Los Angeles Department of Water and Power: WATER LOSS AUDIT & COMPONENT ANALYSIS PROJECT

Fiscal Year 2010-2011

FINAL REPORT

SEPTEMBER 2013

WSO

LA DWP
Los Angeles Department of Water & Power
Water Resources

RECLAMATION
Managing Water in the West

EXECUTIVE SUMMARY

The goal of the Water Loss Audit and Component Analysis Project (Project) was to fulfill the requirements of Best Management Practice (BMP) 1.2 in the California Urban Water Conservation Council (CUWCC) Memorandum of Understanding (MOU) that were due on June 30, 2013. The BMP requires an annual audit of the water system, and the completion of a component analysis every 4 years. With the passage of Assembly Bill 1420 in 2009, compliance with the CUWCC BMPs is mandatory for a water agency to qualify for state grants and loans.

For the Project, Water Systems Optimization (WSO) examined the efficiency of the Los Angeles Department of Water and Power (LADWP) water distribution system. Specifically, WSO investigated the current ability to accurately identify real and apparent losses, determined the economic optimum level of water losses, and identified, prioritized, and recommended the most efficient and cost-effective loss intervention strategies to minimize water loss. The audit period examined was from July 1, 2010 to June 30, 2011 (FY 2010-2011). A Water Conservation Field Services Program Grant was received from the United States Bureau of Reclamation to partially fund contract costs for the Project.

This report includes the results of the required BMP water audit, the component analysis of real and apparent losses, the economic level of leakage (ELL) analysis, and the results of the pilot leak detection and District Metered Area (DMA) efforts. The Project results indicate an efficient water system, per national standards, with low levels of water losses. However, the research located several components in the water system that will improve the system's efficiency while saving costs.

ES.1 Overview of Project

ES.1.1 AWWA Water Balance

The American Water Works Association (AWWA) Water Balance uses methodology developed by the International Water Association (IWA) to account for all water entering and leaving the distribution system. The water audit utilizes the IWA/AWWA standardized Water Balance methodology to disaggregate and validate components of System Input Volume, Consumption Volume, Apparent Loss Volume, and Real Loss Volume in an effort to identify potential for reduction of Water Loss Volumes. The basic components of the Water Balance for LADWP are as follows:

> ***System Input Volume (SIV)*** includes water produced at all water treatment plants, water pumped from wells, and bulk water imports. Three main sources supply LADWP's potable water distribution network: the Los Angeles Aqueduct (LAA), purchased water from the Metropolitan Water District of Southern California (MWD), and groundwater from LADWP's well fields. The metering accuracy for each of these supplies was carefully examined for the

FY 2010-2011 water loss audit. When dealing with such high volumes, meter accuracy can have a significant impact on the water balance results. The methodology used to determine the final System Input Volume is discussed in detail in Section 1.

Authorized Consumption includes metered and un-metered water taken by customers and other uses that are authorized by LADWP. The main component of Authorized Consumption is Billed Metered Authorized Consumption (BMAC). The billing database was examined, checking the data integrity of the billing records on the whole and analyzing consumption by meter size and customer type to isolate instances of potential meter under-registration or over-registration. Other components of Authorized Consumption include water from system flushing and fire fighting. The components of Authorized Consumption are calculated and explained in Section 2.

Water Losses are calculated by subtracting Authorized Consumption from System Input Volume. Water Losses are divided into two main categories: Apparent Losses and Real Losses. This calculation is detailed in Section 3 and is shown in Table ES-1.

Table ES-1: Water Losses Calculation

VALUE	FY 2010-2011 VOLUME	
	(MG)	(AF)
System Input Volume (A) – see Section 1	175,575.83	538,822.44
Authorized Consumption (B) – see Section 2	166,662.61	511,468.77
Water Losses ((A) - (B))	**8,913.22**	**27,353.67**

Apparent Losses are non-physical losses that occur due to customer meter inaccuracies, data handling errors, and water theft. The term “apparent” is applied because water is consumed but is not properly measured. For small meters (2” or smaller), a representative sample of meter test results were analyzed to determine the meter accuracy for the whole small meter population (see Section 4.2.1). Based on these test results, WSO also completed an economic analysis of meter replacement scenarios (see Section 10). For large meters (3” or larger), WSO examined the current meter maintenance schedule and analyzed an alternative routine that would keep under-registration at an economically efficient level (see Section 10.2).

Real Losses are physical water losses such as leaks, breaks and overflows. It is the remaining volume after Authorized Consumption and Apparent Losses are subtracted from System Input Volume. Real Losses are characterized as Reported Leaks, Unreported Leaks, and Background Leaks. Discussion on how Real Losses are calculated through the water balance is presented in Section 5. Additionally, District Metered Areas (DMAs) in three distribution system service zones were set up as a pilot project to estimate the amount of Water Losses and Unreported Leaks that occur on a smaller scale (see Section 9). An analysis of economically efficient Real Loss reduction strategies was also performed based on the component analysis of Real Losses and the results of the DMA pilot (see Section 11).

Table ES-2 shows the LADWP Water Balance Summary for FY 2010-2011, highlighting each of the Water Balance components.

Table ES-2: Water Balance Summary [1]

System Input Volume 175,581.37 MG (100.00%)	**Authorized Consumption** 166,668.15 MG (94.92%)	**Billed Authorized** 166,448.68 MG (94.80%)	**Billed Metered Water Exported** 5.54 MG (0.00%)	**Revenue Water** 166,448.68 MG (94.80%)
			Billed Metered Authorized 166,443.14 MG (94.80%)	
			Billed Un-metered Authorized - MG (0.00%)	
		Un-billed Authorized 219.47 MG (0.12%)	**Un-billed Metered Authorized** - MG (0.00%)	**Non-Revenue Water** 9,132.69 MG (5.20%)
			Un-billed Un-metered Authorized 219.47 MG (0.12%)	
	Water Losses 8,913.22 MG (5.08%)	**Apparent Losses** 2,795.04 MG (1.59%)	**Unauthorized Consumption** 439.06 MG (0.25%)	
			Meter Error 2,355.98 MG (1.34%)	
		Real Losses 6,118.18 MG (3.48%)		

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[1] The data and estimates used to calculate the water balance are subject to errors and uncertainty. These errors accumulate in the calculation of Real Losses. To understand how these uncertainties influence the results, 95% confidence limits were calculated for each component of the water balance.

ES.1.2 Water Loss Performance Indicators

With a complete AWWA Water Balance, it is possible to calculate a variety of performance indicators (PI) that further describe the total volumes of real and apparent losses. In the late 1990's, the IWA initiated a large-scale effort to assess water supply operations, which resulted in the publication of *Performance Indicators for Water Supply Services,* 2001 (updated in 2006). These performance indicators are now accepted industry-wide as the best way to gain an understanding of how well losses are being managed, and to set targets for reducing water loss.

Table ES-3 describes these performance indicators and provides the performance indicator results calculated for LADWP during FY 2010 – 2011.

Table ES-3: Performance Indicators

Performance Indicator (PI)	Description of Use	PI for LADWP FY 2010-2011
Infrastructure Leakage Index (ILI)	The ILI is calculated by comparing the annual volume of Real Losses against an internationally derived standard related to the lowest Real Losses that can be technically achieved for that water system. The methodology takes into account all the factors affecting Real Losses. ILI values close to 1 indicate a water system with very low leakage.	1.26
Real Losses in gallons per service connection per day	This is the preferred basic operational performance indicator for analyzing leakage management performance and one of the most reliable when there are more than 30 services connections per mile, as is the case with the LADWP system.	23.21
Apparent Losses in gallons per service connection per day	This performance indicator is useful for comparing losses against average annual consumption per customer. It can also be used to provide a quick estimate on the value of Apparent Losses when multiplied by an average sales cost for water.	10.60
Non-Revenue Water as a % of System Input Volume	Though this performance indicator is still commonly used in the U.S., it is not a good benchmark for measuring water losses because it is unduly influenced by consumption. For example, if customer demand decreases due to conservation, the percentage of loss will increase even if leakage levels have not changed. This performance indicator should therefore be interpreted with caution.	5.2%

All of the indicators suggest that LADWP's water distribution system does not have significant volumes of real or apparent losses. Each of the performance indicators reflects a well-performing system in California. However, it is important to take the data quality concerns noted throughout this report into serious consideration before such good performance is regarded as final and accurate. Further, the component analysis of real losses (introduced below) presents useful information on cost-effective proactive measures to reduce real loss volumes even more.

ES.1.3 Component Analysis of Real Losses

Equipped with the results of the Water Balance, a closer examination of the real losses in LADWP's distribution system was undertaken. This involved collecting infrastructure failure data from the audit period and breaking the total Real Loss Volume into components of Reported Leakage, Unreported Leakage, and Background Leakage. This process is an approach called the Break and Background Estimate (BABE) component analysis methodology. The details of this analysis are outlined in Section 8.

Real Losses were calculated using two different methodologies:

- The AWWA Water Balance methodology; and
- The Break and Background Estimate (BABE) component analysis methodology.

By comparing the results of the two methodologies it is possible to estimate the volume of Hidden Losses (losses from leaks running undetected in the distribution system), as outlined in Section 8.6 and shown in Figure ES-1.

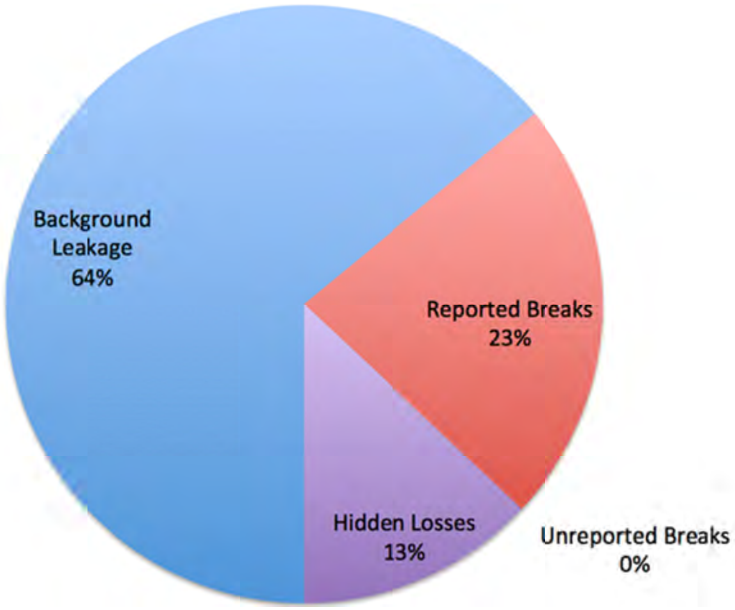

Figure ES-1: FY 2010-2011 Real Loss Components for LADWP

A District Metered Area (DMA) analysis was conducted to determine actual water loss volumes and detect leaks in three pilot system service zones. This analysis is further detailed in Section 9. Additionally, upon determining and properly categorizing the types of leakage throughout the LADWP distribution system, the Economic Level of Leakage (ELL) was determined. Cost-effective tools to reduce the Real and Apparent Losses are identified in Section 10 and Section 11.

ES.2 Findings & Recommendations

Each of the following sections includes findings and recommendations for improvement in both future water audit efforts and management of water losses within the LADWP system.

ES.2.1 System Input Volume

ES.2.1.1 Findings

Table ES-4 summarizes the main components of the System Input Volume (SIV) for LADWP in FY 2010 – 2011.

Table ES-4: System Input Volume

SYSTEM INPUT VOLUME COMPONENT	**FY 2010-2011 VOLUME**	
	(MG)	**(AF)**
Los Angeles Aqueduct Filtration Plant	134,056.68	411,404.84
MWD Treated Imports	24,376.16	74,807.70
Groundwater Well Field Production	17,114.66	52,522.96
Microfiltration Plants	33.87	103.93
LA County Waterworks District Exports	-5.54	-17.00
TOTAL WATER SUPPLIED (= TOTAL SYSTEM INPUT – EXPORT VOLUME)	**175,575.83**	**538,822.44**

Assessment of the Los Angeles Aqueduct Filtration Plant:

The Los Angeles Aqueduct Filtration Plant (LAAFP) volume introduced the greatest amount of uncertainty to the calculation of total SIV. The LAAFP volume includes inflows from the Los Angeles Aqueducts (LAAs) and the LA-35 Metropolitan Water District (MWD) connection. This volume is measured at several different meters that combine to represent the total LAAFP influent and effluent. A wide confidence limit of +/-5.00% was assigned to the volume of LAAFP, which accounted for approximately 76% of the total SIV during the audit period.

It was discovered that the final LAA meters located in Santa Clarita showed a discrepancy between manually-recorded volumes and SCADA readings in May 2011. A comparison of the sum of LAA volumes recorded by these meters and the LA-35 meter versus the influent meters at LAAFP also suggested that the LAA meters are under-registering volume. In addition, process water used at LAAFP is recycled back through the influent meters, further complicating the analysis.

Effluent volume was determined to be a better representation of SIV from LAAFP than influent or LAA volumes. LAAFP effluent volume is split into two branches – treated water from one branch flows into the Van Norman Pumping Station and directly into the distribution system and water from the other branch is stored in the Los Angeles Reservoir and subsequently released into the distribution system. Currently, two meters account for these volumes – one insertion magnetic meter located on Van Norman Pumping Station branch (known as the “Flow to City” meter), and one ultrasonic meter located at the Los Angeles Reservoir main outlet (known as the “LA Reservoir Outlet” meter). In 2011, two new ultrasonic meters were installed in Vaults 104 and 106, at a split directly downstream of the Flow to City meter; the volume from these two new meters combined represents the same volume from the Flow to City meter. Also in 2011, another new ultrasonic meter was installed in Vault 204 directly south of the LA Reservoir Outlet meter. The data from the old meters (Flow to City and LA Reservoir Outlet) was compared to the new meters (Vaults 104, 106, and 204) and it was determined that the Flow to City meter under-registers by 4.42% and the LA Reservoir Outlet meter under-registers by 0.91%.

Lastly, for approximately 1-2 months annually, the Los Angeles Reservoir main outlet is closed for maintenance. During this time, the West Outlet is used to provide water to the distribution system from the Los Angeles Reservoir. However, the West Outlet connection from the LA Reservoir into the distribution system is not metered. Operations records show that the West Outlet was opened from December 17, 2010 to February 7, 2011 during the audit period. A volume of 3,957.56 MG (or 12,145.31 AF) was estimated for the West Outlet during these two months.

Assessment of Purchased Water from Metropolitan Water District:

Installation conditions at seven of the MWD connections to LADWP’s distribution system were examined. It was determined that all of the examined input meters had sufficient upstream and downstream straight lengths (however confirmation of exact setup at LA-5 and the sizes of the LA-17 meters were not provided).

Furthermore, SCADA data for each MWD connection is available in a public database online. For each connection, this data was compared to the billed volumes to guarantee that the volumes used for the water balance corresponded to the operational data on registered flow and did not include financial adjustments. Most all of the billed volumes matched the SCADA totals for the audit period; however, a more significant discrepancy for LA-31 was found and documented.

Assessment of Groundwater Wells:

Select meters in each well field were examined to check whether the manufacturer’s installation condition requirements were satisfied. It was determined that none of the well field meters have sufficient straight lengths of pipe to satisfy the manufacturer’s installation conditions. Therefore, it is not guaranteed that any of the well meters perform within the manufacturers’ quoted accuracy ranges.

Additionally, the sum of the individual well meters at Tujunga well field was compared against the outflow meters at the collector basin that leads to the distribution system. The results of this comparison suggest that the well field meters under-register by 5.43%.

ES.2.1.2 Recommendations

1. Use the new meters located in Vaults 104, 106, and 204 for all future calculations of System Input Volumes from LAAFP. These meters are the most accurate representation of LAAFP effluent flow and are closest to the point of distribution system entry. The only volume from LAAFP these do not capture is volume that leaves the LA Reservoir from the West Outlet. LADWP should install a flow meter at this site to accurately and reliably record the volume supplied into the distribution network. Specifically, it is recommended to install an ultrasonic multi-point meter to capture all flow through the West Outlet.
2. Improve the accuracy of metering the well field production. Currently, the installation conditions for the individual well meters will not provide for accurate flow measurement. For each of the well fields, meters installed on the collector line (the pipeline supplying the combined well field production into the distribution network) should meter the total well field production. At some of the well fields such a meter already exists; however, the site inspections showed that these meters are currently not regularly tested and maintained and may also not be sized correctly to capture variable flow volumes. Where necessary new meters should be installed and maintained to accurately capture all flow levels.
3. Consider streamlining the SCADA system organization. For the LAAFP volume analysis alone, data from three separate SCADA systems was required. With different data extraction procedures and permissions for each SCADA system, the data collection process for System Input Volume determination becomes quite cumbersome.
4. Track level data for a complete inventory of reservoirs so that a total increase or decrease in storage volume can be accounted for in the System Input Volume determination.
5. Even though it is recommended to no longer use the LAA meters for the System Input Volume calculation, the LAA SCADA data (from the Northern District Hydrographic Database) and manual reads should be routinely compared on a monthly basis. The difference between manual reads and SCADA data should stay within 0.5%.
6. Routinely compare the MWD billed volumes to the MWD published SCADA totals for each month (available at: https://wins.mwdsc.org/Reports/WAMIReports.aspx).
7. Consider installing a meter at the LA-25 MWD connection to simplify the accuracy assessment process at this site. However, the current setup provides a reasonably accurate volume calculation. Relative to the meter installation at LAAFP, this is not a priority (due to lesser volume and better current accuracy).

ES.2.2 Authorized Consumption

ES.2.2.1 Findings

Table ES-5 summarizes the four main Authorized Consumption components for LADWP in FY 2010 – 2011.

Table ES-5: Authorized Consumption

CONSUMPTION COMPONENT	FY 2010-2011 VOLUME	
	(MG)	(AF)
Billed Metered Authorized (Retail Sales)	166,443.14	510,795.24
Billed Un-Metered Authorized Consumption	NA	NA
TOTAL BILLED AUTHORIZED CONSUMPTION	**166,443.14**	**510,795.24**
Un-billed Metered Authorized Consumption	NA	NA
Un-billed Un-Metered Authorized Consumption	219.47	673.53
TOTAL UN-BILLED AUTHORIZED CONSUMPTION	**219.47**	**673.53**
TOTAL AUTHORIZED CONSUMPTION	**166,662.61**	**511,468.77**

Billed Metered Authorized Consumption:

Overall, the review of the Billed Metered Authorized Consumption (BMAC) volume determined that the billing system data is in good condition and provides reliable information on consumption volumes. The majority of the BMAC is determined from actual meter readings; only 3.61% of the BMAC was submitted to the billing database as an estimated read.

The water audit process focuses exclusively on the potable water system. As such, all recycled accounts were excluded from the calculation of BMAC. A majority of these accounts are flagged with Rate Code “44”, which represents recycled water, but it was determined that a handful of accounts have a different rate code but still received recycled water. Beyond the Rate Code “44” accounts, an additional 544.95 MG or 1,672.39 AF was excluded from the final BMAC volume determination.

All consumption included in the BMAC volume determination must be accounted for in the System Input Volume. It was determined this is not the case for two accounts that use potable water before the points of measurement for the System Input Volume. These two meters, which track process water at LAAFP, were excluded from the final BMAC volume determination.

In addition, the size of the customer meter was compared to average daily consumption through the meter for all meters in LADWP’s billing system. Several meters were noted to be under-sized or over-sized based on the volumes recorded (see Appendix E). Meter size is stored in two main databases - the Customer Information System (CIS) and the Work Management

Information System (WMIS); for this exercise, the size information was retrieved from CIS. A cross-check between CIS and WMIS discovered many inconsistencies between these two databases that need to be addressed.

Unbilled Unmetered Authorized Consumption:

Unbilled Unmetered Authorized Consumption volumes, such as system flushing and fire fighting, are not tracked. These volumes were estimated to be 0.125% of the total water supplied by LADWP for FY 2010-2011.

ES.2.2.2 Recommendations

1. For the determination of total consumption during the audit period, this analysis suggests that the billing database has reliable and consistent information. However, for use as a meter inventory database, CIS requires a great deal of data cleaning and data integrity improvement (see section ES.2.3 on Apparent Losses).
2. The large number of inaccuracies between WMIS and CIS should be addressed. The current number of inconsistencies could have a big impact on revenue collection and analysis of meter use by size or customer class. Ideally one central database would have up to date information for all meter characteristics and billing data for consumption analysis.
3. For consistency of water audit results from year to year, two groups of accounts should be excluded from the determination of BMAC: all recycled water accounts (Rate Code 44 and additional miscellaneous accounts) and the accounts that receive water before the point of measurement of the System Input Volume.
4. Investigate the meters/accounts highlighted in Appendix E for proper sizing and potential for revenue improvement.
5. Introduce tracking of Unbilled Unmetered Authorized Consumption volumes.
6. For determination of the Unbilled Metered Authorized Consumption, track all of the reservoir levels from first to last day of the audit period in addition to volume estimations for reservoir drainage events.
7. For determination of Unbilled Metered Authorized Consumption, LADWP should further investigate what portion of fire line detector meters register consumption. The manual meter reading exercise carried out in the three trial DMAs has highlighted that a noteworthy number of fire line meters registered consumption over a 7-day period. As an intermediate step, it is recommended that the fire line detector check meters are read on a regular basis. As Automated Meter Reading and Advanced Metering Infrastructure (AMR/AMI) technology is implemented throughout LADWP's service area, these fire line detector check meters should also be upgraded to be AMR/AMI compatible for easier tracking.

ES.2.3 Apparent Losses

ES.2.3.1 Findings

Table ES-6 summarizes the volumes of Apparent Losses determined for FY 2010–2011.

Table ES-6: Apparent Losses

Apparent Losses Component	**Annual Volume (MG)**	**Annual Volume (AF)**
UNAUTHORIZED CONSUMPTION	**439.06**	**1,347.43**
METER DATA HANDLING ERROR	**0.00**	**0.00**
CUSTOMER METER UNDER-REGISTRATION SUBTOTAL	**2,355.98**	**7,230.26**
Small Customer Meter Under-Registration	1,991.64	6,112.14
Large Customer Meter Under-Registration	364.34	1,118.12
TOTAL APPARENT LOSSES	**2,795.04**	**8,577.69**

Small Meter Accuracy Assessment:

A small meter accuracy testing effort was completed to determine the volume of apparent losses due to small meter under-registration. This involved testing 1,073 small meters at multiple flow rates. The results of this testing program indicate that the average accuracy of LADWP's small meter stock (grouped by size and make) ranges from 84.24% to 99.76%. The 3/4" x 1" meter population test results indicate that the majority of these meters are performing well (presenting an average accuracy of 98.72%). These results are especially notable because the 3/4" x 1" meters make up the majority of the small meter population. Overall, the test results suggest that LADWP's small meter stock is performing well; 60% of the small meters tested complied with AWWA recommended accuracy limits at all flows, while only 8% of the small meters tested did not comply with the recommended accuracy limits at any flow rate. Of the 1,073 small meters tested, 14 of the meters pulled were completely stuck at all flows.

The apparent loss volume from small meter under-registration was determined to be 1,991.64 MG (or 6,112.14 AF). The largest contributing meter group by size is the 5/8" x 3/4" meter group, which incurred a total of 579.26 MG (or 1,777.69 AF) of apparent losses.

Large Meter Accuracy Assessment:

The maintenance of the large meter population was reviewed in depth, and the overhaul schedule was analyzed to optimize replacement frequency according to potential revenue loss due to under-registration. For the purposes of calculating an apparent loss volume for the large meter population during the audit period, an estimated accuracy of 99% was applied to all large meters. This was an assumption informed by the existing large meter testing/replacement program and the overall good performance of the small meter population. For the FY 2010-

2011 an assumed under-registration of 1% results in an apparent loss volume from large meters of 364.34 MG (or 1,118.12 AF).

Unauthorized Consumption and Systematic Data Handling Errors:

The amount of Unauthorized Consumption for FY 2010 – 2011 was estimated at 439.06 MG (or 1,347.43), applying the AWWA recommended default value of 0.25% of the Water Supplied. No specific sources of data handling errors were identified in the billing system; therefore, no volume was allocated to this category for FY 2010 – 2011.

ES.2.3.2 Recommendations

Recommendations for Reducing Small Meter Under-Registration:

1. The small meter test results indicate that the small meter population is operating at a relatively high level of accuracy. The accuracy results and economic analysis here do not present a case for any immediate action on widespread small meter replacement. However, isolating the worst performing, most economic meter groups (by size and make) for a targeted meter replacement program is recommended. The following small meter groups should be targeted for replacement given that the internal rate of return on the required meter replacement investment was positive:
    - 5/8 x 3/4” Sensus meters
    - 3/4 x 1” Sensus meters
    - 1 1/2” Sensus meters
    - 2” Sensus meters
2. Continue regular testing of random small meter samples (100 to 200 meters per year). Regular testing will allow tracking of the average accuracy of each size/make groups of meters. With this type of monitoring, LADWP will be able to initiate meter replacement when a certain meter make/size group reaches the threshold where meter replacement becomes an economically viable option.
3. The small meter test effort for this analysis revealed inconsistencies in actual meter characteristics and CIS meter records. Improving the data quality on the size, make, and age of meters in the billing database is critical to any meter maintenance program going forward. As the Apparent Loss analysis demonstrates, grouping accuracy test results by meter make and size and aligning these tests with the groups’ annual consumption volumes allows for calculating detailed apparent loss volumes and prioritizing subsets of meters.
4. To best apply small meter test results, it is recommended to pursue consumption profiling research specific to LADWP’s customer base. Volume weighting factors can have significant impact in determining average meter accuracies, influencing all subsequent calculations of apparent losses and economic evaluations of replacement.

Recommendations for Reducing Large Meter Under-Registration:

1. It is economically infeasible to overhaul each of the 21,250 large meters on a regular basis; it is necessary to identify those meters where potential losses in accuracy would result in the largest losses in revenue generation. It is recommended to rank the large meter population by annual consumption registered by meter.
2. For the large meter population, it is recommended to implement the evaluation approach as outlined in Section 10.2 (comparing annual revenue losses due to under-registration to cost of overhaul) to create prioritized overhaul schedules.
3. Since consumption patterns and consumption volumes of large customers can change over time it is recommended that the overhaul schedule be updated regularly.
4. For the top one hundred large customer meters (ranked by revenue generated), it is recommended to undertake consumption profiling and targeted selection of appropriate metering technology. An improvement of 1% in metering accuracy (achievable by switching from a standard compound meter to an electromagnetic flow meter, for example) will results in significant revenue increases for these meters.

ES.2.3.3 Summary of Recommended Apparent Loss Intervention Strategies

Table ES-7 summarizes the main recommendations for reducing apparent losses to an economically efficient level. It includes a general timeline by fiscal year to provide an overall roadmap for the upcoming five years.

Table ES-7: Apparent Loss Intervention Strategies

Fiscal Year	**Small Meter Testing**	**Small Meter Replacement**	**Large Meter Maintenance**	**Unbilled Consumption**
FY 2013 – 2014	Ongoing Random Small Meter Testing	Replace targeted size/make meter groups, outlined in Section 10	Initiate the overhaul program, as outlined in Section 10.2.4	Read fire service detector checks regularly
FY 2014 – 2015			Begin consumption profiling for highest revenue-generating customers	
FY 2015 – 2016		Revisit replacement economics and target revised group of small meters	Pursue meter right-sizing and appropriate technology replacement where necessary	Upgrade fire service detector checks to AMI/AMR for consistent surveillance
FY 2016 – 2017				
FY 2017 – 2018				

ES.2.4 Real Losses & Component Analysis

ES.2.4.1 Findings

The Water Balance shows that system-wide Real Losses (physical losses from the distribution system) are to be 6,118.18 MG (or 18,776.00 AF) for FY 2010 -2011. The component analysis of Real Losses produced the following results shown in Table ES-8:

Table ES-8: Real Losses

Leakage Component		**FY 2010-2011 Volume**	
		(MG)	**(AF)**
Background Leakage	*volume lost through continuously running seeps and drips throughout the system, cannot detect through leak detection*	3,917.01	12,020.86
Reported Losses	*volume lost through failures on mains, service connections, and appurtenances that are reported to LADWP and repaired*	1,409.59	4,325.87
Unreported Losses[2]	*volume lost through failures on mains, service connections, and appurtenances that are uncovered through a proactive leak detection survey*	0	0
Hidden Losses	*volume of losses that ran undetected in the system*	791.59	2,434.06
Total Real Losses		**6,118.18**	**18,776.00**

Assessment of Reported Losses:

To determine the Reported Losses volume, records for all infrastructure failures during the audit period were requested. The process of collecting and analyzing this leak repair data presented notable challenges. Five different database sources provided records that did not consistently have all of the information necessary to determine Reported Leakage (i.e. awareness time of failure, time of repair, size of pipe, type of failure, etc).

With the available data for repairs on mains, LADWP's main break frequency was determined to be 17 breaks per 100 miles per year. This is less than the average North American break frequency (as determined in a Water Research Foundation Project #4372) of 25 breaks per 100 miles per year. In fact, it approaches the "optimum" break frequency of 15 breaks per 100 miles per year (as determined by another Water Research Foundation Project #4109 on target performance indicators for distribution systems).

With the available data for repairs on service connections, LADWP's service connection break frequency was determined to be 1.2 breaks per 1,000 service connections per year.

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[2] As LADWP did not have a pro-active leak detection program in FY 2010-2011, the volume of Unreported Losses is zero.

These are relatively low break frequencies and suggest that LADWP may have a distribution system in overall good condition; however, the low break frequencies may also suggest that the repair data is not yet capturing all of the failures repaired.

Assessment of Unreported Losses:

The Unreported Losses volume is zero because no proactive leak detection was undertaken by LADWP in FY 2010-2011.

Assessment of Background Leakage:

Background Leakage was estimated using the method outlined in the AWWA M36 Manual for Water Audits and Loss Control Programs. See Section 8.4 for details on the Background Leakage calculation.

ES.2.4.2 Recommendations

1. The break data provided from LADWP was sourced from multiple databases and required much coordination. Streamlining of break record information will make future efforts to produce a real losses component analysis much more manageable. Currently, different record keeping routines and data collection processes are maintained for different types of breaks and sections of pipe. All instances of distribution system failure should be documented to ensure a complete and thorough record-keeping of reported losses in the future.
2. Ideally, all of the repair record information should be kept in one database. Appropriate codes should be developed to allow for the complete data entry for all leak relevant work. Further, all attributes should be recorded in separate fields for ease of analysis and data export.
3. In the component analysis, the reliability of leak run times has an important impact in determining reported leakage volumes. It is important that each repair record’s start and finish times reflect the run-time of the leak from awareness to containment as best as possible. Linking the timestamps directly in the repair records (and not separately in the Trouble Board) will expedite the location and repair time calculations.
4. It is recommended to consider reducing the average location and repair time for main leaks, service connection leaks, and appurtenance leaks. An initial modeling of savings suggests that a significant real loss reduction could be achieved (approximately $1.6 million annually based on MWD water rates) if the average location and repair time was reduced by 50%. This initial savings analysis is based on the average location and repair time as determined from the leak repair records from FY 2010-2011; before response time improvements are pursued, it is important to revisit the reliability and completeness of the response time data.

ES.2.5 Field Quantification of Real Losses: District Metered Area & Leak Detection Pilots

ES.2.5.1 Findings

Three pressure zones (517/Boyle Heights, 1960/Tujunga, and 540/Westwood) were selected for isolation as District Metered Areas (DMAs) with the aim of collecting field data to validate levels of leakage in smaller parts of the LADWP distribution system. Comprehensive leak detection surveys in each of the three zones are summarized in Table ES-9. The leak detection results indicate that the volume of hidden leakage in these zones – and overall in LADWP's entire distribution network – is relatively low.

Pressure fluctuations in these pressure zones are noteworthy with maximum recorded pressure surges of about 16 PSI. Pressure fluctuations immediately downstream of the pressure regulating value (PRV) stations and then within the distribution network would indicate that the pressure control valves were not able to provide a smooth fixed outlet pressure curve. This could be due to not enough flow through the PRVs, not enough pressure differential across the PRV, or current PRV set points that are not optimized, etc.

During the meter reading phase of the task, it was noted that a significant number of the fire line detector meters registered consumption. This consumption, which should theoretically be insignificant, is usually not billed since those meters are not read on a regular basis.

Table ES-9: Leak Detection Survey Findings

Pressure Zone	Leak #	Leak Type	Est. Flow (gpm)	Est. Flow			
				(gal/day)	(HCF/day)	(MG/Year)	(AF/year)
517/Boyle Heights	1	Service	10				
	2	Service	10				
	3	Valve	1				
	4	Valve	2				
	5	Valve	2				
	6	Hydrant	2				
	7	Hydrant	5				
	8	Hydrant	2				
	9	Service	10				
	10	Hydrant	5				
	11	Hydrant	1				
540/Westwood	12	Hydrant	1				
1960/Tujunga	0	NA	NA				
Total			**51**	**73,440**	**98.2**	**26.8**	**82.2**

The number of leaks identified in each pressure zone varies significantly reflecting a typical picture found in most distribution networks; leakage is not evenly distributed.

ES.2.5.2 Recommendations

Pilot DMA Implementation Recommendations:

1. The selection of appropriate flow meters is crucial for accurate flow measurements in DMAs. It is suggested that for future DMAs permanent meter installations should be considered using turbine or electromagnetic flow meters.
2. If a DMA has multiple feeds it is necessary to consider that during low demand periods (or in some cases, most of the time), some feeds will show only very little demand. This will be the case if one feed takes the lead, supplying the vast majority of DMA demand. As a result, the feeds with low demand do not experience enough flow for the flow meter to record accurately. In these cases the feeds providing very little to no flow should be used as standby feeds, only opening up in case demand in the DMA requires additional supply.
3. All boundary valves and check valves need to be investigated to guarantee that the DMA is hydraulically discrete.
4. Future DMAs should be combined with Advanced Meter Infrastructure (AMI) trial areas for accurate and easily available consumption data.
5. In the effort to comprehensively read all of the meters in each DMA, discrepancies between the meter information in CIS and the actual meters were unveiled. A reliable billing database with up-to-date meter characteristics is an important tool in determining water losses (as demonstrated both for the water loss baseline calculations for each DMA and for the apparent loss analysis).
6. Since LADWP is considering trials of Advanced Metering Infrastructure (AMI), it is recommended that for the pressure zones with AMI, a water loss mass balance is calculated on a regular basis to identify pressure zones with higher levels of leakage that should be targeted for proactive leak detection. The three pressure zones used for the DMA trial should be considered as candidates for trial AMI installation projects.

Pilot Pressure Management Recommendations:

1. At around 82 PSI the average pressure in Zone 540/Westwood is about 10 PSI higher than in the other two pressure zones, which indicates that the average pressure could be reduced further to achieve savings in real losses and extend the infrastructure life span.
2. High frequency pressure logging should be performed in all three pressure zones to assess the full extent of the pressure surges. Necessary steps to avoid pressure surges in the pressure zones should be taken.

Pilot Leak Detection Recommendations:

1. Even though the volume of hidden leakage detected and recovered in these three areas was relatively small, the leak detection pilot has a simple payback period of 0.8 years (about 10 months), indicating that proactive leak detection is an economically viable water loss control strategy for LADWP.

ES.2.6 Economically Efficient Intervention Strategies to Reduce Real Losses

ES.2.6.1 Findings

Four intervention tools against Real Losses were evaluated to determine if there is room for improvement in LADWP's current leakage management policy. Proactive leak detection and improved leak repair time were found to be short-term tools against Real Losses with potential for improvement. Since LADWP already has plans to increase infrastructure replacement, there is no recommendation to improve infrastructure management. Pressure management was found to be a medium term tool against Real Losses with potential for improvement. Table ES-10 summarizes the findings for Real Loss Intervention Strategy evaluation.

Table ES-10: Real Loss Intervention Strategy Evaluation

Intervention Tool	Currently employed by LADWP	Potential for improvement	Assess benefit/cost ratio of new/improved intervention tool
Proactive leak detection	No	Yes	Yes
Improved leak repair time	Yes	Yes	Yes
Pressure management	Yes	Yes	Yes
Infrastructure management	Yes	No[3]	No

ES.2.6.2 Recommendations

Proactive Leak Detection:

1. The analyses indicate that given the high value of Real Losses, it is economic to periodically survey the distribution network for unreported leaks. However, at this point it is recommended to consider the results of the proactive leak detection intervention frequency model discussed in this report as preliminary since the accuracy of the water balance and real loss component analysis needs to be further improved before significant investments in this real loss reduction strategy are made.
2. It is recommended that LADWP targets surveying about 10% to 15% of the distribution network per year for the next five years using in-house resources and carefully documenting the results and findings to inform LADWP's future proactive leak detection strategy.

Improved Leak Repair Time:

1. It is important to note that a significant portion of the break data - 25% of main failure repair records and 30% of service connection break data – do not have sufficient timestamp data to calculate the location and repair time. As such, improving the completeness of the leak repair data should be the first step in refining the evaluations of possible reductions in average location and repair time.

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[3] Since LADWP already has plans to increase infrastructure replacement, there is no recommendation to improve infrastructure management.

2. Reducing the average location and repair time on mains failures by 50%, would save about 472 MGY (or 1,448.61 AFY), resulting in a cost savings of $1,227,425 (using the MWD Tier 1 rate). The assumed reduction of average location and repair time by 50% was used to get an initial idea of the potential savings that could be achieved. Before a substantial recommendation can be made on a target location and repair time for main failures, the currently available leak repair data needs to be substantially improved in terms of data quality/availability.
3. Reducing the average location and repair time on service connection failures by 60% would save about 157 MGY (or 481.82 AFY), resulting in a cost savings of $409,029. This indicates significant potential for real loss and cost savings. The assumed reduction of average location and repair time by 60% was used to get an initial idea of the potential savings that could be achieved. Before a substantial recommendation can be made on a target location and repair time for service line failures, the currently available leak repair data needs to be substantially improved in terms of data quality/availability.

Pressure Management:

1. It is recommended to follow the three-step process outlined in Section 11 to achieve the pressure reductions that would produce an estimated annual savings of $1,414,000 per year (by reducing losses by 544 MGY or 1,669.47 AFY).
2. It is recommended that LADWP implement a small pressure monitoring pilot (5 to 10 pressure zones) over the first 12 months of the pressure management program before implementing Step 1 over the next 36 months, followed by Step 2 over the next 48 months and Step 3 over the subsequent 48 months (see Section 11.4 for details on each Step).
3. Demand-based pressure control should be investigated as an option to optimize the current pressure management scheme in each pressure zone.

ES.2.6.3 Summary of Recommendations for Real Loss Intervention Strategies

Table ES-11 summarizes the main recommendations for reducing real losses to an economically efficient level. It includes a general timeline by fiscal year to provide an overall roadmap for the upcoming five years.

Table ES-11: Recommendations for Reduction of Real Losses

Fiscal Year	Proactive Leak Detection	Improved Location and Repair Times for Reported Leaks	Pressure Management Program
FY 2013 – 2014	Prepare for implementation of proactive leak detection program	Focus on collection of better leak repair data	Prepare for implementation of pressure monitoring pilot in 5 to 10 pressure zones
FY 2014 – 2015	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff	Focus on collection of better leak repair data	Implement **Step 1** of the pressure management program as detailed in Section 11.4.2
FY 2015 – 2016	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff	Update analysis on improved location and repair times and evaluate the necessary additional budget for reducing the average location and repair time for reported mains leaks	
FY 2016 – 2017	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff	If found cost effective Deploy additional repair crews to reduce average location and repair times to optimum levels	
FY 2017 – 2018	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff		Implement **Step 2** of the pressure management program as detailed in Section 11.4.2
FY 2018– 2019	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff		
FY 2019 – 2020	Evaluate results of detailed leak detection efforts and update strategy according to findings over past 4 years		
FY 2020 – 2021	Implement updated proactive leak detection strategy and if/where AMI is implemented utilize AMI and SCADA data for prioritizing areas for ongoing leak detection based on calculated leakage loss levels by pressure zone		
FY 2021 – 2022			Implement **Step 3** of the pressure management program as detailed in Section 11.4.2
FY 2023 – 2024			
FY 2024 – 2025			
FY 2025 – 2026			

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ABI: Annual Budget for Intervention
AF: Unit of volume in Acre-Feet
AFY: Unit of Acre-Feet per Year
AMI: Advanced Metering Infrastructure
AMI/AMR: Advanced Metering Infrastructure or Automated Meter Reading
AWWA: American Water Works Association
BABE: Break and Background Estimate
BMAC: Billed Metered Authorized Consumption
BMP: Best Management Practice
CARL: Current Annual Real Losses
CI: Cost of Leak Detection Survey Intervention
CIS: Customer Information System
CPS: Construction Productivity System
CUWCC: California Urban Water Conservation Council
CV: Cost of Real Losses
DMA: District Metered Area
EBMUD: East Bay Municipal Utility District
EIF: Economic Intervention Frequency
ELL: Economic Level of Leakage
EP: Economic Percentage of the system that should be covered by a leak detection survey each year
FY 2010-2011 or FY10-11: Fiscal Year from July 1, 2010 to June 30, 2011; the audit period for this project
FAVAD: Fixed and Variable Area Discharge
GPM: unit of flow in gallons per minute
HCF: unit of volume in hundred cubic feet
ICF: Infrastructure Condition Factor
ILI: Infrastructure Leakage Index
ISO: International Standards Organization
IWA: International Water Association
JPI: Jensen Plant Inlet
KGAL: unit of volume in thousands of gallons
LAA: Los Angeles Aqueduct (of which there are two: LAA 1 and LAA 2)
LAAFP: Los Angeles Aqueduct Filtration Plant
LADWP: Los Angeles Department of Water and Power
MFP: Micro Filtration Plant
MG: unit of volume in millions of gallons
MGD: unit of flow in millions of gallons per day
MGY: unit of millions of gallons per year
MNF: Minimum Night Flow
MOU: Memorandum of Understanding
MWD: Metropolitan Water District

NNF: Net Night Flow
PRS: Pressure-Regulating Station
PRV: Pressure Regulating Valve
PSI: Unit of pressure in pounds per square inch
PWD: Philadelphia Water Department
RR: Rate of Rise
SCADA: Supervisory Control and Data Acquisition
SFO: Sepulveda Feeder Outlet
SIV: System Input Volume
UARL: Unavoidable Annual Real Losses
WIR: Water Investigation Report
WMIS: Work Management Information System
WSO: Water Systems Optimization

SECTION 1. SYSTEM INPUT VOLUME

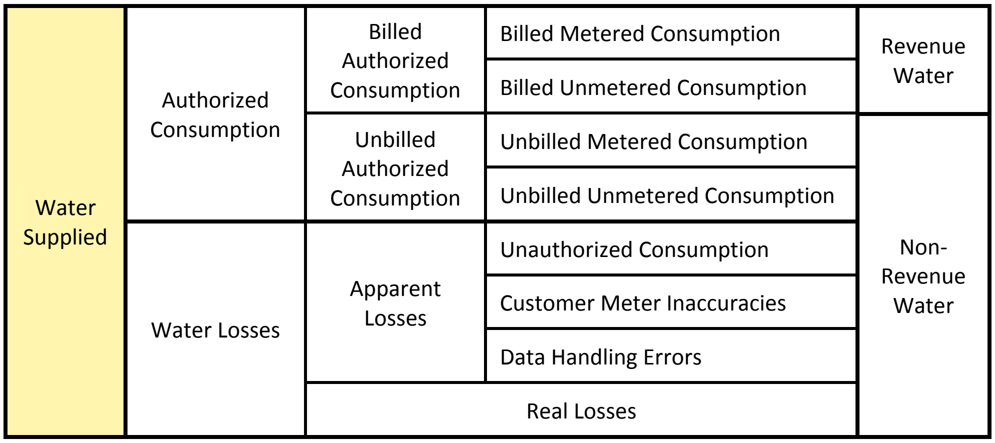
1.1 System Input Volume Background

The System Input Volume (SIV) is the total amount of water supplied into the distribution system and is obtained by adding the volume of water owned and operated by LADWP to the volume of water imported from wholesale providers. In other words, the SIV consists of:

- Own Sources: This is the volume of water input to a system from the water supplier's own sources.
- Water Imported: This is the volume of bulk transfers from other water agencies or distributors into the distribution system.

The Water Supplied Volume is the total amount of water that directly supplies the customers of LADWP. The Water Supplied Volume is equal to the System Input Volume minus wholesale exports to neighboring water agencies.

Figure 1 highlights in yellow the components of the Water Balance assessed and validated in this report. Note that the table is not formatted to scale (the size of each box is not proportional to its volume).



<table>
<tr><td rowspan="8">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="6">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="4">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies</td></tr>
<tr><td>Data Handling Errors</td></tr>
<tr><td colspan="2">Real Losses</td></tr>
</table>

Figure 1: International Water Association's standardized components of Annual Water Balance – Water Supplied highlighted

1.2 Introduction to LADWP's Inputs & Exports

LADWP supplies water to a population of 3.9 million residents, serving a total of 722,112 service connections. The service area covers 465 square miles.

Three main sources supply LADWP's potable water distribution network: the Los Angeles Aqueduct (LAA), purchased water from the Metropolitan Water District of Southern California (MWD), and groundwater from LADWP's well fields. Two microfiltration plants that provide treatment for overflows from Encino and Stone Canyon Reservoirs also contribute small volumes to the system.

The LAA pipelines (LAA 1 and LAA 2) source water from the Mono Basin and Owens Valley. They supplied the majority of LADWP's potable water supply during FY 2010-2011. Though this water travels a significant distance, LADWP owns and operates the LAA infrastructure so this is considered as part of the "Own Sources" component. Both the LAA pipelines and the MWD untreated water connection, LA-35, are treated at the Los Angeles Aqueduct Filtration Plant (LAAFP) in Sylmar. The treated water from LAAFP directly supplies the distribution system; a portion of the water is also used for operational use at the plant ("LAAFP Backwash").

While LAA 1, LAA 2 and LA-35 track the raw water inputs into LAAFP, it is best to use measurements that are as close to the point of distribution system input as possible. A collection of meters tracks LAAFP outputs of treated water at two different sites. At the first, the "Flow to City" meter tracks the majority of the LAAFP treated water, headed directly to the distribution system. In close proximity to this meter, there are two newer meters (in vault 104 and Vault 106) that track the same volume. The remaining LAAFP treated water volume goes to the LA Reservoir. The following meters track the water from the LA Reservoir into the distribution system: the LA Reservoir meter tracks the majority of volume leaving from the mainline off of the LA Reservoir; another newer meter is along this same line (in vault 204); and lastly, another route from the LA Reservoir into the distribution system is through the "West Outlet", which is not metered. The newer meters off the Flow to City line and the new meter off the LA Reservoir will be heretofore referenced as the "New Meters". Section 1.4.2 outlines the arrangement of these meters in greater detail.

LADWP also received potable water from MWD through a total of 12 treated water connections during the audit period. MWD has two main sources of raw water: one is from the Sacramento-San Joaquin Delta, transferred south through the State Water Project, and the other is from the Colorado River through the Colorado River Aqueduct (and treated at various MWD facilities).

LADWP's groundwater supply was extracted from 11 different well fields during the audit period. These included the Aeration, Erwin, Manhattan, Mission, North Hollywood, Pollock, Rinaldi-Toluca, Tujunga, Verdugo, Whitnall, and 99th St well fields.

Though LADWP has historically supplied water to its neighboring water agencies (Las Virgenes and Calleguas Municipal Water Districts), this transfer did not occur during the audit period. During the audit period, LADWP did provide LA County Waterworks District a small volume of water (through its five connections).

Table 1 summarizes the input meters in use during the audit period of July 1, 2010 to June 30, 2011. Figure 2 presents a flow diagram of the SIV components for LADWP.

Table 1: LADWP System Input and Export Components for FY 2010-2011

System Meter		Description
LAAFP Meters		The following 8 meters track input or output volume for LAAFP. Comparisons of these meters allowed for the estimation of volume from LAAFP.
	LAA 1 Soledad Station	Point of measurement for the first of the Los Angeles Aqueduct pipelines
	LAA 2 Soledad Station	Point of measurement for the second of the Los Angele Aqueduct pipelines
	MWD LA-35	The MWD connection that supplies raw water; later treated at LAAFP.
	Flow to City Meter	These meters track the majority of treated water from LAAFP.
	New Meters in Vaults 104 and 106	
	LA Reservoir Meter	These meters track the water transferring from the LA Reservoir into the distribution system.
	New Meter in Vault 204	
MWD Treated Water: LA 4, LA-5, LA-9, LA-12, LA-13, LA-16, LA-17A, LA-17C, LA-21B, LA-25, LA-31, LA-35B		Treated water imports from MWD that were active during the audit period.
Aeration Wells #2,3,4,6,7,8		Active meters in the Aeration well field.
Erwin Wells # 6, 10		Active meters in the Erwin well field.
Manhattan Forebay		This forebay meter tracks the total production from the Manhattan well field. [4]
Mission Wells #6,7		Active meters in the Mission well field.
North Hollywood Wells #7, 22, 23, 25, 26, 32, 33, 34, 36, 37, 43A, 45		Active meters in the North Hollywood well field.
Pollock Wells #4,6		Active meters in the Pollock well field.
Rinaldi-Toluca Wells # 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15		Active meters in the Rinaldi-Toluca well field.
Tujunga Wells # 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12		Active meters in the Tujunga well field.
Verdugo Wells #11, 24		Active meters in the Verdugo well field.
99th St Wells # 12, 13, 14, 15		Active meters in the 99th St well field.
Encino Reservoir Microfiltration Plant		No treated water meter at this site – estimates submitted.
Stone Canyon Reservoir Microfiltration Plant		No treated water meter at this site – estimates submitted.
LA County Water Works District		Small volumes were exported to LA County during the audit period.

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[4] Unlike for other well fields, the Manhattan forebay meter is used for total production because the individual well meters were deemed unreliable.

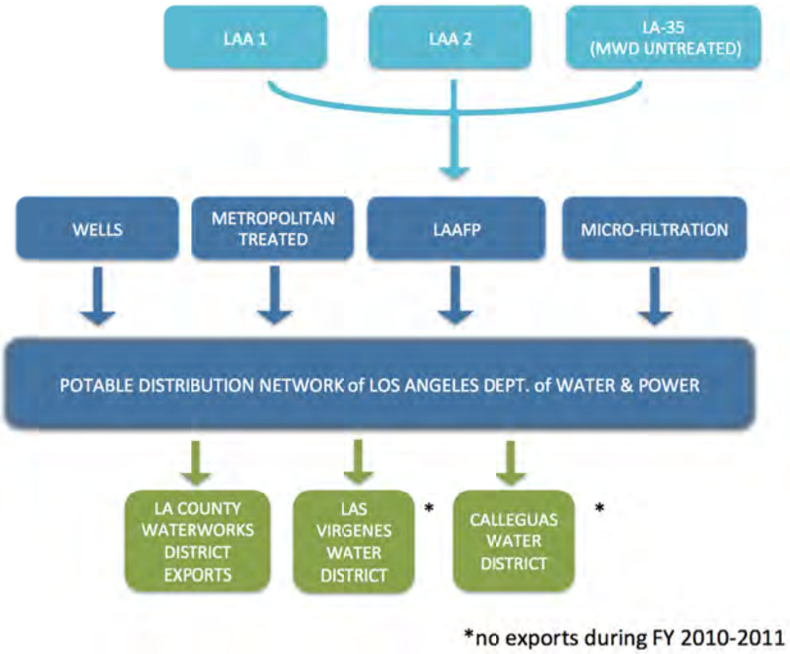

Figure 2: Flow diagram of LADWP SIV components

1.3 System Input Meter Testing Approach & Procedures

Table 2 outlines the approaches used to determine the SIV and its accuracy.

In all cases, in-situ tests (comparative meter tests or volumetric tests) were not feasible for the system input meters. It was not possible to arrange a test for either LAA 1 or LAA 2 mainly because of two insurmountable challenges. First, the closest reservoir or contact basin is over 20 miles away: this setup is not conducive to a successful volumetric drop test because there is so much opportunity for interference between the meter location and the comparative volume measurement. Secondly, there were operational constraints to consider: the time to draw down and start up the LAA 1 and LAA 2 meters would be too disruptive to supply and was concluded to be prohibitive. Further, upon confirming the availability of data for the meters that track treated water from LAAFP, it was no longer necessary to depend on the raw water meter data.

Instead, installation conditions and meter testing procedures were examined to best estimate how accurately each meter is performing. The quoted accuracy range for each meter depends largely on the proper implementation of the required installation conditions. Installation requirements call for a minimum length of straight, uninterrupted pipe upstream and downstream of the meter (the specific length of which is determined by the meter's specifications – manufacturer, model, size, etc. Table 14 and Table 18 outline the specific straight-length requirement for each meter examined.

Ensuring sufficient straight-length is necessary to avoid turbulence and allow for the most uniform velocity profile as possible. Upon confirming that the straight-length installation requirements are met, the meter manufacturer's accuracy range can be more confidently applied. If the straight-length installation requirements are not met, a conservative estimate of the accuracy range is assigned to the meter.

It is important to note that a majority of the system input meters are Venturi models made in-house. Without specifications available from a commercial manufacturer, industry standards were used for the accuracy ranges and installation requirements for these meters. The AWWA Manual 33, "Flowmeters in Water Supply"[5] provides a standard accuracy for Venturi flowmeters of +/- 0.75%. The International Standards Organization (ISO) provides information on installation requirements based on the size of the Venturi meter[6].

For all the input meters that do not meet the installation condition requirements a confidence level of +/-5% was assigned as a conservative estimate because these meters are not operating under recommended conditions. Note that this is a best guess based on industry experience and not a statistically derived confidence limit.

For the LAAFP Filtration Plant, WSO determined that the most reliable data was produced at the New Meters. However, these meters were only recently installed so data was not available for the whole audit period. Select comparisons and extrapolations allowed for estimation of the System Input Volume component from LAAFP. Volumetric testing was not possible at any of the meters here. Installation condition assessments were made for accuracy estimations at the LAA meters and the LA-35 meter. Section 1.4 outlines the volume analysis at LAAFP in detail.

For the groundwater well field inputs, installation condition assessments were also conducted. A volumetric test at the Tujunga well field site was considered. It was not pursued at the time because the wells that are currently in operation do not overlap with those operating during the audit period. Though the test was not feasible at this time, the procedure for the test is included here for future pursuit (see Appendix B). Section 1.6 outlines the analysis of groundwater production in detail.

For the treated imports from MWD, billed volumes for the audit period were collected and examined. A select number of MWD connections – those that provided the largest imported volumes during the audit period – were visited to assess the meter installation conditions and setup as well. Further, the SCADA data for each connection was downloaded from MWD's online database to cross-reference with the billed volumes and guarantee that no financial adjustments were included. Section 1.5 outlines the MWD imported volume in detail.

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[5] American Water Works Association. "Flowmeters in Water Supply: AWWA Manual M33, First Edition." Denver, CO. 1989.

[6] International Standards Organization. "Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 4: Venturi tubes". Geneva, Switzerland. 2003.

Since the production volumes from the two Microfiltration Plants are responsible for less than 0.1% of the total SIV, no further review of the procedures used to estimate the production volumes was undertaken. The same goes for the LA County Waterworks District exports, which also account for less than 0.004% of the total SIV.

Table 2: Components of input volume accuracy determination

System Input Volume Component	**Approach to Assess Meter Accuracy**
LAAFP	Data comparison: LAAFP outputs vs. LAA + LA-35, Installation Assessment
Groundwater Well Fields	Installation Condition Assessment
MWD Wholesale Connections	Installation Condition Assessment
Microfiltration Plants	No assessment
LA County Waterworks District Exports	No assessment

1.4 Los Angeles Filtration Plant

LAAFP provides the largest component of treated water into the distribution system. As such, the plant's production is a critical part in calculating the System Input Volume (SIV) used for the water balance and analysis of system losses.

The following section outlines the data comparison between the sum of the inputs into LAAFP and the total volume of treated water that flows from LAAFP into the distribution system.

1.4.1 LAAFP Input Data

WSO examined the available points of measurement upstream of LAAFP. The first is the LAAFP inflow, which involves two Venturi meters used to measure the raw water volume into the plant. The other points of measurement to work with come from the sources of raw water: the two LAA pipelines and the purchased raw water from MWD through connection LA-35. The schematic in Figure 3 shows the setup of the meters that track the input volume into LAAFP.

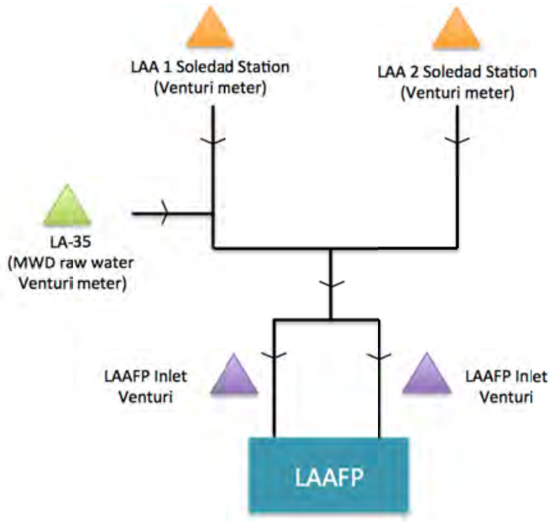

Figure 3: Meter Setup for Water Sources into LAAFP

Table 3 outlines the different data available for each of the relevant points of measurement into LAAFP. For both the LAA pipelines and the MWD LA-35 connection, two data sources are available. These sources were checked against each other to verify consistency.

Table 3: Data Available Related to LAAFP Volume Production

Measurement Point	**Data Source 1**	**Data Source 2**	**Location**	**Description**
LAA Pipelines	Northern District Hydrographic Database	Manual Reads	At the Soledad meters in Santa Clarita	Flow data received for each of the two LAA pipelines' Venturi meters from the Northern District Hydrographic Database system and from copies of manual daily reads.
MWD LA-35	Billed Volumes from MWD	MWD Online SCADA Data[7]	At the Jensen Plant before treatment	Billed data from MWD shows volume purchased through the LA-35 connection. MWD's SCADA records also track the flow.

1.4.1.1 LAA Pipelines

Raw water is delivered through the two LAA pipelines, and a Venturi meter on each registers the flow. Anecdotally, it was shared that the two meters here are calibrated every 6 months, but it was not possible to collect the calibration records. Beyond this intermittent calibration (which checks that the pressure differential transmitter reads zero flow and its maximum flow setting properly), there is no volumetric or comparative testing for the meters' flow measurement accuracies.

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[7] https://wins.mwdsc.org/Reports/WAMIReports.aspx

Historic flow data from each meter was provided from archived SCADA records retrieved from the Northern District Hydrographic Database. Average flow data (in cubic feet per second) for each day in the audit period was provided. These flows were converted into volumes by extrapolating the average flow for each 24-hour period. To confirm this SCADA data, WSO requested copies of the daily manual reads taken from the Soledad meters on the LAAs. Daily recordings of the flow at the time of visit (in cubic feet per second) and the totalizer readings were compiled and examined.

Table 4 and Figure 4 show the comparison results for LAA 1 (note that the totals are applied only to the months that are included in the audit period that are shaded). The SCADA and manual volumes at LAA 1 show volumes within the same range: the overall comparison shows that SCADA readings total 2.69% more than the manual reads. The main contribution to this difference is in May 2011 where the manual reads show production of 5,339.82 MG and the SCADA system reports flows that led to a calculation of 7,280.11 MG.

It is recommended that the discrepancy between the SCADA data and manual reads for May 2011 is examined. A preliminary look at the data by Water Operations staff shows that the manual reads may have been incorrect from April 28, 2011 to May 17, 2011, and the SCADA readings may have also read incorrectly from May 11, 2011 to May 16, 2011. These potentially erroneous volume records result in a high difference between the manual and SCADA volume totals for May 2011. A comparison check between manual reads and SCADA readings should be conducted as standard procedure.

Table 4: LAA 1 Manual and
SCADA Read Comparison

MONTH		**MANUAL** (MG)	**SCADA** (MG)	**% DIFF**
May-10		1,293.67	1,393.41	7.71%
Jun-10		6,322.02	6,261.52	-0.96%
Jul-10		5,559.73	5,565.44	0.10%
Aug-10		5,230.02	5,125.29	-2.00%
Sep-10		4,802.68	4,807.31	0.10%
Oct-10		6,323.59	6,302.88	-0.33%
Nov-10		5,358.22	5,197.03	-3.01%
Dec-10		5,198.60	5,255.20	1.09%
Jan-11		6,384.25	6,229.85	-2.42%
Feb-11		1,592.42	1,644.23	3.25%
Mar-11		6,732.67	6,775.99	0.64%
Apr-11		6,645.31	6,790.21	2.18%
May-11		5,339.82	7,280.11	36.34%
Jun-11		7,347.30	7,333.11	-0.19%
Jul-11		7,621.82	7,584.53	-0.49%
Aug-11		7,635.51	7,607.15	-0.37%
FY 2010 -2011:		**66,514.63**	**68,306.65**	**2.69%**

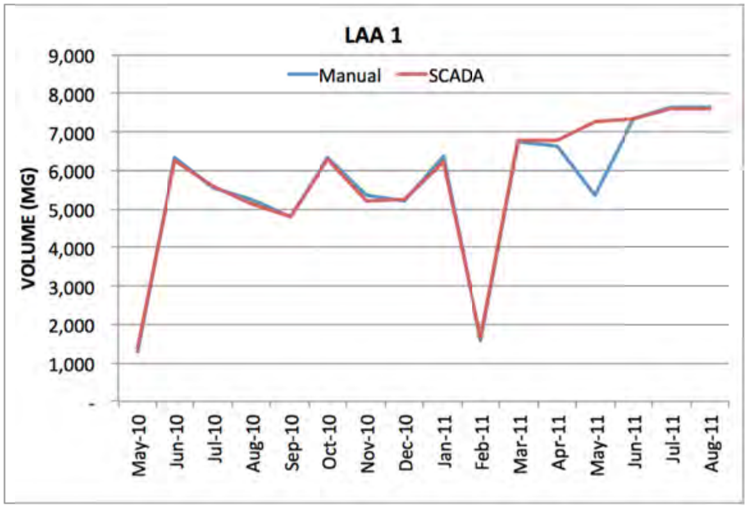

Figure 4: LAA 1 Manual and SCADA Reads Comparison

Table 5 and Figure 5 show the comparison results for LAA 2. The SCADA and manual volumes at LAA 2 show volumes within the same range: the overall comparison shows that SCADA readings total 0.47% more than the manual reads.

Table 5: LAA 2 Manual and
SCADA Read Comparison

MONTH		**MANUAL**	**SCADA**	**% DIFF**
		(MG)	(MG)	
May-10		5,628.85	5,618.43	-0.19%
Jun-10		5,034.79	5,042.56	0.15%
Jul-10		5,269.51	5,293.34	0.45%
Aug-10		4,767.15	4,703.25	-1.34%
Sep-10		1,162.32	1,121.23	-3.53%
Oct-10		381.11	419.20	10.00%
Nov-10		708.43	749.47	5.79%
Dec-10		719.80	667.39	-7.28%
Jan-11		1,264.05	1,242.35	-1.72%
Feb-11		2,114.37	2,191.08	3.63%
Mar-11		1,101.13	1,027.00	-6.73%
Apr-11		3,588.38	3,793.56	5.72%
May-11		5,231.44	5,204.14	-0.52%
Jun-11		5,519.72	5,545.40	0.47%
Jul-11		5,674.40	5,692.76	0.32%
Aug-11		5,730.13	5,727.66	-0.04%
FY 2010 - 2011:		**31,827.40**	**31,957.40**	**0.41%**

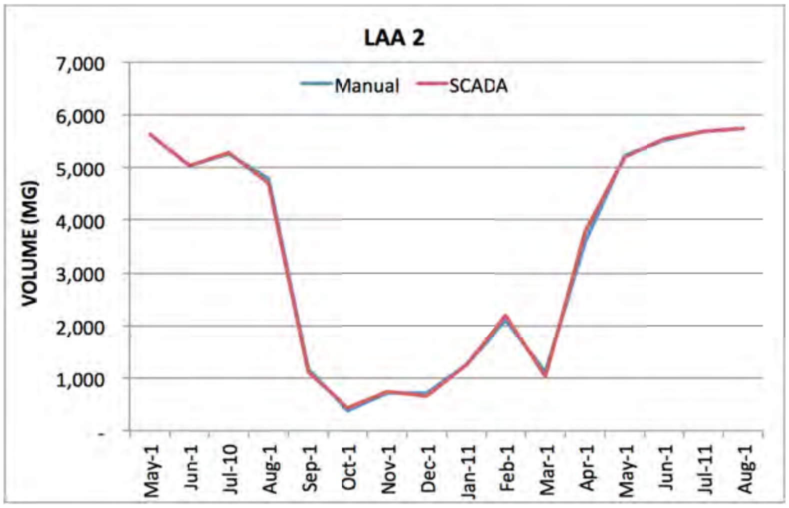

Figure 5: LAA 2 Manual and SCADA Reads Comparison

LADWP should compare the LAA1 and LAA2 SCADA data and manual reads on a monthly basis. The difference between manual read and SCADA data should stay within 0.5%. This is an important quality check to consistently conduct for one of the main components of the System Input Volume. If the comparison shows a difference greater than +/- 2% a more detailed examination of the data should be pursued.

1.4.1.2 MWD LA-35 Connection

MWD provides LADWP with raw water through connection LA-35. Monthly bills were examined to determine the purchased volume for the audit period. These billed volumes were compared to the LA-35 data in MWD's public database that features an archive of each connection's flow and volume information. Table 6 shows the results of that comparison: during the audit period there were little to no differences between the billed volumes and the volumes in the SCADA system.

Table 6: LA-35 MWD Billed Volumes
and Comparison to SCADA Data

	LA - 35 Connection		
	MWD BILLING DATA	**MWD SCADA DATA**	**% Difference**
	(MG)	(MG)	
May-10	4,546.44	4,399.74	-3.23%
Jun-10	1,262.77	1,262.78	0.00%
Jul-10	2,054.07	2,054.07	0.00%
Aug-10	3,700.98	3,700.98	0.00%
Sep-10	6,657.27	6,657.28	0.00%
Oct-10	3,983.98	3,983.97	0.00%
Nov-10	4,044.20	4,044.19	0.00%
Dec-10	3,623.10	3,623.11	0.00%
Jan-11	2,836.70	2,836.68	0.00%
Feb-11	839.91	839.91	0.00%
Mar-11	1,560.96	1,560.96	0.00%
Apr-11	436.18	436.19	0.00%
May-11	78.92	78.92	0.00%
Jun-11	187.30	187.31	0.01%
Jul-11	611.17	611.16	0.00%
Aug-11	667.70	667.71	0.00%
FY 2010 - 2011:	**30,003.58**	**30,003.58**	**0.00%**

1.4.2 LAAFP Output Data

A collection of meters tracks the treated water production from LAAFP. Figure 6 shows the configuration of these meters, presenting two main metered volumes from LAAFP: the volume that goes directly to the distribution system through the Flow to City meter (a 120” Metron insertion magnetic flow meter) and the volume that goes first to the LA Reservoir before going through the LA Reservoir Outlet meter (a Panametrics multipoint ultrasonic meter). Each of these two volumes is metered at additional points. The Flow to City meter is followed by two New Meters in vault 104 and vault 106 (each of which is a multipoint ultrasonic meters). The LA Reservoir Outlet meter is also followed by a New Meter in vault 204 (a Rittmeyer multipoint ultrasonic meter).

It is important to note that the flow data for these meters is stored in two different SCADA databases: the LAWSDAC system houses the data for the Flow to City meter and the LA Reservoir meter, and the TOCC / Wave Server houses the data for the New Meters. Multiple locations of flow data increase the difficulty and time required to analyze the comparisons and determine the System Input Volume component from LAAFP.

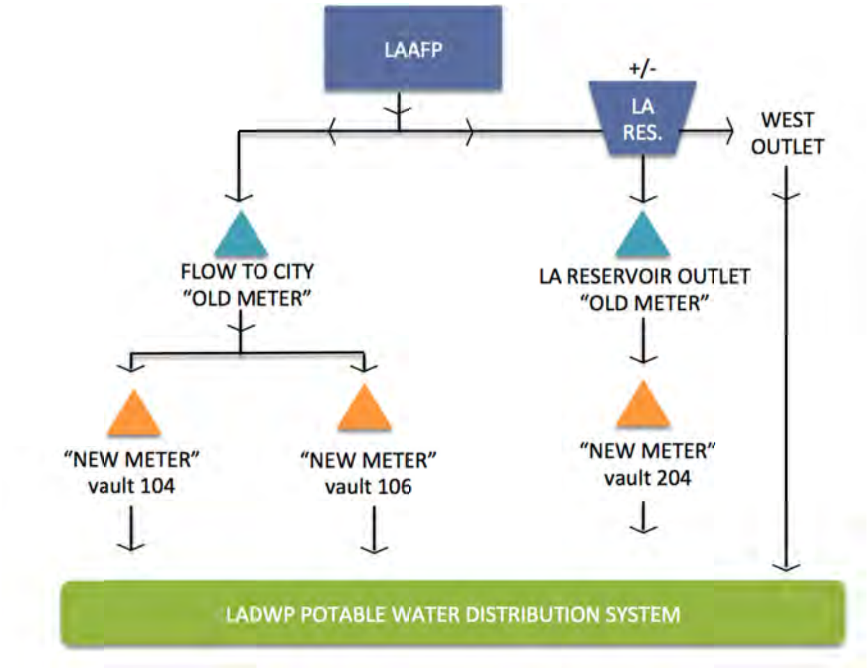

Figure 6: Schematic of Meters that Track LAAFP Treated Water Production

For the most accurate estimate of the System Input Volume component from LAAFP, it would be best to use the three New Meters: they are closest to the point of input into the distribution system and are newly installed multi-path ultrasonic flow meters. However, only going online in January 2012, the New Meters were not in place for the audit period.

To validate the audit period volumes for the Flow to City and LA Reservoir meters (the "Old Meters"), the 2012 data was examined. Assuming the New Meter registration is a relatively accurate reference, the accuracy of the Old Meter can be estimated. Figure 7 and Table 7 show the results of comparing the New Meters to the Old Meter for the Flow to City output from January 2012 to October 2012. Monthly volume comparisons show accuracies for the Old Meter that range from 94.17% to 97.42%. Comparing the total volume for the ten-month period, the old meters show an accuracy of 95.58% (under-registering by 4.42%).

Figure 7: Flow to City Meter Comparison for 2012

Table 7: Monthly Volumes for Flow to City:
New and Old Meters Comparison

	NEW METERS TOTAL (MG)	OLD METER TOTAL (MG)	ACCURACY
Jan-12	5,436.95	5,296.90	97.42%
Feb-12	5,570.15	5,245.30	94.17%
Mar-12	6,035.09	5,688.80	94.26%
Apr-12	5,963.76	5,639.40	94.56%
May-12	6,577.43	6,236.60	94.82%
Jun-12	7,088.64	6,753.20	95.27%
Jul-12	7,347.20	7,005.90	95.35%
Aug-12	11,163.75	10,675.70	95.63%
Sep-12	11,498.47	11,107.80	96.60%
Oct-12	10,475.35	10,093.40	96.35%
TOTAL 2012	77,156.79	73,743.00	95.58%

Figure 8 and Table 8 show the results of comparing the New Meter to the Old Meter for the LA Reservoir output from January 2012 to October 2012. Monthly volume comparisons show accuracies for the Old Meter that range from 97.97% to 99.61%. Comparing the total volume for the ten-month period, the Old Meter shows an accuracy of 99.09% (under-registering by 0.91%).

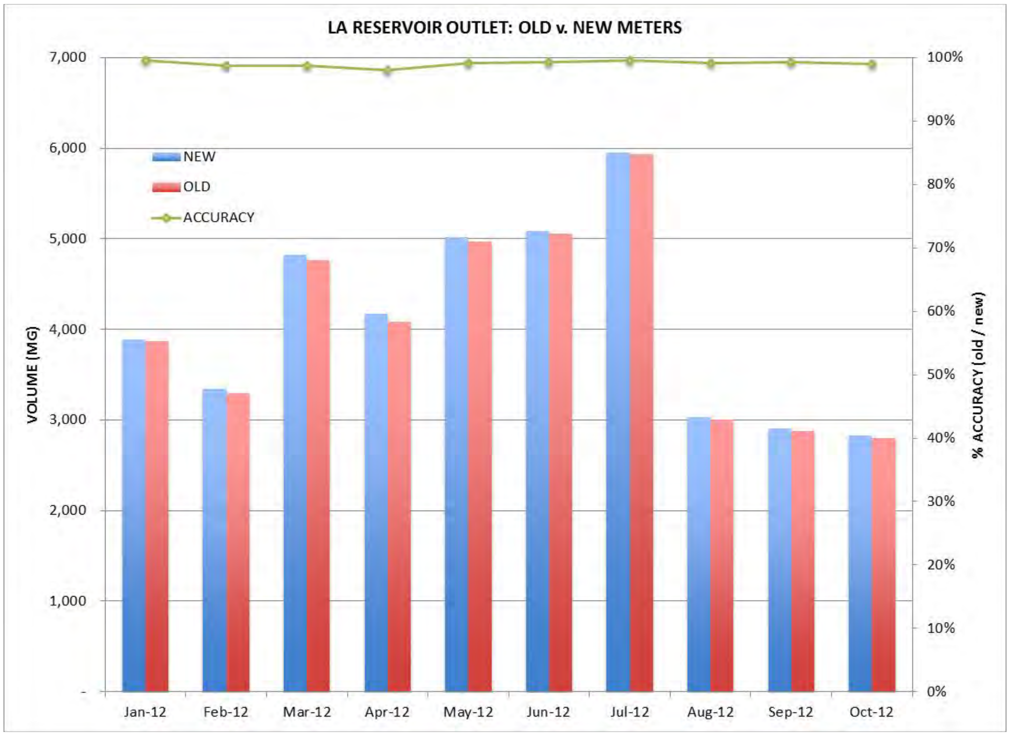

Figure 8: LA Reservoir Meter Comparison for 2012

Table 8: Monthly Volumes for LA Reservoir:
New and Old Meters Comparison

MONTH	NEW METER (MG)	OLD METER (MG)	ACCURACY
Jan-12	3,887.28	3,871.94	99.61%
Feb-12	3,340.66	3,298.72	98.74%
Mar-12	4,819.80	4,762.06	98.80%
Apr-12	4,168.17	4,083.51	97.97%
May-12	5,016.76	4,974.67	99.16%
Jun-12	5,087.24	5,054.20	99.35%
Jul-12	5,955.72	5,931.44	99.59%
Aug-12	3,029.15	3,002.70	99.13%
Sep-12	2,902.33	2,881.38	99.28%
Oct-12	2,826.23	2,799.85	99.07%
2012 TOTAL:	41,033.33	40,660.48	99.09%

Based on these comparisons, it appears that the Old Meters are under-registering. To account for this, the overall accuracies for each Old Meter (as determined by the above 2012 data comparisons with the New Meters) were applied, back-calculating a corrected volume for FY 2010 -2011. Table 9 shows the results of this calculation, presenting the corrected volumes for the old meters in FY 2010-2011.

Table 9: Flow to City and LA Reservoir Old Meter Corrections for FY 2010 -2011

	RAW SUM (MG)	CORRECTED SUM (MG)	UNDER-REGISTRATION APPLIED
120" FLOW TO CITY:	86,354.67	90,348.06	4.42%
LA RESERVOIR	39,389.85	39,751.07	0.91%
TOTAL:	**125,744.52**	**130,099.12**	

1.4.3 LAAFP Input and Output Data Comparison

Another check for consistency of the LAAFP data was made by comparing the sum of the LAAFP inputs ("LAAFP Input Volume") to the sum of its outputs ("LAAFP Outputs Volume"). The sum of the purchased water from the LA-35 connection (using the MWD billed volume records) and the LAA production (from SCADA flows) was used as the base of the LAAFP Input Volume. To make the comparison valid, the change of the LA Reservoir volume was also accounted for. For each month, if the total reservoir volume increased, the change would be detracted from the total LAAFP Input Volume; if the total reservoir volume decreased, the change would be added to the total LAAFP Input Volume. In this way, a direct comparison could be made to the LAAFP Output Volume.

The LAAFP Output Volume was determined using the corrected measurements from the LA Reservoir and Flow to City meters (as determined in Section 1.4.2). Figure 9 shows a schematic of the comparison made here.

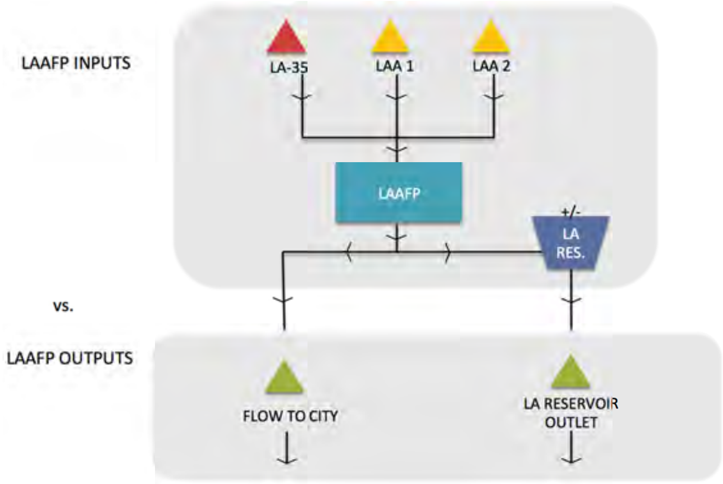

Figure 9: LAAFP Data Validation Comparison: Inputs v. Outputs

Table 10 shows the results of the comparison. Over the course of the total audit period, the total LAAFP output volume is 603.07 MG more than the LAAFP input volume, which amounts to only a 0.46% difference.

However, the monthly differences are significantly more sizeable. Figure 10 shows the variation in the difference between the LAAFP Input and the LAAFP Output Volume. For a majority of the months (eight months within the audit period), the LAAFP Output Volume is larger than the LAAFP Input Volume, ranging from 0.82% and 6.63% larger. Though specific accuracy conclusions cannot be made from this comparison, it suggests a general trend of under-registration at any or all of the LAAFP Input Volume meters (LAA 1, LAA 2 and LA-35). Considering the frequent calibration of MWD meters, it is likely that LAA 1 and/or LAA 2 is a source of under-registration.

The most significant finding here are the large discrepancies revealed for December 2010 and January 2011. Unlike most of the other months of the audit period, the LAAFP Output Volume is significantly less than the LAAFP Input Volume for these two months.

Table 10: LAAFP Input Volume and LAAFP Output Volume Comparison

MONTH	LAAFP OUTPUT VOLUME (MG)	LAAFP INPUT VOLUME (MG)	DIFFERENCE	
			(MG)	% OF OUTPUT VOLUME
Jul-10	13,398.09	12,962.80	435.30	3.25%
Aug-10	13,394.28	13,530.76	-136.48	-1.02%
Sep-10	13,068.75	12,707.93	360.82	2.76%
Oct-10	11,238.74	10,759.23	479.51	4.27%
Nov-10	10,933.52	10,208.65	724.87	6.63%
Dec-10	8,643.80	9,527.14	-883.34	-10.22%
Jan-11	7,381.10	9,896.24	-2,515.14	-34.08%
Feb-11	4,731.65	4,692.78	38.87	0.82%
Mar-11	9,410.75	9,534.65	-123.90	-1.32%
Apr-11	11,585.12	11,359.82	225.30	1.94%
May-11	12,978.87	12,734.27	244.60	1.88%
Jun-11	13,334.45	12,787.92	546.53	4.10%
FY 2010 - 2011	130,099.12	130,702.19	-603.07	-0.46%

Figure 10: Monthly Difference between LAAFP Input Volume and LAAFP Output Volume (Output Minus Input)

Excluding the negative differences (where the LAAFP Output Volume is less than the LAAFP Input Volume, unlike the trend of the rest of the audit period), the remaining months show that each month the LAAFP Output Volume is 279.54 MG more than the LAAFP Input Volume on average. The purple line in Figure 10 highlights this average.

