CATAWBA WATEREE WATER MANAGEMENT GROUP

CAVANAUGH
Stewardship Through Innovation

T E C H N I C A L M E M O R A N D U M **FINAL**

Catawba-Wateree Water Management Group (CWWMG)
Catawba Water Loss Program Phase 5a: Water Loss Profiles & Statistical Analysis

PREPARED FOR:	CWWMG	**DATE:**	December 05, 2018
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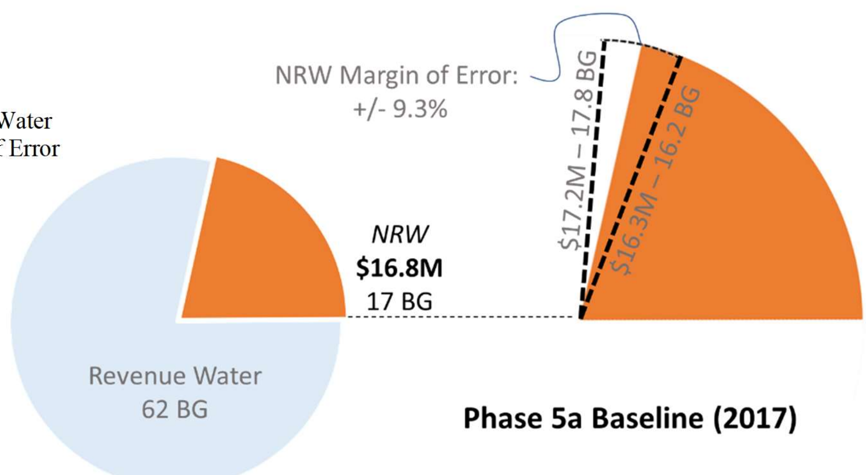
Executive Summary:

The most recently completed portion the multi-phase Catawba Water Loss Program (Phase 4) was presented to CWWMG in December 2017, with the final report delivered in January 2018. The results of Phase 4 presented an aggregated baseline level of Non-Revenue Water (NRW) across the CWWMG membership of approximately 15 billion gallons with a cost impact of nearly $16,000,000 annually, based on 2016 audit period. As NRW is a compounding issue, the cumulative cost for the CWWMG membership for a 5-year horizon approaches $100,000,000. The baseline results of Phase 4 for NRW had a statistical margin of error of +/-13.6%, based on the preliminary nature of the input data. The outcome of Phase 5 will be determination of cost-effective targets for NRW reduction across the CWWMG membership. Phase 5 will inform the remaining Phases (6-8) for cost-effective intervention and reductions. Based on timing of funding availability, Phase 5 was sub-divided into two phases 5a and 5b. Phase 5a is the subject of this technical memo and includes the development of detailed water loss profiles and statistical analysis for each CWWMG utility and the resultant aggregation. Phase 5a results will flow directly into subsequent Phase 5b efforts for economic (cost-benefit) analysis and target setting. It is important that the economic analysis and target setting proceed relatively close to the statistical analysis, as the driving cost factors of water rates and production/purchase costs should be tied to the audit year used for loss profiling.

For the CWWMG members, the aggregation of all systems equates to a total of 17 billion gallons of Non-Revenue Water at a total value of $16.8 million dollars, based on 2017 audit period. These Phase 5a results have a statistical margin of error of 9.3% and indicate an increase in NRW from the 2016 audit period results presented in Phase 4.

Figure E1 – Total Non-Revenue Water Volume and Value with Margin of Error



Of the total 2017 NRW volume and value, real losses equate to approximately 82% volumetrically and 31% by value. The reason for this paradox between volume and value is the inherent difference in how real losses are valued (at marginal supply rate) and apparent losses are valued (at marginal retail rate). Of the total real losses, two-thirds (67%) is classified as unreported/hidden leakage, thus potentially recoverable through conventional, proactive leak detection activities.

