Residential Water Meter Replacement Economics

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Abstract

This paper analyzes an important apparent water loss component of the IWA water audit methodology; namely, losses in revenue due to customer meter inaccuracy. There has been an ongoing water utility debate over which criterion to use as a guideline for small residential water meter replacement in public and private water utilities. The primary criterion has been length of field service of the water meter. Nominally, most water utilities have used a range of service between 10 and 20 years for meter replacement due to the perception of decreasing meter accuracy with length of service. Recently, meter manufacturers have included age of meter, as well as cumulative water registered by the meter, as joint criteria for their national warranty for new and repaired meter accuracy. Obviously, meter manufacturers recognize the relationship between cumulative flow through the meter and meter accuracy deterioration with wear on meter measurement components and have quantified cumulative volume warranty for new meter and repaired meter accuracy for different meter sizes. Meter manufacturer warranty is likened to a new car warranty such as the ten years or 100,000-mile power train coverage offered by competing foreign auto manufacturers.

Additionally of note, more utilities are recognizing that low initial bid should not be the sole criterion for selection of small, domestic water meters. Some utilities have adopted multiple selection criteria, including life cycle cost, where lost revenue due to meter inaccuracy is considered as accuracy reduces over the "life" of a water meter. Due to national issues of population and water demand growth, drought, increasing costs for new water supplies, increasing operational costs to achieve higher water quality standards, increasing costs to replace aging infrastructure, and the emphasis on the utility being a good steward of its water resource as an example to its customers, water meter accuracy and reduction of non-revenue water are becoming more important to water utility management and their customers.

The purpose of this paper is to present the results of multiple accuracy tests of 5/8-inch by 3/4-inch domestic residential water meters, all having the same age of field service but varying amounts of cumulative water flow through the meter. The relationship between accuracy and cumulative flow will be presented and discussed for AWWA low, medium, and high flow regimes. The economics of water meter replacement will be discussed relative to the accuracy-flow relations for the three flow test ranges, and the process for determining the economic optimum cumulative volume through the meter will be described. For the Arizona utility from which the meters tested were derived, the recommended replacement timeframe will be presented utilizing the specific average annual residential water use and water rate structure in effect. The optimum replacement volume for different utilities will vary based on water meter environment and water use. To determine optimal meter replacement based on cumulative flow, a methodology has been developed that is defensible for all water utilities which collect the required meter accuracy data and apply their own unique economic and water usage circumstances. Results for the Arizona utility are presented and described herein for the low, medium, and high accuracy test flow ranges and the resultant optimum replacement volume.

Introduction

Many water utilities face multiple challenges throughout the world, and the issue of water loss accountability and subsequent revenue recovery through meter accuracy are no exception. Water losses affect water utilities in terms of resource impacts and economic impacts. Both can be quantified through a comprehensive utility water audit, such as that sanctioned by the International Water Association (IWA) and adopted by the AWWA. This audit methodology categorizes water losses as either real or apparent. Water losses through meter inaccuracies are in the apparent water loss category. Quantifying and reducing water losses, real or apparent, are significant undertakings for many water utilities. The subject of this paper primarily deals with apparent water losses through small, residential meter inaccuracies which increase over time and cumulative volume. This paper documents the findings, conclusions, and recommendations of a multi-year data collection and domestic water meter accuracy testing process by the Metropolitan Domestic Water Improvement District Northwest of Tucson, Arizona to determine the optimum meter replacement time based on cumulative volume registered through the meter. This study focuses on results from accuracy testing of small, single-manufacturer residential water meters (5/8-inch by 3/4-inch positive displacement type) having a nominal field service life of ten years.

The Metropolitan Domestic Water Improvement District is a sole service water provider serving approximately 16,000 customers representing a population of 45,000. The District encompasses approximately 25 square miles of service area and is primarily residential with some multi-unit housing. Ninety-five percent of District meters serve residential customers. The only potable water source at this time is groundwater pumped through multiple wells.