This comparison between LAAFP Input Volume and LAAFP Output Volume led to suspicions that the calculation of the LAAFP Output Volume was incomplete: using the total of the corrected volumes for the Flow to City and LA Reservoir meters did not capture all of the treated water leaving LAAFP.

1.4.3.1 LA Reservoir West Outlet Estimation

Upon further investigation, it was found that there was some amount of volume transferred to the distribution system through another outlet at the LA Reservoir, the “West Outlet”. Water Operations records show that the West Outlet was opened from December 17, 2010 to February 7, 2011. The West Outlet is not metered, so the LAAFP Input Volume and LAAFP Output Volume data was used to devise an estimated volume.

The average difference between the LAAFP Input Volume and the LAAFP Output Volume was used to estimate the volume for the West Outlet in December 2010 and January 2011. Table 11 outlines this estimation process. It details how a total of 3,957.56 MG was added to the audit period’s LAAFP Output Volume to account for the West Outlet flow.

Table 11: West Outlet Estimation Calculations for December 2010 and January 2011

West Outlet Estimation Component		**DECEMBER 2010**	**JANUARY 2011**
		(MG)	(MG)
LAAFP Input Volume	(A)	9,527.14	9,896.24
Average Monthly Difference *(Output minus Input)*	(B)	279.54	279.54
Extrapolated LAAFP Output Volume	(C) = (A) + (B)	9,806.68	10,175.78
LAAFP Original Output Volume	(D)	8,643.80	7,381.10
West Outlet Estimation	(C) – (D)	1,162.88	2,794.68

Incorporating the West Outlet volume estimation, Table 12 outlines the monthly volume from LAAFP for FY 2010 -2011.

Table 12: Final Calculation of Monthly LAAFP Output Volume for FY 2010 -2011

MONTH	**FINAL LAAFP OUTPUT VOLUME (MG)**
Jul-10	13,398.09
Aug-10	13,394.28
Sep-10	13,068.75
Oct-10	11,238.74
Nov-10	10,933.52
Dec-10	9,806.68
Jan-11	10,175.78
Feb-11	4,731.65
Mar-11	9,410.75
Apr-11	11,585.12
May-11	12,978.87
Jun-11	13,334.45
FY 2010 - 2011	**134,056.68**

1.4.4 LAAFP System Input Volume Data Selection for Water Balance

Ideally, system input volumes entered into the water balance are measured at the closest point to system entry. In this case, the closest measurements to the points of entry are the New Meters. Without this data for the audit period, 2012 data was used to determine the accuracy estimates for the Old Meters – the Flow to City and LA Reservoir meters. The audit period flow data was then corrected according to these accuracy estimates (see Section 1.4.2).

To make sure that the volume used for the water balance includes all water that enters the distribution system, an estimation for the flow through the West Outlet was also included (see Section 1.4.3.1).

For the water balance, the monthly volumes outlined in Table 12 will be used as the basis for the finished water introduced to the system from LAAFP. A total of 134,056.68 MG will be used as the System Input Volume component from LAAFP.

1.5 MWD Imports

Treated water from MWD is delivered into LADWP's system through 31 connections. This section outlines the efforts to verify the volumes from each of the MWD connections that were active during the audit period.

MWD actively maintains their population of wholesale meters. MWD calibrates each Venturi meter twice every year. Documentation of the calibration results is stored in their work order system. For the multi-point ultrasonic meters, the operating conditions and parameter data is downloaded periodically to check for consistency, and the transducers are frequently checked for signs of degradation.

1.5.1 MWD Treated Water Connection Volumes

Of the 31 MWD treated water connections, only 12 provided water to LADWP during the FY 2010-2011 audit period. For each connection, WSO reviewed the bills produced by MWD and compiled all the monthly deliveries. Table 13 shows the sum of MWD treated water deliveries for each active connection during the audit period (based on billing data provided). LA-25 provides treated water into the distribution system only when LAAFP is not in service for maintenance, approximately two weeks per year.

Table 13: MWD Treated Water Deliveries for FY 2010-2011

MWD Connection	TOTAL AUDIT PERIOD (MG)
LA-4	687.28
LA-5	2,822.00
LA-9	1,409.24
LA-12	0.13
LA-13	0.29
LA-16	2,588.04
LA-17A	31.25
LA-17C	9,188.31
LA-21B	3,154.69
LA-25	4,368.88
LA-31	3.32
LA-34B	122.72
TOTAL FY 2010 – 2011:	**24,376.16**

1.5.2 MWD Installation Condition Assessment

Table 14 outlines the results of the site visits to the MWD treated water connections and shows the comparison of actual installation conditions with the manufacturer's or the International Organization for Standardization's installation requirements. The eight connections that registered significant volumes for the audit period were examined.

Since LA-25 is a calculated volume from a mass balance between the Jensen Plant Influent (JPI) meter, Reservoir 1 at the Jensen Plant and the Sepulveda Feeder Output (SFO) (see Figure 11), these meters were examined as they inform the volume reported for LA-25. It is recommended that a meter is installed at LA-25 to simplify the accuracy assessment process at this site.

If the upstream or downstream components were not visible but there was ample unobstructed space for straight-length of pipe, "STRAIGHT" was assigned as the measurement, and sufficient straight length was assumed.

Seven of the examined input meters had sufficient upstream and downstream straight lengths. The examination at LA-5 connection revealed uncertainty about the meter setup. Only part of the meter was visible in the vault and drawings could not be obtained (neither MWD nor LADWP had records of as-built conditions).

For the LA-17 and SFO meters, the specific Venturi dimensions could not be obtained (both the throat size and internal pipe size). As the installation requirements for Venturis are dependent on these size parameters, it was not possible to conduct a comparison here. However, since all these meters have sizeable straight lengths, it was decided that their setup is sufficient to allow for the quoted Venturi accuracy.

Table 14: Installation Condition Assessment for MWD Treated Water Connection Meters

	Type	Size (")	Manufacturer's Reqs for Straight Length of Pipe			Actual Conditions of Straight Length of Pipe		SATISFIES INSTALLN REQ's?	95% CONFIDENCE LIMIT ASSIGNMENT (+/-) %
			Up-stream Req's (")	Down-stream Req's (")	Accuracy	Upstream Straight Length (")	Down-stream Straight Length (")		
LA-5	Venturi	23.7 x 16.2	332	NA	0.75%	?	?	INACCESSIBLE	5.0%
LA-9	Venturi	24.7 x 13.3	247	NA	0.75%	492	STRAIGHT	YES	0.75%
LA-16	Venturi	28.9 x 14.1	260	NA	0.75%	STRAIGHT	0	YES	0.75%
LA-17 A	Venturi	?	?	NA	0.75%	STRAIGHT	0	YES	0.75%
LA-17 B	Venturi	?	?	NA	0.75%	STRAIGHT	0	YES	0.75%
LA-17 C	Venturi	?	?	NA	0.75%	STRAIGHT	0	YES	0.75%
LA-21 A	Venturi	47.2 x 21.7	425	NA	0.75%	480	0	YES	0.75%
LA-21 B	Venturi	18.6 x 10.6	186	NA	0.75%	480	0	YES	0.75%
JPI	Ultrasonic	144	1440	NA	0.5%	STRAIGHT	STRAIGHT	YES	0.5%
SFO	Venturi	120	NA	NA	0.75%	STRAIGHT	STRAIGHT	YES	0.75%

1.5.3 MWD Data Consistency Assessment

MWD publishes all of their flowmeters' SCADA data to a public database (https://wins.mwdsc.org/Reports/WAMIReports.aspx). WSO downloaded each connection's water usage report for the audit period to double check that the billed volumes corresponded to the operational data on registered flow and did not feature financial adjustments.

Table 15 shows that billed volumes largely matched the SCADA totals for the audit period. However, there is a notable difference between the billed volume and the SCADA reads for connection LA-31. A closer examination of this meter's records revealed an inconsistency in MWD's online SCADA system. Using the downloaded output from the "Meter Daily Flow - Last Interval" option and using the meter reads to deduce volume (as was done for each of the other MWD meters), the total volume for LA-31 is 0.34 MG. However, using a different output selection and reviewing data from the "Meter Summary Volumes" output option, a total of 3.32 MG is tabulated (which matches the billed volume). An examination of this connection is recommended. However, the total volume contribution here is so small, it will not significantly affect the total system input.

LA-25 was not included in this comparison because its production volume is calculated through a mass balance (as outlined in Figure 11). Without a meter at this connection, there is no SCADA data to use for comparison. Instead, the accuracy of the meters involved in the mass balance was assessed as detailed in Section 1.5.2.

LA-25 = JPI – SFO +/- Reservoir Change

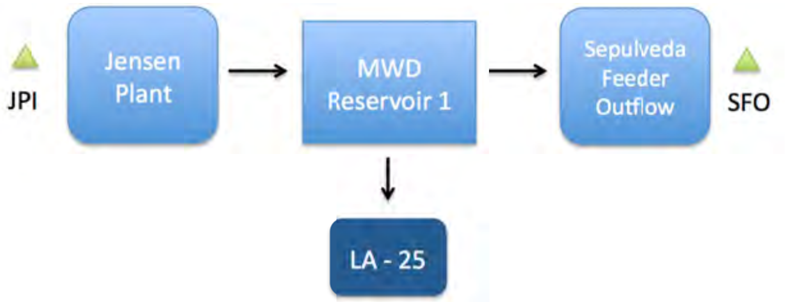

Figure 11: LA – 25 Volume Determination Mass Balance

Table 15: MWD Billed Volumes vs. SCADA Reads

MWD Connection	**BILLED VOLUMES (MG)**	**SCADA REPORTED VOLUMES (MG)**	**DIFFERENCE (MG)**
LA-4	687.28	687.30	0.01
LA-5	2,822.00	2,822.03	0.03
LA-9	1,409.24	1,409.22	(0.02)
LA-12	0.13	0.11	(0.02)
LA-13	0.29	0.29	0.00
LA-16	2,588.04	2,588.02	(0.02)
LA-17A	31.25	31.22	(0.03)
LA-17C	9,188.31	9,188.26	(0.06)
LA-21B	3,154.69	3,154.69	(0.01)
LA-31	3.32	0.34	(2.99)
LA-34B	122.72	122.75	0.03
TOTAL FY 2010 - 2011	**20,007.28**	**20,004.22**	**(3.06)**

1.6 Well Production

1.6.1 Well Production Volumes

LADWP owns and operates wells in 11 different well fields. During FY 2010 - 2011, 65 of these wells were active and registered flow. Table 16 shows a breakdown of well production volumes, organized by well field.

Table 16: Well Production Volumes for FY 2010 - 2011

FIELD NAME	**# Active Wells**	**TOTAL FY 2010 - 2011 (MG)**	**% of TOTAL**
AERATION	6	342.49	2.11%
ERWIN	2	275.63	1.70%
MISSION	2	73.44	0.45%
POLLOCK	2	942.71	5.82%
NORTH HOLLYWOOD	13	1,802.72	11.13%
RINALDI-TOLUCA	15	2,615.55	16.15%
TUJUNGA	12	7,470.08	46.12%
VERDUGO	2	619.03	3.82%
WHITNALL	3	304.86	1.88%
99th St	4	1,504.87	9.29%
MANHATTAN	4	245.61	1.52%
TOTAL	65	16,196.98	100.00%

1.6.2 Current Well Meter Testing Procedures

At the start of 2011, LADWP initiated an ongoing process of testing and calibrating the well meters. Twenty of the well meters have been tested and calibrated to date. Table 17 shows the results of the testing completed.

The North Hollywood, Pollock, and Mission well meters were not tested because new flow meters were installed at these sites. For the remaining 17 meters that were tested at three different flow rates, the results show a wide range of accuracy. An overall accuracy was determined by averaging all three results for each meter; these average accuracies range between 79.06% (under-registration) and 107.43% (over-registration).

Table 17: Completed Well Test Results

	TEST RESULTS			
WELL NAME:	**HIGH FLOW**	**MEDIUM FLOW**	**LOW FLOW**	**AVERAGE**
TUJUNGA 10	108.00%	107.00%	107.30%	107.43%
RINALDI TOLUCA 15	106.42%	105.90%	102.92%	105.08%
RINALDI TOLUCA 11	105.45%	104.77%	100.34%	103.52%
RINALDI TOLUCA 2	105.06%	104.72%	97.28%	102.35%
RINALDI TOLUCA 8	105.46%	104.22%	92.83%	100.84%
TUJUNGA 11	103.10%	103.40%	96.50%	101.00%
RINALDI TOLUCA 4	104.25%	103.79%	93.29%	100.44%
RINALDI TOLUCA 6	103.45%	102.68%	97.24%	101.12%
RINALDI TOLUCA 14	101.42%	100.50%	94.06%	98.66%
RINALDI TOLUCA 7	101.06%	99.78%	95.68%	98.84%
RINALDI TOLUCA 3	100.43%	99.70%	93.20%	97.78%
RINALDI TOLUCA 12	100.00%	99.69%	91.32%	97.00%
RINALDI TOLUCA 1	100.43%	99.31%	91.79%	97.18%
RINALDI TOLUCA 13	99.85%	98.89%	86.53%	95.09%
RINALDI TOLUCA 5	99.86%	99.60%	82.97%	94.14%
RINALDI TOLUCA 9	99.12%	98.26%	84.19%	93.86%
RINALDI TOLUCA 10	98.15%	90.78%	48.24%	79.06%
NO. HOLLYWOOD 26*	NA	NA	NA	NA
Pollock 6*	NA	NA	NA	NA
MISSION WELL 7*	NA	NA	NA	NA

* These flowmeters were replaced; the replacements were not tested.

The well meter population tested so far has a wide range of accuracy results. Without any clear trend of well meter performance, no extrapolations regarding the accuracy of the remaining well meters can be made.

The AWWA manual on testing and maintaining meters (AWWA M6) recommends that 12” propeller meters (the type of most of the well field meters) should test within 98% and 102%. Many of the test results shown in Table 17 do not meet this industry standard.

1.6.3 Well Meter Installation Condition Assessment

Table 18 outlines the results of the site visits to the well meters and shows the comparison of actual installation conditions with the manufacturer’s installation requirements. For each well field, a number of wells were examined: since the well meter setup is duplicated throughout each field, the results of these installation condition investigations were extrapolated for all the wells of a given field location. See Appendix C for representative photos from each of the visited well field sites.

As the comparisons in Table 18 detail, none of the well meters satisfied their manufacturer’s installation conditions. Without sufficient straight lengths of pipe, it is not guaranteed that a meter performs within its quoted accuracy (even with mitigating measures such as straightening vanes[8]). Given the installation conditions of the individual well meters it can be assumed that even newly calibrated well meters will not provide accurate results. These meters should therefore only be used for general operational purposes and not for accurate production volumes.

Table 18: Well Meter Installation Condition Assessment Results

Connection Name	**Size (")**	**Make**	**Manufacturer's Reqs for Straight Length of Pipe**			**Actual Conditions of Straight Length of Pipe**		**SATISFY REQ’S?**	**95% CONFIDENCE LIMIT (+/-) %**
			UPSTREAM (")	**DOWNSTREAM (")**	**Accuracy**	**UPSTREAM (")**	**DOWNSTREAM (")**		
North Hollywood - #34	12	Water Specialties	120	24	2%	48	12	NO	10%
Erwin - #6	12	Hersey Sparling	60	12	2%	36	11	NO	10%
Manhattan - # 5	12	Water Specialties	120	24	2%	36	18	NO	10%
Manhattan - # 2	12	Hersey Sparling	60	12	2%	36	11	NO	10%
Manhattan - # 3	8	Sparling	40	8	2%	28	16	NO	10%
Manhattan - # 6	12	Sparling	60	12	2%	24	11	NO	10%
Pollock - #6	12	Water Specialties	120	24	2%	48	12	NO	10%
Pollock - #4	12	Water Specialties	120	24	2%	48	12	NO	10%
Rinaldi-Toluca - #8	12	Water Specialties	120	24	2%	30	10	NO	10%
Tujunga - #8	12	DOWN FOR MAINTENANCE							10%
Tujunga - #7	12	Water Specialties	120	24	2%	48	12	NO	10%
Tujunga - #9	12	DOWN FOR MAINTENANCE							10%
Tujunga - #12	12	Water Specialties	120	24	2%	240	18	NO	10%

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[8] Further evidence of the unreliable performance of the individual well meters is provided in Section 1.6.4 where the accuracy of the Tujunga Well Field’s meters is examined.

1.6.4 Tujunga Well Field Volume Validation

The Tujunga well field provides an opportunity to compare the individual well meter production volumes with another meter measurement. Figure 12 shows the setup at the Tujunga well field: the water from this well field passes through one of 12 well meters and then collects in a collection basin (where there is another meter). Two meters – on the "Haskell Line" and the "City Line" – track the transfer of water from the collection basin into the distribution system.

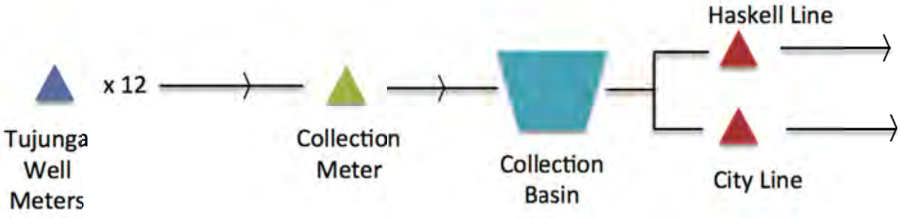


Figure 12: Tujunga Well Field Meter Setup

SCADA data from the Haskell Line meter and the City Line meter was collected for FY 2010 – 2011 and compared to the total production from the individual well meters. The meter at the collection basin was not used for this comparison: it was anecdotally described as unreliable, confirmed by anomalous data throughout the audit period.

It was found that there were SCADA data transfer errors in June 2011 (from June 9th through June 18th, the SCADA data for the Haskell Line meter reports unrealistically high flows). To correct for these incorrect reads, an average volume for the other days of June 2011 was calculated (equal to 20.32 MG) to replace the erroneous volumes.

Table 19 shows the monthly volumes for the Haskell Line meter and the City line meter, tabulated from the SCADA data provided. The corrected volume for June 2011 for the Haskell Line meter is also included.

Table 19: Haskell Line and City Line Volumes for FY 2010 -2011

MONTH	HASKELL LINE (MG)	CORRECTED HASKELL LINE (MG)	CITY LINE (MG)	DISTRIBUTION TOTAL (MG)
Jul-10	613.79	-	0.01	613.80
Aug-10	727.80	-	0.01	727.80
Sep-10	798.04	-	4.96	803.00
Oct-10	675.66	-	0.00	675.66
Nov-10	679.23	-	0.00	679.23
Dec-10	474.95	-	0.00	474.95
Jan-11	593.32	-	0.00	593.32
Feb-11	818.88	-	0.00	818.88
Mar-11	735.15	-	0.00	735.15
Apr-11	567.97	-	0.00	567.97
May-11	558.94	-	40.31	599.26
Jun-11	3,952.81	609.63	0.00	609.63
FY 2010-2011:	11,196.54	**7,853.35**	45.29	7,898.65

The total volume registered by the Haskell and City Line meters was compared to the total production registered by the individual well meters. Table 20 shows the results of this comparison: the individual well meters registered 5.42% less than the Haskell and City Line meters.

Table 20: Tujunga Well Field
Volume Comparison

TUJUNGA WELL FIELD MEASUREMENT	FY 2010 -2011 VOLUME (MG)
DISTRIBUTION METERS:	7,898.65
WELL METERS:	7,470.08
% DIFFERENCE:	5.43%

All of the individual well meters across most well fields throughout LADWP have consistent setups, wherein the actual meter installation does not meet the required minimum installation conditions. The only exception is the Manhattan well field where the total production is already based on a single meter located after the collection basin because the individual well meter readings were found highly unreliable. Therefore for all the well fields except for the Manhattan well field, it was assumed that the level of under-registration found from the Tujunga well field data comparison applied. As such, each well field production volume (except for the Manhattan well field), was corrected, as outlined in Table 21. The total FY 2010 – 2011 corrected well field production is 17,114.66 MG.

To improve the accuracy of the well field production volumes it is recommended to meter the production at a point before or after the collector basin and not to rely on the results of the individual well meters.

Table 21: Correction Well Field Production for FY 2010-2011

FIELD NAME	TOTAL PRODUCTION (MG)	CORRECTED PRODUCTION (MG)
AERATION	342.49	362.19
ERWIN	275.63	291.48
MISSION	73.44	77.67
POLLOCK	942.71	996.94
NORTH HOLLYWOOD	1,802.72	1,906.43
RINALDI-TOLUCA	2,615.55	2,766.02
TUJUNGA	7,470.08	7,899.83
VERDUGO	619.03	654.64
WHITNALL	304.86	322.40
99th St	1,504.87	1,591.45
MANHATTAN	245.61	245.61
TOTAL	**16,196.98**	**17,114.66**

1.7 Microfiltration Plant Production

Two microfiltration plants (MFP) – the Encino Reservoir MFP and the Stone Canyon Reservoir MFP – provided a relatively small volume of treated water to the system during the audit period. These plants treat water overflows from two out-of-service reservoirs. The treated overflows are introduced to the distribution system. Table 22 outlines the monthly volumes produced for each MFP.

Table 22: Volumes from Encino MFP and Stone Canyon MFP

Month	**Encino Reservoir MFP (MG)**	**Stone Canyon Reservoir MFP (MG)**
May-10	0.72	0.00
Jun-10	0.96	0.00
Jul-10	0.72	0.00
Aug-10	2.16	0.00
Sep-10	0.73	0.00
Oct-10	0.00	0.00
Nov-10	0.00	0.00
Dec-10	0.00	0.00
Jan-11	0.00	0.00
Feb-11	0.00	0.00
Mar-11	0.00	2.37
Apr-11	0.00	6.53
May-11	0.00	10.68
Jun-11	0.00	10.68
Jul-11	0.00	3.56
Aug-11	0.00	4.45
FY 2010 – 2011 TOTAL:	**3.61**	**30.26**

estimated values	monthly report calculations

For the MFP production, a combination of calculated and estimated volumes was submitted. The cells that are highlighted green show the monthly volumes that were calculated directly from operational data. The remaining volumes (highlighted yellow) are extrapolated from the calculated data, based on how many days the plant was in operation.

1.8 Reservoir Change Volume

Changes in reservoir storage volume can affect the System Input Volume. If there is an overall change in storage volume from the first to last day of the audit period, that change is accounted for as a consumption volume (if the volume of water in the reservoirs has increased) or additional system input volume (if the volume of water in the reservoirs has decreased).

However, only a fraction of LADWP's reservoirs have level data sufficient to estimate whether the storage volume increased or decreased over the course of the audit period. Without complete data, it was decided to exclude a reservoir storage consideration in the determination of the System Input Volume, and it is recommended to track all the reservoirs levels so that this volume can be incorporated in future audits.

1.9 Los Angeles County Waterworks District Exports

In order to isolate the Water Supplied to the LADWP distribution system, we need to deduct any wholesale exports from the System Input Volume. The only exports transferred during the FY 2010-2011 audit period were to LA County Waterworks District. Las Virgenes Water District and Calleguas Water District did not receive water from LADWP during the audit period. Table 23 outlines the volumes from each account that serves LA County Waterworks District. The total volume, 5.54 MG, only accounts for 0.0032% of the total volume of the water supplied so a thorough data validation analysis was not pursued.

Table 23: LA County Waterworks District Export Volumes by Account

ACCOUNT	FY10-11 TOTAL (HCF)	FY10-11 TOTAL (MG)
San Feliciano Dr	4,127.00	3.09
Lincoln Blvd #1	173.00	0.13
Lincoln Blvd. #2	3,092.00	2.31
Via Dolce #1	7.00	0.01
Via Dolce #2	7.00	0.01
TOTAL LA County Waterworks District Exports:	**7,406.00**	**5.54**

1.10 Assessment of 95% Confidence Limits Related to System Input Volumes

Table 24 summarizes the total System Input Volumes for the audit period. For each component, the following information is given: the total volume for the audit period, the 95% confidence limit, and the error range volume, and the variance value.

The variance is a calculated and dimensionless value based on the 95% confidence limit and the recorded volume for each component. The bigger the volume supplied by the meter, the bigger its related variance. Variance values are shown here because they are used to calculate the aggregate 95% confidence limits. It is important to note that variance is different than the error range volume (which is also provided). Variance is calculated as follows:

$$\text{Variance} = (\text{Volume} * 95\% \text{ confidence limit} / 1.96)^{2}$$

The confidence limits assigned to the System Input Volume are typically related to the accuracy of each system input meter. However, no system input meters were tested for the purposes of this audit, so the other evaluation approaches of installation assessments and data comparisons will inform the assignment of confidence limits for each volume.

The system input volume from LAAFP is calculated as outlined in Section 1.4. For the final production volume from LAAFP, a conservative confidence limit of +/-5% will be applied (tot the total production, not the individual meter estimations). Numerous extrapolations and estimations were used to calculate the monthly totals from LAAFP. This wide confidence limit is reflective of the problems related to determining an accurate system input volume form the LAAFP for the audit period.

For the MWD inputs, most all of the meters inspected satisfied their installation requirements and MWD regularly conducts accuracy tests on these meters. Accordingly, a confidence limit of 0.75% was assigned to the following visited connections: LA-9, LA-16, LA-17A, LA-17C, and LA-21B. For the MWD connections that were not visited (since they did not register very significant volumes during the audit period), a confidence limit of 0.75% was assigned, under the assumption that they meet their installation requirements as the majority of MWD connections do. This applies to connections LA-4, LA-12, LA-13, LA-31 and LA-34B.

For the LA-25 volume, a slightly more conservative 95% confidence limit was assigned because this connection does not have a meter – its volume is derived from a mass balance with two meters (see Section 1.5.3).

The only visited MWD connection that did not satisfy its installation requirements was LA-5: without access to view the buried meter and no documented as-built plans, a conservative confidence limit of +/- 5% was assigned.

For the system input volumes from the well fields, 95% confidence limits equal to each meter's accuracy range (as determined by installation condition assessments) were assigned. Since none of these meters satisfied their installation requirements, conservative 95% confidence limits of +/- 10% were assigned.

For the MFP volumes, conservative 95% confidence limits of +/- 25% were assigned for both the Stone Reservoir MFP and the Encino Reservoir MFP production due to the fact that these are estimated volumes. For the reservoir change volume inputs, conservative 95% confidence limits of +/- 5% were assigned because not all of the reservoirs have data available. For the LA County Waterworks District exports, conservative 95% confidence limits of +/- 5% were assigned because none of the sites were visited and no testing history was submitted.

The Water Supplied volume is defined as the System Input Volume (SIV) minus the Water Exported to neighboring agencies. The total Water Supplied for LADWP during the audit period was 175,575.83 MG +/- 3.85%.

The total input volume 95% confidence limit was calculated according to the 95% confidence calculation guidelines as outlined in Appendix A. The total input volume 95% confidence limit takes into consideration the variance related to each single component contributing to the total System Input Volume. It is important to note that aggregate 95% confidence limits are *not sums*.

Table 24: System Input Volumes and Related Confidence Limits

SYSTEM INPUT VOLUME COMPONENT	**FY 2010-2011 VOLUME**		**95% CONFIDENCE LIMIT**	**ERROR VOLUME**		**VARIANCE**
	(MG)	**(AF)**	**(+/- %)**	**(+/-MG)**	**(+/-AF)**	
CORRECTED FLOW TO CITY METER	90,348.06	277,268.02	NA	NA	NA	NA
CORRECTED LA RESERVOIR METER	39,751.07	121,991.55	NA	NA	NA	NA
ESTIMATED WEST OUTLET FLOW	3,957.56	12,145.31	NA	NA	NA	NA
LAAFP TOTAL:	**134,056.68**	**411,404.84**	**5.00%**	**6,702.83**	**20,570.24**	**11,695,122.77**
LA-4	687.28	2,109.20	0.75%	5.15	15.82	6.92
LA-5	2,822.00	8,660.40	5.00%	141.10	433.02	5,182.53
LA-9	1,409.24	4,324.80	0.75%	10.57	32.44	29.08
LA-12	0.13	0.40	0.75%	0.00	0.00	0.00
LA-13	0.29	0.90	0.75%	0.00	0.01	0.00
LA-16	2,588.04	7,942.40	0.75%	19.41	59.57	98.07
LA-17A	31.25	95.90	0.75%	0.23	0.72	0.01
LA-17C	9,188.31	28,197.90	0.75%	68.91	211.48	1,236.18
LA-21B	3,154.69	9,681.40	0.75%	23.66	72.61	145.72
LA-25	4,368.88	13,407.60	1.00%	43.69	134.08	496.85
LA-31	3.32	10.20	0.75%	0.02	0.08	0.00
LA-34B	122.72	376.60	0.75%	0.92	2.82	0.22
MWD TREATED IMPORT TOTAL:	**24,376.16**	**74,807.70**	**0.68%**	**166.26**	**510.23**	**7,195.59**
AERATION	362.19	1,111.52	10.00%	36.22	111.15	341.48
ERWIN	291.48	894.53	10.00%	29.15	89.45	221.16
MISSION	77.67	238.36	10.00%	7.77	23.84	15.70
POLLOCK	996.94	3,059.50	10.00%	99.69	305.95	2,587.19
NORTH HOLLYWOOD	1,906.43	5,850.62	10.00%	190.64	585.06	9,460.84
RINALDI-TOLUCA	2,766.02	8,488.59	10.00%	276.60	848.86	19,915.78
TUJUNGA	7,899.83	24,243.70	10.00%	789.98	2,424.37	162,451.47
VERDUGO	654.64	2,009.01	10.00%	65.46	200.90	1,115.56
WHITNALL	322.40	989.41	10.00%	32.24	98.94	270.57
99th St	1,591.45	4,883.97	10.00%	159.14	488.40	6,592.83
MANHATTAN	245.61	753.75	10.00%	24.56	75.38	157.03
WELL TOTAL:	**17,114.66**	**52,522.96**	**5.16%**	**883.37**	**2,710.96**	**203,129.61**
ENCINO MFP	3.61	11.07	25.00%	0.90	2.77	0.21
STONE MFP	30.26	92.86	25.00%	7.57	23.22	14.90
MICROFILTRATION PLANT TOTAL:	**33.87**	**103.93**	**22.50%**	**7.62**	**23.38**	**15.11**
LA COUNTY WATERWORKS DISTRICT EXPORTS	-5.54	-17.00	5.00%	(0.28)	(0.85)	0.02
TOTAL WATER SUPPLIED:	**175,575.83**	**538,822.44**	**3.85%**	**6,762.84**	**20,754.40**	**11,905,463.10**

Figure 13 depicts the monthly fluctuations in total System Input Volumes and its sources. The major source of water for LADWP during the audit period was the water treated at LAAFP, providing about 76% of the annual total input volume. With such a wide confidence limit, it also accounts for the most uncertainty in calculating the overall System Input Volume.

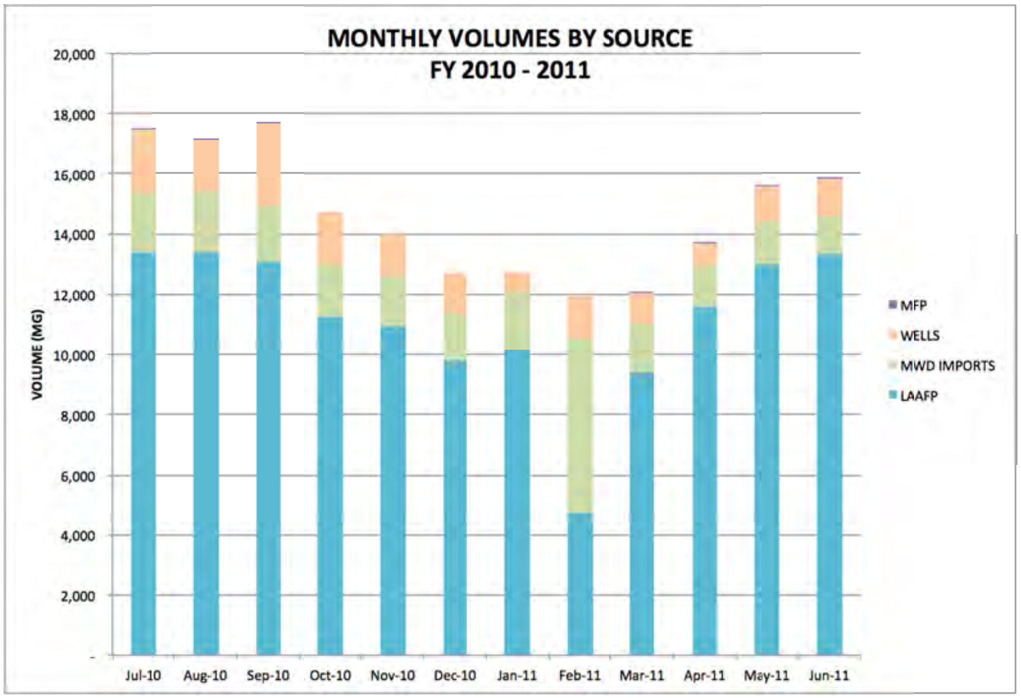


Figure 13: Monthly system input volumes

1.11 System Input Volume Recommendations

1. LADWP should use the New Meters for all future calculations of System Input Volumes from LAAFP. These meters are the newest in the area and closest to the point of distribution system entry. The only volume from LAAFP they do not capture is volume that leaves the LA Reservoir from the West Outlet. LADWP should install a water flow meter at this site to accurately and reliably record the volume supplied into the distribution network. Specifically, it is recommended to install an ultrasonic multi-point meter to capture all flow through the West Outlet.

2. LADWP should improve the accuracy of metering the well field production. Currently, the installation conditions for the individual well meters will not provide for accurate flow measurement. For each of the well fields, meter installed on the collector line (the pipeline supplying the combined well field production into the distribution network) should meter the total well field production. At some of the well fields such a meter already exists; however, the site inspections showed that these meters are currently not

regularly tested and maintained and may also not be sized correctly to capture variable flow volumes. Where necessary new meters should be installed and maintained to accurately capture all flow levels.

3. LADWP should consider streamlining its SCADA system organization. For the LAAFP volume analysis alone, data from three separate SCADA systems was required. With different data extraction procedures and permissions for each SCADA system, the data collection process for System Input Volume determination becomes quite cumbersome.

4. LADWP should track level data for all of its reservoirs so that a total increase or decrease in storage volume can be accounted for in the System Input Volume determination.

5. Even though it is recommended to no longer use the LAA meters for the System Input Volume calculation, LADWP should routinely compare the LAA 1 and LAA 2 SCADA data (from the Northern District Hydrographic Database) and manual reads on a monthly basis. The difference between manual reads and SCADA data should stay within 0.5%.

6. LADWP should routinely compare the MWD billed volumes to the MWD published SCADA totals for each month (available at: https://wins.mwdsc.org/Reports/WAMIReports.aspx).

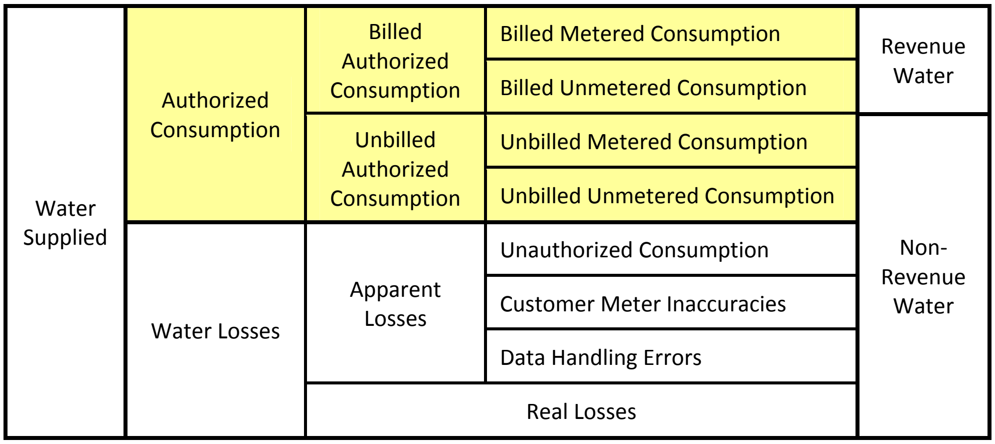
7. LADWP could consider also installing a meter at LA-25 to simplify the accuracy assessment process at this site. However, the current setup provides a reasonably accurate volume calculation. Relative to the meter installation at LAAFP, this is not a priority (due to lesser volume and better current accuracy).

SECTION 2. AUTHORIZED CONSUMPTION

2.1 Authorized Consumption Background

Authorized Consumption represents the volume of water taken by customers and others, who are implicitly or explicitly authorized to do so by LADWP. It includes many uses such as residential use, commercial use, municipal use, industrial use, fire fighting, flushing of mains and sewers, street cleaning, watering of municipal parks and gardens, public fountains, building water, etc. Authorized consumption may be billed or unbilled, metered or un-metered.

Figure 14 highlights in yellow the components of the Water Balance assessed and validated in this section. Note that the table is not formatted to scale (the size of each box is not proportional to its volume).



Water Supplied	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Customer Meter Inaccuracies	
			Data Handling Errors	
		Real Losses		

Figure 14: IWA standardized components of Annual Water Balance – Authorized Consumption highlighted

2.2 Billed Metered Authorized Consumption (BMAC)

This section details the Billed Metered Authorized Consumption (BMAC) volume and outlines the validation effort. The BMAC was determined through an analysis of a data extract from LADWP's billing system for the audit period. All LADWP potable water customer accounts were included in the analysis: the only two excluded groups of records included those that receive recycled water during the audit period (mainly those with Rate Code "44" and a number of other accounts) and those that receive water before the System Input Volume measurements were taken. See Section 2.2.2.5 for these exceptions.

The total BMAC volume was determined to be 166,443.14 MG or 510,795.24 AF.

2.2.1 Billing System Data Validation and Integrity Analysis

This section reviews the steps taken to review the overall integrity of the billing data.

LADWP provided sixteen months of billing data files (from May 2010 to August 2011), exported from the “Customer Information Services” (CIS) database. The fields provided included: Account Number, Service Code, Type Utility, Status Code, Rate Code, Class Code, Meter Install Date, Meter Manufacturer, Meter Size, Meter Number, Last Bill Date, Current Bill to Read, Prior Bill to Date, Previous Read, Number of Billing Days, Consumption, and Consumption Type. An additional database was provided from the Work Management Information System ("WMIS"); this database contains more up-to-date meter information for each customer account.

As one of the first steps in organizing the billing data, WSO attempted to merge the two databases. The goal was to link each account from CIS to the WMIS data in order to populate each account with both the consumption data (from CIS) and the most current meter information (from WMIS).

After some initial data analyses and review, it was determined that linking the databases was not possible. The service code was first used as a possible linking identifier between the two databases. However, CIS has 364,979 unique service codes and WMIS provides 691,297 unique service codes. Another attempt was made to link the databases based on the meter number provided. Here, it was also determined that there was insufficient overlap between the two databases: there are 721,997 unique meters in CIS and only 700,433 unique meters numbers in WMIS. Without the consistency in account information necessary to merge the two databases, it was decided to use the information provided in CIS for the complete billing data analysis.

Before turning to the consumption volumes for the audit period, it is instructive to examine the trends in number of records and database consistency from month to month. The following sections use these fields to make standard assessments of completeness and consistency.

2.2.1.1 Analysis of Number of Records

The first validation of data quality involves comparing the number of unique records in the database to the number of unique account numbers and the number of unique serial numbers. Only readings during the audit period were examined here. Table 25 shows a summary of active accounts and meters with readings during the audit period.

Table 25: Number of Records, Meter Numbers, and Account Numbers

Number of Unique Records	4,662,577
Number of Unique Meter Numbers	721,997
Number of Unique Account Numbers	789,554

The results in Table 25 are within an expected range, and they suggest that the billing database passes this preliminary test of integrity. Bi-monthly reading for the majority of accounts explains how the number of unique records is approximately six times the number of unique accounts. There are two explanations for how there are more account numbers than meter numbers: sometimes account numbers are assigned to new potential customers who have not yet received a meter, and sometimes meters are removed but the account number is not yet removed from CIS.

2.2.1.2 Lag Time Analysis

It is important to consider whether there is a significant delay between time of consumption and time of bill generation. The existence of such a delay can adversely affect the BMAC calculation so that it does not properly compare with the System Input Volume (SIV).

The analysis for the FY 2010-2011 audit period concluded that there are no lag times in LADWP's billing system that would have significant impact on the calculation of the BMAC volume. Two months preceding the audit period and two months following the audit period were included in the billing data export to allow for this analysis. Using these additional months' data, different 12-month consumption totals were compared. Table 26 shows the results of this comparison. Low variability between these volumes suggests that there is no significant lag time, and the monthly volumes within the audit period will suffice to calculate the BMAC volume.

Table 26: Lag Time Analysis Results

Period	**Number of Bills**	**Consumption Total (HCF)**	**Consumption Total (MG)**	**Consumption Period (days)**	**Average Consumption per Bill (HCF)**	**Average Consumption per Bill per day (HCF)**	**Average Bill Period (days)**	**Estimate of effect of meter reading lag**
5/2010 – 4/2011	4,635,869	220,807,363	165,164	255,347,983	48	0.86	55	-1%
6/2010 – 5/2011	4,658,598	220,950,459	165,271	256,421,059	47	0.86	55	-1%
7/2010 – 6/2011	**4,662,577**	**222,517,608**	**166,443**	**256,491,471**	**48**	**0.87**	**55**	**0%**
8/2010 – 7/2011	4,647,749	221,997,913	166,054	255,685,249	48	0.87	55	0%
9/2010 – 8/2011	4,613,281	220,526,190	164,954	253,769,896	48	0.87	55	-1%

If a significant time lag is determined in future assessments (if any time period varies from the audit period by more than 1% difference in total consumption), it is advised to apportion each bill's volume by month, as described in Appendix D.

2.2.2 BMAC Determination

2.2.2.1 BMAC by Month

After verifying that no significant lag time effect exists in the dataset, that dataset's monthly variability was examined.

The monthly breakdown of BMAC during the audit period is shown in Figure 15. BMAC varies monthly and displays an overall trend of higher consumption in the summer months and lower consumption in the winter months, which is typically experienced by utilities. The slightly anomalous increase in consumption for March 2011 was reviewed with the billing department: no concerns were raised and it was hypothesized that this is the result of the fewer days in February. This is substantiated by examining the number of reads per month as depicted in Figure 16 – more reads need to be taken during March to make up for fewer reading days in February.

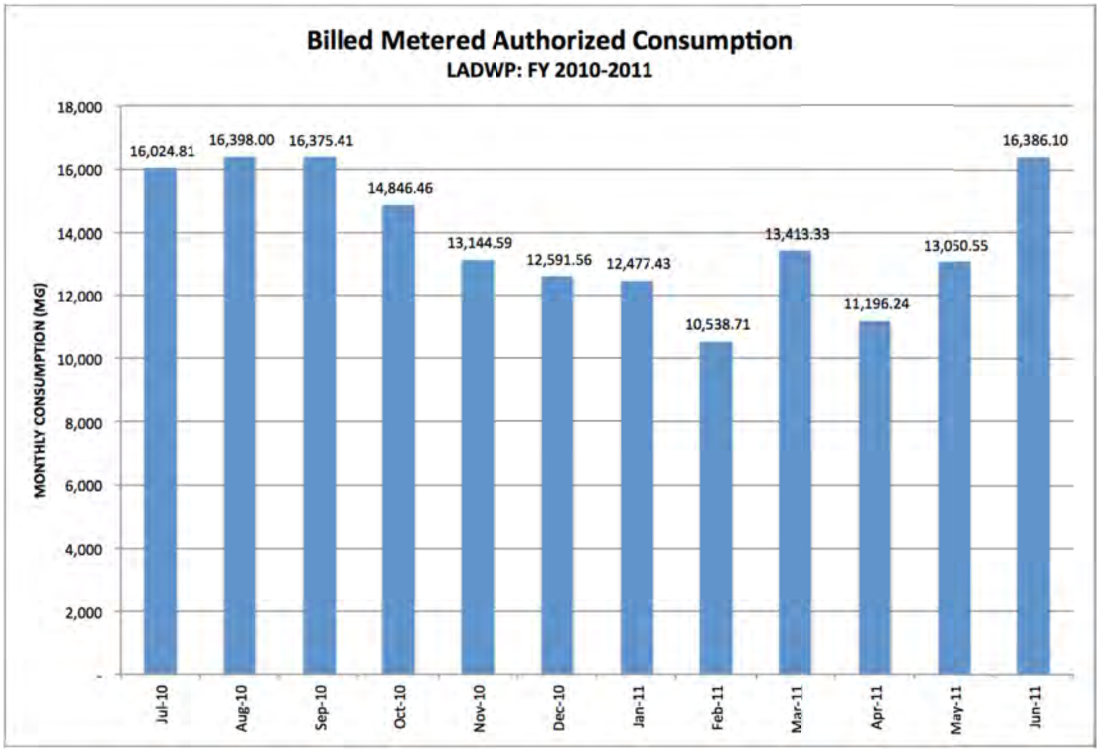


Figure 15: Billed Metered Authorized Consumption by months

Figure 16 shows the count of reads by month.

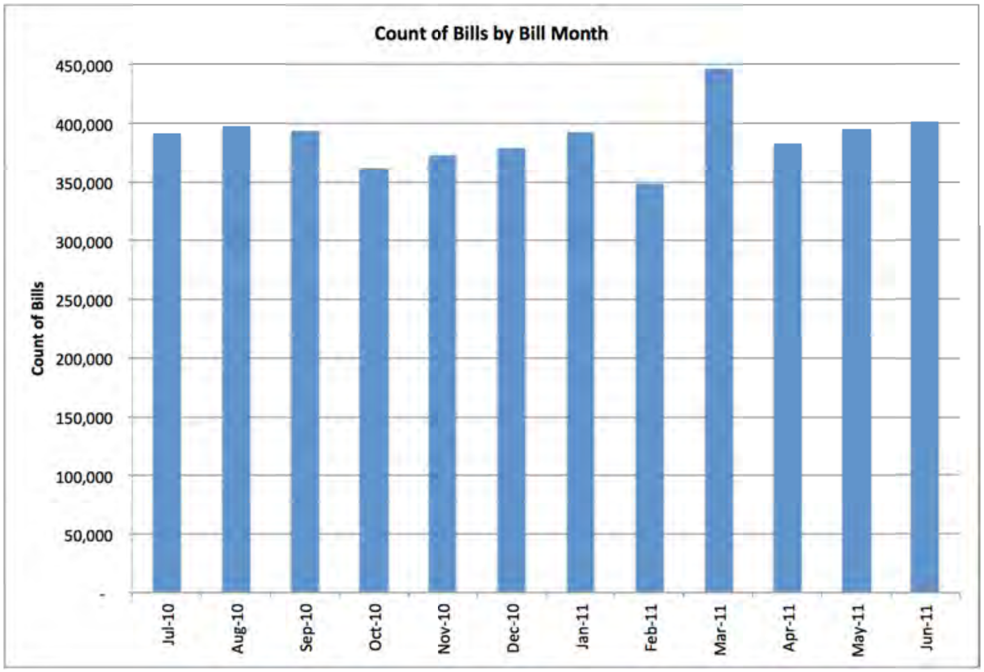


Figure 16: Number of Bills per Month

Total daily average consumption for LADWP during the FY 2010-2011 audit period ranged from 373.21 MGD to 546.20 MGD. Table 27 shows a monthly breakdown of BMAC volumes, and Figure 17 shows the average daily consumption per bill by month, highlighting the seasonal trend in consumption.

Table 27: Monthly Consumption and Average Daily Consumption

	TOTAL CONSUMPTION			**AVERAGE DAILY CONSUMPTION**		**AVG CONS PER BILL**
	(CCF)	**(MG)**	**(AF)**	**(MGD)**	**(AF/day)**	**(HCF)**
Jul-10	21,423,537	16,024.81	49,178.32	516.93	1,586.40	54.73
Aug-10	21,922,457	16,398.00	50,323.61	528.97	1,623.34	55.17
Sep-10	21,892,254	16,375.41	50,254.28	545.85	1,675.14	55.66
Oct-10	19,848,211	14,846.46	45,562.12	478.92	1,469.75	54.91
Nov-10	17,572,979	13,144.59	40,339.26	438.15	1,344.64	47.06
Dec-10	16,833,635	12,591.56	38,642.08	406.18	1,246.52	44.40
Jan-11	16,681,056	12,477.43	38,291.83	402.50	1,235.22	42.50
Feb-11	14,089,185	10,538.71	32,342.11	376.38	1,155.08	40.40
Mar-11	17,932,254	13,413.33	41,163.99	432.69	1,327.87	40.16
Apr-11	14,968,229	11,196.24	34,359.98	373.21	1,145.33	39.13
May-11	17,447,256	13,050.55	40,050.66	420.99	1,291.96	44.20
Jun-11	21,906,555	16,386.10	50,287.10	546.20	1,676.24	54.57
TOTAL AUDIT PERIOD	**222,517,608**	**166,443.17**	**510,795.34**	**455.58**	**1,398.12**	**47.74**

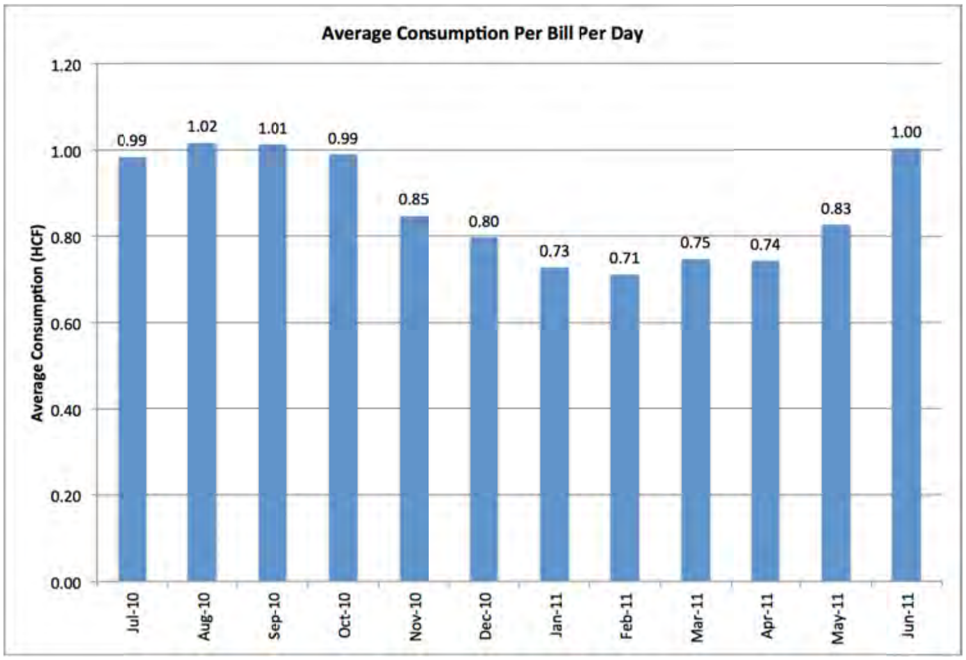


Figure 17: Average Consumption per Bill per Day by Month

2.2.2.2 BMAC Breakdown Meter Size

The first step in disaggregating the billing data was to break down the consumption by meter size. Table 28 identifies the number of meters by meter size and the sum of BMAC by meter size from audit period's billing data extract. Figure 18 also breaks down the total BMAC by meter size.

Table 28: Count of meters and consumption by meter size

METER SIZE		**COUNT OF METERS**	**% OF METER POPULATION**	**FY 2010 - 2011 CONSUMPTION**			
SIZE	**CODE**			**TOTAL (MG)**	**TOTAL (AF)**	**%**	**CONS per METER (HCF)**
UNKNOWN	00000	115	0.02%	46.19	141.75	0.03%	536.97
5/8"	00580	3,636	0.50%	371.95	1,141.48	0.22%	136.76
5/8 x 3/4"	00340	196,973	27.28%	20,057.51	61,554.25	12.05%	136.13
3/4 x 1"	01000	289,343	40.07%	37,350.07	114,623.15	22.44%	172.57
1"	01001	126,900	17.57%	21,195.27	65,045.88	12.73%	223.29
1 1/2"	01120	47,953	6.64%	19,069.62	58,522.52	11.46%	531.65
2"	02000	33,447	4.63%	32,283.07	99,073.09	19.40%	1,290.38
3"	03000	3,579	0.50%	6,144.61	18,857.12	3.69%	2,295.26
4"	04000	10,101	1.40%	10,604.53	32,544.10	6.37%	1,403.54
6"	06000	6,470	0.90%	14,349.36	44,036.56	8.62%	2,965.01
8"	08000	2,715	0.38%	1,698.65	5,212.98	1.02%	836.44
10"	10000	863	0.12%	3,268.44	10,030.46	1.96%	5,063.23
12"	12000	11	0.00%	0.83	2.55	0.00%	101.09
20"	20000	6	0.00%	3.08	9.44	0.00%	685.67
TOTAL:		722,112	100.00%	166,443	510,795.34	100.00%	308.15

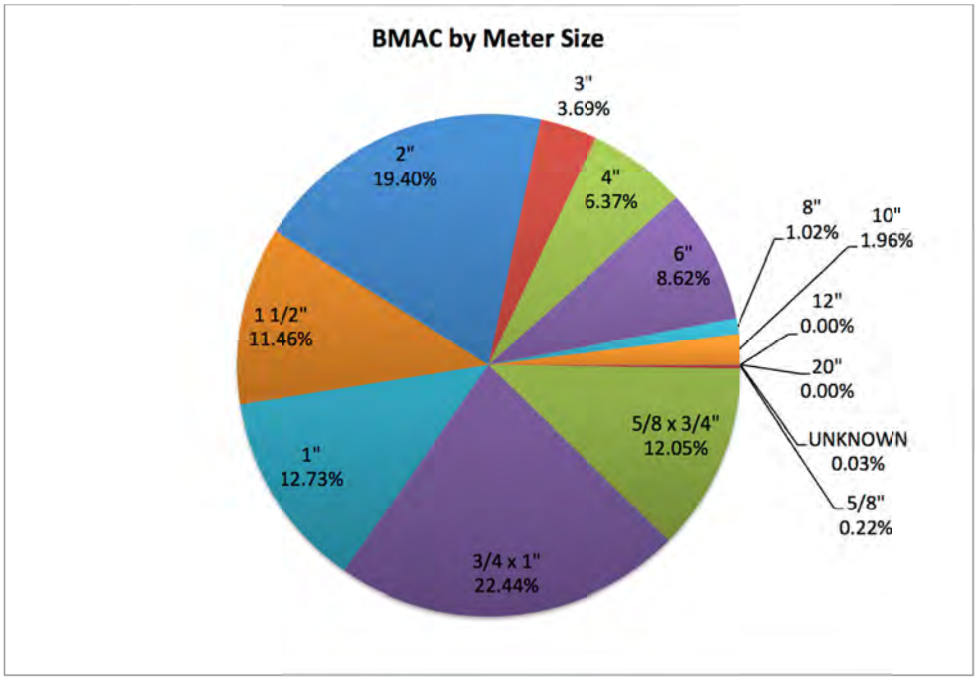


Figure 18: Percentage of Total BMAC by Meter Size

The meters were also grouped by average daily consumption in a series of ranges, 0 to 0.125 HCF per day, 0.125 to 0.25 HCF per day, 0.25 to 0.5 HCF per day, etc. Figure 19 shows the proportion of total FY 2010-2011 consumption by meter size and consumption range. This allows for conclusions such as the following: approximately 9.29% of the total consumption in FY 2010-2011 was registered by 3/4x1 inch meters that had daily average consumption between 0.5 and 1 HCF per day. Looking at all the meter sizes that fall within a given consumption range unveils how much overlap exists between different meters sizes in terms of average daily consumption.

Meter records with the “Private Fire Service” rate code are excluded from this analysis.

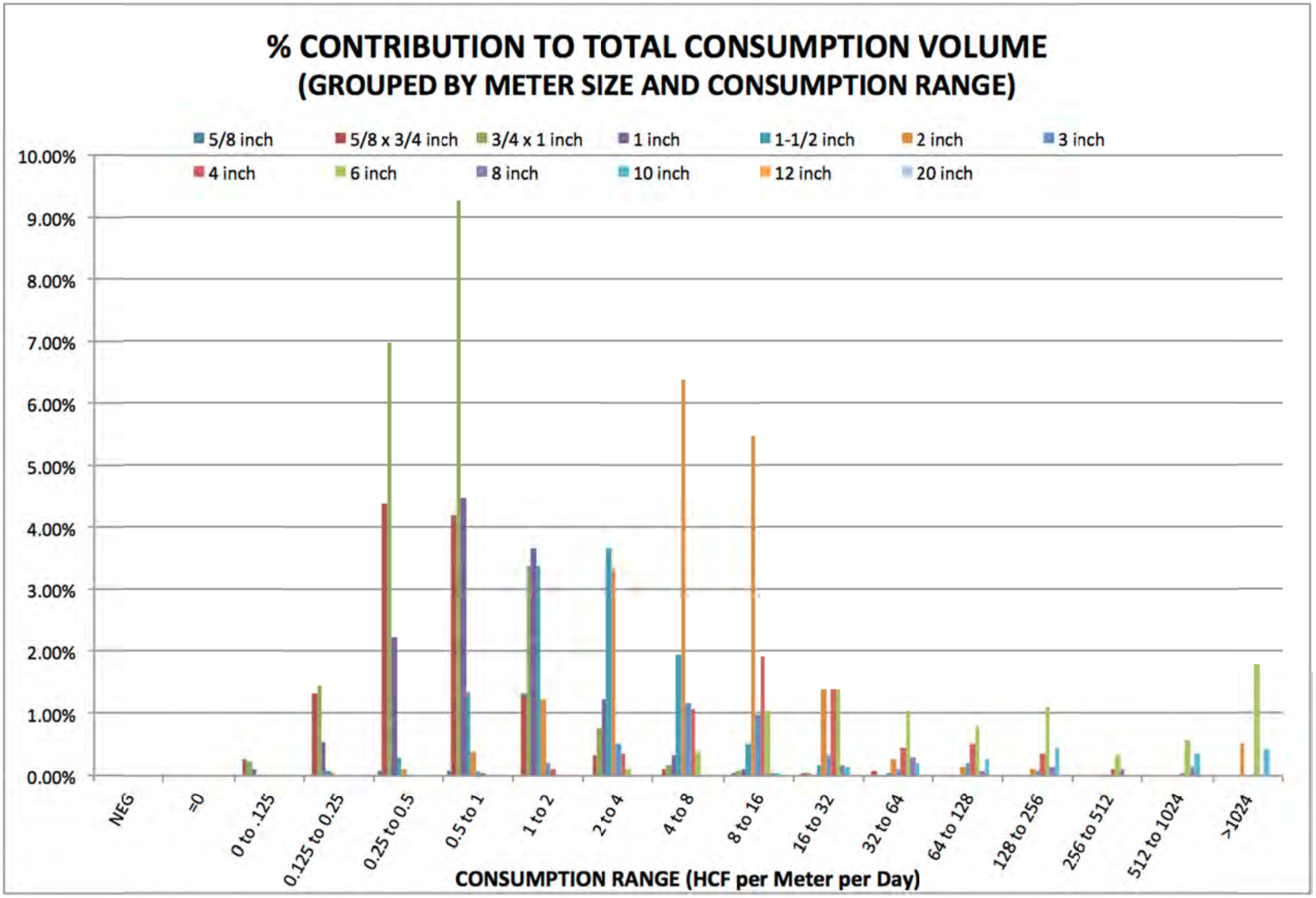


Figure 19: Contribution to total consumption by consumption range and meter size

Figure 19 shows that each of the consumption ranges is registered by a variety of small and large customer meters. Within each consumption range (especially in the lower consumption ranges), multiple sizes share significant portions of the consumption registered. For example, customers using water in the range between 1 and 2 HCF per day may currently have any meter size from 5/8” to 10”. This suggests that the customers in this consumption range with the smallest size meters have meters that may be under-sized for their daily consumption. The customers with larger meter sizes in this consumption range may have over-sized meters for their daily consumption.

Customers with either over-sized meters or under-sized meters can result in loss of the meter’s registration accuracy. Over-sizing of customer meters has the potential for increasing the amount of under-registration since meters tend to be less accurate in the lower ranges of their measuring capacity. Under-sizing of customer meters may result in a meter wearing out quickly, which also eventually causes the meter to under-register. It is important to qualify that the consumption analysis performed here is the first step in the process of a meter right-sizing program. Identifying outliers highlights meter populations that may be at risk for under or over registering.

In some instances, meters that fall in consumption ranges outside of their meter size population’s normal range are not candidates for over or under registration. For example, this analysis assumes that each bill represents the volume registered by *one* meter. There are some customers that have multiple meters but only one bill is created. In this situation, the consumption information does not accurately reflect the volume that passes through each individual meter. In this analysis, it was not possible to isolate the examples of this scenario (the WMIS meter information provided did not have any matches in CIS). In future consumption range analyses (especially upon implementing the new billing database which should allow for better meter information and consumption information alignment), these accounts should be excluded or the total consumption should be appropriately allocated to each individual meter’s readings. This way the consumption range analysis will be more instructive in highlighting potentially problematic meters.

Appendix E shows the consumption range profile for each meter size separately. Inventories of meter numbers that are outside of the most common consumption ranges are provided as addendums to this memo. These meters should be prioritized for accuracy assessment and/or replacement as they are the most likely to be inappropriately sized for the customer’s average daily consumption. However, to verify the incorrect sizing of a meter it is best to conduct consumption profiling that would record the exact 24-hour consumption profile of a specific meter. Appendix G outlines an example of what a right-sizing program would require in terms of data collection and analysis.

Lastly, it’s also important to review this analysis with an understanding of the small meter sizing parameters as dictated by fire flow requirements. Going forward, LADWP is planning to install small meters no smaller than 1”, limiting the options in right-sizing low consumption accounts.

2.2.2.3 BMAC Breakdown by Account Class Code

LADWP's billing database provides a field, "Class Code" that distinguishes each account by general type of use. Table 29 outlines the different type codes and provides a description for each.

Table 29: Class Code Descriptions

Class Code		**Description & Examples**
10	Residential	Residential use
20	Commercial	Commercial use
30	Industrial	Industrial use
40	Governmental	Governmental use outside of LADWP and Municipal City of LA (i.e. LA Unified School District)
50	Other Department	LADWP Power Department system usage
60	Purpose of Enterprise	LADWP Water Department system usage
70	Other Utilities	Service to other utilities outside of LADWP
80	Municipal City of LA	All City of LA Departments (except LADWP) – i.e. Recreation and Parks

Table 30 and Figure 20 provide a breakdown of BMAC by consumption in each Class Code. It shows that a large majority (71.60%) of BMAC is for residential accounts, followed by commercial accounts, which account for 18.53% of the total. It is also notable that 3.57% of the total consumption comes from accounts with the Class Code "80" assigned, which is Municipal City of Los Angeles. Appendix F shows a monthly consumption breakdown for each class code.

Table 30: BMAC by Class Code

Class Code	**Description**	**FY2010-2011 Consumption**		**% of Total Consumption**
		(MG)	**(AF)**	
10	Residential	119,167.01	365,710.13	71.60%
20	Commercial	30,843.61	94,655.56	18.53%
30	Industrial	5,507.85	16,902.97	3.31%
40	Governmental	4,477.73	13,741.65	2.69%
50	Other Department	292.08	896.36	0.18%
60	Purpose of Enterprise	213.58	655.45	0.13%
70	Other Utilities	-	-	0.00%
80	Municipal City of LA	5,941.32	18,233.24	3.57%
	TOTAL:	**166,443.17**	**510,795.34**	**100.00%**

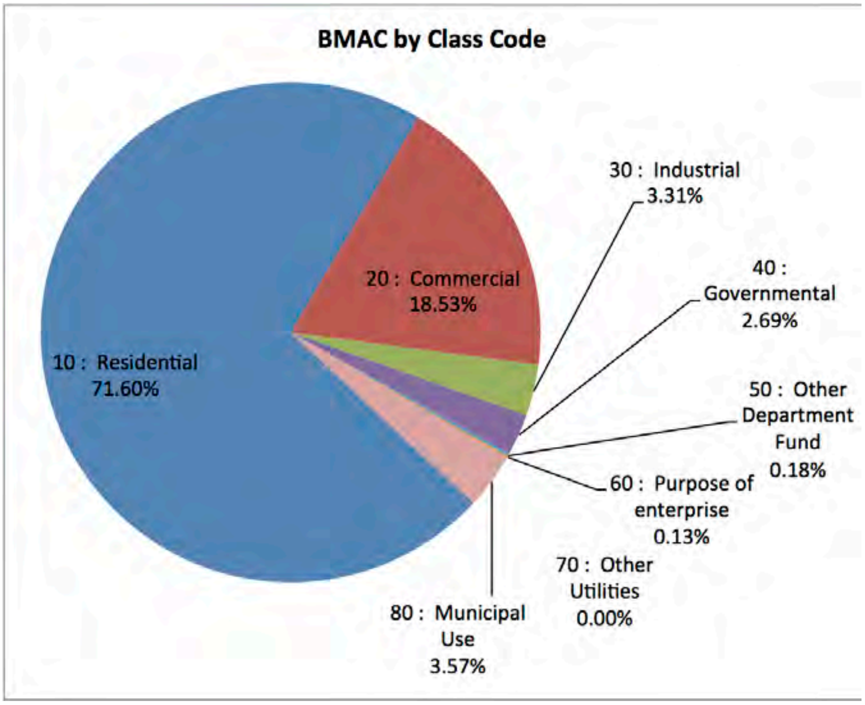


Figure 20: BMAC by Class Code

2.2.2.4 BMAC Breakdown by Consumption Type

Each record in the billing database has the “Consumption Type” field that describes the type of reading taken and whether or not it was estimated. Table 31 describes the different possible consumption types, and it shows that four of the nine Consumption Types indicate that the record features a wholly or partially estimated read.

Table 31: Description of Consumption Type Codes

Consumption Type	Category Name	Description	Estimated?
1	Actual	Based on actual meter reads or fixed flat rate	NO
2	Verified	Actual meter read; later re-read and verified	NO
3	Forced	An estimate generated when no attempt was made to read the meter	YES
4	Part Actual Part Estimate	Combined/part actual and estimated consumption or read	YES
5	Manual	Manually estimated by meter reading, account services, or by field investigation	YES
6	System Estimate	Computer estimated - no read or read unacceptable	YES
7	No-bill	No-bill calculated	NO
8	Odd Day Bill	Billed for irregular number of days (outside of regular billing cycle)	NO
9	Prior History	Previous customer's history	YES

Table 32 shows that the large majority of the reads taken during the audit period (91.85% of the total) is classified as “Actual”. The second largest component – with 4.35% of the reads

reads during the audit period – is the Consumption Type category "Odd Day Bill". Neither of the two most prevalent Consumption Type categories introduces estimation into the billing process. Figure 21 shows the BMAC volume by Consumption Type: the categories that involve any estimation are highlighted in green, whereas those based on meter reads alone are in blue.

Table 32: BMAC by Consumption Type

Class Code	Description	FY2010-2011 CONSUMPTION		% TOTAL
		(MG)	(AF)	
1	Actual	152,883.65	469,182.69	91.85%
2	Verified	310.96	954.30	0.19%
3	Forced	23.10	70.89	0.01%
4	Part Actual Part Estimate	2,925.75	8,978.80	1.76%
5	Manual	1,433.94	4,400.60	0.86%
6	System Estimate	1,627.88	4,995.78	0.98%
7	No-bill	-	-	0.00%
8	Odd Day Bill	7,237.89	22,212.27	4.35%
9	Prior History			
	TOTAL:	**166,443.17**	**510,795.34**	**100.00%**

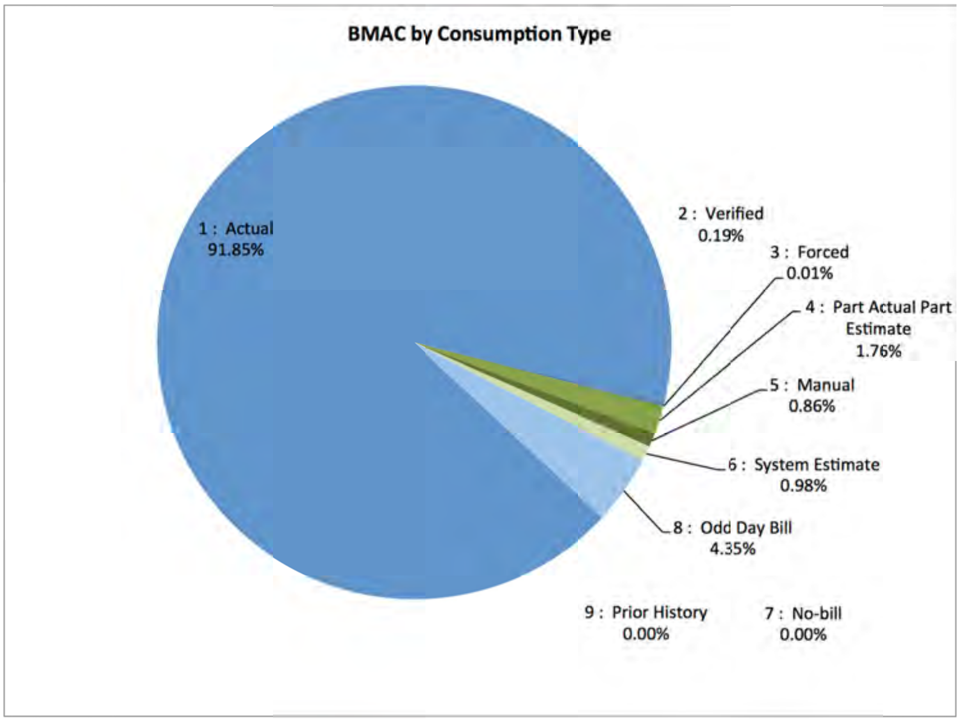


Figure 21: BMAC by Consumption Type

The Consumption Type codes that show the use of estimation in creating a bill include: Forced, Part Actual Part Estimate, Manual, System Estimate, and Prior History. In order to determine the potential effect of estimations in the billing database, the consumption in the categories were further examined. It was assumed that a majority of the estimations in the audit period would be corrected by the following months' reads (thereby not affecting the audit period consumption total). However, for the estimations made in the last two months of the audit period (May 2011 and June 2011), it is assumed that there are no later reads for corrective records. Table 33 shows the total consumption for estimated Consumption Type records in May and June of 2011.

Table 33: Uncorrected Estimated Totals by Consumption Type for May and June 2011

Consumption Type	**Category Name**	**JUNE & MAY 2011 SUM**		**% of FY 2010-2011 TOTAL**
		(MG)	**(AF)**	
3	Forced	17.21	52.81	0.01%
4	Part Actual Part Estimate	459.27	1,409.45	0.28%
5	Manual	218.17	669.54	0.13%
6	System Estimate	221.15	678.68	0.13%
9	Prior History	-		0.00%
	TOTAL ESTIMATIONS:	915.79	2,810.46	0.55%

Only 0.55% of the total audit period consumption is categorized with a Consumption Type that indicates estimation. The actual error introduced by these estimations will be a fraction of this percentage based on the accuracy of the estimations. In any case, the portion of total consumption that is estimated is minor enough that the overall error introduced by estimations will not have a significant effect on the BMAC determination.

2.2.2.5 Accounts Excluded from BMAC

The following sections detail the accounts and corresponding consumption volumes that are excluded from the final BMAC determination. For the purposes of creating a consistent and complete water balance, the consumption volume determination must correspond with the System Input Volumes: only consumption that draws from the water supplied (as calculated in the System Input Volume calculation) qualifies as BMAC in the water balance. As such only potable water that is consumed after the points of System Input Volume metering is included in BMAC.

2.2.2.5.1 Exclusion of Recycled Water Accounts

The first group of exclusions from the BMAC volume includes the accounts that receive recycled water. This audit is limited to the potable water system, so any recycled water accounts tracked in CIS must be excluded. In CIS, the rate code "44" highlights records that refer to recycled water. In the first review of the CIS data, all billing records with rate code "44" were removed.

Upon further investigation, it became clear that a handful of accounts receive recycled water without the rate code "44" distinction on their billing records. The Water Recycling and Planning Group provided their documentation of these accounts' information, which was then cross-referenced with CIS.

Through this effort, beyond the rate code "44" accounts, an additional 544.95 MG or 1,672.39 AF was excluded from the final BMAC volume determination. In future water audits, it will be important to exclude all accounts that receive recycled water.

2.2.2.5.2 Exclusion of Treatment Plant Accounts outside of System Input Volume Boundary

All consumption included in the BMAC volume determination must be accounted for in the System Input Volume. This is not the case for a small number of accounts that use potable water before the points of measurement for the System Input Volume.
Table 34 presents the two accounts of this type that were present in CIS records: these meters appear to track process water at the LAAFP.

Table 34: Treatment Plant Accounts to Exclude from BMAC Determination

Meter Number	**Name**	**FY 2010 – 2011 Consumption Volume**		
		(HCF)	**(MG)**	**(AF)**
90119347	@DWP-P OF E	41	0.031	0.095
96101258	@DWP-P OF E	0	0	0
Grand Total		**41**	**0.031**	**0.095**

A particular account of note is Meter Number 96101258 (Account Number 3597809313101000000000). It is a six-inch Badger meter that is classified in Class Code 60, "Purpose of Enterprise" and is located near the Los Angeles Aqueduct Filtration Plant. As Table 34 shows, CIS does not include any records with consumption from this account during the audit period. However, in July 2011, a bill reports a consumption of 960,053 HCF (718.12 MG). The prior reading was made in September 2008, when the meter was installed. It appears that this meter is rarely read, and due to its high volume records, careful attention should be made to exclude it from future consumption volumes in water balance calculations.

The examination of these exclusions occurred after the above analyses were made. These accounts were not yet excluded from the billing database when the above analyses and breakdowns were conducted. Detracting 0.031 MG or 0.095 AF from the billing database records to account for these exclusions, the final BMAC determination is 166,443.14 MG or 510,795.24 AF.

2.3 Billed Un-metered Authorized Consumption

LADWP does not have any billed un-metered authorized consumption in its system.

2.4 Unbilled Metered Authorized Consumption

Most all metered consumption in LADWP is billed. One exception here is the change in storage reservoir volume. Reservoir levels are monitored, and if there is an overall change in storage volume from the first to last day of the audit period, that change is accounted for as a consumption volume (if the volume of water in the reservoirs has increased) or additional system input volume (if the volume of water in the reservoirs has decreased).

Data for the storage change between the first and last day of the audit period was only available for approximately half of the reservoirs in the system. As such, it was decided that the total change in storage volume could not be reliably determined as either a consumption volume or a system input volume. Without complete data here, no volume was categorized as Unbilled Metered Authorized Consumption.

2.5 Unbilled Un-metered Authorized Consumption

Un-billed Un-metered Authorized Consumption is the volume of water estimated as taken from the system un-metered and for which no bill is issued. For LADWP, uses of Un-Billed Un-metered Authorized Consumption include fire-fighting and mains flushing. However, records of estimates for these volumes are unavailable for the audit period. Anecdotally, LADWP staff reports that flushing was kept at a minimum during the audit period due to the mandatory conservation measures.

For the water balance, an estimate of 0.125% of the Water Supplied (total System Input Volume minus Billed Water Exported), which equals 219.47 MG or 673.53 AF, will be used for Un-billed Un-metered Authorized Consumption.

2.6 Assessment of 95% Confidence Limits Related to Authorized Consumption

Table 35 summarizes the total Authorized Consumption for the audit period. For each component, the following information is given: the total volume for the audit period, the 95% confidence limit, and the error range volume, and the variance value. The variance is a calculated and dimensionless value based on the 95% confidence limit and the recorded volume for each component (see Section 1.10 for details)

For the Billed Metered Authorized Consumption, no obvious data quality issues were found in the process of review (as detailed in the preceding sections). One of the components of this review was a lag time analysis. This process examines the impact of the audit period boundary definitions; using two months of addition consumption data on either end of the FY 2010-2011 period, different 12-month consumption totals were compared. Low variability between these volumes suggests that there is no significant lag time. The comparison with the largest discrepancy presented a difference in total volume of 0.89%. As it indicates an upper limit of volume determination error, this value is assigned as the 95% confidence limit for the Billed Metered Authorized Consumption Volume.

For the Un-billed Un-metered Authorized Consumption, a conservative 95% confidence limit of /-20.00% was assigned because a calculated estimation was used (0.125% of Water Supplied) without any system specific data.

The total Authorized Consumption for LADWP during the audit period was 166,662.61 MG +/- 0.89%. The total Authorized Consumption volume's 95% confidence limit was calculated according to the 95% confidence calculation guidelines as outlined in Appendix A. This calculation of an aggregate confidence limit takes into consideration the variance related to each of its components. It is important to note that aggregate 95% confidence limits are *not sums*.

2.7 Authorized Consumption Summary

The total Authorized Consumption for the audit period was 166,662.61 MG or 511,468.77 AF. Of this total volume, 166,443.14 MG or 510,795.24 AF was Billed Authorized Consumption and 219.47 MG or 673.53 AF was Un-billed Authorized Consumption. The following components of Authorized Consumption were validated and established for the Water Balance.

Table 35: Authorized Consumption Components

AUTHORIZED CONSUMPTION COMPONENT	FY 2010-2011 VOLUME		95% CONFI-DENCE LIMITS	ERROR VOLUME		VARIANCE
	(MG)	(AF)		(+/- MG)	(+/- AF)	
Billed Metered Authorized (Retail Sales)	166,443.14	510,795.24	0.89%	1,481.34	4,546.08	571,214.09
Billed Un-Metered Authorized Consumption	NA	NA	NA	NA	NA	NA
TOTAL BILLED AUTHORIZED CONSUMPTION	**166,443.14**	**510,795.24**	**0.89%**	**1,481.34**	**4,546.08**	**571,214.09**
Un-billed Metered Authorized Consumption	NA	NA	NA	NA	NA	NA
Un-billed Un-Metered Authorized Consumption	219.47	673.53	20.00%	43.89	134.71	501.53
TOTAL UN-BILLED AUTHORIZED CONSUMPTION	**219.47**	**673.53**	**20.00%**	**43.89**	**134.71**	**501.53**
TOTAL AUTHORIZED CONSUMPTION	**166,662.61**	**511,468.77**	**0.89%**	**1,483.30**	**4,552.07**	**571,715.62**

2.8 Recommendations – Consumption Data

- For consistency of water audit results from year to year, LADWP should note to exclude two groups of accounts from its determination of BMAC: all recycled water accounts (Rate Code 44 and additional miscellaneous accounts) and the accounts that receive water before the point of measurement of the System Input Volume should be excluded.

- The large number of inaccuracies between WMIS and CIS should be addressed. The current number of inconsistencies could have a big impact on revenue collection and analysis of meter use by size or customer class. Ideally one central database would have up to date information for all meter characteristics and billing data for consumption analysis.