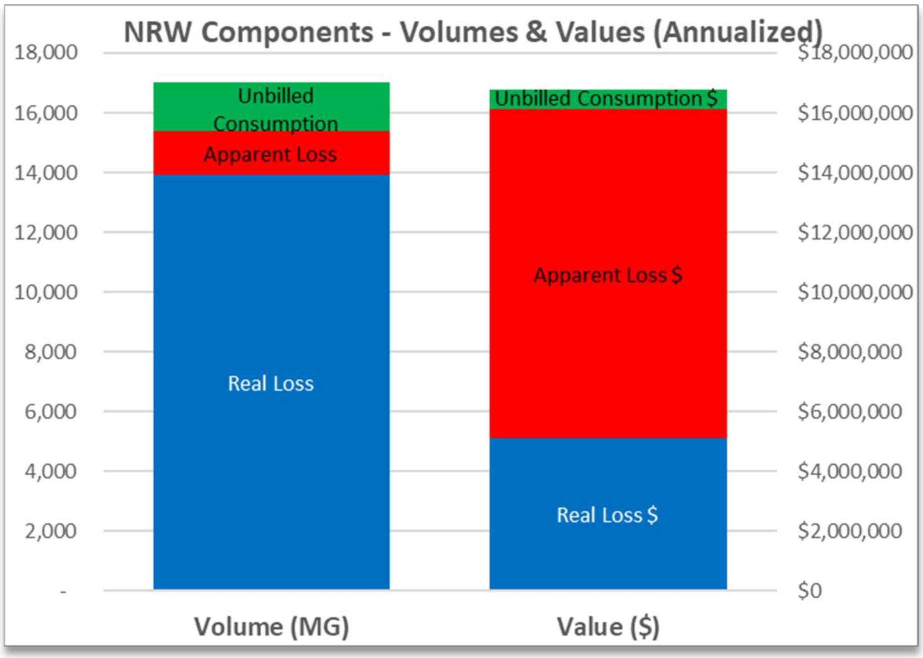


Figure E2 – Total Non-Revenue Water Volumes and Values by Component

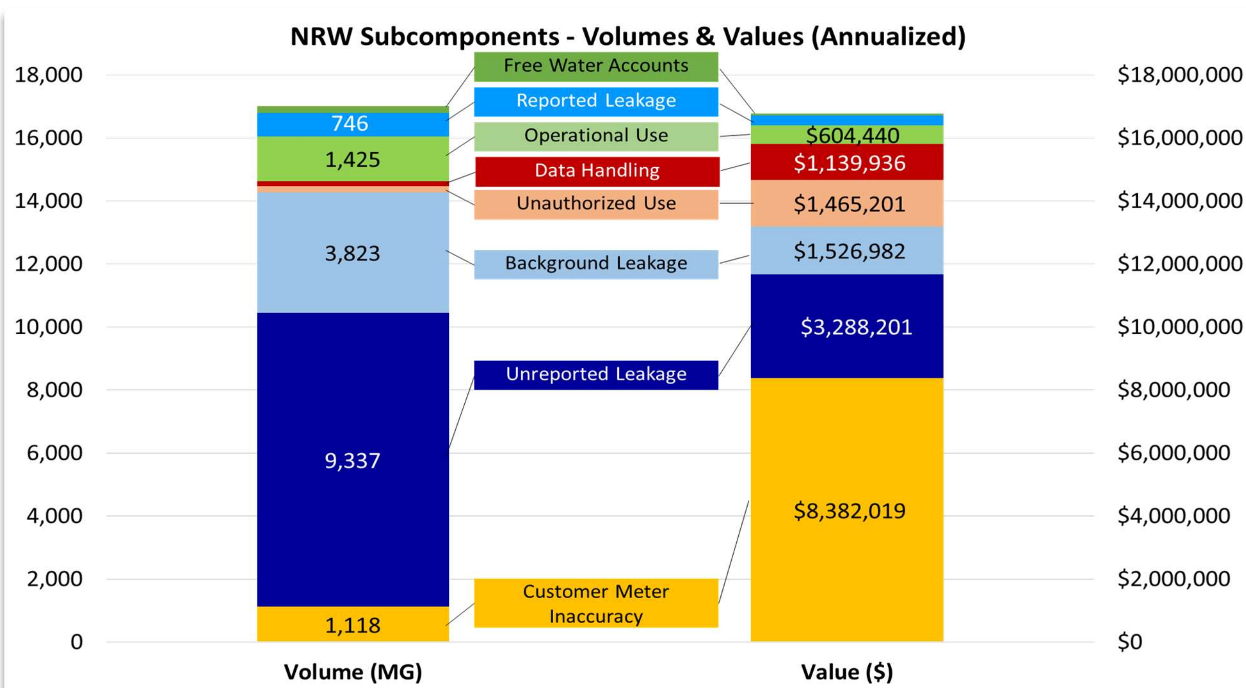


Figure E3 – Total Non-Revenue Water Volumes and Values by Sub-Component

Real Loss Component Analysis – Description of Methodology:

The water balance analysis is a top-down process, meaning the analysis starts with water supplied and then subsequently subtracts authorized consumption and apparent losses. The remainder in this top-down process yields an estimate of the real losses. It is important to further evaluate these real losses, by performing a bottom-up quantification of the volumes through a real loss "component analysis". The central aspect in the component analysis, is understanding there are three types of real losses. Most utilities associate all of their real losses with the leaks that come to the surface, are discovered and then repaired. This is "reported leakage". From a volumetric standpoint, reported leakage generally equates to a very small percentage of the total real loss volume. This is because the time period from when a utility becomes aware of the leak, locates the leak to when the repair is made is generally a short period.