By 1999, the District realized that unaccounted for water losses (non revenue water) were increasing annually and exceeding 10% per year, the Arizona regulatory limit. The District was faced with determining where the water losses were occurring and recognized an opportunity to potentially recover lost revenues via a meter replacement program. Since the majority of existing water mains are buried an average of 36 inches deep, real losses attributable to water main leaks typically surface and are easily detectable 90% of the time. The District was determined to focus efforts on apparent water losses, since there had never been a meter replacement program. The initial effort was to replace all small meters that were ten years of age and older, which represented approximately 50% of the existing meters in the system. These meters were identified and replaced during a period of two and one-half years. Thereafter, all 5/8 x 3/4-inch meters were anticipated to be replaced on a 10% replacement schedule, replacing a tenth of the meters per year over a ten-year period.

A primary indicator that meter replacement could be beneficial was the generation of random test results on a series of meters that had been known to be in the system longer than ten years. Those results showed dramatic inaccuracies in the water meters at multiple flow ranges. Since the inception of the meter replacement program, over 9,800 meters have been replaced through 2004, representing over 60% of the total 5/8 x 3/4-inch meters. Subsequent water measurement and revenue recovery through greater meter accuracy indicate that the program is successful. Water losses for calendar years 2003 and 2004 were reduced to 5.6% and 5.2% of total water delivery, respectively. Budget considerations for an aggressive meter replacement program must be balanced against revenue savings.

The District determined that it currently costs $45 to replace a 5/8 x 3/4-inch meter. Therefore, the District was tasked with determining the economic breakpoint at which the cumulative losses due to meter inaccuracy would economically equal the cost of the replacement program. In its initial meter replacement effort, the District recognized that ten-year-old meters had a variance of cumulative usage ranging from 300,000 to 3,000,000 gallons based on individual water use patterns. To allow the District to be more effective in its replacement program, it was felt that a cumulative flow-based meter replacement program would be more economically prudent and efficient.

Purpose of this Paper

The purpose of this paper is to document the procedures used for determining the optimum time for residential water meter replacement based on cumulative flow through the meter during service in the field, rather than length of time that the meter is in service. To determine optimal meter replacement based on cumulative flow, a methodology is developed that is defensible not only for the District, but also for all other water utilities having interest in collecting the required data, applying their own unique economic and water usage circumstances, and determining their specific optimum meter replacement volume.

Using the methodology developed in this paper, lost revenue per year specific to the District and the cumulative dollar loss from the decreased accuracy resulting from cumulative flow volume through the meter are calculated. The cumulative loss in revenue is compared with the cost of meter replacement to determine optimum meter life in terms of cumulative flow and average length of service.

Background

Water meters serve as both yardsticks and cash registers for water-conscious modern water utilities. Not only do they provide information on water usage and help to determine potential losses in the system, but water usage as recorded through meters is the basis for water user fees and the majority of a utility's recurring revenue. The District relies heavily on accurate monthly water usage as measured by its small residential water meters. Inaccuracies in water meter readings mean a loss of revenue for the District. Meter inaccuracy also results in apparent losses affecting total Non-Revenue Water (NRW) calculation in a standard water audit and reported total losses to the Arizona Department of Water Resources (ADWR) in the required annual report. Higher utility water loss affects customer confidence in the utility and credibility during times of drought and requests for individual customer water conservation. Many states, including Arizona, are legislating audit requirements and setting limits on allowable Non-Revenue Water. Meter accuracy is, therefore, an ongoing concern of many water utilities, and strategically replacing meters to optimize revenue is of key importance.

For many years, utilities and water professional researchers have been trying to determine the optimum time for meter replacement with no conclusive answer. The evaluation described herein proposes meter replacement when the cumulative revenue lost due to meter inaccuracy exceeds the amount it costs to replace the meter. Cumulative revenue loss depends on change in meter accuracy over the service life of a meter. Factors such as water quality and specific meter characteristics contribute to the degradation and loss of accuracy of the water meter over time in service. Many of the studies and articles previously published attempting to determine the optimum life of a residential water meter focus primarily on a direct correlation between the loss of accuracy and time.

The evaluation described herein seeks to statistically correlate meter accuracy and cumulative volume through the meter as the determinant of the optimum meter replacement criterion. If, in fact, it is cumulative flow rather than time that affects meter accuracy, then this would explain why there is no definitive utility standard time for meter replacement. Each utility has a unique set of water usage patterns, water quality, and environmental conditions which impact the degradation and accuracy of their various water meters. Armed with this hypothesis, the District conducted tests and provided multiple meter accuracy data sets and results from time-of-day residential meter flow readings for in-depth analyses. This study demonstrates that cumulative flow rather than time is the primary factor affecting residential water meter accuracy. The cumulative flow method accounts for the specific water use conditions for various utilities and can be utilized by any water utility collecting the relevant data.

