How Critical is “Start Flow” to Accuracy Requirements?

A WHITE PAPER BY NEPTUNE TECHNOLOGY GROUP INC.

5/8″ MACH 10® Meter

A LOOK AT LOW FLOW CAPABILITIES IN RESIDENTIAL SOLID STATE METERS

Non-Revenue Water (NRW) is water that is supplied, but not billed, and comes in two forms: real losses and apparent losses. Real losses include water lost as a result of events such as main breaks, leaks at service connections, and overflow at storage tanks. Apparent loss is water consumed by an end customer, but not billed for. In a well-managed system, most loss is apparent and can be traced back to inaccuracies in the water meter[1]. Although quality solid state meters (meters with no moving parts) eliminate apparent losses attributed to wear and tear, poor maintenance, and inadequate calibration, losses may still exist due to unmetered low flow.

The American Water Works Association’s (AWWA) C715 Standard requires that ⅝” solid state meters have low flow capabilities of at least 0.13 gallons per minute — about the rate of a leaky toilet[2]. A peer-reviewed paper published by the *Journal of Water Supply: Research and Technology - Aqua* shows that up to 13% of all residential consumption occurs *below* 0.13 gpm[1]. This means that a ⅝” solid state meter adhering to the minimum AWWA specs will not register 13% of the low flow consumption: 13% apparent loss = 13% lost revenue.

Most residential solid state meters’ low flow capabilities are well below 0.13 gpm. In fact, some have capabilities that extend even further below the low flow. This extension beyond low flow has been called “start flow”. The term start flow, although not recognized by AWWA, has been used to refer to the flow rate at which a meter will begin registering flow. The predominant difference between start flow and low flow is that start flow has no accuracy requirements. Understanding AWWA accuracy requirements for normal flow is critical to making this distinction.

NORMAL TEST-FLOW LIMITS

Normal flow is a range between which most meters will see flow during *normal* operation. Most of the water measured by a meter will fall in this range, making it a critical point of accuracy for utilities looking to maximize revenue. AWWA requires that manufacturers ensure meter accuracy is between 98.5-101.5% (i.e., 100% +/- 1.5%) to be considered within the