- For the determination of total consumption during the audit period, this analysis suggests that the billing database has reliable and consistent information. However, for use as a meter inventory database, CIS requires a great deal of data cleaning and data integrity improvement. The forthcoming Apparent Losses Technical Memo will detail the completeness and accuracy of the meter information in CIS.

- Investigate the meters/accounts highlighted in Appendix E for proper sizing and potential for revenue improvement.

- Introduce tracking of Unbilled Unmetered Authorized Consumption volumes.

- For determination of the Unbilled Metered Authorized consumption, track *all* of the reservoir levels from first to last day of the audit period in addition to volume estimations for reservoir drainage events.

SECTION 3. WATER LOSSES

Water Losses are the different between the Water Supplied and Authorized Consumption volumes. Water Losses consist of Real Losses and Apparent Losses.

The Water Loss calculation in this audit is based on the IWA/AWWA standardized top down Water Balance. Section 1 details the determination of Water Supplied, which was 175,575.83 MG (or 538,822.44 AF) for FY 2010 – 2011. Section 2 details the determination of Authorized Consumption, which was 166,662.61 MG (or 511,468.77 AF) for FY 2010 – 2011. The Water Losses are calculated by subtracting the Authorized Consumption volume from the total Water Supplied volume.

Table 36 shows the final volumes used in calculating the water loss volume for FY 2010-2011. For each component, the total volume for the audit period, the 95% confidence limits (as calculated in Section 1.10 and Section 2.6), and the variance value are given.

Table 36: Water Loss Calculation and Related Confidence Limits

WATER LOSSES CALCULATION	FY 2010-2011 VOLUME		95% CONFIDENCE LIMITS	ERROR VOLUME		VARIANCE
	(MG)	(AF)		(+/- MG)	(+/- AF)	
Water Supplied (A) – see Section 1	175,575.83	538,822.44	3.85%	6,759.67	20,744.66	11,894,296.94
Authorized Consumption (B) – see Section 2	166,662.61	511,468.77	0.89%	1,483.30	4,552.07	571,715.62
Water Losses ((A) - (B))	**8,913.22**	**27,353.67**	**77.67%**	**6,922.90**	**21,245.60**	**12,467,019.42**

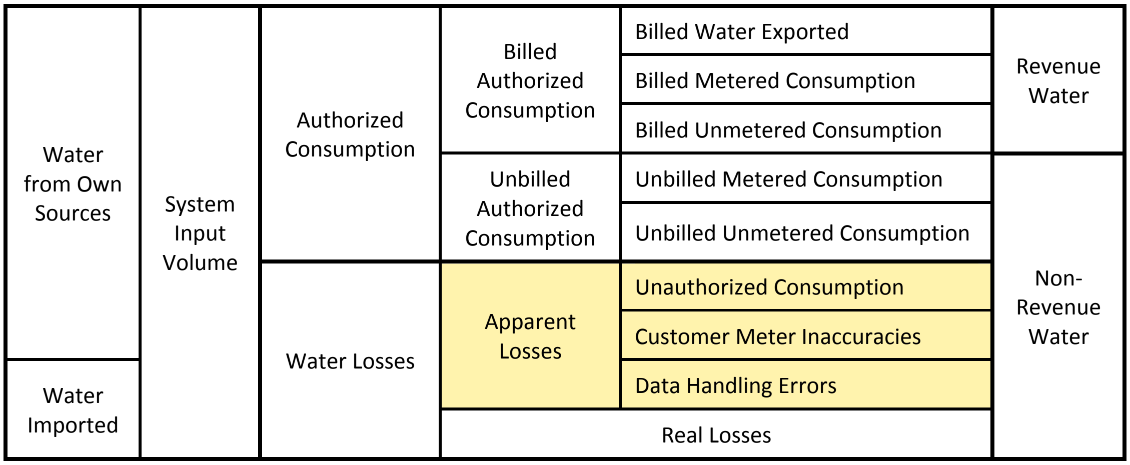
Next, the Water Losses are broken down into two components: Apparent Losses (detailed in Section 4) and Real Losses (detailed in Section 5). Following the top down approach, the Apparent Losses are identified and subtracted from the total Water Losses figure to finally arrive at the Real Losses. The following sections describe this process and the resulting findings.

SECTION 4. APPARENT LOSSES DETERMINATION

4.1 Apparent Losses Background

Apparent Losses include all types of inaccuracies associated with customer metering and consumption data handling, plus any form of Unauthorized Consumption (theft or illegal use). This section outlines the process behind determining the Apparent Loss volumes for LADWP in FY 2010-2011. Section 10 outlines the economic analysis of potential small meter replacement programs and a new large meter overhaul schedule, evaluating economically efficient options toward reducing apparent losses.

Figure 22 highlights in yellow the components of the Water Balance assessed and validated in this report. Note that the table is not formatted to scale (the size of each box is not proportional to its volume).



Water from Own Sources	System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Water Exported	Revenue Water
				Billed Metered Consumption	
				Billed Unmetered Consumption	
			Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water
				Unbilled Unmetered Consumption	
		Water Losses	Apparent Losses	Unauthorized Consumption	
				Customer Meter Inaccuracies	
Water Imported				Data Handling Errors	
			Real Losses		

Figure 22: IWA standardized components of Annual Water Balance – Apparent Losses highlighted

4.2 Meter Under-Registration

4.2.1 Small Meter Under-Registration

WSO analyzed meter test results provided by LADWP in order to calculate the overall accuracy of the small meter population. For the purpose of this analysis, small meters qualify as customer meters that are 2” or less in size. The following sections provide general information on the small meter population, the data provided by LADWP, and the analysis undertaken by WSO.

LADWP does not have a routine small meter testing program in place. Field investigations of meter accuracy are initiated by a series of billing anomalies, on a case-by-case basis. In order to apply meter test results for the whole small meter population, this program called for a meter testing on a random, representative sample of meters. To develop a list of small meters to be tested, customer meters were grouped by size and make: LADWP's Customer Information System (CIS) provided the relevant meter information. The number of meters tested in each size and make category was based on the proportion of consumption by each category during the audit period. Lastly, for each size and make category, the distribution of meter ages was taken into consideration. Upon establishing the number of meters for testing in each size-make-age category, the individual meters to be tested were randomly selected. Of the 1,247 meters included in the test requests, 1,073 (86%) were successfully tested. In most cases, the meters that were not tested were examined but too recently replaced to pull for testing.

It is important to note that the representativeness of the meter test population was reliant on the accuracy of the CIS information on meter make and size. The small meter tests showed that there was significant disparity between the actual meters' makes and sizes and those recorded in the billing database. Table 37 summarizes the findings of make and size errors in the billing database for the meters tested, and it extrapolates to estimate the potential error frequency for the whole meter population.

Table 37: Summary of CIS Meter Characteristic Information Errors

	TEST PROGRAM FINDINGS		**Estimated # Meters in whole CIS System**
	# of Meters within Testing Sample	**%**	
NUMBER OF TESTS REQUESTED	1247	100%	722,112
# Of METERS ALREADY CHANGED OR REPLACED - DIFFERENT AGE & METER NUMBER (NOT TESTED)	114	9%	63,834
# Of METERS DIFFERENT MAKE	48	4%	26,877
# Of METERS DIFFERENT SIZE	29	2%	16,238
TOTAL: CIS INFORMATION IS INCORRECT	191	15%	106,950

It is important that LADWP addresses the accuracy of its meter information database systems. To date, more reliable meter characteristic information is stored in the Work Management Information System (WMIS) database. However, consumption data is required for the apparent loss analysis, and it was impossible to link the two databases (see the Task 2 Consumption Analysis Technical Memo for detailed account of the database inconsistencies). Reliable meter testing programs depend on an accurate grouping of meter populations by size and make and determination of consumption according to those groups.

The following descriptions of the size and make composition of the meter population are derived from the CIS information. Though the meter tests revealed flaws in the billing database's accuracy of meter size and make information, it is the only readily accessible source for describing both the meter characteristics and consumption volumes for the whole meter population and will be used throughout this analysis.

Figure 23 presents the breakdown of small meters by size. LADWP's small meters represent 96.7% of the total meter population and registered approximately 78.3% of the total consumption during FY2010 – 2011.

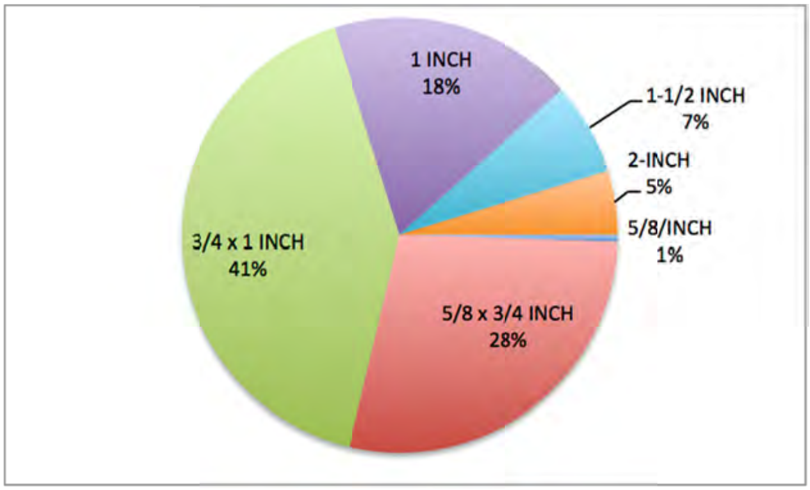


Figure 23: Breakdown of Small Meters by Size

Figure 24 presents the breakdown of meters by make. LADWP has a variety of customer meter makes including ABB, Badger, Hersey, Sensus, Trident, and others. It is important to note that the records of meter makes in CIS did not perfectly align with the provided small meter test results. First, a sizable number of tested meters were documented as Neptune meters (a meter manufacturer that also makes Trident meters); however, this make is not included in CIS. In assigning consumption volumes to each tested group by size and make, it is not possible to isolate the volume registered by Neptune meters during the audit period. As such, Neptune and Trident meter test results were combined for purposes of determining apparent loss volumes. Additionally, there were more test results submitted with meter makes that are not included in CIS. Meter makes "ROC" and "Master" are not documented in CIS: though the test results are reported here, these meter tests did not contribute to the determination of the apparent loss volume.

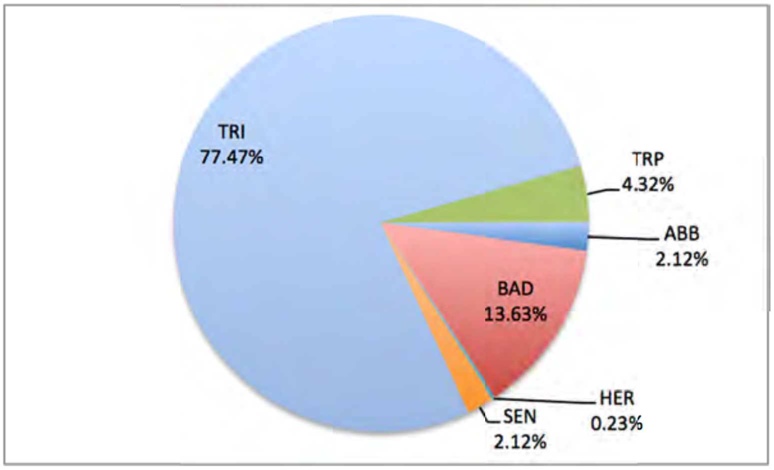


Figure 24: Breakdown of Small Meters by Make

4.2.1.1 Small Customer Meter Accuracy

4.2.1.1.1 Small Meter Testing Method

To assess meter accuracy for the small meter population, 1247 small meter tests were requested. The sample size tested for each meter size and make category was determined based on the ratio of total volume metered by a specific category to the total metered volume. For example, 3.69% of the small meter consumption is registered by two inch badger meters, so approximately 3.69% of the meter tests requested were two inch badger meters.

The AWWA Manual M36 describes a method for determining under-registration (“Sales Meter Error”). The method is based on testing meters at 3 different flow rates (a low flow, a medium flow, and a high flow) and then assigning weighting factors to the accuracy at each flow rate to determine an average accuracy. The weighting factors refer to the proportion of water consumed at the specific flow rate compared to the total volume consumed at all flow rates.

The weighting factors suggested by AWWA assume that a small meter registers 15% of the time at low flow, 70% at medium flows, and 15% at high flows. However, instead of directly using the time-based weighting factors to determine an average accuracy, these time ratios were used to determine volume-based weighting factors. In that way, the weighting factors used to determine an average accuracy are based on the proportion of volume measured by the meters at each flow rate.

For example, even though it is assumed a 5/8 inch meter operates 15% of its time at low flow ranges, it only records about 1% of the total volume recorded at the low flow range. Therefore, it is important to use the percentage of volume as a weighting factor, and not the percentage of time it spends at different flow ranges, to calculate the overall accuracy of a meter based on its accuracy at the three different flow rates.

Table 38 shows an example of the calculated volume distributions for a 5/8 x 3/4 inch meter. It is important to note here that the flow rates used in LADWP's meter tests are lower than average for the "Low" and "Medium" flow rates and higher than average for the "High" flow rate (resulting in different volume weighting factors than featured in the AWWA M36).

Table 38: Example Calculation of Weighting Factors for 5/8 x 3/4 inch Meters,
Determining Volume Percentages for Different Flow Rates
(adapted from AWWA M36 Table 2-7)

Percent of Time	Range		Average	LADWP Test Flow Rate	LADWP Percent of Volume
	(gpm)		(gpm)	(gpm)	
15%	Low	0.50 to 1	0.75	0.25	1.0%
70%	Medium	1 to 10	5.00	2.00	38.0%
15%	High	10 to 15	12.50	15.00	61.0%

For this water audit, the volume-based weighting factors used to determine under-registration for the small meters were obtained assuming the time distributions recommended by AWWA for each flow rate (see Table 38) and the actual test flow rates used by LADWP during the tests. Table 39 provides the test flow rates for the small meters by meter size and the resulting percentage of volume for each flow rate. In order to be able to use weighting factors that apply exactly to the actual consumption patterns found in LADWP it would be necessary to log residential consumption patterns for a sample big enough to be statistically representative. See Section 4.2.1.1.3 for an example of consumption profiling project in East Bay Municipal Utility District (EBMUD) that informed test result weighting factors.

Table 39: Small Meter Test Flow Rates and Resulting Weighting Factors

Meter Size	Meter Type	Low Flow Test		Medium Flow Test		High Flow Test	
		Flow Rate (gpm)	Volume Percentage	Flow Rate (gpm)	Volume Percentage	Flow Rate (gpm)	Volume Percentage
5/8"	Positive Displacement	0.25	1.0%	2	38.0%	15	61.0%
5/8 x 3/4"	Positive Displacement	0.25	1.0%	2	38.0%	15	61.0%
3/4 x 1"	Positive Displacement	0.25	0.6%	3	35.7%	25	63.7%
1"	Positive Displacement	0.75	1.3%	4	31.1%	40	67.3%
1 1/2"	Positive Displacement *	1.5	1.7%	8	42.0%	50	56.3%
2"	Positive Displacement *	2	1.2%	15	40.7%	100	58.1%

* A portion of the 1 1/2" and 2" meters are turbine meters, but since the meter testing documentation does not include meter type, the flow rates and volume percentages for positive displacement meters will be applied in all cases.

4.2.1.1.2 Small Meter Testing Results

Table 40 presents the calculated overall accuracy for each category (grouped by size and make) of small meters based on the meter test results. The average accuracy of the tested small meters ranges from 84.24% to 99.76%.

Table 40: Small Meter Test Results Summary by Meter Size and Make

METER SIZE	METER MAKE	METER POPULATION	TEST SAMPLE SIZE	VOLUME WEIGHTED AVERAGE ACCURACY (%)	C-LIMITS of UNDER-REGISTRATION (+/- %)
5/8”	ABB	49	0	NA	NA
	BAD	443	0	NA	NA
	SEN	277	0	NA	NA
	TRI	2,458	0	NA	NA
	TRP	402	0	NA	NA
5/8 x 3/4”	ABB	5,598	8	96.01	1.518
	BAD	48,904	38	99.60	0.355
	SEN	6,649	9	93.31	4.648
	TRI	130,090	104	96.56	1.568
	TRP	5,366	0	NA	NA
	ROC	NA	5	91.75	NA*
3/4 x 1”	ABB	4,436	8	96.96	2.375
	BAD	19,420	49	99.03	0.144
	SEN	3,802	11	94.29	4.371
	TRI	250,922	252	98.91	0.266
	TRP	9,893	0	NA	NA
	ROC	NA	5	95.88	NA*
	MASTER	NA	1	98.78	NA*
1”	ABB	3,509	6	97.14	3.286
	BAD	15,272	20	99.20	0.083
	SEN	2,408	23	95.23	3.150
	TRI	91,264	122	99.31	0.150
	TRP	13,881	0	NA	NA
	ROC	NA	15	95.05	NA*
1 1/2”	ABB	1,055	14	98.16	0.572
	BAD	6,124	15	99.76	0.293
	SEN	1,021	7	94.36	3.776
	TRI	39,383	119	97.71	1.143
	TRP	236	0	NA	NA
	ROC	NA	1	95.73	NA*
2”	ABB	181	1	98.81	NA**
	BAD	4,978	35	99.74	0.128
	SEN	640	8	95.91	3.545
	TRI	26,811	195	98.88	0.668
	TRP	400	0	NA	NA
	ROC	NA	2	84.24	NA*

*Meters in these size-make categories were tested but had different makes than their CIS records suggest, therefore, the confidence limit cannot be calculated. For the purposes of the water audit, a confidence limit of +/- 5% will be applied in these instances.

**Confidence limits cannot be calculated since only 1 meter in this group was tested. For purposes of the water audit, the 95% confidence limits are assumed to be +/- 5%

Table 41 summarizes the above results to present average accuracy by meter size. Appendix F includes charts of these meter test results further broken down by meter make.

Table 41: Summary of Small Meter Test Results by Meter Size

SIZE	TOTAL METER POPULATION (CIS)	TEST SAMPLE SIZE	VOLUME WEIGHTED AVERAGE ACCURACY (%)	C-LIMITS of UNDER-REGISTRATION (+/- %)
5/8”	3,636	0	NA	NA
5/8 x 3/4”	196,973	161	96.88	1.074
3/4 x 1”	289,343	322	98.72	0.275
1”	126,900	181	98.35	0.497
1 1/2”	47,953	156	97.93	0.897
2”	33,447	239	98.49	0.583
ALL SIZES	698,252	1059	98.21	0.277

The 3/4 x 1” meter population test results indicate that the majority of these meters are performing well. These results are especially notable because the 3/4 x 1” meters make up the majority of the small meter population. Within this size group, the Badger meters showed the highest levels of accuracy with 99.03% while the Sensus meter test results showed the most under-registration with an average accuracy of 94.29%.

None of the 5/8” meter tests requested were completed so average accuracies for this size group could not be assessed. The 5/8” meters compose less than 1% of the total meter population, so this will not significantly affect the apparent loss analysis.

4.2.1.1.3 Consumption Profiling for Improved Accuracy Determinations: EBMUD Example

Consumption trends particular to a utility’s consumer base are important factors in best analyzing meter accuracy test results. Logging and evaluating high-frequency consumption data allows for better test result weighting: volume recorded at each flow rate range is critical in calculating a volume-based accuracy weighting (as described in Section 4.2.1.1.1).

The East Bay Municipal Utility District (EBMUD) is currently working on a study on exactly this matter: flow rate data was logged at one-minute intervals for 117 meters over the course of 12 days. The total consumption registered at each flow range was tabulated for each studied meter, allowing for an understanding of what percentage of consumption occurs in each flow range. Table 42 shows the results of this study, outlining the percentage of consumption in three different flow ranges. It is important to note that this study is still in its very early stages. EBMUD plans to investigate additional seasonal demand patterns and plans to increase the testing sample size to achieve statistical significance.

Table 42: EBMUD Preliminary Study Results - Consumption Distribution by Flow Range

FLOW RATE RANGE	% of Volume Recorded EBMUD Sample
<=1 GPM (AWWA Low Flow Rate Range)	12.78%
1> GPM <=10 (AWWA Medium Flow Rate Range)	57.72%
>10 GPM (AWWA High Flow Rate Range)	29.50%

Comparing these results to the volume-based weighting outlined in Table 38 (which uses the AWWA recommended time distribution of 15% low flow, 70% medium flow, and 15% high flow), much more volume occurs at medium and low flow rates for EBMUD than the AWWA guidelines would suggest.

To demonstrate the impact of the volume weighting factors, EBMUD's results were applied to LADWP's test results. Table 43 shows how applying the preliminary EBMUD consumption flow range results increases the impact of the low and medium flow rate tests. For LADWP's small meter tests, this results in decreased average accuracy across all size groups. When applying the EBMUD based volume weighting factors to LADWP's small meter test results (instead of the AWWA based volume weighting factors), the average accuracy across all sizes is reduced by about 1.26%.

Table 43: Comparison of Average Accuracy Results Using Different Volume Weighting Factors

SIZE	VOLUME WEIGHTED AVERAGE ACCURACY (%)	
	using AWWA guidelines	using EBMUD study results
5/8"	NA	NA
5/8 x 3/4"	96.88	93.74
3/4 x 1"	98.72	97.42
1"	98.35	97.17
1 1/2"	97.93	97.70
2"	98.49	97.80
ALL SIZES	98.21	96.95

It is recommended that LADWP pursue a similar study, logging flow rate data at high frequency intervals to understand the distribution of consumption by flow rate. This will enhance the analysis of any further small meter testing, allowing the application of volume weighting factors that reflect LADWP's specific consumption trends.

4.2.1.1.4 Stuck Meters

In summarizing the accuracy determinations of the small meter tests, the values in Table 40 do not include the meters that were pulled for testing and determined totally defective, stuck at all flows. Incorporating any number of “0%” data points would significantly skew the accuracy averages so these test results were excluded. In this testing program, 14 meters were found to be completely stuck (out of a total of 1073 tests completed).

LADWP has measures in place to review readings where there is “Zero Use on Active” reported. Presumably upon fixing the meter, there are back-calculated adjustments in billing made to account for unregistered volume. In this way, all use is eventually billed and these stuck meters do not contribute to the overall apparent loss volume. To insure that stuck meters do not have significant impacts on proper consumption tracking and revenue generation, it is important the procedures and response protocols around the “Zero Use on Active” flags are consistently implemented.

4.2.1.1.5 Age and Volume Correlation for Small Meter Test Results

Two efforts were made to evaluate whether the test results provide any trends on how the meter population’s accuracy might degrade with use. Toward this end, the small meter test results were compared to meter age and lifetime registration.

For each size-make category, the meters requested for testing represented the group’s age distribution range (provided by the CIS records for installation date). Appendix I shows the results of the comparison between the small meter accuracy and meter age. Assessments for low flow, medium flow, and high flow test results are included. None of these analyses show significant correlation (all R-squared values are below 0.2): based on these comparisons, it does not appear that meter age is a determining factor in small meter accuracy for LADWP. These findings are in line with a recent WaterRF research study “Accuracy of In-Service Water Meters at Low and High Flow Rates” where no statistically significant correlation was found between meter accuracy degradation and age or total throughput.

However, for LADWP it would still be instructive to evaluate the set of small meter tests for correlation with lifetime registration/total throughput. For each meter tested, the accuracy results would be plotted against the register’s last reading. However, without record of the number of rollovers for each meter (when the meter’s register reaches its maximum read and starts over at zero), the lifetime registration cannot be calculated. To enable this kind of analysis, it is recommended to start documenting the number of rollovers for each meter.

4.2.1.1.6 AWWA Small Meter Accuracy Thresholds

The AWWA Manual M6[9] recommends minimum and maximum accuracy limits for meters by type, size, condition, and flow range. Table 44 outlines these accuracy limits for positive displacement meters between 5/8" and 2", defining the ranges for all LADWP meters tested.

Table 44: AWWA Recommended Accuracy Limits[1]

Meter Sizes	**Meter Type**	**Low Flow Accuracy Limits**		**Medium Flow Accuracy Limits**		**High Flow Accuracy Limits**	
		Min	**Max**	**Min**	**Max**	**Min**	**Max**
5/8" to 2"	Positive Displacement	95%	101%	98.5%	101.5%	98.5%	101.5%

[1] Reproduced from AWWA Manual M6 Table 5-3.
Values are for new or rebuilt meters.

The collection of accuracy results for the tested meters were then compared with these recommended limits to determine if the meters passed the recommendations, were below or exceeded these limits. Figure 25 presents the percentage of small meters tested that complied with these requirements at each tested flow rate. Further breakdown of these results by size are provided in Appendix J Overall, 60% of the small meters tested complied with the recommended accuracy limits at all flow rates, while 8% of the meters did not comply with the recommended accuracy limits at any flow rate.

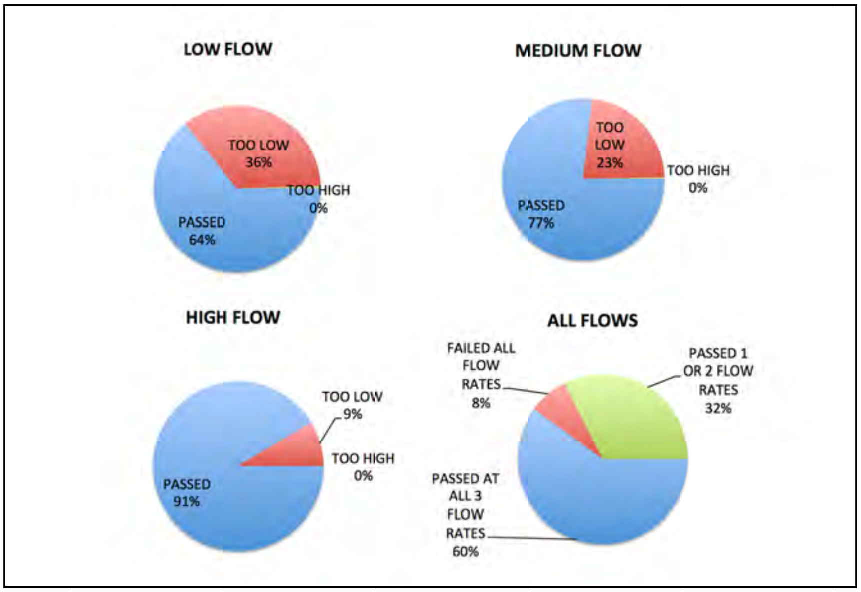


Figure 25: Compliance with AWWA Recommended Accuracy Limits – All Small Meter Sizes

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[9] Water Meters – Selection, Installation, Testing and Maintenance M6 American Water Works Association, Fourth Edition, 1999, ISBN 1-58321-017-2 page 54 table 5-3

4.2.1.1.7 Extra Low Flow Test Results

Small customer meters often encounter flows lower than the AWWA defined “low flow”. To evaluate how small meters perform at these “extra low flows”, WSO requested another test – at half the flow rate prescribed by the AWWA low flow - for each meter pulled for testing. For example, a 1 1/2” meter’s recommended low flow test flow rate is 0.25 gpm, so a 1 1/2” meter would be tested at 0.125 gpm for the extra-low flow test. Table 45 shows the flow rates for each extra low flow test by meter size. Since this request was made after the testing program began, fewer tests were submitted with extra low flow results. Table 46 shows the summary of these extra low flow tests, grouped by size.

Table 45: Extra Low Flow
Test Flow Rates

Meter Size	Extra Low Flow Rate (gpm)
5/8”	0.125
5/8 x 3/4”	0.125
3/4 x 1”	0.125
1”	0.375
1 1/2”	0.75
2”	1

Table 46: Average Accuracy Results for
Extra Low Flow Small Meter Tests

SIZE	Number of Tests at Extra Low Flow	AVG Accuracy at Extra Low Flow (%)	C-Limits of Under-Registration (+/- %)
5/8”	0	NA	NA
5/8 x 3/4”	81	58.94	8
3/4 x 1”	151	76.46	5
1”	64	51.64	10
1 1/2”	1	98.00	NA
2”	2	97.00	NA
TOTAL	299	66.51	4

The wide confidence limits here can be attributed to a relatively small number of tests for each size group. Nonetheless, these results show that meter performance decreases when tested at extra low flows.

These results are particularly important in light of LADWP's future new meter program: all new services will have a 1" meter installed, discontinuing the 5/8" and 5/8 x 3/4" size options previously considered. The specifications for a new 1" Badger positive displacement meter detail that the meter operates within 98.5% to 101.5% accuracy from 1 gpm to 55 gpm[10]. Below this provided range, the accuracy begins dropping off. The extra low flow tests confirmed this: 1" meters were tested at 0.125 gpm and showed an average accuracy of 51.64%.

More detailed understanding of consumption profiles for average LADWP customers is necessary to make any conclusions about the relevance of these extra low flow test results. However – especially in installing 1" meters for all services from now on – it is important to further study the percentage of consumption at extra low flow and meter accuracy at extra low flow.

4.2.1.2 Apparent Loss Volume Determination

Based on the small meter test results, the apparent losses due to under-registration for the small meter population can be calculated (see the equation in Figure 26).

$$\text{Apparent Losses} = \frac{V}{(1-R)} - V$$

where V is the volume registered by the meter

R is the under-registration as a decimal value

Figure 26: Calculation of Apparent Loss Volume

Table 47 shows the apparent loss volume, as calculated for each size-make category. The size-make categories that have test results without any records in CIS are not included in this analysis. Without consumption totals for the audit period, it is impossible to calculate the under-registration for these meters. Table 47 also highlights the size-make categories of small meters that show billed volume during the audit period but were not tested. The average under-registration for the tested small meters of the same size was used in these instances (and are highlighted in yellow where applied).

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[10] Technical Brief for the Badger Recordall Cold Water Bronze Disc Meter; Size 1".

Table 47: Apparent Losses from Small Meter Population

SIZE	MAKE	% OF TOTAL CONSUMP-TION	BMAC FY10/11 ACROSS ALL RATES	AVERAGE UNDER-REGISTRATION	C-LIMITS OF UNDER-REGISTRATION	TOTAL APP LOSSES FOR SIZE/MAKE GROUP	% of TOTAL APP LOSSES
		%	HCF	(%)	(+/- %)	HCF	%
5/8”	ABB	0.00%	7,208.00	3.12%	NA	232.13	0.01%
	BAD	0.05%	78,937.00	3.12%	NA	2,542.15	0.10%
	HER	0.00%	88.00	3.12%	NA	2.83	0.00%
	SEN	0.02%	31,775.00	3.12%	NA	1,023.31	0.04%
	TRI	0.19%	329,844.00	3.12%	NA	10,622.58	0.40%
	TRP	0.03%	48,544.00	3.12%	NA	1,563.35	0.06%
	UNK	0.00%	866.00	3.12%	NA	27.89	0.00%
5/8 x 3/4”	ABB	0.44%	767,682.00	3.99%	1.52%	31,895.70	1.20%
	BAD	3.84%	6,686,109.00	0.40%	0.35%	26,623.46	1.00%
	CAL	0.00%	614.00	3.12%	NA	19.77	0.00%
	EMP	0.00%	3,174.00	3.12%	NA	102.22	0.00%
	HER	0.01%	16,732.00	3.12%	NA	538.85	0.02%
	SEN	0.46%	807,528.00	6.69%	4.65%	57,862.17	2.17%
	TRI	10.26%	17,874,963.00	3.44%	1.57%	636,180.33	23.89%
	TRP	0.36%	629,028.00	3.12%	NA	20,257.76	0.76%
	UNK	0.01%	11,884.00	3.12%	NA	382.72	0.01%
	WOR	0.01%	17,142.00	3.12%	NA	552.06	0.02%
3/4 x 1”	ABB	0.44%	768,851.00	3.04%	2.38%	24,083.49	0.90%
	BAD	2.21%	3,845,460.00	0.97%	0.14%	37,822.87	1.42%
	CAL	0.00%	3,963.00	1.28%	NA	51.49	0.00%
	EMP	0.00%	1,809.00	1.28%	NA	23.50	0.00%
	HER	0.07%	115,268.00	1.28%	NA	1,497.63	0.06%
	SEN	0.34%	586,251.00	5.71%	4.37%	35,506.80	1.33%
	TRI	24.78%	43,180,389.00	1.09%	0.27%	474,513.56	17.82%
	TRP	0.80%	1,398,931.00	1.28%	NA	18,175.74	0.68%
	UNK	0.01%	13,803.00	1.28%	NA	179.34	0.01%
	WOR	0.01%	18,523.00	1.28%	NA	240.66	0.01%
1”	ABB	0.44%	771,030.00	2.86%	3.29%	22,716.59	0.85%
	BAD	1.70%	2,961,186.00	0.80%	0.08%	24,027.83	0.90%
	CAL	0.00%	641.00	1.65%	NA	10.77	0.00%
	EMP	0.00%	880.00	1.65%	NA	14.78	0.00%
	HER	0.04%	71,848.00	1.65%	NA	1,207.00	0.05%
	SEN	0.29%	502,627.00	4.77%	3.15%	25,155.38	0.94%
	TRI	12.10%	21,073,681.00	0.69%	0.15%	145,746.13	5.47%
	TRP	1.67%	2,918,248.00	1.65%	NA	49,024.86	1.84%
	UNK	0.01%	25,072.00	1.65%	NA	421.19	0.02%
	WOR	0.01%	10,703.00	1.65%	NA	179.80	0.01%

1 1/2”	ABB	0.31%	539,721.00	1.84%	0.57%	10,090.69	0.38%
	BAD	1.58%	2,759,895.00	0.24%	0.29%	6,602.22	0.25%
	CAL	0.00%	2,282.00	2.07%	NA	48.29	0.00%
	EMP	0.00%	570.00	2.07%	NA	12.06	0.00%
	HER	0.02%	40,757.00	2.07%	NA	862.41	0.03%
	SEN	0.27%	475,045.00	5.64%	3.78%	28,399.91	1.07%
	TRI	12.36%	21,540,222.00	2.29%	1.14%	504,897.55	18.96%
	TRP	0.06%	102,883.00	2.07%	NA	2,176.99	0.08%
	UNK	0.01%	23,526.00	2.07%	NA	497.81	0.02%
	WOR	0.01%	9,247.00	2.07%	NA	195.66	0.01%
2”	ABB	0.14%	237,223.00	1.19%	NA	2,847.35	0.11%
	BAD	3.69%	6,430,519.00	0.26%	0.13%	16,954.02	0.64%
	EMP	0.00%	148.00	1.51%	NA	2.28	0.00%
	HER	0.09%	151,412.00	1.51%	NA	2,328.27	0.09%
	SEN	0.42%	728,186.00	4.09%	3.54%	31,053.79	1.17%
	TRI	20.14%	35,093,430.00	1.12%	0.67%	396,657.81	14.90%
	TRP	0.26%	453,146.00	1.51%	NA	6,968.06	0.26%
	UNK	0.02%	42,779.00	1.51%	NA	657.82	0.02%
	WOR	0.01%	22,337.00	1.51%	NA	343.48	0.01%
TOTAL (HCF)			174,234,610.00			2,662,625.19	
TOTAL (MG)			130,327.49			1,991.64	
*All of the under-registration values highlighted in yellow are the average under-registration values for the size group. In these cases, no samples of the size-make category were tested, so the averages are applied for apparent loss determination.							

Across each small meter size, the Trident meter make group contributes the most to the total apparent loss volume for the audit period. This is because the Trident meter make group registers a high proportion of the annual consumption volume: the sheer volume passed through these meters leads to relatively high apparent loss volumes. The 5/8 x 3/4” Trident group is the single largest contributor, responsible for 23.89% of the total apparent losses. This is especially noteworthy because this group both registers a significant proportion of annual volume (10.29% of the audit period’s total) and its test results showed a relatively high level of under-registration (3.44%).

Other size-make groups with significant apparent loss volumes include the 5/8 x 3/4” ABB and Sensus meters, the 3/4 x 1” Sensus meters, the 1 1/2” Trident meters, and the 2” Sensus meters. All of these size-make groups both significantly contribute to the apparent loss volume and have test results that suggest room for improvement in accuracy.

Some of worst performing meter tests results are not included in the calculation of apparent losses. For example, the 1” ROC and 2” ROC meter tests showed 95.05% and 84.24% accuracy, respectively (see Table 40). However, without record of any meters of these sizes and makes in CIS, the audit period consumption and resulting apparent losses cannot be calculated. In this way, the apparent loss total will not incorporate all of the small meter test results. In order to increase the accuracy of the apparent loss calculation, it is recommended to improve the reliability and completeness of the meter characteristic information in CIS.

4.2.2 Large Meter Under-Registration

Despite their relatively small number, a poorly managed population of large meters could have a significant impact on the level of apparent losses and revenue generation efficiency for LADWP. Though the number of large meters (3” and larger) accounts for only 3.3% of the total customer meter stock, they register 21.67% of the total audit period’s consumption.

The large meter population is reviewed in depth in the “Review of Large Meter Maintenance Program and Strategy” technical memo. This review includes a full assessment of the large meter overhaul schedule, including recommendations on how to optimize large meter accuracy and contain apparent losses to an economically efficient level.

For the purposes of calculating an apparent loss volume for the large meter population during the audit period, an estimated accuracy of 99% was applied to all large meters. Given that LADWP has a large meter testing/replacement program in place and considering the overall good performance of the small meter population, it is reasonable to assume that the large meter population is operating at a relatively high level of accuracy overall. To calculate the under-registration volume, a 1% under-registration assumption was applied to all of the large meter registration for the audit period (see Figure 26).

Upon implementing the large meter test schedule provided in the “Review of Large Meter Maintenance Program and Strategy” technical memo, it is recommended that LADWP begin compiling a database of large meter test results for better calculation of apparent loss volume.

For FY 2010-2011 large meters registered a total of 48,221,246 HCF (36,069.49 MG), which results in a calculated apparent loss total of 487,083.29 HCF (364.34 MG).

4.2.3 Customer Meter Under-Registration Summary

Table 48 summarizes the total apparent loss volume from customer meter under-registration for FY 2010-2011.

Table 48: Summary of Apparent Losses due
to Customer Meter Under-Registration

METER SIZE		TOTAL APPARENT LOSSES for FY 2010 - 2011	
		(MG)	**(AF)**
SMALL METER TOTAL:		**1,991.60**	**6,112.00**
	5/8”	11.98	36.76
	5/8 x 3/4”	579.26	1,777.69
	3/4 x 1”	442.89	1,359.17
	1”	200.84	616.36
	1 1/2”	414.23	1,271.23
	2”	342.40	1,050.79
LARGE METER TOTAL:		**364.34**	**1,118.12**
GRAND TOTAL:		**2,355.94**	**7,230.12**

4.3 Unauthorized Consumption

In water distribution systems, unauthorized consumption may occur through:

- misuse of fire hydrants and fire fighting systems in unmetered fire lines
- buried, vandalized, or bypassed consumption meters
- illegal connections

In most cases, the unauthorized consumption is not measured and the utility may not have sufficient data to make reasonable estimates of this volume. LADWP staff anecdotally described rates of hydrant misuse and theft off fire connections as quite high (though no specific volumes could be provided). Without volume estimations, the AWWA recommends assuming a default value of 0.25% of the water supplied as the volume of unauthorized consumption[11].

For the FY 2010-2011 water audit for LADWP, the estimated unauthorized consumption volume is then 439.06 MG. A conservative confidence limit of +/- 20% was assigned to this volume due to its estimated derivation.

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[11] AWWA M36 manual.

4.4 Data Handling Errors

WSO reviewed the billing system and customer bill generation process to determine areas for introduction of data handling errors. The details of this review are outlined in a separate technical memo (the “Meter Reading and Bill Generation Technical Memo”).

Though areas for improvement were identified, it is not possible to estimate a volume associated with data handling errors at this point. No volume was allocated to this category.

4.5 Assessment of 95% Confidence Limits Related to Apparent Losses

Table 49 summarizes the total Apparent Loss volumes for the audit period. For each component, the following information is given: the total volume for the audit period, the 95% confidence limit, the error range volume, and the variance value. The variance is a calculated and dimensionless value based on the 95% confidence limit and the recorded volume for each component (see Section 1.10 for details)

For the Unauthorized Consumption volume, a 95% confidence limit of +/- 20.00% is assigned because it is purely an estimated value.

For the small customer meter under-registration, the 95% confidence limit of 0.39% was calculated according to the aggregate 95% confidence calculation guidelines as outlined in Appendix A For each size-make group of meters tested, a 95% confidence limit was derived based on representativeness and variance within the tested sample. These size-make group test results informed the total small customer meter under-registration 95% confidence limit.

For the large customer meter under-registration, a 95% confidence limit of 5.00% was assigned. An estimated accuracy of 99% was applied to all large meters for the calculation of the large meter under-registration volume. It is reasonable to assume that the large meter population is operating at this relatively high level of accuracy (considering the overall good performance of the small meter population). However, no large meter testing was conducted for this analysis so there remains a significant level of uncertainty around the large meter under-registration volume. Without specific test results, a conservative confidence limit of +/- 5.00% was applied.

The total Apparent Losses volume for LADWP during the audit period was 2,795.04 MG +/- 3.22%. The total Apparent Losses volume’s 95% confidence limit was calculated according to the 95% confidence calculation guidelines as outlined in Appendix A. This calculation of an aggregate confidence limit takes into consideration the variance related to each of its components. It is important to note that aggregate 95% confidence limits are *not sums*.

4.6 Summary of Apparent Loss Volumes

Table 49 shows the final apparent loss volumes for FY 2010-2011.

Table 49: Summary of Apparent Loss Volumes

APPARENT LOSSES COMPONENT	FY 2010-2011 VOLUME		95% CONFIDENCE LIMITS	ERROR VOLUME		VARIANCE
	(MG)	(AF)		(+/- MG)	(+/- AF)	
UNAUTHORIZED CONSUMPTION	**439.06**	**1,347.43**	**20.00%**	**87.81**	**269.49**	**2,007.22**
METER DATA HANDLING ERROR	**0.00**	**0.00**	NA	NA	NA	NA
CUSTOMER METER UNDER-REGISTRATION SUBTOTAL	**2,355.98**	**7,230.24**	**0.84%**	**19.79**	**60.73**	**101.84**
Small Customer Meter Under-Registration	1,991.64	6,112.12	0.39%	7.77	23.84	15.45
Large Customer Meter Under-Registration	364.34	1,118.12	5.00%	18.22	55.91	86.39
TOTAL APPARENT LOSSES	**2,795.04**	**8,577.67**	**3.22%**	**90.00**	**272.20**	**2,109.06**

4.7 Apparent Loss Volume Determination Recommendations

- LADWP should continue regular testing of random small meter samples. Regular testing will allow tracking of the average accuracy of each size/make groups of meters. With this type of monitoring, LADWP will be able to initiate meter replacement when a certain meter make/size group reaches the threshold where meter replacement becomes an economically viable option.

- The small meter test effort for this analysis revealed inconsistencies in actual meter characteristics and CIS meter records. Improving the data quality on the size, make, and age of meters in the billing database is critical to any meter maintenance program going forward. As this analysis shows, grouping accuracy test results by meter make and size and aligning these tests with the groups' annual consumption volumes allows for calculating detailed apparent loss volumes prioritizing subsets of meters.

- To best apply small meter test results, it is recommended to pursue consumption profiling research specific to LADWP's customer base. Volume weighting factors can have significant impact in determining average meter accuracies, influencing all subsequent calculations of apparent losses and economic evaluations of replacement. This is especially important given that moving forward any new residential meter will be a 1 inch meter, which could result in significant revenue losses due to unregistered consumption at low flow.

SECTION 5. REAL LOSSES – WATER BALANCE DETERMINATION

Real Losses are the physical water lost from the distribution system. It is the annual volume of water lost through all types of leaks, breaks, and overflows. The Real Loss volume depends on break frequencies, flow rates, and the duration of individual failures. The Real Losses for a given year's audit period are referred to as the Current Annual Real Losses (CARL).

In the Water Balance, the volume of Real Losses (or CARL) is determined by deducting the total Apparent Loss volume (see Section 4) from the total Water Losses volume (see Section 3). Table 50 outlines the calculation of Real Losses for FY 2010 – 2011.

The total Real Losses volume's 95% confidence limit was calculated according to the 95% confidence calculation guidelines as outlined in Appendix A. This calculation of an aggregate confidence limit takes into consideration the variance related to each of its components. It is important to note that aggregate 95% confidence limits are *not sums*.

Table 50: Calculation of Real Losses for FY 2010 - 2011

REAL LOSSES CALCULATION	**FY 2010-2011 VOLUME**		**95% CONFIDENCE LIMITS**	**ERROR VOLUME**		**VARIANCE**
	(MG)	**(AF)**		**(+/- MG)**	**(+/- AF)**	
Water Losses (C) – see Section 3	8,913.22	27,353.67	77.64%	6,920.22	21,237.39	12,467,019.42
Apparent Losses (D) – see Section 4	2,795.04	8,577.67	3.22%	90.00	276.20	2,109.06
Real Losses ((C) - (D))	**6,118.18**	**18,776.00**	**113.12%**	**6,920.89**	**21,239.41**	**12,469,128.48**

The 95% confidence limit related to the Real Loss volume is wide. This is explained by the fact that the Real Loss volume is very small compared to the System Input Volume and total Billed Authorized Consumption and their related variances. Hence, the variance related to Real Losses is large compared to the actual Real Loss volume resulting in a wide confidence limit.

This is a widely accepted phenomenon: in a water loss management manual written for Australian utilities, it is warned that even "for well managed systems with low leakage and reliable metering of inputs and consumption, it is very difficult to achieve 95% confidence limits of less than +/- 15% for the Real Losses volume calculated from a 'top-down' water balance."[12] Given that there still remain sizable uncertainties regarding the System Input Volume and that LADWP does not currently have complete and 'reliable metering of inputs', it is expected that the 95% confidence limit calculated for the Real Loss volume is especially wide.

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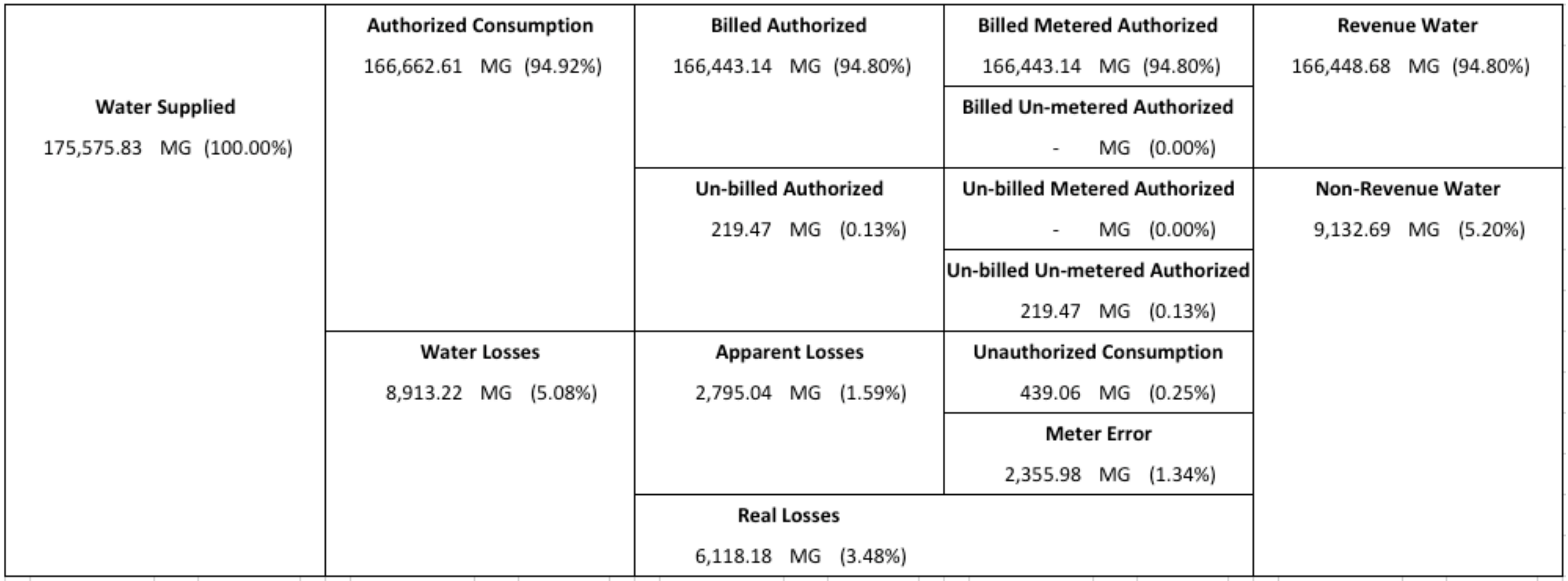
[12] Lambert, A.O & Fantozzi M. "Recent Advances in Calculating Economic Intervention Frequency for Active Leakage Control, and Implications for Calculation of Economic Leakage Levels", July 2005.

SECTION 6. WATER BALANCE FOR FY 2010 – 2011

6.1 Water Balance Summaries

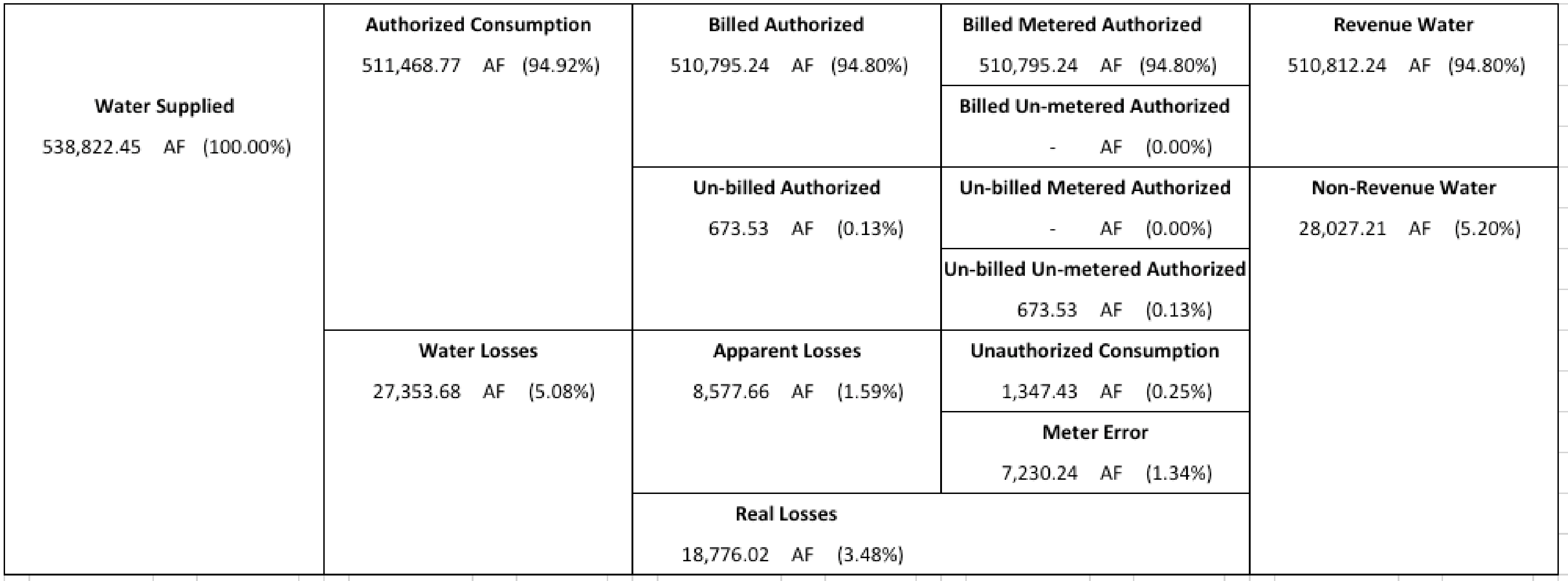
The calculation of Real Losses using the AWWA standardized water balance is effectively an accounting exercise that subtracts the measured or estimated volume of all known uses of water from the measured or estimated volume of water entering the system. The difference is the amount of water that is physically lost from the system.

In the preceding sections all components of the Water Balance were assessed and validated. The results of the Water Balance are presented in Figure 27 (in MG) and Figure 28 (in AF).



Water Supplied 175,575.83 MG (100.00%)	**Authorized Consumption** 166,662.61 MG (94.92%)	**Billed Authorized** 166,443.14 MG (94.80%)	**Billed Metered Authorized** 166,443.14 MG (94.80%)	**Revenue Water** 166,448.68 MG (94.80%)
			Billed Un-metered Authorized - MG (0.00%)	
		Un-billed Authorized 219.47 MG (0.13%)	**Un-billed Metered Authorized** - MG (0.00%)	**Non-Revenue Water** 9,132.69 MG (5.20%)
			Un-billed Un-metered Authorized 219.47 MG (0.13%)	
	Water Losses 8,913.22 MG (5.08%)	**Apparent Losses** 2,795.04 MG (1.59%)	**Unauthorized Consumption** 439.06 MG (0.25%)	
			Meter Error 2,355.98 MG (1.34%)	
		Real Losses 6,118.18 MG (3.48%)		

Figure 27: FY 2010 – 2011 Water Balance Summary in Millions of Gallons



Water Supplied 538,822.45 AF (100.00%)	**Authorized Consumption** 511,468.77 AF (94.92%)	**Billed Authorized** 510,795.24 AF (94.80%)	**Billed Metered Authorized** 510,795.24 AF (94.80%)	**Revenue Water** 510,812.24 AF (94.80%)
			Billed Un-metered Authorized - AF (0.00%)	
		Un-billed Authorized 673.53 AF (0.13%)	**Un-billed Metered Authorized** - AF (0.00%)	**Non-Revenue Water** 28,027.21 AF (5.20%)
			Un-billed Un-metered Authorized 673.53 AF (0.13%)	
	Water Losses 27,353.68 AF (5.08%)	**Apparent Losses** 8,577.66 AF (1.59%)	**Unauthorized Consumption** 1,347.43 AF (0.25%)	
			Meter Error 7,230.24 AF (1.34%)	
		Real Losses 18,776.02 AF (3.48%)		

Figure 28: FY 2010 – 2011 Water Balance Summary in Acre-Feet

Table 51 summarizes all of the volumes in the Water Balance and associated 95% confidence limits, error volumes, and variance values.

Table 51: Summary of Water Balance Volumes and Related Confidence Limits

	FY 2010-2011 Volume		**95% Confidence Limits**	**ERROR VOLUME**		**Variance**
	(MG)	**(AF)**		**(+/- MG)**	**(+/- AF)**	
WATER SUPPLIED	**175,575.83**	**538,822.44**	**3.85%**	**6,762.84**	**20,754.40**	**11,905,245.73**
Billed Metered Authorized Consumption	166,443.14	510,795.24	0.89%	1,481.34	4,546.08	571,214.09
Billed Un-metered Authorized Consumption	-	-	0.00%	-	-	-
BILLED AUTHORIZED CONSUMPTION	**166,443.14**	**510,795.24**	**0.89%**	**1,481.34**	**4,546.08**	**571,214.09**
Un-billed Metered Authorized Consumption	-	-	0.00%	-	-	-
Un-billed Un-metered Authorized Consumption	219.47	673.53	20.00%	43.89	134.71	501.53
UN-BILLED AUTHORIZED CONSUMPTION	**219.47**	**673.53**	**20.00%**	**43.89**	**134.71**	**501.53**
AUTHORIZED CONSUMPTION	**166,662.61**	**511,468.77**	**0.89%**	**1,483.30**	**4,552.07**	**571,715.62**
WATER LOSSES	**8,913.22**	**27,353.67**	**77.67%**	**6,920.22**	**21,237.39**	**12,467,019.42**
Unauthorized Consumption	439.06	1,347.42	20.00%	87.81	269.49	2,007.22
Meter Error	2,355.98	7,230.24	0.84%	19.79	60.73	101.84
APPARENT LOSSES	**2,795.04**	**8,577.66**	**3.22%**	90.00	276.20	**2,109.06**
REAL LOSSES	**6,118.18**	**18,776.00**	**113.12%**	**6,920.89**	**21,239.41**	**12,469,128.48**

6.2 Data Validation Scores for the AWWA Free Water Audit Software

AWWA provides a free worksheet – the "Free Water Audit Software" – that compiles each component of the water balance and generates performance indicators. Submission of the AWWA Free Water Audit Software's reporting worksheet is one of the main components of the CUWCC's BMP 1.2. Figure 107 and Figure 108 in Appendix K show the reporting worksheets for LADWP's FY 2010-2011 audit year in units of MG and AF, respectively.

The AWWA Free Water Audit Software also calls for a data validation score for each volume component entered. The sheet titled "Grading Matrix" outlines exactly how to determine the data validation score for each volume, given its level of validation and accuracy. Table 52 summarizes the data validation scores selected for the FY 2010-2011 audit period.

Table 52: AWWA Free Water Audit Software
Data Validation Scores for FY 2010 – 2011

Water Balance Component	**Data Validation Score**
Volume from Own Sources	5
Water Imported	10
Water Exported	5
Billed Metered	9
Billed Unmetered	n/a
Unbilled Metered	n/a
Unbilled Unmetered	2
Unauthorized Consumption	2
Customer Metering Inaccuracies	6
Systematic Data Handling Errors	5
Length of Mains	10
Number of Active and Inactive Service Connections	7
Average Length of Customer Service Line	10
Average Operating Pressure	5
Total Annual Cost of Operating Water System	10
Customer Retail Unit Cost	9
Variable Production Cost	10

SECTION 7. PERFORMANCE INDICATORS

With a complete AWWA Water Balance, it is possible to calculate a variety of performance indicators that further describe the total volumes of real and apparent losses.

The calculated values for operational Performance Indicators (PI) for the LADWP system for FY 2010-2011 are summarized in Table 53 and described below. All of the indicators suggest that LADWP's distribution system does not have significant volumes of real losses. Each of the following indicators reflects a well-performing system in California. However, it is important to take the data quality concerns noted throughout this process into serious consideration before such good performance is regarded as final and accurate.

Table 53: Performance Indicator Summary for FY 2010-2011

Performance Indicator	**Values**
Non-Revenue Water as % of System Input Volume	5.2%
Apparent Losses (gallons/connection/day)	10.60
Real Losses (gal/connection/day)	23.21
Infrastructure Leakage Index	1.26

***Non-Revenue Water as a % of System Input Volume** – This is a financial performance indicator (not an operational performance indicator).*

***Apparent Losses (gallons per service connection per year)* —** This performance indicator is useful for comparing losses against average annual consumption per customer. It can also be used to provide a quick estimate on the value of Apparent Losses when multiplied by an average sales cost for water.

***Real Losses (gallons per service connection per day)* —** This is the preferred basic operational performance indicator for analyzing leakage management performance and one of the most reliable when there are more than 30 services connections per mile, as is the case with the LADWP system.

***Infrastructure Leakage Index (ILI)* —** The ILI is calculated by comparing the annual volume of Real Losses against an internationally derived standard related to the lowest Real Losses that can be technically achieved for that water system. The methodology takes into account all the factors affecting Real Losses.

SECTION 8. COMPONENT ANALYSIS OF REAL LOSSES

8.1 Background on the Break and Background Estimate (BABE) Component Analysis

Real Losses were calculated using two different methodologies:

- The AWWA Water Balance methodology; and
- The Break and Background Estimate (BABE) component analysis methodology.

By comparing the results of the two methodologies it is possible to estimate the volume of Hidden Losses (losses from leaks running undetected in the distribution system).

The first methodology – using the AWWA Water Balance – estimates the total annual volume of Real Losses to be 6,118.18 MG (or 18,776.00 AF) during the audit period. This is equivalent to a system wide average of 23 gallons per service connection per day. Section 5 outlines the details of this Real Loss determination.

The second approach to determining Real Losses was developed during the UK National Leakage Initiative between 1991 and 1993. This concept recognizes that the annual volume of Real Losses consists of numerous leakage events, where each individual loss volume is influenced by flow rate and duration of leak run time before it is repaired. The BABE component based leakage analysis breaks leakage down into three categories:

- **Reported Breaks:** high flow rate, relatively short duration
- **Unreported Breaks:** moderate flow rates, the run time depends on the intervention policy
- **Background Leakage** (undetectable): small flow rate, continuously running

The length of time for which a break/leak runs is divided, using the BABE concepts, into three separate time components: awareness, location, and repair. The duration of each is separately estimated and modeled, as summarized below.

- Awareness Duration - the length of time taken from a leak first occurring – whether it is reported or unreported - to the time when LADWP first becomes aware that a leak exists, although not necessarily aware of its exact location. For reported leaks and breaks, this duration is usually very short, while for unreported leaks and breaks, it is a function of the active leakage control policy.
- Location Duration - for reported leaks and breaks, this is the time it takes for the water service organization to investigate the report of a leak or break and to correctly locate its position so that a repair can be initiated. For unreported leaks and breaks, the location duration is zero since the leak or break is detected during the leak detection survey and awareness and location occur simultaneously.

- Repair Duration - the time it takes to make the repair once a leak has been located. By knowing the number of reported and unreported breaks, their average leak flow rate and their awareness, location and repair time it is possible to calculate the volume of water lost due to those leaks. Further background on the BABE concept is provided in Appendix L.

The following sections outline each element of the BABE Component Analysis.

8.2 Reported Breaks

8.2.1 Reported Breaks: Data Sources

As one of the main data collection efforts for the component analysis of real losses, records for all infrastructure failures during the audit period were requested. Failures on service connections, mains, and mains appurtenances are required for a complete component analysis of real losses. This proved to be an especially effort intensive task given LADWP's current tracking system for Reported Leaks.

To capture all the failures in the system for the audit period, three different groups of leak events – each differentiated by data compilation processes – were considered. Figure 29 shows the location of each of the different leak types in relation to the main and the curb. The following sections describe how the reported leak data was compiled for each type of leak.

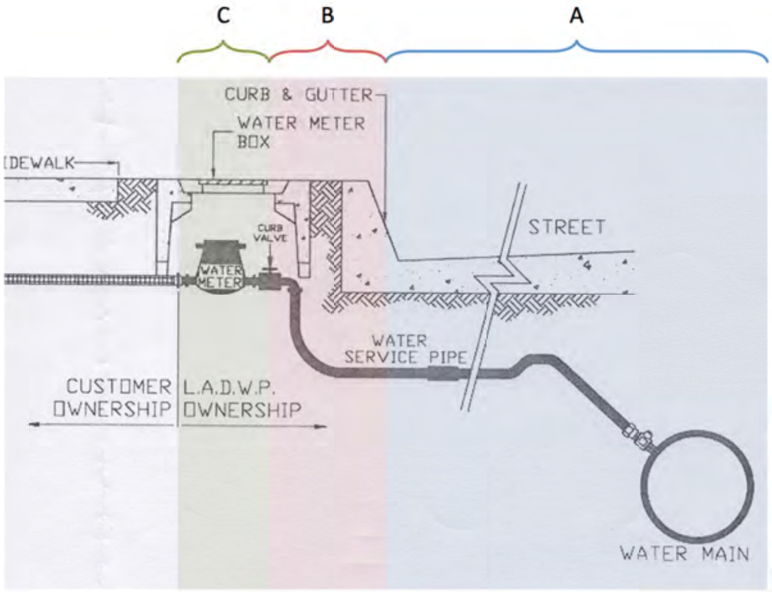


Figure 29: Three service leak locations with different data collection routines

8.2.1.1 Main Breaks and Service Leaks between the Main and the Curb

The first data collection effort involves main leaks and service leaks found within portion "A" as noted on Figure 29. This section spans from the main to the curb. For all leaks that occur in this area, after confirmation of the leak and its subsequent repair, a Leak Report is filed in LADWP's GIS system. The Leak Report contains information on the leak characteristics, including pipe size, pipe material, and type of leak.

The Leak Reports do not capture the run time of the leaks. To include this information, Trouble Board records must be referenced. The Trouble Board stores data on timestamps relevant to the reported leaks: for each leak, it has a time of awareness, "ORDER_DATE_RCV", and a time when the leak repair was complete, "ORDER_CMP_TS". Using these two timestamps, a run time for each leak can be calculated.

To connect the leak characteristics and the run time information for each leak reported during the audit period, the GIS Leak Report database must be merged with the Trouble Board information by manually connecting records with the same time and location information.

Section 8.2.3.1 and Section 8.2.3.2 summarize how this data was used for the determination of failures for FY 2010-2011.

8.2.1.2 Service Leaks between the Curb and the Meter Box

The second data collection effort produces service leaks found within portion "B" as noted on Figure 29. This section spans from the curb to the meter box. For all leaks that occur in this area, GIS Leak Reports are *not* filed. Instead, documentation of work completed can be found in the Construction Productivity System (CPS). Searching this database for leak references produces an inventory of leaks in the area between the curb and the meter box.

The records from CPS also need to be cross-referenced with the Trouble Board information (by shared location and date) in order to include timestamp information and calculate an estimation of leak run time.

Section 8.2.3.1 and Section 8.2.3.2 summarize how this data was used for the determination of failures for FY 2010-2011.

8.2.1.3 Meter Leaks and Flooded Meter Boxes

The third group of service leaks is found within portion "C" as noted on Figure 29. This section covers leaks in the meter box. Upon encountering a flooded meter box, a meter reader will request a Water Investigation Report (WIR). Each day the meter shop receives an inventory of meters with these WIR requests. In most cases, the flooded meter boxes are not a result of an actual leak. However, the meter shop representative investigating the case does not document any confirmation of a leak. Instead, repairs are simply completed as necessary. The only cases of documented and archived work in these instances involve a full meter replacement, in which case the meter number will be updated in the Work Management Information System (WMIS).

Section 8.2.3.3 outlines the meter leak and flooded meter box data for FY 2010 – 2011.

8.2.2 Leak Repair Data Completeness Review

It is important to note that the leak repair data presented notable challenges in collection and analysis. The majority of leak repair data submitted characterizes reported leaks from the main to the curb (the group described in Section 8.2.1.1 including both mains and service connection failures). For this set of FY 2010 -2011 leak repair data, a significant percentage of leak repair data for main leaks is missing various leak data relevant information. For example about 24% of reported and repaired main leaks had missing information on start or end date of the work order. Further details on completeness of main repair data is provided in Table 54.

Table 54: Main Leaks Data Quality

Total Number of Reported Main Leaks	**1194**	
Leak Repair Data Quality Stats	**Count**	**Percentage**
Reports with missing start or end date or both	289	24%
Reports with missing size information	19	2%
Reports with missing material information	37	3%
Reports with missing leak type	208	17%
Reports with missing year installed	196	16%

The service connection leak repair data (for those failures between the main and the curb, as described in Section 8.2.1.1) has similar data completeness issues as the main leak repair data (see Table 55).

Table 55: Service Connection Leaks between Main and Curb Data Quality

Total Number of Reported Service Leaks	**893**	
Leak Repair Data Quality Stats	**Count**	**Percentage**
Reports with missing start or end date or both	270	30%
Reports with missing size information	36	4%
Reports with missing material information	54	6%
Reports with missing leak type	404	45%

The data provided on the failures between the curb and the meter box (in the CPS dataset) was especially difficult to organize and classify for inclusion in the reported break analysis. The source of this set of leak repair data is outlined in Section 8.2.1.2. Table 56 outlines the data completeness issues encountered in the CPS dataset.

Most of the record's information was entered in a "Comments" field, providing narrative descriptions without any standard format or consistent level of detail provided. For proper analysis and categorization, the comments fields were examined to extract failure type information and determine whether or not each record involved a leak. Only 425 of the 909 records were possible to categorize.

Table 56: Service Connection Leaks between Curb and Meter Box Data Quality

Total Number of Reported Service Leaks	**909**	
Leak Repair Data Quality Stats	**Count**	**Percentage**
Reports with missing start or end date or both	168	18%
Reports with missing size information	909	100%
Reports with missing material information	909	100%
Records Possible to Categorize by Leak Type	425	47%

Recommendations on improving data management and ease of analysis can be found in Section 8.8.

8.2.3 Repair Data Summary

8.2.3.1 Main Leak Repair Data Summary

The total amount of leak repairs carried out during FY 2010-2011 by pipe size can be seen in Table 57. Most all of reported main leak repair data summarized here were provided in the first dataset (see Section 8.2.1.1). A handful of main breaks were also documented in the CPS dataset. These 31 records were not classified by size so were added to the "Blank" Section here. In addition to the 19 records from GIS without pipe size information, this totals 50 main failures that did not include pipe size information.

The majority of main leaks occurred on 6 inch mains, reflecting the fact that 6 inch mains are the predominant main size in the LADWP system. Section 8.2.4 elaborates more on break frequency by size.

Table 57: Count of Main Leaks by Size

Main Size (inches)	Water Main Mileage (miles)	Count of Main Leaks By Size (#)
2	48.39	50
4	604.21	290
6	3,109.82	568
8	1,838.85	193
10	30.02	2
12	810.55	49
16	181.55	7
20	76.55	6
24	124.38	6
30	63.53	2
36	69.59	1
39	2.29	1
BLANK	NA	50
TOTAL	**7,227.16**	**1,225**

Figure 30 provides a comparison of main breaks by size (red bars) versus the percentage of pipe diameter in the system (blue bars). This diagram only includes main failure records with size data provided. As expected, the smaller pipes – 2 inch and 4 inch – are responsible for a higher percentage of breaks than what their percentage of network length. For example 4 inch mains contribute close to 25 percent of all main leaks repaired during FY10/11 while 4 inch mains only make up about 8 percent of the distribution system. On the other hand 8 inch and larger mains contribute a smaller percentage of main breaks in comparison to their percentage of network length.

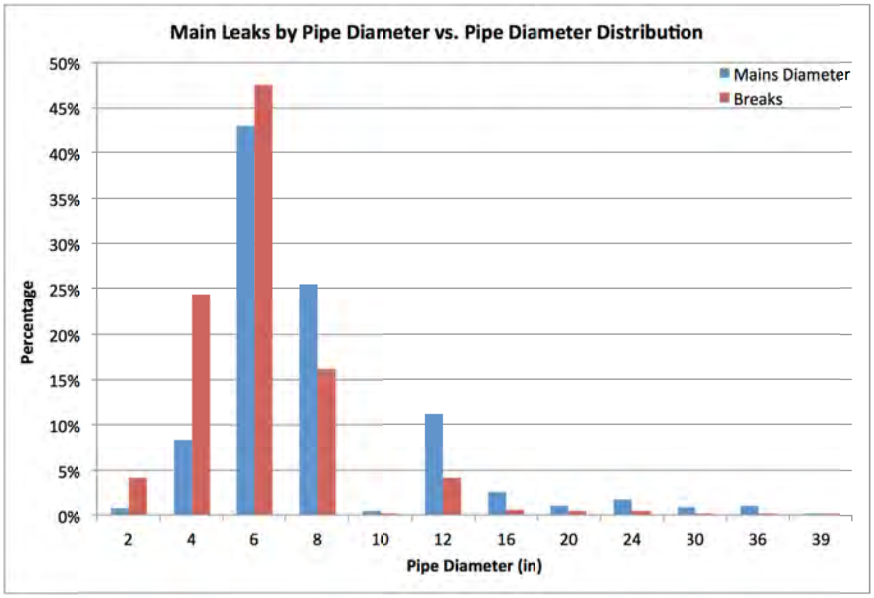


Figure 30: Main Leaks by Pipe Diameter vs. Pipe Diameter Distribution

Figure 31 provides a comparison of main breaks by material (red bars) versus the percentage of pipe material in the system (blue bars). This comparison shows that cast iron ("C.I.") pipe has a notable difference between its percentage of total breaks and its distribution prevalence: C.I. pipes had 75.29% of the total breaks but only compose 64.52% of the pipes throughout the distribution system. Conversely, ductile iron "D.I." pipes have a relatively low level of breaks: D.I. pipes had only 3.09% of the total breaks but compose 11.42% of the pipes throughout the distribution system.

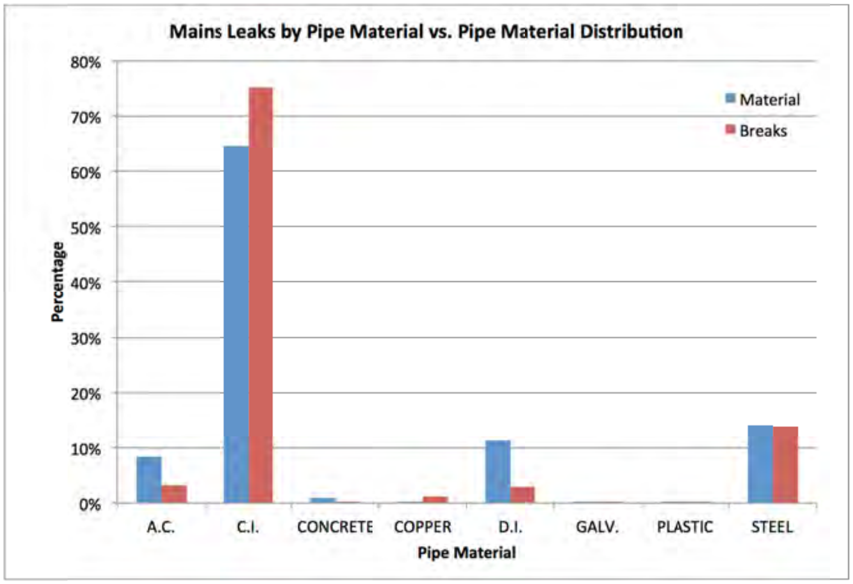


Figure 31: Main Leaks by Pipe Material vs. Pipe Material Distribution

A more detailed breakdown of the audit period's main failures by size and material are outlined in Appendix M.

8.2.3.2 Service Leak Repair Data Summary

The total amount of leak repairs carried out on service connections during FY 2010 – 2011, organized by pipe size, can be seen in Table 58 and Figure 32. Most all of reported service connection leak repair data summarized here were provided in the first dataset (see Section 8.2.1.1). A handful of service connection failures were also documented in the CPS dataset. These 8 additional records were not classified by size so were added to the "Blank" section here. In addition to the 36 records from GIS without service connection size information, this totals 44 service connection failures that did not include size information.

The majority of service leaks occurred on 1-inch service connections.

Table 58: Count of Service Breaks by Size

Size (inches)	Count of Service Breaks	% of Total Service Breaks
0.5	3	0.3%
0.625	2	0.2%
0.74	1	0.1%
0.75	89	10.0%
1	541	60.6%
1.5	67	7.5%
2	132	14.8%
3	4	0.4%
4	12	1.3%
6	4	0.4%
8	2	0.2%
BLANK	44	4.0%
TOTAL	**901**	**100.0%**

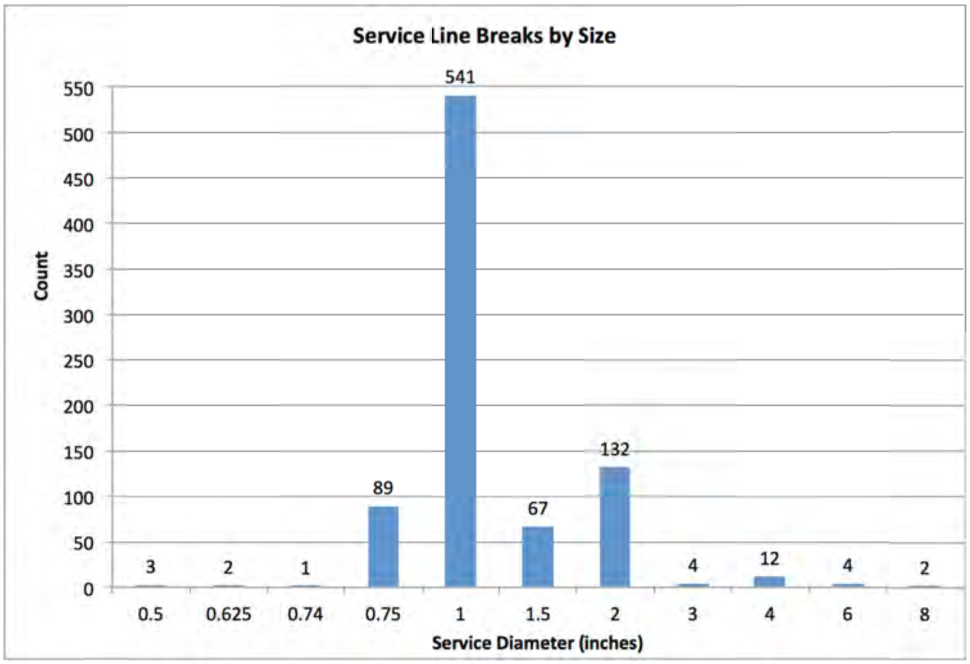


Figure 32: Service Line Breaks by Size

Table 59 and Figure 33 show the service line break reported repairs, organized by material. A significant majority (78.7% of the total) was found on copper service connections.

Table 59: Count of Service Breaks by Material

Material	Count of Service Breaks	% Total Service Breaks
BRASS	1	0.1%
BRASS NIPPLE	1	0.1%
C.I.	71	8.0%
COPPER	703	78.7%
D.C.I.	6	0.7%
D.I.	2	0.2%
GALV.	52	5.8%
OTHER	2	0.2%
STEEL	1	0.1%
(blank)	62	6.0%
Total	**901**	**100.0%**

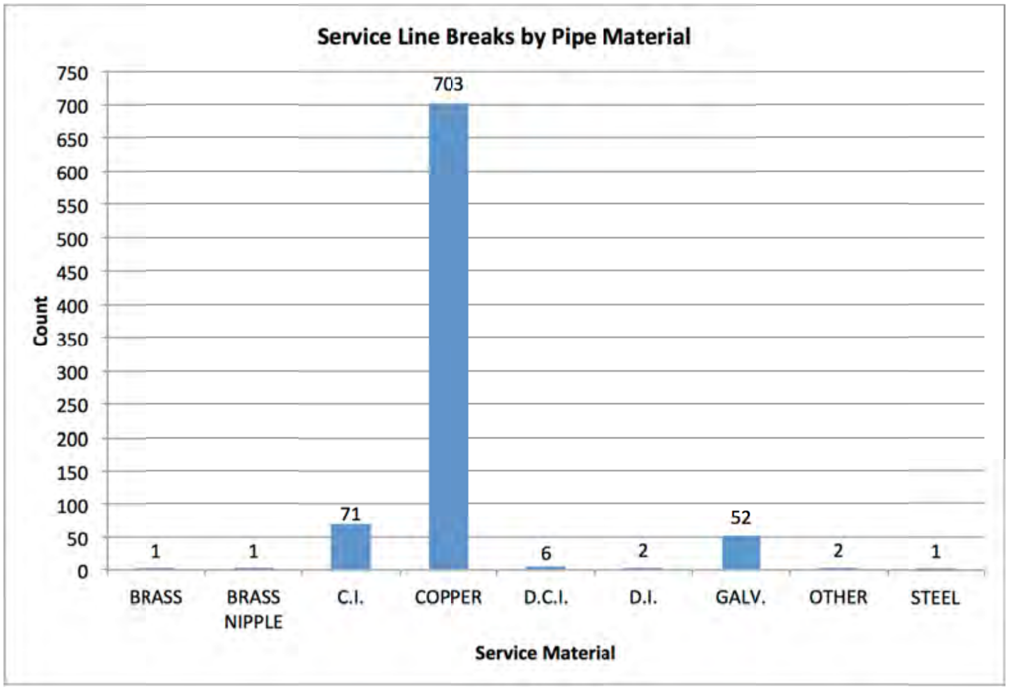


Figure 33: Service Line Breaks by Pipe Material

A more detailed breakdown of the audit period's service connection failures by size and material are outlined in Appendix N.