Study Assumptions and Criteria

The following assumptions and criteria provide the basis for the technical portion of this study:

- All meters tested were 5/8"x 3/4" positive displacement residential water meters.
- Accuracy at zero cumulative flow is assumed to be 100% at low, medium, and high test flow rates.
- Trend lines (linear best data fit) are used to statistically normalize meter accuracy versus cumulative flow test data for each test flow rate.
- Meter test accuracies measuring below 10% and above 102% were assumed to be "bad data" and were purged from the database.
- Meter accuracy testing was conducted by a limited number of trained District staff using its own in-house designed, constructed, calibrated, and operated testing bench.
- Cumulative flow was assumed as measured in actual field service by the individual water meters.
- Time in service is based on the dates the meter was installed and subsequently removed from the field. For the single meter manufacturer analyzed in this study, the meter number depicts the year of manufacture.
- The average service life of the meters tested for accuracy in the large-sized database, which serves as the primary database, is ten years.
- The meter life for the meters tested used for the smaller-sized databases, for trending only, varies between two and eleven years.

Data Collection

Multiple data types are required for this evaluation, including: meter accuracy tests with low, medium, and high flows for meters with the same nominal service life; meter accuracy tests with low, medium, and high flows for meters removed from system service regardless of service life; percentage of time residential customers use water at the low, medium, and high flow rates by season; nominal residential meter replacement cost; annual average residential water use per customer; and residential water rates.

A large-sized database of water meter accuracy tests was provided by District staff to Malcolm Pirnie for analysis in Microsoft Excel format. The large database consisted of typical 5/8-inch by 3/4-inch meters manufactured by a single manufacturer and placed in service in 1993. One thousand five hundred sixteen (1,516) meters were removed from the District water system over a three-year period and tested for accuracy.

The average nominal service life for these meters is ten years. The meters were tested within several days of their removal by a limited number of trained District staff using its own in-house designed, constructed, calibrated, and operated testing bench. Accuracy tests were conducted at low, medium, and high flows as established by AWWA Water Meter testing standards for this size meter. Test flows are defined as shown in Table 1 below.

Table 1: AWWA 5/8-inch by 3/4-inch Water Meter Testing Standards

Flow	Defined Flow Range	Test Flow Rate
Low	0 – 0.25 gpm	0.25 gpm
Medium	0.25 – 2 gpm	2 gpm
High	2 – 15 gpm	15 gpm

A meter accuracy results database was set up, and data were recorded. Recorded data included the date the meter was removed from the system, meter number, cumulative flow as recorded on the meter, meter size, and the tested accuracy at low, medium, and high flows. An additional element of data collection and analysis involved evaluating the percentage of time meters within the system operate at the various flow ranges. This data is relevant, since meter accuracy changes with flow rate through the meter. District staff installed seven-day flow recorders on selected residences during each of the four seasons as defined in the table below. A summary of the “Meter-Master” time-of day flow range results can be found in Table 2 below, entitled *Percentage of Residential Flow by Season*. This summary shows the average percentage of time that selected households operate at the various low, medium, and high flow ranges by season. Also included is the number of meters measured for each season. The Meter-Master database includes 132 customers with measured flow at the low, medium, and high flow rates. Water use by residential customers in the three flow ranges varies by season, but the low flow usage varies the least of the three ranges. Higher flow variation exists in the medium and high flow ranges.

Table 2: Percentage of Residential Flow by Season

Seasons	Percentage of Time				Total Percentage	Number of Meters Counted
	Low Flow	Med Flow	High Flow			
	0 - 0.25	0.25 - 2	2-15+			
	gpm	gpm	gpm			
Spring	13.9	19.0	67.1		100.0	27
Summer	10.5	16.0	73.4		100.0	48
Fall	11.5	25.3	63.3		100.0	30
Winter	7.8	33.6	58.6		100.0	27
Annual Weighted Average	10.87	22.31	66.81		100.0	132

Figure 1, Percent Variation in Water Use by Season, shows a graphical representation of this seasonal data. But, more importantly, the annual weighted average at which the sampled residential customers use water within a given flow range is an essential factor in estimating meter replacement.

