Experience of Using the IWA/AWWA Water Audit Methodology in Salt Lake City Public Utilities Public Utilities Department

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Keywords: Water audit; Meter validation; Consumption validation

Introduction

The Salt Lake City Public Utilities Department (SLCPUD) has been very pro-active in reducing both real and apparent water losses through a capital improvement program focused on replacing the aging small diameter pipes in the system, a residential meter change out program, maintaining good records for the past 12 years of water use and loss and monitoring the 100 largest customers. Nevertheless, water loss records using the traditional Unaccounted for Water (UfW) percentage indicator showed a steady increase in losses over recent years.

In order to ensure accountability and efficient operation as the water supplier, SLCPUD conducted a detailed water audit using the IWA/AWWA recommended water audit methodology. This paper will briefly describe the audit process used, the results of the audit and SLCPUD's water loss management performance. In particular, the paper will focus on the key issues identified, including:

- input meter design
- the importance of input meter validation
- difficulties of meter validation
- validation of consumption data
- large customer meter accuracy
- service line repair times

These issues are believed to be common to many US utilities in the western states and the lessons learned from the SLCPUD audit are therefore believed to be of broad relevance to US utilities.

Project Approach

The water audit project was undertaken with a project team established with Stakeholders from all departments with an input to the water audit. The project commenced with an introductory Stakeholder meeting, followed by detailed individual interviews and data collection with each Stakeholders. The audit period was decided at the introductory meeting to be the calendar year 2003. Data collected and used in the audit included:

- Prior consultants & internal reports
- Water production data

  - Water sources/imports/exports, production amounts, plant usages, supply/demand balance, SCADA data, meter test data
- Distribution system information
  - Inputs, miles of mains, # connections, pressures, pressure management, district metering, reservoirs, leakage programs, repair data, practices, materials, maintenance practices, reservoir tests, pumping stations, GIS data, service / coverage data, hydraulic model data, network maintenance data
- Consumption data
  - Extract from the billing system of meter reading and consumption data, metering policies & practices, rates, routes, meter reading, metering and billing data, meter test data, details of all unmeasured uses
- Cost data – production costs and retail rates

It had been the intention to flow test all the key system inputs in order to validate the system input volume, making corrections to system input volumes where meters were found to be in error. In practice, it was only possible to partially achieve this objective, for reasons detailed later in the paper.

The accuracy of the customer meter population was assessed by analyzing existing meter test data. It had been expected that it may be necessary to undertake sample meter testing to obtain sufficient representative meter test data, but it was found that the available meter test data was sufficient to support a robust analysis of apparent losses due to meter under-registration.

An extract was taken from the billing system to investigate any data handling errors and the handling of estimates and adjustments within the billing system which may lead to apparent losses.

All unmeasured uses of water were identified and estimates built up for each of these estimates using a use component based approach. The level of unauthorized use, primarily from fire hydrants was estimated based on the likely number of contractors connecting illegally to hydrants and their typical daily consumption.

Based on the data collected and analyzed, volumes were allocated to each of the IWA water balance components, together with 95% confidence limits on all input values and calculated components. All the IWA performance indicators were also calculated with 95% confidence limits. The use of the 95% confidence limits clearly shows that inaccuracies in the system input metering have the greatest influence in the confidence of the real loss volume calculated in the water balance. For this reason, this paper focuses on validating the system input volumes.

System Input

The main sources of bulk supply into Salt Lake City are illustrated in Figure 7 below. SLCPUD operate three treatment works at City Creek, Parley and Big Cottonwood, in addition to wells and springs (not shown in Figure 7). These supplies are supplemented by bulk imports from Little Cottonwood (Metropolitan) and Jordan Valley treatment works. The relative contribution of these sources to the 2003 system input volume is illustrated in Figure 8.

Meter Validation

The existing metering and options for meter validation, as well as the test results are briefly discussed in the following sections.