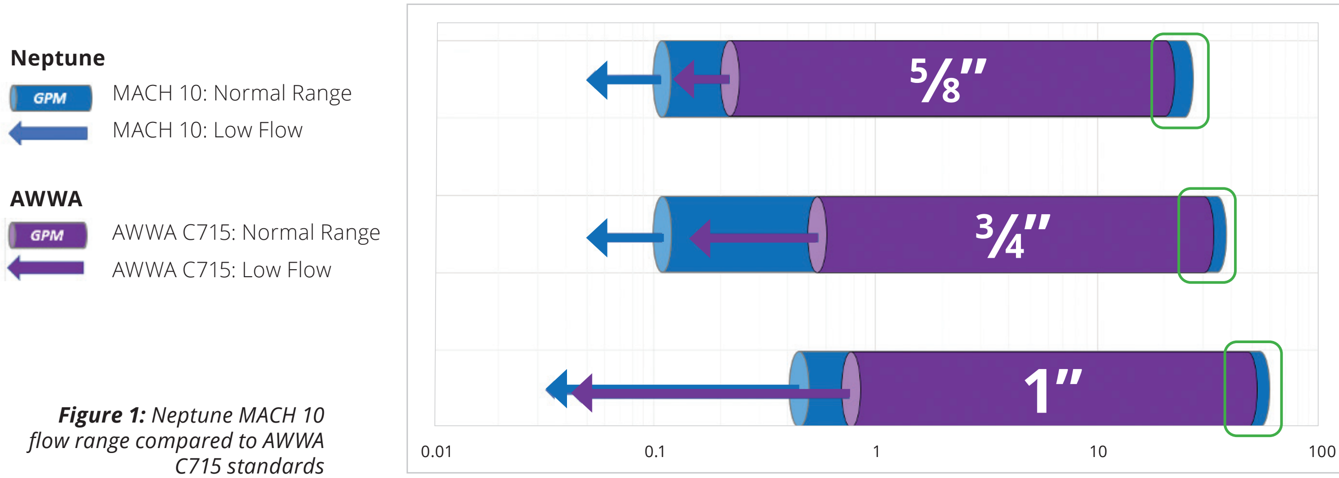

***Figure 1:** Neptune MACH 10 flow range compared to AWWA C715 standards*

normal range. For example, if you run 100 gallons of water through the meter at a *normal* flow rate, it should record between 98.5 and 101.5 gallons. Normal range differs by meter size, but all are required to measure within 98.5-101.5% accuracy. AWWA sets the standard for the minimum acceptable normal range; however, it is not uncommon for a manufacturer to exceed the standard. The flow rates assigned by the manufacturer are often referred to as the meter's "rated" flow rate. Figure 1 above illustrates Neptune's MACH 10 meter flow range compared to AWWA C715 standards. The left side of the chart shows normal range and the arrows indicate low flow.

The high end of the normal flow range goes by many names, including high flow and max flow, and is also synonymous with Safe Maximum Operating Capacity (SMOC). This value represents the highest flow rate that a meter can safely and accurately measure. The danger of going above this rate includes breaking the meter or possibly causing damage to the line and anything downstream. Mechanical meters, such as turbines, are particularly susceptible. AWWA states that these meters should only operate intermittently at their SMOC so as not to exceed 33% of usage (8 hours/day). No such constraint exists for solid state meters.

Pressure losses at high flow rates can be drastic, but with careful design, a meter's max flow can be rated as a higher flow rate than AWWA's minimum SMOC requirements. The right side of Figure 1 highlights this point with green boxes, showing how the high flow of the Neptune MACH 10 exceeds AWWA's standards.

Regardless of whether the AWWA standard is exceeded or not, surpassing the meter's max rated flow can cause a loss of accuracy. This accuracy loss is generally due to a phenomenon known as "cavitation," which occurs when a large pressure drop turns water into steam and negatively impacts measurement capability. This accounts for one of the main reasons manufacturers do not guarantee accuracy for flow above the respective rated normal range. Just as higher than normal flow can cause measurement inaccuracies, lower than normal flow, "low flow," also impacts measurement accuracy.

MINIMUM TEST FLOW (AKA LOW FLOW)

Minimum flow, or low flow, is the lowest possible flow where a meter can accurately measure water. As the flow rate of water decreases, it becomes increasingly more difficult for the meter to measure accurately. Unlike high flow, this accuracy loss is not due to pressure drops, which are generally incredibly small at low flow. Low flow accuracy in mechanical meters is limited because the forces of friction and gravity must be overcome before the parts are able to start to move. Extremely low flows do not have enough kinetic energy to overcome these forces and move the measuring

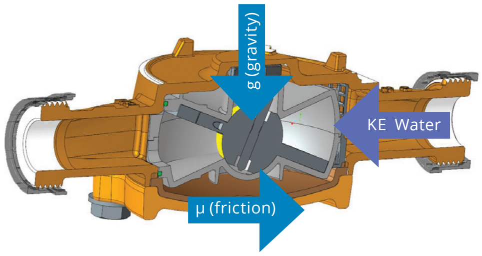

Figure 2: *Simplified view of the forces inside a nutating disc meter*

element (turbine, ball and disc, piston, etc.) so the water going through the meter will not be registered until the flow rate increases, as shown in Figure 2 above.

Solid state meters — electromagnetic and static are the most common types today — have unique considerations for measuring low flow.

Electromagnetic meters generate a magnetic field in the flow path and measure the induced voltage through the water, which is proportional to the water velocity. Relatively high water velocities are required to induce a voltage robust enough to make an accurate measurement. High velocities are needed because the conductive value of water is low and electromagnetic meters rely on good conductivity to generate signals (induce voltages) and make measurements. At low velocities, the meter's signal may be lost in the noise generated by its own electronics, known as low signal-to-noise ratio, or SNR, as illustrated in Figure 3 below. This greatly diminishes measurement capabilities.

Alternatively, ultrasonic meters do not rely on water velocity for robust SNR. This is because ultrasonic meters use sound waves to measure water and the strength of sound waves does not depend on the water's velocity. Ultrasonic meters use transducers to generate a sound wave that travels with the flow of water and another one that travels against the flow of water. The difference in travel time between the two sound waves is proportional to the water velocity. Unlike electromagnetic meters, ultrasonic meters generate consistent signal strength (typically 1MHz) regardless of water velocity. The limitation of ultrasonic meters lies with the onboard computer's ability to calculate extremely small differences in the travel time of soundwaves (trillionths of a second). Well-defined algorithms can efficiently compute these extremely small periods of time, making ultrasonic meters the most well-suited technology for accurately capturing low flows.

