Using an AMR System to Aid in the Evaluation of Water Losses: A Small DMA Case Study at East Bay Municipal Utility District, USA

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Abstract

This paper outlines the development and evaluation of two small residential District Metered Areas (DMAs) within the East Bay Municipal Utility District service area in northern California. The two areas have significantly different non-revenue water characteristics. The District evaluated the system usage through analysis of hourly SCADA, reservoir level data, and customer consumption using Automatic Meter Reading (AMR) systems recording on hourly intervals. This data was recorded, validated, and analyzed to better define the non-revenue water and the variation of apparent and real losses in both systems.

This is one of the first projects of its kind that evaluates water losses by using all the data integrated in close to real time. It adds a further dimension to the possibilities of district metering by allowing the District to assess the changes in system flows on an hourly basis rather than just during the low-flow minimum night flow periods. As will be noted in the paper, there are still issues, errors, and estimates in this data. However, this provides insight into the nature of the meters and enables the District to improve metered data accuracy and assess the minimum night flow usage at the same time.

The paper details the technology of AMR utilized, the results obtained, and the knowledge gained during the analysis.

Introduction

In 2005 EBMUD embarked upon an extensive pilot program to evaluate the conservation benefits of AMR systems within its service area. EBMUD conducted field studies with mobile and fixed-network systems each equipped with data-logging capabilities. The results of the mobile network system used on the Holly and Round Hill Pressure Zone were the subject of this analysis. The Holly Pressure Zone was selected based on its high discrepancy between billed consumption and water delivery to the zone. The Round Hill Pressure Zone was selected because of its relatively low discrepancy. Currently EBMUD is developing additional pressure zone balance studies with fixed network AMR technology.

WPRC, in cooperation with EBMUD, has completed detailed audits of the pressure zones in order to determine the true nature of lost water — leaks, flushing, fire flow, system meter error, customer meter error, theft, leaks from one zone to another, or any combination thereof. The tools and data used in these audits were hourly consumption from AMR- and data-logging-equipped customer meters, hourly operations data from SCADA system historian of pumping plants flow rates and reservoir level indicators, acoustic leak-detection equipment, and customer-meter testing equipment. Both locations and equipment had some issues with installation and/or operation; however, all data from each meter was available for this study. It should be noted that EBMUD meters 100% of its customers.

Background

The Round Hill Pressure Zone consists of the Round Hill Pumping Plant and Reservoir, and approximately six kilometers (4 miles) of primarily 200 mm and 150 mm piping. The majority of piping was installed in 1981 and is a mix of steel and asbestos cement. At the time of the study, the Round Hill Pressure Zone had 137 affluent customers with large homes and very large landscapes, two (2) irrigation-only accounts, and two (2) homes under construction. The meter size distribution is shown on the following table.

Table 1. Round Hill Meter Information

Meter size	Number of meters	Average Daily Use (l/conn/d)*
15 mm (5/8-inch)	116	3713
19 mm (3/4-inch)	6	7,211
25 mm (1-inch)	4	8,301
38 mm (1.5-inch)	15	5,984
Total	**141**	**4,175**

*2004 annual consumption (from bimonthly billing records)

Actual water usage in these homes is much higher than typical single family homes and averages more than (1,600 gallons) per day in the summer months. Some of the homes use as much as (37,500 litres) per day during summer months. The resolution of these meters ranges from 0.1 cubic feet to 10 cubic feet (2.83 litres to 283 litres) depending on the size and manufacture of the meter register. Based on a review of historical bi-monthly billing records the zone customer demand tracks well although the losses are comparatively high due to the very high usage (approximately .250 litres/connection/day, or 6% of total production) compared to supply records.

The Holly Pressure Zone consists of the Holly Pumping Plant and Reservoir. There are approximately four (4) miles of piping ranging in size from 150 mm to 400 mm in diameter. This piping is primarily mortar-lined steel which was installed between 1988 and 1995 with a small amount of plastic (PVC) piping installed in 1998. At the time of the study, the customer breakdown in the Holly Pressure Zone was as follows: 62 fourplexes, 62 single-family homes, 19 estates, 15 irrigation-only, and two (2) apartment buildings. The meter size distribution is shown on the following table.