8.2.3.3 Meter Leak Repair Data Summary

Meter leak repair data was also reviewed for inclusion in the total reported leak losses volume. As outlined in Section 8.2.1.3, potential meter leaks are documented through requests of Water Investigation Reports (WIR). A compilation of WIR's from August 2012 was provided as a representative sample of one month of leak reporting. Within this month's data, two record types were relevant to documentation of leakage: the meter leaks and flooded meter boxes. For the flooded meter boxes, it was assumed that only 25% of the total count were actually meter leak related. Table 60 outlines how the WIR records were counted and extrapolated to give an estimate for an annual meter leak total.

Table 60: Meter Leak Repair Data Summary

	August 2012 Total	Yearly Estimate	% Leak Relevant	Total Leak Estimate
Meter Leaks	126	1,512	100%	1,512
Flooded Meter Boxes	538	6,456	25%	1,614
			Total Meter Leaks:	**3,126**

8.2.3.4 Hydrant Leaks and Leaking Gaskets Repair Data Summary

Two categories of failures were documented for main appurtenances: leaking gaskets and hydrant leaks. The leaking gasket data was provided in the CPS dataset (as described in Section 8.2.1.2). In total, 26 gasket leaks were reported for FY 2010-2011. The hydrant leaks were provided in a separated tab within the GIS dataset (as described in Section 8.2.1.1). For the FY 2010 – 2011, a total of 57 hydrant leaks were reported.

8.2.4 Break Frequency Determination & Comparisons

Based on the repair data provided by LADWP, break frequencies were calculated and then compared with industry averages. First, the number of main repairs for each main size was divided by the relevant length of main to determine the main break frequency (in number of main repairs per 100 miles per year). Table 61 shows the break frequencies derived from the FY 2010 – 2011 repair data, grouped by main size.

Table 61 also includes a break frequency comparison with the theoretical minimum break frequency. The AWWA theoretical minimum level of leakage for a system is known as Unavoidable Annual Real Losses (UARL). In determining the UARL, a minimum frequency of reported breaks on mains used to calculate the minimum losses attributed to this component is 20 breaks/100 miles.

Table 61 shows that for the 6-inch size group and larger, all of LADWP's break frequencies are a fraction of the UARL minimum break predictions.

Table 61: Comparison of LADWP Main Break Frequencies with Minimum Frequencies used in UARL Formula

Size/Type	LADWP Total Repairs	Percent of Total Main Repairs	LADWP Water Main Mileage	LADWP Main Breaks Frequency (#/100 miles/yr)	UARL Component of Reported Breaks on Mains (Breaks/100 miles/year)	Ratio LADWP Break Frequency to UARL Break Frequency
2-inch	50	4.2%	48.39	103	20	5.2
4-inch	290	24.3%	604.21	48	20	2.4
6-inch	568	47.6%	3,109.82	18	20	0.9
8-inch	193	16.2%	1,838.85	10	20	0.5
10-inch	2	0.2%	30.02	7	20	0.3
12-inch	49	4.1%	810.55	6	20	0.3
16-inch	7	0.6%	181.69	4	20	0.2
20-inch	6	0.5%	76.55	8	20	0.4
24-inch	6	0.5%	124.38	5	20	0.2
30-inch	2	0.2%	63.53	3	20	0.2
36-inch	1	0.1%	69.59	1	20	0.1
39-inch	1	0.1%	2.29	44	20	2.2
Mains All Sizes*	**1,225**		**7,227.16**	**17**	**20**	**0.8**
*Includes break records without size information						

Other comparisons here are also valuable. As a piece of the Water Research Foundation project "Effective Organization and Component Analysis of Utility Leakage Data", WSO researched studies on average break frequencies at water utilities throughout North America. It was found that the average main break frequency is approximately 25 reported breaks per 100 miles per year.

Another Water Research Foundation study, "Criteria for Optimized Distribution Systems"[13], published metrics that indicate a well-managed "optimized" distribution system. One of the key performance indicators studied here was break frequency, and the research established that a reasonable target break frequency for optimized systems is 15 reported breaks per 100 miles per year.

Figure 34 summarizes how these average and optimized main break frequencies compare to LADWP's main break repair data. It shows that LADWP's break frequency is well below the average North American break frequency and approximates the break frequency associated with optimized distribution systems.

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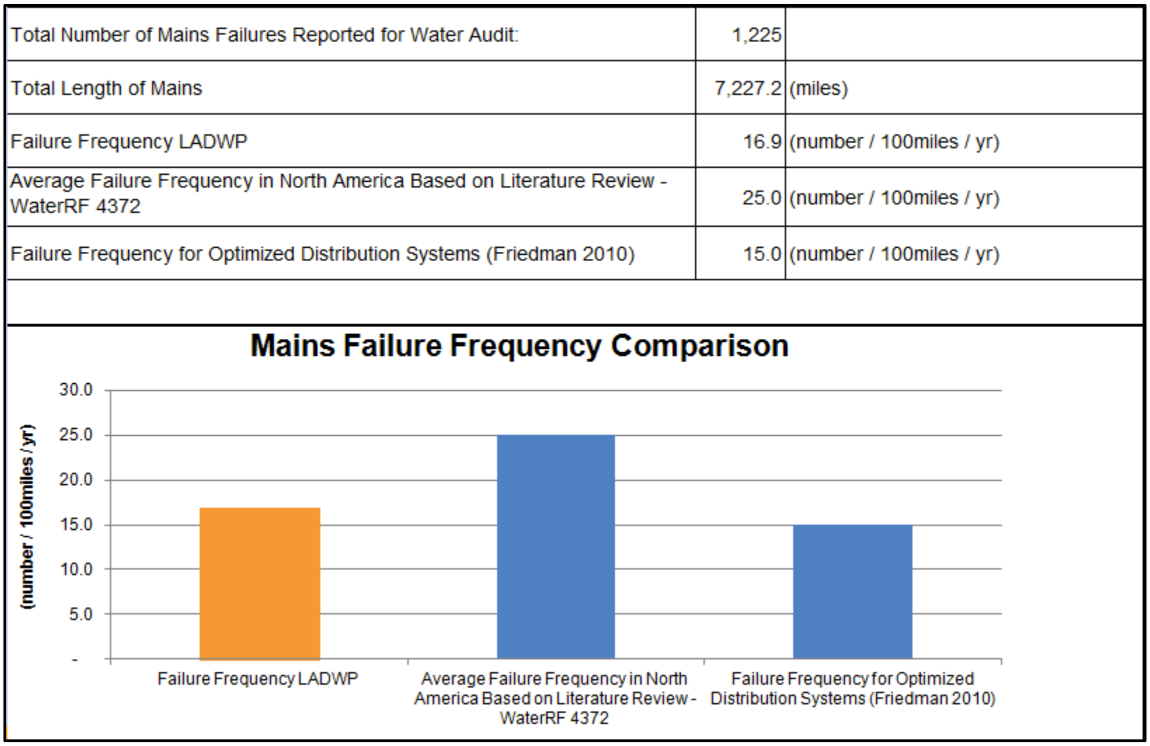
[13] Friedman, 2010 Citation



Total Number of Mains Failures Reported for Water Audit:	1,225	
Total Length of Mains	7,227.2	(miles)
Failure Frequency LADWP	16.9	(number / 100miles / yr)
Average Failure Frequency in North America Based on Literature Review - WaterRF 4372	25.0	(number / 100miles / yr)
Failure Frequency for Optimized Distribution Systems (Friedman 2010)	15.0	(number / 100miles / yr)

Figure 34: LADWP Main Break Frequency Comparison to National Average and Optimized Break Frequencies

The results presented in Table 61 and Figure 34 indicate that the system may experience a lower percentage of breaks surfacing than other utilities and that the distribution network is in overall good condition. The fact that about 70 percent of the pipe network is 6 inches and larger is a contributing factor to the overall low break frequency. However, the low break frequency might also suggest that the main leak repair data is not yet capturing all of the leaks repaired. LADWP should focus on thoroughly documenting each instance of leak repair activity to properly track reported losses and maintain data that aligns with a realistic break frequency.

Similar comparisons were applied to the service connection repair data: service connection break frequencies were calculated and then compared with industry averages. The number of service connection repairs was divided by the number of total service connections to determine the service connection break frequency (in number of service connection repairs per 1000 service connections per year). Table 62 shows the service connection break frequency derived from the FY 2010 – 2011 repair data.

In determining the UARL component for service connection failures, the minimum frequency of reported breaks on service connections used is 2.25 breaks/1000 service connections (AWWA M36: Water Audits and Loss Control Programs). Table 62 shows that LADWP's service connection break frequency is just over half of the UARL minimum service connection break predictions. This suggests that the service connection leak repair data is not yet capturing all of the leaks repaired. It is important that LADWP focus on thoroughly documenting each instance of leak repair activity to properly track reported losses and maintain data that aligns with a realistic break frequency.

Table 62: Comparison of LADWP Service Connection Break Frequency with Minimum Frequency used in UARL Formula

Size/Type	Total Leaks/ Breaks	Total # of Service Lines	LADWP Service line Break Frequency (breaks/ 1,000 serv conn/year)	UARL Component of Reported Service Line Leaks (breaks/1,000 serv conn/year)	Ratio LADWP Break Frequency to UARL Break Frequency
Services	**901**	**721,997**	**1.2**	**2.25**	**0.55**

8.2.5 Awareness Time for Reported Breaks/Leaks

Awareness duration is the time it takes for LADWP to become aware that a leak or break exists from the moment the leak first occurs. Reliable data on the amount of time between the occurrence of a leak and the leak being reported is not readily available, as is the case for all systems that do not operate on a District Metered Area (DMA) basis (allowing for permanent leakage monitoring). Although it is possible to record the moment a leak or break is reported, it can only be estimated when the leak first occurred.

Conventional wisdom states that for reported leaks and breaks with high flow rates and high nuisance value or water showing on the surface, the awareness duration is relatively short. For example, a major main break on a trunk main will be highly visible, because of widespread disruption to the water supply and possibly failure of the road surface. Such leaks will be reported immediately after they occur. Main breaks of less disruptive nature may be tolerated for several days before being reported to LADWP.

The situation is similar with service leaks. In cases where a leak causes a sudden loss of supply, customers will notice and report quickly. On the other hand, smaller service leaks that only cause a drop in supply pressure take longer to notice and customers may wait for a day or two before notifying LADWP.

Typical awareness duration times for reported leaks and breaks used in previous studies are compared to awareness duration assigned to LADWP for this analysis in Table 63. Since it is not possible to record how long it takes to become aware of a break it is necessary to make assumptions about the awareness duration based on the local conditions. An awareness time of 30 days was assigned to meter leaks: given that the bi-monthly billing period is 60 days for a residential customers (which comprise the majority of customer meters in the LADWP's system), a meter leak will run for 30 days on average before any action is initiated.

Table 63: Awareness duration for reported breaks

	Typical Awareness Duration Ranges for Reported Leaks and Breaks (days)	**Awareness Duration for Reported Leaks and Breaks assumed for LADWP situation (days)**
Main Breaks		
Pipe Diameter >12 inch	0.1 to 0.5	0.1
Pipe Diameter 6 inch to 12 inch	0.25 to 2	0.25
Pipe Diameter 3 inch to 4 inch	0.5 to 2	0.5
Pipe Diameter <3 inch	1 to 5	3
Service Leaks> 1inch	1 to 5	3
Service Leaks< 1inch	1 to 5	3
Hydrant Leaks	3 to 7	3
Valve Leaks	3 to 7	5
Meter Leaks		30

8.2.6 Location and Repair Time for Reported Breaks

8.2.6.1 Location and Repair Time for Reported Main Breaks

The combined location and repair duration for reported leaks and breaks was determined by the documentation submitted by LADWP. The combined location and repair duration is assumed to be the duration between the date of the creation of the service request or work order and the date of the completion of the individual work order (see Section 8.2.1 for details on the database merging efforts required to access these dates and times). To calculate the location and repair time, the difference was taken between the fields (provided by the trouble board data) “ORDER_CREATE_TS” and “ORDER_CMP_TS”. The resulting location and repair times are summarized in Table 64 and Figure 35.

Table 64: Summary of Calculated Location and Repair Times by Main Size for FY 2010-2011

Size of Main (inches)	**Number of Breaks Per Year**	**Average Duration of Location and Repair/Shutoff of Leak (DAYS)**
2	50	5.5
4	290	5.5
6	568	4.7
8	193	4.6
10	2	N/A*
12	49	9.8
16	7	7.4
20	6	2.7
24	6	1.9
30	2	2.0
36	1	N/A*
39	1	2.2
BLANK	19	11.7

*For the 10” and 36” mains, one or both of the two timestamps necessary to calculate the location and repair time were not provided.

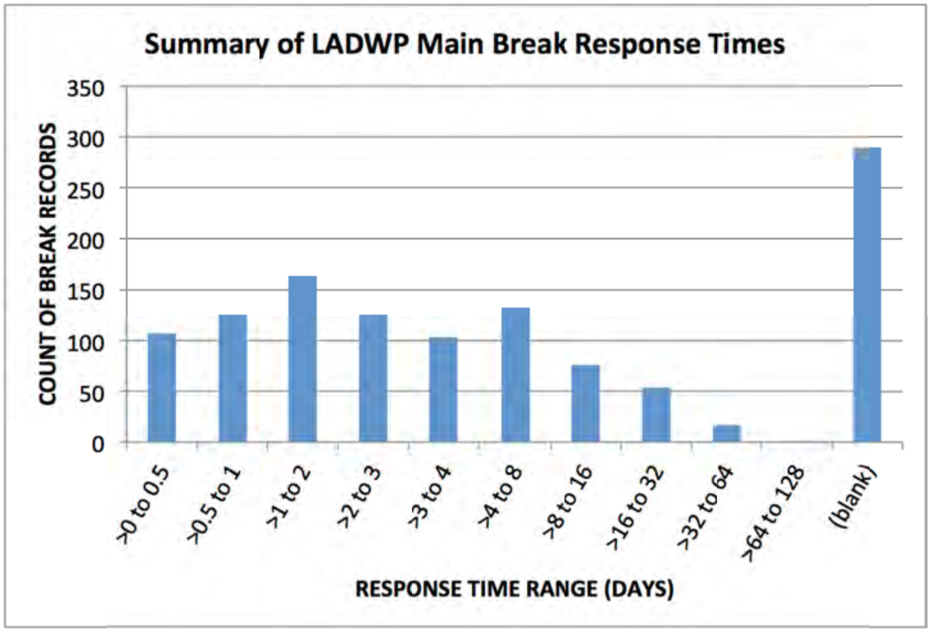


Figure 35: Summary of LADWP Main Break Repair Response Times

It is important to note that a majority of the main break repair records do not have sufficient timestamp data to calculate the location and repair time: 25.2% of all records do not have this information on file (or the work order record's information did not match with the trouble board database). Main break where the location and repair time could not be calculated based on the available records were assigned the average location and repair time of their main size group.

A more detailed breakdown of the audit period's main failure response times are outlined in Appendix O.

8.2.6.2 Location and Repair Time for Reported Service Connection Breaks

Just as for the main breaks, the combined location and repair duration for reported leaks and breaks on service connections was determined by the documentation submitted by LADWP. The combined location and repair duration is assumed to be the duration between the date of the creation of the service request or work order and the date of the completion of the individual work order (see Section 8.2.1 for details on the database merging efforts required to access these dates and times). To calculate the location and repair time, the difference was taken between the fields (provided by the trouble board data) "ORDER_CREATE_TS" and "ORDER_CMP_TS". The resulting location and repair times are summarized in Table 65 and Figure 36.

Table 65: Summary of Calculated Location and Repair Times by Service Connection Size for FY 2010-2011

Service Connection Size	**Number of Breaks**	**Average Duration of Location and Repair/Shutoff of Leak (days)**
Service < 1"	95	10.5
Service >= 1"	798	11.7
Total	**893**	**11.38**

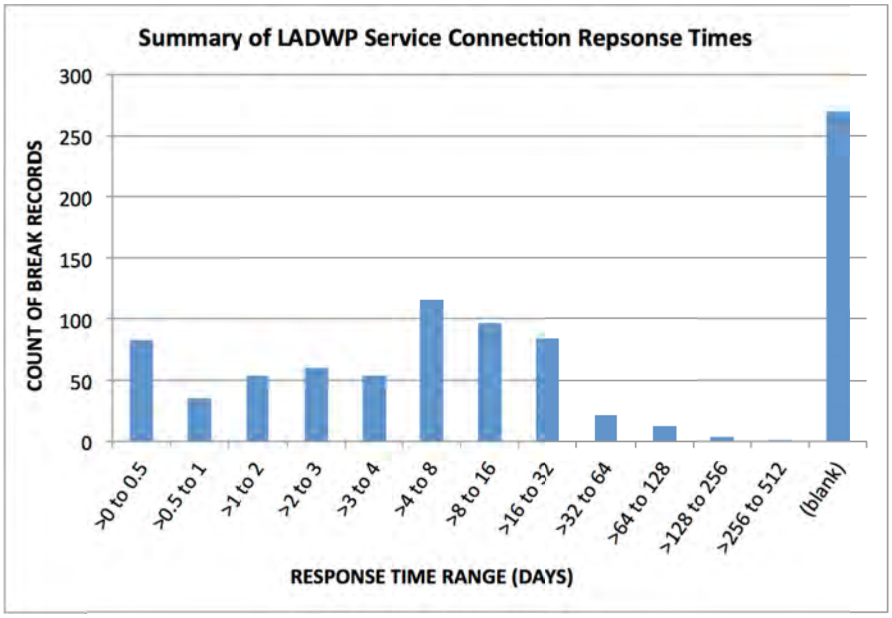


Figure 36: Summary of LADWP Service Connection Repair Times

It is important to note that a majority of the service connection break repair records do not have sufficient timestamp data to calculate the location and repair time: 30.24% of all records do not have this information on file (or the service leak record's information did not match with the trouble board database). Service connection breaks where the location and repair time could not be calculated based on the available records were assigned the average location and repair time of their main size group.

For meter leaks, which do not have work order documentation to provide location and repair times, it was assumed that the location and repair time approximated 15 days.

Further breakdowns of the audit period's service connection failure response times are outlined in Appendix P.

8.2.7 Recommended Break/Leak Flow Rates for the Component Analysis

In the U.S there is very limited data available on flow rates of reported and unreported leaks. Therefore data from the UK, Germany, Brazil, and Canada in addition to data from Philadelphia Water Department (PWD) was used to compose a list of recommended flow rates for breaks/leaks (see Table 66). More information on how those values were derived can be found in Appendix Q.

Table 66: Recommended Leak and Break Flow Rates at 70 PSI Reference Pressure

	Reported Leaks and Breaks (gpm)
Main Breaks	
Less than 4 inch	13.9
4 inch	44
6 inch	92
8 inch	92
10 inch	92
12 inch	222
Greater than 12 inch	222
Service Leaks	
<1 inch	6.9
Equal or > 1 inch	13.9
Meter Leaks	0.5
Hydrant Leaks	3.0
Main Fittings	0.5

8.2.8 Estimated Annual Volume of Water Lost from Reported Breaks/Leaks in LADWP

The annual volume of water lost through reported breaks/leaks can be estimated by simply multiplying the number of reported leaks and breaks, the average reported leak and break duration, and the average leak and break flow rate at the specified system pressure. The leak and break flow rate at 70 psi was corrected to the actual average system pressure for each component using the Fixed and Variable Area of Discharge (FAVAD) pressure correction technique (see Appendix R).

Within this approach, an important parameter is the N1 value, which represents the power-law relationship between flow and pressure, taking into account the pressure dependency of discharge coefficient and cross-sectional area. For fixed size holes, such as bursts, N1 will be 0.5 (square root relationship). As most reported breaks qualify in this category, an N1 value of 0.5 is applied.

The total estimated volume of water lost from reported breaks/leaks is 1,409.59 MG for the audit period of FY 2010-2011. Main breaks composed the majority of this volume, accounting for 1,010.99 MG. Appendix S shows the compilation of all the components of the reported breaks/leaks volume.

8.3 Unreported Breaks/Leaks

There was no leak detection conducted during the FY 2010-2011 time frame. Since no leaks were proactively detected during the audit period the volume of water lost due to unreported break/leaks is zero MG in the BABE component analysis.

8.4 Background Leakage

8.4.1 Background Leakage Overview

Background Leakage is defined as the loss of water from individual leak events for which the rate of loss is less than 2.2 gpm at 70 psi. These leaks are undetectable using current leak noise detection technology. They continue to flow undetected unless either found by chance (during some other maintenance work for instance) or gradually worsen to the point they are detectable.

Background leaks typically comprise of small corrosion holes ("pin-holes") in metallic pipes and minor leaks at pipe joints and fittings. The level of Background Leakage in a water supply system will be dependent on the following variables:

- Length of pipe network
- Number of service connections
- Pressure at which the system is operated
- Condition of the infrastructure

The volume of Background Leakage tends to increase with age of the network and is higher for systems operated at higher pressure. The type of pipe materials and jointing techniques are also contributory factors.

The AWWA theoretical minimum level of leakage for a system is known as Unavoidable Annual Real Losses (UARL) and includes values for the minimum level of Background Leakage from mains and service connections called the Unavoidable Background Leakage (UBL). The values are based on international data from analysis of night flows after all detectable leaks and breaks were located and repaired. The values also relate to normal distribution systems in good condition with rates of infrastructure replacement around 1.5 to 2 percent per year.

The UBL values are presented in Table 67. To clarify, Table 67 shows the technical minimum of Background Leakage for a system with LADWP's infrastructure; LADWP's actual background leakage is calculated in Section 8.4.2.

Table 67: Unavoidable Background Leakage Rates

Infrastructure Component	**Unavoidable Background Leakage**	**Units**
Mains	2.870	gallons / mile of main / day / psi of pressure
Service Connection: main to curb-stop	0.112	gallons / service connection / day / psi of pressure
Service Connection: curb-stop to meter	4.780	gallons / mile of service connection / day / psi of pressure

The purpose of separating the two components of the service connection is that the part of the service connection that lies between the main and the curb-stop is subject to traffic loading and therefore, has a higher incidence of joint failure than the part which lies in the sidewalk or on the customer's property. The length of the service connection from curb-stop to meter has been found to be a significant factor in the different levels of background loss on this component seen in various water utilities.

An additional component of Background Leakage exists, which comes from undetectable losses on reservoirs. There are no set minimum values for estimating losses caused by Background Leakage on reservoirs. Therefore, certain assumptions need to be made (see Section 8.4.3).

8.4.2 Background Leakage from Distribution Network

The UBL is used to calculate the actual background losses throughout the distribution system using an assigned Infrastructure Condition Factor (ICF). The ICF is a ratio comparing the actual background leakage to the UBL:

Infrastructure Condition Factor (ICF) = Actual Background Leakage / Unavoidable Background Leakage

Using an estimated ICF, it is possible to calculate the actual Background Leakage from the UBL (the volume of minimum Background Losses determined in Section 8.4.1). Based on the results of a sensitivity analysis, an Infrastructure Condition Factor (ICF) of 1.15 was applied to the UBL, to calculate the volume of annual loss from Background Leakage from the distribution network. This calculation is detailed in Table 68, and an example calculation of the determination of Background Losses from the Distribution Mains (mains under 12") is given here:

> *UBL for Distribution mains = 2.870 gallons/miles/day/psi * mileage of Distribution Mains * audit period length * operating pressure*
>
> *UBL for Distribution Mains = 2.870 gallons/miles/day/psi * 6.448.64 miles * 365 days * 90 PSI*
>
> *UBL for Distribution Mains = 607.97 MG*

*Actual Background Losses for Distribution Mains = ICF * UBL for Distribution Mains*

*Actual Background Losses for Distribution Mains = 1.15 * 607.95 MG = 699.17 MG*

LADWP meters the customer outside of the property boundary, effectively at the curb-stop. The length of service connection between curb-stop and meter is therefore assumed to be zero. All losses on the customer's pipes after the meter are assumed to be included in authorized billed metered consumption.

Usually in calculating background leakage, the "N1" variable (which defines the relationship between pressure and leakage) of 1.5 is applied. However, in this analysis, the volume parameters determined by the top-down audit did not allow for this approach. Given the constraints of the low levels of real losses, it was decided to use a direct relationship between pressure and leakage (where N1 =1).

The total estimated volume of water lost from Background Leakage in the distribution network is 3,838.89 MG or 11,781.12 AF for the audit period of FY 2010-2011.

Table 68: Annual Volume of Loss from Distribution Network Background Leakage

Infrastructure Component	**Background Leakage at ICF=1.0** [14]	**Units**	**Miles** **Number of Services**	**Average Operating Pressure (psi)**	**ICF**	**Annual Volume of Background Leakage**	
						(MG)	**(AF)**
Distribution Mains (<=12")	2.870	gallons / mile of main / day / psi of pressure	6,448.64	90.0	1.15	699.17	2,145.68
Trunk Mains (>12")	2.870	gallons / mile of main / day / psi of pressure	778.52	90.0	1.15	84.41	259.04
Service Connection: main to curb-stop	0.112	gallons / service connection / day / psi of pressure	722,112	90.0	1.15	3,055.31	9,376.40
Service Connection: curb-stop to meter	4.780	gallons / mile of service connection / day / psi of pressure	NA	90.0	1.15	0	0
Total Background Leakage from Distribution Network						**3,838.89**	**11,781.12**

---

[14] IWA/AWWA Values

8.4.3 Background Leakage from Reservoirs

No study data is available for LADWP regarding Background Leakage from reservoirs. Therefore, the average Background Leakage rate was estimated and assumed to be 0.125 gpm/MG of the total reservoir capacity (this estimation does not include evaporative losses or rain gains).[15] The reservoir volume used here was the storage volume as of the first day of the audit period. The LA Reservoir, Lower Stone Canyon Reservoir, and Encino Reservoir storage volumes were excluded as they store water before the system input volume points of measurement.

The total Background Leakage from reservoirs was calculated to be 78.12 MG per year (see Table 69).

Table 69: Total Background Leakage from Reservoirs

Background losses on reservoirs				
Reservoirs	Total Capacity (MG)	Background Leakage Rate (gpm/MG)	Annual Volume (MG)	Annual Volume (AF)
All reservoirs	1,189	0.125	**78.12**	**239.74**

8.4.4 Total Background Leakage for FY 2010 - 2011

The total volume of Background Leakage for the audit year was estimated to be 3,995.13 MG (see Table 70).

Table 70: Total Volume of Background Leakage for FY 2010-2011

Background Losses from	**Annual Volume (MG)**	**Annual Volume (AF)**
Distribution Network	3,838.89	11,781.12
Reservoirs	78.12	239.74
Total	**3,917.01**	**12,020.86**

---

[15] This is based on review of a reservoir leakage study for the City of Phoenix: "City of Phoenix Reservoir Assessment, Black & Veatch, 2000."

8.5 Total Real Losses from BABE Component Analysis

The total Real Losses from the identified BABE components for FY 2010-2011 is summarized in Table 71.

Table 71: Total Real Loss from BABE Component Analysis for FY 2010-2011

BABE Component	**Annual Volume of Water Loss**	
	(MG)	**(AF)**
Total Real Losses from Reported Leaks and Breaks (see Section 8.2.8)	1,409.59	4,325.87
Total Real Losses from Unreported Leaks and Breaks (see Section 8.3)	0.0	0.0
Total Real Losses from Background Leakage (see Section 8.4.4)	3,917.01	12,020.86
Total Real Losses from BABE Components	**5,326.60**	**16,346.74**

8.6 Estimation of Hidden Losses

Comparing the calculated volumes of Real Losses derived from the two different independent methods (AWWA top-down Water Balance and BABE component analysis) shows a balancing error between the two volumes, as presented in Table 72.

Table 72: Comparison of Real Loss Estimate from AWWA Water Balance and BABE Component Analysis

	Annual Volume of Water Loss	
Real Loss Component	**(MG)**	**(AF)**
A. Total Real Loss Estimate from AWWA Annual Water Balance	6,118.18	18,776.00
B. Total Real Loss Estimate from Component Based Analysis (Section 8.2.8)	5,326.60	16,346.74
Hidden Loss Estimate (A – B)	**791.59**	**2,429.30**

While a certain amount of the difference between the two volumes is due to errors in the two methods of estimation, the difference mainly reflects the volume of Hidden Losses, i.e., the presence of detectable leaks that are not being identified. In effect, Hidden Losses are a backlog of leaks and breaks waiting to be detected and repaired. Individually, each hidden leak may not cause a customer service problem and may not be visible at the ground surface. Collectively however, Hidden Losses can account for a considerable volume of Real Losses each year. Section 11 evaluates the optimum strategy for achieving an economically optimized level of hidden losses.

8.7 Summary of Component Analysis

Table 73 and Figure 37 present the real loss component analysis results for LADWP in FY 2010-2011. Background leakage comprises the majority of real losses, accounting for 64% of the total real loss volume.

Table 73: Real Losses Component Analysis Results for FY 2010 -2011

Leakage Component	**FY 2010-2011 Volume**	
	(MG)	**(AF)**
Background Leakage	3,917.01	12,020.86
Reported Breaks	1,409.59	4,325.87
Unreported Breaks	0	0
Hidden Losses	791.59	2,434.06
Total Real Losses	**6,118.18**	**18,776.00**

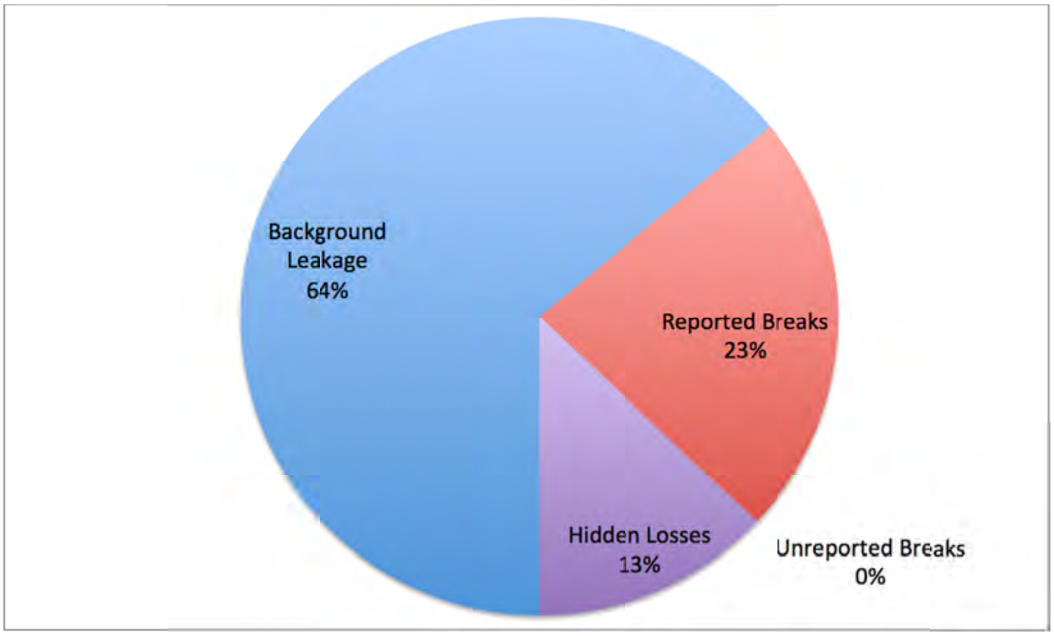


Figure 37: Real Loss Component Analysis Results for FY 2010-2011

8.8 Real Losses (Component Analysis) Recommendations

Repair Data Streamlining and Organization

- The break data provided from LADWP was sourced from multiple databases and required much coordination. Streamlining of break record information will make future efforts to produce a real losses component analysis much more manageable. Currently, different record keeping routines and data collection processes are maintained for different types of breaks and sections of pipe. All instances of distribution system failure should be documented (with the following break characteristics) for complete and thorough documentation of reported losses in the future.

- Ideally, all of the following information will be kept in one database. Appropriate codes should be developed to allow for the following data entry for every leak relevant work order:
  - **Dates and Times**
    - When each break was reported / identified (if unreported)
    - When each break was pin-pointed/located
    - When each break was contained (water shut off) for repair

  - **Reported / Unreported: how was the break identified?**
    - Customer report
    - Meter reader
    - By Leak Detection Squad (unreported only)
    - Reported from sewer inspection
    - Reported from storm drain inspection
    - Reported by other LADWP staff

  - **Infrastructure Data**
    - Material
    - Diameter
    - Pressure class
    - Corrosion protection – internal
    - Corrosion protection – external
    - Date of installation
    - Soil type

  - **Type of Break: which (of the following types) best describe the leak/break?**
    - Main breaks
    - Circumferential fracture
    - Longitudinal fracture
    - Corrosion hole
    - Joint leak

  - Service line breaks
  - Tap point leak
  - Meter leak
  - Fitting leaks
  - Hydrant
  - Valve
  - Air valve
  - Washout / blow off

  - **Types of Repair**
  - New section
  - Repair clamp
  - Plug / weld patch
  - Repair
  - Replace

  - **Location of Break**
  - Minimum – address
  - Best – located on GIS

- The above fields should be recorded in separate (sortable) fields for ease of analysis and data export.

Repair & Location Time Data Quality

- In the component analysis, reliability of leak run times has an important impact in determining reported leakage volumes. It is important that each repair record's start and finish times reflect the run-time of the leak from awareness to containment as best as possible.

- Linking the timestamps directly in the repair records (and not separately in the trouble board documentation) will expedite the location and repair time calculations.

SECTION 9. FIELD VALIDATION OF REAL LOSSES

9.1 Approach for Field Quantification of Real Losses

This piece of the project aimed to provide field data on leakage loss reduction through proactive leak detection and quantification of real loss savings. Comparing the results of the real loss reduction through leak detection to the results of LADWP's water balance and component analysis for the FY 2010-2011 audit period should provide further validation of the calculated system wide volume of hidden losses. Together with LADWP three existing pressure zones were selected for use as temporary District Metered Areas (DMA). The approach for field quantification of real losses was designed as follows:

1. Supply Volume Determination: for each of the three pressure zones the supply into the zone is monitored for seven days
2. Total Consumption Determination: the total consumption for each zone is assessed by reading each customer meter at the beginning and end of the seven day period
3. Basic Mass Balance Calculation: Total Supply Volume – Total Consumption = Real Loss Volume
4. Leak Detection Survey: After the initial assessment of real losses in the DMA, a detailed leak detection survey in each DMA is completed; all detected leaks repaired by LADWP
5. Repeat steps 1 and 2 after all leaks have been repaired in each DMA and quantify real losses savings in each DMA

9.1.1 District Metered Area Principle

A DMA is a hydraulically discrete area of a distribution system that ideally receives its supply from a single feed (though it is also possible to design a DMA with multiple feeds). All of the water entering the DMA is measured by a flow meter. This allows continuous monitoring of the DMA inflow. Using this data from the nighttime hours, it is possible to quantify the leakage volume and then model leakage over the entire 24hour period. This is called a Minimum Night Flow (MNF) Analysis and is explained in the following section.

Breaking up a system into DMAs has proven to be one of the most effective methods for reducing the awareness time for unreported leaks and reducing the overall volume of real losses.[16] In more advanced systems, the pressure is monitored by DMA and can be modulated based upon the demand in the system. This type of control lets a utility minimize background losses, a component of real losses whose flow rates are solely dependent on system pressure. This is an especially important leakage management opportunity because background losses cannot be found through active leak detection.

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[16] Julian Thornton, Reinhard Sturm and George Kunkel, P.E., *Water Loss Control* (McGraw-Hill, 2002), 281-283

9.1.2 Minimum Night Flow Analysis Principle

The basic concept of a MNF analysis is to measure flow into a discrete area with a defined boundary (DMA) at a time when demand is at its lowest, ultimately allowing for an estimation of real losses within the DMA. Two main data points are required for this analysis: the total supply volume during the minimum night flow period (this volume is referred to as MNF) and an estimation of the amount of legitimate night consumption for each of the customers connected to the mains in the area (DMA) being studied.

The minimum night-time flow in urban environments usually occurs between 2:00 am and 4:00 am. This is a meaningful window of opportunity as far as leakage analysis is concerned: during this period, authorized consumption is at a minimum and, therefore, leakage is at its maximum percentage of the total inflow. The result obtained by subtracting the legitimate night use from the minimum night-time flow is known as the Net Night Flow (NNF) and provides an estimation of the volume of real losses during the MNF period (see Figure 38).

NNF = MNF – Legitimate Night-Time Consumption

The NNF is mostly composed of real losses from the distribution network and the service connection up to the customer meter. However, it may also include leakage on the customer side of the meter and consumption through unauthorized connections.

In systems where irrigation is responsible for a significant part of the demand during the minimum night-time flow period (typically during the summer), the accuracy and the confidence in the calculated real loss figures will diminish. The maximum daily inflow to a DMA can even occur during the typical minimum night use period, 2:00 am to 4:00 am. Therefore, it is not recommended to perform MNF analyses during these periods of heavy night use.

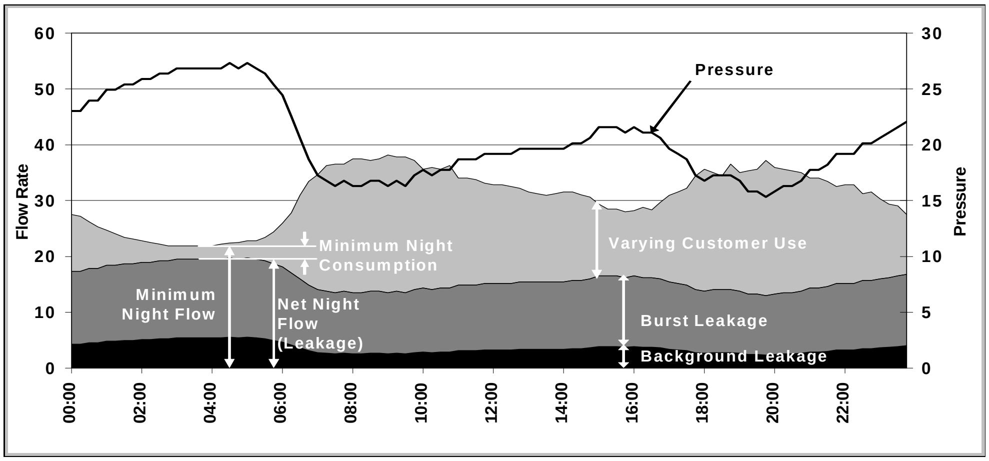

Figure 38: Example of 24-hour leakage modeling
based on minimum night flow analysis

In addition to the basic mass balance described in Section 9.1 DMA MNF analyses in each DMA before and after detection and repair of all leaks were planned.

9.2 LADWP – District Metered Areas Introduction

The three pressure zones selected to be used as temporary DMAs are:

1. 517/Boyle Heights – in the Central District
2. 1960/Tujunga – in the East Valley District
3. 540/Westwood – in the Western District

Each of the zones was equipped with insertion flow meters[17] at each pressure control station supplying water into the zones. In addition, pressure loggers were deployed within the DMAs to record the system pressure (see Table 74 for general characteristics of each DMA). In installation, there was an attempt to place the pressure loggers at points in each DMA that captured both the low and high points.

Table 74: DMA/Pressure Zone Characteristics

Zone Name	**517/ Boyle Heights**	**1960/ Tujunga**	**540/ Westwood**
Length of distribution network (miles)	46.91	25.98	21.48
Total Number of Service Connections	6,285	1,657	1,814
Average Pipe Diameter (in.)	6.9	6.6	7.0
Average Pipe Age (years)	73.5	41.3	65.7
Max Pressure Recorded (PSI)	108.7	110.6	100.5
Min Pressure Recorded (PSI)	50.8	38.5	58.3
Maximum Pressure Surges (PSI)[18]	6.2	15.8	15.5
Average Zone Pressure (PSI)[19]	73.4	73.9	82.4

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[17] A Metron Flowmat electromagnetic insertion flow meter was used for the flow measurements. The meters were inserted using hot taps installed by LADWP.

[18] Maximum pressure surges represent the maximum difference in pressure between consecutive reads (1.5 minute reading intervals)

[19] The average pressure represents a simple average based on DMA pressure logging sites (excluding pressures recorded at pressure regulating stations).

9.3 Total Consumption in Each DMA

For each of the three DMAs every customer meter was read manually by the LADWP first on April 7 and again on April 14. The following subsections discuss the results and findings of this manual meter reading exercise for each DMA.

9.3.1 Manual Meter Reading Results – 517/Boyle Heights

In 517/Boyle Heights 6,285 meters were manually read by LADWP with an estimated total consumption of 27,403,215 gallons between April 7, 2013 and April 14, 2013. The consumption by meter type (i.e. large commercial/industrial/institutional, fire lines with detector check meters, large meter on a dedicated fire line, and small meters) is shown in Table 75.

Table 75: Manual Reading Results for 517/Boyle Heights[20]

Meter Types	Number of Meters	Percentage of Meters with Data Quality Concerns[21]	Consumption over 7 days		Average Consumption per meter per day	
			(gal)	(HCF)	(gal/day)	(HCF/day)
Large Meters Commercial/Industrial/Institutional	33	0%	4,444,600	5,941.0	19,241	25.7
Large Meters – Fire Lines with Detector Check Meters *Note: 61 of the fire line detector check meters registered consumption* *Note: 3 of the fire line detector check meters had non valid reads*	72	88.9%	12,784	17.1	29[22]	0.04
Large Meters – Fire Service	1	0%	4,020,505	5,375.0	574,358	767.9
Small Meters *Note: 41 of the small meters had consumption over 70,000 gal per week (93.6 HCF/week)* *Note: 118 of the small meters had non valid reads*	6,179	2.6%	18,925,326	25,301.2	438	0.6
Total	6,285	3.6%	27,403,215	36,634.3	623	0.8

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[20] Volumes have been rounded to the nearest gallon and 0.1 HCF

[21] Data quality concerns include non-valid reads, detector check meters with consumption, small meters with consumption greater than 70,000 gallons per week

[22] Average consumption per meter that registered consumption

The manual meter reading results included a wide range of inconsistencies: for example, some meters were found in the field that were not on the original route list, there were errors in the recorded meter reads, some meters were only read once, some meters on the route list were taken out, etc. Due to these inconsistencies within the meter reading data provided, WSO had to perform some manual data cleaning to account for the following data quality concerns:

- *Non-valid reads on fire lines with detector check meters:* Meters with negative consumption (caused by data entry or meter reading errors) were classified as non-valid and filtered out of the entire large meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) fire lines with detector check meters and substituted non-valid reads. There were 3 fire lines with detector check meters with non-valid reads out of a total of 72 fire lines with detector check meters read by LADWP in 517/Boyle Heights.

- *Non-valid reads on small meters:* As with the non-valid reads on fire lines with detector check meters, small meters with negative consumption were classified as non-valid and filtered out of the entire small meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) small meters and substituted for the non-valid reads. There were 118 small meters with non-valid reads out of a total of 6,179 small meters read by LADWP in 517/Boyle Heights

Small meters with greater than 70,000 gallons during the DMA measurement period: Out of the 6,179 small meters read by LADWP in 517/Boyle Heights, 41 of the meters registered consumption over 70,000 gallons per week. The high consumption of these meters may be attributed to meter reading error but it would be in the best interest of LADWP to further investigate these meters. If the consumption is legitimate, then it is likely that these meters are undersized, which can lead to additional wear and tear on a water meter. These meters were filtered out of the small meter dataset and an average per week consumption was determined for the remaining meters that read less than 70,000 gallons during the DMA measurement period. This average consumption per meter (3,063 gallons per week/438 gallons per day) was then substituted for each of the small meters with greater than 70,000 gallons (see Appendix U for list of meters with consumption greater than 70,000 gallons per week).

- *Fire Service Meter* – In 517/Boyle Heights there was a single fire service meter that provides both domestic and fire demands. It read more than 4 MG of consumption during the DMA measurement period. Since this meter is classified as a large meter, it has not been altered and included in the total consumption during the DMA measurement period. It is possible that this meter was read incorrectly (as this read is almost double its average consumption) and should be further investigated by LADWP.

It is also important to note that 61 of the 72 fire line detector check meters registered consumption during the DMA measurement period. It would be to the benefit of LADWP to investigate the fire line detector meters with consumption for unbilled consumption (see Appendix T for list of fire line detector check meters that registered consumption).

9.3.2 Manual Meter Reading Results – 1960/Tujunga

In 1960/Tujunga, 1,657 meters were manually read by LADWP with an estimated total consumption of 5,352,568 gallons between April 7, 2013 and April 14, 2013. The consumption by meter type (i.e. large commercial/industrial/institutional, fire lines with detector check meters, large meter on a dedicated fire line, and small meters) is shown in Table 76.

Table 76: Manual Reading Results for 1960/Tujunga[23]

Meter Types	Number of Meters	Percentage of Meters with Data Quality Concerns[24]	Consumption over 7 days		Average Consumption per meter per day	
			(gal)	(HCF)	(gal/day)	(HCF/day)
Large Meters Commercial/Industrial/Institutional *Note: 1 of the large meter had non valid reads*	6	16.6%	8,348	11.2	199	0.3
Large Meters – Fire Lines with Detector Check Meters *Note: 11 of the fire line detector check meters registered consumption* *Note: 2 of the fire line detector check meters had non valid reads*	43	30.2%	369	0.5	1.2[25]	0.002
Large Meters – Dedicated Fire Line	0	N/A	0	0	0	0
Small Meters *Note: 15 of the small meters had consumption over 70,000 gal per week (93.6 HCF/week)* *Note: 80 of the small meters had non valid reads*	1,608	5.9%	5,343,851	7,144.2	475	0.6
Total	1,657	6.6%	5,352,568	7,155.9	462	0.6

The manual meter reading results included a wide range of inconsistencies: for example, some meters were found in the field that were not on the original route list, there were errors in the recorded meter reads, some meters were only read once, some meters on the route list were taken out, etc. Due to these inconsistencies within the meter reading data provided, WSO had to perform some manual data cleaning to account for the following data quality concerns:

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[23] Volumes have been rounded to the nearest gallon and 0.1 HCF

[24] Data quality concerns include non-valid reads, detector check meters with consumption, small meters with consumption greater than 70,000 gallons per week

[25] Average consumption per meter that registered consumption

- *Non-valid reads on large meters*: Meters with negative consumption were classified as non-valid and filtered out of the entire large meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) large meters and substituted for the non-valid reads. There was one large meter with non-valid reads out of a total of 6 large meters read by LADWP in 1960/Tujunga. It is also worth noting that the average consumption of 199 gal/day/meter is unexpectedly low for the group of Commercial/Industrial/Institutional meters examined.

- *Non-valid reads on fire lines with detector check meters:* As with the non-valid reads on large meters, meters with negative consumption were classified as non-valid and filtered out of the entire large meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) fire lines with detector check meters and substituted non-valid reads. There were 2 fire lines with detector check meters with non-valid reads out of a total of 43 fire lines with detector check meters read by LADWP in 1960/Tujunga.

- *Non-valid reads on small meters:* As with the non-valid reads on large meters, meters with negative consumption were classified as non-valid and filtered out of the entire small meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) small meters and substituted for the non-valid reads. There were 80 small meters with non-valid reads out of a total of 1,608 small meters read by LADWP in 1960/Tujunga.

Small meters with greater than 70,000 gallons during the DMA measurement period: Out of the 1,608 small meters read by LADWP in 1960/Tujunga, 15 of the meters registered consumption over 70,000 gallons per week. The high consumption of these meters may be attributed to meter reading error but it would be in the best interest of LADWP to further investigate these meters. If the consumption is legitimate, then it is likely that these meters are undersized, which can lead to additional wear and tear on a water meter. These meters were filtered out of the small meter dataset and an average per week consumption was determined for the remaining meters that read less than 70,000 gallons during the DMA measurement period. This average consumption per meter (3,323 gallons per week/475 gallons per day) was then substituted for each of the small meters with greater than 70,000 gallons (see Appendix U for list of meters with consumption greater than 70,000 gallons per week).

It is also important to note that 11 of the 43 fire line detector check meters registered consumption during the DMA measurement period. It would be to the benefit of LADWP to investigate the fire line detector meters with consumption for unbilled consumption (see Appendix T for list of fire line detector check meters that registered consumption).

9.3.3 Manual Meter Reading Results – 540/Westwood

In 540/Westwood, 1,814 meters were manually read by LADWP with an estimated total consumption of 228,371,868 gallons between April 7, 2013 and April 14, 2013. The consumption by meter type (i.e. large commercial/industrial/institutional, fire lines with detector check meters, large meter on a dedicated fire line, and small meters) is shown in Table 77.

Table 77: Manual Reading Results for 540/Westwood[26]

Meter Types	Number of Meters	Percentage of Meters with Data Quality Concerns[27]	Consumption over 7 days		Average Consumption per meter per day	
			(gal)	(HCF)	(gal/day)	(HCF/day)
Large Meters Commercial/Industrial/Institutional *Note: 10 of the large meters had non valid reads*	101	9.9%	221,404,439[28]	295,995.2	313,160	418.7
Large Meters – Fire Lines with Detector Check Meters *Note: 81 of the fire line detector check meters registered consumption* *Note: 13 of the detector check meters had non valid reads*	210	44.8%	205,695	275.0	140[29]	0.2
Large Meters – Dedicated Fire Line	0	N/A	0	0.0	0	0
Small Meters *Note: 8 of the meters had consumption over 70,000 gal per week (93.6 HCF/week)* *Note: 82 of the small meters had non valid reads*	1,503	6.0%	6,761,734	9,040.8	643	0.9
Total	1,814	10.7%	228,371,868	305,310.8	17,985	24.0

The manual meter reading results included a wide range of inconsistencies: for example, some meters were found in the field that were not on the original route list, there were errors in the recorded meter reads, some meters were only read once, some meters on the route list were taken out, etc. Due to these inconsistencies within the meter reading data provided, WSO had to perform some manual data cleaning to account for the following data quality concerns:

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[26] Volumes have been rounded to the nearest gallon and 0.1 HCF

[27] Data quality concerns include non-valid reads, detector check meters with consumption, small meters with consumption greater than 70,000 gallons per week

[28] Includes the consumption from Meter #91022460, which registered 117,453,563 gallons during the measurement period

[29] Average consumption per meter that registered consumption

- *Non-valid reads on large meters*: Meters with negative consumption were classified as non-valid and filtered out of the entire large meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) large meters and substituted for the non-valid reads. There were 10 large meters with non-valid reads out of a total of 101 large meters read by LADWP in 540/Westwood.

- *Non-valid reads on fire lines with detector check meters:* As with the non-valid reads on large meters, meters with negative consumption were classified as non-valid and filtered out of the entire small meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) fire lines with detector check meters and substituted non-valid reads. There were 13 fire lines with detector check meters with non-valid reads out of a total of 210 fire lines with detector check meters read by LADWP in 540/Westwood.

- *Non-valid reads on small meters:* As with the non-valid reads on large meters, meters with negative consumption were classified as non-valid and filtered out of the entire large meter dataset. In order to account for the possible consumption of these meters, an average per meter consumption was determined for the remaining valid (positive consumption) small meters and substituted for the non-valid reads. There were 82 small meters with non-valid reads out of a total of 1,503 small meters read by LADWP in 540/Westwood.

Small meters with greater than 70,000 gallons during the DMA measurement period: Out of the 1,503 small meters read by LADWP in 540/Westwood, 8 of the meters registered consumption over 70,000 gallons per week. The high consumption of these meters may be attributed to meter reading error but it would be in the best interest of LADWP to further investigate these meters. If the consumption is legitimate, then it is likely that these meters are undersized, which can lead to additional wear and tear on a water meter. These meters were filtered out of the small meter dataset and an average per week consumption was determined for the remaining meters that read less than 70,000 gallons during the DMA measurement period. This average consumption per meter (4,499 gallons per week/643 gallons per day) was then substituted for each of the small meters with greater than 70,000 gallons (see Appendix U for list of meters with consumption greater than 70,000 gallons per week).

It is also important to note that 81 of the 210 fire line detector check meters registered consumption during the DMA measurement period. It would be to the benefit of LADWP to investigate the fire line detector meters with consumption for unbilled consumption (see Appendix T for list of fire line detector check meters that registered consumption).

The consumption by the large meter population in 540/Westwood was also much greater than anticipated during this week of DMA measurement with an average per meter consumption of 313,160 gallons/meter/day. This is likely due to a data quality concern with one of the meters read during this exercise. Meter number 90122460 recorded 117,453,563 gallons (157,023 HCF) of water during the measurement period. This accounts for more than half of the total volume read by all of the large meters in 540/Westwood. This volume has not been removed from the final results but should be investigated further by LADWP.

9.4 Total Supply in Each DMA

For each DMA/Pressure Zone insertion flow meters were installed at the pressure regulating stations to record the total volume of water supplied into each DMA. The following sections provide the results of the supply volumes recorded for each DMA over the first seven-day period (April 7, 2013 to April 14, 2013).

9.4.1 Total Supply – 517/Boyle Heights

The supply into 517/Boyle Heights was recorded at two pressure-regulating stations (PRS), namely Evergreen & Wabash PRS and Barlow & Soto PRS (see Figure 39 and Figure 40).

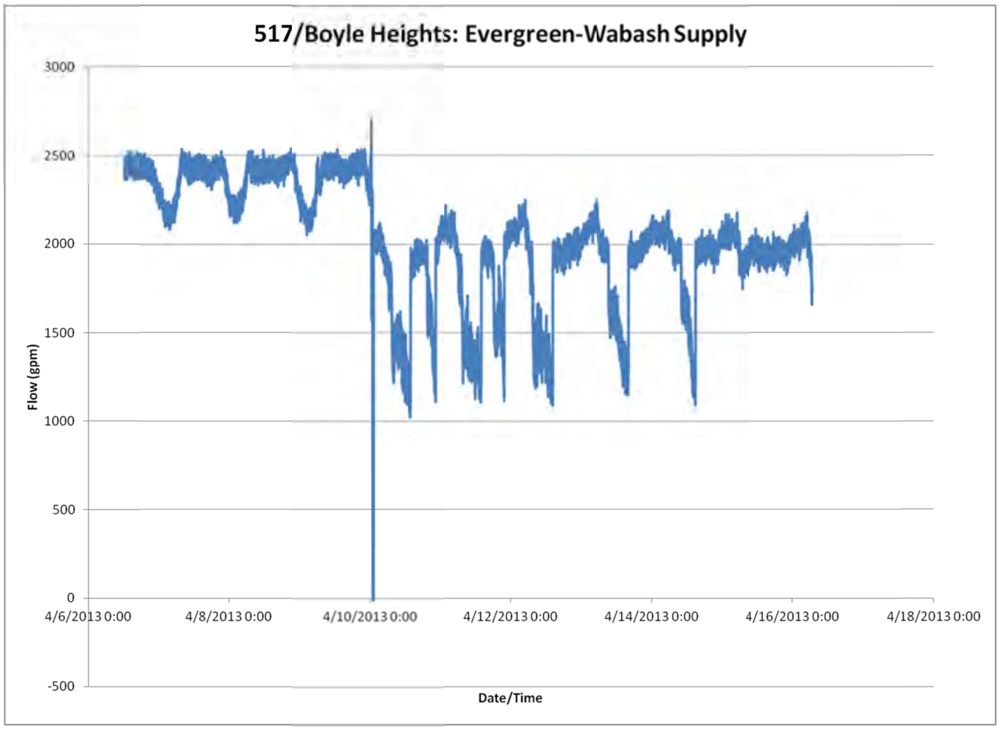

Figure 39: Supply into 517/Boyle Heights recorded at Evergreen-Wabash PRS[30]

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[30] Note: the drop in supply is due to a temporary change in supply arrangement

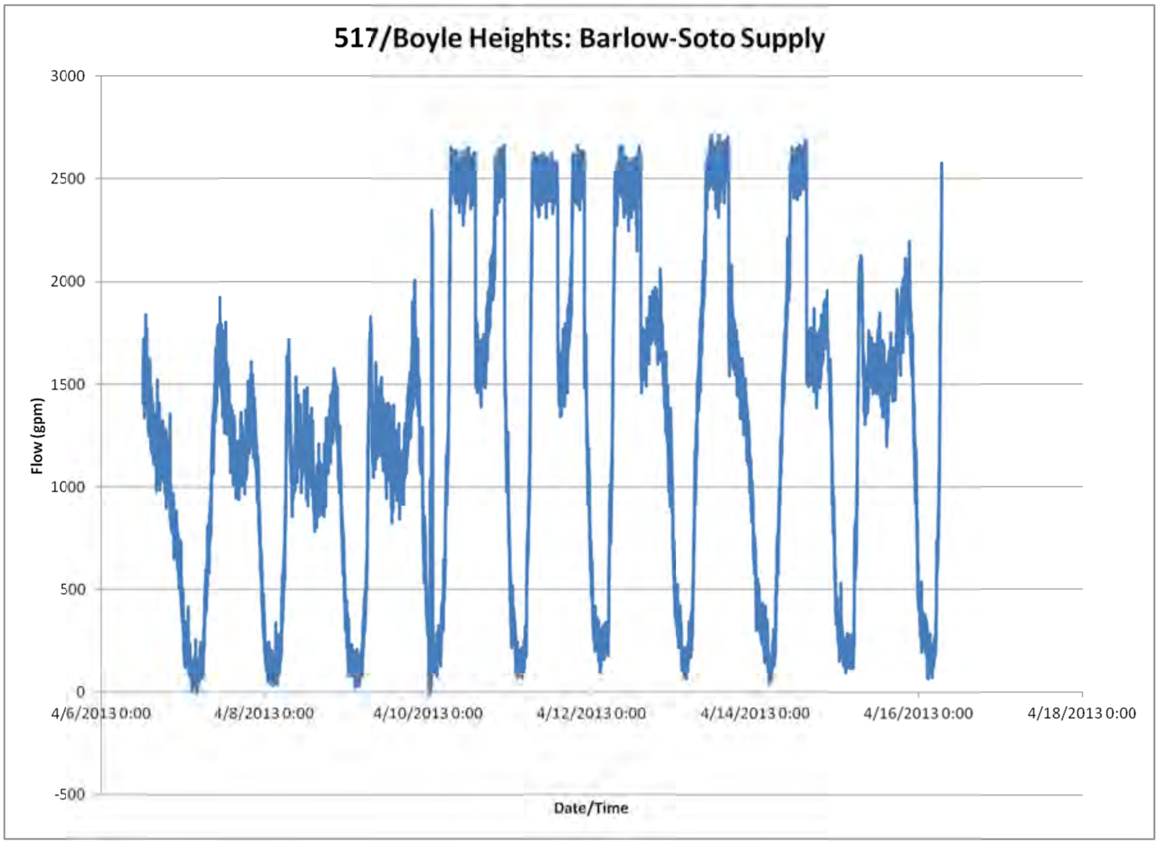

Figure 40: Supply into 517/Boyle Heights recorded at Barlow-Soto PRS[31]

The combined supply into 517/Boyle Heights (see Figure 41) reveals that the total supply into 517/Boyle Heights never drops below 2,000 gpm even during the nighttime. For a zone the size of 517/Boyle Heights such high continuous demands are highly unlikely. Together with LADWP it was agreed that the recorded supply data for 517/Boyle Heights is not reliable and therefore could not be used for assessing a leakage baseline before leak detection and repair.

Possible reasons for the unrealistic supply volumes are that the flow meter at the Evergreen & Wabash PRS is not operating properly, that one/several of the boundary valves or check valves are not closing tight and therefore feed water into an adjacent pressure zone, or that there are customers in 517/Boyle Heights that use a significant amount of water during the nighttime consistently (the results of the manual customer meter reading exercise in 517/Boyle Heights would indicate that this was not the case).

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[31] Note: the increase in supply is due to a temporary change in supply arrangement.

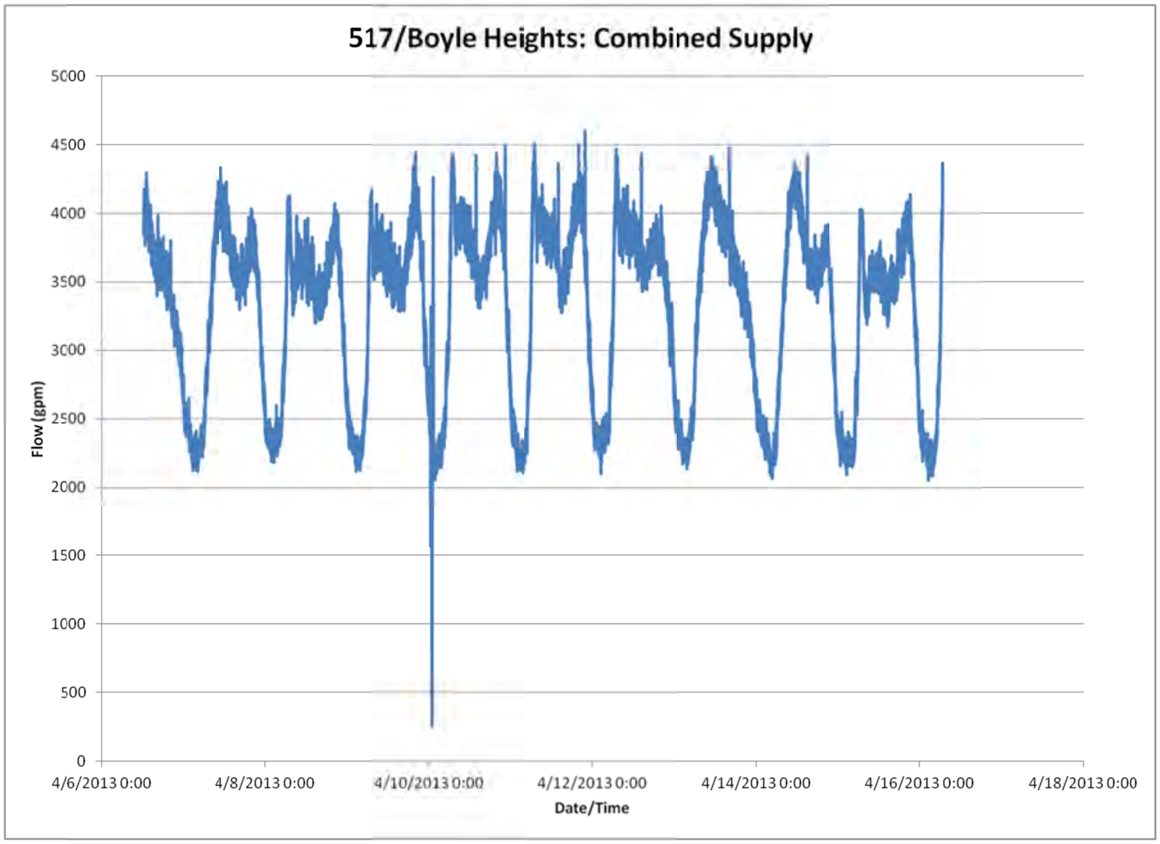

Figure 41: Total Recorded Supply into 517/Boyle Heights

9.4.2 Total Supply – 1960/Tujunga

The supply into 1960/Tujunga was recorded at three pressure-regulating stations (PRS), namely Haines Canyon & St. Esteban PRS, Redmont & Summitrose PRS, and Valmont & Commerce PRS.

The supply data recorded at Haines Canyon & St. Esteban PRS (see Figure 42) shows flow volumes with high fluctuations and even occurrences of negative flows. This sort of data often indicates that the supply volume was too low for the flow meter to accurately record the volume, ultimately making this data unreliable.

The supply data recorded at Redmont & Summitrose PRS (see Figure 43) is the only of the three supply volume recordings for 1960/Tujunga that provides reliable data. The supply data shows a typical urban diurnal supply pattern with maximum daily supplies around 1,700 gpm and minimum demands around 190 gpm.

The supply data recorded at Valmont & Commerce PRS (see Figure 44) show flow volumes with high fluctuations. This sort of data often indicates that the supply volume was too low for the flow meter to accurately record the volume, ultimately making this data unreliable.

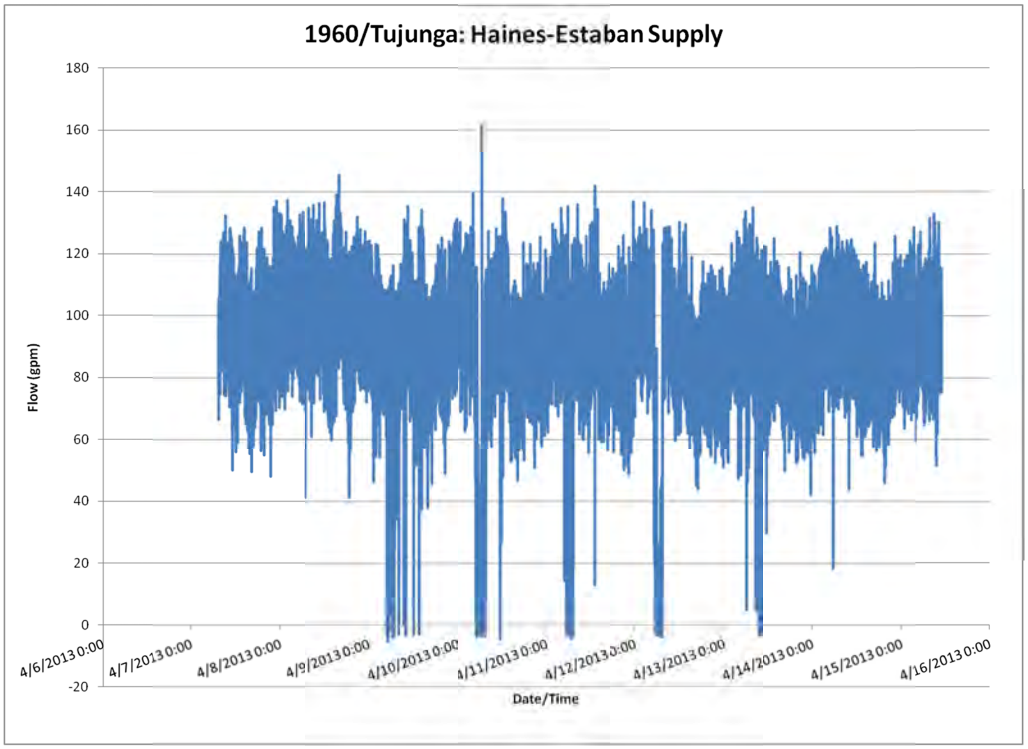

Figure 42: Supply into 1960/Tujunga recorded at Haines-Esteban PRS

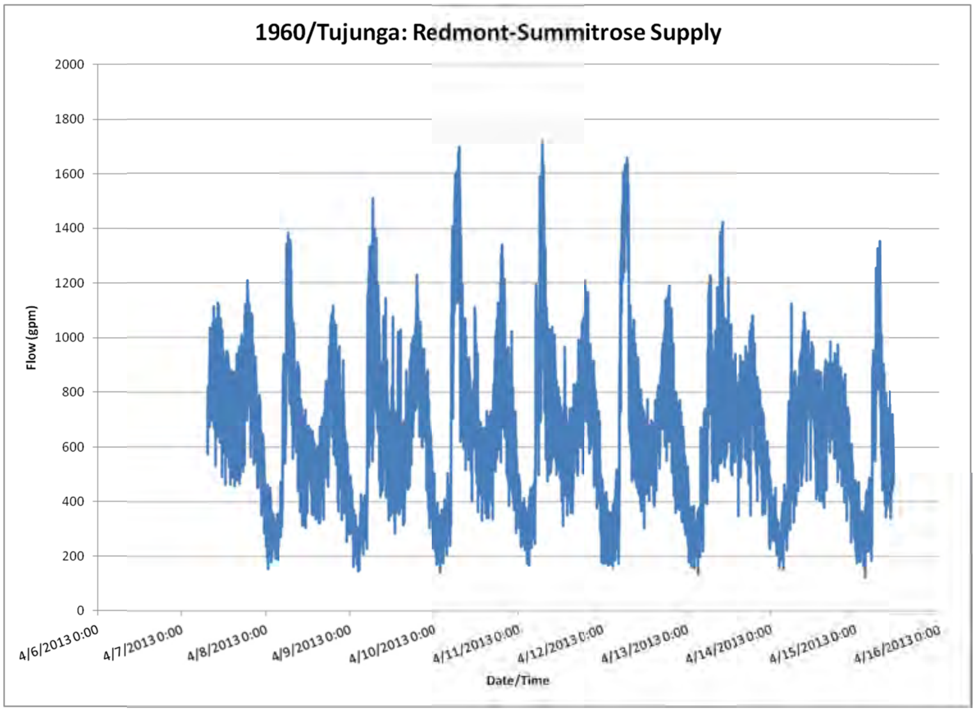

Figure 43: Supply into 1960/Tujunga recorded at Redmont-Summitrose PRS

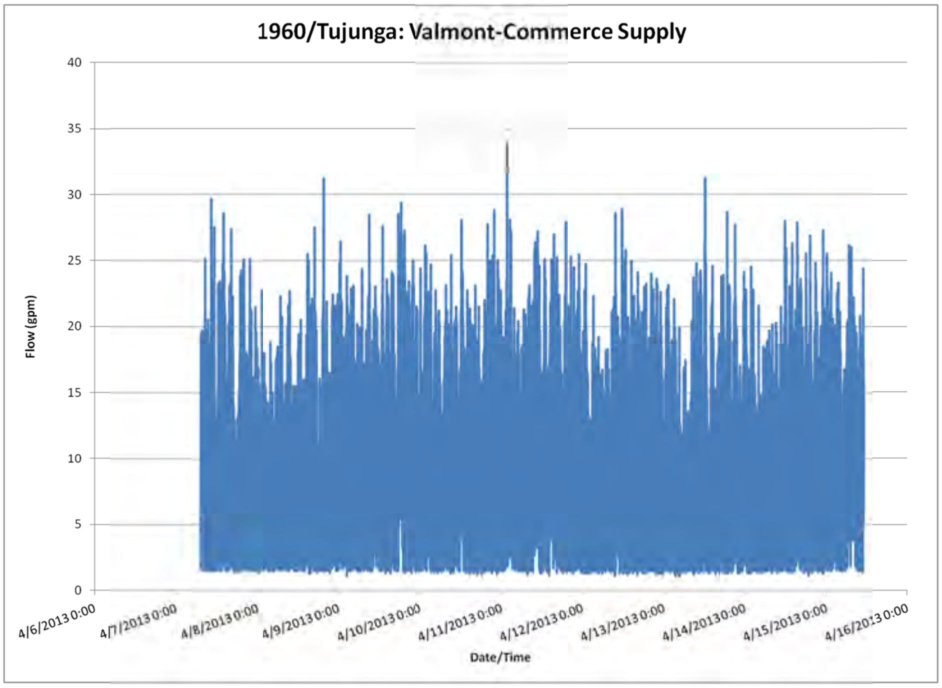

Figure 44: Supply into 1960/Tujunga recorded at Valmont-Commerce PRS

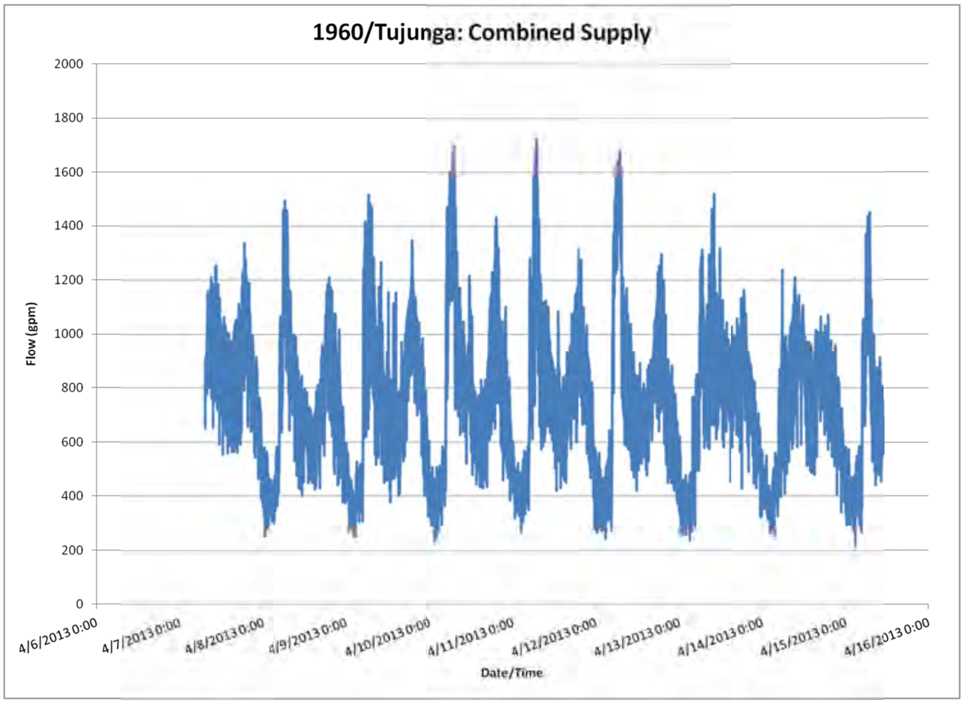

Figure 45: Total Recorded Supply into 1960/Tujunga

The unreliable supply data recorded at the Haines Canyon & St. Esteban PRS and Valmont & Commerce PRS introduces a potential error between 5 and 10 percent to the combined supply volume into 1960/Tujunga (see Figure 45). Therefore, it was not possible to calculate a reliable leakage baseline before leak detection and repair for 1960/Tujunga.

9.4.3 Total Supply – 540/Westwood

The supply into 540/Westwood was recorded at three pressure-regulating stations (PRS), namely Gayley & Landfair PRS, Manning & Wilshire PRS, and Warner & Lindbrook PRS.

The flowmeter at the Manning & Wilshire PRS in the 540/Westwood area had a much higher flow during the testing period than anticipated, and therefore, the maximum flow that was programmed for the meter was not high enough (see Figure 46). Due to this error, the total volume supplied over the seven-day monitoring period could not be calculated reliably. Therefore, it was not possible to calculate a reliable leakage baseline before leak detection and repair for 540/Westwood.

The supply data recorded at the Gayley-Landfair PRS (see Figure 47) show flow volumes with high fluctuations. More investigation is required to determine the cause of these fluctuations at this site, but this first review suggests that the data is unreliable.

The supply data recorded at the Warner-Lindbrook PRS was captured at two points: a 6 inch supply line and 12 inch supply line, presented in Figure 48 and Figure 49 respectively. Both of these supply points show high fluctuations in recorded flow. The 6 inch supply site even presents occurrences of negative flow. More investigation is required to determine the cause of these fluctuations at this site, but this first review suggests that the data is unreliable.

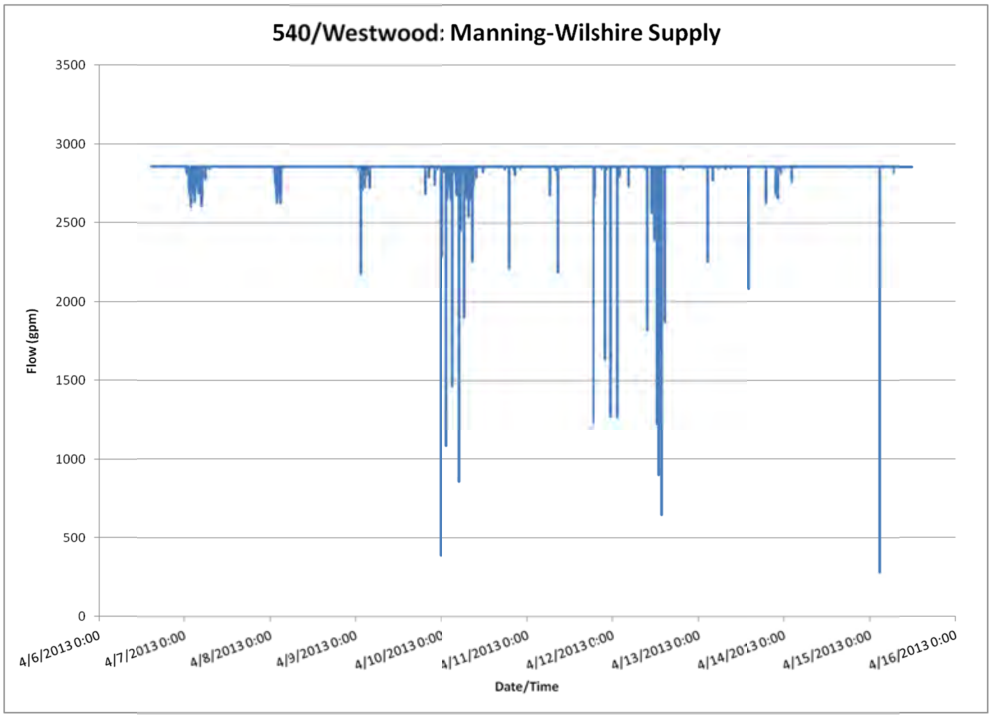

Figure 46: Supply into 540/Westwood recorded at Manning-Wilshire PRS

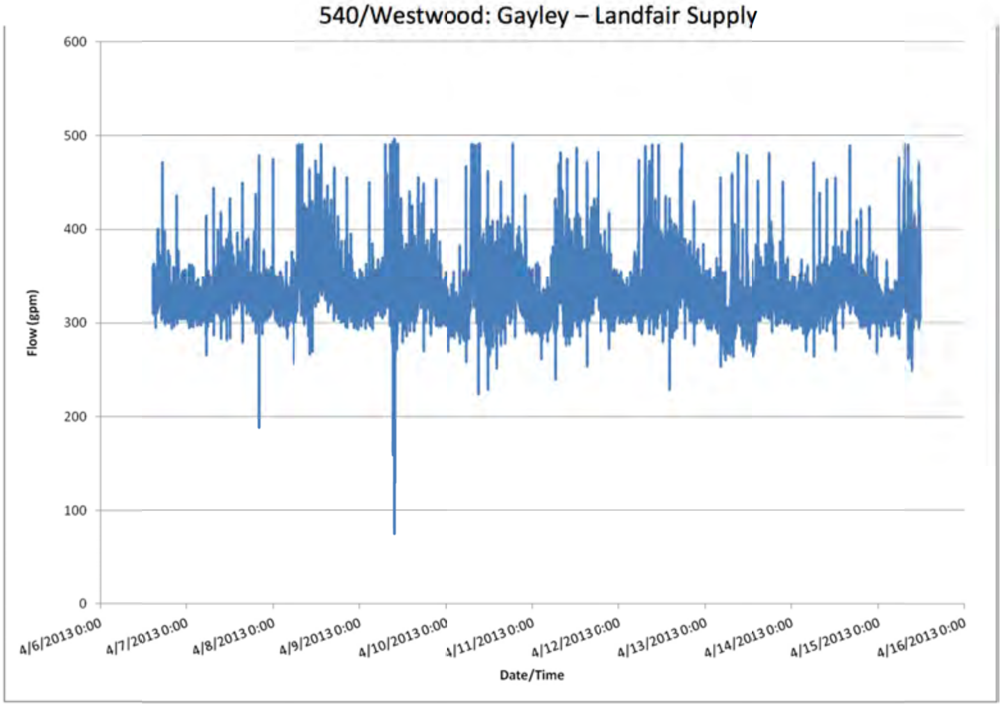

Figure 47: Supply into 540/Westwood recorded at Gayley-Landfair PRS

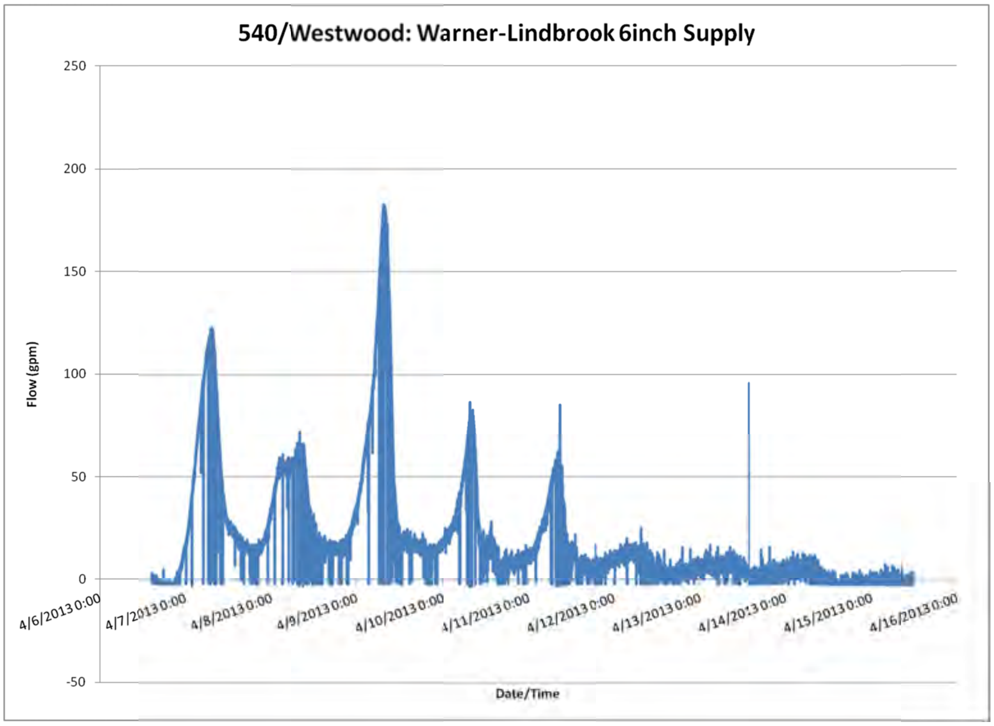

Figure 48: Supply into 540/Westwood recorded at Warner-Lindbrook 6 inch Supply

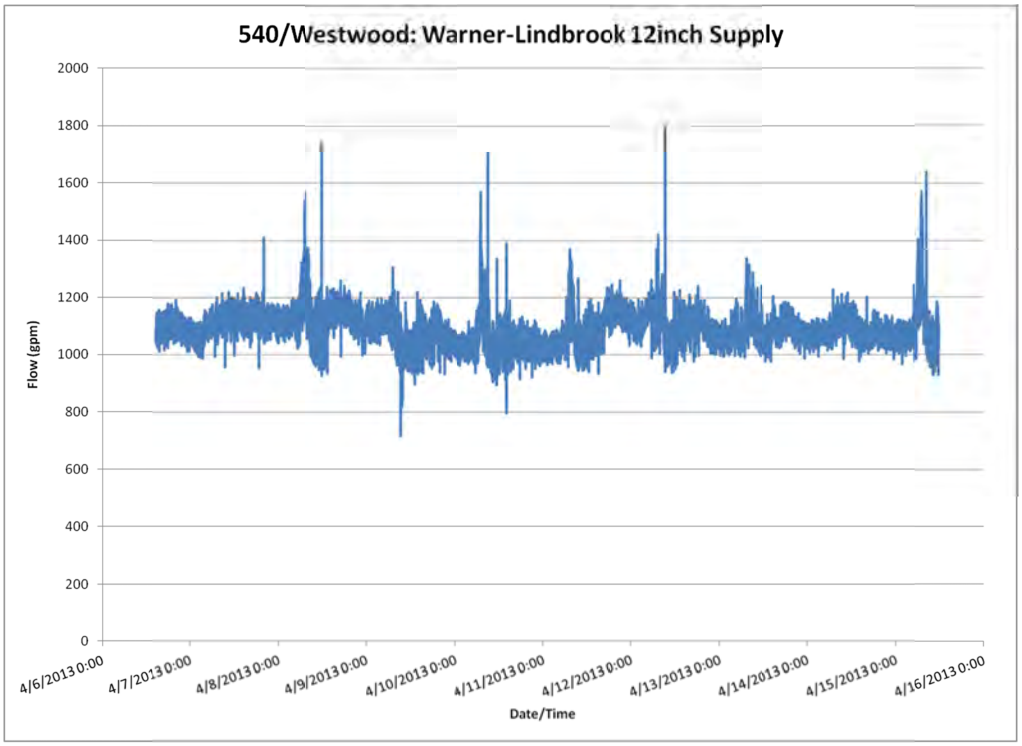

Figure 49: Supply into 540/Westwood recorded at Warner-Lindbrook 12 inch Supply

9.5 DMA Pressure Measurements

In each DMA pressure was recorded over a ten-day period. Between two and three pressure loggers were installed in each DMA's distribution network in addition to pressure loggers installed just downstream of each DMA's PRS. The following sections provide the findings of the pressure measurements.