Regardless of the technology, very low flow rates can be difficult to measure accurately. Therefore, AWWA allows a lower level of accuracy for measurements between the lower bound of the normal range and the low flow rate. As previously outlined in Figure 1, the AWWA low flow accuracy requirements for residential meter types are outside the 98.5-101.5% range.

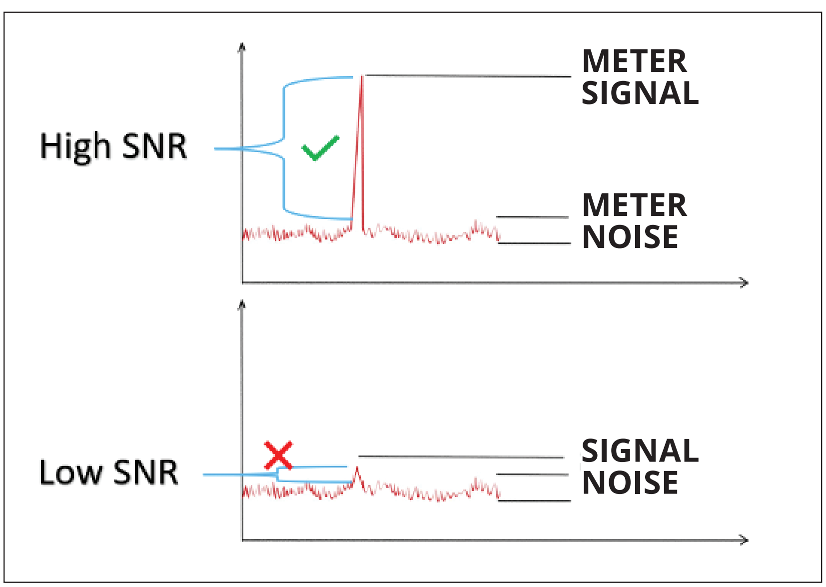

Figure 3: *Comparison of a high and low signal-to-noise ratio (SNR)*

Meter Type	Low Flow Accuracy Req.	AWWA Standard
Displacement	95-101%	C700, C710
Multijet	97-103%	C708
Singlejet	95-101.5%	C712
Fluidic-Oscillator	95-101.5%	C713
Mechanical Fire Service, Residential	95-103%	C714
Solid State, Type I & II	95-105%	C715

Table 1: *Comparison of residential meter low flow accuracy standards identified in the latest M6 Manual (excluding repaired)*

As shown in Table 1 however, accuracy requirements for different measurement technologies vary. This is in part due to the measuring capabilities of different metering technologies. For example, AWWA requires the minimum test flow of a ⅝" mulitjet be 0.25gpm while for a newer type I solid state, it is 0.13gpm. In this case, the solid state meter is expected to measure almost twice as low as the multijet meter but has a wider accuracy allowance (+/-2%).

Despite this extra allowance for solid state meters, some manufacturers choose to hold themselves to a higher standard of accuracy. An example of this would be meters that have 100% +/-3% accuracy at low flow instead of accepting AWWA's allowance for a less accurate +/-5%. This additional accuracy means that reported consumption is less likely to be over- or under-billed. To help visualize this difference in accuracy, let's examine the average accuracy of a ⅝" Neptune MACH 10 meter in Figure 4.