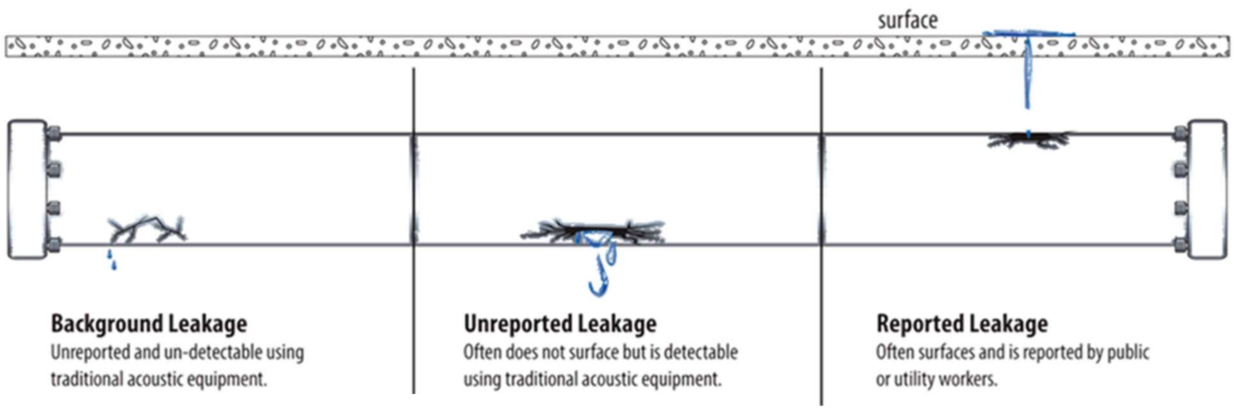


Figure 1 – Sub-Components of Real Loss (graphic credit WRF)

The other types of real loss are "background" and "unreported leakage". Unreported leakage is described as detectable using proactive leak detection methods, but they generally do not surface. It takes a proactive action to discover these leaks. Therefore, the volume of unreported leaks can often be substantial if proactive leak detection is not occurring (i.e. the utility is not "aware" that the leakage is occurring, and the resulting cumulative leakage can be quite large as a result of the protracted run times).

The third type of real loss is classified as background leakage. This form of leakage is described as the small weeps and seeps present in all pressurized piping systems. The volume of background leakage in a system is dependent on the condition of the distribution system and service connection laterals. The age and condition of the pipelines is used in the determination of the Infrastructure Condition Factor. The background leakage is a calculated volume that incorporates Infrastructure Condition Factor, miles of main/number of service connections and average operating pressure.

The goal of the component analysis is to understand the volume of each of the three types of real loss. This is important because the primary intervention strategy for most utilities is active leak detection. However, active leak detection is only an effective strategy for one of the sub-components, unreported leakage. If the top-down water balance analysis results in a large real loss volume, most utilities would immediately move to active leak detection, but if most of the leakage is a result of reported breaks and background leakage, the proactive leak detection efforts are likely to yield poor results.

One of the primary results of the real loss component analysis is understanding the potential recoverable leakage in the system. Using this information, an intervention frequency can be calculated providing direction on how often the system should be surveyed. This intervention frequency is an economic-based calculation, considering both the cost of the leak detection survey effort and the "value" of the recovered leakage. Finding the optimum point will result in the economic level of leakage and thus the utility will neither be spending too much on leak detection efforts nor too little, leaving potential recoverable leakage undetected.

The real loss component analysis quantifies the volumes of the reported breaks based on the actual results from breaks. For each system, data was provided by the utility based on their existing data collection and tracking methods. In the summary of each utility, specific recommendations for improvements in these tracking methods, if needed, are identified.