Little Cottonwood WTP (Metropolitan)

The system input from Little Cottonwood WTP is measured by three meters operated by Metropolitan Water Department (MWD):

Input to the 1.75m (69”) Salt Lake Aqueduct is measured by an AccuSonics eight point multi-path ultra-sonic meter installed on the aqueduct downstream of the plant.

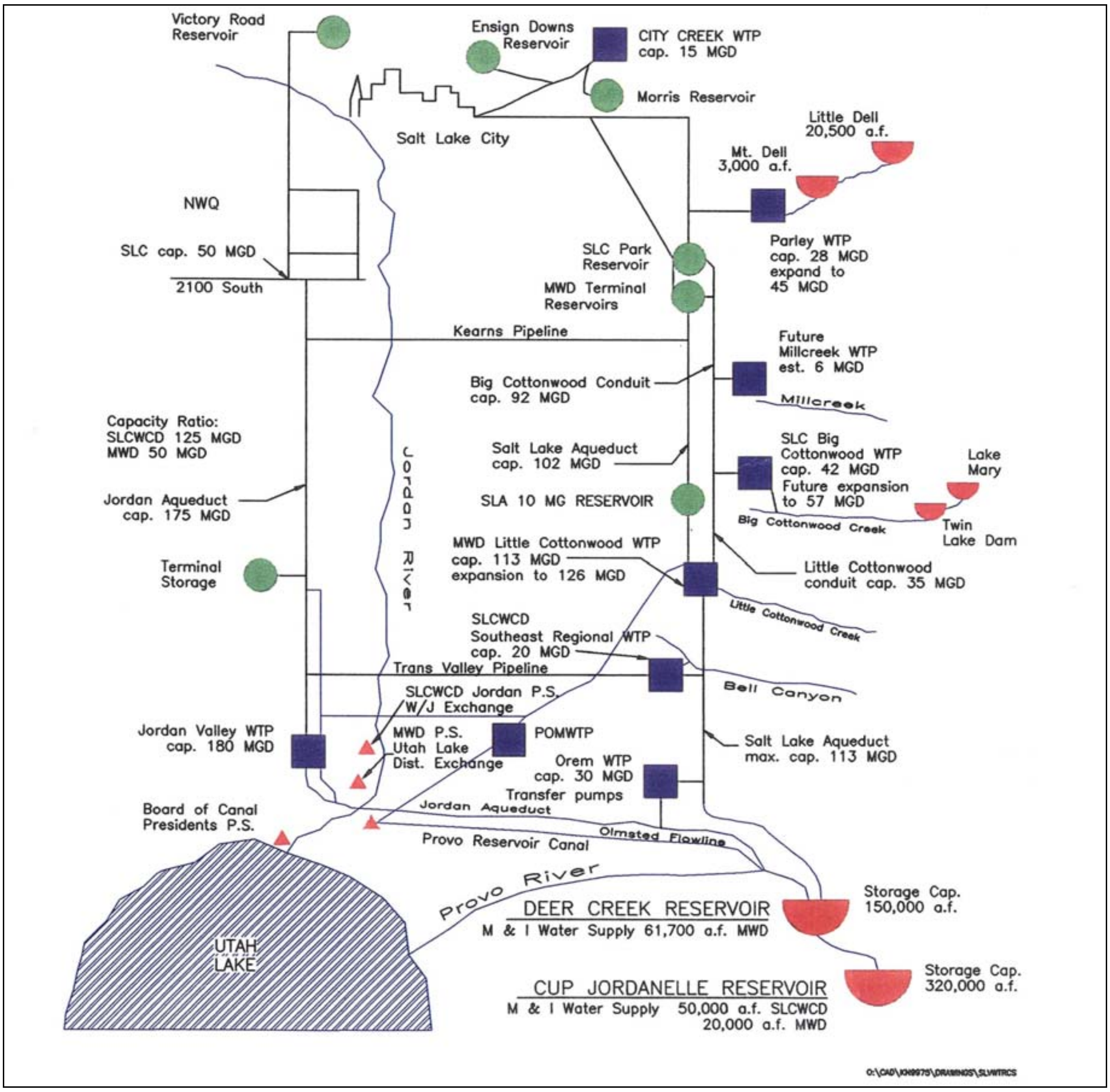

Figure 7 Main sources of supply to Salt Lake City

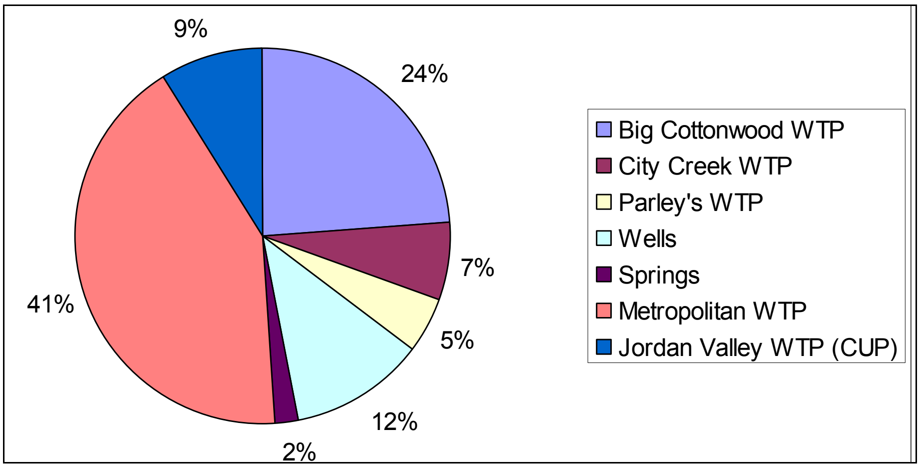

Figure 8 Relative contribution of sources in 2003

Input to the Little Cottonwood conduit is measured by two meters within the treatment plant, a 914mm (36") venturi meter on the main 914mm (36") line and a 152mm (6") electromagnetic meter on the 152mm (6") bypass waterline, which is used for accurate measurement of lower flowrates.

All three of the meters at this plant are installed in appropriate locations, are relatively modern meters and they appear to be well maintained. However, there are no regular checks undertaken to verify that these meters are reading correctly, except for annual calibration of the electronics for zero and span.

There is nowhere within the Little Cottonwood WTP upstream of these metering points that could be used for a temporary check meter test point. Nor is there any storage at the treatment plant that could be used for volumetrically testing the accuracy of these meters. Downstream of the meter, two possible options were identified for validating the accuracy of the 1.75m (69") ultrasonic meter:

- Install an insertion meter tapping point downstream of the meter test with an insertion EM meter.
- Close off all the turnouts from the Aqueduct between the treatment plant and Terminal reservoir and undertake a volumetric test of the meter using the storage in Terminal reservoir.

It is not possible to install an under-pressure tapping on the Aqueduct because of its construction. The Aqueduct is such a key element of the SLCPUD supply system that considerable work is required in planning, timing and reconfiguring the distribution system to maintain service during this work. It will be necessary to take the Aqueduct out of service during 2005 to facilitate the construction of additional process units at the treatment plant. The installation of a tapping point could not be undertaken until the Aqueduct is taken out of service in 2005 as it would not be possible to undertake this level of work twice within a short interval. For the same reasons, it was concluded that it would also not be possible to undertake a volumetric test using Terminal reservoir during the timescale of this audit. It therefore proved to be impossible to undertake independent validation of the 1.75m (69") ultrasonic meter.

A suitable location for an insertion meter tapping point was identified on a straight run of 914mm (36") main leaving the plant to the east. This insertion metering point would facilitate validation of the combined flow through the 914mm (36") venturi and the 152mm (6") bypass. However, this main is constructed from pre-stressed concrete pipes and it therefore cannot be tapped without destroying the structural integrity of the pipe.