Table 2. Holly Meter Information

Meter size	Number of meters	Average Daily Use (l/conn/day)*
15 mm (5/8-inch)	13	4,603
19 mm (3/4-inch)	0	-
25 mm (1-inch)	13	5,470
38 mm (1.5-inch)	127	2,805
50 mm (2-inch)	6	25,730
76 mm (3-inch)	1	101,373
Total	**160**	**4,630**

*2004 annual consumption (from bimonthly billing records)

The resolution of these meters ranges from 0.1 cubic feet to 50 cubic feet (2.83 litres to 1,415 litres) depending on the size and manufacture of the meter register. Based on a review of 3 years of historical bimonthly billing records the zone demand tracks poorly (greater than 25% loss – 1150 litres per connection per day) compared to supply records.

Aside from the 19 large estates in the Holly Pressure Zone, the rest of the services are part of a senior-living community. Homes in the senior center consist of separately metered single-family homes, townhouses connected as fourplexes with a common meter, and several apartments. In the center, all landscape and irrigation services are provided by one of several homeowners' associations and paid for through association fees. Water supplied to the fourplexes is also paid for by the homeowners' fees. All but 12 of the fourplexes and all of the single family homes in center are connected to 1.5-inch or 38 mm meters as required to meet flow requirements of fire sprinklers in each of the homes. However, because all of the demand on these 38 mm meters is from indoor uses, a significant percentage of their usage is at the bottom end of or below the AWWA-recommended operating range of $1^1/_2$ to 120 gpm (5.7 to 454 litres per minute).

Pressure Zone Audit and Balance Process

Audits of the pressure zones were first conducted by comparing billing records based on bimonthly meter reads and average supply rates from SCADA system records. After a supply vs. demand discrepancy was identified the audit process was formally begun in the following steps:

1. **Demand Data.** Hourly data was downloaded from AMR-equipped customer meters.
2. **Demand Calculation.** Hourly AMR data was summed to determine total customer demand.
3. **Supply Data.** Hourly pumping plant and reservoir operating data from EBMUD's SCADA historian was extracted and added to the database. Neither of these zones had regulated subzones so there was no bulk outflow.
4. **Supply Calculation.** Hourly system supply was calculated from hourly pumping and changes in reservoir storage.
5. **Calibration.** SCADA data was corrected for system anomalies, loss of signal, and calibration errors. Pump-flow meters were calibrated to pump curves and reservoir fill rates . System accuracy was rechecked once the typical loss rate was established.
6. **Time Shift.** When necessary, AMR data was shifted by one hour to accommodate for daylight savings time to match SCADA records.
7. **Averaging.** A three-hour rolling average was used to compare hourly demand as measured by the SCADA system and hourly demand as measured by the AMR system.
8. **Statistical Analysis.** Statistics were developed to measure the loss percentage as a function of month, pumping plant operation times, overall demand, several large-user demands, and various other factors.
9. **Meter Testing.** A small number of meters with extensive usage history and/or known excess usage along with new/unused meters were shop-tested for accuracy at flows ranging from much below design flow rate to much above design flow rate.

10. **Pipeline Leak Detection.** Acoustic leak detection equipment was used to identify any distribution pipeline or valve leaks.
11. **Audits.** Customer audits were completed to ensure that there was no unmetered use.

Authorized Uses

Authorized uses in both pressure zones are shown mainly by the billed consumption data. There were no known fireflows (testing or otherwise) during the project. Water quality flushings did not occur during the periods examined. Furthermore, there were no known contractor or other authorized hydrant uses. The Round Hill Pressure Zone had several lateral repairs but the loss was minimal and accounted for. Therefore, the data can be evaluated as it is organized with little known interference from other factors.

Leaks

A surprisingly large percentage of total water usage discovered by the AMR systems in Round Hill Pressure Zone was customer-side leaks. These leaks were identified by the absence of any zero consumption hourly readings over a 24 hour cycle. 40% of the customers had leaks which were recorded as a continuous flow of water use. Typical leaks averaged between 0.5 litre and 1 litre per minute, which is typical of a small toilet leak and amounted to a total of 91 gallons (340 litres) per household per day or approximately 12,500 gallons (47,300 litres) per day for the whole pressure zone. A 0.5 litre per minute leak equals approximately 1 cubic foot per hour consumption, which is the minimum unit recorded by most AMR-equipped meters. Ninety percent of the meters in the zone recorded 1 cubic foot or better resolution.