The methodology, as developed, has determined that the leakage to pressure relationship is governed by the following formula[1]:

Relationships between Pressure (P) and Leakage Rate (L):

$$L_1/L_o = (P_1/P_o)^{N1}$$

As shown, the ratio of leakage after and before pressure change is equal to the ratio of pressure after and before to the N1 power. The N1 exponent is used to represent the impact of pressure on various types of pipes (cast iron, PVC, DIP, etc.) and ranges from 0.5 to 1.5 (rigid to flexible pipe types).

For the background leakage on mains and services, a system-wide ICF of was assigned based on the average age of the distribution system. The background leakage is then calculated for the mainline, service laterals and the service connections. N1 exponent for background leakage is assigned as 1.5 as background leakage is highly sensitive to pressure changes. Background leakage was also attributed to all storage volumes in the system at a constant rate of 0.25 gallons per minute, a default estimate derived from WRF Project 4372A.

For each system, the following data was input into a model for analysis and evaluation:

- 2017 Top-Down Water Audit Inputs:
    - Water Supplied (Adjusted)
    - Authorized Consumption
    - Apparent Losses
    - System Data
        - Length of Mains
        - Service Connections
        - Average Operating Pressure
    - Cost Data
- Capacity of Storage Tanks/Reservoirs
- Infrastructure Condition Factor – selected based on average age of system
- Reported Leakage
    - Documented storage tank overflows
    - Reported breaks by mains size
    - Length of mains by line size
    - Reported breaks by service connection size (less than 1" and 1" and larger)

[1] Kunkel, et al. *M36 Manual – Water Audits and Loss Control Programs*. 4th Ed, 2016. American Water Works Association, Denver CO.

  - Service connections by size (less than 1" and 1" and larger)
  - Reported break by appurtenance (Hydrants, Valves, Meters & Other)
  - Awareness time
  - Location and Repair time
- Unreported Leakage
  - Unreported breaks by main size
  - Length of mains by line size
  - Unreported breaks by service connection size (less than 1" and 1" and larger)
  - Service connections by size (less than 1" and 1" and larger)
  - Unreported break by appurtenance (Hydrants, Valves, Meters & Other)
  - Awareness time (assumed to be 180 days)
  - Location and Repair time

All volumes of real losses are valued at the Variable Production Cost (including the cost to purchase water if applicable). For many systems, only primary costs such as power and treatment chemicals are included meaning the value is simply the cost to replace the water that has escaped the distribution system. It should be noted that secondary costs such as wear and tear on pumping assets, liability claims, and supply expansion costs could also be applicable but require an in depth analysis beyond the scope of this evaluation. These costs when appropriately added would only increase the value of the recoverable leakage in the economic analysis, thereby justifying a lower leakage target.

Apparent Loss Component Analysis – Description of Methodology:

Apparent losses can be broken into three sub-components: Unauthorized Consumption, Customer Metering Inaccuracies and Systematic Data Handling Errors. These volumes are valued at the Customer Retail Unit Cost and can be classified as opportunities for revenue recovery as the volume of water reached an end user, however the utility is not properly compensated for the use.

Unauthorized Consumption or "theft" includes all potable water delivered to end users that have not obtained authorization to use the water. This can include illegal filling from hydrants, individual customer meter tampering or unauthorized taps. Additionally, any use of fire suppression connections for purposes other than testing or fire suppression would also be classified as Unauthorized Consumption. Quantification is difficult for most utilities unless advanced theft mitigation programs are in place. In interviews with the utilities, feedback was provided on the nature and frequency of unauthorized consumption activities in their system. Theft volumes were estimated from default values as 0.25% of the Water Supplied, based upon determinations through staff interviews. This is also the default value in the FWAS and often serves as a starting point for utilities to conduct advanced study of unauthorized use, and enhance mitigative measures.

Customer Metering Inaccuracies (CMI) includes any under-registration of volumes delivered to metered customers. While any given meter has potential to over-register, over time the aggregate CMI for a utility's customer meter stock will bias towards under-registration from age and wear. Under-registration can be caused by wear and tear of constant use on mechanical style meters (i.e. nutating disc), improper calibration of electronic style meters or volumes delivered to customers outside of the designed flow range of the meters. Meter inaccuracy is typically analyzed and evaluated in two separate categories, small meters and large meters. Small meters generally make up most of a utility's service connections and therefore are evaluated using a sampling of the overall population. Small meters are usually removed and tested on a test bench. Large meters are typically smaller in count, but often constitute a substantial percentage of the volume sold. Therefore, large meters are typically evaluated on an individual meter basis and generally tested in the field. The input for CMI should be calculated as a volumetrically weighted average utilizing meter testing results. Estimates are made based on the age as the best available proxy for meter throughput, and integrity of the customer meter population.

