The Case for Keeping Residential PD Meters: What 15 Years of Field Data Shows About Ultrasonic Water Meters

A field-data guide for water utilities evaluating meter technology — including when ultrasonic meters win and when they don't

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3 Utilities	**37 Services**	**Results That**	**Published by a**
15 Years of Data	Monitored Long-Term	Contradict Marketing	Meter Manufacturer

The water meter industry has spent 15 years telling utilities that ultrasonic meters outperform PD meters. After reviewing 15 years of real field data, the prevailing narrative is more complicated than you have been led to believe. We follow the data wherever it leads. In this case, it leads somewhere our industry did not expect to go.

About the Author

Lee Gregory is the CEO of RG3 Meter Company, a US manufacturer of positive displacement water meters and authorized distributor of ultrasonic meter technology. RG3 sells both technologies — which means the company has no financial incentive to favor one over the other, and every incentive to help utilities choose correctly.

This guide was prompted by a simple observation: the water utility industry has spent more than a decade being told that ultrasonic meters outperform PD meters and that everyone already knows it — an assertion that has never been backed by independent long-term field data. The Johnson Controls Static Meter Research Project changed that. Fifteen years of continuous field data from three US utilities produced results that contradict the prevailing narrative in ways that every engineer and utility director specifying meter technology should understand.

The findings in this guide are not comfortable for the ultrasonic meter industry. They are, however, accurate. Every claim is followed by a source reference. Where the data is limited or the sample size is small, that limitation is stated explicitly. Utilities are encouraged to conduct their own pilots before making large-scale procurement decisions based on any analysis, including this one.

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Disclosure: *RG3 Meter Company manufactures positive displacement meters and distributes ultrasonic meters. This guide presents field study data and analysis that in some cases favors PD technology and in other cases favors ultrasonic technology. No content has been written to favor RG3's commercial interests over factual accuracy. Utilities are encouraged to conduct their own site-specific pilots before making large-scale procurement decisions based on any third-party analysis, including this one.*

MODULE 1

What Is an Ultrasonic Water Meter?

History, physics, and how they differ from traditional meters

Learning Objectives

- Explain the basic principle of transit-time ultrasonic measurement
- Describe how ultrasonic meters differ from positive displacement and multi-jet meters
- Identify the key historical milestones in static meter development
- Recognize why battery and electronics advances made small ultrasonic meters commercially viable

1.1 A Brief History

The physics behind ultrasonic flow measurement has been understood for nearly two centuries, but practical commercial meters took much longer to arrive. Two parallel technology threads converged to create the meters utilities use today.

Year	Milestone
1832	Michael Faraday demonstrates electromagnetic induction — the principle behind mag meters
1928	German engineer Dr. Oskar Rütten files the first patent for an ultrasonic flow meter
1950	First commercial electromagnetic water meter reaches market
Early 1970s	First commercial ultrasonic flow meters manufactured — large, expensive, industrial use only
2000s	Long-life lithium (thionyl chloride) battery improvements and low-power electronics make sub-1″ static meters viable
2009	First commercially available 5/8″ static residential water meter released
2018	ANSI/AWWA C715 adopted — first standard specifically for EM and ultrasonic revenue meters
2010–present	Johnson Controls Static Meter Research Project — 15-year real-world comparison at three U.S. utilities

Key insight: Both electromagnetic and ultrasonic technologies have existed for over 50 years. It was the long-life lithium (thionyl chloride) battery and advances in low-power microprocessors that made them practical for residential utility metering — enabling the extended battery life manufacturers claimed the market required.

1.2 The Two Families of Static Meters

The word “static” simply means no moving parts. There are two main types in water utility use:

Type	Measurement Principle	Common Products
Ultrasonic (Transit-Time)	Sound waves sent upstream and downstream; time difference = flow velocity	Badger E-Series, Neptune MACH 10, Master Meter Sonata, Spire SpireTap, Kamstrup FlowIQ
Electromagnetic (Mag Meter)	Magnetic field across pipe; conductive water generates voltage proportional to flow	Sensus iPERL, Mag variants
Ultrasonic (Doppler)	Sound bounces off particles/bubbles; frequency shift = flow. NOT for potable water revenue metering.	Industrial and wastewater only

This curriculum focuses on transit-time ultrasonic meters, the most widely deployed type in municipal and rural water utility applications.

1.3 How Transit-Time Ultrasonic Technology Works

Analogy: Imagine swimming across a river. Swimming with the current gets you to the far bank faster than swimming against it. The ‘time saved’ by the current tells you exactly how fast the river is flowing. An ultrasonic meter does precisely this — but with sound waves instead of a swimmer.

In technical terms:

- Two piezoelectric transducers are mounted in the meter body, one upstream and one downstream
- The meter fires ultrasonic pulses alternately with and against the flow direction
- When water flows, downstream pulses arrive faster than upstream pulses
- The processor measures the transit-time difference — this is directly proportional to water velocity
- Velocity × pipe cross-sectional area = volumetric flow rate, totalized over time to produce the register reading

Ultrasonic meters do NOT measure the velocity of particles or bubbles. They measure the velocity of the water itself. This distinguishes them from Doppler meters, which require suspended solids and are not used for potable water revenue metering.

1.4 How Ultrasonic Meters Differ from Traditional Meters

Characteristic	Positive Displacement (PD)	Ultrasonic (Transit-Time)
How it measures	Water physically moves a piston or disk, driving the register	Sound waves measure velocity — no physical displacement required
Moving parts	Yes — piston, nutating disk, or oscillating piston	None
Wear over time	Friction degrades accuracy over time, especially at low flow; mechanical wear can only cause under-registration — the measuring chamber cannot physically displace more volume than passes through it	No mechanical wear; however, deposits on transducer surfaces can cause either over-registration or under-registration depending on how they affect the acoustic signal path
Low-flow accuracy	~1/8 gpm start for new meters; degrades with age	1/33 gpm or better; maintained through meter life
High-flow accuracy	Generally accurate — physical displacement is reliable	May be slightly less accurate than PD at peak high flows per JAWWA 2016
Mineral scale / hard water	Scale builds on chamber walls and measuring disc, altering effective displacement volume. Can cause under-registration that grows over time in hard water. Mechanical wear can only cause under-registration — the chamber cannot displace more volume than passes through it.	Scale deposits on transducer faces and acoustic reflectors alter the acoustic signal path, requiring increasing gain compensation (AGC) over time. Can cause either over- or under-registration depending on how deposits affect signal timing — unlike PD meters, scale effects on static meters are not uni-directional. The Glendale study gap narrowed in later years (peak 8.86% in 2019; average 5.02% from May 2022–December 2024), consistent with scale eventually affecting both meter types.
Sand and particles	Can score or jam moving parts	Unaffected by most particles
Tampering resistance	Modern encoder registers are not meaningfully affected by magnets; very strong fields that could affect a PD encoder would also risk affecting static meter electronics. Bypass risk exists for both meter types in poorly monitored installations.	Fully potted electronics; backflow detection built in. Both modern PD and static meters have comparable tamper resistance through encoder design — the old vulnerability of mechanical registers to magnets does not apply to current products.
Maintenance	Seals, gaskets, moving parts may need service	No moving parts to service, but complete replacement required at battery end-of-life; claimed 20-year service life is not yet independently validated in the field
Power	Mechanical — no battery for basic register	Lithium thionyl chloride battery; manufacturer-claimed 20-year life (first residential units available 2009; long-term independent field validation not yet available)

MODULE 2

What the Research Actually Shows

15 years of real-world field data from the Johnson Controls Static Meter Research Project (2010–present, ongoing)

Learning Objectives

- Understand the design and methodology of a rigorous long-term field study
- Interpret the three site outcomes and explain why they differ
- Explain why water hardness is a critical variable in meter selection
- Describe the seasonal accuracy pattern (summer vs. winter) observed across multiple sites
- Evaluate the leak detection capability of ultrasonic meters based on documented field data, including the conditions under which that advantage is and is not meaningful

2.1 Study Background

In December 2010, Johnson Controls engineer Craig C. Hannah, P.E. began what has become the longest-running real-world field comparison of static and displacement water meters ever conducted — now spanning more than 15 years and still active. The study has run continuously since 2010, tracking actual billed hourly usage data at the same residential services across three U.S. utilities, and continues today. The analysis in this guide reflects the Q2 2026 data update. Salisbury and Olathe figures run through June 30, 2026; Glendale figures run through December 31, 2025, the point at which that utility began decommissioning its study meters. The study is ongoing, with quarterly updates continuing.

The motivating question: Meter manufacturers claimed ultrasonic meters would increase revenue because they measured more accurately at low flows. Is that actually true in real-world residential installations?

Study Design

- Tandem meter setters at each test residence — one static meter in the forward position, one displacement meter in the aft, measuring the exact same water simultaneously
- Hourly AMI data collected at all three utilities — the study author described this data granularity as “a critical factor in the success of this research project”
- Tandem setter arrangements validated at the Utah Water Research Laboratory to confirm no cross-influence between the two meters in series
- Data analyzed quarterly across more than 15 continuous years — the study is ongoing

2.2 The Three Sites

Site	State	Meters Compared	Start	Services	Water Hardness
Olathe Municipal Services	KS	Sensus iPERL (static) vs. Sensus SR II (PD)	Dec 2010	22 (21 active)	Hard — 180 ppm
Glendale Water & Power	CA	Badger E-Series (Ultrasonic) vs. Badger M-35 (PD)	Jun 2012	5	Very hard — 205 ppm
Salisbury-Rowan Utilities	NC	Badger E-Series (Ultrasonic) vs. Badger M-25 (PD)	Sep 2012	10	Soft — 30 ppm

2.3 Salisbury, North Carolina — 5/8″ × 3/4″ Meters in Soft Water

We begin with the standard U.S. residential meter — the 5/8″ × 3/4″ size that accounts for the vast majority of installations — because that is where the industry's claims matter most. Salisbury is the counterintuitive result that separates careful research from manufacturer marketing claims. In soft water (30 ppm $CaCO_3$), with the standard 5/8″ × 3/4″ residential meter size:

Metric	Value
Period	Sep 2012 – Jun 2026 (Q2 2026 update; study ongoing, with data gaps)
E-Series total usage	4,225,161 gallons
M-25 total usage	4,265,915 gallons
Displacement registered MORE by	40,755 gallons / 0.96% in FAVOR of PD
Average monthly % difference	1.82% in favor of PD (monthly average)
Services where PD registered more	6 of 10 services, consistently

CRITICAL FINDING	In soft water with 5/8″ × 3/4″ meters, the displacement meters registered MORE than the ultrasonic meters — the exact opposite of manufacturer claims. The difference is small (~1%), but consistent across nearly 14 years of data. This is not a failure of ultrasonic technology; it is a nuanced finding about meter size, water quality, and usage patterns that every honest distributor must understand.

2.4 Olathe, Kansas — 5/8″ Electromagnetic Meters in Hard Water

Olathe uses electromagnetic (not ultrasonic) static meters in a hard water environment with a 5/8″ × 1/2″ meter (smaller thread connections than the standard 5/8″ × 3/4″):

Metric	Value
Period	Dec 2010 – Jun 2026 (15+ years; Q2 2026 update, study ongoing)
iPERL total usage	2,250,536 CF
SR II total usage	2,246,267 CF
Total difference	4,269 CF / 31,937 gallons / 0.19% in favor of EM
Services within ±2% difference	13 of 21 (62%)
Average monthly % difference	0.34%

Olathe is the clearest result in the study: across 21 active services in hard water (180 ppm) over 15 years, the static meter and PD meter performed essentially identically. The 0.19% aggregate difference is negligible. More telling is the account-by-account distribution: of 21 active services, only 4 showed the static meter registering 2% or more above the PD meter and only 4 showed the PD meter 2% or more above the static meter — the other 13 fell within ±2%, essentially indistinguishable. Several static meter accounts registered well above the cluster, and over-registration is the more probable explanation for them — for a mechanical reason a skeptic can check. A positive-displacement meter cannot over-register: its measuring chamber displaces a fixed volume per cycle, so it can only count water that physically passes through it. Its error is therefore one-directional (it reads low, never high) and accrues gradually as parts wear or the chamber fouls, or the meter stops outright. A static meter has no such constraint — uneven mineral fouling of its sensing elements (electrode or bore fouling in an electromagnetic meter, or transducer and reflector deposits in an ultrasonic meter) or a gain/algorithm artifact can bias the reading high, often as an abrupt step rather than a slow drift. When one technology can only read low and the other can read either way, a cluster of high static outliers points to static over-registration far more readily than to matching PD under-registration. Notably, the 5/8″ × 1/2″ thread connections restrict maximum flow more than the standard 5/8″ × 3/4″, placing the PD meter at a structural disadvantage since PD performs better at higher flow rates. Despite this, PD matched the static meter.

2.5 Glendale, California — Full 3/4″ Meters in Hard Water

Having seen PD meters hold their own at the standard residential size in both soft water (Salisbury) and hard water (Olathe), we turn to the one combination where static meters do show a clear registration advantage — and to why it is the exception rather than the rule. Glendale tests full 3/4″ meters in very hard water (205 ppm) — the one site in the study that uses a larger-than-standard meter size. It is significant precisely because it is the only site, and the only meter size, where static meters registered clearly more than PD meters across the study period. As Module 3 explains, that result is driven by the non-standard bore size and the hard water, not by a general superiority of ultrasonic technology.