By comparison, only a small number of customer leaks (12%, or 19 of the 156 properties) were found by the AMR system in the Holly Pressure Zone, although the authors contend the actual leakage rate was much higher. Two of the 19 meters with recorded leaks were measuring water consumption in apartment buildings where the total leakage rate was 0.5 and 2.5 gpm (2 litres and 9.5 litres per minute) respectively. The other 17 meters that recorded leakage were associated with accounts on 15 mm (5/8-inch) and 25 mm (1-inch) meters. None of the 127, 38 mm (1.5-inch) meters recorded any leakage. However, all 12 of the fourplexes connected to 25 mm meters recorded leaks. There are two likely reasons the smaller meters were able to record the leak rates and the 38 mm meters were not: 1) the AWWA lower accuracy range of 15 and 25 mm meters (1 and 3 litres per minute) is lower than 38 mm meters (5.5 litres per minute); 2) the resolution of the electronic registers was 0.1 cubic foot (3 litres) vs. 1.0 cubic foot (28 litres) of the 38 mm size.

The Round Hill Pressure Zone has considerably smaller meters than the Holly Pressure Zone. This enabled more precise measurement of leaks because the AWWA Standard accuracy range of the meters themselves was lower (1 to 75 litres per minute). However, the resolution of the majority of the electronic meter registers in the Round Hill Pressure Zone was 1.0 cubic feet, thus requiring a continuous leak of at least 0.5 litre per minute to register. Several reasons led the authors to believe that customer leaks in the Holly Pressure Zone 38 mm meters were at least as prevalent as Round Hill even though they were not being measured by the majority of the meters:

1. The presence of 40% leaks in Round Hill where the homes were of similar age and location.

2. All 12 of the 25 mm (1-inch) meters in the fourplexes in the senior center subdivision of the Round Hill zone recorded leaks.
3. Both apartment buildings in the senior center had identifiable leaks.
4. Since the study has been completed, the senior center management has completed a toilet testing and repair program, which found and repaired numerous leaks.

EBMUD conducted a basic distribution system leakage survey in each pressure zone and found no major leaks. EBMUD maintains a GIS record of all recorded main breaks and none were reported during the study period.

Study Findings

During the study, the losses were significantly different between the two areas. The Holly Pressure Zone has significantly more measured supply-side water loss than Round Hill both in percentage terms (20% vs. 8% of total system input) and per connection (545 litres per connection per day (lpcd) in Holly, and 242 lpcd in Round Hill over the periods of record). However, both zones do have significant customer-side leakage that was metered in Round Hill but undetected in the Holly zone.

Round Hill Pressure Zone

The results of the analysis for the Round Hill Pressure Zone suggest that the SCADA system is the main source for the recorded apparent losses and the system appears relatively tight overall once this error is removed. The study also helped identify several high use meters that were no longer working which were suspected after review of graphs similar to Figure 1 which shows a marked difference between the peak supply and peak demand on certain days. These meters were most likely damaged by excessive flow over a period of time. However, there are still customer-side leaks that need to be addressed to improve the water use efficiency of this zone.