9.5.1 Pressure Reading Results – 517/Boyle Heights

Pressure in DMA 517/Boyle Heights was recorded at five locations. Downstream of the PRS's at Soto-Wabash and Evergreen-Wabash and at three locations within the DMA at the intersections of Chavez & Mott, Evergreen & 1st, and Whittier & Caldoza. The pressure characteristics provided in Table 78 are derived from the three pressure logging locations within the DMA and do not include the pressure recorded downstream of the PRS's. The average pressure in 517/Boyle Heights is relatively moderate at around 73 PSI, with maximum pressure around 109 PSI and minimum pressure at around 51 PSI. A maximum pressure surge of about 6 PSI (maximum pressure difference between two consecutive pressure recordings) was recorded at Whittier & Caldoza.

Table 78: 517/Boyle Heights Pressure Characteristics

Zone Name	**517/Boyle Heights**
Max Pressure Recorded (PSI)	108.7
Min Pressure Recorded (PSI)	50.8
Maximum Pressure Surges (PSI)	6.2
Average Zone Pressure (PSI)[32]	73.4

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[32] The average pressure represents a simple average based on DMA pressure logging sites (excluding pressures recorded at pressure regulating stations)

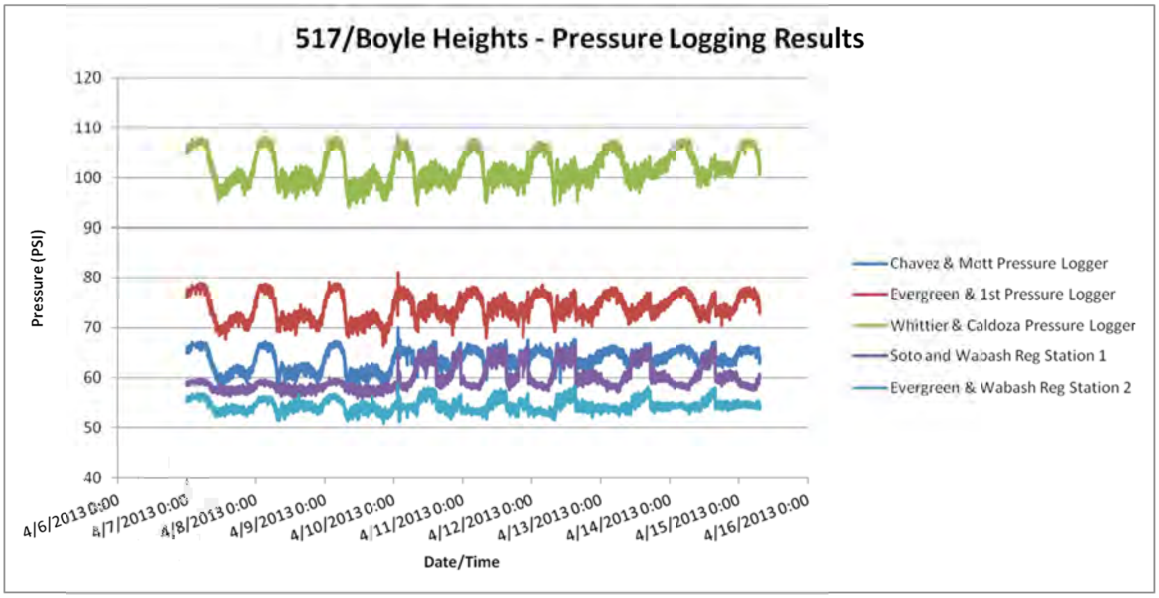

Figure 50: Pressure Recordings in 517/Boyle Heights

The pressure recorded within the DMA shows a consistent pattern of system pressure increasing by about 10PSI when demand is low and then dropping by up to 10 PSI when demand increases. Even though the pressure zone is controlled through fixed outlet pressure control valves, daily pressure fluctuations are noteworthy. These findings indicate that the settings of the PRVs could be revisited and that the pressure zone could benefit from demand based pressure control.

The pressure spikes recorded in Zone 517/Boyle Heights were smaller than the pressure spikes/surges recorded in the other two DMAs. However, it is important to note that the pressure was recorded only at 1.5 minute intervals. Therefore, the true magnitude of the pressure surges in Zone 517/Boyle Heights is likely much higher. High frequency pressure logging should be conducted in Zone 517/Boyle Heights to further validate the magnitude of surges and inform the correct strategy to improve the current pressure management scheme.

9.5.2 Pressure Reading Results – 1960/Tujunga

Pressure in DMA 1960/Tujunga was recorded at five locations. Downstream of the PRS's at Valmont & Commerce PRS, Redmont & Summitrose PRS, and Haines Canyon & St. Esteban PRS and at two locations within the DMA at Hillhaven & Viva and Floramorgan Trail. The pressure characteristics provided in Table 79 are derived from the two pressure logging locations within the DMA and do not include the pressure recorded downstream of the PRS's. The average pressure in 1960/Tujunga is relatively moderate at around 74 PSI, with maximum pressure around 111 PSI and minimum pressure at around 39PSI. The maximum pressure surge of about 16 PSI (maximum pressure difference between two consecutive pressure recordings) was recorded at Hillhaven & Viva.

Table 79: 1960/Tujunga Pressure Characteristics

Zone Name	**1960/ Tujunga**
Max Pressure Recorded (PSI)	110.6
Min Pressure Recorded (PSI)	38.5
Maximum Pressure Surges (PSI)	15.8
Average Zone Pressure (PSI)[33]	73.9

The pressure recorded within the DMA shows a typical pattern of system pressure increasing when demand is low and then dropping when demand is increasing (see Figure 51). Even though the pressure zone is controlled through fixed outlet pressure control valves daily pressure fluctuations are noteworthy. Furthermore, the maximum surges of 15.8 PSI recorded in this zone are significant and should be further investigated. High frequency pressure logging should be conducted in 1960/Tujunga to further validate the magnitude of surges and inform the correct strategy to improve the current pressure management scheme.

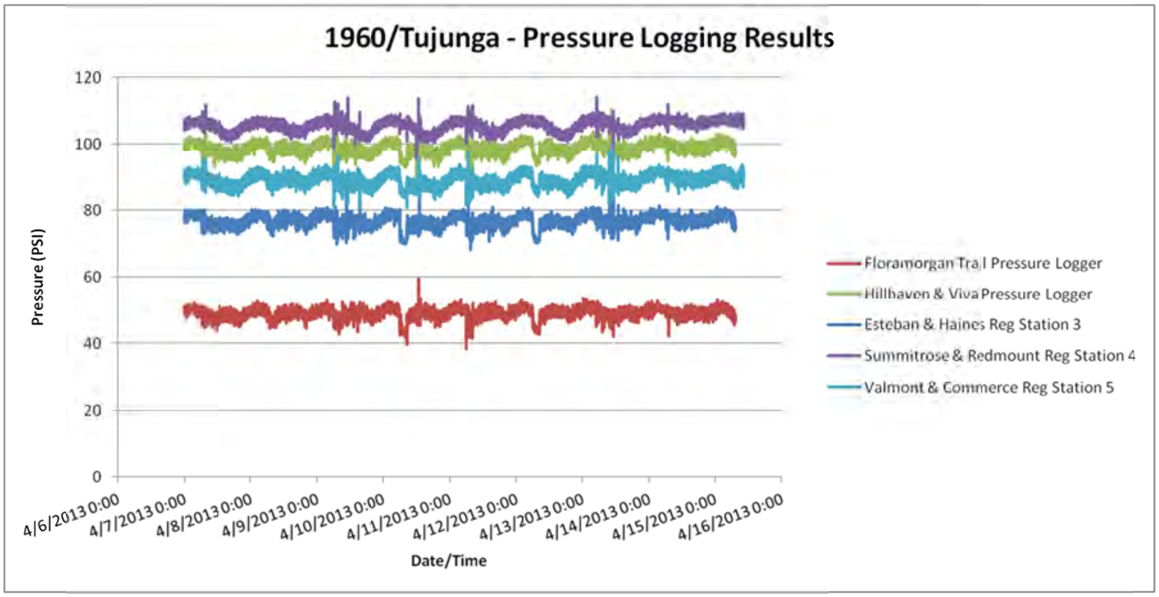

Figure 51: Pressure Recordings in 1960/Tujunga

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[33] The average pressure represents a simple average based on DMA pressure logging sites (excluding pressures recorded at pressure regulating stations)

9.5.3 Pressure Reading Results – 540/Westwood

Pressure in DMA 540/Westwood was recorded at five locations. Downstream of the PRS's at Gayley & LeConte PRS, Manning & Wilshire PRS, and Warner & Lindbrook PRS and at two locations within the DMA at the intersections of Warnal & Rochester and Beverly Glen & Wilshire. The pressure characteristics provided in Figure 52 are derived from the two pressure logging locations within the DMA and do not include the pressure recorded downstream of the PRS's. The average pressure in 540/Westwood is about 10 PSI higher than in the other two pressure zones at around 82 PSI, with maximum pressure around 101 PSI and minimum pressure at around 58 PSI. The maximum pressure surge of about 16 PSI (maximum pressure difference between two consecutive pressure recordings) was recorded at Warnal & Rochester.

Table 80: 540/Westwood Pressure Characteristics

Zone Name	**540/ Westwood**
Max Pressure Recorded (PSI)	100.5
Min Pressure Recorded (PSI)	58.3
Maximum Pressure Surges (PSI)	15.5
Average Zone Pressure (PSI)[34]	82.4

The pressure recorded within the DMA shows a typical pattern of system pressure increasing when demand is low and then dropping when demand is increasing (see Figure 52). Even though the pressure zone is controlled through fixed outlet pressure control valves, pressure fluctuations are noteworthy. Furthermore the maximum surges of 15.5 PSI recorded in this zone are significant and should be further investigated. High frequency pressure logging should be conducted in 540/Westwood to further validate the magnitude of surges and inform the correct strategy to improve the current pressure management scheme. The average pressure of about 82 PSI would also indicate that there is room to reduce the average pressure by about 10%, which would result in Real Loss savings of around 10%.

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[34] The average pressure represents a simple average based on DMA pressure logging sites (excluding pressures recorded at pressure regulating stations)

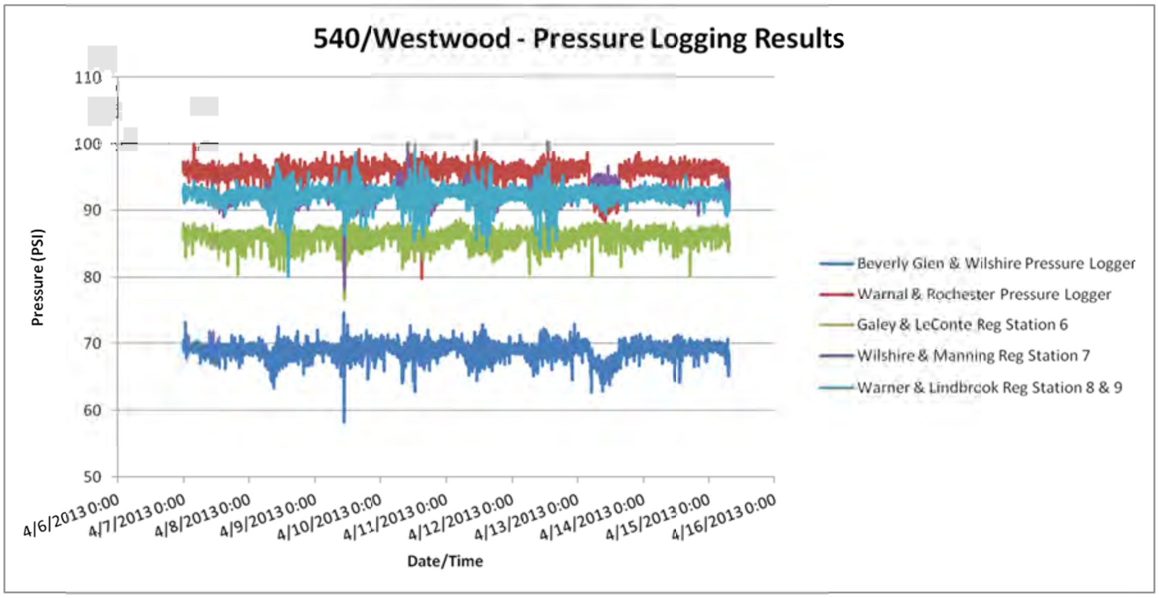

Figure 52: Pressure Recordings in 540/Westwood

Figure 53 provides a more detailed picture of the pressure surge recorded in 540/Westwood. It is important to note that the pressure was recorded only at 1.5 minute intervals. Therefore, the true magnitude of the pressure surges is likely much higher.

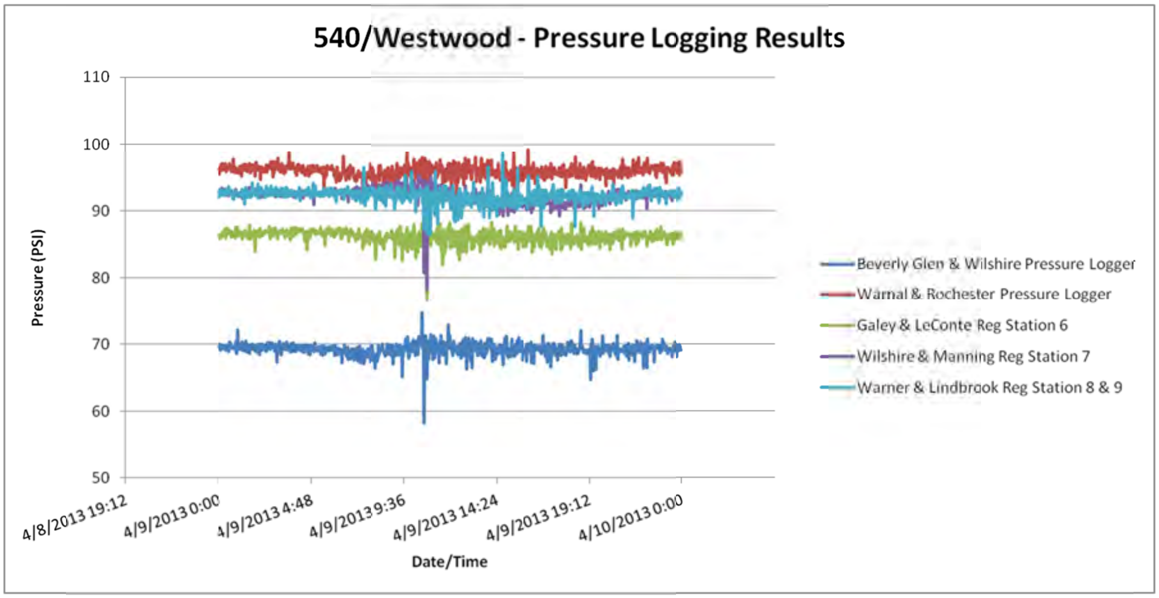

Figure 53: Pressure Recordings in 540/Westwood

9.6 Leakage Loss Baseline before Leak Detection and Repair

Due to the difficulties encountered with recording the volume supplied into each DMA it was not possible to establish a reliable Real Loss baseline for any of the three DMA's. In addition, the leak detection results (described in Section 9.7) indicate a relatively small volume of real losses in each DMA (no leaks were found in Zone 1960/Tujunga). Therefore, it would have been very difficult to accurately discern the recoverable real loss volume in a baseline measurement even with reliable supply volume measurements.

9.7 Pilot Leak Detection

9.7.1 Background

A detailed/comprehensive leak survey was undertaken in all three pressure zones/DMAs to identify all hidden leaks currently running unreported (517/Boyle Heights, 1960/Tujunga, 540/Westwood). This leak survey covered about 95 miles of LADWPs distribution network. Even though this represents only a small portion of the total distribution network it is assumed that the selected pressure zones/DMAs are fairly representative of the conditions found in the rest of the distribution network.

The results of these field investigations (total volume of hidden leakage recovered) can then be compared against the volume of hidden leakage losses estimated for the entire LADWP system. The total volume of hidden leakage losses for the entire system is based on the results of the AWWA water balance and real loss component analysis (see Section 5 and Section 8).

9.7.2 Methodology

The acoustic leak detection survey is probably the most common and familiar leak detection methodology because this approach has been around for many years. There are, however, two distinct types of survey methods that employ different types of acoustic sounding equipment in two distinctly different levels of detail. (*Source: Water Loss Control, Second Edition; Thornton, Sturm & Kunkel, 2008*)

- **General Survey -** This survey method is often referred to as a valve and hydrant survey in the United States. The method involves only listening to fire hydrants and valves on distribution system mains in order to detect any leak sound. Service connections are not sounded. Fire hydrants can be found at more or less constant distances providing a good coverage of most areas. In this survey mode geophones and leak noise correlators are generally only used for pinpointing a leak. It is a time-saving leak detection methodology which has one shortfall; service connection leaks often go undetected in this mode, especially if the area mainly consists of non-metallic mains and service connections.

- **Comprehensive Survey -** This survey method listens to all available fittings on the mains ***and*** service connections. Geophones are used to sound above the mains in case contact points are far apart. Once a leak sound is detected, geophones and leak noise correlators can be used for pinpointing the leak. Even though this leak detection method is time consuming it is the most effective way to detect all detectable leaks in the system, including service connection leaks.

WSO's leak detection work throughout North America and research conducted for the Water Research Foundation (formerly the American Water Works Research Foundation) has clearly highlighted that a comprehensive leak detection approach is necessary to detect all unreported hidden leaks in a distribution network.

The leak detection survey was conducted by using sonic leak detection equipment, which included a Fluid Conservation System (FCS) Lmic survey instrument and a FCS ACCUCOR 3000 digital leak noise correlator. WSO's leak detection specialist, Cliff McAfee, completed a detailed leak detection campaign in which he made direct contact with all accessible distribution system appurtenances, including customer meters, fire hydrants, blow-off valves and back flow preventers with a FCS Lmic sonic leak detection probe. In areas devoid of accessible appurtenances, a ground microphone was used to investigate the underground mains at intervals smaller than 15 feet.

All leaks identified were documented, the leak flow rate was estimated, and the location of the leak was identified using a standard leak report to guide the repair efforts. These leak reports were then handed over to the LADWP repair crews to implement the necessary repairs.

9.7.3 Leak Detection Results

WSO found 11 leaks in 517/Boyle Heights, one leak in 540/Westwood and no leaks in 1960/Tujunga (see Table 81). Out of the total twelve leaks detected, three leaks were service connection leaks, three were valve leaks and six were hydrant leaks.

The fact that the number of leaks identified in each pressure zone varies significantly is typical of most distribution networks; leakage is not evenly distributed. Each system has areas with higher break frequencies and resulting leakage and areas where only a small number of hidden leaks exist. Therefore it's important to develop a leakage management strategy that allows LADWP to direct leak detection efforts towards areas where leakage is higher than the average and where the system is experiencing higher break frequencies.

It is estimated that by repairing all leaks that have been identified through proactive leak detection about 73,440 gallons per day (26.8 MG/Year, 82.2 Acre-ft/year) in leakage losses will be saved. This estimated reduction in leakage loss volume is based on the estimated flow rates of each leak detected during the comprehensive leak detection survey. It is important to consider that the estimated leak flow rates represent best estimates and therefore have a certain level of uncertainty.

Table 81: Leak Detection Results for the Detailed Leak Detection Pilot

Pressure Zone	Leak #	Leak Type	Est. Flow (gpm)	Est. Flow			
				(gal/day)	(HCF/day)	(MG/Year)	(AF/Year)
517/Boyle Heights	1	Service	10				
	2	Service	10				
	3	Valve	1				
	4	Valve	2				
	5	Valve	2				
	6	Hydrant	2				
	7	Hydrant	5				
	8	Hydrant	2				
	9	Service	10				
	10	Hydrant	5				
	11	Hydrant	1				
540/Westwood	12	Hydrant	1				
1960/Tujunga	0	NA	NA				
Total			**51**	**73,440**	**98.2**	**26.8**	**82.2**

9.7.4 Cost Benefit Analysis

It is estimated that as a result of the leak detection survey conducted by WSO and the leak repair work carried out by LADWP about 26.8 MG/year (82.2 Acre-ft/year) in hidden leakage losses will be saved. This estimated reduction in leakage loss volume is based on the estimated flow rates of each leak detected during the leak detection campaign. It is important to consider that these leak flow rates represent best estimates and have therefore a certain level of uncertainty. Therefore, in order to be conservative, it is recommended to assign a confidence limit of +/- 25% associated to the estimated leakage flow rates. As a result the annual savings from all leaks detected, range from 20.1 MG to 33.5 MG (61.7 Acre-ft to 102.8 Acre-ft), with the best estimate being 26.8 MG (82.2 Acre-ft/year).

Table 82 shows a cost benefit analysis of the leak detection campaign based on the leakage estimates by WSO and the assigned confidence limits of the results. With a total cost of $28,120 for a detailed and comprehensive leak detection survey (using LADWP internal cost of $296/mile) and a cost of water of $2,599/MG ($847 per acre foot - MWD Tier 1 treated water rate for 2013) the leak detection program in these three pressure zones has a simple payback period of 0.8 years (about 10 months) based on the best estimate of recovered hidden leakage. Even when considering the most conservative estimate for hidden leakage recovered, the payback for the leak detection efforts is only 1.1 years. Section 11 discusses the economic optimum leak detection frequency for the entire system and provide a general strategy for proactive leak detection in LADWP’s distribution network.

Table 82: Cost Benefit Analysis for the Combined Leak Detection Results in all Three Pressure Zones

	Lower Estimate	**Best Estimate**	Upper Estimate
Detailed Leak Detection Campaign Recovered Leakage (gall/service connection/day)	6	**7.5**	9
Detailed Leak Detection Campaign Recovered Leakage (MGD)	0.055	**0.073**	0.092
Total Annual Recovered Leakage (MG)	20.1	**26.8**	33.5
Cost of Water per MG ($847/ac-ft)	$2,599	**$2,599**	$2,599
Estimated Cost/Value of Recovered Water per Year	$52,258	**$69,677**	$87,096
Cost of Leak Detection ($296/mile)	$28,120	**$28,120**	$28,120
Cost of Leak Repair ($2,500/repair)	$30,000	**$30,000**	$30,000
Payback Period (yr)	1.11	0.83	0.67

It is important to note that leaks will continue to occur due to the aging infrastructure. This is referred to as the natural rate of rise of leakage. The natural rate of rise of leakage is not a fixed rate: it can vary seasonally or with an operational change for the utility.

9.7.5 Hidden Loss Volume based on Leak Detection Results vs. Hidden Losses based on Water Balance and Real Loss Component Analysis.

As initially mentioned one of the purposes of this pilot leak detection task was to collect data on recoverable hidden leakage volume from the field and compare these results against the system wide estimates of recoverable hidden leakage volume. The standardized performance metric of hidden losses per connection per day was used for comparison.

Based on the manual meter readings carried out in each of the three pressure zones the total number of service connections in all three zones was determined to be 9,756. By dividing the total volume of hidden losses identified and recovered by the number of service connections, a standard leakage performance indicator can be calculated, namely, hidden losses per service connection per day. For the three pressure zones examined in the WSO Leak Detection Pilot, the hidden losses per connection per day were about 8 gallons per service connection per day.

For the system wide estimate of hidden losses, the results of the component analysis of real losses were used. In this process, the system wide level of real losses is determined by deducting authorized consumption from the system input volume for the audit period. Next, the hidden loss volume is determined by deducting the real loss volumes of reported failures and background leakage from the total real loss volume. Section 8 outlines this analysis in great detail.

In addition to the leak detection pilot discussed in this section, LADWP also implemented leak detection training with another leak detection consultant (ME Simpson). As part of this training 248 miles of distribution network were surveyed. However, the level of detail of this survey was not comparable to the leak detection work carried out by WSO. The leak detection work carried out as part of the leak detection training program did not listen to every service connection. Instead, the survey only listened to a select number of service connections, which makes comparing the results of the two leak detection surveys unreliable.

Table 83: Comparison of Hidden Loss Volume Assessments

		Water Audit and Real Loss Component Analysis for Entire System	**WSO Leak Detection Pilot**	**Leak Detection Training**
Miles of Mains		7,227	95	248
Number of Service Connections		722,112	9,756	24,800
Total # of Leaks		NA	12*	13*
Hidden Losses/ Undetected Leakage	(MG/Year)	792	26.81	21.94
	(acre-ft/Year)	2,430.56	82.28	67.33
Hidden Losses per Connection per day	(gal/serv conn/day)	3	8	2
	(HCF/serv conn/day)	0.004	0.011	0.003

*The total number of leaks found in the WSO Leak Detection Pilot is detailed in Table 81; the total number of leaks found in the Leak Detection Training is detailed in ME Simpson's report.

Comparing the hidden loss volume identified and recovered in the field by WSO leak detection efforts against the system wide estimated volume of hidden losses indicates that the water balance and real loss component analysis results are potentially underestimating the true volume of hidden losses in LADWP's system. This is due to the water audit data quality issues discussed in Section 8. The hidden loss volume calculated by the water audit and component analysis has a relatively wide level of confidence, mainly due to uncertainties in the accuracy of the system input volume.

The results of the leak detection training are difficult to interpret since the survey method used was not the same as survey method used by WSO (detailed survey listening to every service connection and valve and hydrant). Since two different survey methods were used, it is not feasible to compare the two leak detection results.

An important take away from this analysis is that the hidden loss volume as estimated by any of the three results is low and reflects a system with an overall low level of leakage. However, as the cost benefit analysis shows, given the relatively high cost of water, proactive leak detection to identify hidden losses is an economically viable option. The economic level of leakage analysis will further analyze the potential for proactive leak detection in LADWP's distribution system and develop an intervention strategy (see Section 11).

9.8 Field Quantification of Real Losses Recommendations

The results of this component of the project provide valuable information on opportunities to improve LADWP's water loss control strategies.

District Metered Area Approach: the installation of temporary pilot DMAs has provided valuable insight. The main lessons learned moving forward are:

- The selection of appropriate flow meters is crucial for accurate flow measurements in the DMAs. It is suggested that for future DMAs permanent meter installations should be considered using turbine or electromagnetic flow meters.
- If a DMA has multiple feeds it is necessary to consider that during low demand periods, or in other cases most of the time, some feeds will show only very little demand if one feed is taking over as the lead supplying the vast majority of DMA demand. As a result the feeds with low demand do not experience enough flow for the flow meter to record accurately. In these cases the feeds providing very little to no flow should be used as standby feeds, only opening up in case demand in the DMA requires additional supply.
- All boundary valves and check valves need to be investigated to guarantee that the DMA is hydraulically discrete.
- Future DMAs should be combined with AMI trial areas for accurate and easily available consumption data.

Customer metering: The manual meter reading exercise provided valuable insight. The main findings are:

- In the effort to comprehensively read all of the meters in each DMA, discrepancies between the meter information in CIS and the actual meters were unveiled. A reliable billing database with up-to-date meter characteristics is an important tool in determining water losses (as demonstrated both for the water loss baseline calculations for each DMA and for the apparent loss analysis outlined in Section 4).
- A significant number of the fire line detector meters registered consumption which is consumption that usually goes unbilled since those meters are not read on a regular bases. It would be to the benefit of LADWP to further investigate what portion of fire line detector meters register consumption and based on the findings take actions that will reduce the volume of unbilled consumption from these fire lines. As an intermediate step, it is recommended that the fire line detector check meters are read on a regular basis. As AMR/AMI technology is implemented throughout LADWP's service

area, these fire line detector check meters should also be upgraded to be AMR/AMI compatible.

Pressure Management: the pressure data recorded in each of the three pressure zones provided valuable insight into the distribution of pressure in these pressure zones. The main findings of the pressure data analysis are:

- Pressure fluctuations in these pressure zones are noteworthy with maximum recorded pressure surges of about 16 PSI. Since the pressure was only recorded every 1.5 minutes the actual pressure surges can be assumed to be much higher.
- Pressure fluctuations immediately downstream of the PRV stations and then within the distribution network would indicate that the pressure control valves were not able to provide a smooth fixed outlet pressure curve. This could be due to not enough flow through the PRVs or not enough pressure differential across the PRV, or current PRV set points that are not optimized, etc.
- At around 82 PSI the average pressure in Zone 540/Westwood is about 10 PSI higher than in the other two pressure zones, which indicates that the average pressure could be reduced further to achieve savings in real losses and extend the infrastructure life span.
- High frequency pressure logging should be performed in all three pressure zones to assess the full extent of the pressure surges. Necessary steps to avoid pressure surges in the pressure zones should be taken.
- Demand based pressure control should be investigated as an option to optimize the current pressure management scheme in each pressure zone.

Proactive Leak Detection: the results of the comprehensive and detailed leak detection pilot in the three pressure zones provided field data on the volume of hidden leakage in LADWPs distribution network. The main findings from the leak detection results are:

- The leak detection results indicate that the volume of hidden leakage in these zones – and overall in LADWP’s entire distribution network – is relatively low.
- The number of leaks identified in each pressure zone varies significantly reflecting a typical picture found in most distribution networks; leakage is not evenly distributed.
- Even though the volume of hidden leakage detected and recovered in these three areas was relatively small, the leak detection pilot has a simple payback period of 0.8 years (about 10 months), indicating that proactive leak detection is an economically viable water loss control strategy for LADWP.
- A proactive leak detection strategy should be implemented according to the economic intervention strategy developed under Task 8 and 9.

SECTION 10. ECONOMICALLY EFFICIENT APPARENT LOSS REDUCTION STRATEGIES

10.1 Apparent Loss Reduction Strategies for Small Meter Under-Registration

To better understand how much LADWP should invest to reduce apparent loss volumes incurred from small meter under-registration, WSO examined the costs and benefits of small meter replacement. Evaluating whether a small meter should be replaced requires a close look at whether the revenue savings in improved registration accuracy outweigh the upfront costs of the purchase and installation of a new meter.

10.1.1 Example of Evaluation of Small Meter Replacement: 5/8 x 3/4" Trident Meters

The following example presents the evaluation of meter replacement for the group of 5/8 x 3/4" Trident meters. Table 84 describes the count, consumption, and test results for this meter group.

Table 84: Test Results and Apparent Loss Totals for 5/8 x 3/4" Trident Meters

METER GROUP	SIZE	5/8 x 3/4"
	MAKE	Trident
	METER POPULATION	135,316
TEST RESULTS	SAMPLE SIZE TESTED	104
	AVERAGE UNDER-REGISTRATION	3.44 %
	CONFIDENCE LIMIT OF UNDER-REGISTRATION	+/- 1.57 %
FY 2010 -2011 VOLUMES	BILLED METERED AUTHORIZED CONSUMPTION	17,874,963.00 HCF
	APPARENT LOSSES	636,180.33 HCF

In order to convert the total apparent loss volume to a value of lost revenue, the audit period's consumption was allocated to each of the four water prices used in LADWP for different rate schedules (an average price was assigned to rate codes without a rate schedule assigned). Upon partitioning the consumption to these rate schedules, an apparent loss volume was calculated for each rate schedule and the lost revenue was determined. Table 85 outlines the calculation of lost revenue for the 5/8 x 3/4" Trident meters.

Table 85: Lost Revenue Calculation for 5/8 x 3/4” Trident Meters

RATE SCHEDULE PRICE	FY 2010 – 2011 BMAC	APPARENT LOSSES	LOST REVENUE
($ / HCF)	**(HCF)**	**(HCF)**	**($)**
1.432	4,215	150.01	$ 214.82
3.165 (avg)	8	0.28	$ 0.90
3.706	12,019,095	427,766.58	$1,585,302.95
3.716	4,967,428	176,793.65	$ 656,965.21
3.806	884,217	31,469.80	$119,774.05
TOTAL	**17,874,963**	**636,180.33**	**$2,362,257.93**

After replacing this group of meters, not all of the $2,362,257.93 in lost revenue due to under-registration would be recovered. New meters also under-register and incur apparent losses; for this analysis, we assume that new meters under-register by 0.5% (this is a common manufacturer’s quote for accuracy of new meters). To determine the recovered revenue, we must compare the new meters’ revenue loss to the replaced meters’ revenue loss. Table 86 outlines the calculation behind the increasing water earnings.

Table 86: Calculation of Increased Water Earnings
for 5/8 x 3/4” Trident Meter Replacement

OLD METER LOST REVENUE (A)	$2,362,257.93
APPARENT LOSSES FOR NEW METERS *(assuming 0.5% under-registration)*	89,823.93 HCF
WEIGHTED AVERAGE PRICE / HCF	$ 3.71
LOST REVENUE FOR NEW METERS (B)	$333,533.26
INCREASE IN WATER EARNINGS (A-B)	**$2,028,724.67**

These increased water earnings must be compared to the costs of meter replacement. To evaluate the cost of a new meter, LADWP provided cost figures for the new meter purchase, installation labor, and benefits. Table 87 shows the cost of replacing all the 5/8 x 3/4” Trident meter according to these figures.

Table 87: Cost of Replacement for 5/8 x 3/4” Trident Meters

COST OF ONE 5/8 x 3/4” METER (including labor and benefits)	$196.07
COUNT OF METERS	135,316
TOTAL COST OF REPLACEMENT	$ 26,531,408.12

To properly weigh the benefits (increase in water earnings due to less apparent losses) against these costs, a 10-year Net Present Value (NPV) calculation was undertaken. In Table 88, ten years of increased earnings are presented. For these analyses to be conservative in its assumptions, each year the savings diminish slightly based on the assumption that the new meter's accuracy will decrease with use (0.1% decrease in accuracy per year is used here).

Table 88: Increased Earnings Projections for 10 Years –
5/8 x 3/4" Trident Meter Replacement

INITIAL INVESTMENT		$(26,531,408.12)
INCREASED EARNINGS	**YEAR 1**	$ 2,028,724.67
	YEAR 2	$ 1,961,615.36
	YEAR 3	$ 1,894,370.88
	YEAR 4	$ 1,826,990.84
	YEAR 5	$ 1,759,474.81
	YEAR 6	$ 1,691,822.38
	YEAR 7	$ 1,624,033.14
	YEAR 8	$ 1,556,106.68
	YEAR 9	$ 1,488,042.58
	YEAR 10	$ 1,419,840.41
	TOTAL INCREASED EARNINGS	$ 17,251,021.74
NET PRESENT VALUE		$ (13,001,220.66)
INTERNAL RATE OF RETURN		- 8%

Table 88 also shows two indicators of long-term investment appraisal: net present value and internal rate of return. In this case, the net present value (using a standard discount rate of 5%) is -$13,001,220.66 and the internal rate of return is -8%. Both measures return a negative value, suggesting that the initial investment far outweighs the savings generated over the course of ten years. Using the first year's savings and the initial investment cost, the simple payback would amount to 13.08 years.

This analysis shows that replacing all of the 5/8 x 3/4" Trident meters is not cost-effective.

10.1.2 Summary of Economic Analysis for Small Meter Replacement

The same analysis featured in Section 10.1.1 was applied to all size-make categories for small meters, and Table 89 summarizes the results.

Table 89: Economic Analysis of Small Meter Replacement

				REPLACED METER			NEW METER						
SIZE	MAKE	Total Population (CIS)	BMAC FY10/11 ACROSS ALL RATES	APP LOSSES	TOTAL REVENUE LOSS	COST TO REPLACE ALL METERS	APP. LOSSES (.5% under-registration)	WEIGHTED AVG PRICE	REVENUE LOSSES	INCREASED WATER EARNINGS per YEAR (based on year 1)	SIMPLE PAYBACK	NET PRESENT VALUE	INTERNAL RATE OF RETURN
		Meters	HCF	HCF	$	$	HCF	$/HCF	$	$	years	$	%
5/8”	ABB	53	7,208	232	$861	$10,392	36	$3.71	$134	$727	14.3	($5,640)	-9%
5/8”	BAD	457	78,937	2,542	$9,433	$89,604	397	$3.71	$1,472	$7,962	11.3	($37,550)	-5%
5/8”	HER	2	88	3	$11	$392	0	$3.71	$2	$9	44.2	($334)	-24%
5/8”	SEN	290	31,775	1,023	$3,796	$56,860	160	$3.71	$592	$3,203	17.8	($35,916)	-13%
5/8”	TRI	2,569	329,844	10,623	$39,427	$503,704	1,658	$3.71	$6,152	$33,275	15.1	($286,144)	-10%
5/8”	TRP	421	48,544	1,563	$5,803	$82,545	244	$3.71	$905	$4,897	16.9	($50,525)	-12%
5/8”	UNK	6	866	28	$104	$1,176	4	$3.72	$16	$88	13.4	($604)	-8%
5/8 x 3/4”	ABB	5,825	767,682	31,896	$118,467	$1,142,108	3,858	$3.71	$14,328	$104,139	11.0	($429,697)	-4%
5/8 x 3/4”	BAD	50,332	6,686,109	26,623	$98,847	$9,868,595	33,599	$3.71	$124,743	($25,897)	-381.1	($10,867,098)	NA
5/8 x 3/4”	CAL	4	614	20	$73	$784	3	$3.71	$11	$62	12.7	($380)	-7%
5/8 x 3/4”	EMP	22	3,174	102	$380	$4,314	16	$3.72	$59	$321	13.4	($2,214)	-8%
5/8 x 3/4”	HER	153	16,732	539	$2,001	$29,999	84	$3.71	$312	$1,689	17.8	($18,958)	-13%
5/8 x 3/4”	SEN	6,921	807,528	57,862	$214,876	$1,357,000	4,058	$3.71	$15,069	$199,807	6.8	$89,388	6%
5/8 x 3/4”	TRI	135,316	17,874,963	636,180	$2,362,258	$26,531,408	89,824	$3.71	$333,533	$2,028,725	13.1	($13,001,221)	-8%
5/8 x 3/4”	TRP	5,584	629,028	20,258	$75,177	$1,094,855	3,161	$3.71	$11,730	$63,447	17.3	($680,027)	-12%
5/8 x 3/4”	UNK	83	11,884	383	$1,425	$16,274	60	$3.72	$222	$1,203	13.5	($8,408)	-8%
5/8 x 3/4”	WOR	119	17,142	552	$2,048	$23,332	86	$3.71	$320	$1,728	13.5	($12,032)	-8%
3/4 x 1”	ABB	4,617	768,851	24,083	$89,444	$975,849	3,864	$3.71	$14,349	$75,095	13.0	($487,836)	-8%
3/4 x 1”	BAD	19,989	3,845,460	37,823	$140,376	$4,224,875	19,324	$3.71	$71,719	$68,657	61.5	($4,153,826)	NA
3/4 x 1”	CAL	23	3,963	51	$191	$4,861	20	$3.71	$74	$117	41.5	($4,430)	NA
3/4 x 1”	EMP	10	1,809	24	$87	$2,114	9	$3.71	$34	$54	39.5	($1,916)	NA
3/4 x 1”	HER	670	115,268	1,498	$5,564	$141,611	579	$3.72	$2,152	$3,412	41.5	($129,040)	NA
3/4 x 1”	SEN	3,917	586,251	35,507	$131,682	$827,897	2,946	$3.71	$10,926	$120,757	6.9	$34,614	6%
3/4 x 1”	TRI	258,820	43,180,389	474,514	$1,760,861	$54,704,195	216,987	$3.71	$805,211	$955,650	57.2	($52,479,419)	NA
3/4 x 1”	TRP	10,184	1,398,931	18,176	$67,408	$2,152,490	7,030	$3.71	$26,071	$41,337	52.1	($2,000,191)	NA
3/4 x 1”	UNK	95	13,803	179	$666	$20,079	69	$3.71	$257	$408	49.2	($18,576)	NA
3/4 x 1”	WOR	104	18,523	241	$894	$21,981	93	$3.71	$346	$548	40.1	($19,963)	NA

				REPLACED METER			NEW METER						
SIZE	MAKE	Total Population (CIS)	BMAC FY10/11 ACROSS ALL RATES	APP LOSSES	TOTAL REVENUE LOSS	COST TO REPLACE ALL METERS	APP. LOSSES (.5% under-registration)	WEIGHTED AVG PRICE	REVENUE LOSSES	INCREASED WATER EARNINGS per YEAR (based on year 1)	SIMPLE PAYBACK	NET PRESENT VALUE	INTERNAL RATE OF RETURN
		Meters	HCF	HCF	$	$	HCF	$/HCF	$	$	years	$	%
1”	BAD	15,560	2,961,186	24,028	$89,244	$3,781,080	14,880	$3.71	$55,268	$33,975	111.3	($3,872,526)	NA
1”	CAL	3	641	11	$40	$729	3	$3.71	$12	$28	26.1	($589)	-24%
1”	EMP	5	880	15	$55	$1,215	4	$3.71	$16	$38	31.6	($1,023)	-26%
1”	HER	378	71,848	1,207	$4,452	$91,854	361	$3.69	$1,332	$3,120	29.4	($76,286)	-25%
1”	SEN	2,453	502,627	25,155	$93,343	$596,079	2,526	$3.71	$9,372	$83,970	7.1	($7,677)	5%
1”	TRI	93,027	21,073,681	145,746	$541,450	$22,605,561	105,898	$3.72	$393,413	$148,037	152.7	($23,980,860)	NA
1”	TRP	14,105	2,918,248	49,025	$182,083	$3,427,515	14,665	$3.71	$54,466	$127,618	26.9	($2,790,743)	-24%
1”	UNK	141	25,072	421	$1,563	$34,263	126	$3.71	$468	$1,096	31.3	($28,796)	-26%
1”	WOR	51	10,703	180	$670	$12,393	54	$3.72	$200	$469	26.4	($10,051)	-24%
1 1/2”	ABB	1,060	539,721	10,091	$37,589	$683,064	2,712	$3.73	$10,103	$27,486	24.9	($535,500)	-21%
1 1/2”	BAD	6,146	2,759,895	6,602	$24,572	$3,960,482	13,869	$3.72	$51,617	($27,045)	-146.4	($4,499,735)	NA
1 1/2”	CAL	5	2,282	48	$181	$3,222	11	$3.76	$43	$138	23.3	($2,429)	-19%
1 1/2”	EMP	1	570	12	$45	$644	3	$3.72	$11	$34	18.9	($449)	-16%
1 1/2”	HER	82	40,757	862	$3,195	$52,841	205	$3.70	$759	$2,436	21.7	($38,887)	-18%
1 1/2”	SEN	1,026	475,045	28,400	$105,698	$661,154	2,387	$3.72	$8,884	$96,813	6.8	$29,538	6%
1 1/2”	TRI	39,546	21,540,222	504,898	$1,880,601	$25,483,442	108,242	$3.72	$403,172	$1,477,429	17.2	($16,656,001)	-14%
1 1/2”	TRP	237	102,883	2,177	$8,133	$152,723	517	$3.74	$1,931	$6,201	24.6	($117,201)	-20%
1 1/2”	UNK	31	23,526	498	$1,879	$19,976	118	$3.77	$446	$1,433	13.9	($11,770)	-12%
1 1/2”	WOR	14	9,247	196	$732	$9,022	46	$3.74	$174	$558	16.2	($5,824)	-14%
2”	ABB	182	237,223	2,847	$10,570	$125,689	1,192	$3.71	$4,425	$6,145	20.5	($106,568)	NA
2”	BAD	4,992	6,430,517	16,954	$60,458	$3,447,475	32,314	$3.57	$115,232	($54,774)	-62.9	($4,608,072)	NA
2”	EMP	1	148	2	$8	$691	1	$3.71	$3	$6	121.6	($664)	-41%
2”	HER	332	151,404	2,328	$8,433	$229,279	761	$3.62	$2,756	$5,677	40.4	($203,084)	-31%
2”	SEN	642	728,186	31,054	$115,897	$443,365	3,659	$3.73	$13,657	$102,240	4.3	$258,683	16%
2”	TRI	26,848	35,088,428	396,601	$1,464,604	$18,541,229	176,324	$3.69	$651,144	$813,460	22.8	($16,428,150)	NA
2”	TRP	396	453,146	6,968	$22,148	$273,478	2,277	$3.18	$7,238	$14,910	18.3	($204,677)	-22%
2”	UNK	92	42,779	658	$2,468	$63,535	215	$3.75	$806	$1,661	38.2	($55,869)	-31%
2”	WOR	10	22,337	343	$1,287	$6,906	112	$3.75	$421	$867	8.0	($2,907)	-8%

Table 89 shows that for a majority of cases, replacing all small meters within one size-make category does not yield a return on investment within ten years. At this time, the cost of replacing all meters within a majority of the size-make categories is too expensive in most cases and outweighs the recovered revenue from reducing apparent losses.

For a select few of the size-make categories, the Internal Rate of Return is positive and suggests a potentially worthwhile investment. The highlighted rows in Table 89 show the size-make categories that present favorable economic scenarios. If a replacement program were pursued now, the analysis reveals that the Sensus meters (across each size group except the 5/8" meters) should be targeted first.

10.2 Large Meter Overhaul Schedule Review

This section outlines the review of LADWP's current large meter testing and maintenance schedule. Proactive management of the large meter population is an important component of apparent loss control, guaranteeing that LADWP generates the maximum amount of revenue for water delivered to its customers.

10.2.1 Large Meter Information – Data Sources

Large meters are defined as meters that are 3 inches or larger. LADWP provided information from multiple datasets to inform the large meter maintenance program review. First, the "Large Meter Data List" is used internally for tracking a select number of large meters. For clarity, it will be referenced as the "Overhaul Schedule Inventory" in this review. The Overhaul Schedule Inventory compiles select information from the Customer Information Services ("CIS") database and information from the "Work Management Information System" ("WMIS") for up-to-date meter characteristic information (Meter Manufacturer, Meter Type, and Service Code). A total of 6,642 larger meter records are included in the Overhaul Schedule Inventory and each meter is assigned an overhaul frequency.

In an effort to use consumption data that is as up-to-date and accurate as possible, it was determined best to use the audit period's billing data for the review of the large meter maintenance program review. Billing records from May 1, 2010 to August 31, 2011 (two months before and after the audit period) were exported from the CIS database and reviewed for large meter accounts. For all large meter accounts that were billed during the audit period, the following fields were provided: Account Number, Type Utility, Status Code, Rate Code, Class Code, Meter Install Date, Meter Manufacturer, Meter Size, Meter Number, Last Bill Date, Current Bill to Read, Prior Bill to Date, Previous Read, Number of Billing Days, Consumption, Consumption Type[35]. A total of 21,250 large meters records are in CIS.

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[35] LADWP noted that the data quality of Meter Manufacturer Information was questionable in CIS and LADWP usually refers to the WMIS data base for the Meter Manufacturer Information

To combine the audit period's billing data with the current overhaul frequency information, accounts from the billing data were merged with the information from the Overhaul Schedule Inventory, using the meter number as the common filed to join the two data sources. It is important to note that the information provided in these two databases did not perfectly overlap, as detailed in Table 90.

Table 90: Overhaul Schedule Inventory and CIS Data Comparison for Large Meters

	# of Unmatched Records	# of Unmatched Records with Zero Consumption (% of Total)	# of Unmatched with non-Zero Consumption (% of Total)
Records in CIS but not in Overhaul Schedule Inventory	14,846	13,990 (94.23%)	856 (5.77%)
Records in Overhaul Schedule Inventory but not in CIS	335	122* (36.41%)	213* (63.58%)

*Without records on CIS, these consumption distinctions were made from information provided on the Overhaul Schedule Inventory

Table 90 shows that though there are many records that are unmatched between databases, only a fraction of those are significant. Many of the unmatched records do not document any consumption, out of which 13,930 are fire service meters and the remainder are assumed to be inactive accounts. The remaining meters that show consumption deserve some investigation. There are 856 meters that register volume during the audit period in the CIS billing data but are not included in the Overhaul Schedule Inventory. The majority of these 856 meters show a relatively low consumption volume and it's assumed that that's the reason why they have not been included in LADWP's current overhaul schedule.

There are 213 meters that show non-zero consumption in the Overhaul Schedule Inventory that are not included in the audit period's CIS billing data. Most likely these meters have been replaced by LADWP since the original large mete overhaul schedule was created and are no longer in the CIS billing data base.

Overall, consistency and completeness of data is important for any proactive management of large meter stocks so it is recommended that these unmatched meters are further examined (an inventory is provided in a separate document).

For this large meter maintenance review, WSO used the CIS data as its primary source to inform the large meter population assessments and projected maintenance scenarios. The recommendations for maintenance program improvement revolve around annual consumption per meter so it is important to use up-to-date and accurate consumption information. The Overhaul Schedule Inventory information was used to inform the costs and practices of the current program.

10.2.2 Large Meter Population Summary

Figure 54 shows a breakdown of the large meter population by size: it shows that a majority of large meters are either 4 or 6 inches. Only the meter records included in the Overhaul Schedule Inventory contain information on Meter Manufacturer and Meter Type that is deemed accurate (as extracted from the WMIS database). Looking only at the meters with records that contained this information, approximately 84% are compound type meters, 10% are turbine meters, and 6% are fire line meters.

Table 91 provides a breakdown of the large meter population by size and rate code. On first review the existence of 164 single dwelling units (as classified by rate code) with 10 inch meters appears suspicious (highlighted in yellow). This indicates another area where the currently available information should be verified and if necessary corrected (see attached document provided for list of meters with questionable size and rate code combination).

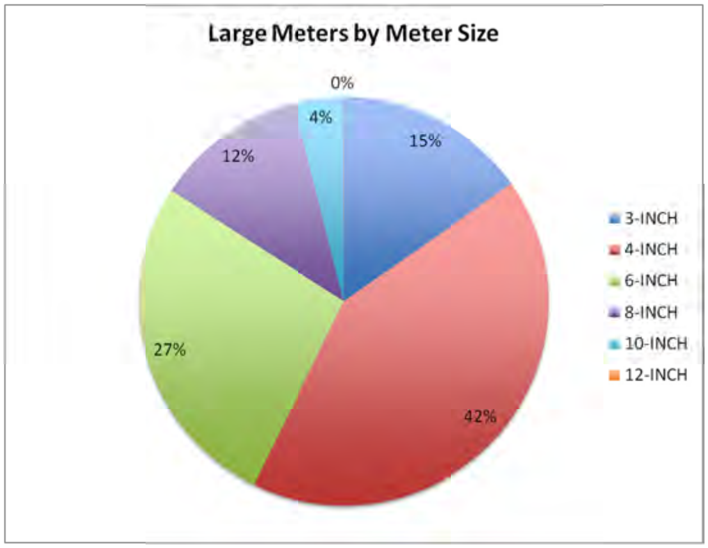

Figure 54: Large Meters by Size

Table 91: Large Meter Population by Size and Rate Code

COUNT OF METERS								
Rate Code	**Description**	**3-INCH**	**4-INCH**	**6-INCH**	**8-INCH**	**10-INCH**	**12-INCH**	**TOTAL**
30	Single-dwelling unit residential	38	7	1	0	164	0	210
31	Commercial	1648	1333	815	33	58	0	3887
32	Private fire service	268	6493	4440	2366	392	7	13966
33	Multi-dwelling unit residential	819	850	266	33	41	0	2009
34	Temporary construction	250	1	2	0	0	0	253
35	Publically-owned grounds and agriculture	157	166	61	22	3	0	409
36	Single-dwelling unit residential lifeline	1	1	0	0	20	0	22
37	Single-dwelling unit residential low-income	0	0	1	0	18	0	19
38	Youth sports and community gardens	0	0	0	0	0	0	0
39	Single-dwelling unit residential lifeline - outside city	0	0	0	0	0	0	0
40	Purpose of enterprise	11	11	11	1	3	0	37
42	Single-dwelling unit residential - outside city	2	0	0	0	0	0	2
43	Commercial - outside city	18	19	18	1	1	0	57
44	Reclaimed water	0	2	2	0	0	0	4
45	Multi-dwelling unit residential - mobile home park	3	5	6	2	0	0	16
46	Multi-dwelling unit residential - outside city	25	9	2	0	0	0	36
47	Factory mutual - commercial	0	25	82	77	122	2	308
48	Temporary construction - outside city	0	0	0	0	0	0	0
49	Factory mutual - commercial - outside city	0	0	0	2	1	0	3
77	Factory mutual - multi-dwelling residential	0	2	2	5	3	0	12
78	Factory mutual - multi-dwelling residential - outside city	0	0	0	0	0	0	0
TOTAL		**3240**	**8924**	**5709**	**2542**	**826**	**9**	**21250**

10.2.3 Current Large Meter Overhaul Schedule

A tentative large meter overhaul schedule was provided by LADWP in the Overhaul Schedule Inventory. This document outlines a potentially feasible – though not yet implemented – maintenance program that prioritizes meters based on consumption data from 2008. For each meter, a frequency (in years) is assigned: if a meter is given an overhaul frequency of "5" then every 5 years, the meter shop will replace the moving parts of the large meter. This process effectively resets the meter so that it operates within its maximum accuracy range. For the meters included in the Overhaul Schedule Inventory, a majority (49%) are overhauled every 5 years, followed by 25% overhauled every 6 years and 22% overhauled every 4 years. The program outlined here calls for 1,349 meters to be overhauled each year. However, recent meter maintenance records show that the number of meter overhauls successfully completed each year is significantly lower. In Fiscal Year 2010-2011, 153 overhauls were completed, and in

Fiscal Year 2011-2012, 169 overhauls were completed. Going forward, it will be important to devise an overhaul maintenance schedule that is feasible and realistic.

A cost-effective and efficient large meter overhaul program should be based on the meter's consumption and/or revenue generation. Therefore it is paramount that the overhaul frequencies are updated according to the meter's consumption and/or revenue generation on a regular basis. A comparison of the current overhaul frequency assignments with meter consumption and revenue generation suggests that the current overhaul schedule does not consistently take these factors into account. Table 92 shows the number of meters that fall within a given consumption range, distributed by overhaul frequency assignment. There are numerous instances where meters within the lower consumption ranges are being replaced quite often (highlighted in red). Conversely, there are meters in the higher consumption ranges that are not replaced very frequently (highlighted in green). For example, there are two meters in the "20,000 to 30,000 HCF" range that are overhauled every two years while there are seven meters in the "over 70,000 HCF" range that are only overhauled every six years.

Table 92: Count of Meters by Consumption Range and Assigned Overhaul Frequency

	ASSIGNED OVERHAUL FREQUENCY								
CONSUMPTION RANGE (HCF)	**0**	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**UN-ASSIGNED***	**TOTAL**
ZERO	2	-	-	-	1	2	91	144	13,990	14,230
0 to 10,000	-	-	-	1	9	1,035	2,736	1,441	830	6,052
10,000 to 20,000	-	-	1	1	16	310	236	34	11	609
20,000 to 30,000	-	-	1	2	34	49	58	4	2	150
30,000 to 40,000	-	-	-	1	16	26	11	-	-	54
40,000 to 50,000	-	1	1	1	12	21	4	-	1	41
50,000 to 60,000	-	-	1	4	4	12	-	-	1	22
60,000 to 70,000	-	1	-	6	9	1	-	-	1	18
> 70,000		-	23	14	14	3	7	3	10	74
TOTAL	2	2	27	30	115	1,459	3,143	1,626	14,846	21,250

*These records do not have matches in the Overhaul Schedule Inventory so do not have overhaul frequency assignments.

¤ Of the 14,230 meters with zero consumption, 13,939 meters (98%) have the rate code for private fire service.

Another comparison was possible after each annual consumption volume per meter was converted to an annual revenue, using the rate codes provided in the billing database. Figure 55 shows how the overhaul frequency assignments correlate to revenue generation by meter. This graph shows that there is a general trend where higher revenue relates to more frequent overhauls, however the correlation is not strong and there are many instances of outliers.

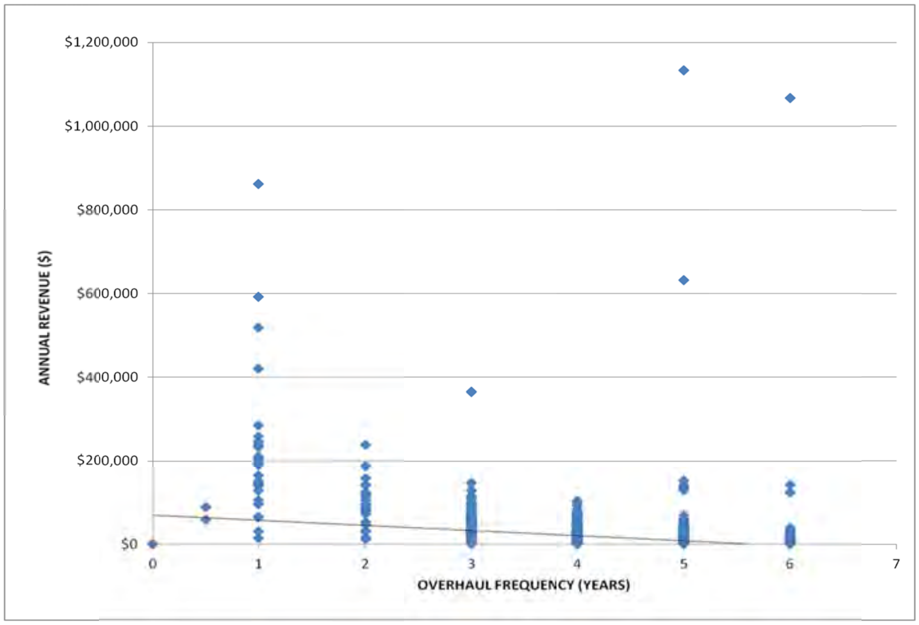

Figure 55: Comparison of Overhaul Frequency v. Annual Revenue

Overall, the analysis of current overhaul practices suggest that there is room for improvement in better informing the overhaul frequency assignments based on each meter's consumption and/or revenue generation information.

10.2.4 Alternative Large Meter Testing and Overhaul Schedule

Since it is economically infeasible to overhaul each of the 21,250 large meters on a regular basis it is necessary to identify those meters where potential losses in accuracy would result in the largest losses in revenue generation. This necessitates ranking the large meter population by annual consumption registered by meter.

Table 93 provides a breakdown of number of meters by size and total annual consumption range. This analysis reveals that only a relatively small number of meters are recording annual consumption volumes that would require frequent overhaul to guarantee accurate metering of water delivered and revenue generated. For example, 253 large meters are responsible for registering an annual volume greater than 25,600 HCF/meter. However, these 253 meters account for about 43% of the total annual volume registered by the entire large meter population.

Table 93: Count of Large Meters by Annual Consumption Range

	Annual HCF	Annual HCF	Annual HCF	Annual HCF	Annual HCF	Annual HCF		Total Count
METER_SIZE	0	0 > < 3200	3200 > < 6400	6400 > < 12800	12800 > < 25600	> 25600		
3 INCH	369	1,997	586	240	37	11		3,240
4 INCH	6,579	1,028	603	494	168	52		8,924
6 INCH	4,473	423	224	273	184	132		5,709
8 INCH	2,378	72	21	21	24	26		2,542
10 INCH	424	316	14	14	26	32		826
12 INCH	7	2	-	-	-	-		9
Total Count	14,230	3,838	1,448	1,042	439	253		**21,250**
Percentage of Total Annual Consumption registered	NA	8.69%	13.90%	18.96%	15.79%	42.65%		100.00%

The next step in this review was to analyze each account individually and assess the revenue impact of potential meter under registration. Additionally, the cost to test/overhaul each meter was determined.

An optimized testing/overhaul frequency for a given meter is achieved when the cost of intervention (regular testing/overhaul of the meter) is less than or equal to the cost of under registration (revenue loss). In other words an optimized point is reached when the cost of regular meter testing/overhaul does not exceed the value of revenue saved by the large meter testing/overhaul policy.

The frequency of meter testing/overhaul will depend on the inaccuracy of registration and the consequent revenue loss. A meter's accuracy will be impacted by many factors such as total volume registered, age of meter, quality of meter, metering technology, water quality, consumption patterns, etc. Currently, the degree by which a given large meter deteriorates in accuracy each year is not known. However, this information should be assessed by LADWP over the upcoming years as an updated meter testing/overhaul schedule is implemented. Without this system specific information, it was decided to run three scenarios where the average under registration by meter is 0.5%, 0.75% and 1% per year (based on general experience with large meter accuracy). The three scenarios looked at the volume of under registration and the associated loss of revenue from each meter. Next the cost to test/overhaul each meter was calculated and the optimum testing schedule was determined in comparing the potential revenue loss and cost to test/overhaul the meter.

Table 94 provides an example of how each single large meter account was analyzed in order to determine the appropriate testing/overhaul frequency. A theoretical annual under-registration of 0.5% for this meter would result in an annual revenue loss of about $5,692 for total purchased potable water. The cost to test/overhaul this meter is about $1,022. So in theory, it could be argued that this meter could be tested every 2.2 months to make sure that the meter is always performing at a maximum accuracy. However, realistically the meter should probably be tested every 6 months.

Further, with volumetric based sewer service charges for commercial customers, each large meter's registration dictates two revenue streams: both the purchased potable water revenue and the service sewer charge revenue. To capture the full cost of under-registration, the loss in sewer service charges should also be incorporated into the overhaul schedule analysis. For FY 2010-2011, the sewer service charge was $3.27/HCF and was applied to 93% of the purchased water volume for a given account. Table 95 expands the example provided in Table 94 to include the sewer service charge.

For each under-registration scenario, two overhaul frequency schedules were developed: one that compares overhaul costs to only the purchased water revenue loss and another that incorporates the sewer service charge for a complete of the value of under-registration.

Table 94: Example of Determination of Overhaul Frequency for One Large Meter

METER NUMBER	90119257
SIZE	6 inch
RATE CODE	31
ANNUAL REVENUE GENERATED BY METER	$1,132,688
ASSUMED LOSS IN ACCURACY (%)	0.50
ANNUAL VOLUME OF UNDER-REGISTRATION	4,005.56
ANNUAL REVENUE LOSS	$5,691.90
COST TO REPLACE/OVERHAUL	$1,021.73
RATIO ANNUAL REVENUE LOSS VS COST TO REPLACE/OVERHAUL	5.6
BREAK EVEN FREQUENCY OF REPLACEMENT/OVERHAUL [MONTHS]	2.2
REPLACEMENT/OVERHAUL FREQUENCY ASSIGNED [MONTHS]	6

Table 95: Example of Determination of Overhaul Frequency for One Meter – with Sewer Revenue Loss Included

METER NUMBER	90119257
SIZE	6 inch
RATE CODE	31
ANNUAL REVENUE GENERATED BY METER	$1,132,688
ASSUMED LOSS IN ACCURACY (%)	0.50
ANNUAL VOLUME OF UNDER-REGISTRATION	4,005.56
ANNUAL PURCHASED WATER REVENUE LOSS	$5,691.90
ANNUAL VOLUME UNDER-REGISTRATION FOR SEWER SERVICE CHARGE (93% of purchased water)	3,725.17
ANNUAL SEWER SERVICE CHARGE REVENUE LOSS	$12,181.30
COST TO REPLACE/OVERHAUL	$1,021.73
RATIO ANNUAL REVENUE LOSS VS COST TO REPLACE/OVERHAUL	11.9
BREAK EVEN FREQUENCY OF REPLACEMENT/OVERHAUL [MONTHS]	1
REPLACEMENT/OVERHAUL FREQUENCY ASSIGNED [MONTHS]	6

In developing a meter testing schedule/frequency seven testing schedules based on the potential revenue loss and cost to test the meters were established:

1. Test meter once every 6 month
2. Test meter once every 12 month
3. Test meter once every 18 month
4. Test meter once every 24 month
5. Test meter once every 36 month
6. Test meter once every 48 month
7. Test meter once every 60 month

10.2.4.1 Scenario # 1 - Results of Meter Overhaul Schedule at 0.5% Under Registration per Year

Under the scenario where it's assumed that each meter is under recording by 0.5% each year (without any maintenance program implementation) the results indicate that a relatively small number of meters need to be tested annually. A total of 99 meters need to be overhauled annually at a cost of about $97K. In this scenario, it is not cost-effective to overhaul 6,805 meters: 0.5% annual under registration for these meters does not result in a revenue loss that would justify overhauling the meter, even at lowest frequency of once every 5 years (see Table 96).

Table 96: Scenario #1 – Large Meter Overhaul Schedule

GROUP	**COUNT IN EACH GROUP**	**VOLUME REGISTERED**	**UNDER-REGISTRATION VOLUME (HCF)**	**VALUE of APP LOSSES RECOVERED BY OVERHAUL FREQUENCY**	**# of OVERHAULS PER YEAR**	**# of TESTS PER GROUP PER YEAR**	**ANNUAL COST PER GROUP**
ZERO CONSUMPTION ACCOUNTS	14230	0	0.00	$0.00	NA	NA	NA
6	9	5,074,735	25,501.18	$34,690.61	2.0	18	$19,258.54
12	15	3,287,231	16,518.75	$22,348.56	1.0	15	$15,166.12
18	28	3,012,561	15,138.50	$20,798.65	0.7	19	$17,275.91
24	20	1,455,898	7,316.07	$9,754.83	0.5	10	$8,675.37
36	46	2,706,113	13,598.56	$17,737.38	0.3	15	$14,649.13
48	44	1,973,000	9,914.57	$13,604.25	0.3	11	$11,730.52
60	53	1,755,623	8,822.23	$11,704.01	0.2	11	$10,426.32
more than 60month	6805	29,131,760	146,390.75	$197,235.54	NA	NA	NA
TOTAL:	21250	48,396,921.	243,200.61	$327,873.84		99	$97,181.92

Under the scenario where it's assumed that each meter is under recording by 0.5% each year (without any maintenance program implementation) and the sewer service charge losses are incorporated, the results indicate that significantly more meters need to be tested annually. A total of 579 meters need to be overhauled annually at a cost of about $541K. In this scenario, it is not cost-effective to overhaul 5,611 meters: 0.5% annual under registration for these meters does not result in a revenue loss that would justify overhauling the meter, even at lowest frequency of once every 5 years (see Table 97).

Table 97: Scenario #1 with Sewer Service Charge Revenue Losses – Large Meter Overhaul Schedule

GROUP	**COUNT IN EACH GROUP**	**VOLUME REGISTERED**	**UNDER-REGISTRATION VOLUME (HCF)**	**VALUE of APP LOSSES RECOVERED BY OVERHAUL FREQUENCY (including sewer revenue)**	**# of OVERHAULS PER YEAR**	**# of TESTS PER GROUP PER YEAR**	**ANNUAL COST PER GROUP**
ZERO CONSUMPTION ACCOUNTS	14230	0	0.00	$0.00	NA	NA	NA
6	58	11,817,018	59,382.00	$268,943.47	2.0	116	$110,559.26
12	78	4,643,651	23,334.93	$105,038.29	1.0	78	$76,903.86
18	85	2,956,792	14,858.25	$66,950.64	0.7	57	$55,560.77
24	96	2,306,498	11,590.44	$52,215.82	0.5	48	$46,757.07
36	317	5,174,687	26,003.45	$117,170.54	0.3	106	$97,979.96
48	396	4,565,777	22,943.60	$103,561.10	0.3	99	$89,039.12
60	379	3,155,876	15,858.67	$71,582.59	0.2	76	$64,142.52
more than 60month	5611	13,776,622	69,229.26	$313,819.39	NA	NA	NA
TOTAL:	21250	48,396,921.00	243,200.61	$1,099,281.85		579	$ 540,942.55

In a separate document (a MS excel workbook), the overhaul frequency assigned for each large meter under Scenario #1 – both with and without sewer service charge revenue losses included – is provided.

10.2.4.2 Scenario # 2 - Results of Meter Overhaul Schedule at 0.75% Under Registration per Year

Under the scenario where it's assumed that each meter is under recording by 0.75% each year (without any maintenance program implementation) the results indicate that a relatively small number of meters need to be tested annually. A total of 171 meters need to be tested annually at a cost of about $167K. In this scenario, it is not cost-effective to overhaul 6,650 meters: 0.75% annual under registration does not result in a revenue loss that would justify overhauling the meter, even at the lowest frequency of once every 5 years (see Table 98).

Table 98: Scenario #2 – Large Meter Overhaul Schedule

GROUP by OVERHAUL FREQUENCY (in months)	**COUNT IN EACH GROUP**	**VOLUME REGISTERED**	**UNDER-REGISTRATION VOLUME (HCF)**	**VALUE of APP LOSSES RECOVERED**	**# of OVERHAULS PER YEAR**	**# of TESTS PER GROUP PER YEAR**	**ANNUAL COST PER GROUP**
ZERO CONSUMPTION ACCOUNTS	14230	0	0.00	$0.00	NA	NA	NA
6	16	7,071,726	53,438.74	$72,873.15	2.0	32	$34,553.88
12	36	4,302,801	32,514.87	$44,177.67	1.0	36	$33,432.31
18	33	2,384,350	18,017.76	$23,836.03	0.7	22	$20,137.46
24	33	1,777,661	13,433.21	$17,506.16	0.5	17	$15,545.98
36	76	3,108,215	23,487.77	$31,808.24	0.3	25	$26,422.05
48	70	1,843,070	13,927.48	$18,692.43	0.3	18	$16,431.37
60	106	2,289,585	17,301.65	$23,175.14	0.2	21	$20,807.02
more than 60 month	6650	25,619,513	193,598.34	$260,980.75	NA	NA	NA
TOTAL:	21250	48,396,921	365,719.81	$493,049.57		171	$167,330.07

Under the scenario where it's assumed that each meter is under recording by 0.75% each year (without any maintenance program implementation) and the sewer service charge losses are incorporated, the results indicate that significantly more meters need to be tested annually. A total of 1,003 meters need to be overhauled annually at a cost of about $922K. In this scenario, it is not cost-effective to overhaul 4,669 meters: 0.75% annual under registration for these meters does not result in a revenue loss that would justify overhauling the meter, even at lowest frequency of once every 5 years (see Table 99).

Table 99: Scenario #2 with Sewer Service Charge Revenue Losses - Large Meter Overhaul Schedule

GROUP	**COUNT IN EACH GROUP**	**VOLUME REGISTERED**	**UNDER-REGISTRATION VOLUME (HCF)**	**VALUE of APP LOSSES RECOVERED BY OVERHAUL FREQUENCY (including sewer revenue)**	**# of OVERHAULS PER YEAR**	**# of TESTS PER GROUP PER YEAR**	**ANNUAL COST PER GROUP**
ZERO CONSUMPTION ACCOUNTS	14230	0	0.00	$0.00	NA	NA	NA
6	97	14,440,026	109,118.58	$493,010.67	2.0	194	$182,133.41
12	125	4,998,964	37,775.55	$170,786.49	1.0	125	$125,189.68
18	157	3,484,424	26,330.66	$118,687.83	0.7	105	$100,293.01
24	259	4,025,607	30,420.20	$137,040.09	0.5	130	$119,879.92
36	592	6,254,896	47,266.22	$213,335.72	0.3	197	$173,681.49
48	575	4,194,962	31,699.96	$143,158.81	0.3	144	$124,998.46
60	546	3,146,109	23,774.12	$107,450.52	0.2	109	$96,240.41
more than 60month	4669	7,851,933	59,334.51	$269,606.10	NA	NA	NA
TOTAL:	21250	48,396,921.	365,719.81	$1,653,076.23		1,003	$ 922,416.36

In a separate document, the overhaul frequency assigned for each large meter under Scenario #2 – both with and without sewer service charge revenue losses included – is provided.

10.2.4.3 Scenario #3 - Results of Meter Overhaul Schedule at 1.0% Under Registration per Year

Under the scenario where it's assumed that each meter is under recording by 1.0% each year (without any maintenance program implementation) the results indicate that a relatively small number of meters need to be tested annually. A total of 264 meters need to be tested annually at a cost of about $255K. In this scenario, it is not cost-effective to overhaul 6,392 meters: 1.0% annual under registration does not result in a revenue loss that would justify testing the meter, even at the lowest frequency of once every 5 years (see Table 100).

Table 100: Scenario #3 – Large Meter Overhaul Schedule

GROUP BY OVERHAUL FREQUENCY (in months)	COUNT IN EACH GROUP	VOLUME REGISTERED	UNDER-REGISTRATION VOLUME (HCF)	VALUE of APP LOSSES RECOVERED	# of OVERHAULS PER YEAR	# of TESTS PER GROUP PER YEAR	ANNUAL COST PER GROUP
ZERO CONSUMPTION ACCOUNTS	14230	0	0.00	$0.00	NA	NA	NA
6	24	8,361,966	84,464.30	$114,654.50	2.0	48	$49,590.78
12	49	4,555,324	46,013.37	$62,549.74	1.0	49	$44,394.66
18	45	2,619,248	26,457.05	$34,519.77	0.7	30	$28,544.89
24	44	1,973,000	19,929.29	$27,345.91	0.5	22	$23,461.04
36	102	2,978,285	30,083.69	$40,158.35	0.3	34	$32,689.85
48	160	3,220,205	32,527.32	$43,488.30	0.3	40	$38,129.56
60	204	3,077,330	31,084.14	$41,744.41	0.2	41	$37,773.30
more than 60month	6392	21,611,563	218,298.62	$294,598.56	NA	NA	NA
TOTAL:	21250	48,396,921	488,857.79	$659,059.53		264	$254,584.09

Under the scenario where it's assumed that each meter is under recording by 1.0% each year (without any maintenance program implementation) and the sewer service charge losses are incorporated, the results indicate that significantly more meters need to be tested annually. A total of 1,387 meters need to be overhauled annually at a cost of about $1.27 MM. In this scenario, it is not cost-effective to overhaul 4,062 meters: 1.0% annual under registration for these meters does not result in a revenue loss that would justify overhauling the meter, even at lowest frequency of once every 5 years (see Table 101).

Table 101: Scenario #3 with Sewer Service Charges – Large Meter Overhaul Schedule

GROUP	COUNT IN EACH GROUP	VOLUME REGISTERED	UNDER-REGISTRATION VOLUME (HCF)	VALUE of APP LOSSES RECOVERED BY OVERHAUL FREQUENCY (including sewer revenue)	# of OVERHAULS PER YEAR	# of TESTS PER GROUP PER YEAR	ANNUAL COST PER GROUP
ZERO CONSUMPTION ACCOUNTS	14230	0	0.00	$0.00	NA	NA	NA
6	136	16,460,669	166,269.38	$751,741.11	2.0	272	$264,366.99
12	184	5,305,935	53,595.30	$241,406.23	1.0	184	$178,717.37
18	318	5,182,417	52,347.65	$235,982.14	0.7	212	$197,036.58
24	395	4,546,231	45,921.53	$207,263.93	0.5	198	$177,760.64
36	777	5,930,896	59,908.04	$270,500.59	0.3	259	$223,075.38
48	662	3,712,307	37,498.05	$169,575.79	0.3	166	$145,724.65
60	486	2,039,094	20,596.91	$93,431.32	0.2	97	$83,158.57
more than 60month	4062	5,219,372	52,720.93	$239,766.44	NA	NA	NA
TOTAL:	21250	48,396,921	488,857.79	$2,209,667.55		1,387	$ 1,269,840.

In a separate document, the overhaul frequency assigned for each large meter under Scenario #3 – both with and without sewer service charge revenue losses included – is provided.