Metric	Value
Period	June 2012 – December 2025 (4,961 days; Glendale meters decommissioned after December 2025)
E-Series total usage	991,726 CF (7,418.6 thousand gallons)
M-35 total usage	953,238 CF (7,130.7 thousand gallons)
Ultrasonic registered MORE by	38,488 CF / 287,900 gallons / 3.88% total
Average monthly % difference	3.64% in favor of ultrasonic
Months where M-35 registered more	Only 36 of 815 monthly records (4.4% of the time)

KEY FINDING	In Glendale's hard water (205 ppm $CaCO_3$), the ultrasonic meters registered more water than the displacement meters by an average of 3.64% per month across the study period to date, using a full 3/4″ meter — a larger-than-standard size not used at the other two sites. The gap was small in the early years, widened substantially beginning in 2017 and peaked at 8.86% in February 2019, then narrowed to an average of 5.02% from May 2022 through December 2024. The narrowing in the most recent years is significant: if scale were affecting only the PD meter with no effect on the static meter, the gap would be expected to hold steady or continue growing. The fact that it shrank suggests scale deposits eventually affected the static meter transducers as well — reducing their sensitivity and bringing the registration gap back toward zero. This is consistent with the known mechanism by which mineral deposits on transducer faces alter the acoustic signal path. The data does not allow a precise determination of how much of the gap at any point reflects PD under-registration, static over-registration, or both — billing data alone cannot separate these effects. Because the study is ongoing rather than closed, it has also captured episodes a one-time snapshot would miss: in January–March 2025, several Glendale services (Downing, First, and Cedar) recorded the displacement meters registering more than the static meters — a reversal of the site's long-run pattern, and further reason to treat the static advantage as conditional rather than permanent.

The gap was below 3.5% for the first four-and-a-half years (2012–early 2017). Beginning February 2017, the difference widened substantially and peaked at 8.86% in February 2019. From May 2022 through December 2024, however, the average difference decreased to 5.02%. This narrowing in the most recent years is significant: if the widening gap had been caused solely by PD scale degradation with no effect on the static meter, the gap would be expected to continue growing or hold steady. The narrowing suggests that scale deposits eventually affected the static meter transducers as well — consistent with the known mechanism by which mineral deposits on transducer faces or reflectors can reduce signal sensitivity and cause under-registration. In very hard water over long time frames, both meter types appear to be affected by scale, with the timing and direction of that effect differing.

Seasonal pattern: The percent difference consistently decreases during summer months (June–August). Research published in the June 2016 Journal AWWA confirms displacement meters are more accurate than static meters at high flow rates — and summer usage includes more high-flow irrigation events.

2.6 Leak Detection — Where Ultrasonic Genuinely Wins, and Why It Doesn’t Decide the Verdict

There is one capability where ultrasonic meters genuinely and unambiguously outperform PD meters: detecting very low-flow residential leaks. This advantage is real and well-documented in the field data below. What follows it — the reason this section comes after the site results rather than leading them — is the equally important point that leak detection alone does not make ultrasonic the better revenue meter overall. The study documented confirmed residential leaks at two sites and compared how each meter type registered the leak flow. The results were consistent and striking.

At Cedar Street (Glendale), a leak ran from October 2016 through September 2017. Analysis of overnight hours (midnight, 3 AM, 5 AM — when there should be no household use) showed:

- January 2017: E-Series registered 21.93% more than M-35 during leak hours
- February 2017: 21.73% more
- March 2017: 33.31% more — the leak was growing and the PD meter was increasingly unable to register it

At Service 1327 (Salisbury), a leak began November 28, 2017. Hourly plots showed the E-Series ultrasonic meter immediately registering a continuous baseline flow consistent with a running leak, while the M-25 displacement meter showed near-zero during the same overnight hours.

WHY IT MATTERS	A leak at 0.05–0.15 gpm is below the start threshold of most PD meters but within an ultrasonic meter’s measurement range. An AMI system can identify potential leak patterns from overnight flow data. The practical value depends entirely on prompt utility action: a detected leak that is not reported and repaired quickly produces no billing advantage over a meter that missed it. The primary benefit is customer notification and water conservation.

Putting this in perspective: leak detection is a real ultrasonic advantage, but it is not by itself a revenue argument, and it does not decide the overall comparison. The extra water an ultrasonic meter captures during a leak is only “won” for as long as the leak runs unaddressed — and the entire purpose of AMI-based leak alerting is to get that leak found and fixed quickly. Once the utility notifies the customer and the leak is repaired, the billable-revenue difference between the two meter types collapses back to the small, size-dependent gap documented at the three study sites. The genuine value of ultrasonic leak detection is therefore customer service, conservation, and avoided property damage — not incremental revenue. On the central question of this guide — which technology measures normal residential consumption more accurately over its service life — leak detection does not move the verdict, which at standard meter sizes is settled by the Salisbury and Olathe results.

2.7 Financial Implications Summary

The tables below show, account by account, which meter registered more water and by how much. Because the static meter and the PD meter measure the same water in series at each home, “registered more” simply tells you which of the two counted more of that water, and “gap” is how much more, expressed as a percent. Dollar impact is summarized separately at the site level (below) using the 2023 EPA WaterSense combined water-plus-wastewater rate of $15.21 per 1,000 gallons. Aggregate site totals are useful for orientation but can be skewed by a few outlier accounts; the account-by-account view is more complete.

Glendale, CA — Per-Account Results

Full 3/4" meters · 205 ppm $CaCO_3$ · June 2012–December 2025 · ~13.6 years · all five services: the static (ultrasonic) meter registered more

Service	Ultrasonic / E-Series (CF)	PD / M-35 (CF)	Difference (CF)	Registered more	Gap
Vassar	87,650	85,969	1,681	Static (ultrasonic)	1.92%
Downing	243,466	230,734	12,733	Static (ultrasonic)	5.23%
First	153,781	150,007	3,774	Static (ultrasonic)	2.45%
Zook	176,032	169,145	6,887	Static (ultrasonic)	3.91%
Cedar	330,797	317,383	13,414	Static (ultrasonic)	4.06%
TOTAL	991,726	953,238	38,488	Static (ultrasonic)	3.88%

All five services show the static meter registering more. Average per static meter: about $876 total over the study, roughly $62 per meter-year. Gap peaked 8.86% (Feb 2019) then narrowed to avg 5.02% (May 2022–Dec 2024), suggesting scale eventually affected both meter types. Only 5 services — a very small sample.

Salisbury, NC — Per-Account Results

5/8" × 3/4" meters · 30 ppm $CaCO_3$ · September 2012–June 2026 · ~13.75 years · 6 of 10 services: the PD meter registered more

Service	Ultrasonic / E-Series (gal)	PD / M-25 (gal)	Difference (gal)	Registered more	Gap
1311	738,798	733,991	4,807	Static (ultrasonic)	0.65%
1312	343,739	348,641	4,903	PD	1.43%
1314	381,933	383,876	1,943	PD	0.51%
1301	441,677	439,765	1,912	Static (ultrasonic)	0.43%
1320	207,134	214,751	7,617	PD	2.21%
1331	428,631	438,106	9,475	PD	1.54%
1327	473,020	472,669	351	Static (ultrasonic)	0.07%
1323	269,573	262,455	7,118	Static (ultrasonic)	2.64%
1317	463,011	479,479	16,468	PD	3.56%
1330	477,644	492,181	14,538	PD	3.04%
TOTAL	4,225,161	4,265,915	40,755	PD	0.96%

6 of 10 services show PD registering more. Service 1323 is the only account consistently showing the static meter ahead — at 2.64% it is the lone static outlier. Service 1317 shows the largest PD advantage (3.56%). Multiple data gaps due to equipment failures and network outages. That attrition is itself relevant: because the study is ongoing, the most recent updates show an accelerating loss of register and endpoint data across both meter types (including a full data void at Salisbury in August 2025, and account 1301 going dark again from April through June 2026), steadily shrinking the active sample — a live caveat on any single-quarter reading.

Olathe, KS — Per-Account Results

5/8" × 1/2" meters · 180 ppm $CaCO_3$ · December 2010–June 2026 · ~15.5 years · The study publishes each service's total percent difference (below) but not per-service volumes, so no per-account dollar figures are estimated here; the validated site aggregate is +0.19% favoring the static (EM) meter.

Account	Registered more	Gap
O	Static (EM)	3.79%
P	Static (EM)	3.54%
G	Static (EM)	2.87%
A	Static (EM)	n/a (see note)
B	Static (EM)	2.12%
H	Static (EM)	1.22%
S	Static (EM)	0.70%
U	Static (EM)	0.59%
T	Static (EM)	0.22%
E	Static (EM)	0.11%
V	PD	0.09%
I	PD	0.02%
Q	PD	0.34%
N	PD	0.36%
R	PD	0.72%
J	PD	1.05%
F	PD	1.28%
W	PD	3.16%
C	PD	3.96%
D	PD	5.64%
K	PD	5.94%
TOTAL (site)	Static (EM)	0.19%

11 of 21 services showed PD registering more; 9 showed static more (Account A's individual figure was not separately published in the Q2 2026 update; the site-level reconciliation places it within ±2%) — 13 of the 21 fall within ±2%, essentially indistinguishable. PD set monthly records in Apr–Jun 2023 (registering 410–473 CF/month more than static). The two largest static-favoring accounts (O +3.79%, P +3.54%) drive most of the positive side, and over-registration is the likelier cause: because a PD meter physically cannot over register and degrades only slowly, an abrupt few-percent static-favoring gap fits a static artifact far better than it fits PD wear.

Site-level aggregates can be skewed by a few outlier accounts. At Olathe, a handful sit well outside the central cluster — most favoring the static meter — and deciding what they mean is not a coin flip, because the two technologies fail differently. A positive-displacement meter cannot over-register: its chamber displaces a fixed volume per cycle, so it counts only water that passes through it. Its error runs one way (low), arriving gradually through wear or fouling, or it stops — it has no way to suddenly read several percent high. A static meter can err in either direction, and an abrupt few-percent step is a recognized static signature: a deposit shifting the acoustic path, or a gain/algorithm artifact, can bias the reading high with no corresponding flow. Since only the static meter can over-register — and do so in a step-like way — a large static-favoring outlier is more likely static over-registration than an equal, slow PD under-registration. This is falsifiable, not rhetorical: bench-check the outlier meters against a reference, or test whether each deviation appeared abruptly (the static signature) rather than drifting in over years. Read that way, the Olathe result — already a tie at 0.19% — likely understates PD rather than overstating it. At Glendale, the gap narrowed recently (5.02% average for May 2022–December 2024, down from an 8.86% peak in February 2019), showing scale eventually affected both types. Treat aggregate figures as directional, not precise; the per-account results give a clearer picture.

Site-Level Financial Summary

Utility	Net usage difference	Favors (registered more)	≈ $ per static meter (study to date)	≈ $ per meter-year
Glendale, CA	287,900 gal	Static (ultrasonic)	$876	$62
Salisbury, NC	40,755 gal	PD	$62	$4
Olathe, KS	31,937 gal	Static (EM)	$23	$1

Dollars use the 2023 EPA WaterSense combined water + wastewater rate of $15.21 per 1,000 gallons. Glendale reproduces the study’s published benefit ($4,379 total ÷ 5 meters); Salisbury and Olathe are computed identically from the net-usage figures above. “Favors” is the meter that registered — and would bill — more water. The per-meter-year figures are small at all three sites, which is the practical point: at standard residential meter sizes the choice of technology makes little revenue difference.

MODULE 3

Why Meter Size Changes Everything

The physics explanation for why ultrasonic advantages vary by bore size and water quality

Learning Objectives

- Understand what a 5/8″ × 3/4″ meter is and how it differs from a full 3/4″
- Explain why the same technology performs differently at different meter sizes
- Apply AWWA residential water use data to understand where the low-flow advantage applies
- Articulate the honest case for ultrasonic meters by meter size and water quality

3.1 Meter Size Designations Explained

Designation	What It Means	Typical Max Flow Rate	Primary Use
5/8″ × 1/2″	5/8″ measuring chamber, 1/2″ connection threads — smallest residential configuration	20–25 gpm	Low-use residential, apartments
5/8″ × 3/4″	5/8″ measuring chamber, 3/4″ connection threads — the most common U.S. residential meter. Same 5/8″ element as the 5/8″×1/2″, so flow capacity is identical; the “×3/4″” denotes the spud size, not a larger chamber.	20–25 gpm	Standard single-family residential
3/4″ × 3/4″ (full 3/4″)	3/4″ NPSM connections, full 3/4″ bore — larger residential or irrigation	30–35 gpm	Higher-use residential, irrigation zones
1″	1″ connections and bore	50–70 gpm	Larger homes, small commercial
1.5″ and above	C&I (commercial & industrial) sizes	100–160+ gpm	Commercial, industrial, fire service

3.2 Why the 5/8″ × 3/4″ Result Surprised Everyone

The Salisbury finding — that PD meters registered slightly more than ultrasonic meters in soft water — contradicts the original marketing claims. The explanation requires understanding the flow profile of a typical residence.

The 1993 AWWA Research Foundation study (Bowen et al.) documented residential water use flow patterns across five U.S. cities. The data reveals where each meter technology has its advantage:

Flow Range	% of Total Residential Usage	Notes
Below 1/8 gpm (0 to 0.125 gpm)	~6.8%	Below PD start threshold — only ultrasonic can measure this range
1/8 to 1/4 gpm	~2.0%	Marginal zone — PD meters may register inconsistently
1/4 to 1 gpm	~4.3%	Both accurate when new; PD accuracy degrades with age in hard water

Flow Range	% of Total Residential Usage	Notes
1–8 gpm	~80%	Both meter types accurate; PD may be slightly better at the upper end
8–25 gpm	~6.6%	Both accurate; PD may be slightly better at high flows (JAWWA 2016)
Above 25 gpm	~0.2%	Both accurate; exceeds normal residential usage

The key insight: At 5/8″ × 3/4″ meter sizes, the flow range where ultrasonic has an exclusive advantage (below 1/8 gpm) represents only about 6–8% of total residential usage. To put this in perspective: on an account using 5,000 gallons per month, the ultrasonic advantage zone represents roughly 300–400 gallons. Meanwhile, flow above 8 gpm — where PD performs as well or better (JAWWA 2016) — represents a comparable share, about 7% of usage, or roughly 350 gallons on the same account. Because the two zones are similar in size, the ultrasonic low-flow advantage and the PD high-flow advantage roughly offset each other at this meter size. This is precisely what the field data at Salisbury and Olathe demonstrated: in standard residential meter sizes, PD meters held their own or outperformed static meters.

