERL Usage
SRII Usage

Olathe, KS – Results from 07/2011 – 01/2013

"Day" and "Night" Registration

Accounts with iPERL >> SRII Usage					Accounts with SRII >> iPERL Usage				
Account	Total iPERL "Day" Usage (CF)	Total SRII "Day" Usage (CF)	Total iPERL "Day" Usage - Total SRII "Day" Usage (CF)	% Difference	Account	Total iPERL "Day" Usage (CF)	Total SRII "Day" Usage (CF)	Total iPERL "Day" Usage - Total SRII "Day" Usage (CF)	% Difference
S	7,756.98	7,295.63	461.35	5.95%	B	804.59	797.84	6.75	0.84%
U	3,358.46	3,158.84	199.62	5.94%	K	1,874.28	1,930.01	-55.73	-2.97%
G	4,719.15	4,641.69	77.46	1.64%	D	3,606.93	3,837.38	-230.45	-6.39%
Account	Total iPERL "Night" Usage (CF)	Total SRII "Night" Usage (CF)	Total iPERL "Night" Usage - Total SRII "Night" Usage (CF)	% Difference	Account	Total iPERL "Night" Usage (CF)	Total SRII "Night" Usage (CF)	Total iPERL "Night" Usage - Total SRII "Night" Usage (CF)	% Difference
S	3,460.78	2,538.78	922.00	26.64%	B	339.95	351.01	-11.06	-3.25%
U	1,000.43	415.52	584.91	58.47%	K	1,493.49	1,639.72	-146.23	-9.79%
G	2,191.67	1,995.69	195.98	8.94%	D	1,857.49	1,990.37	-132.88	-7.15%

- "Night" = 00:00 hours to 06:59 hours (12:00 AM through 6:59 AM).
- "Day" = 07:00 hours to 11:59 hours (7:00 AM through 11:59 AM).
- At the locations in which the iPERL meters significantly register more usage than do the SRII meters , it appears to be primarily during the "night".

Olathe, KS – Results to Date

Conclusions

- The iPERL electromagnetic meter registered significantly higher usage than did the SR2 positive displacement meter at 4 of the 21 accounts.
- The SR2 positive displacement meter registered a significantly higher usage than did the iPERL electromagnetic meter at 5 of the 21 accounts.
- **There was less than a 2% difference in billed usage between the iPERL and SRII at the remaining 12 accounts, and the electromagnetic water meter appears to be very comparable in performance to a relatively *new* positive displacement water meter (27 months of service).** ***This may change in time, however, as viscous effects and water quality issues adversely affect the accuracy of the positive displacement meters***.

A very Special Thank You to…

- City of Olathe, KS: Merv Gleason, Dave Bries, Tonya Roberts
- Sensus Water Meters: Bob Whittaker, Joey Mitchell, Jeff Krausse
- Johnson Controls: Dennis Siegert, Greg French, Derek Clayton
- Tom Brewer from the City of Anderson, IN
- John Strolsee, Cuong Hong, and Davie Massie from the City of Glendale, CA
- Pat Hayes, P.E., formerly of the City of Glendale, CA
- Devan Shields, former Research Assistant at the Utah Water Research Laboratory
- Badger Meter: John Fillinger, Jan Boyer, Brooke Lange, and Craig Cardella

Johnson Controls