For this database, 10.87 percent of the total measured flow was used at the low flow range, 22.31 percent was used at the medium flow range, and 66.81 percent was used at the high flow range. It is important to note that typical District residential customers use most water at the medium and high flow rates, for which water meters typically have higher accuracy. As will be shown below in the analysis section of this paper, it is the low flow percentage that drives lost revenue due to meter inaccuracy and, thus, the optimum meter replacement criterion.

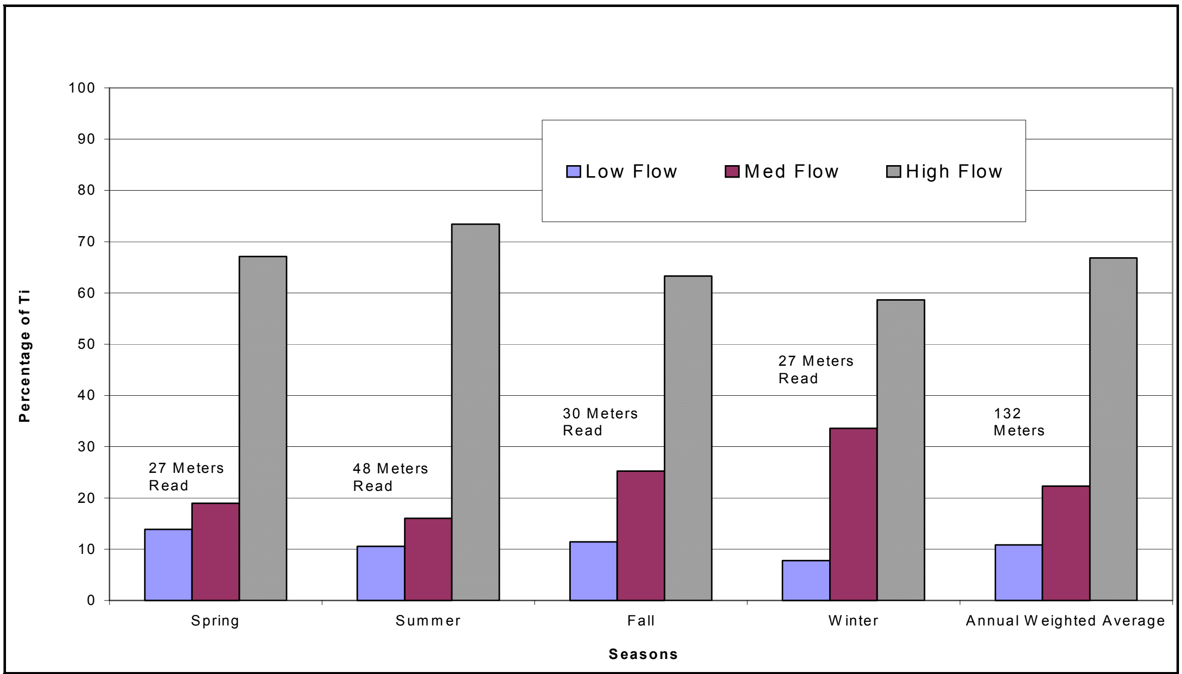

Figure 1: Percent Variation in Water Use by Season (Percentage of Time versus Seasons)

Analysis of Meter Accuracy Tests

The single manufacturer database was analyzed for completeness and reasonableness of accuracy test results. With the ten-year average service life data collected in one large database, the data were reviewed and screened. Accuracy tests not having all test ranges were eliminated. All accuracy test readings below ten percent and above one hundred two percent were assumed faulty readings and were purged from the database, leaving a total of one thousand two hundred ninety-seven (1,297) data points for each of the low, medium, and high flow test ranges.

Once the database was screened, a data plot of cumulative flow versus accuracy for each of the low, medium, and high flows was produced. Figures 2, 3, and 4 indicate data results of accuracy versus cumulative flow for the large database at low, medium, and high test flow rates, respectively. Data indicates higher scatter for the low flow test, as expected, and lesser scatter for the medium and high flow test rates. Also indicated on the plots are Microsoft Excel-calculated trend lines indicating best linear fit. The slope of the trend line was used as the normalized indicator of the decrease in meter accuracy for a specific flow range with increasing cumulative flow volume measured by the meters.