Unfortunately there is no other practical option for verifying the accuracy of these meters. It was therefore not possible to validate the accuracy of these meters.

Big Cottonwood WTP

Raw water is measured at the head of the treatment plant by a Parshall flume. The next point that flows are measured in the plant is on the effluent from the filters. Each of the 8 effluent lines are fitted with a full bore electro-magnetic meter, prior to discharging into the clear well. Effluent from the treatment plant is measured by a weir, however the plant operators have no confidence in the data from this weir because it was constructed asymmetrically and the weir plate was also reputedly not level. Instead, the plant operators base the plant production on the data from the Parshall flume, subtracting the filter backwash flows from the Parshall flume measurement to obtain the plants' production.

There is nowhere upstream of the plant where it is possible to undertake independent measurement of the plant influent. There is no storage within the plant or downstream of the plant which could be used for undertaking a volumetric test of the plant metering. Also because the effluent conduit does not run full at any point in the vicinity of the plant, it is not possible to utilize a velocity type meter, such as an insertion meter or an ultrasonic clamp-on meter to obtain flow rate data. The only practical options for checking the accuracy of the flume were to use the sum of the filter meter flows and reconstruct the effluent weir as a correctly engineered rectangular weir, which was undertaken by SLCPUD staff.

A pressure transducer was used to record the level of water in the channel upstream of the re-constructed weir. The transducer was installed in the base of the channel upstream of the weir to monitor variations in head over the weir during the test. In addition, 4-20 mA loggers were connected to four of the operating filter meters to capture the raw metered flows from these meters. The corresponding flow through the Parshall flume was taken from the SCADA system. Figure 9 illustrates the results of the test undertaken at Big Cottonwood.

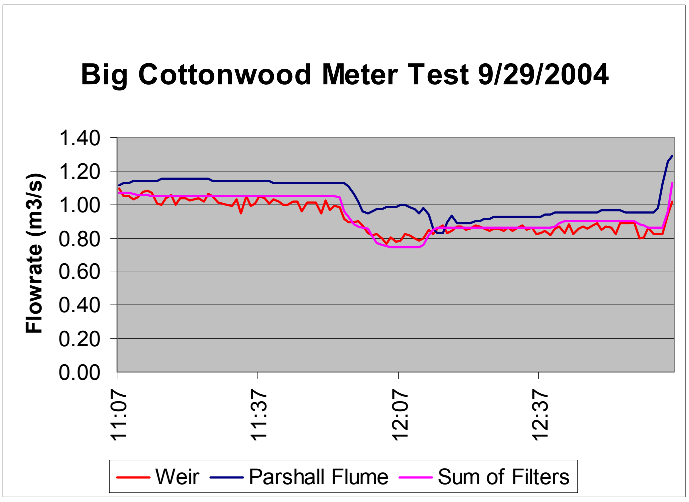

Figure 9 **Big Cottonwood meter test results**

It may be seen from this graph that there is reasonably good correlation between the flow rates recorded from the weir and the sum of the flow rates recorded by the filter meters. The flow recorded over the weir was on average 2.1% less than the flow recorded by the filter meters, but this difference is partially due to the fact that water was being pumped from the clear well to backwash No. 2 filter during a portion of the test. The estimated backwash volume is 37.5 m3 (9,900 gallons), which would account for half of this difference. The flow rates recorded by the Parshall flume are significantly higher than from the other two metering points. Over the period of the test, the flow recorded by the Parshall flume was an average of 10.1% more than the sum of the filter meters.

The same pattern was observed when comparing flows recorded by the Parshall flume with the sum of flows recorded by the filter meters over the whole audit period. At low flow rates there are only small differences in the flows recorded by the two sets of meters, but at higher flow rates the Parshall flume is recording significantly higher flows than the filter meters. On average over the year the flume recorded 4.9% more flow than the filter meters. Based on this test, it is apparent that the filter meters provide a more accurate measurement of the production from Big Cottonwood than the Parshall flume. For the water audit, the system input volume from this plant was therefore based on the sum of the filter meters, less the backwash volume.