10.2.4.4 Summary of Alternative Large Meter Overhaul Schedules

Table 102 shows the summary of meter testing schedules outlined in the six scenarios presented in this technical memo. The scenarios are distinguished by the level of under-registration used to model the apparent losses and whether or not the sewer service charge is included.

Table 102: Summary of Large Meter Overhaul Schedule Scenarios

Level of Under-Registration	Sewer Service Charge Included?	# of Tests Per Year	Annual Cost
0.5%	NO	99	$97 K
0.5%	YES	579	$541 K
0.75%	NO	171	$167 K
0.75%	YES	1,003	$922 K
1.0%	NO	264	$255 K
1.0%	YES	1,387	$1.27 MM

10.3 Apparent Loss Reduction Recommendations

Small Meter Apparent Loss Reduction Recommendations

- The small meter test results indicate that the small meter population is operating at a relatively high level of accuracy. The accuracy results and economic analysis here do not present a case for any immediate action on widespread small meter replacement. However, isolating the worst performing, most economic, meter groups (by size and make) for a targeted meter replacement program is recommended. The following small meter groups should be targeted for replacement given that the internal rate of return on the required meter replacement investment was positive:
    - 5/8 x 3/4” Sensus meters
    - 3/4 x 1” Sensus meters
    - 1 1/2” Sensus meters
    - 2” Sensus meters

- In order to proactively manage the small meter population, LADWP should continue regular testing of random small meter samples (100 to 200 meters per year). Regular random testing will allow tracking of the average accuracy of each the size/make groups of meters. With this type of monitoring, LADWP will be able to initiate meter replacement when a certain meter make/size group reaches the threshold where meter replacement becomes an economically viable option.

- As detailed in Section 4.2.1.1, part of an ongoing and optimized meter management strategy also requires having accurate and consistent data for LADWP's customer meter population (reliable information on meter size, make, and installation date) in the billing database so it can be used as a reliable asset management tool.

Large Meter Apparent Loss Reduction Recommendations

- For the large meter population, LADWP should aim to adopt a large meter maintenance program that compares consumption and revenue data to overhaul costs for an overhaul schedule that optimizes savings. To institutionalize this approach with an appreciation for labor constraints and a pending new central database, it is recommended that LADWP pursue the new large meter maintenance program in the following three phases.
  - **Phase One:** To start the process of adopting this approach, it is recommended to select and implement Scenario #2, without the sewer service charge considerations. This would require overhauling about 20 more large meters than the number completed in FY 2010-2011. Scenario #2 offers an advantageous starting point in that it does not require LADWP to test significantly more meters than tested in 2011.
  - **Phase Two:** With the adoption of the new central database and preparation of sufficient labor resources, it is recommended to adopt Scenario #2 with sewer service rate charge considerations. This will require significantly more overhauls per year but will be based on a more complete cost benefit analysis when taking the sewer service revenue losses into account.
  - **Phase Three:** Down the line, after institutionalizing this consumption based approach for designing the annual meter overhaul programs, it is recommended to fine tune the approach by revisiting the under-registration assumptions. Toward this end, completing more meter accuracy testing as a component of the overhaul process is recommended. This will provide trend data that will allow for better understanding of how the large meter's accuracy decreases between testing intervals.

- For large meters, it is recommended to review mismatches in size and rate code classification: examine if single dwelling units with meters sized between 3 and 10 inches have correct meter size and rate code.
- For large meters, it is recommended to review and improve data quality of the Overhaul Maintenance Schedule and CIS – both systems should have up to date and complete information for each account and meter.
- Since consumption patterns and consumption volumes of large customers can change over time it is recommended that LADWP update the overhaul schedule regularly.

For the top one hundred large customer meters (ranked by revenue generated), it is recommended to undertake consumption profiling and targeted selection of appropriate metering technology. An improvement of 1% in metering accuracy (achievable by switching from a standard compound meter to an electromagnetic flow meter, for example) will results in significant revenue increases for these meters (see Appendix G for an example large meter right sizing and metering technology assessment produced for one of WSO's clients).

Summary of Recommended Apparent Loss Intervention Strategies

Table 103 summarizes the main recommendations for reducing apparent losses to an economically efficient level. It includes a general timeline by fiscal year to provide an overall roadmap for the upcoming five years.

Table 103: Summary Roadmap of Recommended Apparent Loss Intervention Strategies

Fiscal Year	Small Meter Testing	Small Meter Replacement	Large Meter Maintenance	Unbilled Consumption
FY 2013 – 2014	Ongoing Random Small Meter Testing	Replace targeted size/make meter groups, outlined in Section 10.	Initiate the overhaul program, as outlined in Section 10.2.4	Read fire service detector checks regularly
FY 2014 – 2015			Begin consumption profiling for highest revenue-generating customers	
FY 2015 – 2016		Revisit replacement economics and target revised group of small meters	Pursue meter right-sizing and appropriate technology replacement where necessary	Upgrade fire service detector checks to AMI/AMR for consistent surveillance
FY 2016 – 2017				
FY 2017 – 2018				

SECTION 11. ECONOMICALLY EFFICIENT REAL LOSS REDUCTION STRATEGIES

11.1 Introduction to Economically Efficient Real Loss Reduction

Even if it were possible, eliminating leakage altogether would be a wasteful use of resources. The cost of doing so would far exceed the cost of balancing water supply and demand by other means, and that would mean higher bills for customers. The Economic Optimum Volume of Real Losses – also known as the Economic Level of Leakage (ELL) – represents the most cost effective level of leakage given the current valuation of water lost.

Leakage (Real Losses) costs money. It has a cost associated with the intrinsic value of the water that is lost and it has a cost associated with locating and repairing the leak and any damage it may have caused to nearby infrastructure. For all utilities there is a balance between the value of the water that is lost through leakage and the cost of finding and fixing leakage. In simple terms, this balance is achieved upon implementing measures dictated by the Economic Level of Leakage.

For all cost analyses discussed in this section the cost of real losses was based on the Metropolitan Water Department (MWD) Tier 1 Treated Water for 2013.

The ELL represents the most effective level of leakage given current valuation of resources. The economic level of leakage is influenced by each of the four main intervention techniques against real losses (speed and quality of leak repair, pressure management, active leakage control, and infrastructure management – see Figure 56). The circle at the center of the diagram represents the volume of real losses for a distribution network that is currently above the economic level of leakage. The outer black circle represents the current level of real losses. The inner red circle represents the unavoidable real losses based on the UARL values where the Infrastructure Leakage Index (ILI) is equal to 1 (this is the minimum level of leakage that is technically achievable). Somewhere between these latter two circles lies the Economic Level of Leakage. These three circles give rise to three distinct ‘layers’ of real losses.

The first outer layer, shown in the diagram as Economically Recoverable Real Losses, represents the volume of real losses that are both technically and economically recoverable using one or more of the real loss management activities represented by the four arrows.

The middle layer, shown in the diagram as Uneconomically Recoverable Real Losses, represents the volume of real losses that are technically recoverable using one or more of the real loss management activities represented by the four arrows – but it may not be economic to do so.

The inner core represents the volume of real losses that cannot be technically removed due to the inherent limitations of current leakage management technologies. The volume is calculated from the AWWA published Unavoidable Annual Real Losses (UARL) values that show the lowest technically achievable level of real losses for networks operated with 'best practice' leakage management and with infrastructure in good condition. A network with annual volume of real losses equal to the UARL will have an ILI equal to 1.0.

The ELL is a function of the total cost of leakage, which includes both the value of the water that is being lost and the cost of all the leakage control activities that take place to maintain the volume of water being lost in a steady state. Increasing the quantity of leakage control activity in any given year will increase the annual cost of leakage control but will lead to a decrease in the annual volume of water lost and hence the annual cost of water lost. Whether the increase in leakage control activity leads to a reduction in total cost (the sum of both the cost of leakage control activity and the cost of water lost) will depend on the cost factors associated with the leakage control activity, the cost of water and the effectiveness of the leakage control activity in reducing real losses.

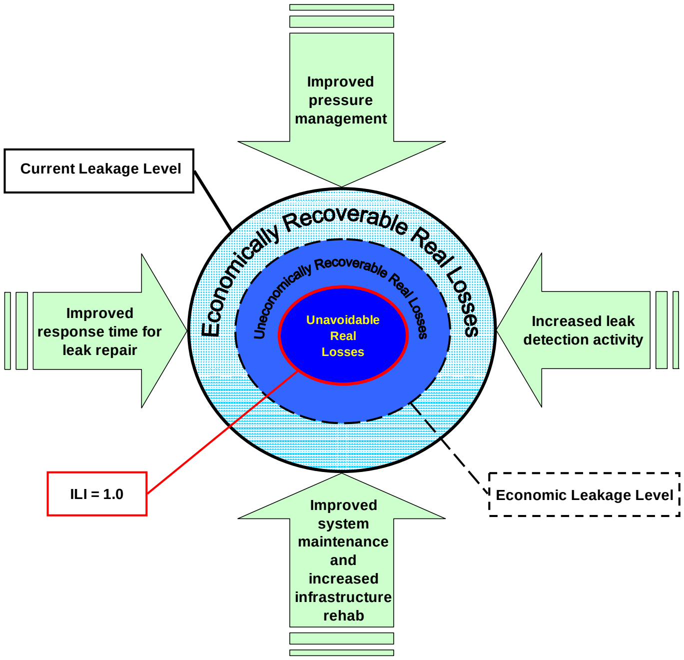

Figure 56: Four-component tool box for intervention against Real Losses

Calculations of ELL can be extremely data intensive, but a practical approach to achieving the ELL for any system can be explained using Figure 56. Every system experiences some number of new leaks and breaks each year, and economic management of the Real Loss volume arising from these events can be achieved in the:

- Short-term, by managing the average duration of reported leakage by optimizing leak run and repair times through efficient repair and through proactive leak detection (to locate and repair unreported breaks) or,
- Medium to long-term, by reducing the Real Losses through improved pressure management, and infrastructure management.

The priority needs to be given to those tools with the highest benefit/cost ratio. Attaining and maintaining the ELL is in line with the CUWCC's Best Management Practice (BMP) 1.2, which calls for implementation of cost effective demand reduction through reduction of Water Losses.

11.1.1 Tools for Real Loss Reduction and Management

Both IWA and AWWA literature refer to the four-component tool box for intervention against real losses as show in Figure 56. It is not always practical or economic to attain the Unavoidable Annual Real Losses (UARL) or short Unavoidable Real Losses, because the cost to reach and maintain the UARL is most likely much higher than the value of water saved through reducing leakage down to the UARL. In fact the economic level of real losses will often lie somewhere between the Current Annual Real Losses (CARL) and the UARL.

All of the four intervention tools against Real Losses were evaluated to determine how to improve LADWP's current leakage management policy in order to attain the most realistic short/medium term ELL for LADWP.

The following describes each tool and potential applicability to LADWPs goal of attaining an ELL.

11.1.1.1 Proactive Leak Detection

This tool (proactive leak detection) is geared at reducing the volume of un-reported leakage (Hidden Losses) from the distribution system.

Based on the results of the water audit and real loss component analysis it was estimated that a total of 792 MGY (or 2,430.56 AFY) of potentially recoverable Hidden Losses exist in the distribution network (see Section 8).

LADWP does not currently undertake proactive leak detection in its distribution system to identify hidden leaks that do not surface. The ELL analysis for proactive leak detection will analyze if it is beneficial to identify un-reported leaks sooner than under the current policy in order to reduce the volume of Hidden Losses.

11.1.1.2 Improved Leak Repair Time

This is a tool for reducing volumes of Real Losses from both reported and unreported leaks that were repaired by LADWP during the audit period (FY10-11). Analyzing the leak repair data from FY10-11 indicates that there might be the potential for reducing the volume of real losses by locating and repairing known leaks more quickly. An economic analysis will analyze if there are cost effective opportunities to reduce the runtime of known leaks.

11.1.1.3 Pressure Management

Pressure management is a tool to manage system pressures to the optimum level of service, ensuring sufficient and efficient supply to legitimate users and consumers, while reducing unnecessary or excess pressures. Pressure management helps eliminating transients and faulty level controls, all of which cause the distribution system to leak unnecessarily. Pressure management reduces the losses from existing leaks and research has shown that pressure management also reduces the number of new leaks and extends infrastructure lifespan. Pressure management is effective in reducing all Real Loss components: Background Leakage, Reported Leakage, Un-reported Leakage and Storage overflows.

Pressure management is already partially being employed by LADWP through the use of reservoir zones and pressure zones within its distribution system where Pressure Reducing Valve (PRV) stations are operated. The current average system pressure is at 90 PSI, which indicates that there is room for improved pressure management.

As part of the economic analysis of medium term real loss management activities the applicability of further pressure management will be assessed.

11.1.1.4 Infrastructure Management

This tool is geared at reducing volumes of Real Losses in all components of the system and is a long-term measure, which is usually tied directly into the asset management program. LADWP currently has plans to increase its infrastructure replacement program. There does not appear to be an immediate need for LADWP to further increase the replacement of infrastructure strictly for a leakage management gain given the relatively low level of leakage, the overall low break frequencies for the system, and the fact that infrastructure replacement is the most expensive option/strategy for real loss reduction. Rather LADWP should continue asset management programs as planned.

11.1.1.5 Summary

All of the four intervention tools against Real Losses were evaluated to determine if there is room for improvement in LADWP's current leakage management policy. Proactive leak detection and improved leak repair time were found to be short-term tools against Real Losses with potential for improvement. Since LADWP already has plans to increase infrastructure replacement, there is no recommendation to improve infrastructure management. Pressure management was found to be a medium term tool against Real Losses with potential for improvement. Table 104 summarizes the findings.

Table 104: Evaluation of real loss reduction strategies/tools

Intervention Tool	Currently employed by LADWP	Potential for improvement	Assess benefit/cost ratio of new/improved intervention tool
Proactive leak detection	No	Yes	Yes
Improved leak repair time	Yes	Yes	Yes
Pressure management	Yes	Yes	Yes
Infrastructure management	Yes	No[36]	No

11.1.2 Valuation of Real Losses and Cost of Intervention Tools

It is necessary to assign a cash value to the volume of Real Losses and to estimate the cost of the intervention tools in order to evaluate the cost effectiveness of each tool. The cost for each of the intervention tools will be discussed under the specific intervention option of the ELL analysis.

11.1.2.1 Valuation of Real Loss

The way in which Real Losses are valued by a utility is crucial to the outcome of any ELL analysis. The higher the value of Real Losses, the more aggressive the intervention needs to be. Based on discussions with LADWP management Real Losses have been valued at MWD Tier 1 Treated Water Wholesale Cost of $847 per AF or $2,599.34 per MG for 2013.

11.2 Economic Frequency of Intervention (Rate of Rise Method) - Proactive Leak Detection

The main method used to control real losses involves regular leak detection surveying of the distribution network. It is clear that an increase in the annual amount of surveying carried out will decrease leakage levels in LADWP's network.

Figure 57 represents the economic model for regular leak detection survey. The x-axis of the chart represents the volume of real losses and the y-axis represents cost. The red curve represents the cost curve for leak detection surveying (cost of labor, materials and equipment for detecting and repairing leaks), the blue curve represents the cost curve for the lost water (typically this will be the marginal cost of water based on production and pumping costs for power and chemicals, or the wholesale cost of purchased water) and the green curve represents the total cost curve which is the sum of the red and blue curves.

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[36] Since LADWP already has plans to increase infrastructure replacement, there is no recommendation to improve infrastructure management.

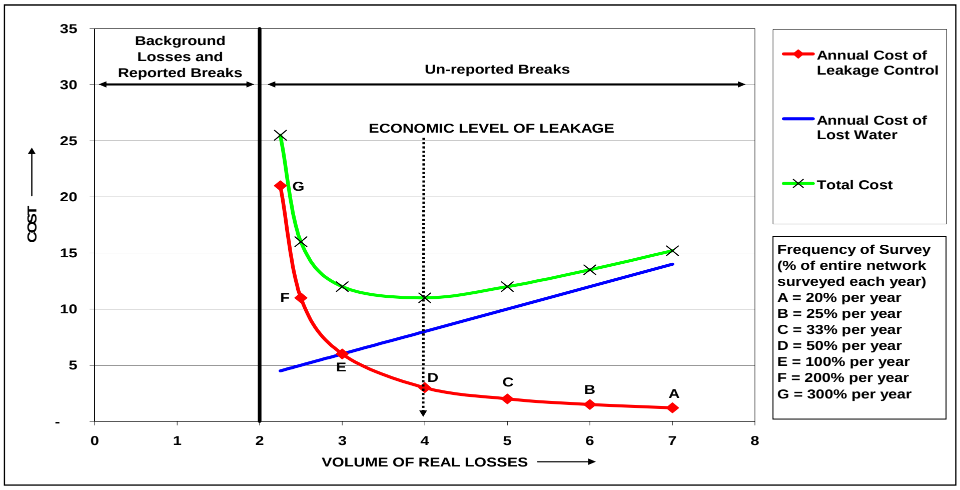

Figure 57: Economic Model for Regular Leak Detection Survey

Leakage Control Cost Curve: In Figure 57's model, it is assumed that increasing leak detection will increase the number of un-reported breaks that are found but will have no impact (reduction) on the amount of leakage that arises from both background leakage and reported breaks. Point A on the red curve represents a leak survey of the entire network every 5 years, or 20% per year. In this example, the volume of losses from un-reported breaks is 5 units and the volume of losses from background leakage and reported breaks is 2 units, making 7 units of real losses in total. At Point B, the leak detection survey frequency is increased to 25% of the network each year (covering the entire network every 4 years) - this would reduce the annual losses from un-reported breaks to 4 units but leave the 2 units of losses from background leakage and reported breaks untouched, making 6 units of real losses in total. The cost carrying out a survey of 25% of the system each year is exactly 25% higher than carrying out a survey of 20% of the system each year due to the increase in the amount of labor and materials required. The leakage control cost curve is developed for a range of survey frequencies as shown in the model. It can be seen that the leakage control cost curve is exponential in nature with rapidly increasing cost for reducing loss as the survey frequency increases. The curve is also asymptotic to the level of background losses and reported breaks.

Cost of Lost Water Curve: For the LADWP, the cost of water lost curve will be based on the MWD Tier 1 Treated Water Wholesale cost of $847 per AF. The costs are purely variable in nature and relate to the costs that would be saved by reducing leakage by one unit volume.

Total Cost Curve: This is simply the sum of the Leakage Control Cost Curve and the Cost of Lost Water Curve. The total cost curve is typically parabolic in nature, as shown in the model in Figure 57.

Economic Level of Leakage: The economic level of leakage is defined in this model by the lowest point on the Total Cost Curve. In the model shown in Figure 57, increasing the leak detection survey frequency above 50% per year (surveying the entire network over a two-year period) will increase the total cost, as the reduction in water lost is not sufficient to offset the increased cost of the extra survey activity. Likewise, decreasing the leak detection frequency below 50% per year will also increase the total cost as the reduction in active leakage control costs are far outweighed by the increased cost of water lost. This model provides explanation of the how to determine the economic level of leakage for regular leak detection surveying.

The purpose of proactive leak detection and control is to find leaks that do not surface or only surface after a long time. Therefore, by undertaking regular leak detection and repair, LADWP has the opportunity to actively control the volume of water lost through unreported leaks.

In order to reduce the level of unreported breaks/leaks and begin accessing the potentially recoverable 792 MGY (or 2,430.56 AFY) of Hidden Losses, it will be necessary to undertake a very comprehensive leak survey, where all mains fittings and all service connections are sounded for leaks. The volume of hidden losses was calculated by a real loss component analysis, which was discussed in Section 8.

The trial leak detection campaign carried out by WSO in three representative areas of LADWPs distribution network, covering a total of 95 miles, clearly showed that it is necessary to sound each service connection, valve and hydrant to make sure that all detectable leaks are found.

Following the AWWA M36 recommended approach for calculating the economic frequency of intervention for active leakage control the following analysis were undertaken. The rate of rise method of calculating the economic frequency of intervention uses the following definition: economic intervention is the frequency of intervention at which the cost of active leakage control equals the cost of leaking water. Utilizing the rate of rise method for determining the economic frequency of intervention three parameters need to be assessed:

- Average rate of rise of unreported leakage (RR)
- The cost of leak detection survey intervention (CI)
- The cost of Real Losses (CV)

Once these three parameters are known it is possible to assess for any size system or subsystem:

- The economic frequency of intervention (EIF) to find unreported leaks

$$\text{EIF (month)} = \sqrt{(0.789 \times \text{CI} \div (\text{CV} \times \text{RR}))}$$

- The economic percentage (EP) of the system that should be inspected each year

$$\text{EP (\%)} = 100 \times 12 \div \text{EIF}$$

- The appropriate annual budget for intervention (ABI) costs, (excluding leak repair cost)

$$\text{ABI (\$)} = \text{EP} \times \text{CI}$$

- The economic annual volume of unreported real losses (EURL), corresponding to the economic intervention frequency.

$$\text{EURL} = \text{ABI} \div \text{CV}$$

As these parameters are calculated using square root functions, they are not very sensitive to random errors in CI, CV, and RR. Using an example discussed in a paper by Lambert and Lalonde[37], errors of +/-10% in CV, 5% in CI and 20% in PR produced a confidence limit of +/-15% in the calculated economic intervention frequency (EIF).

11.2.1 Rate of Rise of Leakage (RR):

The total rate of rise of leakage may be thought of as the continuing increase in leakage that would occur in absence of any leak repairs. It is made up of two components: new leaks occurring in the network plus the growth (increase in volume) of existing leaks. Of this total rate of rise of leakage, a portion will comprise visible leaks which surface and come to the attention of the water utility, which will be promptly repaired by the water utility. It is the remaining portion, which is normally used in leakage economic studies, and defines the leakage that must be overcome through proactive leak detection. The rate of rise of leakage is used to define the economic effort and expenditure required to manage unreported leakage at an economic level.

This simplified model, known as the Natural Rate of Rise of Leakage, is shown in Figure 58. In a part of a distribution system, Minimum Night Flow measurements of leakage levels (MNF Measurement) show the dynamic between the rate of rise of leakage and the efforts to reduce and control leakage through leak detection and repair.

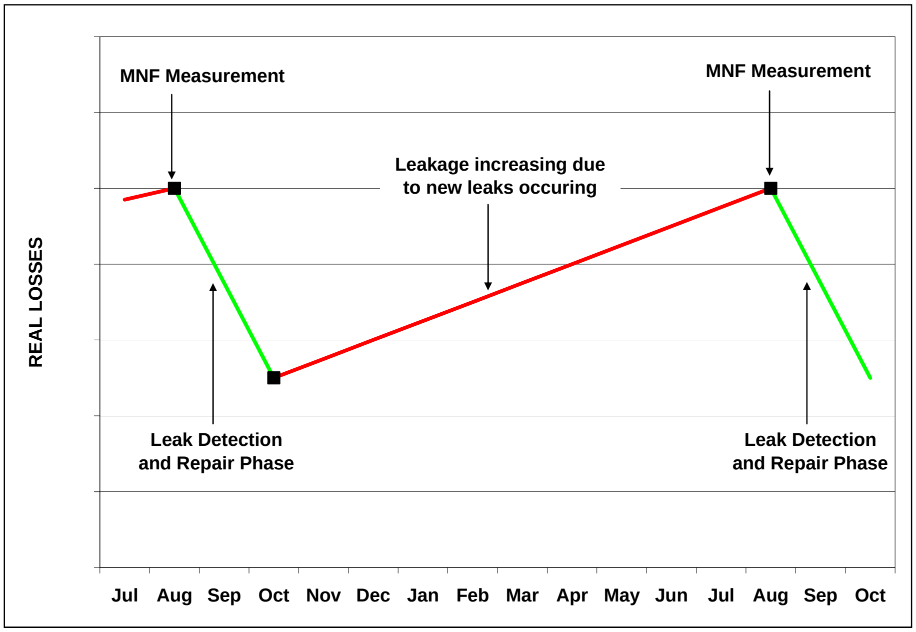

Figure 58: Rate of Rise of Leakage Concept

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[37] Lambert A. & Lalonde A. (2005). Using practical predictions of Economic Intervention Frequency to calculate Short-run Economic Leakage Level, with or without Pressure Management. Proc. of IWA Specialized Conference ‘Leakage 2005’, Halifax, Nova Scotia, Canada

There are three principle ways of assessing the rate of rise of leakage for a distribution system:

- Compare Real Losses from water balances several years apart.
- Use results of proactive leak detection campaign in either entire system or same subsystem.
- Use results of measured leakage night flows (as depicted in Figure 58).

The results of the comprehensive leak detection survey pilot carried out by WSO in about 95 miles of the distribution network and ME Simpson in about 248 miles of the distribution network were combined used to estimate the rate of rise of leakage for the LADWP. The leak surveys found 45 leaks with an estimated total leakage volume of 48.75 MGY (or 149.61 AFY). It was assumed that the unreported leaks detected by this proactive leak detection exercise took on average about three year to build up or an annual rate of rise of unreported leakage in these 248 miles of the distribution network of 16 MGY (49.1 AFY or 130 gal/mile of main/day). Extrapolating this break frequency and volume to the whole system, this would result in an annual rate of rise of leakage for the entire distribution system of about 342 MGY or 1,049.56 AFY (= 130 gal/mile of main /day * 7,227miles *365 days /10^6). This rate of rise of leakage equates to 94 service line leaks occurring each year and running undetected, or fifteen 6 inch main breaks occurring each year and running undetected.

The UARL formula, as provided in the AWWA M36 manual, provides the values for calculating the unavoidable annual volume of leakage due to unreported leaks for any given system. Utilizing the empirical UARL values for unreported leaks and breaks as shown in Table 105 and applying them to the LADWP distribution system, the unavoidable annual real losses from unreported leaks were calculated at 894 MGY (or 2,743.59 AFY).

Table 105: IWA/AWWA values for Unavoidable Annual Real Losses from Unreported Leaks and Breaks

Infrastructure Component	**Unreported Leaks and Breaks** [38]	**Units**
Mains	0.77	gallons / mile of main / day / PSI of pressure
Service Connection: main to curb-stop	0.03	gallons / service connection / day / PSI of pressure
Service Connection: curb-stop to meter	2.12	gallons / mile of service connection / day / PSI of pressure

An example calculation of the determination of the UARL component of unreported leakage on mains for LADWP's system is given here:

> UARL for unreported leakage on mains = 0.77 gallons/mile of main/day/PSI * mileage of mains * audit period length * average operating pressure

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[38] IWA/AWWA Values

UARL for unreported leakage on mains = 0.77 gallons/mile of main/day/PSI *7,227.16 miles * 365 days * 90 PSI

UARL for unreported leakage on mains = 182.81 MG

The calculation for the component of UARL for unreported leakage on service connections for LADWP's system results in a volume of 711.64 MG. Combining these two UARL components together gives the total of 894 MG for the UARL of Unreported Leakage.

This demonstrates that the assumptions made for the rate of rise of unreported leakage in LADWP of 342 MGY (or 1,049.56 AF) are very conservative (the calculated rate of rise is much lower than the rate of rise that the UARL formula suggests as a minimum). This is justified given the low break frequency within the distribution system and the overall low level of leakage as calculated by the water audit and real loss component analysis.

11.2.2 Cost of Leak Detection Survey Intervention (CI)

It was assumed based on discussions with LADWP that the leak detection work will be carried out by LADWP leak detection staff. The cost for undertaking a comprehensive survey by LADWP is $296 per mile. A comprehensive survey is where the operator listens on all available fittings such as valves, hydrants, service connections, and other fittings and also listens above the ground using geophones, as opposed to a hydrant and valve survey where the operator listens on available main line valves and hydrants only.

The cost to repair the leaks found through a proactive leak detection program are not included in the economic evaluation at this point according to AWWA recommendations. Some of the reasons are that:

- Proactive leak detection does not introduce the cost to repair the leak (leak is already there utility is just not aware of it)
- Leak will need to be fixed at one point and proactive leak detection allows for repair before leak grows/catastrophic failure and gets more expensive
- Proactive leak detection avoids potential for contamination through compromised infrastructure

11.2.3 Cost of Real Losses (CV)

In this economic analysis Real Losses were valued at MWD Tier 1 Treated Water Wholesale Cost of $847 per AF or $2,599.34 per MG.

11.2.4 Results of Economic Frequency of Intervention Analysis

When valuing a unit of water lost at the MWD Tier 1 Treated Water Wholesale Cost for 2013 ($847/AF) the results of the economic frequency of intervention analysis are as follows (using the formulas and values outlined in Section 11.2.1, Section 11.2.2, and Section 11.2.3):

- The economic frequency of intervention (EIF) to find unreported leaks: 26.3 months
- The economic percentage (EP) of the system that should be inspected each year: 46%

This means that according to this evaluation the entire LADWP distribution system should be surveyed every 26.3 months or about 46% of the network should be surveyed every year. This results in an average run-time of unreported leaks of about 13 months. In the case of LADWP, it might be most beneficial to focus the leak survey on the older and leak prone sections of the distribution system. However, this should only be decided once the results of more leak detection pilot work are available.

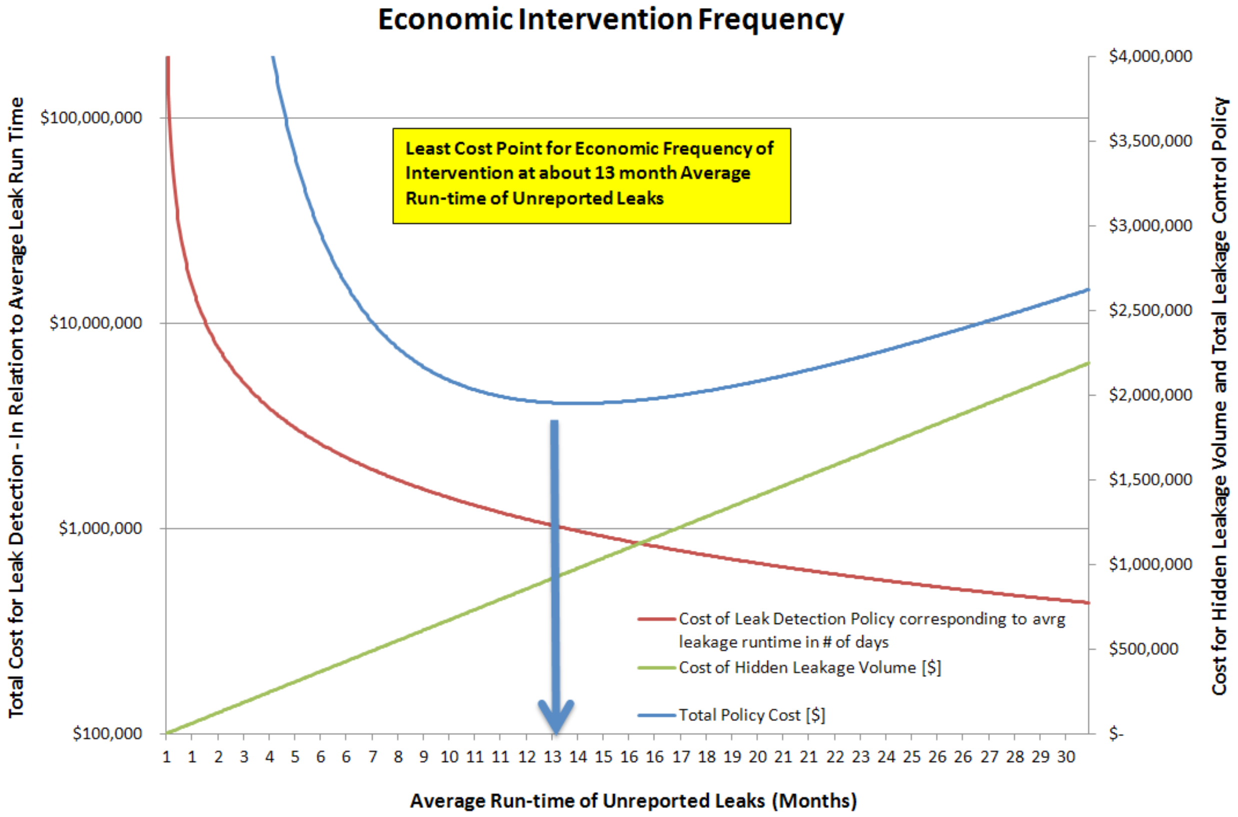

Figure 59: Economic Frequency of Intervention for Proactive Leak Detection

Figure 59 shows the relationships between the leak survey frequency, costs of hidden losses, and cost of leak detection. The x-axis shows the average run-time of Unreported Leaks (in months). To achieve low average run-times, a high frequency of leak surveying is necessary. As the leak survey frequency increases, the cost of leak detection increases (see the red line). At the same time, the average run-time of unreported leaks is reduced. With shorter run-times for unreported leaks, the total hidden loss volume and the associated costs are also reduced (see the green line).

It is notable that as the leak survey frequency increases, the annual cost of leak detection increases exponentially (see the red line near the left axis) whereas the cost of hidden losses decreases approximately linearly. The total cost curve (see the blue line) is the sum of water lost through detectable leaks plus the cost of leak detection survey. The point at which the total cost curve is at a minimum represents the least cost point for real losses from detectable leaks. The least cost point occurs when the leak survey interval is at 26.3 months, or about 13 months average run-time for unreported leaks.

- The appropriate annual budget for intervention (ABI) costs: $975,710/year

Assuming a cost of $296/mile of detailed leak survey the optimal annual budget for leak detection is $975,710/year.

- The economic annual volume of unreported real losses (EURL), corresponding to the economic intervention frequency: 375 MGY (1,150 AFY)

Based on the data currently available and the assumptions made for this economic intervention frequency model an intervention frequency of 26.3 months at an assumed rate of rise of 342 MGY (or 1,048 AFY) will reduce the volume of hidden losses (unreported leakage) from currently 792 MGY (or 2,430 AFY) to around 375 MGY (or 1,150 AFY) (see Figure 60).

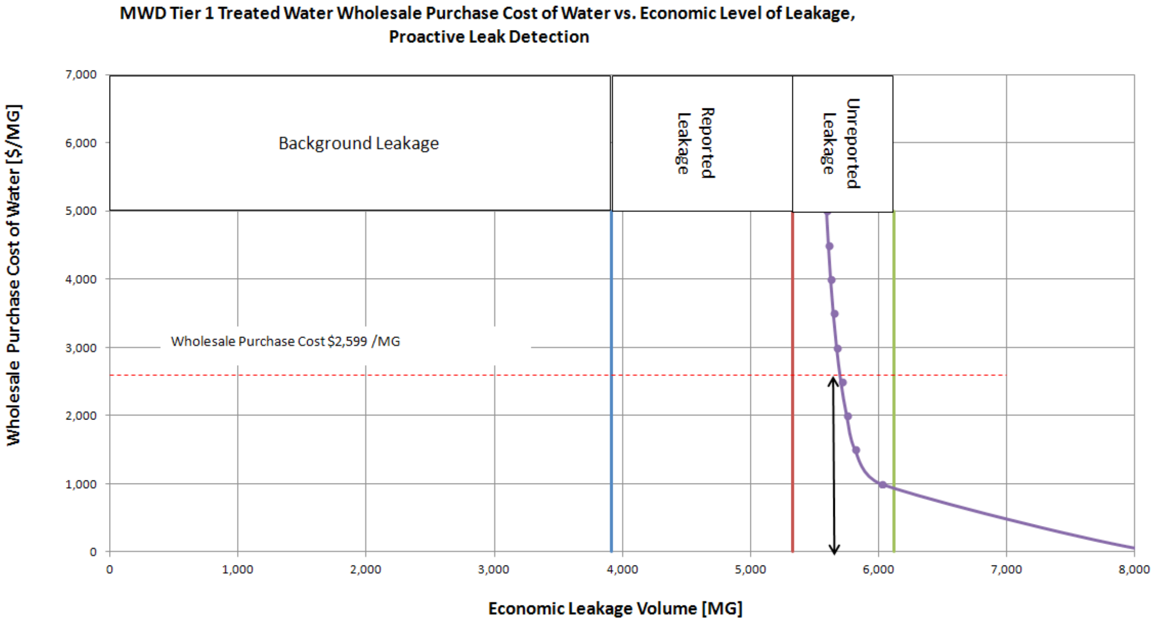

Figure 60: Components of Real Loss Volume and Economic Volume of Unreported Leakage

Figure 60 depicts the three components of real losses in LADWP's distribution system and their loss volumes. The purple line depicts the economic volume of leakage controlled by proactive leak detection. As the wholesale cost increases (thereby increasing the cost of one unit of real losses), a lower level of leakage becomes economic. It can be seen that when valuing real losses at the 2013 MWD Tier 1 Treated Water Wholesale cost of $2,599 / MG (or $847/AF), the model indicates that it is economic to reduce the real loss volume from the current 6,118 MGY (or 18,775.45 AFY) to about 5,702 MGY (or 17,498.80 AFY) through regular proactive leak detection.

11.2.5 Economic Frequency of Intervention Analysis – Summary

The analyses indicate that given the relatively high value of Real Losses, it is economic to periodically survey the distribution network for unreported leaks (about 46 percent of the system should be surveyed annually according to the current model). However, at this point it is recommended to consider the results of this intervention frequency model for proactive leak detection as preliminary since the accuracy of the water balance and real loss component analysis need to be further improved before significant investments are made for proactive leak detection.

It is recommended that LADWP targets surveying about 10% to 15% of the distribution network per year for the next five years using in-house resources and carefully documenting the results and findings to inform LADWP's future proactive leak detection strategy.

Since LADWP is considering trials of Advanced Metering Infrastructure (AMI), it is recommended that for the pressure zones with AMI a water loss mass balance is calculated on a regular basis to identify pressure zones with higher levels of leakage that should be targeted for proactive leak detection. The three pressure zones used for the DMA trial in Section 9 should be considered as candidates for trial AMI installation projects.

11.3 Improved Location and Repair Time

11.3.1 Background

The analysis of reported leaks repaired during FY 2010 - 2011 indicates that LADWP has a certain number of non-emergency leaks that are allowed to run for a significant period of time before being repaired. The leak repair data indicates that reported main leaks took an average of about 5 days to be located and repaired and that reported service line leaks and meter leaks took an average of about 12 days to be located and repaired. Based on the average leakage flow rate of a mains leak or service leak, the average system pressure and the average location and repair time, the total real loss volume lost through reported leaks was calculated and discussed in Section 8. In evaluating options for reducing the volume of real losses in LADWP's system, improving the location and repair times was assessed, and the impact this would have on the volume of real losses was evaluated.

Note: it is important to understand that the repair times shown in this section are averages. For example not all reported main leaks took 5 days to be located and repaired: some were located and repaired within 24hrs and other main leaks with a lower priority were allowed to run for significantly longer before being located and repaired.

It is also important to note that a significant portion of the break data - 25% of main failure repair records and 30% of service connection break data – do not have sufficient timestamp data to calculate the location and repair time. Main break and service connection break data where the location and repair time could not be calculated based on the available records were assigned the average location and repair time of their main size group and service connection size group.

It is important to consider the evaluation of possible reductions in average location and repair times as an initial estimate that needs to be refined once more complete leak repair data is available.

11.3.2 Improved Location and Repair Time for Reported Mains Failures

As shown in Table 106 the total volume of real losses caused by 1,225 main leaks with an average repair time of 5 days was 950 MGY (or 2,915.44 AFY) for FY 2010-2011. The value of this real losses volume was about $2,470,145. Reducing the average location and repair time to 2.5 days, would save about 472 MGY (or 1,448.61 AFY), resulting in a cost savings of $1,227,425 (using the MWD Tier 1 rate). The assumed reduction of average location and repair time by 50% was used to get an initial idea of the potential savings that could be achieved and do not represent industry standards or an actual recommendation since the currently available leak repair data needs to be substantially improved in terms of data quality/availability to be able to make recommendations on a target location and repair time for mains failures.

Table 106: Summary of economic analysis of improved location and repair times for mains failures

Reported and Unreported Failure Events		
Failures on Mains	*Reported*	
Total Number of Failures on Mains in FY10/11	1,225	
Average location and repair duration	5.0	days
Total Volume lost (stemming from location and repair duration)	950.3	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 2,470,145	
What IF Location and Repair Duration is Reduced to	2.5	days
Percent Reduction	50%	
Potential Related Savings in Leakage Volume	472.2	(MG)
Potential Related Savings in Leakage Volume Cost	$ 1,227,425	

Using the currently available leak repair data, this analysis indicates that a reduction in average location and repair time could represent a cost effective option for reducing real losses in LADWP's distribution network. Once better leak repair data is available, LADWP should update this analysis and evaluate the necessary additional budget for reducing the average location and repair time for reported mains leaks.

11.3.3 Improved Location and Repair Time for Service Line Failures and Meter Leaks

As shown in Table 107 the total volume of real losses caused by 4,038 service line failures and meter leaks with average repair times of 12 days was 264 MGY (or 810.19 AFY) for FY 2010-2011. The value of this real losses volume was about $685,400.

Reducing the average location and repair time to 5 days, would save about 157 MGY (or 481.82 AFY), resulting in a cost savings of $409,029. This indicates significant potential for real loss and cost savings. The assumed reduction of average location and repair time by 60% was used to get an initial idea of the potential savings that could be achieved and do not represent industry standards or an actual recommendation since the currently available leak repair data needs to be substantially improved in terms of data quality/availability to be able to make recommendations on a target location and repair time for service line failures.

Table 107: Summary of economic analysis of improved location and repair times for mains failures

Service Line Failures and Meter Leaks	*Reported*	
Total Number of Failures on Service Connections and Meter Leaks in FY10/11	4,038	
Average location and repair duration	12.4	days
Total Volume lost (stemming from location and repair duration)	263.7	(MG)
Total Cost of Volume lost (stemming from location and repair duration)	$ 685,400	
What IF Location and Repair Duration is Reduced to	5	days
Percent Reduction	60%	
Potential Related Savings in Leakage Volume	157.4	(MG)
Potential Related Savings in Leakage Volume Cost	$ 409,029	

Using the currently available leak repair data it would indicate that a reduction in average location and repair time for service connection and meter leaks could represent a cost effective option for reducing real losses in LADWP's distribution network. Once better leak repair data is available, LADWP should update this analysis and evaluate the necessary additional budget for reducing the average location and repair time for service connection and meter leaks.

11.4 Pressure Management

11.4.1 Background

Pressure management as a real loss reduction strategy requires investment, which will have a payback longer than the short run period. For such longer-term real loss reduction strategies, it will become economic to make the investment to reduce real losses if the value of water saved over the investment period would pay for the implementation cost. The volume of real losses is proportional to the average system pressure. Therefore, there will be a break-even point at which the additional cost of pressure reduction equals the cost of the real losses reduced.

Pressure management schemes are designed to reduce real losses by reducing both the background leakage and reducing the leakage flow rates of all reported and unreported leaks and breaks. Reliable and well-tested models are available for calculating the savings in real losses stemming from pressure reduction. Pressure management has many benefits when used to optimize the delivery of water and service to customers (see Table 108).

Table 108: Benefits of Pressure Management

PRESSURE MANAGEMENT: REDUCTION OF EXCESS AVERAGE AND MAXIMUM PRESSURES						
CONSERVATION BENEFITS		WATER UTILITY BENEFITS			CUSTOMER BENEFITS	
REDUCED FLOW RATES		REDUCED FREQUENCY OF BURSTS AND LEAKS				
REDUCED CONSUMPTION	REDUCED FLOW RATES OF LEAKS AND BURSTS	REDUCED REPAIR COSTS, MAINS & SERVICES	DEFERRED RENEWALS AND EXTENDED ASSET LIFE	REDUCED COST OF ACTIVE LEAKAGE CONTROL	FEWER CUSTOMER COMPLAINTS	FEWER PROBLEMS ON CUSTOMER PLUMBING & APPLIANCES

Source: Fantozzi & Lambert 2010[39]

Pressure management also has the added benefit of reducing break frequencies by reducing stress on the infrastructure. The reduction of break frequencies produces the following additional benefits:

- Extended asset life
- Reduced repair cost
- Reduced visit/inspection cost for reported breaks
- Reduced risk of interruption to supply
- Reduced risk of compensation payments

The IWA Water Loss Specialist Group produced a conceptual presentation (Figure 61) of how a combination of factors influencing break frequencies acting together with system pressure can result in reductions or increases in break frequencies.

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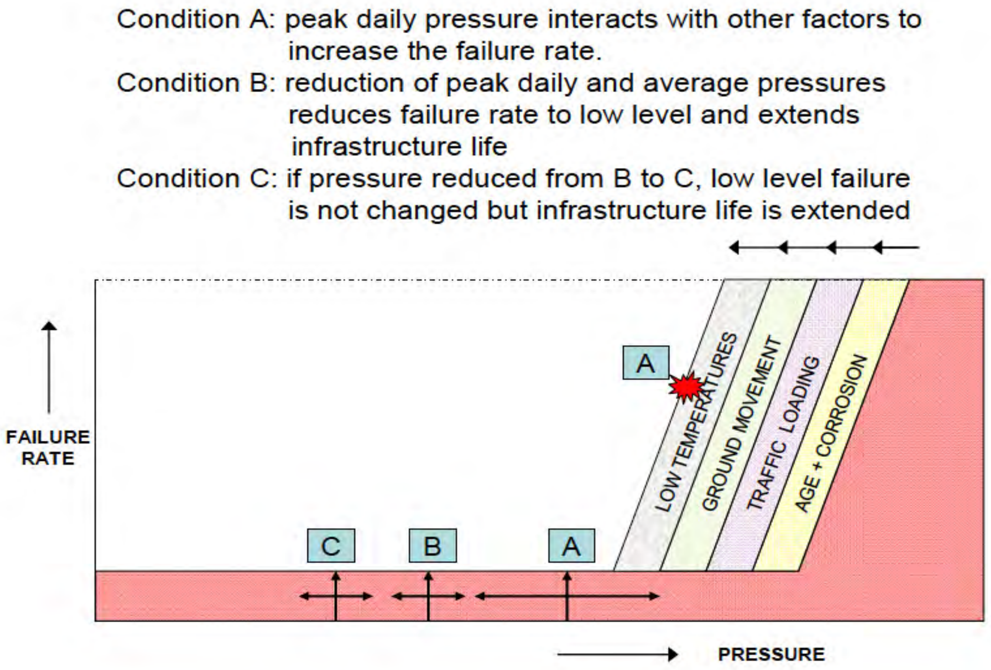
[39] Lambert, A and Fantozzi, M (2010). *Recent developments in pressure management.* Proc. of IWA Specialized Conference 'Water Loss 2010', Sao Paolo, Brazil.



Condition A: peak daily pressure interacts with other factors to increase the failure rate.

Condition B: reduction of peak daily and average pressures reduces failure rate to low level and extends infrastructure life

Condition C: if pressure reduced from B to C, low level failure is not changed but infrastructure life is extended

Figure 61: Conceptual presentation of interaction between system pressure, system and environmental factors and break frequency

11.4.2 Pressure Management Options

Pressure management is already partially being employed by LADWP through the use of reservoir zones and pressure zones within its distribution system where Pressure Reducing Valve (PRV) stations are operated. The current average system pressure is 90 PSI, which indicates that there is room for improved pressure management.

In order to model the reduction of real loss volume due to a reduction of average system pressure it is necessary to estimate or assess the N1 factor for the entire system. In the pressure management model applied here, an N1 of 1.0 was used assuming a linear relationship between pressure and leakage. This will make sure that estimated savings in real loss volume due to reductions in average system pressure are conservative estimates.

Various improvements to current pressure management practices were investigated for their implementation cost and potential to reduce the average system pressure (and consequently reduce water loss). It was assumed that the reduction of average system pressure would be achieved through three steps, where each step builds upon the results of the previous step and reduces the average system pressure further through additional system upgrades and investments. The three steps should be implemented over an eight-year period.

Step 1: LADWP operates a total of 113 pressure zones within its distribution network. Out of these 113 pressure zones 65 pressure zones have average system pressures above 100 PSI.

These 65 pressure zones were selected for implementation of the three-step pressure management program described in this section (see Appendix V for list of prioritized 65 pressure zones).

Through a detailed assessment of current system pressure levels, pump operation, reservoir operation, pressure transients, PRV settings, validation of pressure zone boundary valves and replacement of valves where necessary, and an update of hydraulic model, this step will lay the ground work for the implementation of step 2 and 3. Step 1 will also include optimization of current PRV settings and operations. The first pressure reduction step will be achieved by implementing the following actions:

- System Pressure Study and high frequency pressure logging for detection of transients with 390 pressure logging sites throughout the 65 pressure zones (estimated cost ~ $209K)
- Review and update the detailed inventory of all PRV's, tank level settings and controls, pumping regimes and boundary valves (cost ~ $124K)
- Validation of pressure zone boundary valves by identifying and sounding all boundary valves (cost ~ $84)
- Replacement of boundary valves – assuming two per pressure zone @ $7,000 per valve (cost ~ $910K)
- Update hydraulic model with system pressure study (cost ~ $100K)
- LADWP general engineering and project management (cost ~ $200K)
- Adjustment of Current PRV settings and pumps and tank levels to optimum (cost $159K)

It was assumed that in each of the 65 pressure zones targeted for optimized pressure management the average pressure could be reduced by 4% by adjusting current PRV settings, pump control and tank levels. A reduction of the average system pressure by about 3 PSI would be achieved by implementing all components of Step 1 at a total cost of $1,785K (includes $910K for boundary valve replacement). Step 1 would result in a system wide average pressure reduction of 3 PSI. This would reduce the total real loss volume by 204 MGY (or 626.05 AFY), which has a value of $530K per year (not including savings through possible reduction in break frequency).

Step 2: Building upon the detailed assessment undertaken in Step 1, Step 2 reduces the system pressure further through the implementation of advanced flow modulated pressure control. The second pressure reduction step will be achieved by implementing the following actions:

- Replace existing lead PRVs with Cla-Val Model 98-06 (or similar) PRVs, which allow regulating pressure according to system demand. High pressure is provided when system demand is high and pressure is lowered when system demand is low. A high pressure set point is selected for high flow demand and a low pressure set point is selected for low flow demand. This dual set point arrangement allows for reduction in water loss by not over pressurizing the system during times of low demand, while still providing adequate pressure during high or fire demand. It was assumed that an average 3 PRV's per pressure zone (117 in total) would be replaced or retrofitted to be able to introduce demand based pressure control. The cost for retrofitting an 8 inch Cla-Val is about $3,361 and the cost for a new 8 inch Cla-Val Model 98-06 PRV is about

$10,000. Assuming that 50% of the PRVs can be retrofitted and the rest will need to be replaced the total cost was calculated (cost $1,182,449K).

- Installation of new PRV's at $1,500 per PRV (cost $265K)
- Pressure management engineering consultant - setting the PRVs, analyzing data and results, and managing the project (cost $250K)
- LADWP general engineering and project management (cost $250K)

It was assumed that the average system pressure could be reduced by about 3 PSI by implementing all components of Step 2 at a total cost of $1,948K.

All three steps of the pressure management project build on the results of the previous steps. Therefore, the total cost for Step 2 includes the cost for Step 1, resulting in a total accumulated cost for Step 2 of $3,733K.

Step 2 would achieve a reduction in system wide average pressure of 3 PSI, plus the 3 PSI of average system pressure reduction achieved in Step 1. In total, this would reduce the total real loss volume by 408 MGY (or 1,252.11 AFY), which has a total value of about $1,060K per year (not including savings through possible reduction in break frequency).

Step 3: Building upon Steps 1 and 2, Step 3 will further reduce the system pressure by splitting zones 1134, 1123, 579, 1000, 1449, and 426 (pressure zones with more than 150 miles of distribution network) into subzones for better pressure control in those large zones. It was assumed that 15 new subzones would be created. Each of the new pressure zones will have an average of 3 PRV chambers controlling the pressure for each zone. The third pressure reduction step will be achieved by implementing the following actions:

- 90 PRV's of size 6 inch and 8 inch (cost $774K)
- Installation of new PRV's (cost $135K)
- Pressure zone PRV chambers – 45 in total (cost $2,250K)
- Replacement of boundary valves and installation of new boundary valves ($7000 per valve incl. labor) - 150 valves (cost $1,050K)
- Pressure management engineering consultant - setting the PRVs, analyzing data and results, and managing the project (cost $500K)
- LADWP general engineering and project management (cost $800K)
- Hydraulic Model - for design of 15 zones (cost $200K)
- Cost for distribution piping reconfiguration associated to creation of 15 new zone (cost $3,000K)

It was assumed that the average system pressure could be reduced by about 3 PSI by implementing all components of Step 3 at a cost of $8,709 K.

All three steps of the pressure management project are building on the results of the previous steps. Therefore, the total cost for Step 3 includes the cost for Step 1 and 2, resulting in a total accumulated cost for Step 3 of $12,442K.

Step 3 would achieve a reduction in system wide average pressure of 3 PSI, plus the 6 PSI of average system pressure reduction achieved in step 1 and 2. In total, this would reduce the total real loss volume by 544 MGY (1,669.47 AFY), which has a value of about $1,414K.

11.4.3 Pressure Management Options Cost Benefit Analysis

The three steps of improving the pressure management currently employed by LADWP were evaluated for their cost efficiency. A simple payback period for each of the three steps was calculated (see Table 109). The Real Loss Volume under the "Existing Policy" column is explained in detail in Section 8.

Table 109: Pressure management options and their cost benefit

Real Losses Valued at Retail Cost of Water	**Step 3**	**Step 2**	**Step 1**	**Existing Policy**
Average System Pressure [PSI]	81	84	87	90
Real Loss Volume [MGY]	5,574	5,710	5,914	6,118
Real Loss Volume [AFY]	17,097	17,523	18,149	18,775
Value of Real Loss Volume [$/Yr] – (A)	$14,489,183	$14,842,578	$15,372,670	$15,902,762
Total cost of pressure management policy [$] – (B)	$12,442,329	$3,733,329	$1,785,380	-
Real Loss Volume Saved by Policy [MGY]	544	408	204	NA
Real Loss Volume Saved by Policy [AFY]	1,669.47	1,252.11	626.05	
Value of Real Loss Volume Saved [$/Yr] – (C)	$1,413,579	$1,060,184	$530,092	NA
Simple payback time [Years] – (D = B/C)	8.8	3.5	3.4	NA

11.4.4 Pressure Management Analysis - Summary

The analysis of improved pressure management in the LADWP distribution system shows a clear incentive to reduce average system pressure in order to sustainably reduce the volume of real losses. At this point it is difficult to accurately estimate the cost of Step 2 and 3 of the pressure management project. Only upon completion of the detailed system assessment in Step 1 will be possible to more accurately estimate the costs for Step 2 and 3. That said, conservative cost estimates for Step 2 and 3 are used here, and the economic analysis clearly shows that there is a strong business case for LADWP to improve pressure management and reduce the average system pressure.

A simple sensitivity analysis shows that in case the cost for step 2 and 3 was under estimated by 100%, the required investment for Step 2 and 3 would still have a payback period of less than 8 years (Step 2) or 18 years (Step 3). Considering that the majority of the costs for Step 2 and 3 are infrastructure investments, a payback of less than 9 years (current cost estimate) or less than 18 years (assuming that the cost for Step 2 and 3 are 100% higher) is very attractive for an infrastructure investment.

It is recommended that LADWP implements a small pressure monitoring pilot (5 to 10 zones) over the first 12 month of the pressure management program before implementing Step 1 over the 36 months, followed by Step 2 over the next 48 months, and Step 3 over the subsequent 48 months.

11.5 Summary of Recommended Real Loss Intervention Strategies

Table 110 summarizes the main recommendations for reducing apparent losses to an economically efficient level. It includes a general timeline by fiscal year to provide an overall roadmap for the upcoming five years.

Table 110: Summary Roadmap of Recommended Real Loss Intervention Strategies

Fiscal Year	Proactive Leak Detection	Improved Location and Repair Times for Reported Leaks	Pressure Management Program
FY 2013 – 2014	Prepare for implementation of proactive leak detection program	Focus on collection of better leak repair data	Prepare for implementation of pressure monitoring pilot in 5 to 10 pressure zones
FY 2014 – 2015	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff	Focus on collection of better leak repair data	Implement **Step 1** of the pressure management program as detailed in Section 11.4.2
FY 2015 – 2016	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff	Update analysis on improved location and repair times and evaluate the necessary additional budget for reducing the average location and repair time for reported mains leaks.	
FY 2016 – 2017	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff	If found cost effective Deploy additional repair crews to reduce average location and repair times to optimum levels	
FY 2017 – 2018	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff		Implement **Step 2** of the pressure management program as detailed in Section 11.4.2
FY 2018– 2019	Detailed leak detection in 10% to 15% of the distribution network using LADWP leak detection staff		
FY 2019 – 2020	Evaluate results of detailed leak detection efforts and update strategy according to findings over past 4 years		
FY 2020 – 2021	Implement updated proactive leak detection strategy and if/where AMI is implemented utilize AMI and SCADA data for prioritizing areas for ongoing leak detection based on calculated leakage loss levels by pressure zone.		
FY 2021 – 2022			Implement **Step 3** of the pressure management program as detailed in Section 11.4.2
FY 2023 – 2024			
FY 2024 – 2025			
FY 2025 – 2026			

SECTION 12. APPENDICES

APPENDIX A: Aggregate 95% Confidence Limit Calculations

In order to calculate the overall 95% confidence limit related to the total System Input Volume it is necessary to consider the variance related to each meter contributing towards the total metered volume. Table 111 provides an example for how an aggregated 95% confidence limit is calculated.

Table 111: Example System Input Volumes and related confidence limits

System Input	Volume during FY 04-05 in MG	95% Confidence Limit as +/- %	Variance
Meter A	7,512.80	2.55	9,554
Meter B	10,519.84	2.55	18,732
Meter C	6,580.71	2.55	7,330
Meter D	4,411.61	2.55	3,294
Meter E	7.60	2.55	0.010
Total System Input Volume (TSIV)	**29,032.56**	**1.33**	**38,910**

The confidence limit related to meter results in a certain variance based on the volume recoded by each meter. The bigger the volume supplied by the meter the bigger is the related variance. The variance related to the volume metered by each meter based on its confidence limit, is calculated as follows:

$$\text{Variance} = (\text{Volume in MG} * 95\% \text{ confidence limit}/1.96)^{2}$$

The overall confidence limit related to the Total System Input Volume (TSIV) and its variance is then calculated as follows:

$$95\% \text{ confidence limit for TSIV} = 1.96 * \sqrt{TotalSystemInputVariance} \,/\, TotalSystemInputVolume$$

The above explains the standard approach for calculating an aggregated confidence limit.

APPENDIX B: Tujunga Well Field Drop Test Protocol

WSO recommends completing a volumetric test for calibrating the meter that feeds the Tujunga well collector basin (the “collector meter”). Upon confirming the accuracy of this collector meter, a comparison of historic reads will allow for an accuracy assessment of the total well meter production values from the Tujunga well field.

The test was not feasible during this project, but validating this component of the well production volume would be advisable when the drop test is possible.

Meter calibration requires a comparison of the volume registered by the meter against a known volume of water passed by the meter. The known volume passed will be derived from measuring the rise of the water level in the collector basin reservoir (a.k.a. tank or clearwell). The accuracy of volumetric drop tests is dependent upon the accuracy of determining the change in the collector basin volume. If sufficient care is taken in the basic measurements of the water levels used to calculate the change in stored volume then the accuracy of volumetric tests is typically better than ±2% of true volume and can often approach ±1%.

Meter accuracy can vary with flow rate, so this test should be done at several flow rates across the range of flow rates normally encountered by the collector meter in order to develop a proper calibration curve.

Table 112 outlines the steps involved in executing a successful volumetric drop test at the collector meter.

Table 112: Outline of Tujunga Drop Test Procedure

TASK & DESCRIPTION	DATA/SETUP REQUIRED
1. SECURE CURRENT & HISTORIC SCADA DATA ACCESS	
Without a totalizer at the collector meter, the test will require SCADA data on flow reads at the smallest interval possible for the duration of the drop test. This data will be the basis for calculating the meter’s registered volume. To extrapolate the accuracy results, historic SCADA data for the audit period FY10-11 will also be necessary to obtain.	• Collector meter flow reads from SCADA (for both the duration of the drop test and the complete audit period)
2. ISOLATE & DRAW DOWN COLLECTOR BASIN	
Isolate the collector basin so that there is no withdrawal, insuring that the only contribution to water level change will be volume passed through the collector meter.	• To begin, turn off all well pumps • Draw down the collector basin’s volume (keep distribution pumps on) • Turn off distribution pumps, taking Tujunga collector basin offline to isolate it for the duration of the test

3. MEASURE INITIAL BASIN WATER LEVEL

The accuracy of the initial (and final) collector basin water levels will inform the overall accuracy of the test. Access to a real-time basin water level measurement is a crucial part of the test procedure to determine the known volume used to compare the collector meter's registration.

- Measure collector basin's water level

4. RUN ALL ACTIVE WELLS

Ideally, the wells that pumped the most during the FY 2010 - 2011 period would be turned on – in order of pumped volume these wells are #6,7,1,12,5. However, it is understood that a different selection of meters is currently active and contributes toward the collection meter (wells #2,3,4,5,12). Appropriate flow rates will be selected to test the collector meter at the range of flow rates it normally encounters.

- Take initial readings from each active individual well totalizer
- Turn on well pumps
- Run test to achieve maximum allowable level increase in collector basin volume

5. MEASURE FINAL BASIN WATER LEVEL

The final collector basin water level should be read after the well pumps are turned off and the basin water level has steadied.

- Turn off all well pumps
- Measure collector basin's water level
- Record totalizer reads on each well meter

6. CALCULATE VOLUME REFERENCE

The initial and final collector basin water levels will be used in conjunction with the as-built design for the collector basin to determine the volume passed through the collector meter.

- Calculation of volume will require as-built drawings of collector basin

7. COMPARE FLOW READS TO BASIN VOLUME REFERENCE

The accuracy of the collector meter will be determined by comparing its registered volume (extrapolated from flow reads) to the volume change in the collector basin.

- SCADA flow reads for the collector meter for the duration of the test will be required for calculation of its registered volume

8. COMPARE COLLECTOR METER TO WELL METER READS

If the same well meters are active as in the audit period, another comparison between the collector meter and the well meters can be made.

- SCADA flow reads from FY 2010 - 2011 for the collector meter will be necessary for this comparison.

APPENDIX C: Well Field Site Visit Photos

The following pictures document the conditions of each well field. They were taken on the site visits to each well field that significantly contributed to the SIV during the audit period.

Figure 62: Manhattan Well Site Visit

Figure 63: Erwin Well Site Visit

Figure 64: North Hollywood Well Site Visit

Figure 65: Pollock Well Site Visit

Figure 66: Rinaldi-Toluca Well Site Visit

Figure 67: Tujunga Well Site Visit

APPENDIX D: Apportioning Volume for Time Lag

In future assessments of meter reading time lag, it is possible the comparison of the total consumption by shifted time period will show more significant differences (of greater than 1%). In this case – when the meter reading time lag significantly affects the determination of total consumption volume – apportioning of each bill by month is necessary.

The following example in Table 113 outlines the method employed for apportioning each bill.

Table 113: Example Calculation of Apportioning One Bill's Consumption by Calendar Month

Previous Read Data	March, 23, 2007		
Read Date	May 23, 2007		
Consumption (HCF)	66		HCF
Days Between Reads	61		days
Average Consumption Per Day	1.082		HCF/day
Consumption Apportioned to March *(8 days in March within the billing period)*	= 8 days x 1.082 HCF/day	8.66	HCF
Consumption Apportioned to April *(30 days in April within the billing period)*	= 30 days x 1.082 HCF/day	32.46	HCF
Consumption Apportioned to May *(23 days in May within the billing period)*	=23 days x 1.082 HCF/day	24.89	HCF

This process is then applied to all bills within the audit period to apportion all consumption by calendar month, as outlined in Table 114.

Table 114: Example for Apportioning Audit Period's Consumption by Calendar Month

PREVIOUS READ DATE	READ DATE	USAGE	JAN-07	FEB-07	MAR-07	APR-07	MAY-07	JUN-07	JUL-07	AUG-07	SEP-07	OCT-07	NOV-07	DEC-07	TOTAL
22-Nov-06	24-Jan-07	25	10	0	0	0	0	0	0	0	0	0	0	0	**10**
24-Jan-07	23-Mar-07	33	4	16	13	0	0	0	0	0	0	0	0	0	**33**
23-Mar-07	23-May-07	66	0	0	9	32	25	0	0	0	0	0	0	0	**66**
23-May-07	24-Jul-07	92	0	0	0	0	12	45	36	0	0	0	0	0	**92**
24-Jul-07	24-Sep-07	75	0	0	0	0	0	0	8	38	29	0	0	0	**75**
24-Sep-07	26-Nov-07	48	0	0	0	0	0	0	0	0	5	24	20	0	**48**
26-Nov-07	23-Jan-08	16	0	0	0	0	0	0	0	0	0	0	1	9	**10**
TOTALS			**14**	**16**	**22**	**32**	**37**	**45**	**44**	**38**	**34**	**24**	**21**	**9**	**333**

APPENDIX E: Number of Meters by Average Daily Consumption Range Analysis

E.1 Average Daily Consumption Range Profile: 5/8" Meters

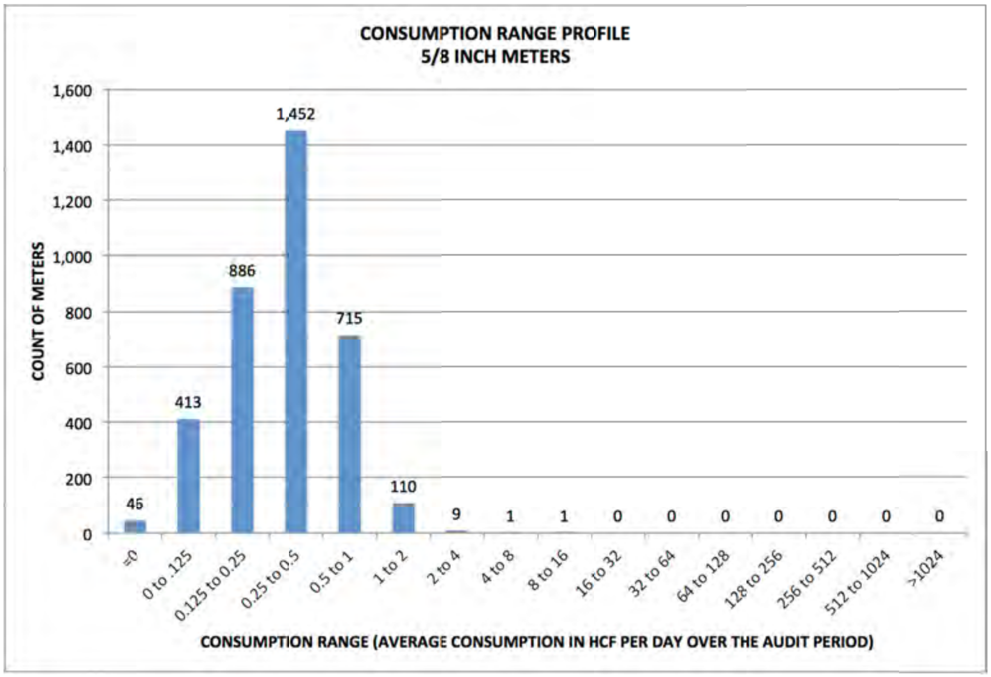


Figure 68: Number of 5/8" Meters by Average Daily Consumption Range

Table 115 shows the distribution of consumption ranges for the 5/8" meters. Meters that registered over 2 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 115: Count of 5/8" meters with high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	46
0 to 0.125	413
0.125 to 0.25	886
0.25 to 0.5	1,452
0.5 to 1	715
1 to 2	110
2 to 4	9
4 to 8	1
8 to 16	1
TOTAL	3,633

E.2 Average Daily Consumption Range Profile: 5/8 x 3/4” Meters

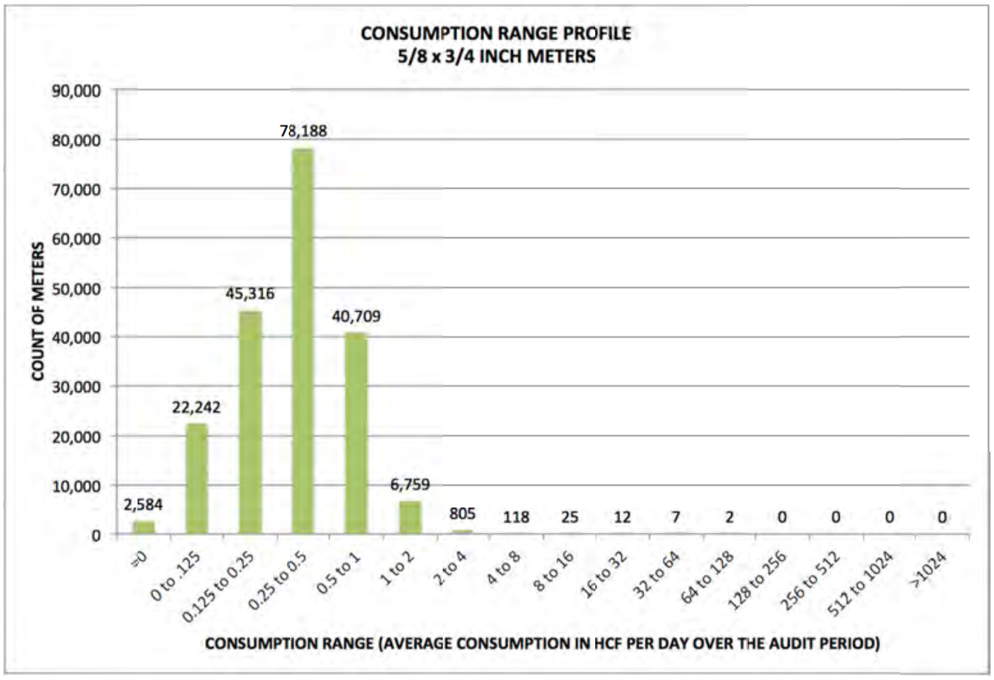


Figure 69: Number of 5/8 x 3/4” Meters by Average Daily Consumption Range

Table 116 shows the distribution of consumption ranges for the 5/8 x 3/4” meters. Meters that registered over 4 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 116: Count of 5/8 x 3/4” meters
with high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	2,584
0 to 0.125	22,242
0.125 to 0.25	45,316
0.25 to 0.5	78,188
0.5 to 1	40,709
1 to 2	6,759
2 to 4	805
4 to 8	118
8 to 16	25
16 to 32	12
32 to 64	7
64 to 128	2
TOTAL	196,806

E.3 Average Daily Consumption Range Profile: 3/4 x 1" Meters

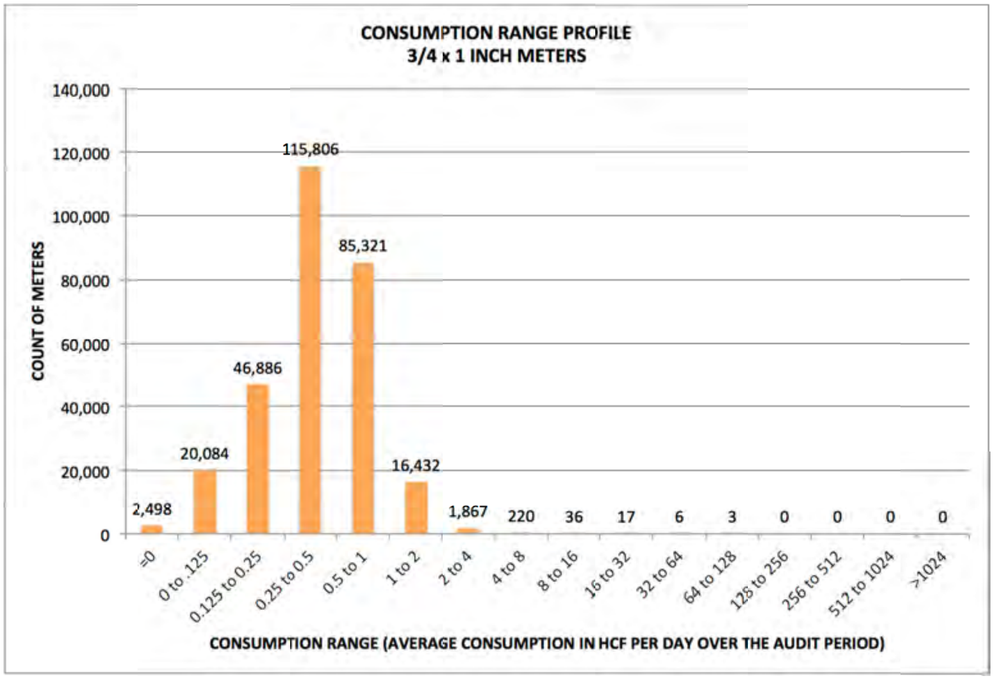


Figure 70: Number of 3/4 x 1" Meters by Average Daily Consumption Range

Table 117 shows the distribution of consumption ranges for the 3/4 x 1" meters. Meters that registered over 8 HCF are highlighted in green. These meters are likely to under-register and should be further examined.