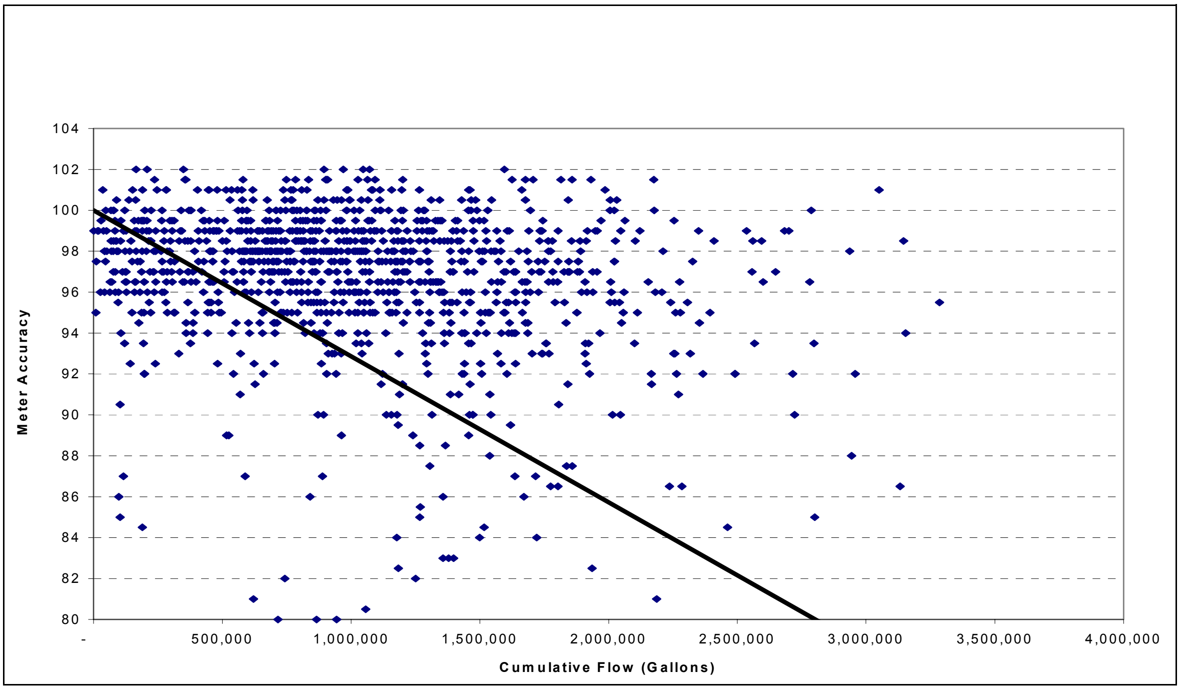

Figure 2: Meter Accuracy versus Cumulative Flow for Low Flow Tests -Ten Year Service (5/8" x 3/4" Positive Displacement Residential Water Meter)