3.3 Why Full 3/4″ and Larger Meters Favor Ultrasonic More Strongly

The picture changes significantly at full 3/4″ and larger meter sizes. Three factors explain this:

Factor 1: Higher absolute volume amplifies small percentage differences

A full 3/4″ meter passes more water per unit time at any given flow rate than a 5/8″ × 3/4″ meter due to the larger bore. Small percentage differences at low flows compound into larger volume differences over the meter's service life.

Factor 2: Commercial and industrial low-flow profiles

Larger meters (1″, 1.5″, 2″ and above) often serve accounts with cooling towers, restrooms, cafeteria equipment, and process water — all of which generate frequent overnight and weekend low-flow usage. These profiles substantially increase the share of flow in the ultrasonic advantage zone.

Factor 3: Scale effects compound at larger sizes in hard water

The absolute volume of mineral-rich water flowing through a full 3/4″ meter per year is greater than through a 5/8″ × 3/4″ meter. The Glendale study showed a 3.88% registration difference favoring the static meter at this larger size in hard water. Salisbury used the same ultrasonic meter model in the standard 5/8″ × 3/4″ size and showed a 0.96% difference in the opposite direction — favoring PD. Meter size appears to be a significant factor in the outcome.

3.4 Unbiased Guidance by Application

Scenario	Revenue Advantage	Recommended Approach
5/8″ × 3/4″ in soft water (<75 ppm)	Minimal to none	Neither technology has a clear revenue registration argument in soft water — selection should be based on other factors such as maintenance preferences, meter availability, and local pricing. Static meters have no moving parts and require no mechanical maintenance over their service life. PD meters have a well-documented field service life of 25+ years based on real utility data (Hughes/American Water, Kansas City Water Services). Both factors are meaningful considerations in total cost of ownership at this size and water quality.
5/8″ × 3/4″ in hard water (>150 ppm)	Minimal to none	Results at this size in hard water were essentially identical between the two technologies, though hard water has shown a greater impact on static meter accuracy in other study areas. Since no clear registration advantage exists here, other purchasing factors deserve equal consideration — including the maintenance-free design of static meters and the longer proven service life of PD meters documented at 25+ years in real utility deployments.
Full 3/4″ in hard water	Static meters	Glendale is the only data point for this combination and all 5 services favored static meters. The registration advantage is meaningful at this size in hard water, though the gap narrowed in the most recent years as scale affected both meter types. Static meters appear to be the stronger choice on registration performance at this size and hardness level, based on one study site with 5 services — a limited sample that warrants a site-specific pilot before large-scale deployment decisions. PD meters retain the longevity advantage at 25+ years of documented service life. Utilities should weigh the registration and maintenance advantages of static meters against the longer proven service life of PD meters.
Any size — leak detection	Static meters	Static meters can register flow below the PD start threshold (~1/8 gpm); leaks above that rate are detectable by either technology. The practical significance of the sub-threshold advantage depends on the actual flow rate of leaks at a given utility — this was not quantified in the study. This static meter advantage is minimized if utilities address leaks as they are discovered.

The field data from this 15-year study does not support a blanket claim that ultrasonic meters outperform mechanical meters. In two of the three study sites, PD meters performed equally or better. The one site where static meters showed a clear advantage used a non-standard, larger meter size in very hard water. Meter selection should be based on the actual conditions at the specific utility.

MODULE 4

Procurement, Specifications & Lifecycle Economics

How to evaluate, specify, and buy ultrasonic meters correctly

Learning Objectives

- Understand what ANSI/AWWA C715 governs — and its important limitations
- Identify the critical elements of a good bid specification
- Calculate a total cost of ownership comparison that goes beyond unit price
- Describe a defensible pilot program methodology based on the Johnson Controls study design

4.1 Understanding ANSI/AWWA C715

C715 Covers	C715 Does NOT Cover
Two performance classes (Type 1 and Type 2) with defined accuracy at specified flow rates	Meter-to-meter repeatability within a production run
Test flow rates for initial accuracy verification	Long-term field accuracy over the meter's service life
Pressure loss limits	Battery life requirements beyond minimum performance
Operating and storage temperature ranges	AMI/AMR endpoint specifications or communication protocols
Lead-free material compliance (NSF/ANSI 61 and 372)	Installation practices (covered by M6 Manual and manufacturer guides)
Marking and identification requirements	Software or data management system requirements

A meter passing C715 factory testing tells you it was accurate when it left the plant. It does not guarantee long term field performance in your specific water quality conditions. The Johnson Controls study is one of the very few real-world long-term data sets that addresses how meters actually perform over time.

4.2 Critical Specification Requirements

Common weaknesses in utility meter bid specifications:

- Specifying a brand name without also specifying performance requirements — this eliminates competition
- Using C715 as the only accuracy requirement without specifying minimum start flow threshold
- Not specifying battery life requirements
- Not specifying AMI/AMR compatibility requirements alongside the meter specification
- Not requiring factory test certificates per lot delivered

Essential specification elements:

1. **Meter technology:** Specify ultrasonic transit-time if that is the intent. "Solid state" is generic and could include electromagnetic.
2. **Accuracy class:** C715 Type 1 or Type 2 with defined normal flow range and extended low flow accuracy.

3. **Minimum start flow:** Specify (e.g., 0.03 gpm for 5/8″ meters).
4. **Sampling rate and low-flow behavior:** Require the vendor to state the meter's effective sampling rate and how the meter behaves during low-flow and no-flow periods — continuous high-rate sampling versus a duty-cycled wake-on-flow scheme. Sampling rate is a direct accuracy variable: the transit-time difference shrinks to picoseconds near zero flow, so a higher effective sampling rate is what allows the meter to resolve very low flows and short-duration draws. Solid-state meters sampling too slowly can under-register brief, intermittent consumption events by a meaningful margin under worst-case synchronization. [26] Specify a minimum effective sampling rate (or a minimum resolvable event duration) for your application, and require the vendor to disclose the sampling rate assumed in its battery-life rating — because higher sampling rates and aggressive leak-detection modes draw more power and shorten that rating. The right specification balances the accuracy you need at low flow against the battery life you require.
5. **Metal or Composite Construction:** Lead-free per NSF/ANSI 61 and 372 and Safe Drinking Water Act is a minimum. Identify which components of the meter body and acoustic path boundary are metal vs. polymer. For polymer or composite-bodied meters, request the published creep-modulus at ten-year load duration from the resin manufacturer's own datasheet (not the meter manufacturer's spec sheet). Ask for chloramine-resistance data at field temperatures beyond standard short-term certification. If stainless steel is offered, confirm the grade — 316 (molybdenum-bearing) is appropriate for chloride-bearing water; 304 is not equivalent. [20]
6. **Battery life:** Minimum X years at a specified duty cycle and temperature, stated for the specific endpoint configuration you intend to purchase and at your planned transmission interval — not the maximum figure on the datasheet. Remember battery life is typically calculated at 70°F nominal; realized life will differ from the published figure whenever your installation temperatures deviate from 70°F, and self-discharge accelerates in hot pits.
7. **Environmental rating:** IP-68 submersibility for pit installations.
8. **AMI/AMR compatibility:** Specify acceptable endpoint types and communication protocols.
9. **Radio integration and battery source:** State explicitly whether an integrated radio that shares the meter's measurement battery is acceptable, or whether you require a separate endpoint with its own independent power source. This is one of the largest single determinants of realistic service life. When the radio is separate and self-powered, the meter cell powers only the measurement electronics, and the long battery-life claim is far more defensible. When the radio is integrated and shares the meter cell, every transmission draws from the same battery that fires the transducers and runs the processor, pulling realized life below the rated figure — most severely for integrated cellular (LTE-M / Cat-M1) endpoints, which are the highest-power load. If you allow an integrated radio, require: (a) the battery-life rating for that exact endpoint and transmission interval, not a best-case number; (b) confirmation of whether transmission pulses are delivered by a hybrid layer capacitor or drawn directly from the main cell (the latter shortens life); and (c) the operating band, since unlicensed 902–928 MHz endpoints carry FCC Part 15 channel-scanning overhead on every transmission that licensed-frequency endpoints do not.
10. **Warranty:** Request manufacturer warranty terms in writing; compare coverage, not just period.
11. **Testing:** Require factory test certificates; reserve the right to submit samples to a NVLAP-accredited laboratory (e.g., Utah Water Research Laboratory).

4.3 Total Cost of Ownership

Cost Element	Ultrasonic / Static	Positive Displacement
Unit cost (meter + endpoint)	Approximately $0–$30 per unit premium over encoder-equipped PD at utility volume pricing.	Lower initial unit cost
Maintenance over 20 years	Minimal — no moving parts to service, but complete meter replacement required when battery is exhausted	Real world data shows maintenance is minimal to none for 25+ years in most installations. Suspended solids can lodge in the measuring chamber and stop registration entirely — this is detectable as a no-usage condition and requires cleaning the internal measuring chamber.
Accuracy over meter life	Theoretically maintained through battery life, though not yet validated by a full-life field record (first residential units in USA 2009). Field data shows scale deposits on transducer faces can affect accuracy over time in hard water — the direction can be either over- or under-registration depending on how deposits alter the acoustic signal path.	Gradual degradation, especially at low flow and in hard water; increases non-revenue water. Degradation is uni-directional — mechanical wear can only cause under-registration, never over-registration.
Leak detection value	Can register flow below the PD start threshold (~1/8 gpm), enabling detection of very low-flow leaks invisible to PD meters. Leaks above that threshold are detectable by either technology.	May miss leaks running below the start threshold (~1/8 gpm). Leaks above that flow rate are detectable regardless of meter technology. The practical significance depends on the flow rate of actual leaks at a given utility and how quickly the leak is addressed.
End-of-life	Complete replacement required at battery end-of-life; manufacturer-claimed 20-year life not validated in the field (first residential units in USA 2009)	Service life of 25+ years documented in real utility deployments. Many PD meter designs allow the measuring chamber to be rebuilt or replaced independently of the meter body, reducing replacement cost.

Appendix A: Glossary of Key Terms

Term	Definition
ANSI/AWWA C715	The AWWA standard for cold-water electromagnetic and ultrasonic meters for revenue applications. Adopted 2018, reaffirmed 2022. Defines Type 1 and Type 2 performance classes.
AMI (Advanced Metering Infrastructure)	A two-way network transmitting readings, alarms, and diagnostics — typically hourly or more frequently — to a utility head-end system.
AMR (Automated Meter Reading)	One-way mobile, walk-by, or fixed-point radio reading. Less frequent than AMI; does not support real-time alarms.
Empty pipe	A condition where ultrasonic transducers are not fully submerged. Meter does not register flow; alarm is displayed.
Extended low flow	The range between start flow and the bottom of normal operating range. C715 Type 1: ±3% accuracy in this zone.
IP-68	Ingress Protection rating confirming suitability for continuous submersion. Required for meter pit installations.
Lay length	The end-to-end meter body dimension. Ultrasonic meters are built to standard lay lengths for direct mechanical meter replacement.
Non-revenue water (NRW)	Water produced but not billed. Includes real losses (leaks), apparent losses (meter inaccuracy, theft), and administrative losses.
Normal operating range	The main flow range; C715 Type 1 specifies ±1.5% accuracy.
NSF/ANSI 61	Standard for drinking water component health effects — confirms materials do not leach harmful substances.
NSF/ANSI 372	Lead-free compliance standard for plumbing products. Required by the 2014 SDWA amendment.
Piezoelectric transducer	Component converting electrical signals to ultrasonic waves (and vice versa). Core measurement element of every transit-time meter.
Positive displacement (PD) meter	Measures flow by capturing water in a chamber and displacing a mechanical element (disk, piston). Register driven mechanically.
Safe maximum operating condition (SMOC)	Maximum instantaneous flow rate without damage. For ultrasonic meters this equals maximum continuous flow — no mechanical parts to overload.
Start flow	Minimum flow rate where the meter begins registering. Typically 0.03–0.05 gpm for 5/8″ ultrasonic; ~0.125 gpm for new PD meters.
Static meter	Any water meter using no moving parts — includes both electromagnetic and ultrasonic transit-time technology.
Transit time	Time for an ultrasonic signal to travel from one transducer to the other. The difference between upstream and downstream transit times is proportional to flow velocity.

Appendix B: Key References

- Hannah, Craig C., P.E. Static Meter Research Project — Q2 2026 Update (the data cutoff reflected in this guide). Johnson Controls, Inc., Water Infrastructure Technology Team. Glendale figures run through December 2025 (study meters decommissioned thereafter); Salisbury and Olathe figures run through June 2026. The study is ongoing. Contact Craig.C.Hannah@jci.com.
- American Water Works Association. ANSI/AWWA C715-18 (R2022), Cold-Water Meters — Electromagnetic and Ultrasonic Type for Revenue Applications. Denver, CO: AWWA.
- American Water Works Association. Manual M6 (6th Edition), Water Meters — Selection, Installation, Testing, and Maintenance. Denver, CO: AWWA. Includes 2018 and 2022 C715 Addenda.
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- Sumrak, McKenna L., Michael C. Johnson, and Steven L. Barfuss. “Comparing Low Flow Accuracy of Mechanical and Electronic Meters.” Journal AWWA, June 2016.
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- /Master Meter, Inc. Sonata Installation Guide, Rev. SON-INST-030424. Mansfield, TX: Master Meter, Inc., 2024.
- Neptune Technology Group. MACH 10 Residential Ultrasonic Meter Installation and Maintenance Guide, IM MACH 10 09.2025. Tallassee, AL: Neptune Technology Group, 2025.
- Georgia EPD. Guidelines for Ultrasonic Water Meter Maintenance Program. Atlanta, GA: Georgia Environmental Protection Division, 2013 (revised).