Systematic Data Handling Errors are the result of any error that occurs between the reading of the customer meter to the bill generation. These errors most commonly occur in the conversion of units read to units billed, often termed as a "multiplier". Additionally, any errors associated with data transcription either manually or digitally are also included. As with Unauthorized Consumption, Systematic Data Handling Errors are often difficult to quantify and was estimated from default values as 0.25% of the Billed Metered Volume, based upon determinations through staff interviews. This is also the default value in the FWAS and often serves as a starting point for utilities to conduct advanced study of process improvements in meter reading and billing and enhance mitigative measures against under-billing events.

Statistical Confidence Analysis:

A similar methodology to Phase 4 was utilized in Phase 5a for quantifying statistical error. 95% confidence intervals (margins of error) were analyzed for the individual utility water loss profiles. The margins of error were then aggregated from individual utilities for each of the nine (9) profile component volumes and values. The result shows a margin of error at +/- 9.3% for the aggregate NRW volume, demonstrating an improved confidence in the metrics from Phase 4 to Phase 5b.

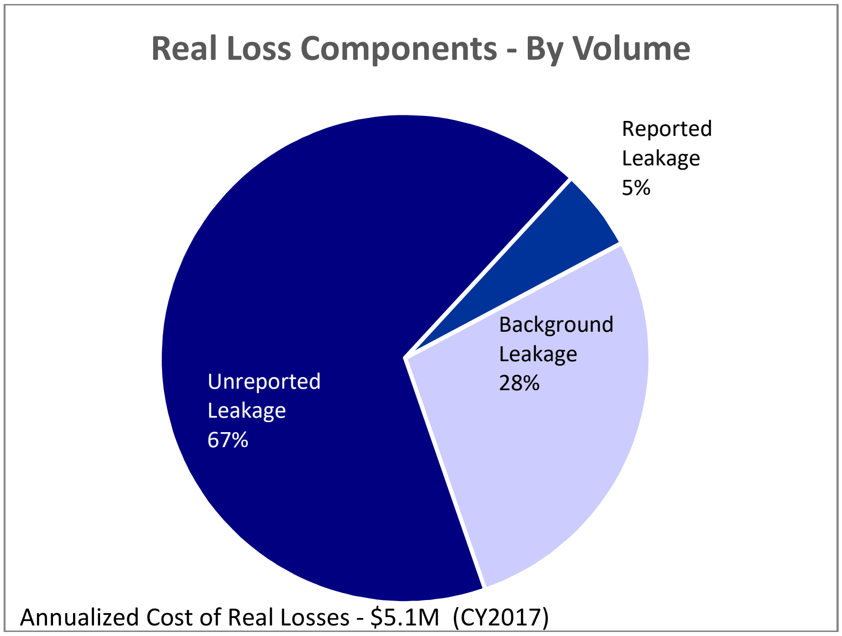
	Best Estimate	95% Confidence Interval	Std. Deviation	Variance
Basin				
Unbilled Metered	207.513	4.9%	5.1	26
Unbilled Unmetered	1,425.021	21.7%	154.7	23,931
Unauthorized Consumption	198.352	26.3%	26.1	679
Meter Inaccuracies - Large	451.000	6.0%	13.5	182
Meter Inaccuracies - Small	667.206	7.8%	26.0	674
Data Handling	155.906	25.9%	20.2	406
Background Leakage	3,823.257	4.8%	91.0	8,286
Unreported Leakage	9,337.156	16.5%	771.2	594,793
Reported Leakage	746.253	8.0%	29.9	896
Unbilled Metered - $	$69,343	4.1%	1419.8	2,015,962
Unbilled Unmetered - $	$604,440	25.0%	75420.1	5,688,190,059
Unauthorized Consumption - $	$1,465,201	31.2%	228318.1	52,129,170,852
Meter Inaccuracies - Large - $	$3,118,109	7.2%	111585.4	12,451,305,882
Meter Inaccuracies - Small - $	$5,263,911	8.7%	229315.3	52,585,505,885
Data Handling - $	$1,139,936	30.8%	175784.6	30,900,211,809
Background Leakage - $	$1,526,982	3.5%	26856.5	721,274,078
Unreported Leakage - $	$3,288,201	10.9%	178738.5	31,947,444,513
Reported Leakage - $	$302,825	7.9%	12024.3	144,583,218
Unbilled Authorized Consumption	1,632.534	19.0%	154.8	23,956
Apparent Losses	1,472.465	6.0%	44.1	1,941
Real Losses	13,906.667	11.2%	777.2	603,975
Unbilled Authorized Consumption - $	$673,783	22.4%	75433.5	5,690,206,022
Apparent Losses - $	$10,987,156	7.0%	384793.7	148,066,194,428
Real Losses - $	$5,118,007	7.1%	181144.4	32,813,301,808
NRW - MG	17,011.666	9.3%	793.6	629,872
NRW - $	$16,778,946	5.1%	431937.2	186,569,702,258