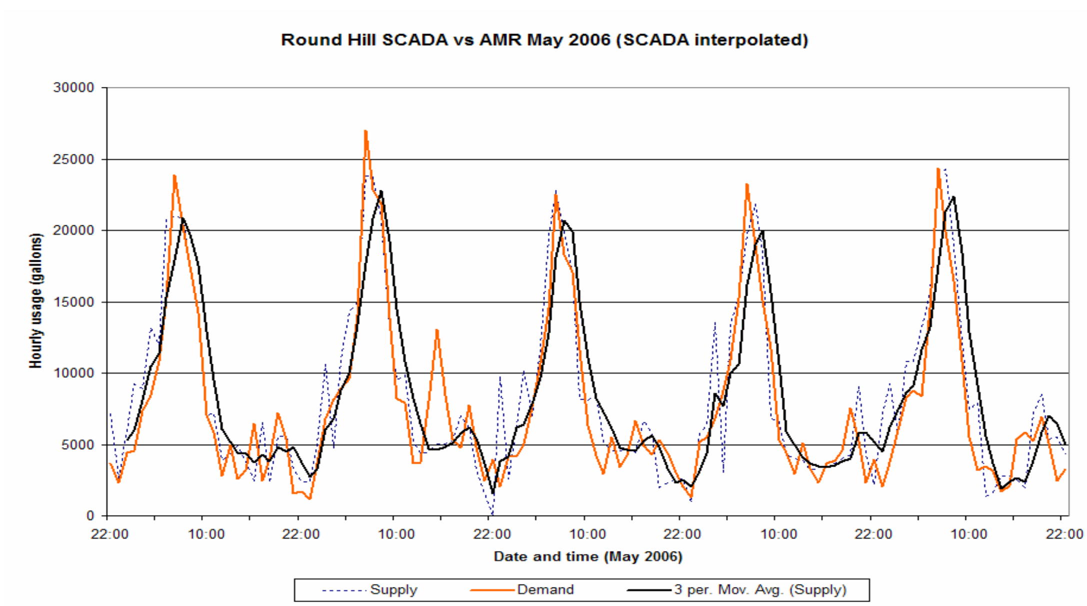

Figure 1. Round Hill supply versus demand graphs.

Holly Pressure Zone

The results of the analysis for Holly Pressure Zone appear to show a good correlation between meter accuracy and water system losses. The problems appear to be greatest above and below the AWWA accuracy ranges. The low-flow periods have significant losses. However, the largest volume problems appear to be during the highest flow conditions at the upper end of the meter flow accuracy ranges. It is quite likely that just a couple of major users are pumping far beyond the accuracy range of the in-place meter. For example, one user is constantly pumping 4.9 l/s as recorded by the AMR system (the property manager who maintains the pumping plant indicated it may actually flow much higher) in the summer months to feed their system – all through a 25 mm (1-inch) meter.

The high flow conditions only occur during the irrigation season during which time there is a massive variation in flow on a daily basis. Figure 2 outlines the demand pattern of the Holly zone, which is very peak-driven due to the irrigation systems. Other than a short time in February when the area received a few days of very warm weather, the irrigation systems were mainly started in late April.

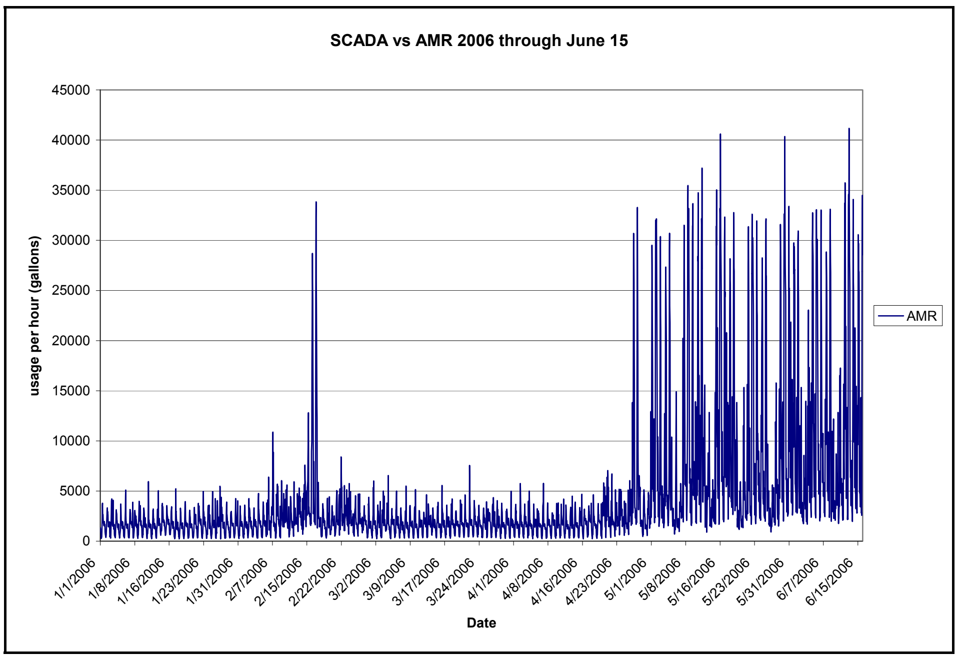

Figure 2. Holly Billed Usage from January 1 through June 15, 2006 showing peak demand for irrigation).