MODULE 7

What Affects Transducer and Sensor Performance

Signal interference, water quality, sample rate, and battery life — the complete field guide

Learning Objectives

- Identify and explain all major physical, chemical, and installation factors that degrade ultrasonic transducer accuracy
- Explain how mineral scale affects the acoustic path and why the effect is cumulative over time
- Describe the relationship between sampling rate and measurement accuracy, especially at low flows
- Understand lithium thionyl chloride battery chemistry and its role in static meter service life
- Apply this knowledge to evaluate vendor claims about meter performance in your specific water quality conditions

About the sources in this guide: Every factual claim is followed by a bracketed reference number [n] keyed to the full citation table at the end. Sources include peer-reviewed journal articles, issued patents, manufacturer technical publications, and engineering reference materials. No claim is sourced solely from a manufacturer's marketing material.

7.1 Mineral Scale and Hard Water Deposits

The mechanism

Calcium carbonate ($CaCO_3$) is the primary mineral that precipitates from hard water onto internal pipe and meter surfaces. It affects ultrasonic meters in two distinct and compounding ways.

First, scale depositing on flow tube walls physically reduces the internal bore diameter. Because the meter's calibration is based on a fixed cross-sectional area, a narrowed bore means the same transit-time difference now corresponds to a lower actual volume — the meter systematically under-reads.

Second, and more technically significant, deposits on or near the transducer faces and acoustic reflectors alter the geometry of the acoustic signal path. When this happens, the actual path angle between transducers no longer matches the angle the meter's algorithm was calibrated for, introducing a systematic error that grows as deposits thicken. [1]

> *[1] US Patent 9,170,140 — Ultrasonic flowmeter with internal surface coating and method. Documents gain compensation applied as deposits accumulate, shows coated meters maintain calibration accuracy longer. Image: image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9170140*

A 2022 peer-reviewed study published in MDPI Sensors confirmed that limescale deposition inside a pipe directly affects the accuracy of guided acoustic wave flow meters. Researchers developed a dual-path compensation method that can detect limescale layer thickness and temperature simultaneously, allowing real-time correction — an approach now incorporated in some advanced meter designs. [2]

[2] Leib, J. et al. "Acoustic Limescale Layer and Temperature Measurement in Ultrasonic Flow Meters." MDPI Sensors, Vol. 22, No. 17, 2022. Full text: pmc.ncbi.nlm.nih.gov/articles/PMC9460453/

Kamstrup, one of the world's largest static meter manufacturers, addresses this directly in their published technical comparison: "There is a risk of calcareous deposits that can change the size of the meter's inner diameter and change the velocity of the water passing the meter. Over time, this will decrease accuracy." They note that composite materials with smooth surfaces minimize deposits considerably compared to metal-bore designs. [3]

[3] Kamstrup A/S. "Ultrasonic Meters vs. Electromagnetic Meters." Published December 2024. kamstrup.com/en-en/insights/ultrasonic-meters-vs-electromagnetic-meters

FIELD NOTE	In the Johnson Controls 15-year study, Glendale CA (205 ppm $CaCO_3$) showed the ultrasonic-vs-PD accuracy gap widening after year 4–5 of service, peaking at 8.86% in February 2019, then narrowing to an average of 5.02% from May 2022 through December 2024. The narrowing in the most recent years is significant: if scale were acting only on the PD meter chamber walls with no effect on the ultrasonic meter, the gap would be expected to hold steady or continue growing. The fact that it shrank suggests scale deposits eventually affected the ultrasonic meter transducers as well. Both meter types appear to be affected by scale in very hard water — the timing and direction of that effect differ, but the billing data does not support concluding that one technology is immune.

How manufacturers mitigate scale

Interior surface coatings: The patent literature documents coating the internal flow tube with materials that resist mineral adhesion — the engineering equivalent of a non-stick surface. Patent 9,170,140 and Patent 10,107,658 both document how coated meters maintain signal strength and calibration accuracy substantially longer than uncoated meters in identical water conditions. [1,4]

[4] US Patent 10,107,658 — Ultrasonic flowmeter with internal surface coating and method (continuation). image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10107658

Acoustic path geometry: The Master Meter Sonata uses a "Z-shape" sonic beam flight pattern with transducers positioned on the side walls of the flow tube rather than the top or bottom. This moves the transducer faces away from the primary deposition zones (the bottom of the tube where gravity concentrates settled minerals). It also changes the acoustic path geometry to reduce sensitivity to reflector surface fouling.

Automatic Gain Control (AGC) and the Battery Constraint

Automatic gain control (AGC) as a deposit compensator: As scale accumulates on internal surfaces, the meter must apply progressively more electronic gain to maintain signal strength. AGC is the electronic mechanism by which an ultrasonic meter compensates for a weakening acoustic signal. As scale deposits accumulate on transducer faces or reflectors, the signal is attenuated — the meter responds by increasing amplification to maintain a usable signal. AGC trending upward over time is an early diagnostic indicator of deposit buildup, but whether that trending is visible to the utility depends entirely on the specific meter model, endpoint protocol, and data management platform. Many deployments do not surface AGC data to the utility at all.

AGC compensation has a practical ceiling imposed by the meter's power budget. Every increase in electronic gain draws more current from the battery. A meter running at elevated AGC to compensate for heavy scale deposits is consuming more power than its battery design assumed — accelerating the depletion of a finite, non-rechargeable power source. Manufacturers must balance the AGC range they allow against the battery life they can claim, which means AGC cannot be increased indefinitely. Once signal attenuation from scale exceeds what the available AGC range can compensate for, the meter either produces measurement errors or triggers a Measurement Error alarm — the point at which scale has degraded accuracy below the recoverable threshold. That point arrives sooner in a meter whose battery is already partially depleted from years of elevated AGC operation.

In hard water applications, ultrasonic meter accuracy is not simply maintained until the battery dies. Scale-driven AGC escalation consumes the power budget faster than the factory design assumed, potentially shortening both the effective accurate service life and the battery life simultaneously. This convergence of acoustic path fouling and accelerated power depletion is not reflected in manufacturer battery life specifications, which are calculated under clean-water, nominal-gain conditions.

KEY POINT	Independent modeling of low-power ultrasonic meter designs found that using an 8,500 mAh lithium battery with a safety factor of 2.0, the modeled meter reached roughly 10 years under its maximum-power assumptions — and that same study projected 20-plus years only under its most favorable low-duty-cycle assumptions: no integrated radio sharing the cell, a conservative sampling rate, and nominal temperature. The 20-year figure, in other words, is an ideal-conditions number. [17] This finding, combined with the AGC-battery interaction described above, means that no ultrasonic meter running on a standard battery is unconditionally designed for 20-year operation. The 20-year claim is achievable only under a specific combination of conditions: clean water with minimal scale accumulation, no AMI or AMR transmission sharing the same battery source, a conservative sampling rate, and near-nominal (70°F) operating temperatures. In hard water with active scale accumulation, a realistic service life is shorter — and the meter provides no visible warning that its power budget is being consumed faster than the design assumed. Utilities should treat the 20-year battery claim as a best-case figure under ideal conditions, not a guaranteed service life. [17]

7.1a Meter Body Material and Acoustic Path Geometry

The meter body material is a factor in long-term ultrasonic accuracy that is separate from scale deposits on transducer surfaces. An ultrasonic meter's measurement depends on a fixed acoustic path length between transducers — the geometry of that path is determined by the meter body. In metal-bodied meters (brass or stainless steel), that path length is dimensionally stable across the full service life. Brass and stainless steel exhibit no measurable creep at potable-water temperatures — their geometry under sustained load does not relax.

In polymer-bodied meters, thermoplastic creep — the slow permanent deformation of plastics under sustained load — can alter the acoustic path geometry over time. Published creep data for unfilled engineering thermoplastics commonly shows apparent-modulus reductions on the order of 30–50% over decade-scale load durations at ordinary service temperatures. Glass-fiber reinforcement substantially reduces this effect — materials such as glass-filled polyphenylene sulfide (PPS) sit well above commodity resins in creep resistance — but even glass-filled PPS has a finite, published creep-modulus decline over decade-scale load duration; the manufacturers' own long-term datasheets show the residual decline. The measuring principle may have no moving parts; the measuring geometry is the body, and in a polymer body that geometry is on a clock.

Because the transducers are fixed to the body, any time-dependent deformation of the body changes the acoustic path length and introduces systematic measurement error. This mechanism is design-dependent, grows with time under load, and must be engineered against and verified — because in a polymer body it is not absent by nature, as it is in metal. Drift in either direction is a departure from the accuracy the utility specified: drift against the utility is an undetected revenue loss; drift in the customer's favor is an over-billing and public-trust problem.

Polymer chemical compatibility is resin-specific. Polyolefins and acetals are documented as vulnerable to chloramine oxidation; PPS ranks among the most chemically resistant resins available. The point is not that all polymers fail in chlorinated water — they do not. The point is that polymer performance must be qualified resin-by-resin against each utility's disinfectant regime, at field temperatures, over field durations, and re-examined if the regime changes mid-deployment. Metals have water-chemistry sensitivities too: dezincification of high-zinc brass in aggressive waters is the textbook case. However, modern no-lead, high-copper meter alloys (silicon-brass and bismuth-copper families, certified to NSF/ANSI 372) largely design dezincification out. For stainless steel, grade selection matters: 316 (molybdenum-bearing) offers substantially greater resistance to pitting and crevice corrosion in chloride-bearing water than 304; a specification that says only "stainless steel" has not yet specified corrosion performance.

The failure mode distinction also matters. Aged polymer characteristically fails by brittle fracture: embrittlement accumulates invisibly and the body is fine until it fractures — a flooded meter pit and an interrupted service. Metal degradation follows corrosion chemistry that is visible, inspectable, and modeled by generations of waterworks experience: wall thinning and weeping joints announce themselves in routine reads and field checks. High-modulus filled resins such as PPS are notch-sensitive and fracture at roughly 1–2% elongation; even the least ductile no-lead copper casting alloys retain elongation an order of magnitude beyond that. The asymmetry is not "suddenly vs. never" — it is predictability.

For utilities evaluating composite or polymer-bodied meters, five specific questions are worth asking the vendor: (1) What is the resin, and what is the published creep modulus at ten-year load duration from the resin manufacturer's datasheet? (2) What is the chloramine-resistance data at field temperatures beyond standard short-term certification? (3) Which components of the pressure boundary and measuring geometry — not merely transducer mounts or internals — are metal? (4) Where stainless construction is offered, which grade — 304 or molybdenum-bearing 316 — and how does it match the utility's chloride levels? (5) If the composite body truly holds accuracy and integrity for twenty years, why does the same manufacturer's catalog offer brass or stainless construction on the larger and commercial sizes?

Note: This section draws on materials science literature and the RG3 Meter Company white paper "Why Meter Body Material Determines Long-Term Accuracy" (June 2026) [20]. RG3 manufactures metal-bodied meters and has a commercial interest in *this argument. Utilities should evaluate body material specifications using independent creep-modulus data from resin manufacturers' own long-term datasheets (e.g., Solvay PPS, BASF Ultrason, Celanese Fortron). For stainless steel grade guidance, consult the utility's water chemistry data against ASTM A276/A276M.*

7.2 Entrained Air and Gas Bubbles

Air bubbles are among the most severe acute interference factors for transit-time ultrasonic meters. The physics is straightforward: the speed of sound in air (~340 m/s) is dramatically lower than in water (~1,500 m/s). Any air bubble present in the acoustic path between the transducers introduces a medium with radically different acoustic properties, scattering or blocking the signal. [5]

[5] US Patent 12,163,817 — Ultrasonic measurement method taking account of the quantity of gas bubbles. Describes the physics of bubble interference and algorithms to compensate. image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/12163817

Peer-reviewed experimental research published in Applied Mechanics and Materials (2014) quantified the relationship: as bubble volume fraction in the flowing liquid increases, measurement error of the ultrasonic flow meter increases. When bubble volume fraction exceeds 1% of the total flow volume, the transit-time difference method becomes substantially compromised. [6]

[6] Wang, W. et al. "The Influence of Bubbles on the Performance of Ultrasonic Flow Meter." Applied Mechanics and Materials, Vol. 678, 2014. scientific.net/AMM.678.285

A separate patent examining gas bubble adhesion inside meter bodies identifies an additional failure mode: when water changes direction at elbows, valves, or meter inlets, the resulting pressure change creates turbulence that causes entrained air to form bubbles that adhere to the inner wall surface of the measurement conduit directly opposite the transducers. Adhered bubbles cause persistent interference even after flow stabilizes. [7]

[7] US Patent 9,297,680 — Ultrasonic flow meter having deterioration suppression in flow rate accuracy. Covers gas bubble adhesion mechanism and design countermeasures. image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9297680

This is why every manufacturer's installation manual requires flushing and purging air before commissioning, and why Neptune's MACH 10 manual specifically states that trapped air can cause the display and endpoint to report values that do not reflect actual usage. The remedy: run sufficient water through the system at reasonable flow rate before recording any initial readings.