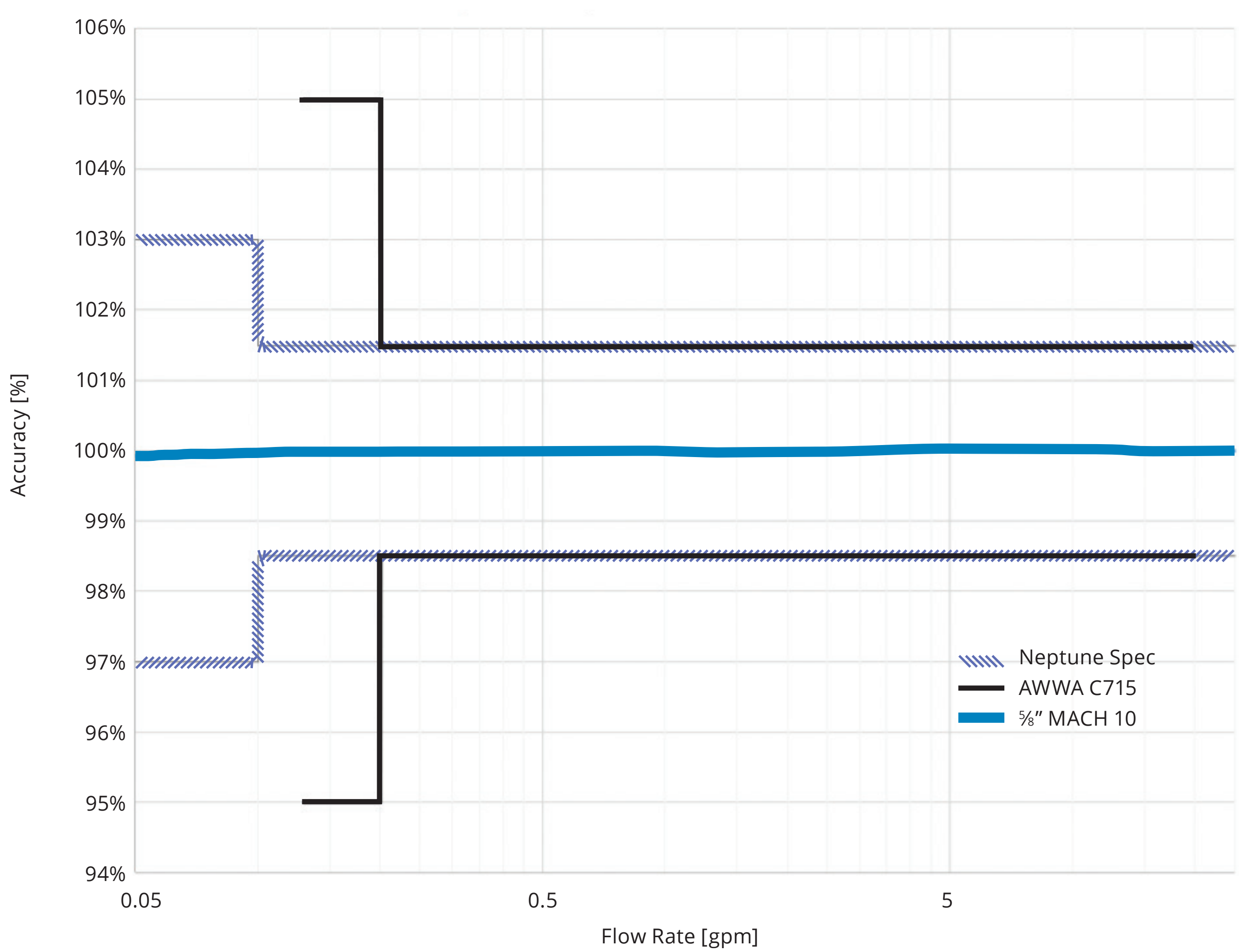

Figure 4: *⅝" Neptune MACH 10 accuracy curve (log scale)*

When the accuracy curve goes up — for example, to 105% — that would represent over-registration, where a customer would be over-billed by 5%. As the accuracy goes down — for example, to 95% — that would indicate under-registration, where the meter did not register actual consumption, meaning a 5% loss in revenue.

The blue line shows the average performance of several ⅝” MACH 10 meters. The average accuracy falls inside both AWWA's requirements of 100% +/- 5% accuracy at low flow and 100% +/- 1.5% at normal flow as well as Neptune's own accuracy bounds, which are more stringent than AWWA's at low flow. This is because Neptune designed its MACH 10 meters to a higher standard of low flow accuracy, measuring between 97% and 103% (100% +/- 3%) versus AWWA's standard of 95% to 105% accuracy (100% +/- 5%).

As previously explained, no manufacturer guarantees accuracy for flows above the normal flow range. The same is also true for flows below the rated low flow. This elicits an important question: is it beneficial to measure water without accuracy in mind?

START FLOW

Start flow describes the flow rate when a meter **starts** to measure water, as opposed to low flow, which is the flow rate when a meter starts to **accurately** measure water.