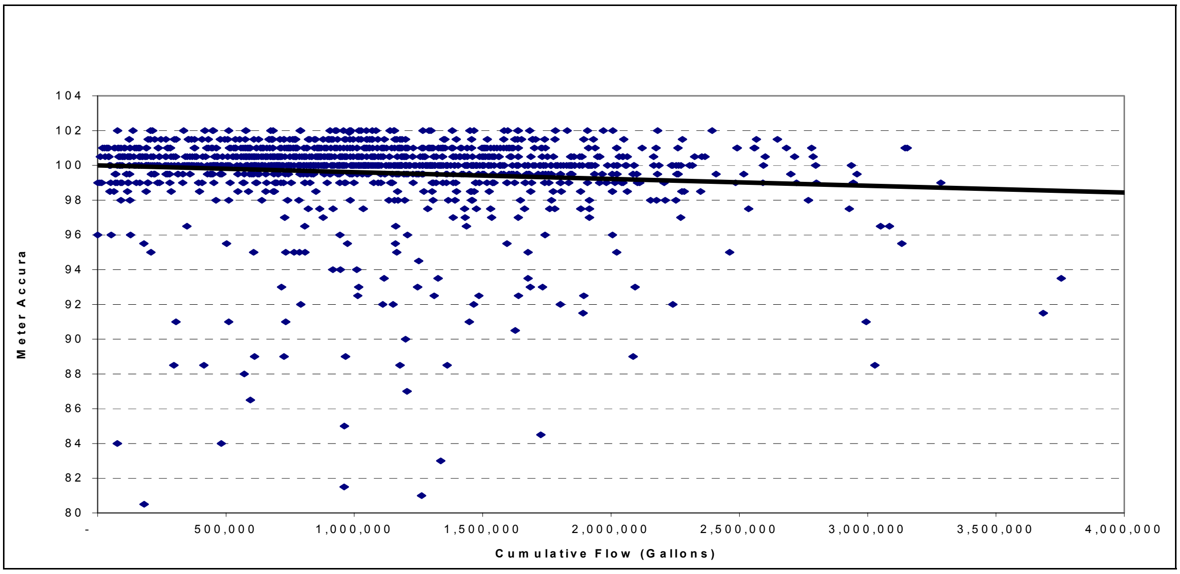

Figure 3: Meter Accuracy versus Cumulative Flow for Medium Flow Tests-Ten Year Service (5/8" x 3/4" Positive Displacement Residential Water Meter)

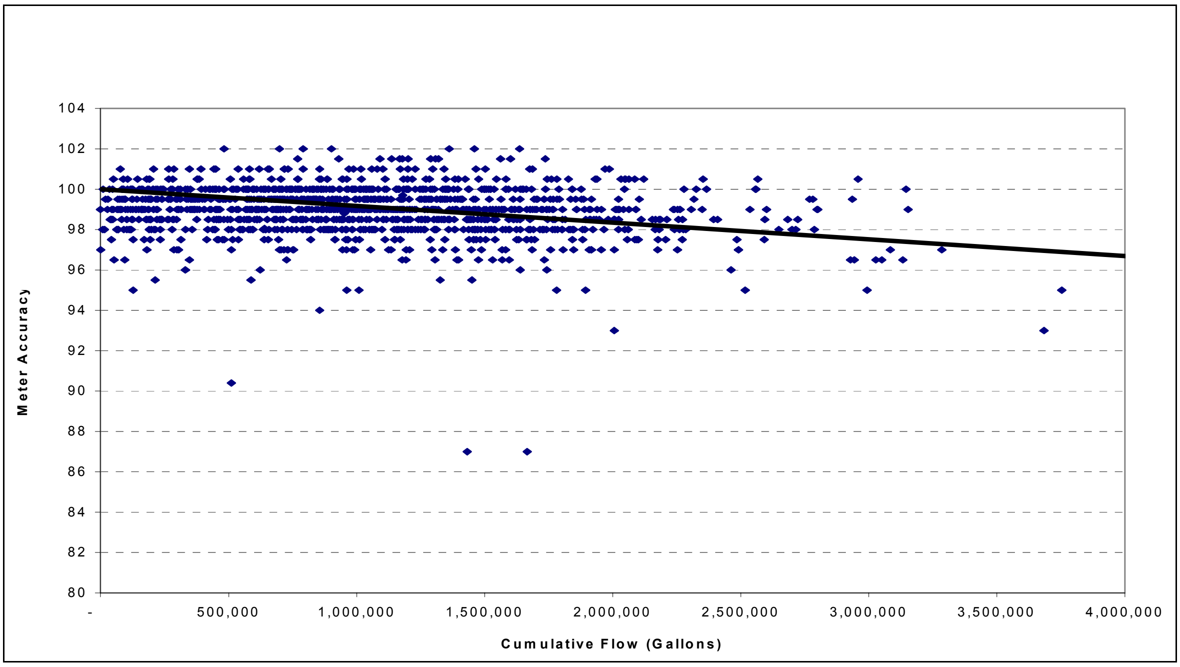

Figure 4: Meter Accuracy versus Cumulative Flow for High Flow Tests-Ten Year Service (5/8" x 3/4" Positive Displacement Residential Water Meter