City Creek WTP

The effluent from each of the plant filters is measured by Simmons venturi meters on the effluent line from the filter. There is no meter on the effluent from the plant. For this reason, the plant operators base the plant production on the data from the Parshall flume on the plant inlet, subtracting the filter backwash flows from the Parshall flume measurement to obtain the plants' production.

There is nowhere upstream or within the plant where it is possible to independently measure the plant influent. However it is possible to measure the plant effluent by installing an insertion meter on a suitable section of one of the effluent lines downstream from the plant, while the other effluent line was isolated.

Data loggers were connected to the 0-20 mA signals from the filter meters of the two filters operating during the test (Filter No.'s 2 and 4) to compare the meter output with the data recorded on the SCADA system. Unfortunately, it has proved to be impossible for SLC to extract the data from the SCADA system for either the Parshall flume or the filter meters.

Hourly flow rate data from both the filter meters and the flume have been provided, both of which indicate a flow rate at the start and end of the hour of the test 8:00pm and 9:00pm of 0.15 m3/s (3.4 MGD). These figures match with the sum of the filter meters calculated from the 0-20mA signals. The following data comparison is therefore limited to a comparison between the flow rates logged from the insertion meter and the sum of the filter flow rates calculated from the 0-20mA signals.

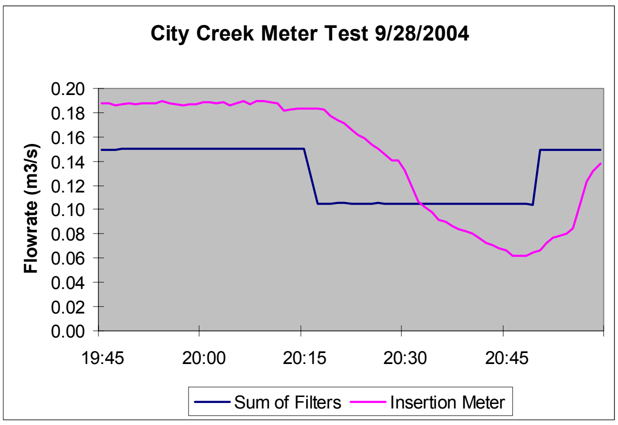

Figure 10 **City Creek meter test**

Figure 10 illustrates the results of the City Creek meter test. The sum of the filter meters is only on average 80.09% of flow recorded by the insertion meter in the high flow test. The result of the low flow test is more difficult to analyze because the upper section of the effluent main only runs partially full and it therefore took much longer than anticipated for the reduction in flow in the treatment works to be fully reflected at the test point. Neverthless, it can be seen that the flow rate at the test point had stabilized for the last five minutes of the low flow test. The low flow performance of the filter meters is 165.12% of the insertion meter.

Normally, with differences between the two meters of this magnitude, the daily system input volumes would be corrected to compensate for meter error. However, the flow range over which it was possible to test the City Creek meter represents only a small part of the plant operating range of the plant in 2003. Furthermore, it was only possible to undertake the test at two flow ranges, which provides insufficient data points for an accurate linear regression curve. For these reasons, the City Creek system input volumes have not been corrected for the current audit, but it is recommended that another test is undertaken at high flow rates at City Creek to enable the development of a reliable correction curve.

Parleys WTP

Raw water influent to the plant is measured by Parshall flume, with the level of water in the flume stilling chamber measured by a Milltronics ultrasonic level recorder. SLCPUD periodically checks the level measurements of the Parshall flume stilling chamber. Effluent from each of the plant filters is measured by venturi meters on the effluent line from the filter. The plant effluent meter is an annubar meter. The plant operators believe that this meter under-registers at low flows. For this reason, the plant operators base the plant production on the data from the Parshall flume, subtracting the filter backwash flows from the Parshall flume measurement to obtain the plants' production.