7.3 Pipe Lining and Interior Coating Materials

Pipe lining is one of the most severe interference factors for clamp-on ultrasonic meters installed on existing distribution mains. For inline wetted meters (the residential and C&I type used in water utility billing), the issue is different but related.

Dwyer Omega’s engineering reference, summarizing published flow meter engineering guidance, states: concrete-lined, plastic-lined, copper, and fiberglass-reinforced pipes create acoustic discontinuities at the liner-metal interface that are significant enough to either completely scatter the transmitted signal or attenuate the return signal. For clamp-on type meters, accuracy can drop to ±20% or the meter may not function at all when the pipe is lined. [8]

[8] Dwyer Omega. “What is an Ultrasonic Flow Meter?” Engineering resource article. April 2026. dwyeromega.com/en-us/resources/ultrasonic-flow-meters

For inline wetted meters: the concern shifts from external pipe linings to the condition of the meter body itself. Pipe joint compound (pipe dope) entering the meter bore during installation creates a coating with acoustic impedance different from water. A thin film of cured pipe dope on a reflector face or transducer surface can attenuate the signal in the same way a mineral scale deposit does. [9]

[9] Oatey Corporation. “Pipe Dope (Pipe Joint Compound): Tips and Best Practices.” oatey.com/faqs-blog-videos-case-studies/blog/pipe-dope-tips-best-practices. Key guidance: ‘Keep sealant out of the pipe bore’ and ‘leaving the first thread free of compound is a good habit.’

Field installation guidance from flow meter practitioners confirms: if dirt or pipe compound coats wetted transducers, the meter may fail to operate until cleaned. Any upstream cleaning or flushing operation that sends debris into the meter (dewatering after main repairs, chlorination flushes, or hydrostatic testing blow-off) should be preceded by removing and protecting the meter from the flow path. [10]

[10] Zero Instrument/JustMeasureIt. “Ultrasonic Flow Meter Installation Guidelines.” zeroinstrument.com/ultrasonic-flow-meter-installation-guidelines/

7.4 Biofilm and Biological Fouling

Biofilm — the thin layer of bacteria and extracellular polymeric substances that can form on any wetted surface in a distribution system — affects ultrasonic meter transducers in the same way as mineral scale: by adding a material layer with different acoustic impedance between the transducer face and the water column.

Research cited in the flow measurement literature indicates that biofilm layers exceeding 0.5 mm thickness on transducer surfaces introduce approximately 0.5% error in flow velocity calculations by altering acoustic impedance at the transducer-water interface. [11]

[11] Zhongpei Electronics / ZPMeter. “Ultrasonic Water Meter Accuracy: How It Works & Key Factors.” zpmeter.com/blog/what-makes-ultrasonic-water-meters-accurate-for-water-measurement. Cites 2023 research on biofilm layer effects on acoustic impedance.

Biofilm risk is highest in systems with: low residual disinfectant (below 0.2 mg/L free chlorine at the point of metering), warm water temperatures (above 20°C / 68°F), stagnant or low-velocity sections, or distribution from surface water sources with higher natural organic matter content. Iron bacteria

(Gallionella, Leptothrix) and manganese-oxidizing bacteria produce dense, adherent deposits that can coat internal meter surfaces and reflectors within months in susceptible systems.

Composite polymer meter housings with smooth bore surfaces reduce biofilm adhesion compared to cast bronze or stainless steel. This is one of the practical design advantages of glass-reinforced polymer (GRP) and polyphenylene sulfide (PPS) composite flow tubes used by Master Meter (Sonata), Sensus (iPERL), and others. This surface adhesion advantage must be weighed against the long-term acoustic path geometry considerations discussed in Section 7.1a.

7.5 Temperature and Speed-of-Sound Variation

Temperature is one of the most fundamental variables in ultrasonic measurement because the speed of sound in water is temperature-dependent. This is not a failure mode — it is a physical property that every meter designer must account for in their measurement algorithm.

The relationship is well-established in the physics literature and can be approximated as: speed of sound in water ≈ 1,404 m/s at 0°C, increasing steeply near freezing (about 4 m/s per °C) but more gradually across the municipal range — roughly 2–3 m/s per °C between 10°C and 30°C. Across that range the speed of sound varies by roughly 50–80 m/s from groundwater (10°C) to summer distribution temperatures (30°C+). [12]

[12] US Patent 8,700,344 — Ultrasonic flow meter. Documents temperature-sound speed relationship and automatic compensation approach. image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8700344

Modern meters handle this through one of two approaches. The traditional approach uses a built-in temperature sensor to look up the correct speed of sound and apply it to the velocity calculation. The more recent approach, developed by researchers at Incheon National University and published in Cogent Engineering (2017), uses a differential transit-time (dToF) algorithm that mathematically cancels out the speed of sound variable, making the flow rate calculation independent of water temperature. [13]

[13] Lee, C.-H., Jeon, H.-K., and Hong, Y.-S. "An Implementation of Ultrasonic Water Meter using dToF Measurement." Cogent Engineering, Vol. 4, 2017. tandfonline.com/doi/full/10.1080/23311916.2017.1371577

A practical implication for utilities: a meter calibrated in a factory test at 60°F that is deployed in a system where groundwater enters at 50°F in winter and distribution temperatures reach 80°F in summer will produce different apparent accuracy results depending on how the meter's temperature compensation handles the full range. When evaluating meters in climate extremes (deep well systems in cold regions, sun-exposed above-ground metering in hot climates), ask vendors specifically what temperature compensation method is used and over what range it has been validated.

7.6 The Critical Role of Sampling Rate

What sampling rate means

Every digital measurement system — including an ultrasonic meter — does not measure flow continuously. It takes a series of discrete snapshots and integrates those snapshots into a totalized volume reading. The sampling rate is the number of those measurement snapshots taken per second (or per unit time). Think of it like the frame rate of a video: a low frame rate captures motion coarsely; a high frame rate captures it accurately.

Kamstrup's published technical comparison states this principle directly: "One of the factors that determine the level of accuracy is the sample rate, which all smart meters use. The measurement is a snapshot of the current flow. Like any type of digital sampling, this will integrate the measurements over time, leading to the calculation of the final volume." [3]

Why higher sampling rate improves accuracy — especially at low flows

The transit-time difference (the signal the meter measures) becomes extremely small at very low flow velocities — down to picoseconds. Research published in MDPI Sensors (2016) by researchers at Université de Lyon quantified this: the transit-time difference can be as low as a few picoseconds at near-zero flow, which requires very high measurement frequency to resolve accurately. The paper proposed and validated a technique using phase difference measurement and least-square fitting to achieve 10 picosecond precision at zero-flow conditions — enabling detection of flows well below what previous techniques could resolve. [14]

[14] Massicot, B. et al. "An Enhanced Technique for Ultrasonic Flow Metering Featuring Very Low Jitter and Offset." MDPI Sensors, Vol. 16, No. 7, 2016. Full text: ncbi.nlm.nih.gov/pmc/articles/PMC4970058/

Neptune Technology Group has published a direct explanation of this in their technical blog: "The primary benefit of a high sampling rate is improved accuracy. When the meter takes more frequent measurements, it can better capture the variations in water flow. This is important in both residential and commercial settings, where water usage can fluctuate significantly throughout the day. A high sampling rate ensures that these fluctuations are accurately recorded, leading to more precise billing and better water management." [15]

[15] Wilderman, D. (Sr. Product Marketing Manager, Neptune). "The Significance of a High Sampling Rate for Accuracy in Ultrasonic Water Meters." Neptune Technology Group Blog, 2025. neptunetg.com/resources/blog/sampling_rate/

Pulsating flow and synchronization errors

A less obvious but documented accuracy risk is pulsating flow — when actual water flow is not steady but oscillates or pulses (e.g., downstream of a pressure-reducing valve, near a pump, or with certain irrigation controller configurations). Research published in peer-reviewed proceedings from Luleå University of Technology showed that pulsating flow at frequencies that interact with the meter's sampling period can introduce errors of 2–4% at normal flows and larger errors at low flows. This is a "sampling error" — the digital measurement happens to capture the high point or low point of each pulse rather than the average, systematically over- or under-reading. [16]

[16] Palmér Gutérrez, H., and Delsing, J. "Installation effects on an ultrasonic flow meter with implications for self diagnostics." Flow Measurement and Instrumentation, Vol. 11, 2000. ScienceDirect: sciencedirect.com/science/article/abs/pii/S0955598600000054

Sampling rate also affects leak detection. Higher sampling rates enable detection of continuous low-level consumption that could indicate a leak, allowing the utility to notify the customer before a bill is issued. [15] A meter sampling at 128 Hz will accumulate more data points confirming sustained low-level flow than one sampling at 1 Hz — but as established in the battery life discussion above, higher sampling rates consume more power. A meter optimized for aggressive leak detection through high sampling frequency is making a battery life tradeoff. Utilities should confirm with vendors what sampling rate is actually used during no-flow periods and what effect that has on the rated battery life.

Sampling rate and battery life: the fundamental tradeoff

Here is the tension that every ultrasonic meter designer faces: higher sampling rate requires more frequent transducer firings, which consumes more battery power. A meter that samples at 128 Hz will drain its battery many times faster than one sampling at 1 Hz, all else equal. The industry's challenge over the past decade has been to achieve high effective sampling rates while keeping total power consumption low enough to sustain 20-year battery life.

Research published in the journal Smart Water (Springer, 2019) by engineers at Incheon National University modeled the power consumption of a low-power ultrasonic water meter design. The study found that using an 8,500 mAh lithium battery with a safety factor of 2.0, the modeled meter reached roughly 10 years under its maximum-power assumptions — and that same paper projected 20-plus years only under its most favorable low-duty-cycle assumptions: no integrated radio sharing the cell, a conservative sampling rate, and nominal temperature. The 20-year figure is therefore an ideal-conditions number. [17]

[17] Lee, C.-H. et al. "A design and implementation of low-power ultrasonic water meter." Smart Water (Springer), Vol. 4, 2019. Open access: link.springer.com/article/10.1186/s40713-019-0018-9

KEY POINT	The National University modeling confirms what the AGC-battery interaction also demonstrates: no ultrasonic meter running on a standard battery is unconditionally designed for 20-year operation. The 20-year claim is achievable only under a specific combination of conditions: clean water with minimal scale accumulation, no AMI or AMR transmission sharing the same battery source, a conservative sampling rate, and near-nominal (70°F) operating temperatures. Any departure from those ideal conditions — hard water driving AGC escalation, cellular AMI sharing the meter battery, higher sampling rates for accuracy, or hot-climate installations — shortens the realistic service life below the manufacturer's stated figure. The meter provides no visible warning that its power budget is being consumed faster than the design assumed. Utilities should treat the 20-year battery claim as a best-case figure under ideal conditions, not a guaranteed service life. [17]

Modern residential meters resolve the sampling tradeoff through two strategies: they sample at high frequency during flow events (when the measurement data actually matters) and enter deep sleep or minimal-power states during periods of no flow, which represent the majority of time in a typical residential meter. The Texas Instruments TDC7200 timing chip — used in modern ultrasonic meter designs — supports an autonomous multi-cycle averaging mode where the host processor can enter sleep mode while measurements are accumulated, waking only when a complete measurement sequence is available. [18]

[18] DigiKey / Audiowell. "How to Use Ultrasonic Sensing in Smart Water Meters." December 2022. digikey.com/en/articles/how-to-use-ultrasonic-sensing-in-smart-water-meters. Documents TI TDC7200 autonomous averaging mode for power efficiency.

Scenario	Sampling Effect	Accuracy Risk
Very low flow (0.03–0.1 gpm)	High sampling rate most critical — each snapshot has tiny transit-time difference; more samples = better average	Low sampling rate: misses flow events entirely or registers them inaccurately; meter may report zero flow when small flow is present
Pulsating flow (valve oscillation, pump cycling)	Sampling rate must be high enough to capture multiple points per pulse cycle	Low sampling rate synchronized with pulse frequency: systematic over- or under-read of 2–4%
Normal steady flow (1–10 gpm)	Moderate sampling adequate; steady flow profile is easy to measure	Low sampling rate acceptable in steady conditions; error is typically <1%
High flow (>15 gpm, summer irrigation)	Less critical — transit-time difference is large and easily resolved	Neither high nor low sampling rate is a meaningful accuracy differentiator at high flow
Leak detection (<0.05 gpm)	Highest sampling rate critical — leak flow is indistinguishable from zero at low sampling	Low sampling rate: continuous leak registers as occasional small volume or zero; leak alarm may never trigger

7.7 Battery Technology and the 20-Year Life Claim

Why battery life is the limiting factor for ultrasonic meters

A well-designed ultrasonic meter has no mechanical wear mechanism. The transducers, housing, and electronics can theoretically last indefinitely. In practice, the meter's service life is determined almost entirely by its battery. When the battery is exhausted, the meter stops measuring. This makes battery chemistry and quality one of the most consequential specifications in a meter procurement — far more consequential than it appears in a line-item comparison.

Lithium thionyl chloride ($LiSOCl_2$): the chemistry explained

All major residential ultrasonic meters specify bobbin-type lithium thionyl chloride ($LiSOCl_2$) batteries, operating at 3.6 volts. This chemistry is used universally in water meter applications because no other battery chemistry meets all the requirements simultaneously. [18,19]

[19] Water Finance & Management / Tadiran Batteries (Sol Jacobs, VP and General Manager). "Ultra-Long-Life Lithium Batteries Bring Enhanced Data Intelligence to AMI Metering." waterfm.com/ultra-long-life-lithium-batteries-bring-enhanced-data-intelligence-to-ami-metering/

The four properties that make $LiSOCl_2$ uniquely suited for water meters:

- High energy density: $LiSOCl_2$ delivers more energy per unit weight than alkaline or NiMH chemistries, and achieves superior self-discharge performance compared to lithium-ion chemistries — the combination of energy density, self-discharge rate, and temperature range that makes it uniquely suited for water meters.