The data shown in Figure 3 outlines the effect of the top ten users on the Holly zone supply and outlines some of the variations between production and billing which are further discussed and explained in Figures 3 and 4.

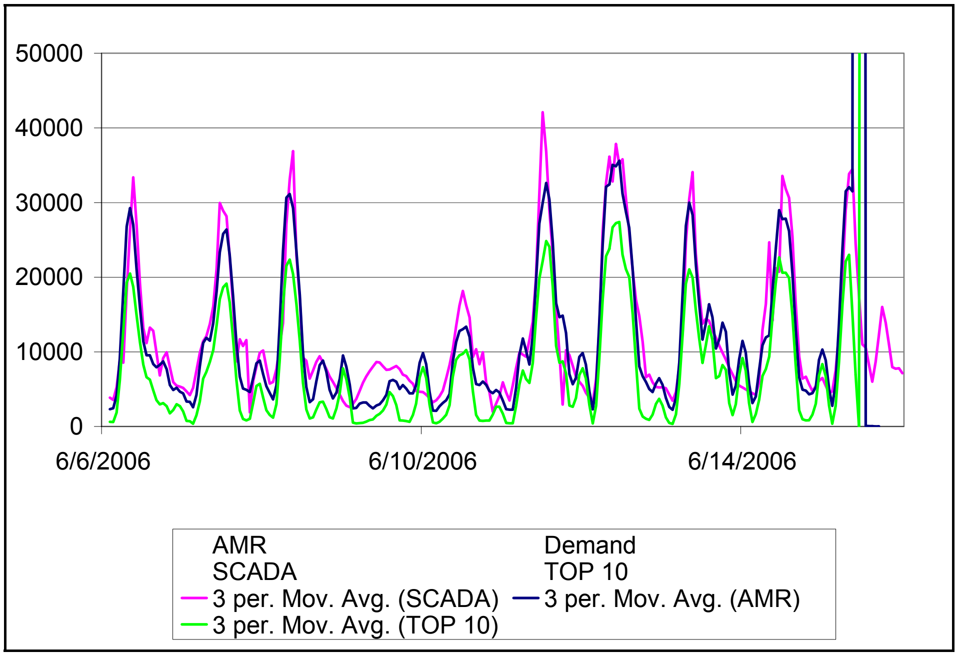

Figure 3. Ten-day production versus billed usage review

Figures 4 and 5 below outline the differences between January and June hourly averages within the project time period in 2006 when more detailed review was conducted. What appears evident is the following:

- January data shows the consistent loss throughout the day associated with the low-flow meter inaccuracy.
- June data shows the highly variable losses throughout the day associated with the high-flow meter inaccuracy.
- There is a very large variation between average and peak water use which will almost certainly cause significant stress on the distribution infrastructure, and meter performance.
- Water losses in June appear to be greater in the early morning hours when lawn irrigation is at its peak.
- The largest 10 result in more than 60% of the peaks in this pressure zone. These users drive the system demand, and the apparent losses.