There is nowhere upstream or within the plant where it is possible to independently measure the plant influent. However it is possible to measure the plant effluent by installing an insertion meter on the effluent line. Although not an ideal location, the only suitable point for installing an insertion meter was in the vault housing the annubar meter.

A Quadrina insertion turbine meter was installed downstream of the annubar meter and the flows recorded by the annubar meter were logged using a 4-20 mA logger. The filter meter flows were taken off the SCADA system. Unfortunately at the time of the test, the flow through the Parshall flume was not being recorded in the SCADA system. Figure 11 illustrates the results of the test. The flow rates calculated from the 4-20mA signal from the annubar effluent meter are within 1% of the test meter at low and high flow rates and just over 2% at medium flow rates. There is therefore good correlation between the test meter and the signals from the effluent meter.

It is clear from the drop in flow through the meter vault after the high flow test that the annubar meter does under-read at very low flow rates and does not record any flow below 0.09 m3/s (2 MGD). The daily production data indicates that the plant operated at flow rates below this level on some days during February, March, April and November 2003.

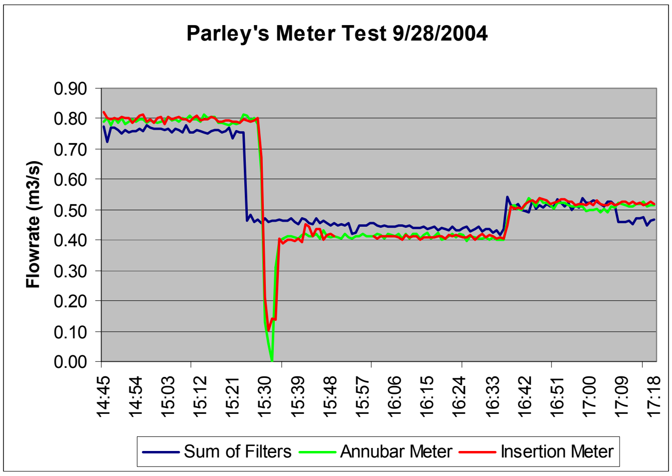

Figure 11 **Parleys meter test results**

Although it has not been possible to compare the test results with the Parshall flume data for the test period, the Parley's system inflow data for 2003 taken from the Parshall flume, after deduction of backwash water, has been compared with the effluent data for 2003 taken from the annubar meter. It is apparent from this data that the system input based on the effluent data is higher than the data from the Parshall flume for most of 2003, until the 13th October 2003, when it appears likely that the effluent meter was re-calibrated. From this point onwards, the daily figures match closely, with an average difference of 1.0%.

If it were not for the fact that the effluent meter was re-calibrated in October 2003, the data from this meter would have been used to determine the system input volume from Parley's for the audit. However, because this meter was probably re-calibrated, the existing system input volume was used for the water balance, but this may significantly under-state the true input from Parley's WTP. For future water audits, the effluent meter data should be used, as this will provide a more accurate figure than the data from the Parshall flume.

Jordan Valley WTP (CUP Connection)

The Jordan Valley Aqueduct connects into the SLCPUD system at the CUP connection. Almost immediately downstream of the venturi meter, within the vault, is a tee connection between the CUP connection and SLCPUD. On one side of the tee is the connection used by SLCPUD for lower flow rates and the connection on the other side is also used for higher flow rates. Downstream of the tee, each connection further divides into four 12" connections into the SLCPUD system.

Almost immediately upstream of the vault, the Aqueduct is running under a major highway.