- Ultra-low self-discharge: The passivation effect — a thin film of lithium chloride (LiCl) forming on the anode of an inactive cell — impedes the chemical reactions that cause self-discharge. Superior-quality $LiSOCl_2$ cells achieve self-discharge rates below 1% per year. A battery retaining 80% capacity after 20 years requires a self-discharge rate of no more than 1% per year. [19]
- Wide operating temperature range: Water meter pits in cold climates can reach well below freezing in winter. $LiSOCl_2$ operates reliably from –80°C to +125°C — no other primary battery chemistry comes close. [19]
- High pulse capability: AMI endpoints must periodically transmit high-power radio bursts (up to 15 amperes peak for some cellular radios). Standard bobbin-type $LiSOCl_2$ is combined with a hybrid layer capacitor (HLC) to deliver these pulses without depleting the main cell capacity.

The passivation effect: the variable that separates good batteries from great ones

The passivation effect is a double-edged phenomenon. It enables the ultra-low self-discharge rate that makes long battery life achievable, but it also creates a temporary voltage depression when a cell that has been in storage is first asked to deliver high current. This matters in practice: a meter installed and then left dormant for an extended period will have a passivated cell. The first high-current demand after a long dormant period — such as an initial radio transmission or a meter activation event — may experience a voltage dip. Well-designed meters account for this in their firmware; poorly designed ones may reset or fail to respond. [19]

The practical procurement implication: not all $LiSOCl_2$ batteries are equal. An inferior quality bobbin-type cell can lose up to 3% of nominal capacity per year due to self-discharge — exhausting 30% of its total capacity in 10 years. A high-quality cell can achieve 0.7% per year self-discharge, retaining 93% of original capacity after 10 years and making 40-year theoretical life achievable. [19]

Aclara (formerly Hexagram) offers a real-world data point on that calendar endurance: during a meter replacement program, random tests of batteries installed in the mid-1980s found they still retained significant unused capacity after 28+ years of service. [19] That result is a genuine confirmation of what high-quality $LiSOCl_2$ chemistry can do at rest — but it must be read for what it actually measured, because it is not an ultrasonic meter result. The battery was not in a meter at all; it powered a standalone radio endpoint (Aclara's Meter Transmission Unit) that read the register of a separate *mechanical* positive-displacement meter and transmitted the reading over an FCC-licensed network. The measurement itself was performed mechanically and drew no battery power; the cell's only job was a brief radio burst on the order of a few times per day — among the lightest loads in all of metering. An ultrasonic meter inverts that arrangement: the battery powers the measurement itself, firing the transducers and running signal processing on every reading, many times a day, and in an integrated unit the radio draws from that same cell. The 28-year figure therefore validates the chemistry's shelf endurance at a trivial drain; it says nothing about how long the same cell can power an active ultrasonic measurement engine. Section 8.4 develops this distinction in full.

How battery life interacts with sampling rate and AMI transmission

The three largest power consumers in a battery-powered ultrasonic meter are, in order: (1) the AMI/AMR radio transmitter, (2) the ultrasonic transducer firing circuit, and (3) the microprocessor and display. The battery must be sized to support all three over the rated service life.

Component	Power Demand	Battery Design Response
Ultrasonic transducer firing	Low continuous; multiple firings per second during flow	Duty-cycle control: fire at high rate during flow events, minimum rate at no-flow
Microprocessor	Very low continuous; spikes during calculation	Sleep modes between measurements; wake on flow event only
Display (LCD)	Very low; only powered when meter lid is opened	Light-sensor activation; zero power when lid closed
AMI cellular radio (e.g., LTE-M / Cat-M1)	High peak current during transmission (up to 15A peak pulse)	Hybrid layer capacitor (HLC) delivers peak pulse; main cell handles background load
AMR/Fixed Network radio — licensed frequency	Moderate peak; transmits immediately on dedicated channel — no channel scanning required	Lower power demand than unlicensed band; standard bobbin $LiSOCl_2$ typically sufficient without HLC
AMR/AMI radio — unlicensed 902–928 MHz band (includes LoRa, most 900 MHz FHSS endpoints)	Moderate-to-high peak; must scan for available channel before each transmission (FCC Part 15 FHSS requirement)	Channel scanning adds power overhead vs. licensed frequencies; increases per-transmission energy cost
Temperature / pressure sensors	Very low when polled; zero when not sampled	Polled on request; not continuously powered
Integrated vs. separate radio	When the radio is separate with its own battery and the meter cell powers measurement electronics only, battery life is at its most defensible — roughly 12–15 years in US field conditions, the realistic best case, though still short of the manufacturer-claimed 20 years. When the radio is integrated and shares the meter cell, every transmission draws from the same battery that powers the transducers and processor, pulling realized life below even that 12–15-year figure.	

A practical consequence: cellular-enabled meters (LTE-M / Cat-M1) consume significantly more battery power per transmission than radio frequency (RF) endpoints. Ultrasonic meters with integrated unlicensed RF endpoints operating in the 902–928 MHz band — including most 900 MHz FHSS systems and LoRa — must scan for an available channel before each transmission under FCC Part 15 requirements, adding power overhead compared to licensed-frequency endpoints that transmit immediately on a dedicated channel. A meter with a 20-year battery life rating may have a materially shorter battery life when integrated with a cellular or RF endpoint — the rating should always be confirmed for the specific endpoint configuration being purchased.

What to ask vendors about battery life

- What is the rated battery life for the specific endpoint configuration we are purchasing (AMR, fixed network 900 MHz licensed, unlicensed 902–928 MHz, or cellular)? Not the maximum — the typical at our planned transmission interval.
- What is the battery's self-discharge rate specification, and which battery manufacturer supplies it?

- Has the battery specification been validated by third-party testing at the extremes of our expected installation temperature range?
- Does the endpoint design use a hybrid layer capacitor (HLC) for pulse delivery, or does the main cell deliver transmission pulses directly? (The latter shortens battery life.)
- Is the radio integrated into the meter housing sharing the meter battery, or is it a separate endpoint with its own independent power source?
- What is your warranty policy if a meter fails due to battery exhaustion before the rated service life?

7.8 Other Installation and Environmental Factors

Flow profile disturbances (turbulence and swirl)

Upstream disturbances from pipe elbows, tees, partially closed valves, or reducers create non-uniform flow profiles. Transit-time meters average the velocity across the acoustic path, and if the path samples a distorted profile, the average may not represent the true volumetric flow. The Luleå University study cited in Section 7.6 found installation effects (elbows, reductions) introduced errors of 2–4% at normal flows in a small test meter. [16]

For inline residential meters this is less critical because the meter body itself typically includes a flow conditioning element (guide vanes or shaped inlet), and residential service line velocities rarely reach turbulent Reynolds numbers. For C&I sizes (≥1″) installed with close-coupled elbows or immediately downstream of pressure-reducing valves, straight pipe runs upstream and downstream should be specified.

Acoustic noise — what it is and what it is not

Acoustic noise is sometimes cited as a challenge for ultrasonic meters in distribution systems near pump stations. This is largely a misunderstanding. Municipal water meters operate at ultrasonic frequencies of approximately 1 MHz. Environmental acoustic noise from pumps, generators, and traffic occurs at frequencies of 20 Hz to 20 kHz — well below the meter's ~1 MHz operating frequency. These frequencies do not interfere with transit-time measurement. [3]

The actual acoustic risk is electronic — not environmental. At very low flows, the transit-time difference is tiny and the signal-to-noise ratio of the electronic measurement circuit becomes the limiting factor for accuracy. This is a design variable addressed through measurement algorithm quality, transducer sensitivity, and circuit noise floor — not by installing acoustic shielding. [3]

Vibration

Mechanical vibration from pumps, compressors, or heavy traffic near a meter vault can affect the alignment of clamp-on transducers. For inline wetted meters, the transducers are fixed rigidly in the meter body and are not subject to vibration-induced misalignment. However, sustained high vibration can gradually loosen coupling nuts and introduce micro-leaks that affect apparent meter readings. Proper torque on coupling nuts (see Module 4) and adequate pipe support on both sides of the meter reduce this risk.

MODULE 8

Meter Service Life & Total Cost of Ownership

Evaluating meter service life, accuracy degradation, and total cost of ownership across technologies

Learning Objectives

- State the documented service life range for positive displacement (PD) meters based on field testing, and understand what ends that service life
- Explain why most PD meters appear to last a long time while a subset fail early — and why that subset drives disproportionate revenue loss
- Distinguish between ultrasonic meter battery life and accurate service life — and understand the conditions under which they diverge
- Explain the mechanisms by which ultrasonic meter accuracy can degrade before battery exhaustion, and why those mechanisms are not reflected in manufacturer specifications
- Apply the American Water / Kansas City Water Services regression to calculate PD accuracy at any point in service life
- Construct a total cost of ownership comparison between PD and ultrasonic metering using documented data

SOURCE NOTE

Every claim in this guide is followed by a bracketed reference [n] keyed to the full citation table at the end. The primary quantitative evidence comes from two independent field data sources: (1) the American Water / Kansas City Water Services dataset presented by Dave Hughes at the Bentley Be Conference, May 2010 [21]; and (2) the Water Research Foundation study by Barfuss, Johnson & Neilsen (2011) [22], whose laboratory endurance methodology was derived from and validated against field meter population data.

8.1 The Service Life Question

Every utility eventually asks the same question: how long should a meter stay in service before it costs more to keep it than to replace it? The answer is different for PD meters and ultrasonic meters — because the mechanisms that end their useful life are completely different.

For a positive displacement meter, service life ends when mechanical wear reduces measurement accuracy below an acceptable threshold. The meter is still physically running, still producing readings — it is simply registering less water than actually passes through it. The revenue loss is invisible and silent.

For an ultrasonic meter, the question is more nuanced than it first appears. The meter has no moving parts and no wear mechanism. In ideal conditions, accuracy is maintained until the battery is exhausted — a visible, detectable event. But in hard water conditions, scale deposits can degrade acoustic performance before the battery dies, creating a period of accuracy loss that may not be visible to the utility. These two failure modes — battery death and accuracy degradation — are addressed separately in Sections 8.4 and 8.4a. [1,3]

8.2 Positive Displacement Meter Service Life — What the Field Data Shows

The Kansas City Water Services dataset (Hughes / American Water, 2010)

The most significant field dataset on PD meter accuracy and service life in the public domain comes from Kansas City Water Services, presented by Dave Hughes of American Water at the Bentley Be Conference on May 19, 2010. [21]

The dataset plots actual measured accuracy (y-axis, 0–100%) against years in service (x-axis, 0–30 years) for a population of in-service PD meters tested by Kansas City Water Services. The scatter plot and regression line are reproduced directly from Slide 9 of that presentation.

Figure 1: Meter Age/Registration Change — Kansas City Water Services Dept. data. Source: Hughes, D. (American Water), “Getting Smarter with AMI,” Bentley Be Conference, May 19, 2010, Slide 9.

Reading the chart: what the scatter plot actually shows

The chart carries two simultaneous messages that are easy to misread if you look only at the regression line.

First message — the majority: Most data points cluster tightly near 100% accuracy across the entire 0–30 year range. This is what Hughes explicitly states on the slide: “Most meters last a long time, only a few fail.”

Second message — the outliers: A meaningful minority of meters drop sharply — some to below 20%, one to near zero around year 20. These outliers represent meters where mechanical wear has compounded to the point of near-total failure. These meters are still installed and still billing, just billing incorrectly. [21]

The regression line — y = −0.2654x + 101.15 — is the mathematical result of fitting a straight line to this entire population, outliers included. It tells you: on average, this population of PD meters loses 0.2654 percentage points of accuracy for every year in service.

KEY DATA	y = −0.2654x + 101.15. Source: Kansas City Water Services Dept., via Hughes / American Water, Bentley Be Conference, May 2010. This is the only published regression of measured in-service PD meter accuracy vs. years in service derived from a large utility field population. [21]

Applying the regression: accuracy at each service milestone

Years in Service	Avg Accuracy	Revenue Lost vs. New	Interpretation
0 (new)	~100%	0%	Calibration baseline; new PD meters typically register slightly over 100% [22]
5	99.8%	0.2%	Within AWWA tolerance; minimal detectable impact
10	98.5%	1.5%	Measurable; a 1,000-account utility loses ~$15,000/yr per 1% at average $15/kgal rates

Years in Service	Avg Accuracy	Revenue Lost vs. New	Interpretation
15	97.2%	2.8%	Approaching meaningful revenue impact; WRF found significant low-flow degradation at 2M gallon throughput (~15 yrs) [22]
20	95.8%	4.2%	Outlier failures multiply; San Diego replacement study showed doubled registration after replacement [21]
25	94.5%	5.5%	Population average; many individual meters significantly worse
30	93.2%	6.8%	Outlier meters potentially at 0–50%

[21] Hughes, D. (American Water). “Getting Smarter with Advanced Metering Infrastructure.” Bentley Be Conference, May 19, 2010. Slide 9. Data courtesy Kansas City Water Services Dept.

The WRF laboratory validation

The Kansas City field regression was independently validated by Barfuss, Johnson & Neilsen, “Accuracy of In-Service Water Meters at Low and High Flow Rates,” Water Research Foundation, 2011. The WRF study tested meters at four levels of cumulative throughput through 2,000,000 gallons — the expected throughput of a household using 400 gallons per day for 15 years. [22]

- Nutating disc and displacement piston meters — both positive displacement types — showed the smallest accuracy degradation of all six meter types tested
- Single-jet and multi-jet meters showed the greatest degradation between 1.5 and 2 million gallons of throughput
- Accuracy degradation is most severe at low flow rates — the flow range that constitutes the largest share of residential water use
- Field-service meters showed more variation than laboratory-tested meters at equivalent throughput, confirming that field variables accelerate degradation beyond lab testing alone [22]

[22] Barfuss, S.L., Johnson, M.C., and Neilsen, M.A. “Accuracy of In-Service Water Meters at Low and High Flow Rates.” WaterRF Project #4028, Water Research Foundation, Denver, 2011. waterrf.org (Project #4028); related open-access material at digitalcommons.usu.edu.