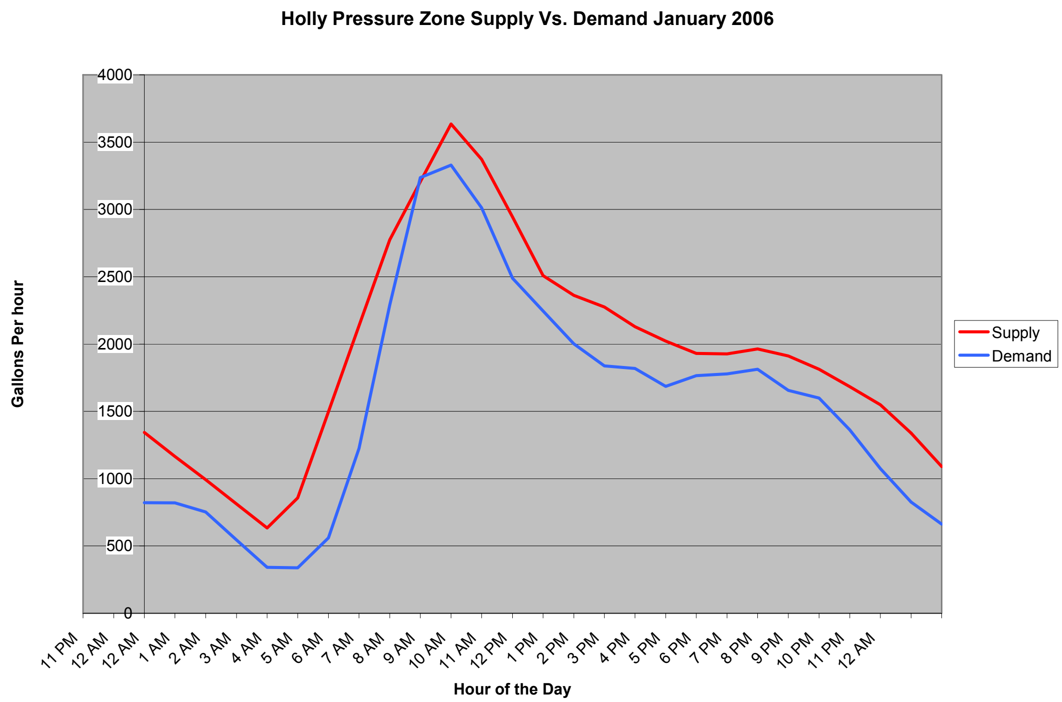

Figure 4. January 2006 average hourly data supply versus demand on Holly Pressure Zone in January 2006 showing apparent water loss from low flow leaks.

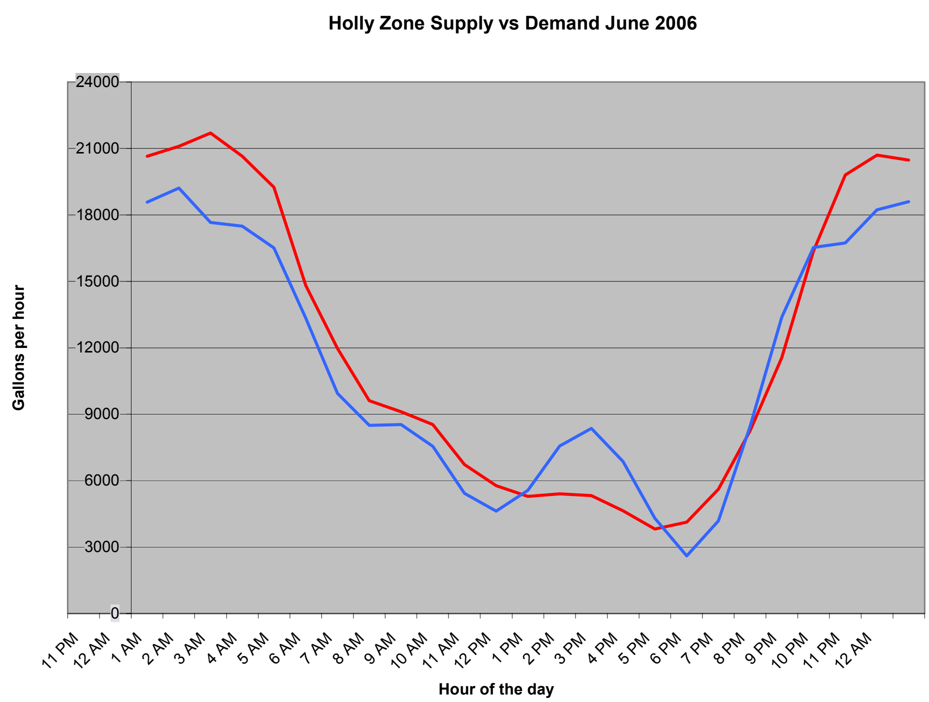

Figure 5. June 2006 average hourly data supply versus demand on Holly Pressure Zone in June 2006 showing apparent water loss from high flow meter inaccuracies.

Meter Testing Results

EBMUD completed a number of different tests on meters outside of normal operation as part of this study. However, EBMUD's meter-testing laboratory was designed to test meters in normal operating range and therefore limited tests were completed at various stable low-end flow rates, which were not easily repeatable.