While minimum test flow (i.e., low flow) and normal test flow accuracy limits are standardized by AWWA, start flow is not recognized in any AWWA literature and therefore has no accuracy standard. This is due in part to the difficulty of accurately measuring water at very low flows, including those below a meter's rated low flow. Only meters with published start flow values offer an accuracy level of 90-110%. However, although the accuracy level of this meter's start flow is published, that accuracy is not guaranteed or covered by any warranty and is a somewhat arbitrary value. This may be due to the fact that properly testing accuracy at such low flow rates would take an impractical amount of time at both the customer site and at the manufacturer in the event of a return. Accuracy is important because it ensures that the utility is not over-billing or losing revenue to unmeasured water. However, any level of accuracy at extremely low flows can help utilities spot leaks.

METER START FLOW AND LEAK DETECTION

The EPA estimates that the average household's leaks can account for nearly 10,000 gallons of water waste every year.[3] Between pipe bursts and various appliance leaks, these 10,000 gallons of waste occur at a variety of different flow rates. For example, a burst ¾” pipe can leak at a rate of 110 gpm, losing 10,000 gallons in 1.5 hours[4]. Alternatively, a faucet leaking at one drip per second can waste more than 3,000 gallons a year, while a showerhead leaking at 10 drips per minute can waste more than 500 gallons a year.[3] These estimates were likely made based on the assumption that the volume of a drop of water is ten-thousands of a gallon (0.0001 gallon), as shown below in Figures 5a and 5b.

$$\frac{1\text{ second}}{1\text{ drip}} \times \frac{1\text{ minute}}{60\text{ seconds}} \times \frac{1\text{ hour}}{60\text{ minutes}} \times \frac{1\text{ day}}{24\text{ hours}} \times \frac{1\text{ year}}{365\text{ days}} \times \frac{3{,}000\text{ gallons}}{1\text{ year}} \approx 0.0001\text{ gallons/drip}$$

Figure 5a: *Size of a drop of water derived from EPA faucet leak estimates*

$$\frac{1\text{ minute}}{10\text{ drips}} \times \frac{1\text{ hour}}{60\text{ minutes}} \times \frac{1\text{ day}}{24\text{ hours}} \times \frac{1\text{ year}}{365\text{ days}} \times \frac{500\text{ gallons}}{1\text{ year}} \approx 0.0001\text{ gallons/drip}$$

Figure 5b: *Size of a drop of water derived from EPA shower head leak estimates*

$$\frac{0.0001 \text{ gallons}}{\text{drip}} \times \frac{1 \text{ drips}}{1 \text{ seconds}} \times \frac{60 \text{ seconds}}{1 \text{ minute}} \approx 0.006 \text{ gallons/minute}$$

Figure 6a: *Flow rate of a faucet leak derived from EPA estimates*

$$\frac{0.0001 \text{ gallons}}{\text{drip}} \times \frac{10 \text{ drips}}{1 \text{ minute}} \approx 0.001 \text{ gallons/minute}$$

Figure 6b: *Flow rate of a shower head leak derived from EPA estimates*

Using this assumed volume, let's look at Figures 6a and 6b to see the rate of water loss for the appliances in the EPA example:

Given the EPA's assumptions, a start flow of 0.001gpm would detect a leaking shower head and a start flow of 0.006gpm would detect a leaking faucet.

THE EXPERIMENT

To test whether start flow may be able to detect one of the EPA-identified leaks, an experiment was performed on ⅝" solid state residential meters from five different manufacturers to determine the lowest possible flow that could be registered.

PROCEDURE:

1. Run a 0.04gpm flow rate through each meter for 20 minutes.
2. For subsequent runs, incrementally reduce flow rate by between 50% to 75%.
3. Repeat this process until all meters measure less than 10% of the test volume (i.e., accuracy ≤ 10%)
4. Meters listed in Table 2 were used as part of the experiment.

RESULTS:

Recall the layout of the accuracy curves previously in Figure 4. In Figure 7, the y-axis now spans from 0% (zero accuracy) to 200% (severe over-registration). The upper and lower accuracy bounds here were set at an extended +/-10%. For reference, on the far right we can see the +/-3% channel from Figure 4.

Duly noting that the sample size of this experiment was small, the results of this experiment compiled in Figure 7 show the Neptune MACH 10 ultrasonic meter (blue) outperforms all of the other meters; it measures approximately 0.0075gpm with 90% accuracy.