There is insufficient room to provide the minimum length of straight pipe required for an accurate test upstream of the meter vault, due to the close proximity to the highway. There is nowhere within the vault suitable for a test point and immediately downstream of the tee connection, the SLCPUD mains split into eight separate mains, so there is no suitable test point downstream of the connection. It was therefore concluded that in order to test the CUP meter, it would be necessary to install a test point on the Jordan Aqueduct on the south side of Highway 201 at a location with more room to tap the pipe. However, the Jordan Aqueduct is owned by JVWCD, therefore SLCPUD would need to seek permission from JVWCD to install a meter test point. SLCPUD staff considered that it could be difficult to obtain this permission and as with the Salt Lake Aqueduct it would probably be a significant project to install such a tapping point, entailing draining the Aqueduct. For these reasons, it was not possible to validate the accuracy of this meter during this audit.

Consumption Data Analysis

A full extract of meter readings, consumption data, customer type data and data processing flags was taken from the SLCPUD billing system and the data analyzed. The analysis found:

- Only 2.15% of readings were estimated, mainly in December when poor weather conditions made meter reading difficult. Excluding December, the level of estimates was only 0.44% of readings. This level of estimates is low and is a tribute to the quality of SLCPUD’s meter reading and billing process.
- Only 3,212 readings were adjusted during 2003, representing 0.29% of meter readings. Most of the adjustments are either because the billing system does not automatically deal with the situation of the meter “going round the clock”, so the large negative consumption has to be manually corrected, or because of an incorrect meter reading, either in the current or previous reading cycle. There are also some instances where adjustments are made to estimated consumption figures where there is no meter reading.
- Inspection of the hi/lo/zero exception reports indicates that the billing processes are being used correctly. It is also clear that customer side leaks are being identified and rectified through this process.
- The quality of the data held in the billing database is exceptionally high. Data anomaly checks were undertaken to identify any data issues which may affect the consumption analysis, these checks only highlighted two very small anomalies within the billing data, which are summarized below, neither of which have any impact on the consumption analysis.
    - 30 records without a meter serial number, but with a meter tag number.
    - 6 records with a default meter installation date of 1/1/1901.
- Based on analysis of the meter reading process, the management of estimates, adjustments and data anomalies, it is evident that the SLCPUD metering and billing processes are well managed. No data handling errors have been identified, so this component of apparent losses in the water balance was allocated a value of zero.

Accuracy of Customer Metering

Meter test data was provided by the metering department of SLCPUD for both small and large meters. The data was analyzed to remove the meter tests that were not representative of a random sample. The remaining meter test results were analyzed to determine the average meter under-registration for different categories of meters. The results were analyzed both by stratifying the data into the number of registers of the meter and by a single stratum for each meter size range. The results of the analysis are detailed in Table 1 to Table 3 below.

Table 1 Results of large meter tests (3" meters and above)

	Three register stratum			Single stratum
Analysis by percentage u/reg	**Single**	**Double**	**Triple**	**Total**
Total pop (N)	730	170	11	911
Average registration % (AWWA method)	96.2%	92.5%	91.0%	94.8%
Total un-registered volume in sample	353984	401670	8175	763828
Total registered volume in sample	23543734	2926537	122587	26592858
Sample count (n)	158	72	**14**	244
Sample variance off % under-reg	0.009	0.019	0.026	0.013
Average under-registration %	3.8%	7.5%	9.0%	5.2%
CI limits +/- of under-registration %	1.3%	2.4%	#NUM!	1.2%

Table 2 Results of medium meter tests (11/2" and 2" meters)

	Two register stratum		Single stratum
Analysis by percentage u/reg	**Single**	**Double**	**Total**
Total pop (N)	2233	165	2418
Average registration % (AWWA method)	95.0%	81.3%	94.7%
Total un-registered volume in sample	1481059	1873	1482933
Total registered volume in sample	10135091	13550	10148641
Sample count (n)	177	**3**	180
Sample variance off % under-reg	0.011	0.019	0.012
Average under-registration %	5.0%	18.7%	5.3%
CI limits +/- of under-registration %	1.5%	18.9%	1.5%

Table 3 Results of small meter tests (1" and below)

	Single stratum
Analysis by percentage u/reg	**Total**
Total pop (N)	84242
Average registration % (AWWA method)	98.8%
Total un-registered volume in sample	1143
Total registered volume in sample	106140
Sample count (n)	**46**
Sample variance off % under-reg	0.000
Average under-registration %	1.2%
CI limits +/- of under-registration %	0.4%

It may be seen from this data that the small meter stock is performing well, with an average under-registration of 1.2%, but the large and medium sized meter stock has an average under-registration of 5.2% and 5.3% respectively, indicating room for improvement.