The first tests EBMUD completed were on new meters with the following results:

- New 15mm (5/8-inch) meters were 99% accurate at flows as low as $^1/_2$ litre per minute (lpm) and as high as 110 lpm. Magnetic disconnect occurred at flows approaching 190 lpm.
- New 25 mm (1-inch) meters were found to be 96% accurate at 1 lpm and 100% accurate at 375 lpm.
- New 38 mm (1.5-inch) meters were found to be an average of 94% accurate at 1 lpm; however, low-flow rates could not be tested.

The second round of tests was completed on used meters from the study area with the following results:

- Six 15 mm (5/8-inch) meters were selected for testing.
  - One meter with more than 2.3 million reported cubic feet (65 million litres) on it was slipping badly and only reporting about 2% in AWWA ranges.
  - Another meter with more than 1.2 million cubic feet (34 million litres) of recorded consumption broke at 75 litres per minute.
  - The remaining four meters were tested at $^1/_2$ lpm and found to be between 90% and 103% accurate, and at 1 lpm they were between 95% and 98% accurate.
  - These meters were also tested at AWWA standard ranges and found to be within targets.
  - One of the 15 mm (5/8-inch) meters was tested to 144 lpm (38 gpm) and found to be 96% accurate.
- One (1) used 25 mm meter that had more than 700,000 cubic feet (20 million litres) put through it in 16 months was 70% accurate at ½ litre per minute (0.135 gpm) and 84% accurate at 1 lpm (0.25 gpm).
- A number of different tests were completed on 38 mm (1.5-inch) meters:
  - Three (3) used 38 mm (1.5-inch) meters were tested at 0.65 litres per minute (0.171 gpm) and found to be 10%, 45%, and 60% accurate.
  - Another three (3) were tested at 0.72 lpm (0.19 gpm) and found to be 38%, 75%, and 80% accurate.
  - Additionally, a field test was conducted on an in-service meter at a very low 0.15 lpm ($^1/_{25}$ gpm) and 0.76 lpm ($^1/_5$ gpm). The meter showed no registration at the lowest flow rate and only 69% registration at 0.76 lpm.
  - The accuracy of these meters generally increased with flow rate. Without actually completing the testing at these rates, the authors felt it was a conservatively reasonable generalization to assume that used 38 mm (1.5-in) meters were less than 50% accurate at a slow leak rate of $^1/_2$ lpm ($^1/_8$ gpm).

Case for Meter Error

As explained above, it appears that used 38 mm (1.5-inch) meters are less than 50% accurate at 1/2 lpm. The authors further believe that 40% of the 62 single-family homes and assuming all of the 50 fourplexes with 38 mm (1.5-inch) meters have system leaks that are only being recorded at a 50% rate. Based on these assumptions, at least

Equation1: = % of metered connections leaking × ½ lpm (1/8 gpm) ×50% accuracy

$$(0.40\times(62 + 50)) \times 0.5\times 1440\times 0.50 \mathbf{= 16{,}128 \text{ litres per day } (0.19\ l/s)}$$

is lost in the pressure zone from demand (customer) -side low flow leaks on these 38 mm (1.5-inch) meters alone. This does not include meter errors in any of the remaining 48 meters with or without slow leaks.

Conclusions

- Data analysis can be time consuming especially if the AMR and SCADA system data do not match with respect to their timesteps.
- Overall in this case, there was a fair amount of manual analysis and organization of data, but it was not overly onerous.
- Round Hill Pressure Zone has relatively low losses which are mainly due to the SCADA calibration and several individual meter failures. In addition, there are a number of demand (customer)-side leaks but these are being metered and are therefore not supply-side water loss).
- The Holly Pressure Zone has significant issues with the low-flow and very high-flow recordings of its meters.
- The top 10 users drive the demand and also create the greatest stress on the infrastructure. Compound meters would be helpful to capture the entirety of the flow range.
- Once the data issues are addressed, this is an excellent method of determining variations in apparent water losses.
- Apparent losses are evident from detailed analysis of the graphics.
- The leakage survey suggested that there were no significant distribution system leaks evident within the pressure zones during the project.
- Slow demand (customer)-side leaks, especially on larger meters, are a sleeping giant of system loss within these pressure zones.