The San Diego large meter dataset

Hughes also presented data from San Diego Water Department showing pre-exchange vs. post-exchange Average Daily Consumption for large meters that were replaced. Meter replacement consistently increased measured consumption — in the most dramatic cases roughly doubling measured ADC. The title of that slide: “Large Meter Replacement Doubled Total Registration.” [21] The same mechanism operates at smaller scale in residential meters — it just accumulates more slowly.

8.3 Defining Positive Displacement Meter Service Life

There is no universal consensus on PD meter service life in years, because the correct answer depends on: (1) average daily throughput; (2) water quality; (3) installation conditions; and (4) the utility's tolerance for under-registration.

Source	Service Life Estimate	Basis
WRF / Barfuss et al. (2011) [22]	15 years (2M gallon full-life endpoint)	400 gpd × 15 years = 2M gallon test endpoint. Accuracy degradation most significant at this throughput.
American Water / Hughes (2010) [21]	"Most meters last a long time, only a few fail" — outliers at 15–25 years drive disproportionate revenue loss	Field population regression: 4.2% avg under-registration at year 20; outliers near zero by year 20–25
AWWA M6 Manual	Statistical sample testing on 10–15 year cycles [24]	Testing interval implies accepted service of 10–20 years before replacement is economically justified
Practical utility experience	20–25 years typical replacement cycle	Most US utilities replace on fixed 20–25-year capital cycles, but the field data does not show the typical PD meter wearing out at that age — the majority retain near-specification accuracy well beyond 20 years (Hughes: "most meters last a long time, only a few fail") [21]. On AMI-equipped systems the shorter-lived component is frequently the endpoint's battery-limited radio (≈12–15 years for a separate endpoint), not the mechanical meter — and the endpoint can be replaced without replacing the meter. Where earlier replacement is economically justified, it is driven by the minority of outlier meters that under-register badly (§8.2), not by degradation of the typical meter.

SYNTHESIS	The WRF study [22] measured accuracy at a 2-million-gallon throughput endpoint — chosen to model roughly 15 years of typical residential use (400 gpd), not a point at which the meters were found to fail — and at that endpoint the nutating-disc and piston PD meters showed the least degradation of the six meter types tested. The Kansas City field regression [21] independently shows population-average PD accuracy declining gradually, reaching economically significant under-registration (≈4%) closer to year 20. Read together, the two sources place the onset of meaningful revenue loss for typical PD meters in the 15–20-year range, while confirming that the typical meter is not mechanically spent at that age.

8.4 Ultrasonic Meter Battery Life

Battery-limited service life: the baseline case

An ultrasonic meter has no moving parts and no mechanical wear mechanism, and at battery death it stops producing any reading at all — a clearly visible, detectable event, unlike the silent accuracy drift of PD wear. Under idealized conditions, accuracy is maintained throughout the battery's service life. Those conditions are specific and worth stating plainly: clean, low-mineral water that does not deposit scale; minimal suspended sediment; little or no biofilm growth on the wetted surfaces and transducer faces; no entrained air; and a stable acoustic path geometry held constant by a dimensionally stable meter body. Each of these is an assumption, not a given.

How often do real systems meet that baseline? There is no regulatory definition of "clean" water and no national statistic that answers the question directly, but the closest available proxy is unfavorable. Roughly 85% of U.S. water is hard, and hardness is the principal driver of the scale deposition that alters the acoustic path. Sediment, biofilm, and entrained air — all common in distribution systems regardless of hardness — act on top of that. The soft, low-sediment, biofilm-free, air-free, thermally stable condition the baseline assumes is therefore closer to a laboratory environment than to what most installed meters experience. The baseline is the right place to begin the analysis; it is not a description of typical field conditions, and the remainder of this section addresses what happens as real water departs from it.

Manufacturers of residential ultrasonic meters specify battery life of 15–20 years under typical operating conditions. That figure is often defended by pointing to lithium thionyl chloride ($LiSOCl_2$) chemistry, which achieves self-discharge rates below 1% per year in high-quality cells. [19] That is true, but it answers only half the question. A self-discharge rate below 1% per year governs how much capacity a cell loses while idle — its calendar or shelf ceiling — and a cell retaining roughly 80% capacity after 20 years does demonstrate that ceiling. It says nothing about how quickly the meter's active load drains the cell. In-service life is set by whichever limit is reached first: the calendar ceiling, or the usable capacity divided by the energy the meter actually consumes each day. For an ultrasonic meter the second limit, not self-discharge, is the binding one — because the measurement itself is an active, repeated power draw rather than an idle hold.

Field validation of long-term $LiSOCl_2$ chemistry does exist, but it has to be read carefully. Aclara (formerly Hexagram) found, during a replacement program, that batteries installed in the mid-1980s still retained significant unused capacity after 28+ years of service. [19] That is a genuine confirmation of the chemistry's calendar endurance, but it is not apples-to-apples with an ultrasonic meter, for two reasons that are easy to miss. First, the battery was not in a meter at all: it powered a standalone radio endpoint — Aclara's Meter Transmission Unit (MTU) — that read the register of a separate mechanical (positive displacement) water meter and transmitted the reading over an FCC-licensed 450–470 MHz network. The measurement was performed mechanically by the displacement meter and drew no battery power whatsoever; the battery's only job was an occasional, very short radio burst — on the order of four transmissions per day lasting a fraction of a second each, among the lowest loads in all of metering. Second, an ultrasonic meter inverts that arrangement: the battery powers the measurement itself, energizing the transducers and running signal acquisition and processing on every reading, many times per day, for the life of the meter — and where the same battery must also power the radio, as in an integrated AMI unit, the active draw is higher still. The 28-year endpoint result therefore shows that the cell chemistry can survive a long time at a trivial drain; it says nothing about whether the same cell can power an ultrasonic measurement engine, let alone an ultrasonic meter plus its radio, for the same span. The rated 15–20 years should be read as a best-case figure anchored to chemistry ceilings and low-draw analogues, not as a field-demonstrated ultrasonic duty-cycle lifespan. Independent battery data from outside the metering industry point the same way. Published characterizations of $LiSOCl_2$

cells show usable capacity falls as average and pulse current rise — one documented sensor design drew only about 8 Ah from a nominally 9 Ah cell at a 100 μA average load, with further reductions once continuous draw exceeds a few milliamps or pulses exceed a few hundred milliamps [30] — and battery makers are explicit that drawing high-rate current negates the passivation effect that produces the low self-discharge in the first place [19]. Elevated temperature compounds this: higher pit temperatures accelerate self-discharge and shorten operational life, not merely shelf life [30]. An ultrasonic meter that fires its transducers many times a day, carries an integrated cellular or RF radio on the same cell, and sits in a hot meter pit is operating well outside the microamp, passivation-intact regime the 20-year rating assumes — which is the realistic basis for the shorter service-life figures used in this guide.

FIELD DATA	Aclara battery life validation: during a replacement program, random tests of batteries from radio endpoints (MTUs) installed mid-1980s found significant residual capacity after 28+ years of service. Source: Tadiran Batteries / Water Finance & Management [19]. Important qualification: the battery was in the MTU radio endpoint, not the meter. It powered a standalone transmitter that read a separate mechanical (PD) meter's register and transmitted infrequently over an FCC-licensed 450–470 MHz network — the measurement itself drew no battery power. This validates the chemistry's calendar endurance at a trivial drain; it cannot be extrapolated to an ultrasonic meter, whose battery powers the measurement itself (and, in integrated units, the radio) at a far higher load.

Realistic battery life by configuration

The 20-year claim is achievable only under a specific combination of conditions: clean water with minimal scale accumulation, no AMI or AMR transmission sharing the same battery source, a conservative sampling rate, and near-nominal (70°F) operating temperatures. Any departure from those conditions shortens the realistic service life:

- Integrated cellular radio (LTE-M / Cat-M1): approximately 10 years (10 ± a year or two) is the realistic planning assumption — and the shortest-lived of the common configurations, because the cellular radio is the highest-power load. Cellular endpoints consume substantially more power per transmission than narrowband RF, and many integrated-radio products were battery-sized for 900 MHz duty cycles and later adapted for cellular without a corresponding increase in battery capacity. Shorter still in hot climates, hard water, or higher transmission frequencies.
- Integrated unlicensed 902–928 MHz radio: modest reduction vs. licensed frequency due to FCC Part 15 channel scanning overhead adding per-transmission power cost.
- Separate endpoint radio (own battery): 12–15 years is realistic in typical US field conditions when the radio has its own power source, since the meter battery powers measurement electronics only. This is the most favorable realistic configuration but still falls short of the manufacturer-claimed 20-year figure in most US deployments.
- Hard water with scale accumulation: AGC escalation consumes the power budget faster than clean-water specifications assume — see Section 8.4a.
- Hot-climate installations: $LiSOCl_2$ battery self-discharge and polymer component aging both accelerate with temperature following Arrhenius kinetics. Manufacturer battery life specifications do not distinguish by installation climate. A utility in a shallow pit in south Texas or Arizona is consuming its battery faster than one in a moderate northern climate, independent of any transmission or sampling considerations. Utilities in temperature-extreme regions should apply a meaningful reduction factor to any published battery life claim.

- International market specifications: The same manufacturers that claim 20-year battery life in the US market specify 12–16 years in their international datasheets for equivalent products. Kamstrup's MULTICAL 21 specifies 12 or 16 years depending on battery size selected. Diehl's HYDRUS specifies up to 16 years internationally vs. up to 20 years on the US datasheet. Sensus iPERL specifies 15 years in international markets vs. 20 years in North America. The fact that the same manufacturers make materially different claims by market suggests the 20-year US figure reflects optimistic design assumptions rather than a validated field result.

KEY POINT	Independent modeling of low-power ultrasonic meter designs found that using an 8,500 mAh lithium battery with a safety factor of 2.0, the modeled meter reached roughly 10 years under its maximum-power assumptions — and that same study projected 20-plus years only under its most favorable low-duty-cycle assumptions: no integrated radio sharing the cell, a conservative sampling rate, and nominal temperature. The 20-year figure, in other words, is an ideal-conditions number. [17] No ultrasonic meter running on a standard battery is unconditionally designed for 20-year operation. Utilities should treat the 20-year battery claim as a best-case figure under ideal conditions, not a guaranteed service life.

8.4a Ultrasonic Meter Accurate Service Life vs. Battery Life

Battery life and accurate service life are not the same thing for an ultrasonic meter, though they are often treated as if they are. Battery life is the point at which the meter stops functioning entirely. Accurate service life is the period during which the meter registers within its specified accuracy tolerance. In ideal conditions these two endpoints coincide. In hard water conditions they can diverge significantly — with the meter continuing to run and bill while its accuracy has already drifted.

Three mechanisms documented in this curriculum can degrade ultrasonic meter accuracy before the battery dies:

Mechanism 1: Scale deposits and AGC escalation

As documented in Module 7, scale deposits on transducer faces and acoustic reflectors attenuate the acoustic signal. The meter compensates by increasing electronic gain (AGC). AGC escalation has a ceiling set by the power budget — every increase in gain draws more current, consuming the battery faster than clean-water specifications assumed. Once scale attenuation exceeds the available AGC range, the meter either produces measurement errors or triggers a Measurement Error alarm. This point arrives sooner in a meter whose battery is already partially depleted from years of elevated AGC operation. In very hard water (>200 ppm $CaCO_3$), this mechanism can materially shorten the accurate service life well before the battery is exhausted.

The Glendale study data supports this: the registration gap between static and PD meters widened through 2019 then narrowed to 5.02% average from May 2022 through December 2024, suggesting scale eventually affected the static meter transducers as well. The accurate service life of those static meters, measured against their original calibration, was already declining within the study period observed to date.

Mechanism 2: Sampling-related accuracy under intermittent flow

As documented via the Arregui et al. study (MDPI Sensors, 2020) [26], ultrasonic meters sampling at 0.2 Hz or less can under-register short-duration consumption events (30 seconds or less) by up to 19.5% in worst-case synchronization scenarios. This is not a wear-related phenomenon — it is present from installation and is driven by the firmware and sampling algorithm. It does not worsen over time in the way mechanical wear does, but it represents an accuracy limitation that exists throughout the meter's service life and is not reflected in steady-state accuracy specifications.

Mechanism 3: Polymer body creep (polymer-bodied meters only)

As documented in Module 7, Section 7.1a, thermoplastic meter bodies deform slowly under sustained line pressure. Since an ultrasonic meter's accuracy depends on the acoustic path length held by the body, any time-dependent deformation of that structure shifts the calibration. Published creep data for unfilled engineering thermoplastics shows apparent-modulus reductions on the order of 30–50% over decade-scale load durations; glass-filled PPS substantially reduces but does not eliminate this effect. This degradation is silent, progressive, and not detectable from billing data or alarm status. Metal-bodied meters do not have this mechanism. [20]

KEY DISTINCTION	PD meters: accuracy degrades continuously and silently through mechanical wear. The meter still reads; the readings are progressively wrong. Degradation is uni-directional — mechanical wear can only cause under-registration. Ultrasonic meters: in ideal laboratory conditions, accuracy is maintained to battery death. In hard water or with polymer body construction, accuracy can degrade before battery exhaustion through scale-driven AGC escalation and/or body creep. Unlike PD wear, ultrasonic accuracy drift can go in either direction depending on how scale affects the acoustic signal path. Neither failure produces a visible alarm until a threshold is crossed. Both technologies can exhibit silent accuracy loss under adverse conditions. They differ in mechanism, direction, and the conditions that trigger it.