Keeping in mind that we have put accuracy aside momentarily, it may be possible to register a single leaking faucet (0.006 gpm) with both the MACH 10 and Kamstrup meters. A single leaking showerhead (0.001 gpm), however, seems likely to go undetected by any of the meters tested.

Make	Model
Neptune	MACH 10®
Kamstrup	flowIQ 2100®
Master Meter	Sonata®
Sensus	iPerl®
Mueller	SSM®
Badger	E-Series®

Table 2: *Meters Tested for Start Flow (MFG 2018 or Newer)*

Now, let's revisit the importance of accuracy. Although it seems a leaky faucet is detectible, the MACH 10 would only register 60% of the leak. the Kamstrup flowIQ® would register even less than 10%. At an annual loss of 3,000 gallons, the MACH 10 may register 1,800 gallons while the flowIQ would report less than 300. Inflating the 2016 average cost of 1,000 gallons of water from $3.38[5] to $4.00, the MACH 10 captures $7.20 annually from the leaky faucet, and the flowIQ less than $1.20.

Water Online estimates that approximately 77% of American households report seeing signs of leaks[6], so it is worth noting that the majority of households will detect and likely fix that leak before much of that captured revenue is realized. So, while a meter *may* be able to measure flow below its rated low flow, due to low accuracy the revenue capture from it is largely negligible.