Table 117: Count of 3/4 x 1" meters
with high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	2,498
0 to 0.125	20,084
0.125 to 0.25	46,886
0.25 to 0.5	115,806
0.5 to 1	85,321
1 to 2	16,432
2 to 4	1,867
4 to 8	220
8 to 16	36
16 to 32	17
32 to 64	6
64 to 128	3
TOTAL	289,176

E.4 Average Daily Consumption Range Profile: 1” Meters

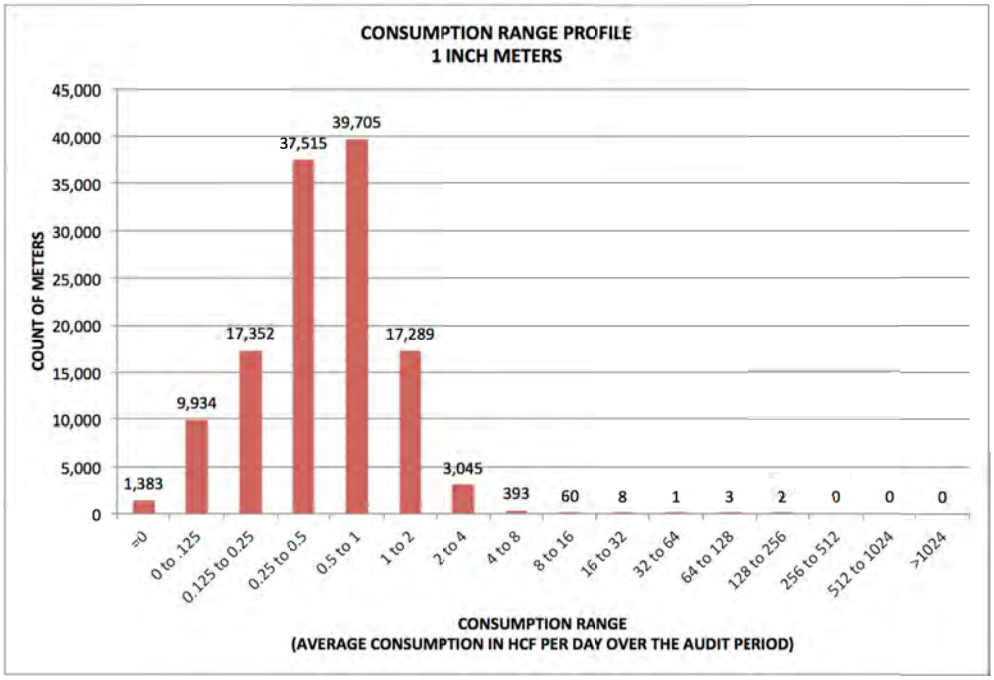


Figure 71: Number of 1” Meters by Average Daily Consumption Range

Table 118 shows the distribution of consumption ranges for the 1”. Meters that registered over 8 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 118: Count of 1” meters with high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	1,383
0 to 0.125	9,934
0.125 to 0.25	17,352
0.25 to 0.5	37,515
0.5 to 1	39,705
1 to 2	17,289
2 to 4	3,045
4 to 8	393
8 to 16	60
16 to 32	8
32 to 64	1
64 to 128	3
128 to 256	2
TOTAL	126,690

E.5 Average Daily Consumption Range Profile: 1 1/2" Meters

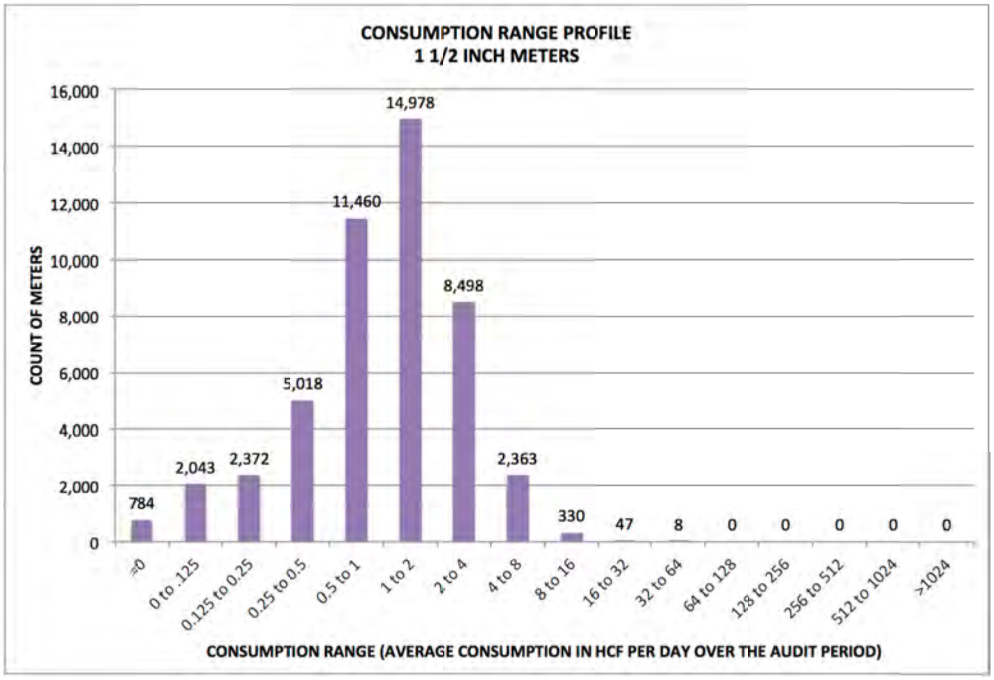


Figure 72: Number of 1 1/2" Meters by Average Daily Consumption Range

Table 119 shows the distribution of consumption ranges for the 1 1/2". Meters that registered over 16 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 119: Count of 1 1/2" meters with high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	784
0 to 0.125	2,043
0.125 to 0.25	2,372
0.25 to 0.5	5,018
0.5 to 1	11,460
1 to 2	14,978
2 to 4	8,498
4 to 8	2,363
8 to 16	330
16 to 32	47
32 to 64	8
TOTAL	47,901

E.6 Average Daily Consumption Range Profile: 2" Meters

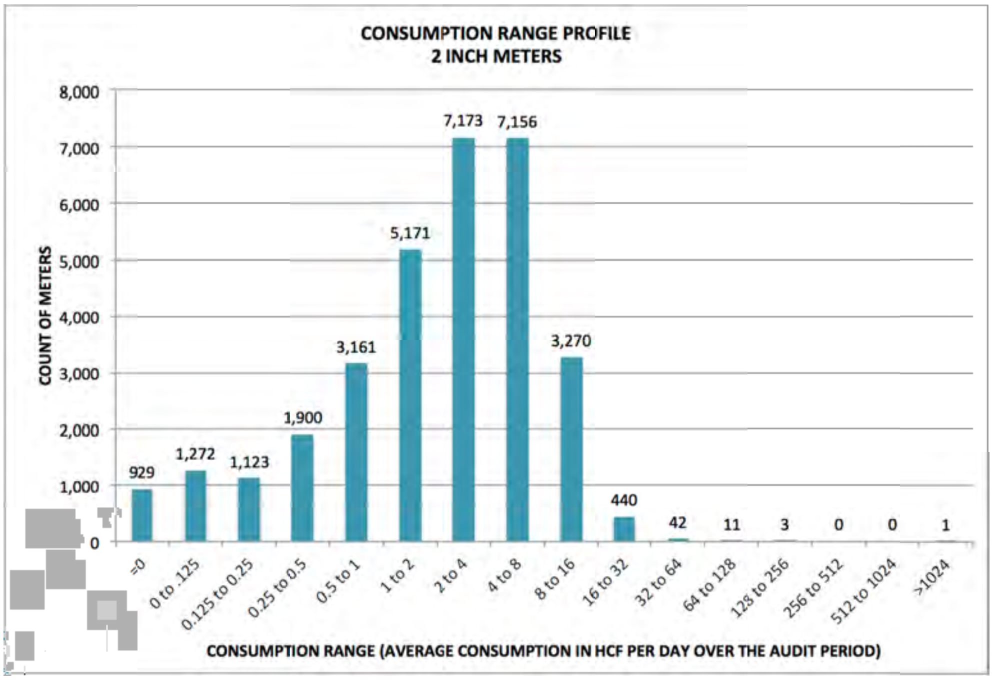


Figure 73: Number of 2" Meters by Average Daily Consumption Range

Table 120 shows the distribution of consumption ranges for the 2" meters. Meters that registered over 32 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 120: Count of 2" meters with high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	929
0 to 0.125	1,272
0.125 to 0.25	1,123
0.25 to 0.5	1,900
0.5 to 1	3,161
1 to 2	5,171
2 to 4	7,173
4 to 8	7,156
8 to 16	3,270
16 to 32	440
32 to 64	42
64 to 128	11
128 to 256	3
256 to 512	-
512 to 1024	-
>1024	1
TOTAL	31,652

E.7 Average Daily Consumption Range Profile: 3" Meters

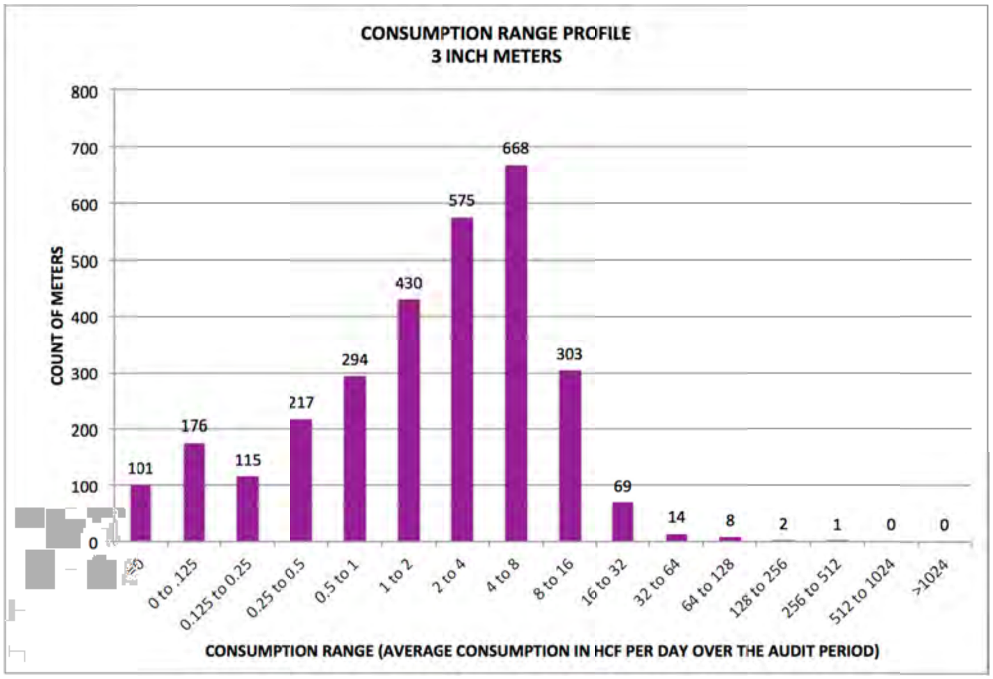


Figure 74: Number of 3" Meters by Average Daily Consumption Range

Table 121 shows the distribution of consumption ranges for the 3" meters. Meters that registered under 0.5 HCF per day or over 64 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 121: Count of 3" meters with high and low consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	101
0 to 0.125	176
0.125 to 0.25	115
0.25 to 0.5	217
0.5 to 1	294
1 to 2	430
2 to 4	575
4 to 8	668
8 to 16	303
16 to 32	69
32 to 64	14
64 to 128	8
128 to 256	2
256 to 512	1
TOTAL	2,973

E.8 Average Daily Consumption Range Profile: 4” Meters

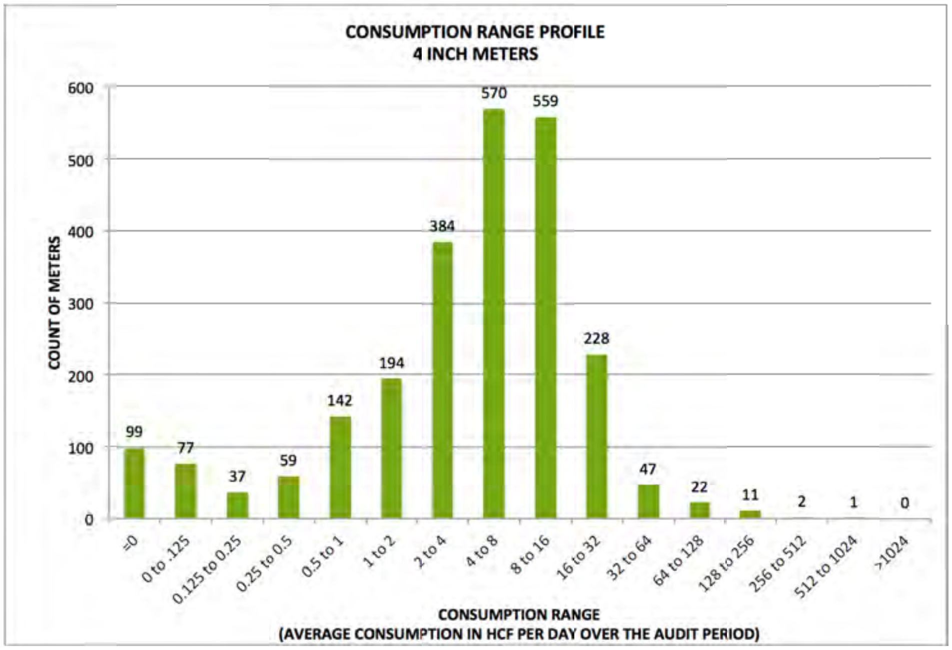


Figure 75: Number of 4”Meters by Average Daily Consumption Range

Table 122 shows the distribution of consumption ranges for the 4” meters. Meters that registered under 1 HCF per day or over 128 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 122: Count of 4” meters with low and high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	99
0 to 0.125	77
0.125 to 0.25	37
0.25 to 0.5	59
0.5 to 1	142
1 to 2	194
2 to 4	384
4 to 8	570
8 to 16	559
16 to 32	228
32 to 64	47
64 to 128	22
128 to 256	11
256 to 512	2
512 to 1024	1
TOTAL	2,432

E.9 Average Daily Consumption Range Profile: 6" Meters

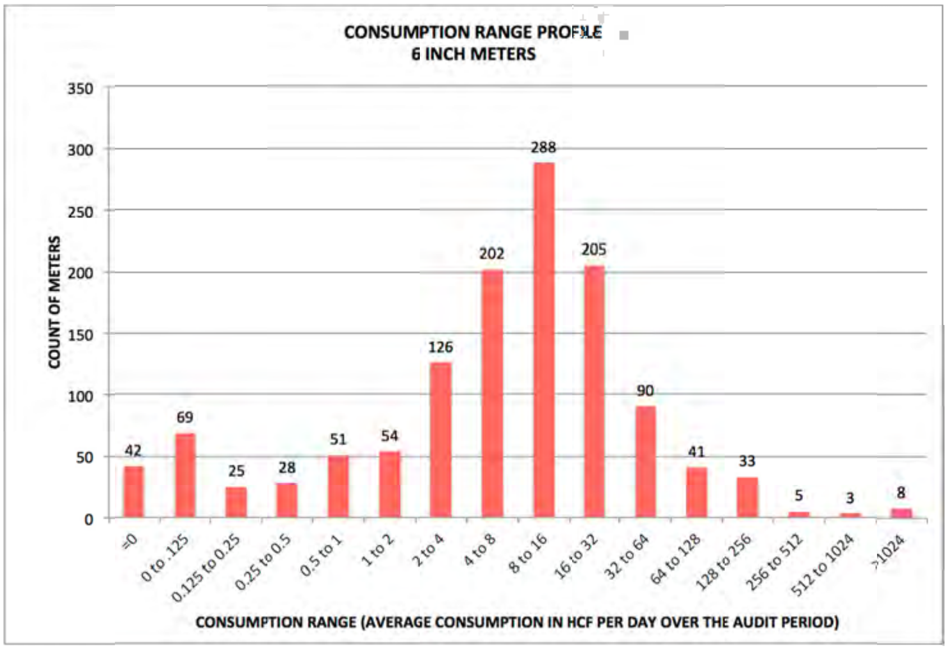


Figure 76: Number of 6" Meters by Average Daily Consumption Range

Table 123 shows the distribution of consumption ranges for the 6" meters. Meters that registered under 1 HCF per day or over 256 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 123: Count of 6" meters with low and high consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	42
0 to 0.125	69
0.125 to 0.25	25
0.25 to 0.5	28
0.5 to 1	51
1 to 2	54
2 to 4	126
4 to 8	202
8 to 16	288
16 to 32	205
32 to 64	90
64 to 128	41
128 to 256	33
256 to 512	5
512 to 1024	3
>1024	8
TOTAL	1,270

E.10 Average Daily Consumption Range Profile: 8" Meters

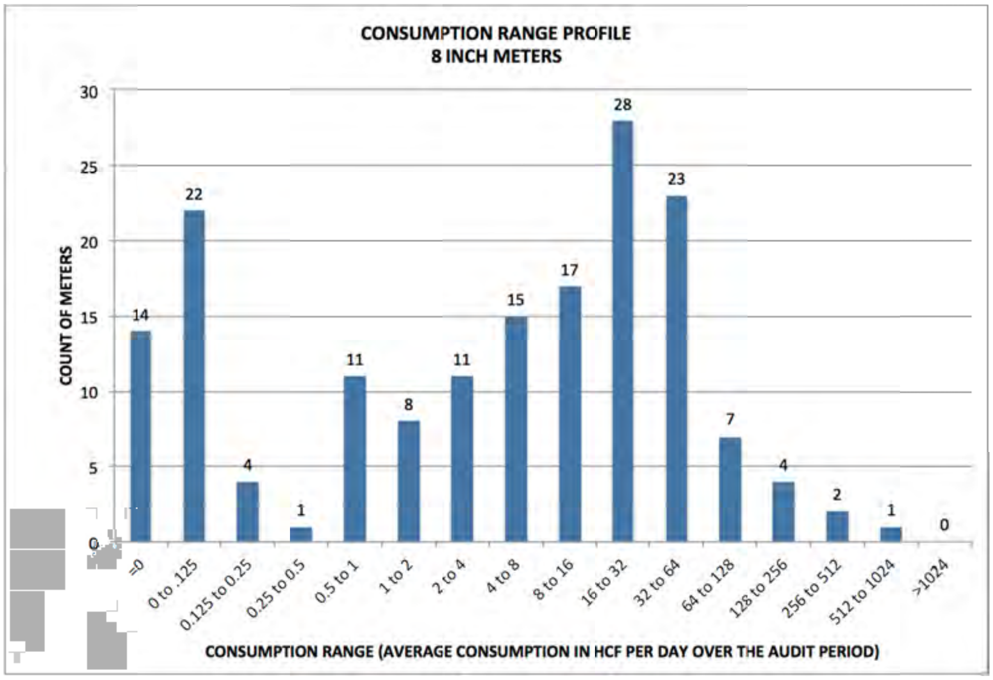


Figure 77: Number of 8" Meters by Average Daily Consumption Range

Table 124 shows the distribution of consumption ranges for the 8" meters. Meters that registered under 2 HCF per day or over 512 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 124: Count of 8" meters with high and low consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	14
0 to 0.125	22
0.125 to 0.25	4
0.25 to 0.5	1
0.5 to 1	11
1 to 2	8
2 to 4	11
4 to 8	15
8 to 16	17
16 to 32	28
32 to 64	23
64 to 128	7
128 to 256	4
256 to 512	2
512 to 1024	1
TOTAL	168

E.11 Average Daily Consumption Range Profile: 10” Meters

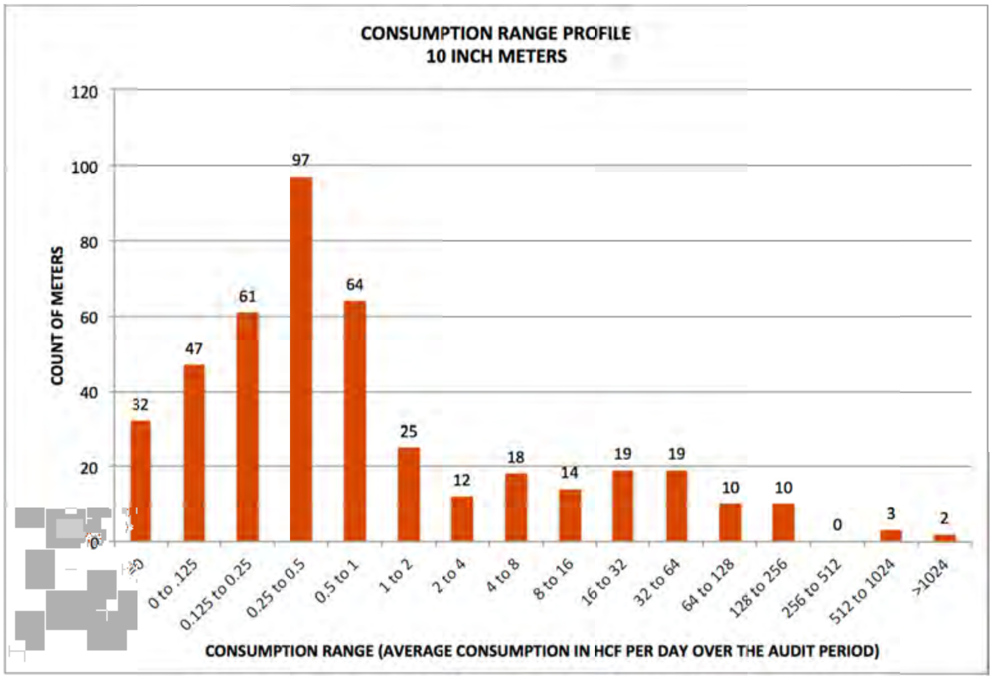


Figure 78: Number of 10” Meters by Average Daily Consumption Range

Table 125 shows the distribution of consumption ranges for the 10” meters. Meters that registered under 2 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 125: Count of 10” meters with low consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	32
0 to 0.125	47
0.125 to 0.25	61
0.25 to 0.5	97
0.5 to 1	64
1 to 2	25
2 to 4	12
4 to 8	18
8 to 16	14
16 to 32	19
32 to 64	19
64 to 128	10
128 to 256	10
256 to 512	0
512 to 1024	3
>1024	2
TOTAL	433

E.12 Average Daily Consumption Range Profile: 12” Meters

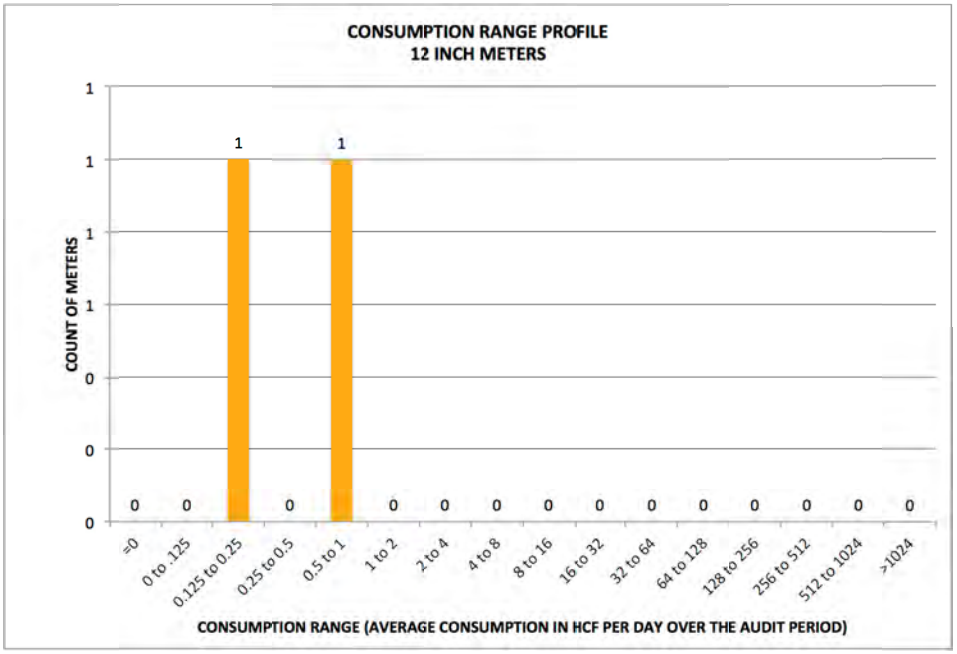


Figure 79: Number of 12” Meters by Average Daily Consumption Range

Table 126 shows the distribution of consumption ranges for the 12” meters. Meters that registered under 2 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined. It is noteworthy that all of the 12” meters register low daily volumes.

Table 126: Count of 12” meters with low consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
0.125 to 0.25	1
0.25 to 0.5	-
0.5 to 1	1
TOTAL	2

E.13 Average Daily Consumption Range Profile: 20” Meters

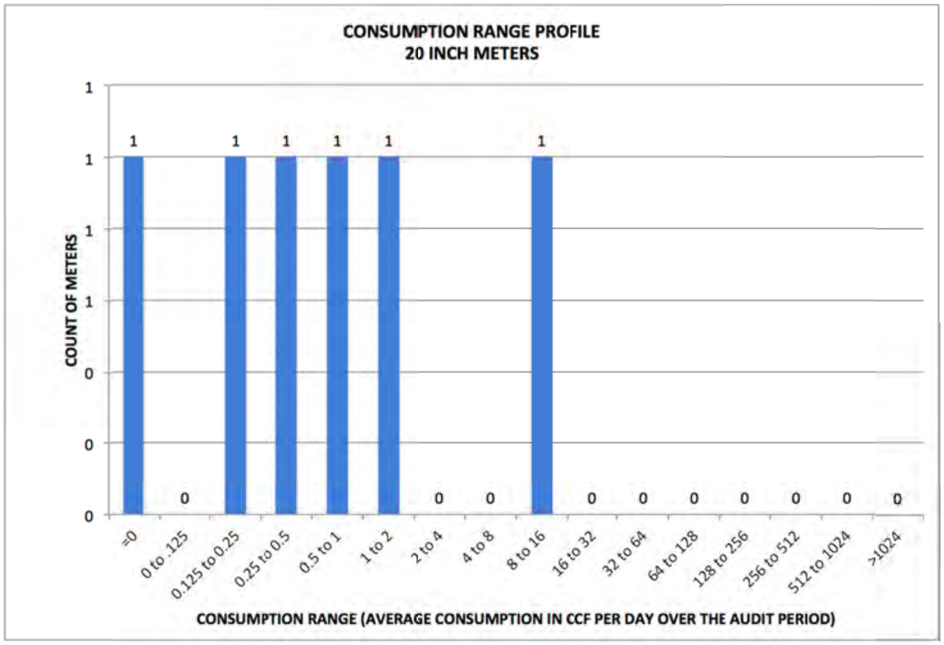


Figure 80: Number of 20” Meters by Average Daily Consumption Range

Table 127 shows the distribution of consumption ranges for the 20” meters. Meters that registered under 2 HCF per day are highlighted in green. These meters are likely to under-register and should be further examined.

Table 127: Count of 20” meters with low consumption highlighted

CONSUMPTION RANGE (HCF/DAY)	NUMBER OF METERS
=0	1
0 to 0.125	-
0.125 to 0.25	1
0.25 to 0.5	1
0.5 to 1	1
1 to 2	1
2 to 4	-
4 to 8	-
8 to 16	1
TOTAL	6

APPENDIX F: Monthly Consumption for Each Class Code

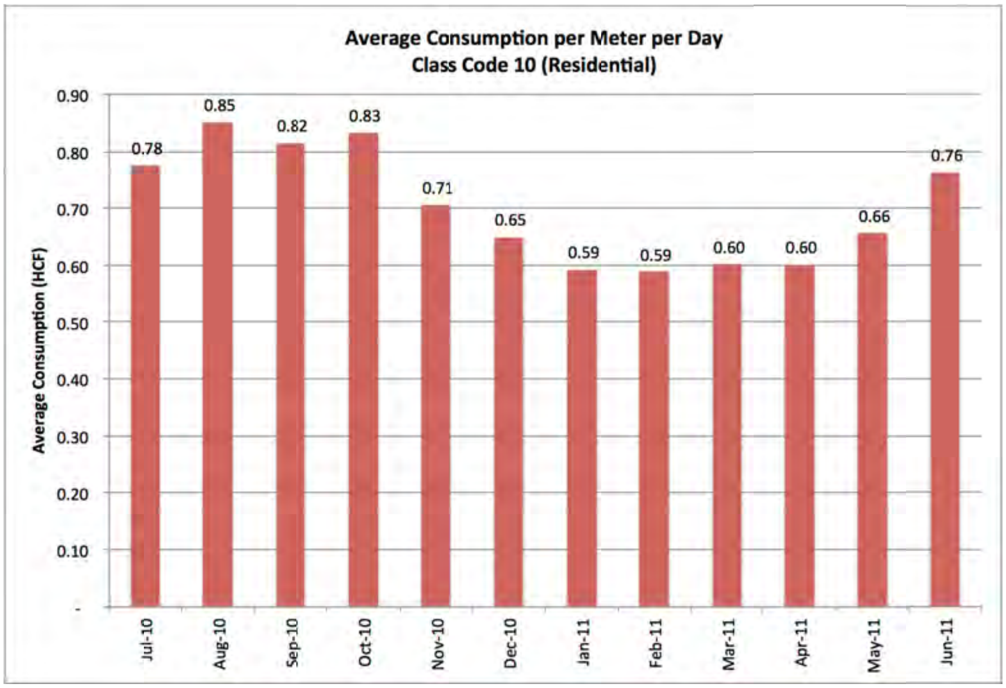


Figure 81: Monthly Consumption for Class Code 10 – Residential

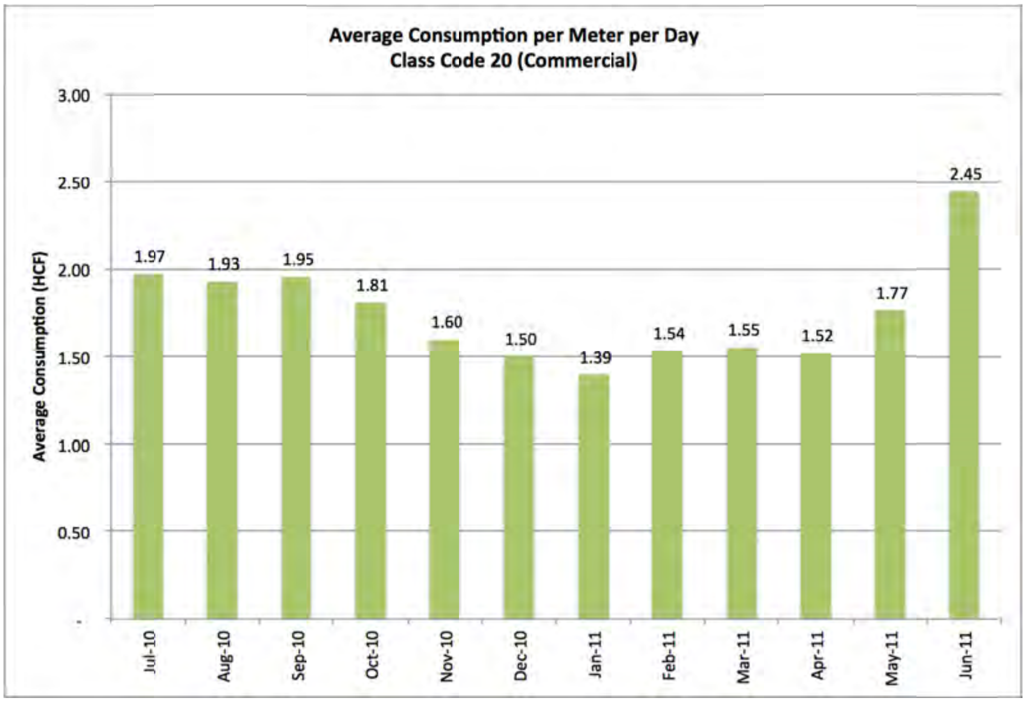


Figure 82: Monthly Consumption for Class Code 20 – Commercial

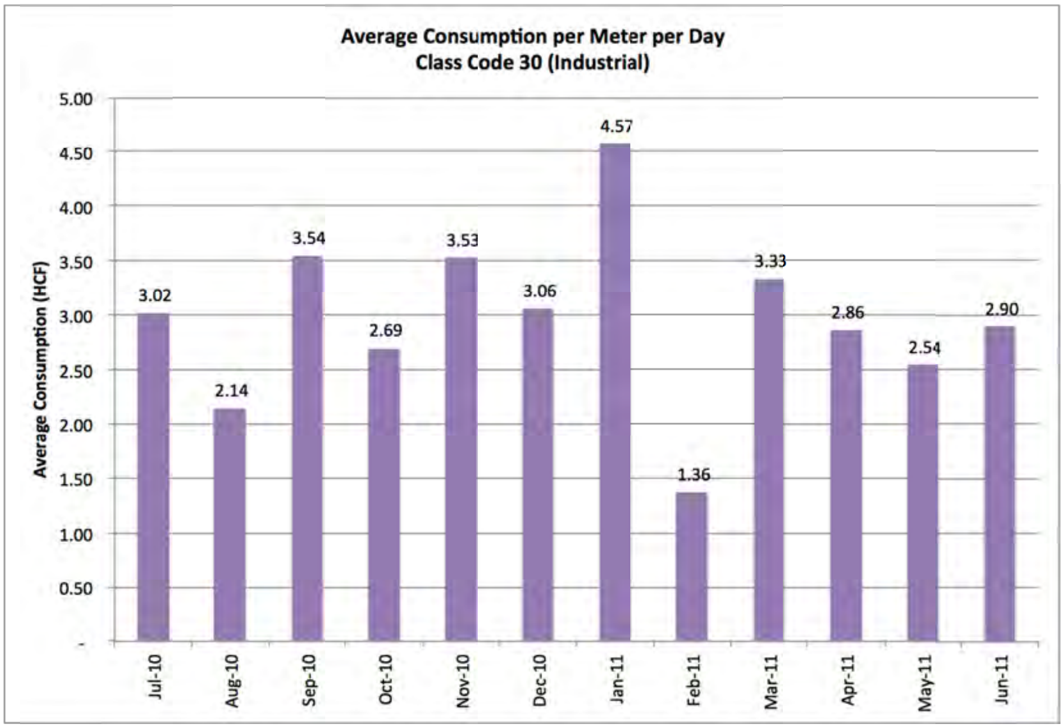


Figure 83: Monthly Consumption for Class Code 30 – Industrial

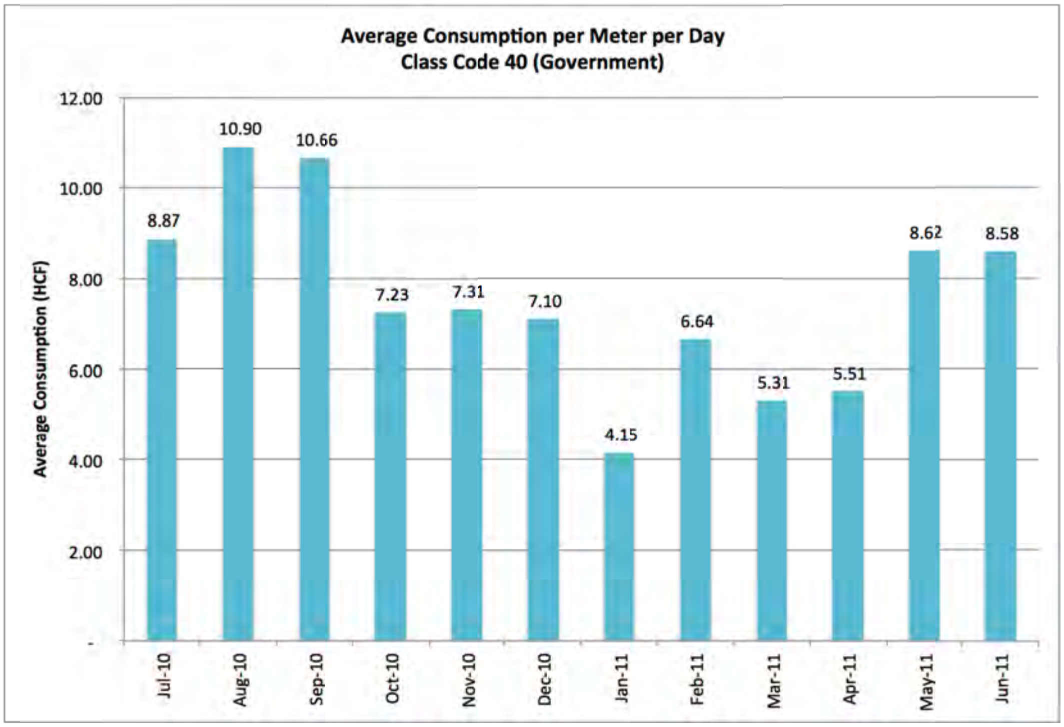


Figure 84: Monthly Consumption for Class Code 40 – Government

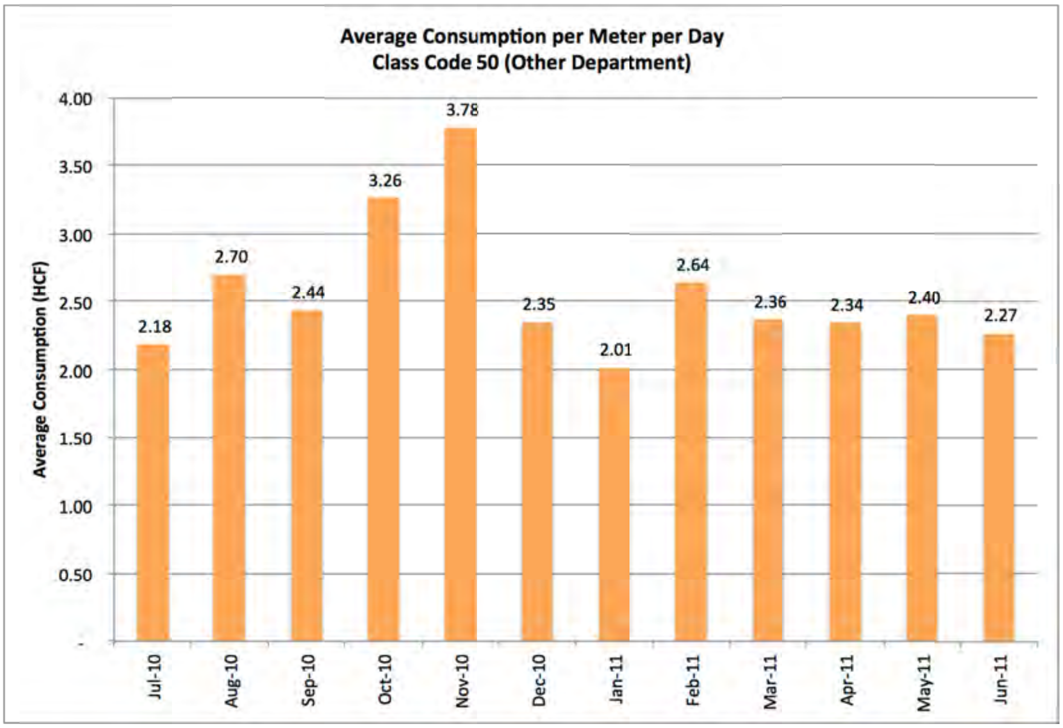


Figure 85: Monthly Consumption for Class Code 50 – Other Department

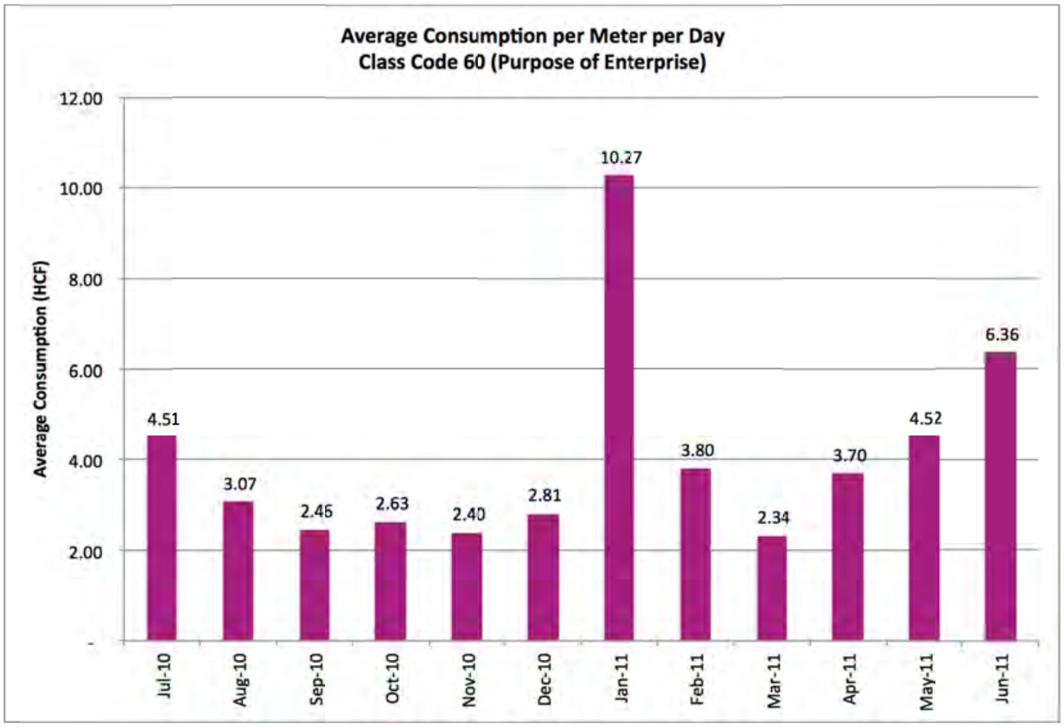


Figure 86: Monthly Consumption for Class Code 60 – Purpose of Enterprise

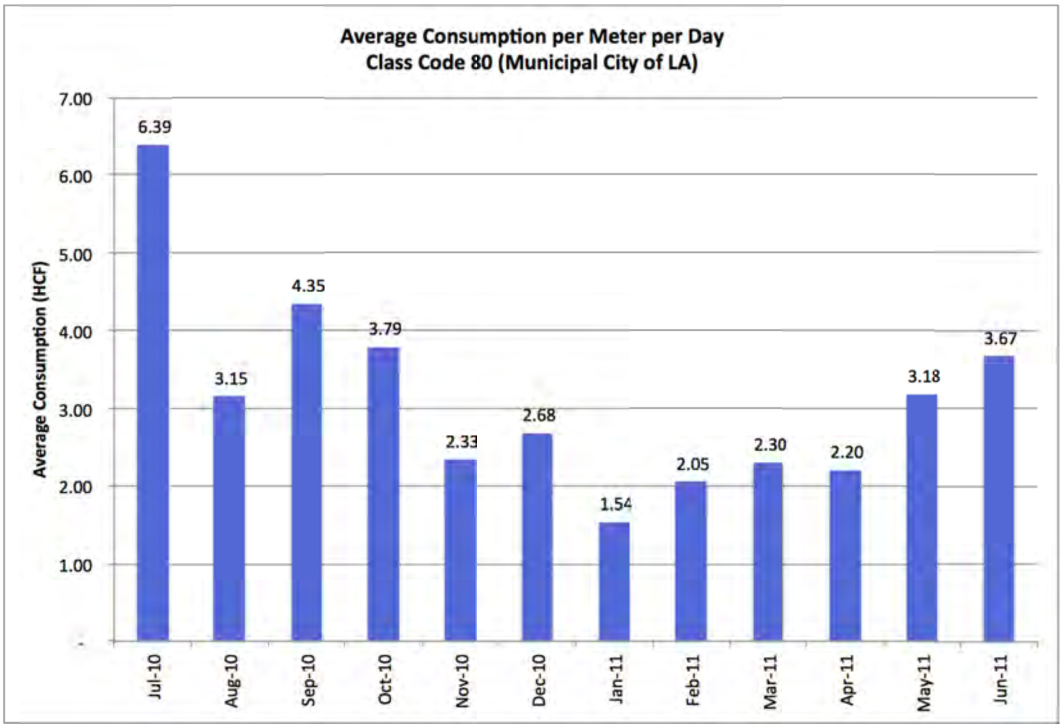


Figure 87: Monthly Consumption for Class Code 80 – Municipal City of LA

APPENDIX G: Example of Meter Profiling and Analysis

G.1 Example of Meter Profiling: TRO Avenue of the Arts LP

The following is an example of a meter consumption profiling analysis completed for the Philadelphia Water Department. The meter examined at the TRO Avenue of the Arts LP is a 3-inch Badger Recordall Turbine. On Tuesday, January 24, 2012, a Meter-Master unit and a data logger were installed for consumption profile logging at 20-second intervals (See Figure 88).

Figure 88: Meter-Master Installation and Data Logger – TRO Ave of the Arts

Table 128 provides information about the TRO Ave of the Arts meter and the results of the consumption profiling (January 24-31).

Table 128: TRO Avenue of the Arts LP – Consumption Profiling Results

Address	1340 Chestnut St, 19107
Customer Description	Art Institute of Philadelphia Building
Billing Account Number	XXXXXXXXXXXXXXXXXXXXXX
Avg. Monthly Consumption	4,697 HCF
Meter Count at Location	1
Meter Size	3-inch
Meter Number	0750833
Meter Type	Badger Recordall Turbine
Start Logging	January 24, 2012 – 03:31 pm
End Logging	January 31, 2012 – 11:52 am
Total Volume Passed	96,513 cubic feet (721,922 gallons)
Average Flow Rate	73.2gpm
Maximum Flow Rate	138gpm
Minimum Flow Rate	0.00gpm

Figure 89 depicts the consumption profile (1-min average) for the first two days of the meter profile logging between January 24 and January 26 for the TRO Ave for the Arts.

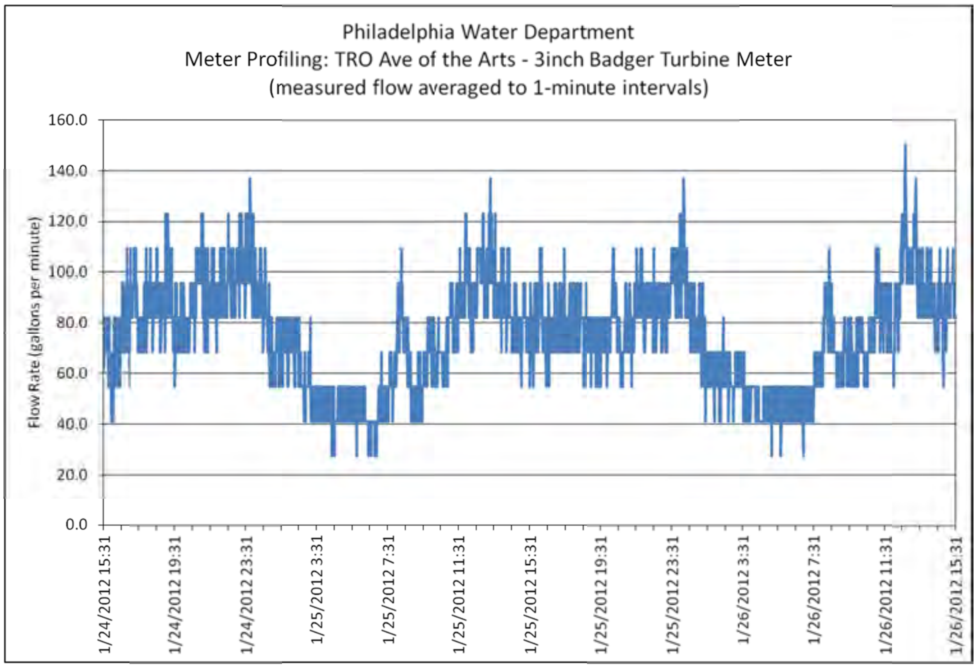


Figure 89: One Minute Average Consumption Volumes at TRO Ave of the Arts

Figure 90 depicts the consumption profile (15-min average) that was recorded between January 24 and January 31 for the TRO Ave of the Arts.

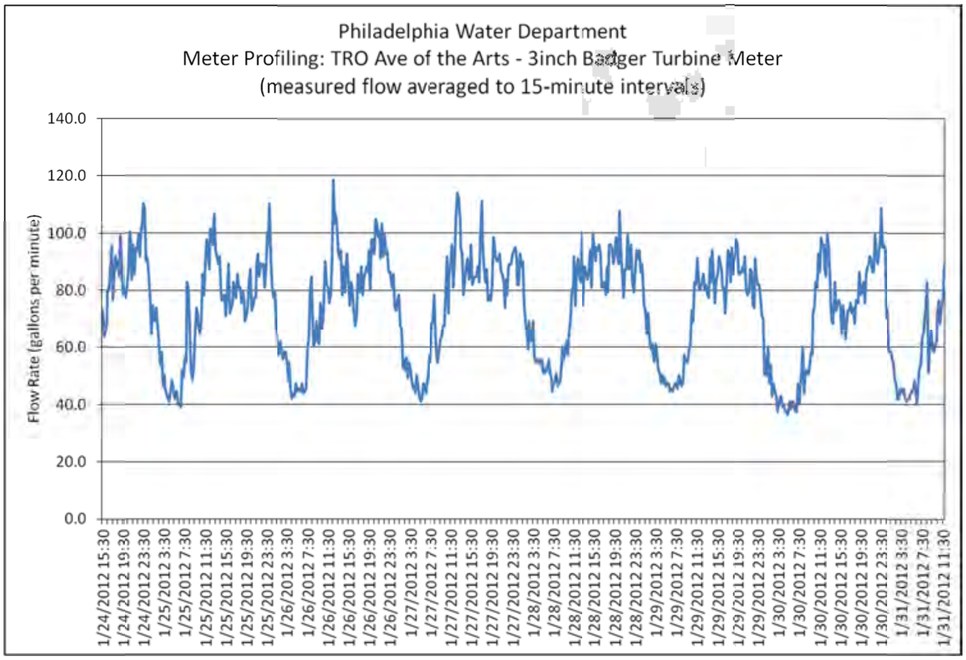


Figure 90: 15 Minute Average Consumption Volumes at TRO Ave of the Arts

Figure 91 depicts the consumption profile (1-hour average) that was recorded between January 26 and January 31 for the TRO Ave of the Arts.

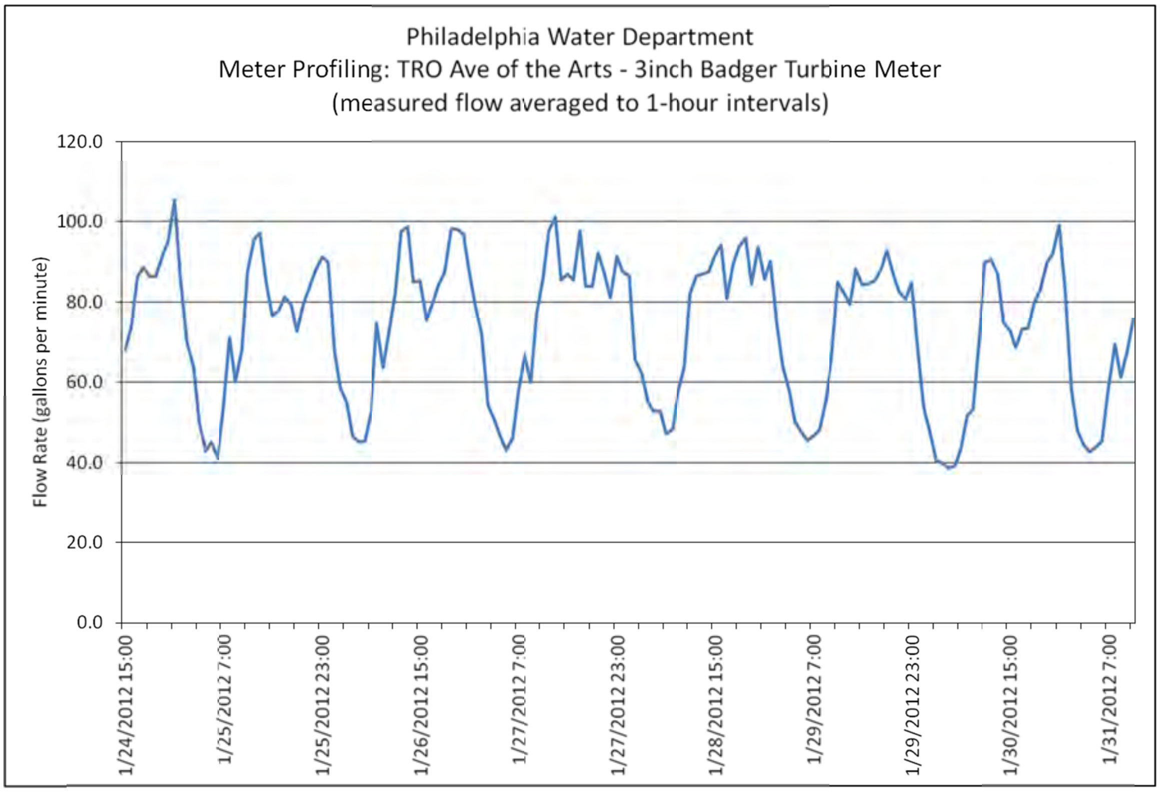


Figure 91: One Hour Average Consumption Volumes at TRO Ave of the Arts

The recommended flow range for a 3-inch Badger Recordall Turbine meter is between 5gpm and 550gpm (normal flow limits) and the recommended low flow limit at 4gpm for this size meter. The data recorded indicates that the TRO Ave of the Arts meter is operating within the recommended flow range. The recorded data indicates that there is constant demand within the lower bounds of the recommended flow range for this site. This suggests that a measurement range from 5 to 550gpm is not completely necessary. A single jet meter with high accuracy at lower flow rates would be an appropriate choice for this location.

G.2 Percentage of Time Spent at Different Flow Rates

The flow data recorded provides the opportunity to analyze how much time the currently installed meter is operating at various flow rates. The analysis looked at how much time the flow is zero, the flow is below the normal flow rate (less than 5gpm), what percentage of time the meter is operating within the normal flow range (5gpm to 550gpm), and if flow rates occur that are above the maximum recommended flow rate (550gpm). The accuracy of a meter is higher when operating at the normal/recommended flow range, than when operating outside of the recommended flow range.

Next it was analyzed how much an alternative meter, in this case a 3-inch Actaris Single Jet meter, would spend at zero flow, below the recommended flow rate (less than 2.5gpm) and within the recommended flow range (2.5gpm to 320gpm).

Figure 92 shows the results of this flow range analysis when applied to the 1-minute average data. It indicates that about none of the recorded flows are 0.0gpm. This analysis also indicates that for both meter types 100% of recorded flows fall within the meters' recommended normal flow ranges (see Figure 92). However, the quoted accuracy (+/-0.5%) of the Actaris meter is higher within the recommended flow range than the quoted accuracy (+/- 1.5%) of the currently installed meter.

Figure 93 depicts the percentage of time the currently installed meter spends at various flow rates between zero and 200gpm – excluding the percentage of time zero flow rates were recorded. About 26% of the flow rates recorded was either zero or between 80gpm and 85gpm. No flows were recorded above either of the meters' operating ranges.

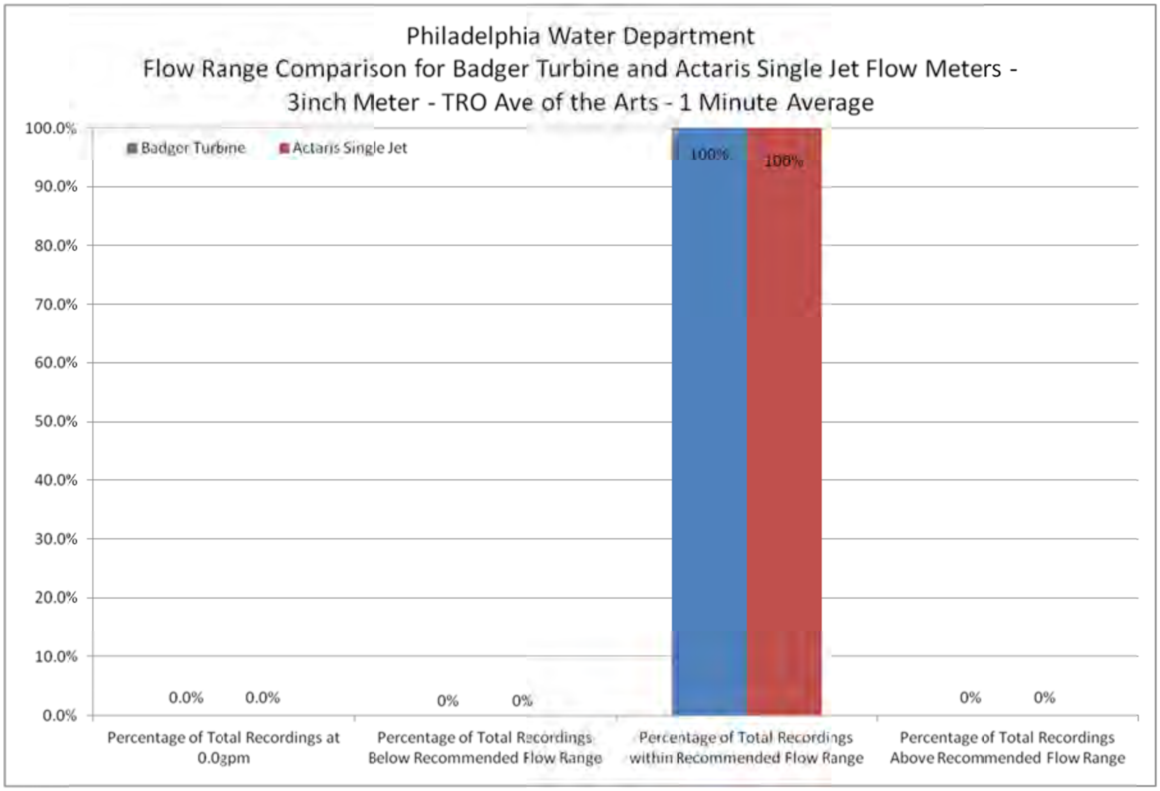


Figure 92: Flow Range Comparison of Current and Alternative Meter – TRO Ave of the Arts

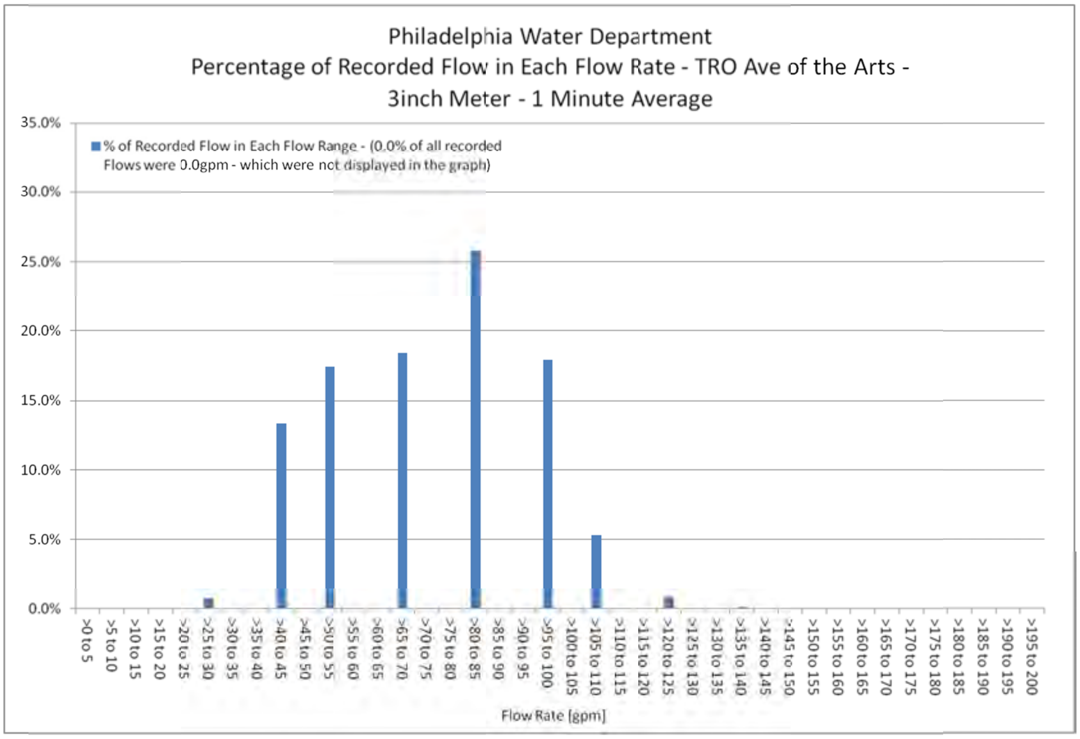


Figure 93: Percentage of Recorded Flow in Each Flow Range – TRO Ave of the Arts

G.3 Apparent Loss Analysis

Next the recorded data was analyzed to calculate how much volume the currently installed flow meter (Badger Recordall Turbine) recorded at the three strategic flow ranges (below recommended flow range, within recommended flow range, above recommended flow range). Applying the manufacturers quoted accuracy at these flow ranges allows calculating the associated volume of apparent losses (see Table 129). The same approach was used to calculate the theoretical apparent loss volume from an alternative meter (Actaris Single Jet).

Table 129: TRO Ave of the Arts – Apparent Loss Analysis – Current Meter and Alternative Meter

	Total Volume Measured	721,921.48	gal
Actaris	Total Volume Registered Below Normal Flow Range - <2.5gpm	-	gal
Actaris	Total Volume Registered at Normal Flow Ranges >2.5gpm <320gpm	721,921.48	gal
Actaris	Total Volume Registered Above Normal Flow Ranges >320gpm	-	gal
Badger	Total Volume Registered Below Normal Flow Range - <5.0gpm	-	gal
Badger	Total Volume Registered at Normal Flow Ranges >5gpm <550gpm	721,921.48	gal
Badger	Total Volume Registered Above Normal Flow Ranges >550gpm	-	gal
	Total Apparent Loss Volume Based on Manufacturers Quoted Accuracy		
Actaris	<2.5gpm	-	gal
Actaris	>2.5gpm <320gpm	3,627.75	gal
Actaris	>320gpm	-	gal
Badger	<5gpm	-	gal
Badger	>5gpm<550gpm	10,993.73	gal
Badger	>550gpm	-	gal

Historical billing data provided by PWD was used to determine the potential annual apparent loss volume for the currently installed meter and an Actaris Single Jet flow meter (see Figure 94).

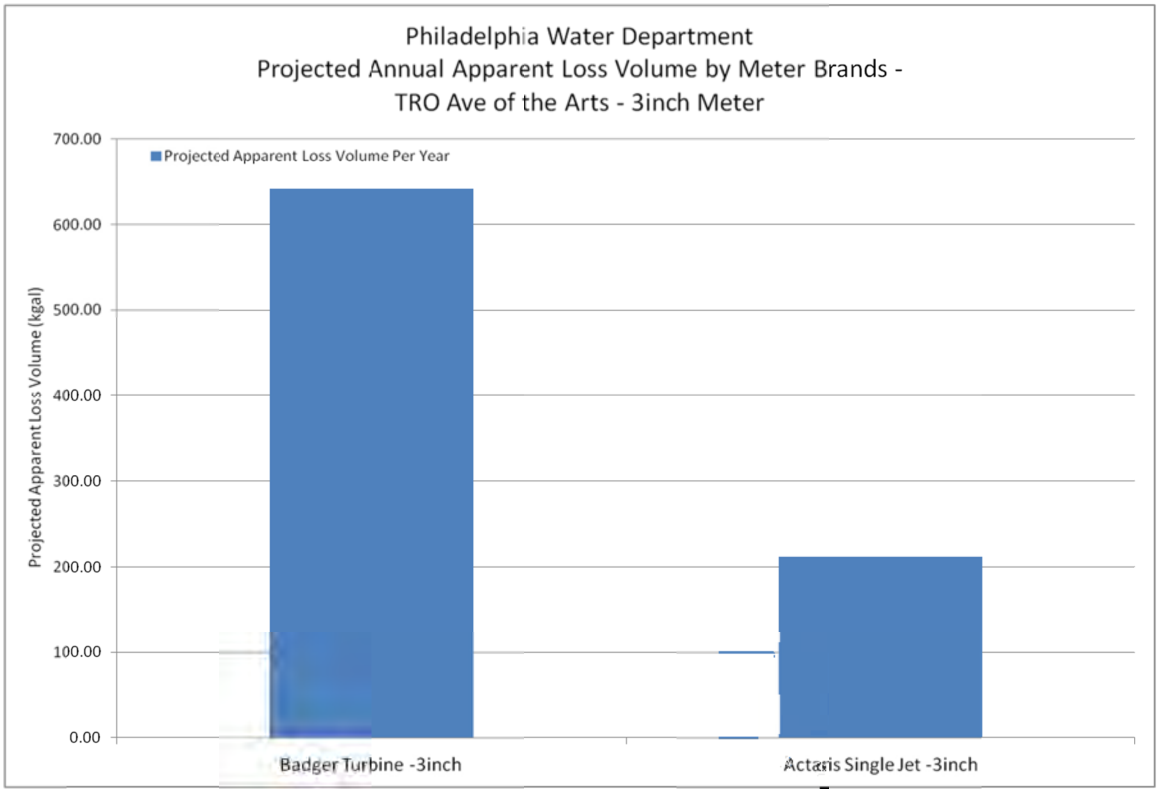


Figure 94: Projected Annual Apparent Loss Volume – TRO Ave of the Arts

Figure 94 shows that the alternative meter (Actaris Single Jet) would reduce the annual volume of apparent losses by about 67 percent.

G.4 Cost Benefit of Meter Replacement

The cost benefit of replacing the current meter with an alternative meter was assessed by applying the PWD volumetric charges for water consumption to the calculated volume of apparent losses (see Table 130). Please note that at the time of analysis, the PWD volumetric charge for water consumption was approximately $6.08/kgal.

Table 130: TRO Avenue of the Arts LP – Projected Volumetric and Revenue Savings through Meter Replacement

Projected Annual Savings	Volume (kgal/year)	Monetary($/year)
Badger Total Apparent Losses	641.88	$3,900.79
Actaris Total Apparent Losses	211.81	$1,287.20
Savings from switching from Badger to Actaris	430.07	$2,613.60
Cost of Meter Replacement		$2,013.76
Resulting Payback Period		0.77 years

The analysis indicates that the volume of apparent losses could be reduced by about 430-kgal/year by replacing the current meter (Badger Recordall Turbine) with an alternative meter (Actaris Single Jet). Based on the current water rate structure in PWD, the reduction in apparent losses would yield an increase in revenue for PWD of about $2,614.

The cost to purchase and install a new 3-inch Actaris meter is $2,013.76. Based upon the monetary value of the apparent loss reduction, this investment would have a payback period of about 0.77 years.

APPENDIX H: Meter Test Results – Breakdown by Make

Figure 95 shows the average accuracy results for all 5/8 x 3/4" meter tested.

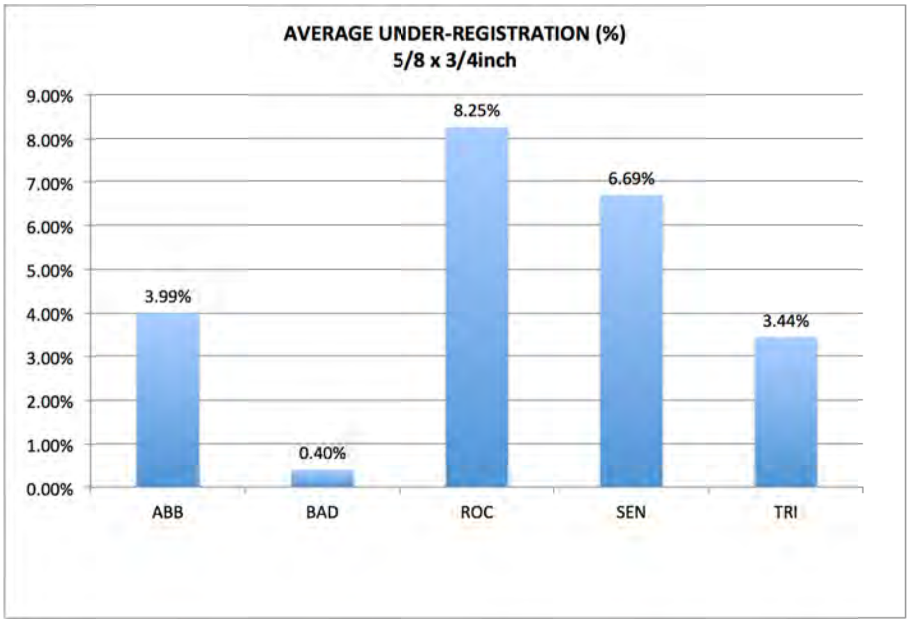


Figure 95: Average Under-Registration for 5/8 x 3/4" Meters

Figure 96 shows the average accuracy results for all 3/4 x 1" meter tested.

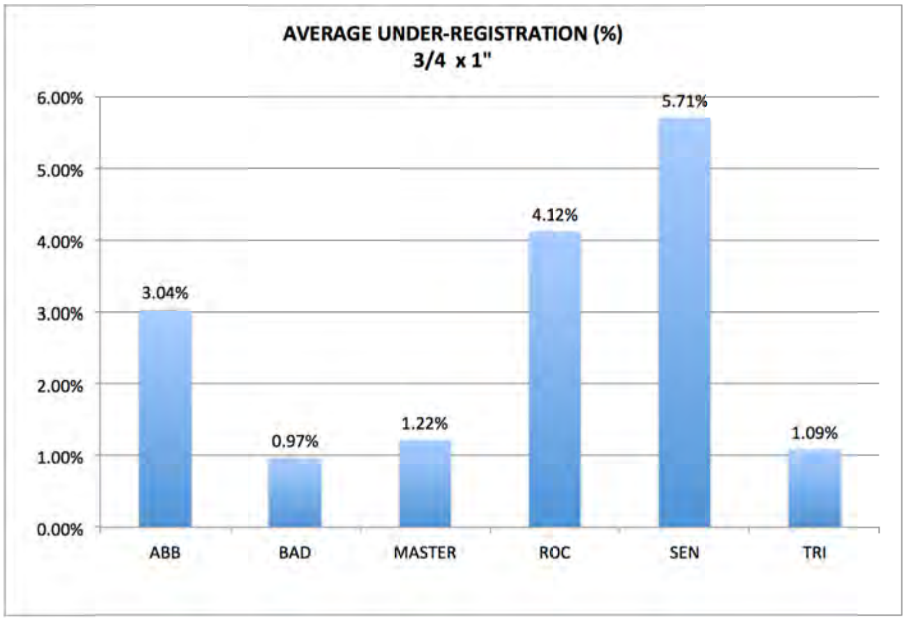


Figure 96: Average Under-Registration for 3/4 x 1" Meters

Figure 97 shows the average accuracy results for all 3/4 x 1” meter tested.

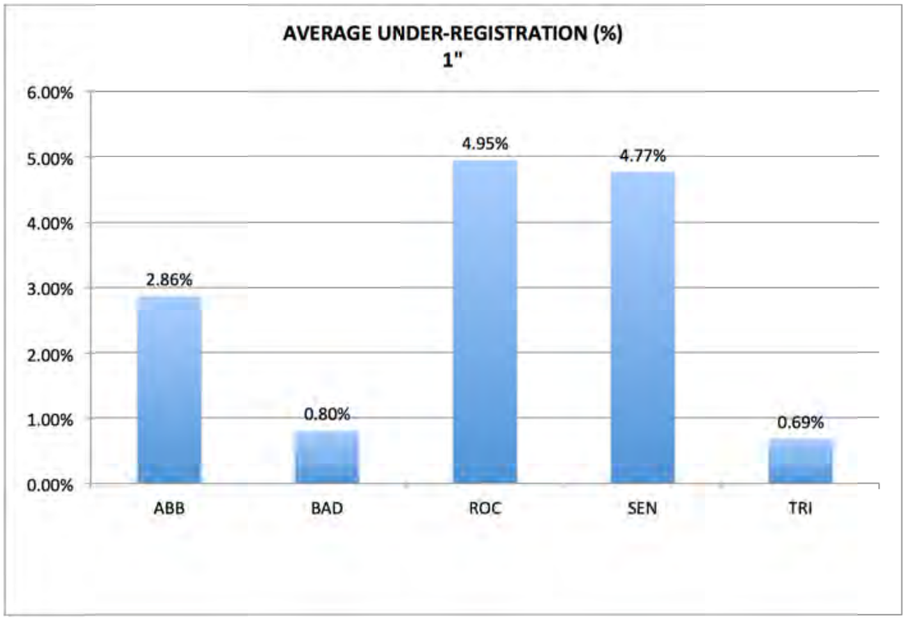


Figure 97: Average Under-Registration for 1” Meters

Figure 98 shows the average accuracy results for all 1 1/2” meter tested.

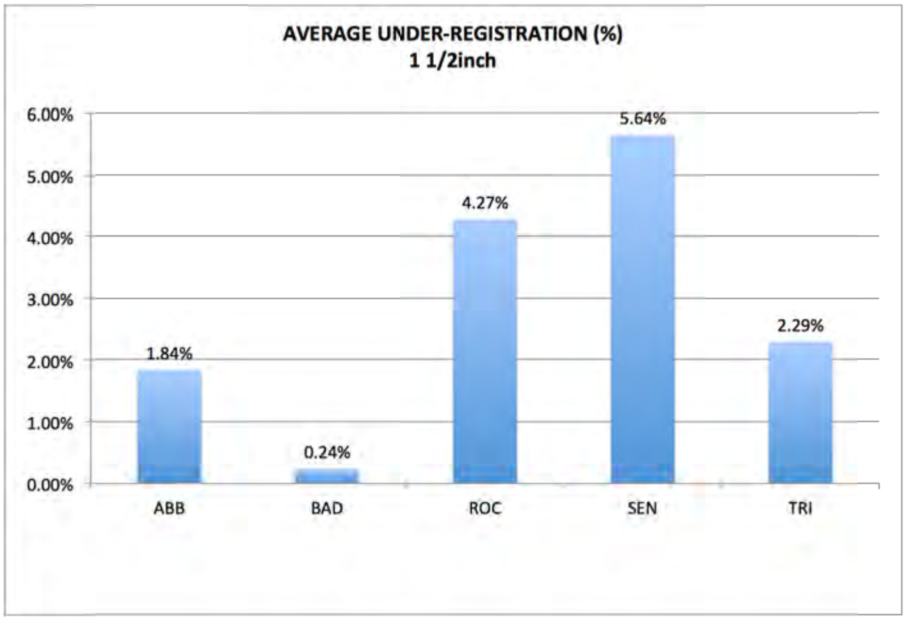


Figure 98: Average Under-Registration for 1 1/2” Meters

Figure 99 shows the average accuracy results for all 2” meter tested.

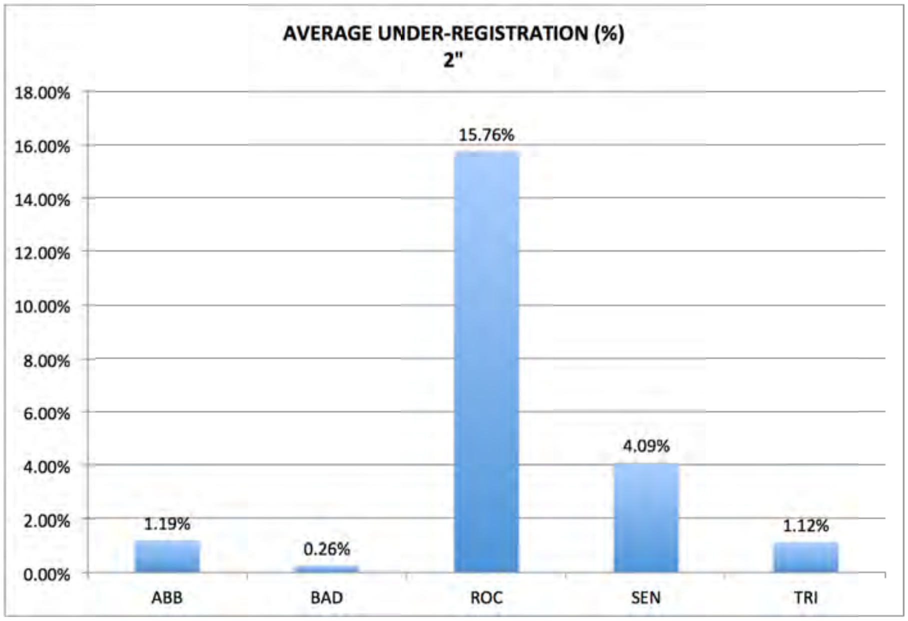


Figure 99: Average Under-Registration for 2” Meters

APPENDIX I: Meter Age & Lifetime Volume Correlation Analysis

Figure 100 shows each small meter test at low flow, plotting the meter age against the determined accuracy. With low correlation (an R-squared value of 0.182), this data suggests that it is unlikely that age is a determining factor in accuracy of the small meter population at low flows.

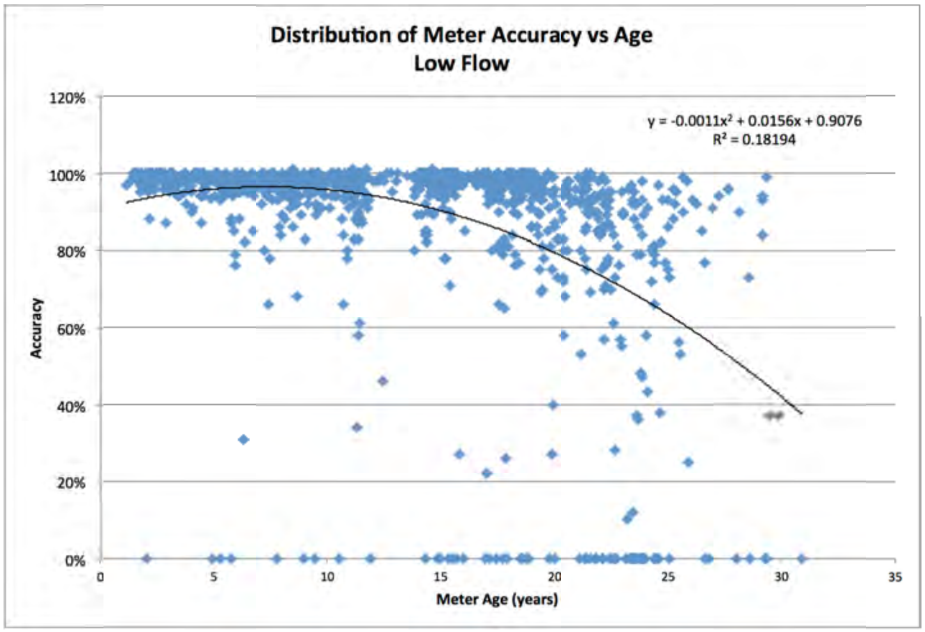


Figure 100: Meter Age v. Accuracy for Small Meter Low Flow Tests

Figure 101 shows each small meter test at medium flow, plotting the meter age against the determined accuracy. With low correlation (an R-squared value of 0.035), this data suggests that it is unlikely that age is a determining factor in accuracy of the small meter population at medium flows.

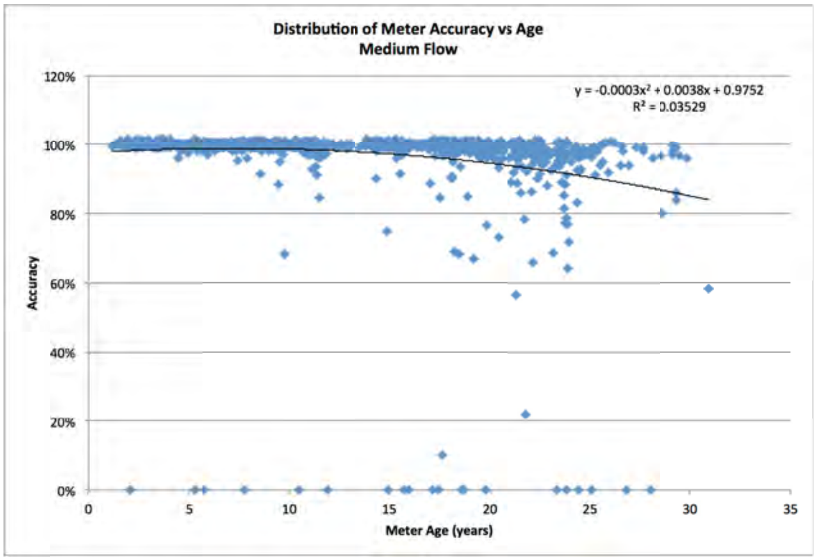


Figure 101: Meter Age v. Accuracy for Small Meter Medium Flow Tests

Figure 102 shows each small meter test at high flow, plotting the meter age against the determined accuracy. With low correlation (an R-squared value of 0.011), this data suggests that it is unlikely that age is a determining factor in accuracy of the small meter population at high flows.

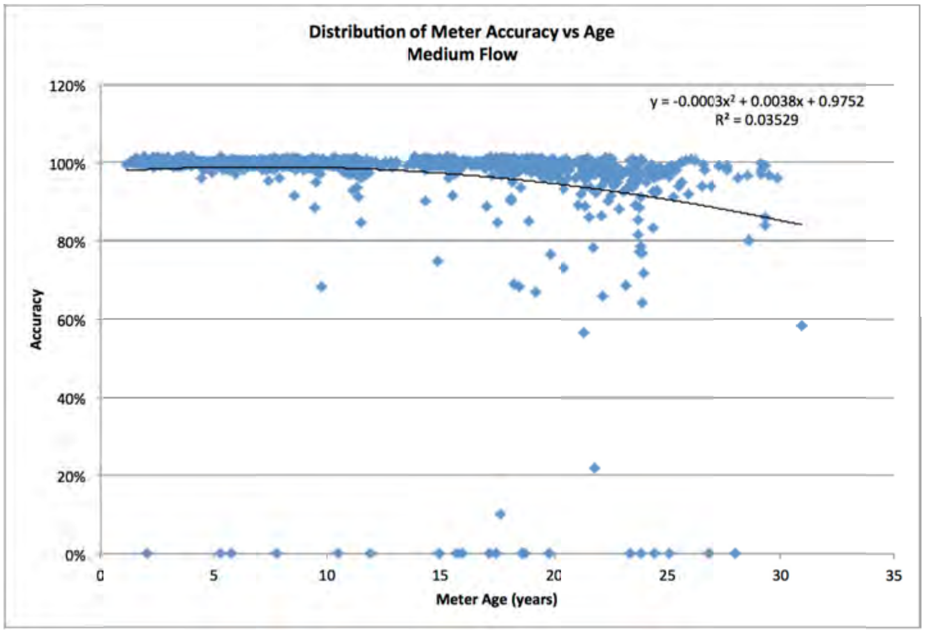


Figure 102: Meter Age v. Accuracy for Small Meter High Flow Tests

APPENDIX J: AWWA Accuracy Thresholds for Small Meters

For each size group, the accuracy results for the tested meters were compared with the recommended AWWA accuracy limits to determine if the meters passed the recommendations, were below or exceeded these limits (see Section 4.2.1.1.6).

AWWA Accuracy Compliance for 5/8 x 3/4" Meters

Figure 103 presents the percentage of 5/8 x 3/4" meters tested that complied with these requirements at each tested flow rate. Overall, 33% of the 5/8 x 3/4" meters tested complied with the recommended accuracy limits at all flow rates, while 9% of the 5/8 x 3/4" meters did not comply with the recommended accuracy limits at any flow rate.

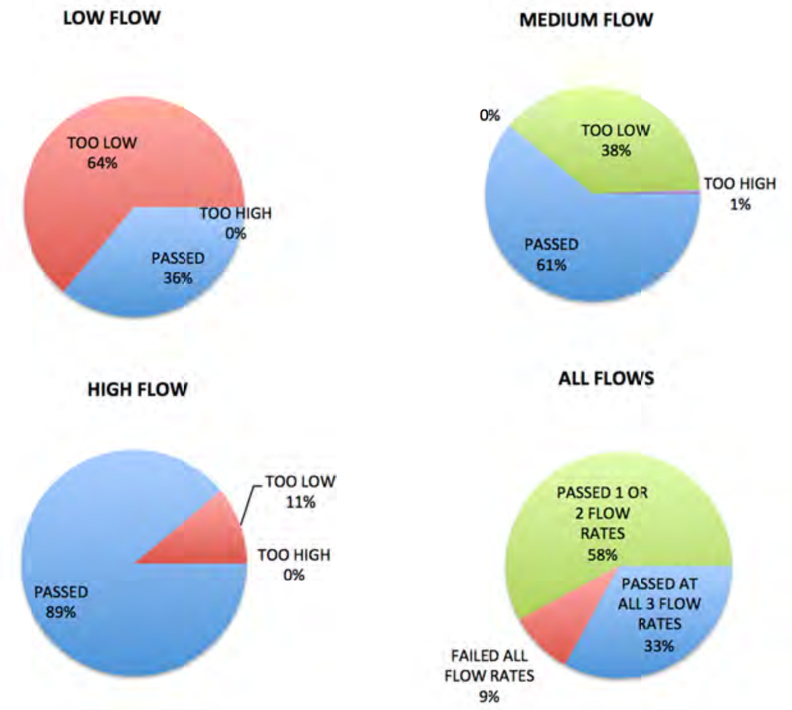


Figure 103: Compliance with AWWA Recommended
Accuracy Limits – 5/8 x 3/4" Meters

AWWA Accuracy Compliance for 3/4 x 1” Meters

Figure 104 presents the percentage of 3/4 x 1” meters tested that complied with these requirements at each tested flow rate. Overall, 54% of the 3/4 x 1” meters tested complied with the recommended accuracy limits at all flow rates, while 8% of the 3/4 x 1” meters did not comply with the recommended accuracy limits at any flow rate.