8.5 Side-by-Side Service Life Comparison

Factor	Positive Displacement	Ultrasonic
Primary failure mechanism	Mechanical wear of disc, piston, chamber walls — cumulative, continuous, irreversible	Battery exhaustion (primary); scale-driven AGC escalation and/or polymer body creep can cause accuracy loss before battery death in hard water or polymer-bodied meters
How wear/aging manifests	Silent under-registration; meter still reads but registers progressively less water. Can only under-register — mechanical wear cannot cause over-registration.	Pre-battery accuracy drift: silent, may go in either direction, no alarm until threshold crossed. Battery death: meter stops reading entirely, immediately visible.

Factor	Positive Displacement	Ultrasonic
Is accuracy loss detectable?	Only through bench testing or interval data analysis — invisible at billing level	Scale/AGC accuracy loss: not visible until Measurement Error alarm triggers or bench test detects drift. Battery death: immediately visible.
Field accuracy at 15 years	Population average: 97.2% (−2.8%) per Kansas City regression [21]	Most configurations are at or near battery end-of-life by year 15 (integrated cellular ≈10 yr; integrated RF 10–14 yr; separate-radio best case 12–15 yr), so for the majority of deployments there is no operating meter at 15 years and the question is moot — the meter has stopped, a visible event. Where a meter is still running (best-case separate-radio configuration in clean, soft water), accuracy is expected to remain within ±1.5%, though this is a design expectation, not a field-validated 15-year outcome. In hard water, accuracy may already be degraded before battery death via the scale/AGC mechanism; Glendale data shows the registration gap narrowing after year 10–12, consistent with transducer fouling.
Typical replacement trigger	Fixed-cycle program (15–20 years) or catastrophic failure detection	Battery exhaustion at roughly 10–15 years depending on radio configuration (≈10 yr integrated cellular; 10–14 yr integrated RF; 12–15 yr separate radio) — the manufacturer-claimed 20-year life is not field-validated; or earlier accuracy failure in hard water via the scale/AGC mechanism.
Revenue risk before replacement	Continuous and compounding — worst-case meters may under-register by 50%+ with no visible signal	Clean soft ideal water: none until battery death. Hard water polymer body: silent accuracy drift possible before battery death. Both are risks that require monitoring.

Factor	Positive Displacement	Ultrasonic
Service life — separate radio	25–30 years mechanical service life is achievable; replacement is typically triggered at 15–20 years by accuracy economics rather than mechanical failure [21, 22, 23]	12–15 years is realistic in typical US field conditions when radio has its own power source; 20-year figure is a calculated best case under near-ideal conditions most deployments do not consistently achieve
Service life — integrated cellular	The 25–30-year figure applies to the mechanical measuring element, not to an integrated-cellular unit. An integrated cellular configuration requires an electronic encoder register and radio on a battery; that battery — driving the same high-drain cellular load as any cellular endpoint — governs the unit's service life at roughly 10 years, well short of the mechanism's mechanical life. The 25–30-year advantage is realized only when the register and radio are a separate, replaceable endpoint, allowing re-endpointing while the mechanical meter remains in service. [21, 22, 23]	10+/- years is a realistic planning assumption in typical US conditions; shorter in hot climates, hard water, or higher transmission frequency deployments; 20-year claim is not field-validated for this configuration and is not supported by the same manufacturer's international datasheets
Service life — integrated RF	The 25–30-year figure applies to the mechanical measuring element, not to an integrated-RF unit. An integrated RF configuration still puts an electronic encoder register and radio on a battery; that battery governs the unit's service life — roughly 11–14 years on a licensed dedicated channel, 10–13 years on unlicensed 902–928 MHz (FCC Part 15 channel-scanning overhead) — well short of the mechanism's mechanical life. The RF load is lighter than cellular, so the unit lasts somewhat longer than an integrated-cellular unit, but it is still battery-limited, not mechanism-limited. The 25–30-year advantage is realized only when the register and radio are a separate, replaceable endpoint, allowing re-endpointing while the mechanical meter remains in service. [21, 22, 23]	Licensed frequency (dedicated channel, no scanning): 11–14 years realistic in typical US conditions. Unlicensed 902–928 MHz (FCC Part 15 FHSS channel scanning required): 10–13 years realistic. Both estimates assume US field conditions including temperature variation and actual sampling rates; shorter in hot climates or hard water.

Factor	Positive Displacement	Ultrasonic
Direction of accuracy error	Only under-registration — mechanical wear cannot cause over-registration	Either direction depending on how scale affects acoustic signal timing; polymer body creep direction is design-dependent
Service life — economic	Replacement justified at ~15 years when accuracy losses exceed replacement cost [23]	Replacement at battery end-of-life; in hard water, monitor for pre-battery accuracy degradation

8.6 The 40-Year Total Cost of Ownership Framework

The 40-year period spans multiple meter replacement cycles for both technologies. The TCO comparison is built on two foundational facts established by the field data in this curriculum:

- The 5/8″ × 3/4″ meter is the standard residential size in the United States by a large margin. At this size, the field studies showed no registration advantage for static meters in either hard or soft water (Salisbury and Olathe). Revenue loss from under-registration is therefore equivalent for both technologies in a standard residential installation.
- Because revenue loss is equivalent at the standard residential size, the TCO comparison for typical installations is driven entirely by hardware and installation costs over the service life. Static meters require more replacement cycles due to shorter realistic battery life, which means higher hardware cost over 40 years.
- A registration advantage for static meters was documented only at the non-standard full 3/4″ meter size in very hard water (Glendale). This scenario is presented separately as an exception, not the baseline.

SCENARIO A — SEPARATE RADIO / ~15-YEAR REALISTIC LIFE	Meters with separate endpoint radios where the radio has its own independent battery. The meter battery powers measurement electronics only. This is the most favorable realistic configuration for ultrasonic battery life. Three ultrasonic meters over 40 years vs. two PD meters.

SCENARIO B — INTEGRATED RF RADIO / ~12-YEAR LIFE	Meters with an integrated RF radio sharing the meter battery. Four ultrasonic meters over 40 years vs. two PD meters. RF power demand and duty cycle vary by protocol; licensed frequencies consume less power than unlicensed band systems that must scan for available channels before each transmission.

SCENARIO C — INTEGRATED CELLULAR RADIO / ~10-YEAR LIFE	Meters with an integrated cellular radio sharing the meter battery. Four ultrasonic meters over 40 years vs. two PD meters. Cellular endpoints consume substantially more power per transmission than RF endpoints.

Meter cost inputs — documented market pricing

Meter Type	Configuration	Utility Volume Pricing (est.)	Source
PD nutating disc / oscillating piston 5/8″ × 3/4″	With encoder register — AMR/AMI ready	\$90–\$130/unit	Perry Park WSD 2025 [28]; industry estimate
Ultrasonic 5/8″ × 3/4″ (Zenner / comparable)	Integrated register and electronics — AMR/AMI ready	\$100–\$120/unit	Perry Park WSD cost estimate, July 2025 [28]
Ultrasonic 5/8″ × 3/4″ (Badger E-Series G2)	Integrated register and electronics — AMR/AMI ready	\$110–\$130/unit	Badger Meter product page [29]

Pricing note: The fair comparison for TCO purposes is PD with encoder register vs. ultrasonic with integrated register — both AMR/AMI ready. At utility volume pricing, the hardware cost premium for ultrasonic over encoder-equipped PD is approximately \$0–\$30 per unit. This narrow unit price difference means TCO in standard residential applications is driven primarily by replacement cycle count, not unit price premium. RG3 Meter Company pricing available through your authorized distributor.

Revenue loss inputs — from Kansas City field data [21]

Using $y = -0.2654x + 101.15$ applied to a 400 gallon/day residential service (~146,000 gallons/year) at the EPA WaterSense combined rate of \$15.21/kgal. These figures apply to PD meters. For standard residential 5/8″ × 3/4″ installations, static meter revenue loss is treated as equivalent since no registration advantage has been documented at this size in either hard or soft water.

Year Range	PD Avg Accuracy	Avg Annual Under-Reg.	Annual Under-Registration Cost	Period Total Cost
Year 1–5	100.4% avg	Slight over-reg (new meter)	+\$7.86/yr (over-reg)	+\$39 (over-reg)
Year 6–10	99.0% avg	~1,421 gal/yr	(−\$21.61/yr)	(-\$108)
Year 11–15	97.7% avg	~3,358 gal/yr	(-\$51.08/yr)	(-\$255)
Year 16–20	96.4% avg	~5,296 gal/yr	(-\$80.55/yr)	(-\$403)
TOTAL — 20-yr PD cycle	**—**	**—**	**—**	**(-\$727)**
Year 21–40 (2nd PD meter)	Restarts at 100%	Same curve repeats	Same as above	(-\$727)
TOTAL — 40 yrs, 2× PD meters	**—**	**—**	**—**	**(-\$1,454)**

Standard Residential 5/8″ × 3/4″ — Typical US Installation

PD pricing reflects encoder-equipped meters, AMR/AMI ready. Ultrasonic pricing reflects integrated register. Both are comparable, AMR/AMI-ready configurations. Revenue loss is equal for both technologies — no registration advantage documented at this size.

Scenario A — Separate Radio, ~15-Year Life: 3 ultrasonic meters

Cost Element	2× PD (40 yrs)	3× Ultrasonic Scenario A	Difference
Meter hardware (encoder-equipped, AMR/AMI ready)	2×$110 = $220	3×$115 = $345	+$125 ultrasonic
Installation	2×$50 = $100	3×$50 = $150	+$50 ultrasonic
Revenue lost — equal at this size; no registration advantage documented	$1454	$1454	Equal
NET 40-YEAR COST PER METER	**$1774**	**$1949**	**PD saves $175**

Scenario B — Integrated RF Radio, ~12-Year Life: 4 ultrasonic meters

Cost Element	2× PD (40 yrs)	4× Ultrasonic Scenario B	Difference
Meter hardware (encoder-equipped, AMR/AMI ready)	2×$110 = $220	4×$115 = $460	+$240 ultrasonic
Installation	2×$50 = $100	4×$50 = $200	+$100 ultrasonic
Revenue lost — equal at this size; no registration advantage documented	$1454	$1454	Equal
NET 40-YEAR COST PER METER	**$1774**	**$2114**	**PD saves $340**

Scenario C — Integrated Cellular Radio, ~10-Year Life: 4 ultrasonic meters

Cost Element	2× PD (40 yrs)	4× Ultrasonic Scenario C	Difference
Meter hardware (encoder-equipped, AMR/AMI ready)	2×$110 = $220	4×$115 = $460	+$240 ultrasonic
Installation	2×$50 = $100	4×$50 = $200	+$100 ultrasonic
Revenue lost — equal at this size; no registration advantage documented	$1454	$1454	Equal
NET 40-YEAR COST PER METER	**$1774**	**$2114**	**PD saves $340**

EXCEPTION — NON-STANDARD FULL 3/4″ METER IN VERY HARD WATER	The only scenario where field data documents a static meter registration advantage is the non-standard full 3/4″ meter size in very hard water (Glendale study, 205 ppm $CaCO_3$). This is not a typical residential installation. At this size and hardness, static meters registered approximately 3.88% more over 13.6 years. If a utility is deploying full 3/4″ meters in very hard water, the TCO comparison shifts: the registration advantage partially or fully offsets the additional hardware replacement costs depending on endpoint configuration. Utilities in this specific application should conduct a site-specific pilot before projecting benefits.

BOTTOM LINE	For standard residential 5/8″ × 3/4″ meters — the vast majority of US residential installations — field data shows no registration advantage for static meters. With encoder-equipped PD and integrated-register ultrasonic compared on equal footing, the hardware unit price difference is minimal ($5/unit). TCO is driven by replacement cycle count: PD needs 2 replacements over 40 years vs. 3–4 for ultrasonic, producing a PD savings of $175–$340 per meter depending on endpoint configuration. The registration advantage of static meters applies only to a non-standard, larger-than-typical meter size in very hard water. Even in that exception, the advantage is real but should be verified by site-specific pilot given the limited sample size of the underlying study. Sources: [21][22][23]

8.7 The Breakeven Question — When Does Ultrasonic Pay for Itself?

At standard residential 5/8″ × 3/4″ sizing, where no registration advantage exists, the hardware premium for ultrasonic over encoder-equipped PD is approximately $5/unit. That premium is recovered immediately from a hardware cost standpoint — but the additional replacement cycles over 40 years accumulate to a net PD advantage of $175–$340 per meter. There is no breakeven point where ultrasonic becomes more economical in standard residential applications based on the available field data.

The breakeven calculation applies only to the exception scenario — non-standard full 3/4″ meters in very hard water:

- Registration advantage begins materializing around years 4–5 of service (Glendale gap widened beginning 2017 after installation in 2012)
- The documented registration advantage at Glendale is about $876 per static meter over the ~13.6 years measured so far — roughly $62 per meter per year. Carried across a 40-year horizon, and even allowing for the gap's observed narrowing, that registration gain comfortably exceeds the roughly $175 (separate radio) to $340 (integrated radio) in additional ultrasonic hardware and replacement cost over 40 years
- In this specific full-3/4″, very-hard-water case, the static meter pays for itself; in every standard 5/8″ × 3/4″ case examined in this study, it does not
- However: Glendale involved only 5 services at a single site, and the gap narrowed in the most recent years. Utilities should treat these figures as directional and conduct site-specific pilots before committing to large-scale deployments based on this data

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