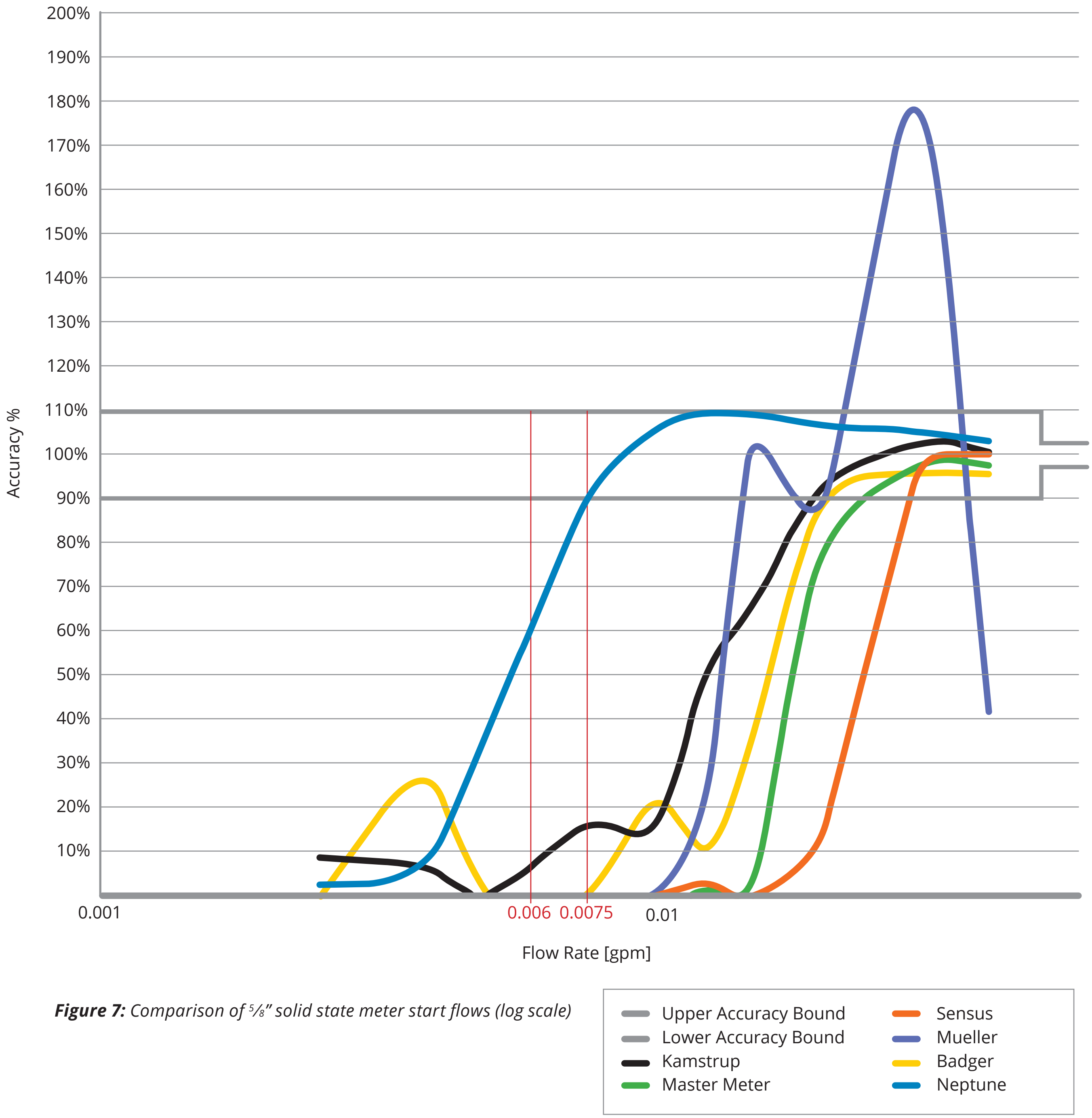

Figure 7: *Comparison of ⅝" solid state meter start flows (log scale)*

CONCLUSION

While common residential leaks, such as a pipe burst and a leaky toilet, would easily be detected by today's solid state meters, smaller leaks from faucets and showerheads may be undetectable. The water lost at these very low flows is minimal compared to larger leaks such as pipe bursts. In the interest of minimizing Non-Revenue Water with limited resources, utilities would be wise to prioritize large leaks and proactive maintenance over small residential losses.

While measuring low flow is important, the revenue capture from start flows adds very little value to a meter's payback schedule. Low flow capabilities, as defined by AWWA, are a far better metric to judge value capture. In fact, based on the EPA estimate that 10% of homes in the United States leak 90 gallons or more per day, nearly half (~460 billion) of the 1 trillion residential leaks that occur in a year[1] can be captured by meters capable of measuring 0.06 gpm. See Figures 8a and 8b below.

Based on these estimates, low flow meters like the MACH 10, which can measure 0.05 gpm at +/- 3% accuracy, are capable of capturing at least 46% of residential leaks by volume. Pipe bursts and other higher flow leaks like leaky toilets occur at much higher flow rates, and likely make up the majority of the remaining 54% of lost water. Leaking faucets and dripping showerheads account for very little water loss in comparison and, as we saw above, will go undetected regardless of start flow capabilities.

New metering technologies provide utilities with the tools to more effectively capture leaks and reduce Non-Revenue Water. And there are potentially billions of gallons of water yet to be captured in leaks. However, start flow may not yet be developed enough to aid in the battle. As the market continues to adopt solid state meters, there will be improvement, but for now, utilities should feel confident about prioritizing resources for larger leak events and accurately capturing residential flow at 0.06gpm.

$$\frac{\text{90 gallons lost}}{\text{1 day}} \times \frac{\text{1 days}}{\text{24 hours}} \times \frac{\text{1 hour}}{\text{60 minutes}} \approx \text{0.06 gallons/minute}$$

Figure 8a: *Flow Rate of Leaks in 10% of Homes (EPA Estimate)*

$$\text{140 million homes}^{7} \times 10\% \times \frac{\text{90 gallons lost}}{\text{1 day}} \times \frac{\text{365 days}}{\text{1 year}} \approx \text{460 billion residential gallons lost/year}$$

Figure 8b: *Annualized Water Loss of 10% of Homes (EPA Estimated)*

Sources:

1. IWA Publishing, Aqua — An experimental analysis on accuracy of customer water meters under various flow rates and water pressures Feb. 2020

2. City of Daytona Beach, FL — High Consumption

3. United States Environmental Protection Agency (EPA) — Fix a Leak Week

4. North Texas Municipal Water District — Broken Pipes and Water Leaks Can Waste Thousands of Gallons Feb. 2021

5. U.S. Department of Energy — Water and Wastewater Annual Price Escalation Rates for Selected Cities across the United States Sept. 2017

6. Water Online — American Water Addresses Most Common Household Leaks During Fix a Leak Week Mar. 2021

7. Data Commons – U.S. Census Bureau 2022

NEPTUNE TECHNOLOGY GROUP

#winyourday
neptunetg.com

Neptune Technology Group
1600 Alabama Highway 229
Tallassee, AL 36078
800-633-8754 f 334-283-7293