Figure 5, *Meter Accuracy versus Cumulative Flow-Summary of Trend Lines,* indicates comparative plotted results for the three test flow ranges. With service life of the meter held constant at ten years to remove age as a variable, Figure 5 clearly reveals that, as total cumulative flow volume increases, the meter accuracy decreases. This is not an unusual concept, since it is documented in water meter manufacturer warranties, and AWWA publications state that "*Registration curves of water meters show that meters in good operating condition follow a general pattern of registration. Above the very low flows that the meter will not register there is an intermediate point of maximum registration. Above and below this point, lower registration is obtained*". Figure 5 shows that the maximum "registration curve" or "the least decrease" of accuracy with the accumulation of flow volume is the medium flow range. What is noteworthy with this analysis is the impact that the low flow water use rates have on meter accuracy as cumulative flow volume increases. This substantial decrease in accuracy with increasing cumulative volume appears to be the primary factor that ultimately drives the need for meter replacement.

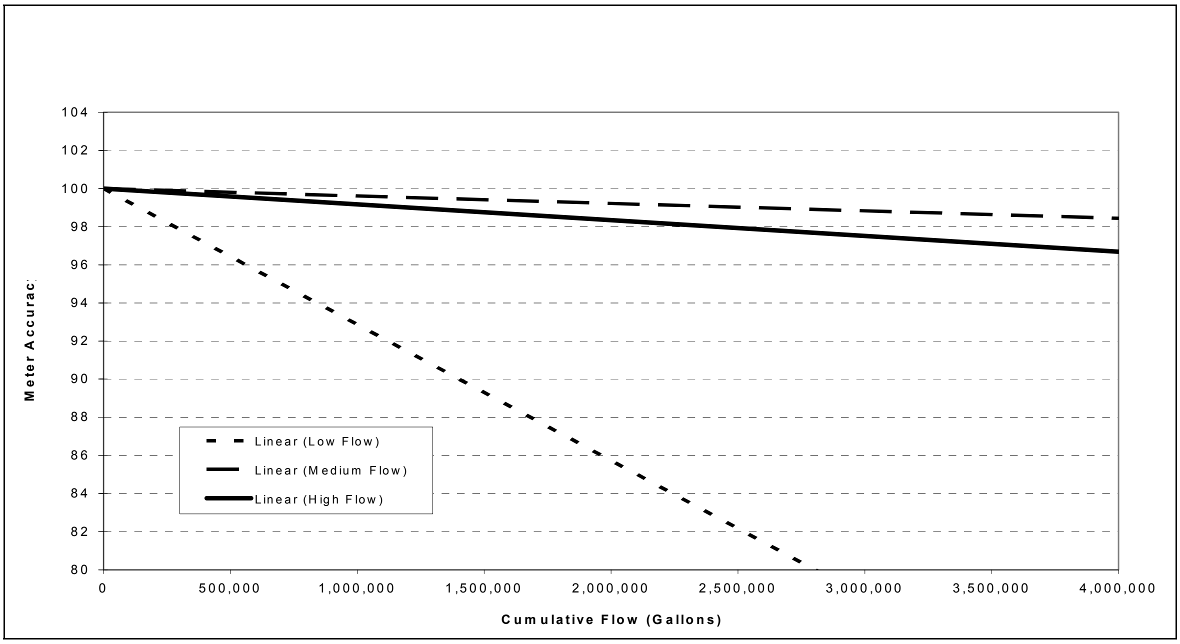

Figure 5: Meter Accuracy versus Cumulative Flow-Summary of Data Trend Lines

(Ten Year Average Service - Low/Medium/High Flow)

Revenue Lost Due to Meter Inaccuracy

The average residential water use per customer for the Metropolitan Domestic Water Improvement District system is 130,000 gallons per year. Using this average, the total number of years to accumulate metered volumes in 500,000-gallon increments was calculated. The average accuracies at each of the cumulative flow volumes (in increments of 500,000 gallons) are calculated from the trend lines for the low, medium, and high flow test ranges as shown in Figure 5. The average annual weighted average for the percentage of time the average residential customer uses water at the low, medium and high flow rates combined with the current District average residential water bill of $33.56 per month were used to calculate the dollars lost per year due to increasing meter inaccuracy.