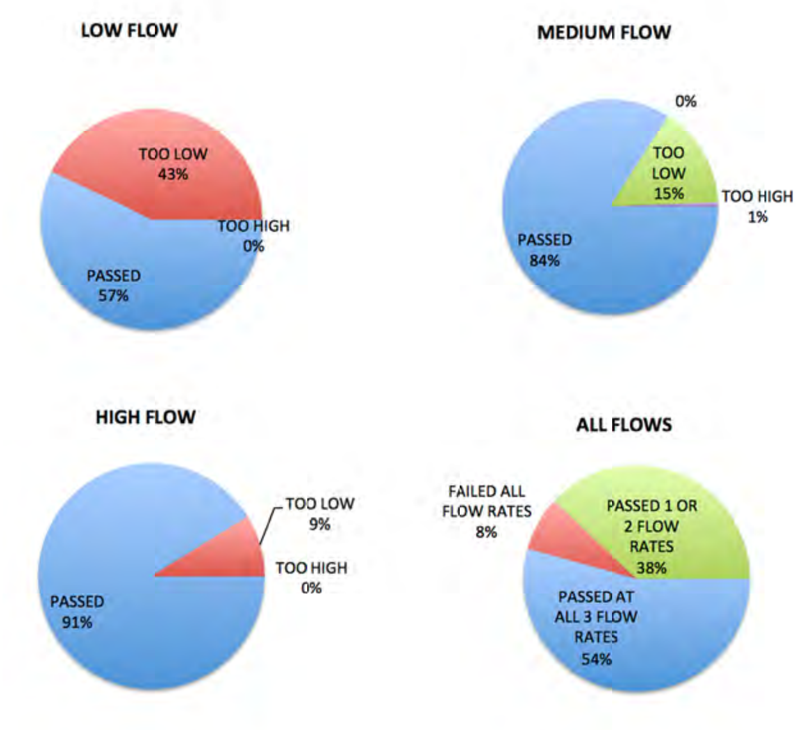


Figure 104: Compliance with AWWA Recommended Accuracy Limits – 3/4 x 1” Meters

AWWA Accuracy Compliance for 1” Meters

Figure 105 presents the percentage of 1” meters tested that complied with these requirements at each tested flow rate. Overall, 66% of the 1” meters tested complied with the recommended accuracy limits at all flow rates, while 8% of the 1” meters did not comply with the recommended accuracy limits at any flow rate.

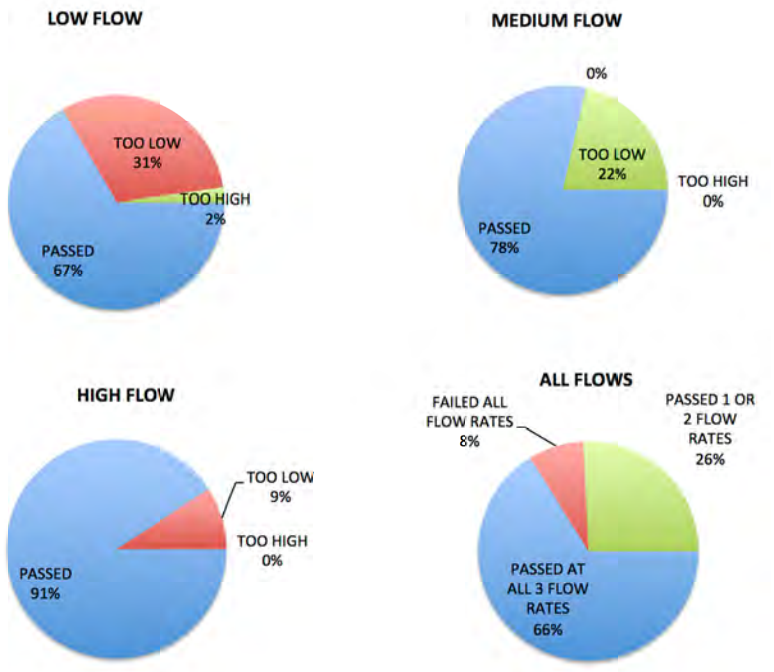


Figure 105: Compliance with AWWA Recommended Accuracy Limits – 1” Meters

AWWA Accuracy Compliance for 1 1/2" Meters

Figure 106 presents the percentage of 1 1/2" meters tested that complied with these requirements at each tested flow rate. Overall, 72% of the 1 1/2" meters tested complied with the recommended accuracy limits at all flow rates, while 10% of the 1 1/2" meters did not comply with the recommended accuracy limits at any flow rate.

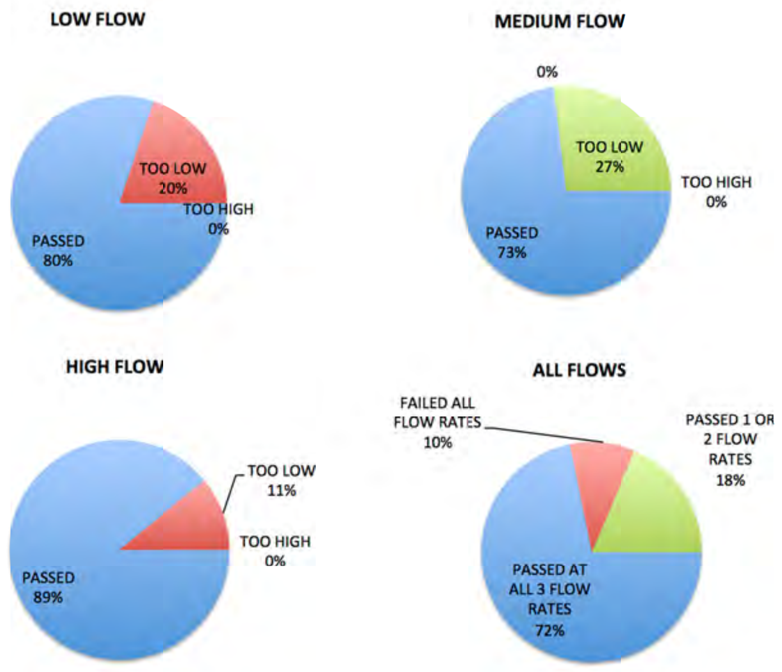


Figure 106: Compliance with AWWA Recommended Accuracy Limits – 1 1/2" Meters

AWWA Accuracy Compliance for 2” Meters

Figure 107 presents the percentage of 2” meters tested that complied with these requirements at each tested flow rate. Overall, 74% of the 2” meters tested complied with the recommended accuracy limits at all flow rates, while 4% of the 2” meters did not comply with the recommended accuracy limits at any flow rate.

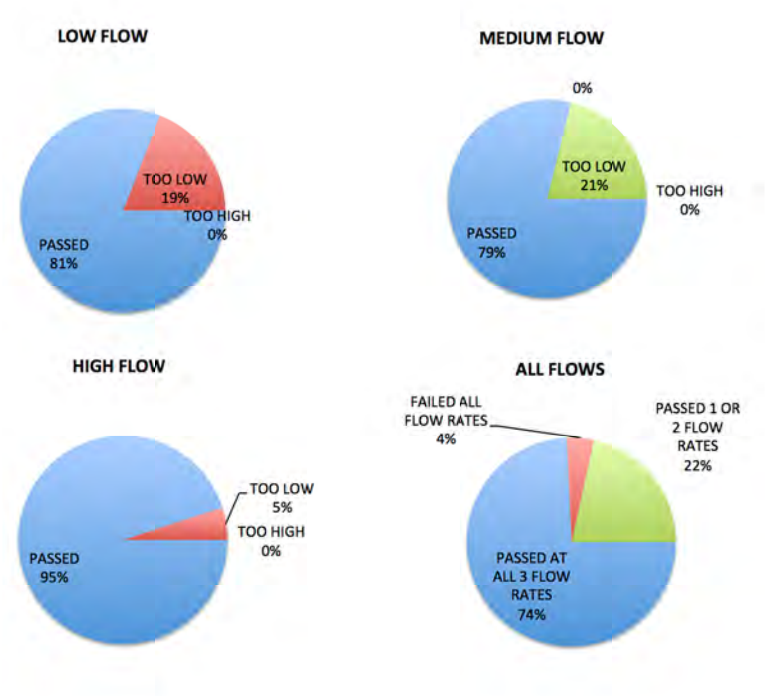
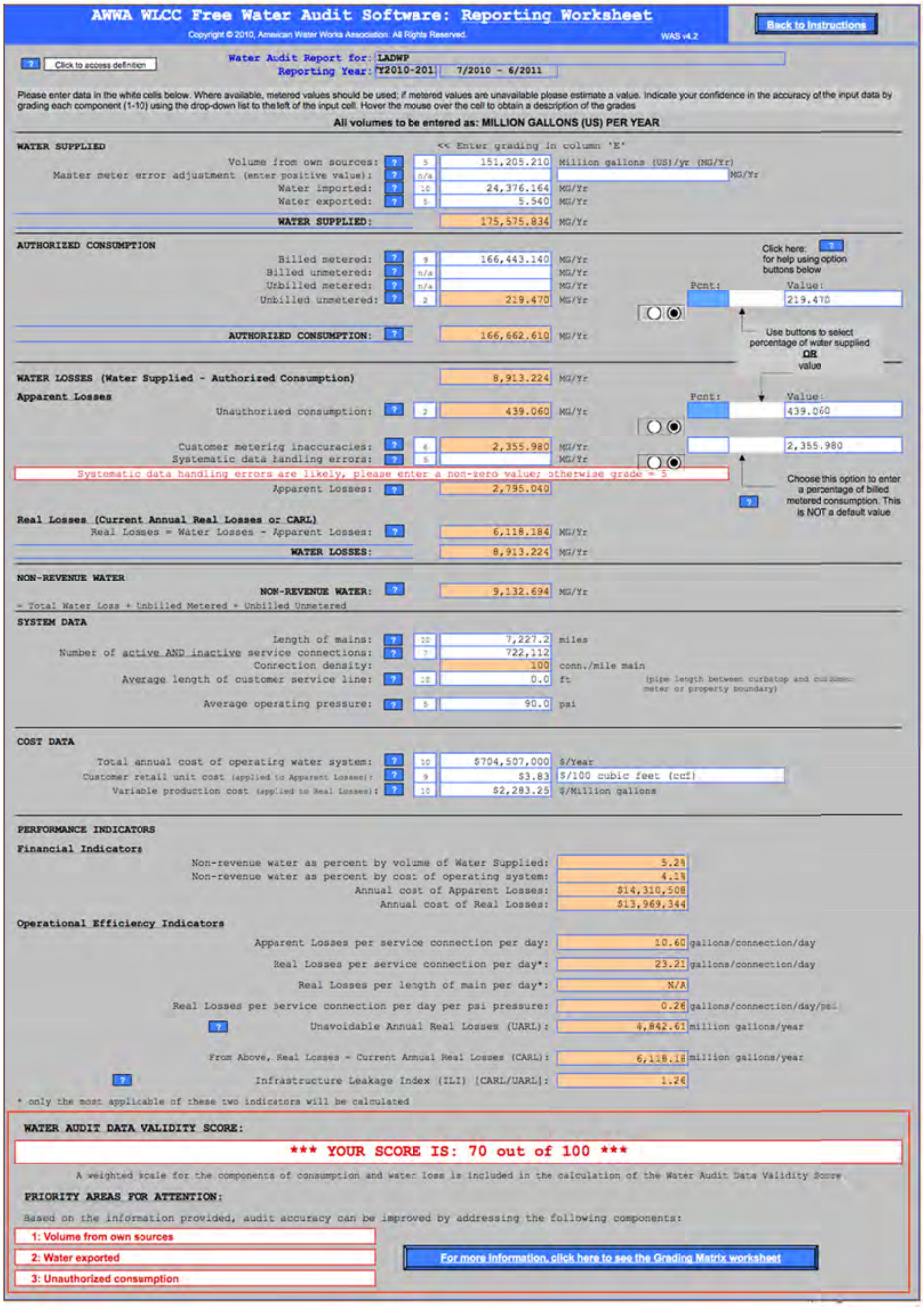


Figure 107: Compliance with AWWA Recommended Accuracy Limits – 2” Meters

APPENDIX K: AWWA Free Water Audit Software



AWWA WLCC Free Water Audit Software: Reporting Worksheet

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WAS v4.2

Water Audit Report for: LADWP
Reporting Year: Y2010-201 7/2010 - 6/2011

Please enter data in the white cells below. Where available, metered values should be used; if metered values are unavailable please estimate a value. Indicate your confidence in the accuracy of the input data by grading each component (1-10) using the drop-down list to the left of the input cell. Hover the mouse over the cell to obtain a description of the grades

All volumes to be entered as: MILLION GALLONS (US) PER YEAR

WATER SUPPLIED << Enter grading in column 'E'

Volume from own sources:	5	151,205.210	Million gallons (US)/yr (MG/Yr)
Master meter error adjustment (enter positive value):	n/a		MG/Yr
Water imported:	10	24,376.164	MG/Yr
Water exported:	5	5.540	MG/Yr
WATER SUPPLIED:		175,575.834	MG/Yr

AUTHORIZED CONSUMPTION

Billed metered:	9	166,443.140	MG/Yr
Billed unmetered:	n/a		MG/Yr
Unbilled metered:	n/a		MG/Yr
Unbilled unmetered:	2	219.470	MG/Yr
AUTHORIZED CONSUMPTION:		166,662.610	MG/Yr

Click here: ? for help using option buttons below

Pcnt: Value: 219.470 ○ ●

Use buttons to select percentage of water supplied **OR** value

WATER LOSSES (Water Supplied - Authorized Consumption) 8,913.224 MG/Yr

Apparent Losses

Unauthorized consumption:	2	439.060	MG/Yr
Customer metering inaccuracies:	6	2,355.980	MG/Yr
Systematic data handling errors:	5		MG/Yr
Apparent Losses:		2,795.040	

Pcnt: Value: 439.060 ○ ●

2,355.980 ○ ●

Systematic data handling errors are likely, please enter a non-zero value; otherwise grade = 5

Choose this option to enter a percentage of billed metered consumption. This is NOT a default value

Real Losses (Current Annual Real Losses or CARL)

Real Losses = Water Losses - Apparent Losses:	6,118.184	MG/Yr
WATER LOSSES:	8,913.224	MG/Yr

NON-REVENUE WATER

NON-REVENUE WATER: 9,132.694 MG/Yr

= Total Water Loss + Unbilled Metered + Unbilled Unmetered

SYSTEM DATA

Length of mains:	10	7,227.2	miles
Number of active AND inactive service connections:	7	722,112	
Connection density:		100	conn./mile main
Average length of customer service line:	10	0.0	ft (pipe length between curbstop and customer meter or property boundary)
Average operating pressure:	5	90.0	psi

COST DATA

Total annual cost of operating water system:	10	$704,507,000	$/Year
Customer retail unit cost (applied to Apparent Losses):	9	$3.83	$/100 cubic feet (ccf)
Variable production cost (applied to Real Losses):	10	$2,283.25	$/Million gallons

PERFORMANCE INDICATORS

Financial Indicators

Non-revenue water as percent by volume of Water Supplied:	5.2%	
Non-revenue water as percent by cost of operating system:	4.1%	
Annual cost of Apparent Losses:	$14,310,508	
Annual cost of Real Losses:	$13,969,344	

Operational Efficiency Indicators

Apparent Losses per service connection per day:	10.60	gallons/connection/day
Real Losses per service connection per day*:	23.21	gallons/connection/day
Real Losses per length of main per day*:	N/A	
Real Losses per service connection per day per psi pressure:	0.26	gallons/connection/day/psi
Unavoidable Annual Real Losses (UARL):	4,842.61	million gallons/year
From Above, Real Losses = Current Annual Real Losses (CARL):	6,118.18	million gallons/year
Infrastructure Leakage Index (ILI) [CARL/UARL]:	1.26	

* only the most applicable of these two indicators will be calculated

WATER AUDIT DATA VALIDITY SCORE:

***** YOUR SCORE IS: 70 out of 100 *****

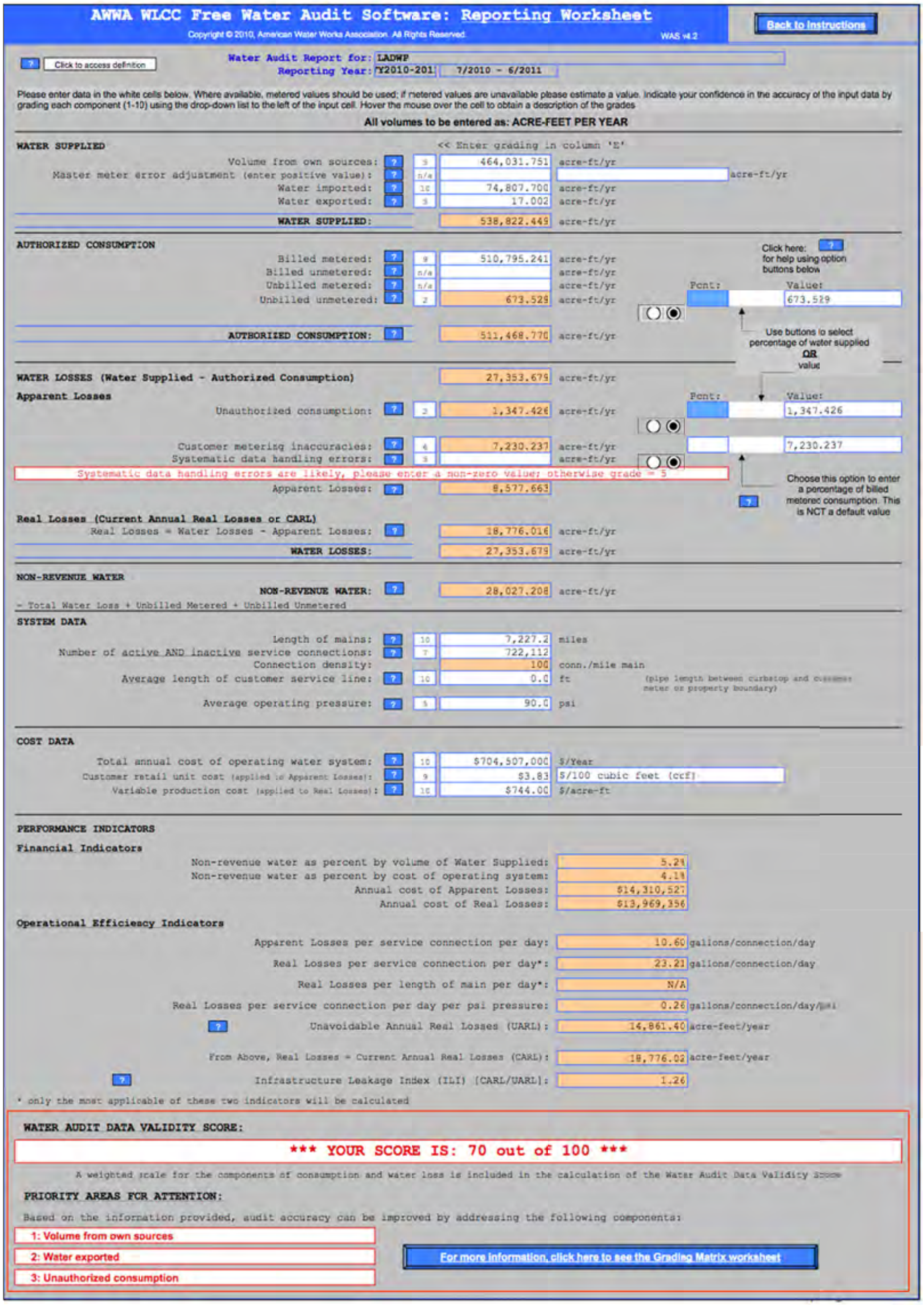
A weighted scale for the components of consumption and water loss is included in the calculation of the Water Audit Data Validity Score

PRIORITY AREAS FOR ATTENTION:

Based on the information provided, audit accuracy can be improved by addressing the following components:

1: Volume from own sources
2: Water exported
3: Unauthorized consumption

Figure 108: AWWA Free Water Audit Software in units of MG



AWWA WLCC Free Water Audit Software: Reporting Worksheet

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WAS v4.2

Water Audit Report for: LADWP
Reporting Year: Y2010-201 7/2010 - 6/2011

Please enter data in the white cells below. Where available, metered values should be used; if metered values are unavailable please estimate a value. Indicate your confidence in the accuracy of the input data by grading each component (1-10) using the drop-down list to the left of the input cell. Hover the mouse over the cell to obtain a description of the grades

All volumes to be entered as: ACRE-FEET PER YEAR

WATER SUPPLIED << Enter grading in column 'E'

Volume from own sources:	5	464,031.751	acre-ft/yr
Master meter error adjustment (enter positive value):	n/a		acre-ft/yr
Water imported:	10	74,807.700	acre-ft/yr
Water exported:	5	17.002	acre-ft/yr
WATER SUPPLIED:		538,822.449	acre-ft/yr

AUTHORIZED CONSUMPTION

				Pcnt:	Value:
Billed metered:	9	510,795.241	acre-ft/yr		
Billed unmetered:	n/a		acre-ft/yr		
Unbilled metered:	n/a		acre-ft/yr		
Unbilled unmetered:	2	673.529	acre-ft/yr	○ ●	673.529
AUTHORIZED CONSUMPTION:		511,468.770	acre-ft/yr		

WATER LOSSES (Water Supplied - Authorized Consumption) 27,353.679 acre-ft/yr

Apparent Losses

				Pcnt:	Value:
Unauthorized consumption:	2	1,347.426	acre-ft/yr	○ ●	1,347.426
Customer metering inaccuracies:	4	7,230.237	acre-ft/yr		7,230.237
Systematic data handling errors:	5		acre-ft/yr	○ ●	

Systematic data handling errors are likely, please enter a non-zero value; otherwise grade = 5

Apparent Losses:	8,577.663	

Real Losses (Current Annual Real Losses or CARL)

Real Losses = Water Losses - Apparent Losses:	18,776.016	acre-ft/yr
WATER LOSSES:	27,353.679	acre-ft/yr

NON-REVENUE WATER

NON-REVENUE WATER: 28,027.208 acre-ft/yr

= Total Water Loss + Unbilled Metered + Unbilled Unmetered

SYSTEM DATA

Length of mains:	10	7,227.2	miles
Number of active AND inactive service connections:	7	722,112	
Connection density:		100	conn./mile main
Average length of customer service line:	10	0.0	ft (pipe length between curbstop and customer meter or property boundary)
Average operating pressure:	5	90.0	psi

COST DATA

Total annual cost of operating water system:	10	$704,507,000	$/Year
Customer retail unit cost (applied to Apparent Losses):	9	$3.83	$/100 cubic feet (ccf)
Variable production cost (applied to Real Losses):	10	$744.00	$/acre-ft

PERFORMANCE INDICATORS

Financial Indicators

Non-revenue water as percent by volume of Water Supplied:	5.2%	
Non-revenue water as percent by cost of operating system:	4.1%	
Annual cost of Apparent Losses:	$14,310,527	
Annual cost of Real Losses:	$13,969,356	

Operational Efficiency Indicators

Apparent Losses per service connection per day:	10.60	gallons/connection/day
Real Losses per service connection per day*:	23.21	gallons/connection/day
Real Losses per length of main per day*:	N/A	
Real Losses per service connection per day per psi pressure:	0.26	gallons/connection/day/psi
Unavoidable Annual Real Losses (UARL):	14,861.40	acre-feet/year
From Above, Real Losses = Current Annual Real Losses (CARL):	18,776.02	acre-feet/year
Infrastructure Leakage Index (ILI) [CARL/UARL]:	1.26	

* only the most applicable of these two indicators will be calculated

WATER AUDIT DATA VALIDITY SCORE:

***** YOUR SCORE IS: 70 out of 100 *****

A weighted scale for the components of consumption and water loss is included in the calculation of the Water Audit Data Validity Score

PRIORITY AREAS FOR ATTENTION:

Based on the information provided, audit accuracy can be improved by addressing the following components:

1: Volume from own sources
2: Water exported
3: Unauthorized consumption

Figure 109: AWWA Free Water Audit Software in units of AF

APPENDIX L: Background on BABE Analysis

The Burst and Background Estimates (BABE) concepts (component based analysis of Real Losses) for estimating physical losses were first elaborated during the 1991 United Kingdom (UK) National Leakage Initiative, jointly set up by the UK Water Services Association and UK Water Companies Association. The findings of the Initiative were published in the Managing Leakage series of reports[40]. The concepts were designed from the outset to (1) use a combination of logical, individual assumptions that are combined systematically, (2) be internationally applicable, and (3) be capable of customization or adaptation to model any individual water distribution and its leakage characteristics.

The BABE concepts were the first to model leakage using physical laws rather than relying on empirical formulae, thus permitting rational planning management and operational control of strategies for leak reduction in any water utility. The basic concepts have undergone significant further development, being progressively adapted to incorporate valid technical advances in the leakage management sector. For example, in 1994, the concepts used for modeling Pressure Reduction and Management (PRAM) were substantially enhanced using the work of May[41] on Fixed and Variable Area Discharge paths (FAVAD). Further improvements have resulted from the testing and application of the concepts and models in a wide variety of situations internationally, through incorporation of advances in technology - particularly in respect to pressure/leakage relationships.

The BABE and FAVAD concepts, and the software developed from them, are valuable management tools that assist water companies to improve their technical and financial credit-worthiness by providing the key to effective active leakage control. They assist in strategic assessments, in leakage management operations and planning and design:

- At an operational level – to plan, prioritize and manage a leakage monitoring, control, and repair program to locate and repair unreported leaks and breaks
- At an operational level – to progressively manage operating pressures to optimum levels
- At a strategic level – to derive a Water Balance and to determine an economically justifiable program of leakage control
- At planning and design levels – to phase network restructuring and rehabilitation programs
- At a managerial level – to set leakage management performance criteria for both water supply entities and for private operation of systems by private sector concessionaires and management contractors

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[40] see: WRc, managing Leakage Series, ISBN 1 898920 21 4, 1994

[41] see: May, J. Pressure Dependent Leakage, World Water & Environmental Engineering, October 1994

The concepts and programs were first calibrated for UK conditions and are widely used there in various forms by almost all of the privatized water companies serving England and Wales. They have also been successfully applied in many other countries. Many of the principles are beginning to be used by regulatory authorities in the UK to set targets that water utilities should meet in respect to leakage management and in the formulation of leakage management performance targets in relation to water service management contracts.

Real Loss Components

The component based analysis of Real Losses can be used to calculate, from first principles, up to 18 components of losses in different parts of the distribution system, and on customer's pipes. The system is considered as consisting of:

- Transmission mains (typically > 12 inches)
- Service reservoirs
- Distribution mains
- Connections from the main to the customer's meter or, in absence of a meter, to the point that customer or property manager becomes responsible for pipes and plumbing, normally at the property boundary
- Losses on the customer's own pressurized pipe work
- Plumbing inside customers' properties.
- Losses are categorized as:
    - Leaks and breaks, being individual events for which the rate of loss is greater than 2.2gpm at 70 psi pressure
    - Background leaks, being individual events for which the rate of loss is less than 2.2gpm at 70 psi pressure. (To give an idea of the flow represented by 2.2gpm, water would typically issue from a garden hose under low pressure at this rate, or a typical 2 gallon bucket would be filled in about a minute.)

This categorization is based on the generally-accepted minimum rate of loss which can be detected by pipe sounding techniques, which is itself influenced by depth of cover to the pipe, pipe material, system pressure, and water temperature.

The minimum detectable rate of loss is considered to be 132 gallons/hour (2.2gpm) where pipes are buried with a normal minimum cover of about three feet and metal pipe materials are used. Background leaks are individual events that will continue to flow undetected by an active leakage control campaign unless either detected by chance or until they worsen gradually to a more easily detectable condition.

Further categorization of leaks and breaks refers to whether a leakage event is reported or unreported:

- Reported Leaks and Breaks are events brought to the attention of the water utility by customers, the general public, or the water utilities own operatives (except for members of the Leak Detection teams). A break or a leak that, under urban conditions, manifests itself at the surface will normally be reported to the water supply organization whether or not it causes nuisance such as flooding.
- Unreported Leaks and Breaks are located by leak detection teams as part of their normal everyday active leakage control duties. These breaks go undetected without some form of active leakage control.
- Hidden Breaks, in a component based analysis, are composed breaks that go un-repaired and remain undetected due to insufficient active leakage control. Left undetected, hidden breaks continue to accumulate and deteriorate. Dependent upon the permeability and nature of the soil in which the pipe is laid, the water lost may continue to percolate away into the ground and feed the water table or infiltrate a drainage system. There will always be some Hidden Losses as it will be impossible to find all the breaks in a system at any one time. Breaks remaining undetected are a function of the intensity and success of the active leakage control campaign. Eventually, the flow from an undetected break may become so great that it becomes visible at the surface and is reported.

The total leakage from unreported and hidden breaks is generally significantly greater than from reported breaks as, virtually by definition, they run for much longer periods - certainly at least until action is taken by which they are detected. Breaks that show at the surface are almost invariably reported quickly and repaired within a short time because of their nuisance value.

Once losses are separated into constituent components, it is necessary to estimate the amount the water being lost from each type of leak.

The amount of water lost on an annual basis through leakage is a function of three main factors: (1) the number of leaks of each component type that occur each year (leak and break frequency), (2) the amount of time each leak will run from first occurring until being repaired, and (3) the flow rate associated with each type of leak. The parameters required to calculate Real Losses based on the BABE component analysis are shown in Table 131.

Table 131: Parameters required for calculation of components of annual Real Losses [42]

Component of Infrastructure	Background Leakage	Reported Breaks	Unreported Breaks
Mains	Length Pressure Min loss rate/mile*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service reservoirs	Leakage through structure	Reported overflows: Flow rates, duration	Unreported overflows Flow rates, duration
Service connections, main to edge of street	Number Pressure Min loss rate/mile*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service connections, after edge of street	Number Pressure Min loss rate/mile*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration

* At a standard pressure

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[42] Lambert, A., G.T. Brown, M. Takizawa, D. Weimer. 1999. Review of Performance Indicators for Real Losses from Water Supply Systems, Journal of Water Supply: Research and Technology-AQUA 48: 227-2237

APPENDIX M: Breakdown of Main Breaks by Size and Material

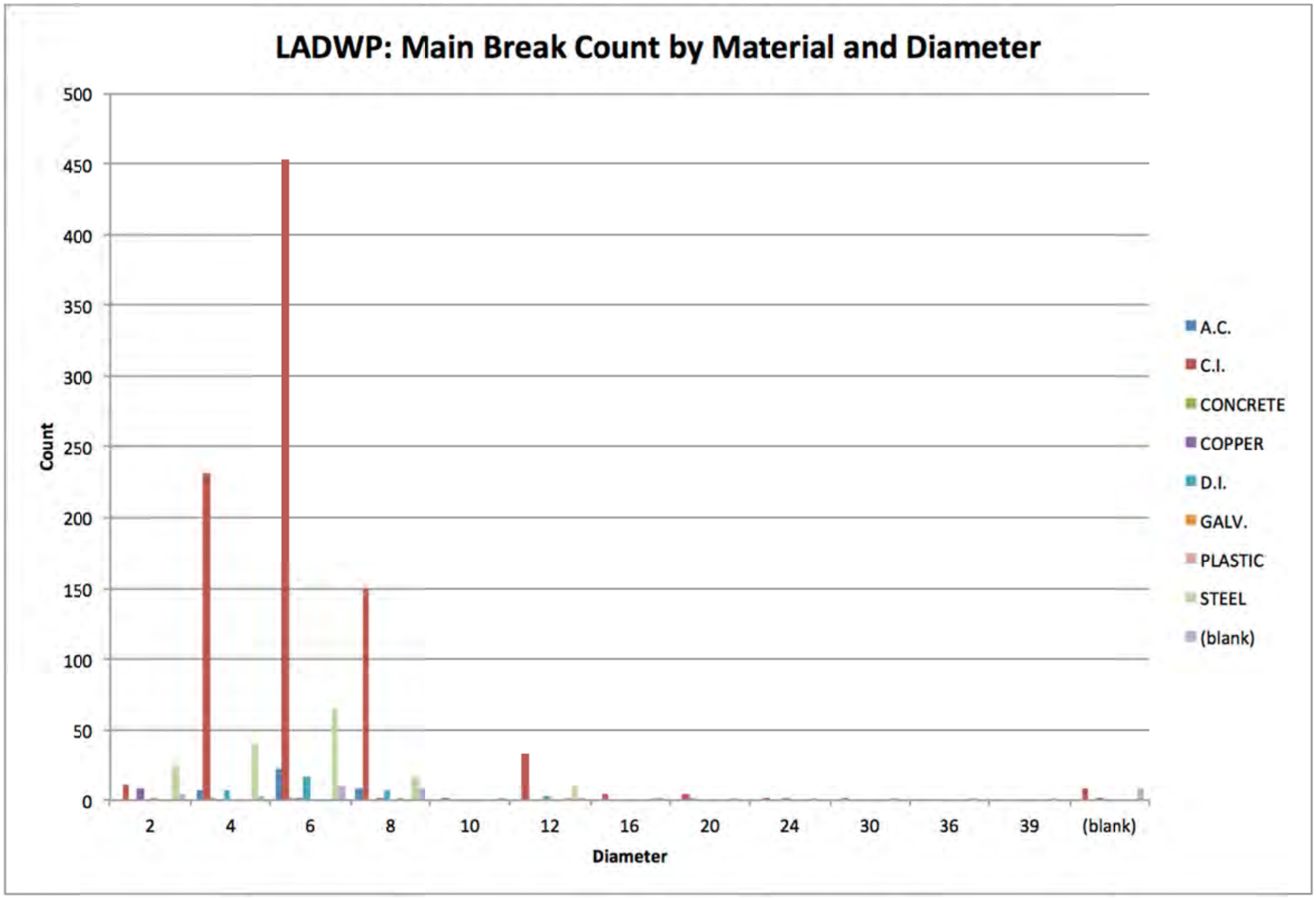

Figure 110: Main Break Count by Material and Diameter

APPENDIX N: Breakdown of Service Connection Breaks by Size and Material

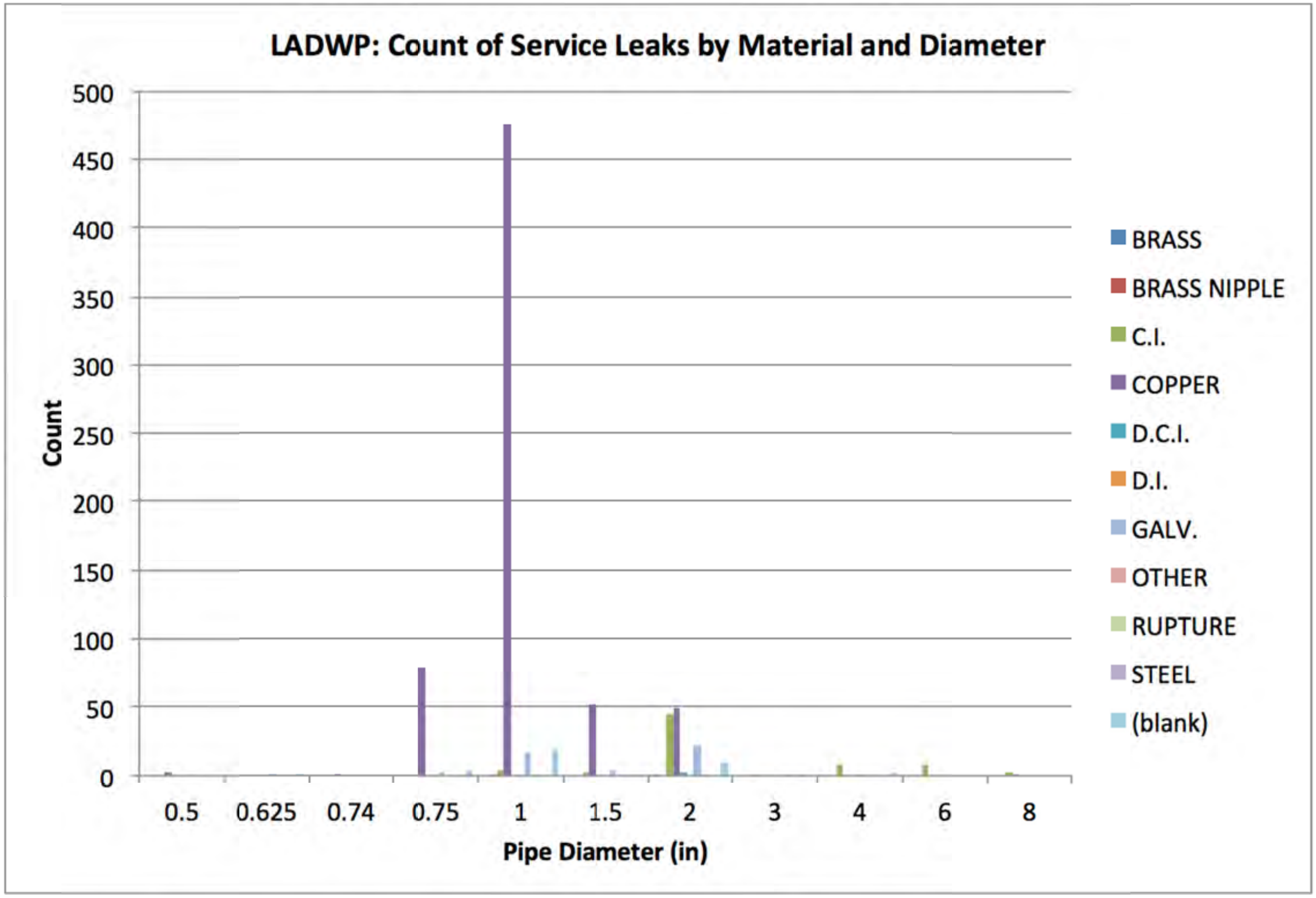

Figure 111: Count of Service Leaks by Size and Material

APPENDIX O: Breakdown of Response Times for Main Breaks

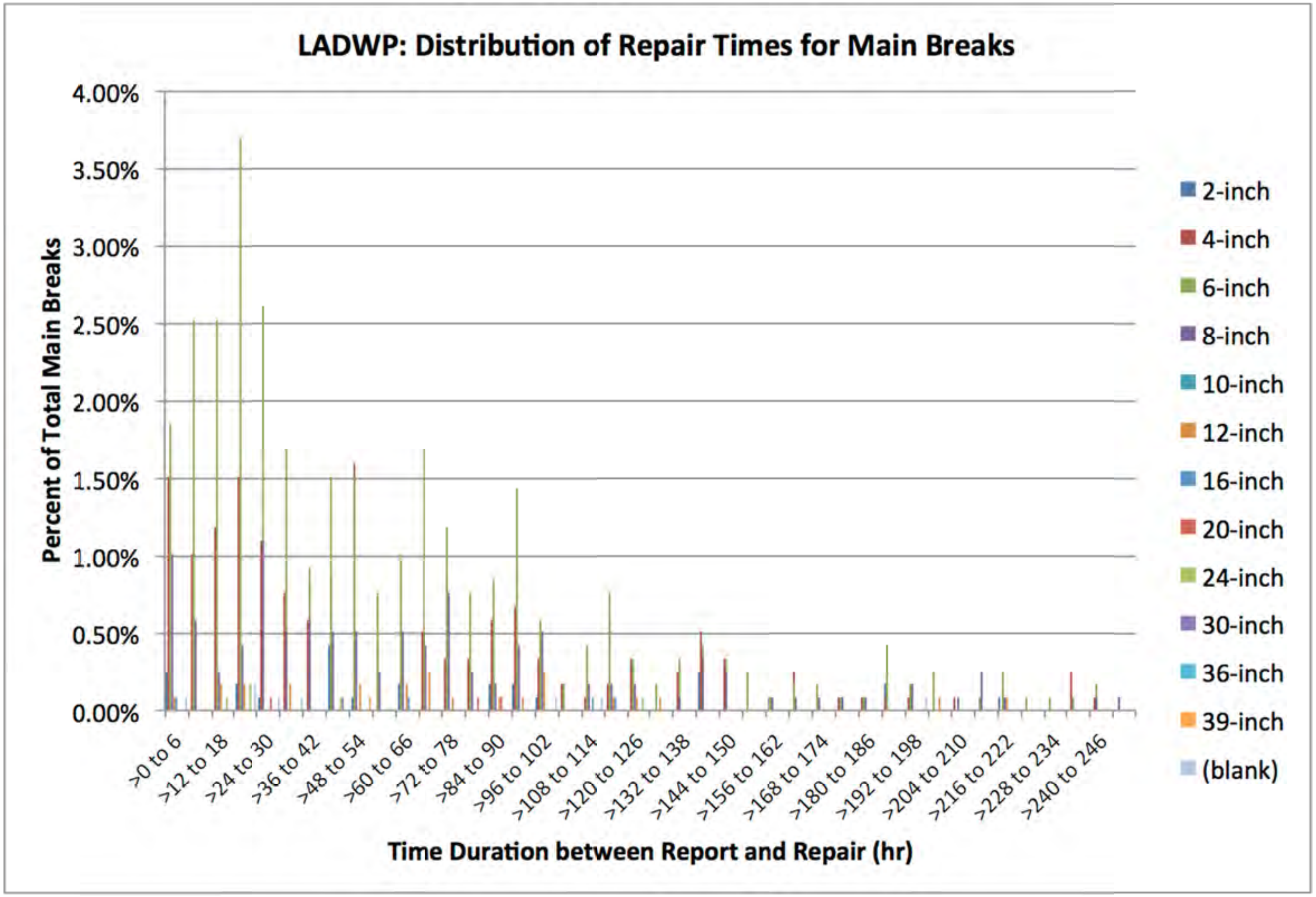

Figure 112: Distribution of Repair Times for Main Breaks (under 250 hours) by Size

APPENDIX P: Breakdown of Response Times for Service Connections

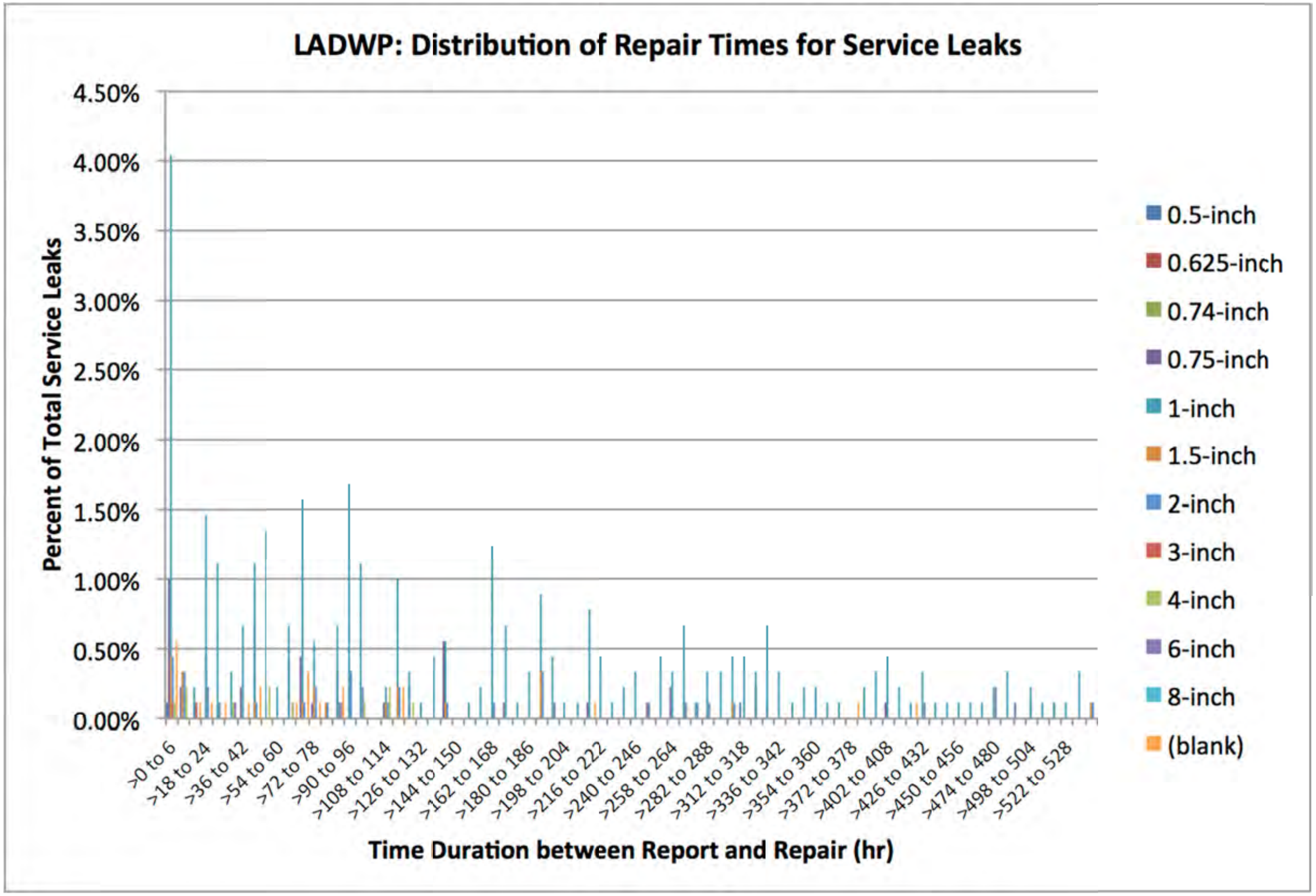

Figure 113: Distribution of Repair Times (under 528 hours) for Service Leaks

APPENDIX Q: Flow rate determination background

In systems where the flow rates of individual leaks and breaks cannot be individually monitored, it is necessary to make some realistic assumptions to estimate the volume of Real Losses arising from these events. The usual technique is to categorize and count events by: (1) whether they occurred on mains, services, valves or hydrants, (2) pipe size and material, and if appropriate by type of failure, (3) whether the events were ‘reported’ or ‘unreported’ events. System pressure is also a significant factor in the flow rate of individual leaks.

WSO carried out previous research on established values of flow rates from various leak types used by water utility operators in the UK, Canada, Brazil, and the United States.

Calculation of Leak and Break Flow Rates

To calculate the volume of Real Losses from an individual leak or break on mains or services, two parameters are required: (1) duration and (2) flow rate.
In systems where the flow rate and duration of individual leaks and breaks cannot be individually monitored, it is necessary to make some realistic assumptions to estimate the volume of Real Losses arising from these events. The usual technique is to categorize and count events by:

- Whether they occurred on mains, services, valves or hydrants
- Pipe size and material, and if appropriate by type of failure
- Whether the events were ‘reported’ or ‘unreported but found by distribution’ events

The average flow rate assigned to each category of the above events also needs to be defined. This section of the report reviews typical values for average flow rates of leaks and breaks used in North America and elsewhere and suggests values that should be used for this study.

Typical Flow Rates Used in North America

WSO carried out a recent leakage management assessment project for the City of Philadelphia Water Department (PWD), which has operated an active leakage control policy for many years. PWD had developed an estimated average flow rate for different types of leaks and breaks on services, mains, valves, and hydrants. These are listed in Table 132. The PWD average leak and break flow rate values were initially compared with the average values for flow rates of 500 reported and unreported events on service connections and mains up to 6 inch diameter standardized to 70 psi pressure from the UK. The UK data was obtained from Appendix D of the UK Managing Leakage Report E[43]. The UK data partially supported the PWD values in that:

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[43] WRc, Managing Leakage Series, ISBN 1 898920 21 4, 1994

- There was no significant difference between average flow rates for reported and unreported leaks on small service connections.
- Average flow rates from reported main breaks were higher than those form unreported main breaks.

For 6 inch mains, the flow rates being used in PWD were similar to those for unreported 6 inch UK main breaks, but around half those for reported 6 inch main breaks. However, PWD assumed flow rates for leaks on service connections (both reported and unreported) that were considerably higher than those found in the UK study.

Table 132: Average Water Loss Flow Rates for Specific Leak Types Previously Used in PWD

Type Of Leak Or Break	**Diameter**	**Unreported Leaks and Breaks (gpm)**	**Reported Leaks and Breaks (gpm)**
Main Break			
Joint Leak or Repair Band Leak	6 inch	10.4	10.4
Joint Leak or Repair Band Leak	8 inch	17.3	17.3
Joint Leak or Repair Band Leak	12 inch to 24	27.8	27.8
Round (circumferential) crack	6 inch	55.5	55.5
Round (circumferential) crack	8 inch	69.4	69.4
Round (circumferential) crack	10 inch	83.3	83.3
Round (circumferential) crack	12 inch	97.2	97.2
Longitudinal crack or split bell	6 inch	69.4	69.2
Longitudinal crack or split bell	8 inch	83.3	83.3
Longitudinal crack or split bell	10 inch	97.2	97.2
Longitudinal crack or split bell	12 inch	111.1	111.1
Service Leaks			
Active Services	½ inch to ⅝inch	10.4	10.4
Active Services	¾ inch	17.3	17.3
Active Services	1 inch	24.3	24.3
Active Services	2 inch to 4inch	34.7	34.7
Abandoned or vacant buildings	½ inch to ⅝inch	17.3	17.3
Abandoned or vacant buildings	1 inch	31.2	31.2
Abandoned or vacant buildings	2 inch to 4inch	34.7	34.7
Fire Hydrant Leaks		3.5	3.5
Valve Leaks		6.9	6.9

Main Break Flow Rates

The PWD data set for main breaks flow rates was assumed to relate most closely to Cast Iron mains, which is the predominant main material type in PWD. Table 133 shows the PWD data, compared with data from four other recent projects:

- UK 'Managing Leakage' series values for reported and unreported bursts, 4 inch to 6 inch mixed pipe materials.
- Canadian average values for ring cracks on Cast Iron mains obtained from SCADA System flow data[44]
- German values for Cast Iron Mains[45] that may include corrosion events.

Table 133: Comparison of average flow rates for main breaks (all values in gpm)

Mains	PWD (unreported)			UK	UK	Canada	Germany
	Leak at Joint or Repair Band	**Long. Crack or Split Bell**	**Ring Crack**	**Unreported Break at 70 psi**	**Reported break at 70 psi**	**Ring Cracks on Cast Iron Mains at 70 psi**	**Breaks on Cast Iron Mains**
4 inch	-	-	-	22	44	75	18.5
6 inch	10.3	69.4	55.5	46	92	132	18.5
8 inch	17.4	83.3	69.4	-	-	201	-
10 inch	-	97.2	83.3	-	-	300	-
12 inch – 48 inch	27.8	111.1	97.2	-	-	-	-

It should be noted that, for the UK data, the average flow rates for reported breaks are twice the average flow rates for unreported breaks, for 4 inch and 6 inch mains.

Analyzing the flow rates used by PWD for pipes between 4 inch and 10 inch, it was concluded that PWD are overestimating the amount of water lost through those leaks and breaks. Since the UK average values relate to mixed materials with a significant proportion of non-metallic pipes, it is recommended that the UK values be used for 4 inch and 6 inch pipes. It is seen to be appropriate to apply the UK flow rates for 6 inch breaks to 8 inch and 10 inch main breaks as well since flow rates tend to be in the same magnitude and in order not to over-estimate the losses from 8 and 10 inch breaks.

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[44] Source: Table of Typical Water Loss Rates based upon Pipe Size – Shear (70 psi), from Halifax (Canada) SCADA System. April 2000

[45] Source: Typische Wassererluste der einzelnen Schadensart, Table attributed to Dr Hoch, Stuttgart, Germany, circa 1992

Very little data is available on average leakage flow rates for pipe size 12 inch and above from other utilities and countries. Hence, the PWD average flow rates were used as representative average flow rates for North America.

Service Leak Flow Rates

Several leakage consultants, based in Canada, the USA, and Brazil (Brazilian values for mixed main materials), experienced in the North American market were invited to comment on an anonymous comparison of the PWD, UK, and German averages for unreported leaks on ½ inch, ¾ inch and 3 inch metal service connections and for unreported breaks on 6 inch cast iron and ductile iron mains. The comparative values for average flows for unreported service pipe leaks are shown in Table 134.

A graphic comparison of the PWD values for leaks on active service connections with the other data is presented in Figure 114.

Table 134: Average flow rates for unreported service pipe leaks (all values in gpm)

Services Size (inches)	**PWD**		**UK (At 70 psi)**	**Germany**	**USA**	**Brazil**	**Canada**	**Average (of data exc. PWD)**
	Active	Abandoned or Vacant						
½ inch	10.4	17.3	5.0	-	7.5	3.5	5.0	5.3
¾ inch	17.3	24.3	6.0	-	8.0	4.4	5.0	5.8
1 inch	24.3	31.2	-	7.5	-	-	-	7.5
2 inch	34.7	34.7	-	7.5	-	-	-	7.5
3 inch	34.7	34.7	-	7.5	-	22.2	10.0	13.2
4 inch	34.7	34.7	-	-	-	-	-	-

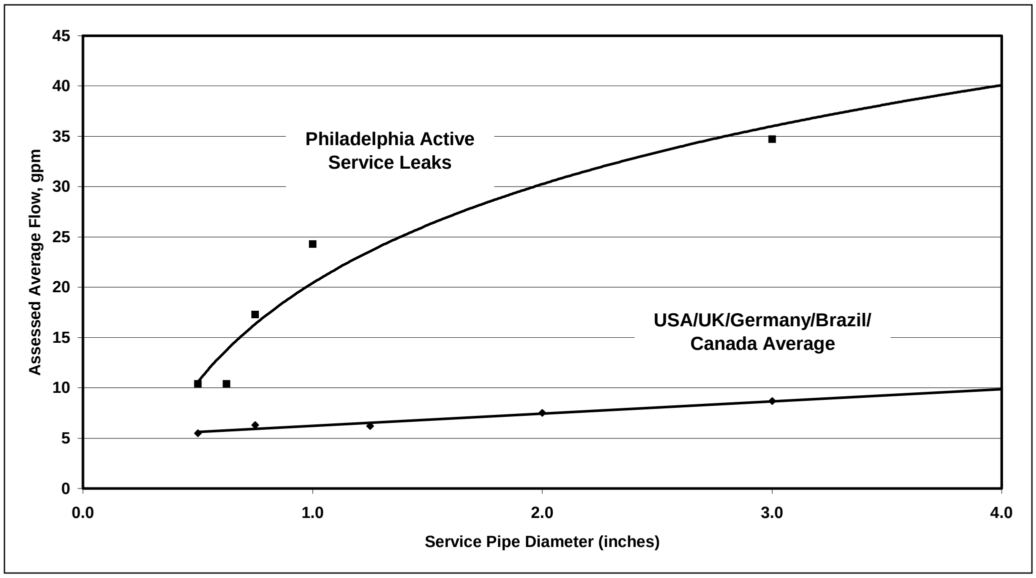

Figure 114: Average flows for unreported leaks on active service pipes

Table 134 and Figure 114 show that the more widely drawn international data set gives average values for flow rates on service pipe leaks substantially less than those being used in PWD.

In reviewing the comparisons, it was noted that the UK, Canadian, and Brazilian data were generally based on changes in night flow measurements taken after leak detection/repair exercises, rather than estimates based on a sonic leak survey or measurement of the size of holes at the time of repair. One of the consultants commented that (in his experience) the sonic leak flow estimate always gave a higher estimate than that recorded by the night flow measurement method, pre and post leak repair.

Experience from the UK has shown that leakage flow rates for pipes with diameters between 1 inch and 3 inch should be estimated at the same flow rate of 13.9gpm at 70 psi (flow rate is equal for reported and unreported leaks and breaks).

For the purposes of calculating volumes of Real Losses from reported and unreported leaks on service connections, the PWD study recommended that the following simplified average values be used in North American situations. A more detailed breakdown based on type of service pipe material or pipe diameter appeared to be unjustified, given the variability of the data. From the values in Table 135, it should be noted that:

- The flow rates for reported leaks on services are assumed to be the same as those for unreported leaks on services (based on the PWD values and experience in UK).
- For abandoned or vacant smaller diameter services, the average flow rates are twice those for active service pipes.

Table 135: Recommended average flow rates for service leaks

Service Pipe Diameter	**Up to & incl. 1 Inch diameter (gpm)**	**Over 1 Inch diameter (gpm)**
Active Services - Reported and Unreported Leaks	6.9	13.9
Abandoned or Vacant Services - Reported and Unreported Leaks	13.9	13.9

Hydrant Leak and Valve Leak Flow Rates

The PWD value for fire hydrant leaks (standard or high pressure) is 3.5 gpm. The only available data for comparison is 0.7 gpm for hydrant seat leaks from Halifax, Canada[46].

The PWD value for leaks on Valves is 6.9 gpm. The only available data for comparison is 2.2 gpm from Germany[47].

In the absence of other sets of comparative data, it is recommended that the PWD values for hydrant and valve leaks be used in the LADWP component analysis as they are the only values from a U.S. system, and that they be used for both reported and unreported leaks on these fittings.

Recommended Leak and Break Flow Rates

The typical flow rates for unreported leaks and breaks currently being used in North America have been reviewed and compared with more recent data from UK, Germany, Brazil, and Canada, and by drawing on the experience of leak detection consultants in Canada, USA and Brazil. A list of recommended typical flow rates for Leaks and Breaks at 70 psi pressure was developed and is presented in Table 136.

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[46] Source: Table of Typical Water Loss Rates based upon Pipe Size – Shear (70 psi), from Halifax (Canada) SCADA System. April 2000

[47] Source: Typische Wassererluste der einzelnen Schadensart, Table attributed to Dr Hoch, Stuttgart, Germany, circa 1992

Table 136: Recommended leak and break flow rates at 70 psi

	Unreported Leaks and Breaks (gpm)	**Reported Leaks and Breaks (gpm)**
Main Breaks		
Less than 4 inch	13.9	13.9
4 inch	22	44
6 inch	46	92
8 inch	46	92
10 inch	46	92
12 inch	111	222
Greater than 12 inch	111	222
Service Leaks		
Up to & including 1 inch diameter	6.9	6.9
Over 1 inch diameter	13.9	13.9
Fire Hydrant Leaks	3.5	3.5
Valve Leaks	6.9	6.9

APPENDIX R: FAVAD background

Leakage and pressure are closely linked. Modeling the relationship between leakage and pressure using basic hydraulic principles rather than empirical formulae enables a more robust analysis of leakage to be carried out. The theories described in this section provide the necessary background for component analysis of Background Leakage, Real Loss analysis based on zonal measurements and Real Losses from reported and unreported breaks.

The velocity of water escaping from a hole in the pipe is governed by the standard velocity-head hydraulic equation as follows:

$$v = (2 g h)^{0.5}$$

where v represents the velocity of water through an individual leak,
g represents acceleration due to gravity
h represents the pressure that the individual leak is subject to
and 0.5 is the square-root power law exponent for the relationship.

Also, it is known that the flow rate for water escaping from a hole in the pipe is governed by the cross-sectional area of the hole and a discharge coefficient as follows:

$$QL = v\ Cd\ A$$

where QL represents the leakage flow rate for an individual leak,
v represents the velocity of water through the leak,
A represents the cross-sectional area of the leak
Cd represents the discharge coefficient,

and by substitution

$$QL = Cd\ A\ (2 g h)^{0.5}$$

It is also known that both Cd and A can vary with pressure. The discharge coefficient, Cd, is variable with very small leaks such as found in small corrosion holes. The cross-sectional area, A, is also variable with leaks at joints and splits in plastic pipes where an increase in pressure will cause an increase in the cross-sectional area of the leak. So whilst the simple form of the equation (3) above indicates that leakage flow rate, Q, will be proportional to pressure to the power 0.5, it is possible that it can actually be proportional to pressure to the power 1.5.

The simple form of the equation is therefore modified as follows:

$$QL = (Cd\ A\ 2 g h)^{N1}$$

where N1 represents the power-law relationship between flow and pressure, taking into account the pressure dependency of discharge coefficient and cross-sectional area. For fixed size holes, such as bursts, N1 will be 0.5 (square root relationship) whilst for variable sized holes, such as Background Leakage at joints and splits in plastic pipes, N1 will be 1.5.

In any distribution network there will be a combination of fixed and variable area discharge paths and this combination will change from one distribution system to another and even within a distribution system.

The leakage-pressure relationship that is described here is commonly called the FAVAD (Fixed Area - Variable Area Discharge-path) relationship. This relationship is represented graphically in Figure 115.

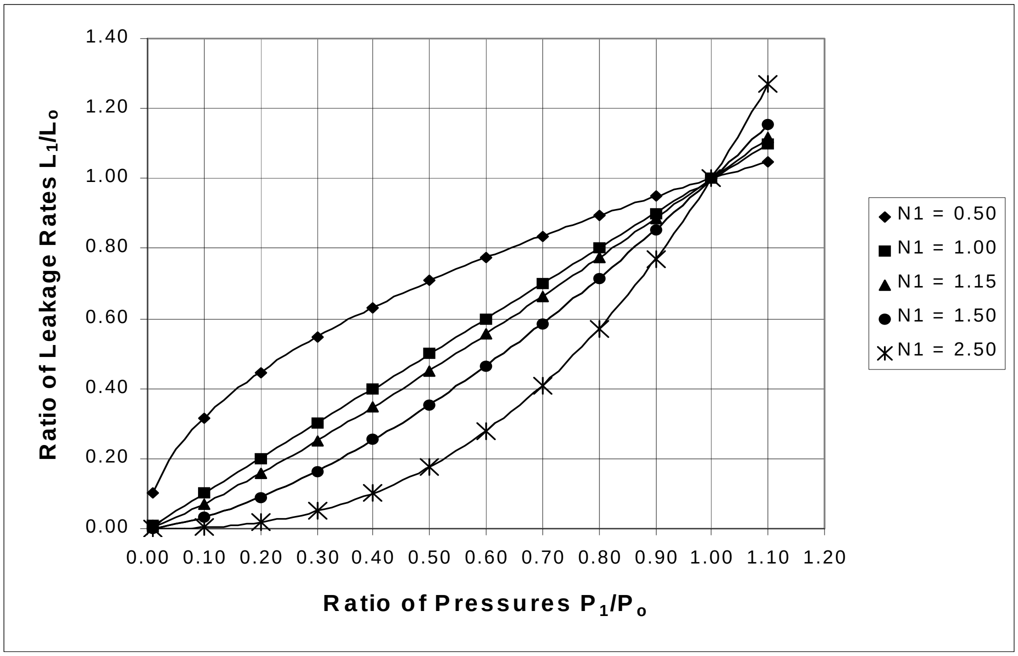
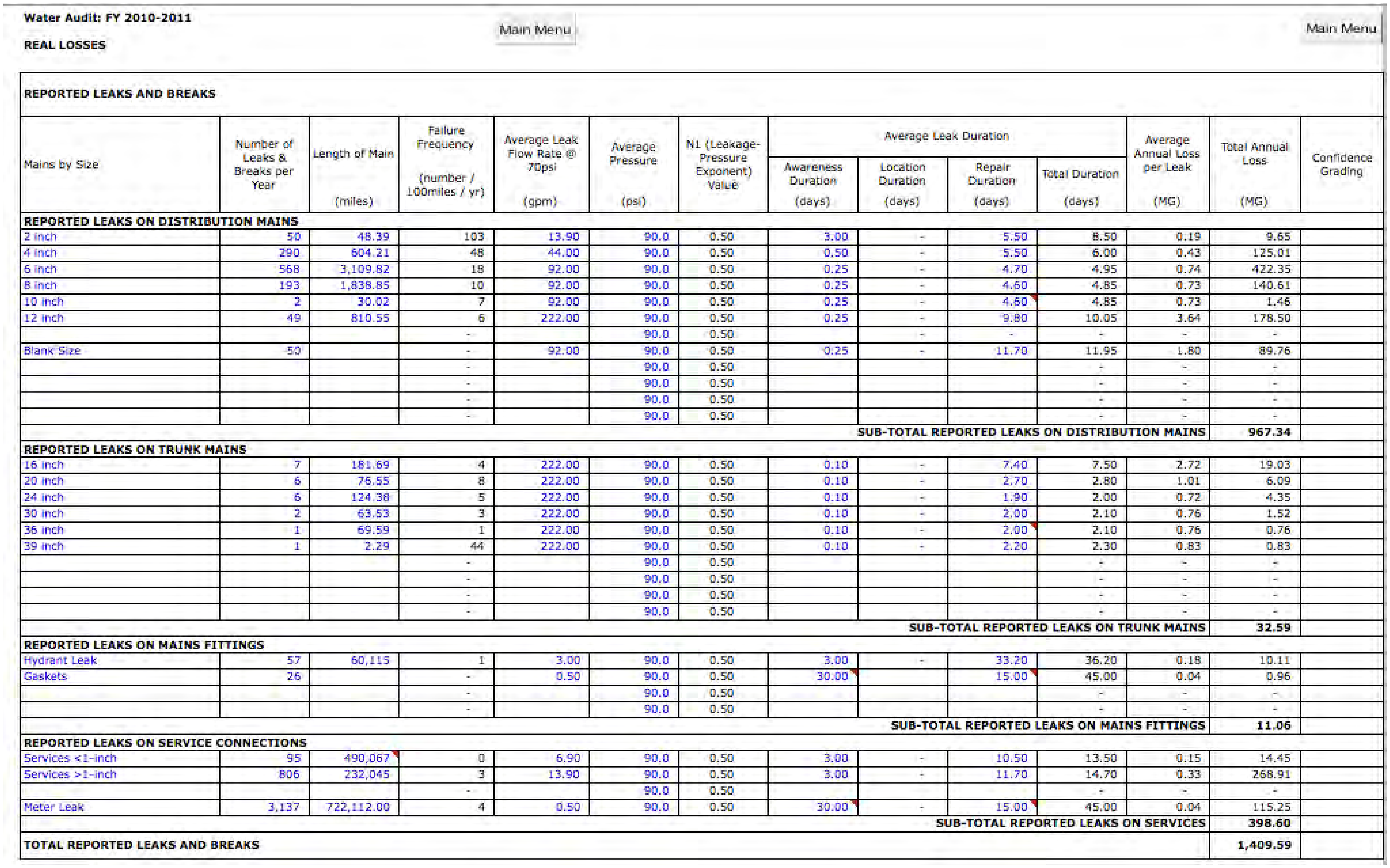


Figure 115: FAVAD pressure/leakage relationship

Recent analysis of apparently diverse research data from Japan and the UK indicated that N1 typically has a value in the range of 1.0 to 1.15 for large distribution systems containing mixtures of pipe materials. This value has subsequently found to be common in many countries. The value can, however, vary widely from area to area across any given network. In the absence of specific DMA data, it is recommended that a value of N1 = 1.0 is always used as was done for the Background Leakage analysis in this study.

In general, fixed area leaks will be breaks which can normally be detected with acoustic leak detection techniques. Fixed area leaks generally can be classified as having an N1 factor 0.5. For this study an N1 of 0.5 was used to calculate the losses from breaks/leaks repaired dependent on system pressure and leakage flow rate.

APPENDIX S: Breakdown of Reported Breaks Details



Water Audit: FY 2010-2011

REAL LOSSES

REPORTED LEAKS AND BREAKS

Mains by Size	Number of Leaks & Breaks per Year	Length of Main (miles)	Failure Frequency (number / 100miles / yr)	Average Leak Flow Rate @ 70psi (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Leak Duration				Average Annual Loss per Leak (MG)	Total Annual Loss (MG)	Confidence Grading
							Awareness Duration (days)	Location Duration (days)	Repair Duration (days)	Total Duration (days)			
REPORTED LEAKS ON DISTRIBUTION MAINS													
2 inch	50	48.39	103	13.90	90.0	0.50	3.00	-	5.50	8.50	0.19	9.65	
4 inch	290	604.21	48	44.00	90.0	0.50	0.50	-	5.50	6.00	0.43	125.01	
6 inch	568	3,109.82	18	92.00	90.0	0.50	0.25	-	4.70	4.95	0.74	422.35	
8 inch	193	1,838.85	10	92.00	90.0	0.50	0.25	-	4.60	4.85	0.73	140.61	
10 inch	2	30.02	7	92.00	90.0	0.50	0.25	-	4.60	4.85	0.73	1.46	
12 inch	49	810.55	6	222.00	90.0	0.50	0.25	-	9.80	10.05	3.64	178.50	
			-		90.0	0.50		-	-	-	-	-	
Blank Size	50		-	92.00	90.0	0.50	0.25	-	11.70	11.95	1.80	89.76	
			-		90.0	0.50				-	-	-	
			-		90.0	0.50				-	-	-	
			-		90.0	0.50				-	-	-	
			-		90.0	0.50				-	-	-	
								SUB-TOTAL REPORTED LEAKS ON DISTRIBUTION MAINS				**967.34**	
REPORTED LEAKS ON TRUNK MAINS													
16 inch	7	181.69	4	222.00	90.0	0.50	0.10	-	7.40	7.50	2.72	19.03	
20 inch	6	76.55	8	222.00	90.0	0.50	0.10	-	2.70	2.80	1.01	6.09	
24 inch	6	124.38	5	222.00	90.0	0.50	0.10	-	1.90	2.00	0.72	4.35	
30 inch	2	63.53	3	222.00	90.0	0.50	0.10	-	2.00	2.10	0.76	1.52	
36 inch	1	69.59	1	222.00	90.0	0.50	0.10	-	2.00	2.10	0.76	0.76	
39 inch	1	2.29	44	222.00	90.0	0.50	0.10	-	2.20	2.30	0.83	0.83	
			-		90.0	0.50				-	-	-	
			-		90.0	0.50				-	-	-	
			-		90.0	0.50				-	-	-	
			-		90.0	0.50				-	-	-	
									SUB-TOTAL REPORTED LEAKS ON TRUNK MAINS			**32.59**	
REPORTED LEAKS ON MAINS FITTINGS													
Hydrant Leak	57	60,115	1	3.00	90.0	0.50	3.00	-	33.20	36.20	0.18	10.11	
Gaskets	26		-	0.50	90.0	0.50	30.00		15.00	45.00	0.04	0.96	
			-		90.0	0.50				-	-	-	
			-		90.0	0.50				-	-	-	
								SUB-TOTAL REPORTED LEAKS ON MAINS FITTINGS				**11.06**	
REPORTED LEAKS ON SERVICE CONNECTIONS													
Services <1-inch	95	490,067	0	6.90	90.0	0.50	3.00	-	10.50	13.50	0.15	14.45	
Services >1-inch	806	232,045	3	13.90	90.0	0.50	3.00	-	11.70	14.70	0.33	268.91	
			-		90.0	0.50				-	-	-	
Meter Leak	3,137	722,112.00	4	0.50	90.0	0.50	30.00	-	15.00	45.00	0.04	115.25	
									SUB-TOTAL REPORTED LEAKS ON SERVICES			**398.60**	
TOTAL REPORTED LEAKS AND BREAKS												**1,409.59**	

116: Detailed Breakdown of Real Loss Determination for Reported Breaks for FY 2010-2011

APPENDIX T: Fire line meters with Consumption

Table 137: 517/Boyle Heights, Detector Meters with Consumption[48]

Meter #	Meter Type	Consumption Volume (gal)
42494	Detector Check	3
17792	Detector Check	6
16453748	Detector Check	0.5
4380519	Detector Check	136
3264	Detector Check	50
2728	Detector Check	32
4039366	Detector Check	1
72865	Detector Check	4
2829181	Detector Check	16
1472	Detector Check	1
1746	Detector Check	101
1098	Detector Check	2
5591818	Detector Check	1
4380505	Detector Check	111
358	Detector Check	2
9013277	Detector Check	1
4473023	Detector Check	190
892	Detector Check	380
41088	Detector Check	76
5132465	Detector Check	142
2370792	Detector Check	9
2541381	Detector Check	3,760
648	Detector Check	2
13303	Detector Check	8
1462389	Detector Check	0.5
40840	Detector Check	0.5
2703037	Detector Check	0.5
2306	Detector Check	13
330	Detector Check	5

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[48] Consumption volumes have been rounded to the nearest gallon for reads consumption greater than 0.5. For all meters with consumption less than 0.5 gal, the consumption volume has been set to 0.5

Table 137 Continued

Meter #	Meter Type	Consumption Volume (gal)
5225949	Detector Check	27
300	Detector Check	23
2955	Detector Check	109
42506	Detector Check	1
1360260	Detector Check	575
41820	Detector Check	0.5
701	Detector Check	18
28	Detector Check	5
41182	Detector Check	0.5
4020	Detector Check	1
1894	Detector Check	0.5
1917	Detector Check	2
411	Detector Check	2
2399	Detector Check	2
240	Detector Check	9
981	Detector Check	1
1197	Detector Check	11
1308062	Detector Check	16
40906	Detector Check	148
41083	Detector Check	5
2049	Detector Check	93
2530	Detector Check	753
5228305	Detector Check	439
728	Detector Check	5
732	Detector Check	2,951
740	Detector Check	3
746	Detector Check	0.5
4380509	Detector Check	1,654
2114	Detector Check	75
41134	Detector Check	0.5
41465	Detector Check	184
8033860	Detector Check	20

Table 138: 1960/Tujunga Detector Meters with Consumption[49]

Meter #	Meter Type	Consumption Volume (gal)
40726	Detector Check	97
40425	Detector Check	67
2805	Detector Check	15
8029657	Detector Check	120
510	Detector Check	7
1122	Detector Check	7
41649	Detector Check	30
4079	Detector Check	22
40953	Detector Check	15
9102298	Detector Check	60
475	Detector Check	7

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[49] Consumption volumes have been rounded to the nearest gallon

Table 139: 540/Westwood Detector
Meters with Consumption[50]

Meter #	Meter Type	Consumption Volume (gal)
3773555	Detector Check	30
90186299	Detector Check	7,196
14828	Detector Check	22
7211131	Detector Check	15
53	Detector Check	135
8868	Detector Check	7
143	Detector Check	105
4581936	Detector Check	22
15929	Detector Check	194
2763045	Detector Check	142
18366	Detector Check	82
1485	Detector Check	52
5591838	Detector Check	1,025
682	Detector Check	150
13592	Detector Check	15
2612	Detector Check	150
856	Detector Check	52
1540	Detector Check	232
5249	Detector Check	52
635	Detector Check	1,197
4870169	Detector Check	150
974	Detector Check	52
2807	Detector Check	90
11954	Detector Check	75
198	Detector Check	172
41395	Detector Check	15
1701	Detector Check	224
40598	Detector Check	45
41505	Detector Check	224
11912	Detector Check	1,197

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[50] Consumption volumes have been rounded to the nearest gallon.

Table 139 Continued

Meter #	Meter Type	Consumption Volume (gal)
2286	Detector Check	2139
7235111	Detector Check	75
1541	Detector Check	15
5591839	Detector Check	494
6111	Detector Check	45
5591450	Detector Check	928
3969	Detector Check	45
7214575	Detector Check	7
3076	Detector Check	67
5334612	Detector Check	45
181	Detector Check	7
5739836	Detector Check	247
11959	Detector Check	269
41316	Detector Check	67
1308128	Detector Check	45
637	Detector Check	7
3118044	Detector Check	7
3118045	Detector Check	7
2662400	Detector Check	45
995	Detector Check	45
5979272	Detector Check	1,354
16402692	Detector Check	67
1670	Detector Check	15
90018136	Detector Check	162,555
42038	Detector Check	7
5485007	Detector Check	120
86026	Detector Check	7
40637	Detector Check	4,069
40870	Detector Check	15
723	Detector Check	1,743

Table 139 Continued

Meter #	Meter Type	Consumption Volume (gal)
735	Detector Check	45
9011190	Detector Check	22
3002993	Detector Check	52
5739837	Detector Check	7
883	Detector Check	75
5979246	Detector Check	1,713
3468631	Detector Check	7
5739829	Detector Check	90
87	Detector Check	15
1175	Detector Check	389
4012	Detector Check	7
18361	Detector Check	60
4891	Detector Check	7
2470275	Detector Check	7
2293416	Detector Check	456
2653620	Detector Check	748
749	Detector Check	202
41273	Detector Check	845
2662385	Detector Check	389
2662422	Detector Check	135
85054	Detector Check	7

APPENDIX U: Small Meters with High Consumption

Table 140: 517/Boyle Heights, Small Meters with High Consumption

Meter #	Meter Type	Consumption Volume (gal)
90108387	Small	2,250,395
90070592	Small	2,157,307
90129549	Small	3,745,692
90020800	Small	8,094,183
95018301	Small	526,405
95018302	Small	1,210,421
90049445	Small	2,997,730
95018717	Small	449,840
90126875	Small	3,112,839
90125516	Small	90,658
90132549	Small	376,790
90108435	Small	408,258
90038253	Small	93,425
96117777	Small	105,019
90137640	Small	135,283
90132431	Small	226,958
90058054	Small	225,687
90038240	Small	71,060
90075832	Small	599,245
90052382	Small	5,993,111
96210112	Small	675,586
90038375	Small	88,264
90027703	Small	377,119
50575410	Small	1,435,517
90000378	Small	1,485,483
50510799	Small	3,646,133
90000473	Small	22,477,849
60051581	Small	3,747,525
90033187	Small	78,854
49094225	Small	604,204
96138010	Small	748,284
96175964	Small	749,212
50603063	Small	337,400

Table 140 Continued

Meter #	**Meter Type**	**Consumption Volume (gal)**
90050710	Small	5,557,550
90057906	Small	273,252
90052392	Small	749,324
90052404	Small	227,220
90051866	Small	208,183
90057770	Small	150,595
90052033	Small	208,251
90043800	Small	155,913
Total		*76,852,026*

Table 141: 1960/Tujunga, Small Meters with High Consumption

Meter #	**Meter Type**	**Consumption Volume (gal)**
96134311	Small	2,246,244
49513264	Small	92,303
50605429	Small	204,054
49432721	Small	1,593,951
50409096	Small	2,250,066
50572619	Small	1,134,536
30976708	Small	626,899
49003407	Small	77,134
46358483	Small	2,444,853
33896632	Small	410,757
32634012	Small	1,999,015
49163403	Small	825,276
49298231	Small	152,727
49418843	Small	2,854,951
50571744	Small	373,461
Total		*17,286,228*

Table 142: 540/Westwood, Small Meters with High Consumption

Meter #	**Meter Type**	**Consumption Volume (gal)**
49243473	Small	5,548,664
49512698	Small	27,712,353
49321201	Small	240,250
38764278	Small	28,646,837
96115758	Small	751,329
96111674	Small	507,496
49100954	Small	339,714
49279344	Small	211,026
Total		*63,957,668*

APPENDIX V: Average Pressure for Zones Prioritized for Pressure Reduction

Table 143: Average Pressure for Prioritized Zones for Pressure Reduction

SYSTEM ZONE	AVERAGE PRESSURE (PSI)		SYSTEM ZONE	AVERAGE PRESSURE (PSI)
1620	223.84		**1134**	129.72
1677	206.99		**855**	127.71
1520	206.93		**477**	127.48
1100	197.3		**1075**	125.3
721	195.3		**1720**	123.64
1216	181.79		**1240**	120.15
2045	179.71		**944**	119.16
1345	175.89		**950**	118.76
865	170.51		**579**	118.54
2440	170.45		**1615**	118.04
1718	166.55		**1123**	116.85
1636	166.23		**1410**	115.24
1424	162.55		**770**	113.88
1275	154.48		**610**	112.41
1750	151.7		**757**	111.9
1137	151.31		**946**	111.5
1096	150.43		**1645**	111.21
1990	147.85		**529**	108.57
890	147.84		**1950**	106.02
930	146.58		**667**	104.59
1305	146.08		**1600**	104.27
1116	144.94		**320**	104.23
1445	144.44		**1540**	103.74
847	143.78		**1500**	103.61
1000	143.15		**1546**	103.54
1050	140.65		**375**	103.07
720	140.13		**2140**	102.88
1030	139.46		**599**	102.61
740	138.37		**1337**	102.47
1280	134.63		**426**	101.7
1449	132.37		**769**	101.63
1440	131.05		**498**	100.74
			1143	100.54