BABE Component Analysis

A BABE component analysis of awareness, location and repair times was undertaken for reported breaks. This analysis indicated that in general SLCPUD was managing repairs of reported leaks well, however 64.3% of the volume of real losses from reported breaks was attributed to service line breaks. This was because the average repair time for a service line break is 11.1 days. The volume lost from these breaks, estimated at 4.14 Mm3/yr (1.093 MGY) could be reduced by improving the response to repairing these breaks.

Results of Water Audit

The performance indicators for the Salt Lake City system for 2003 are summarized in Table 4 together with the 95% confidence limits. The confidence in the results of the water audit is low because of the inability to validate key system input volumes. SLCPUD are taking steps to allow validation of the other meters for future audits. However, based on the system input volumes used, the system has an ILI of 2, which is a very creditable performance for a utility that does not have an active leakage control programme. This is clearly indicated in the comparison of SLCPUDs ILI against international and N. American data sets in Figure 12.

Table 4 Salt Lake City 2003 water audit performance indicators

PERFORMANCE INDICATOR	UNITS OF PERFORMANCE INDICATOR	Best Estimate	Lowest Estimate	Highest Estimate	95%CLs as +/-%
Non Revenue Water Basic (IWA Level 1, Fin36)	% of System Input by Volume	8.5	5.8	11.1	30.9%
Non Revenue Water Basic (IWA Level 1, Fin37)	% of System Input by Value	4.4	3.1	5.8	30.9%
Real Losses Basic (IWA Level 1, Op24)	US Gal/service connection/day	48	25	71	47.9%
Apparent Losses Basic (IWA Level 1, OP23)	US Gal/Service connection/day	26	25	26	2.2%
Real Losses Detailed (IWA Level 3, Op 25)	Infrastructure Leakage Index ILI	2.01	1.0	3.0	47.9%

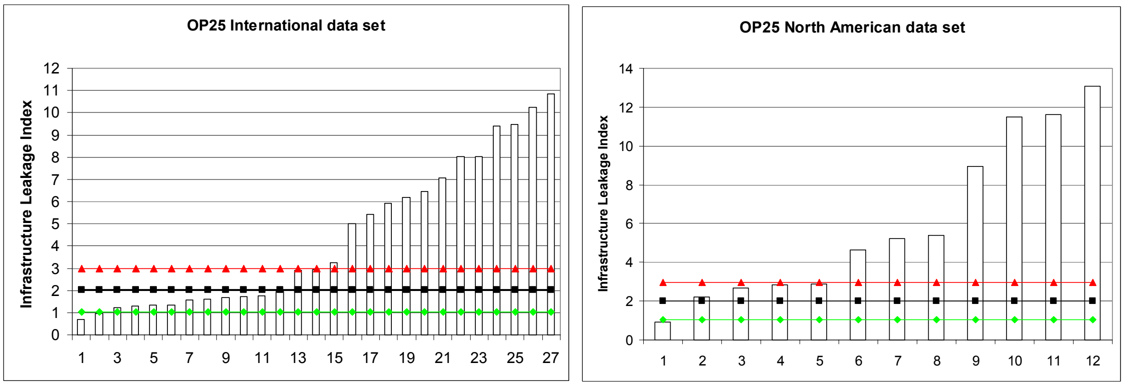

Figure 12 Salt Lake City's ILI compared against international and N. American data sets

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