By plotting the total dollars lost per year versus the total number of calculated years, as calculated from total cumulative volume, and summing the area under the curve, the total cumulative lost revenue is calculated, as indicated on Figure 6, *Lost Revenue versus Cumulative Flow*. With the District's existing cost of meter replacement, the optimum cumulative volume for meter replacement for the District was calculated at 1,420,000 gallons.

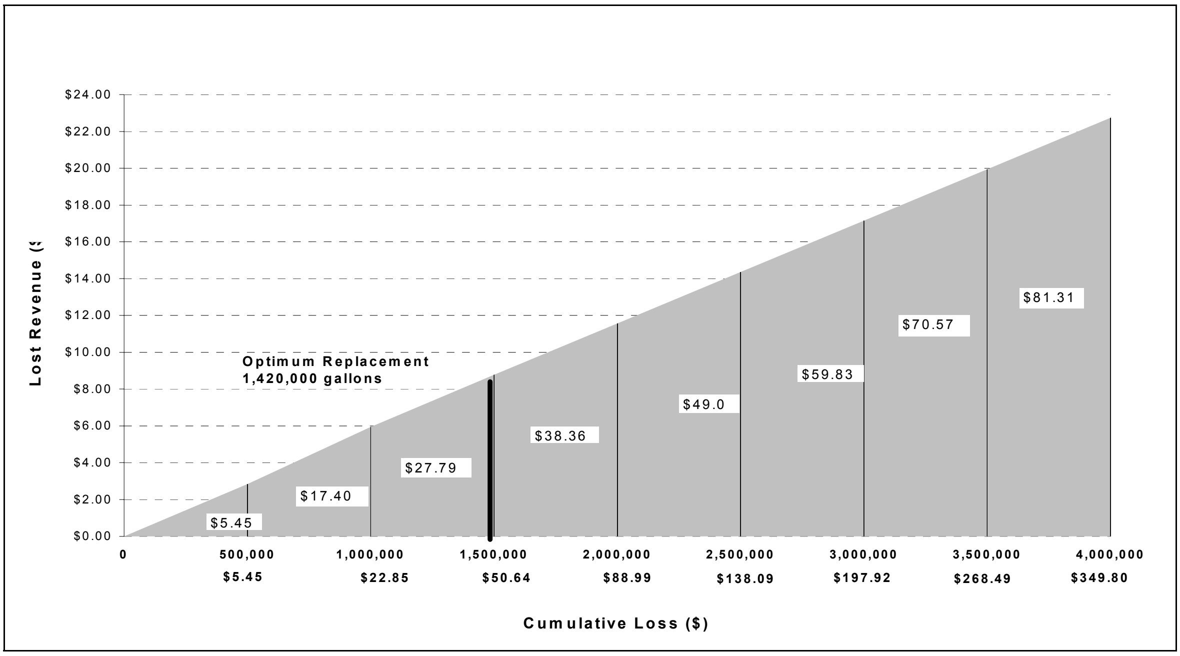

Figure 6: Lost Revenue versus Cumulative Flow

(5/8" x 3/4" Positive Displacement Residential Water Meter)

Summary of Approach

The following steps present a simplified approach for determining optimal meter replacement based on cumulative flow through a typical 5/8 x 3/4-inch residential water meter:

1. Collect time-of-day instantaneous flow measurements for a representative sample of residential water customers to determine average percentage of flow used at the low, medium, and high flow ranges.
2. Conduct meter accuracy testing of 5/8 X 3/4- inch meters pulled from the utility system at the low, medium, and high flow test ranges noting cumulative volume and length of time in service.
3. Plot meter accuracy versus cumulative volume for individual low, medium, and high test flow rates. Determine the best linear fit of the data.
4. Based on Step 1 and Step 3 results, calculate the weighted meter accuracy versus cumulative volume.
5. Based on Step 4 results, calculate lost revenue per year versus cumulative volume.
6. Sum lost revenue versus cumulative volume and compare with utility's economic cost to replace the water meter. The amount where cost and value of lost revenue are equivalent indicates the optimum cumulative volume for meter replacement.

This paper clearly demonstrates that cumulative flow volume of the meter combined with the percentage of average water used by residential customers at low flow levels within the District is the driving factor for meter replacement. Prior to this study, the District was replacing meters every ten years independent of volume, but has now officially adopted a cumulative volume-based program of 1.42 MG for all small meters.