Figure 2 – 95% Confidence Analysis – Aggregate CWWMG (CY2017)

Aggregate CWWMG Results:

Real Loss Components

For the overall CWWMG, the top-down audits revealed an aggregate of 13,907 MG of real losses (leakage). A real loss component analysis was conducted for each system to determine the volume for each of the three components of leakage. The results of this are summarized below. It should be noted that there were two utilities in which the combination of the background leakage and reported leakage was greater than the total top down real loss volume, thus resulting in negative unreported/hidden leakage. These volumes were shown as zero in the analysis.



	Volume (MG)	Value* ($)
Background Leakage	3,823.257	$1,526,981
Unreported Leakage	9,337.156	$3,288,200
Reported Leakage	746.253	$302,824
Total Real Loss	13,906.667	$5,118,007

Figure 3 – Real Loss Component Analysis Breakdown – Aggregate CWWMG (CY2017)

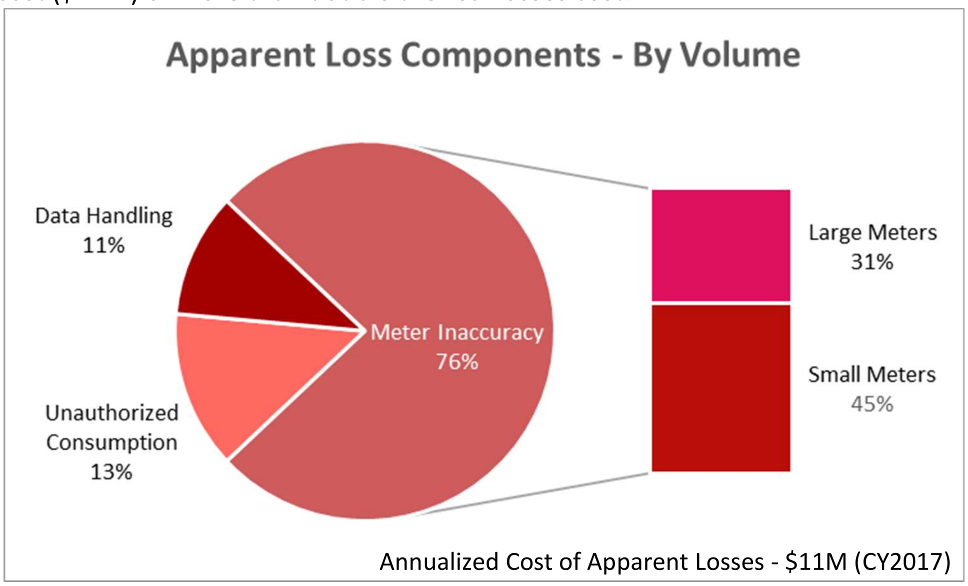
*Values shown are derived from Primary VPC factors only and represent the direct operational cost impacts of leakage. Secondary VPC factors which include the long-term capital impacts of leakage were not available for assessment and inclusion in the costs presented.

The annualized cost of real losses is approximately $5.1M, with the unreported leakage equating to $3.3M. For CY2017, no active leak detection canvassing was performed by any of the utilities, indicating the entire volume of unreported leakage is potentially available for recovery.

Apparent Loss Components

For both Unauthorized Consumption and Systematic Data Handling Errors, the default values provided by the M36 methodology were included for all utilities. For Customer Metering Inaccuracies, most of the inputs were estimated. Most were inferred from limited reactive testing, specifically on small meters. Where applicable, actual test results were used in the calculation of the inputs. For the purposes of this evaluation, residential volume was assumed to have been recorded by small meters and non-residential volume by large meters.

While much smaller than the real losses volume, the 1,472 million gallons of apparent losses have an annualized cost ($11M) of more than double the real losses cost.



	Volume (MG)	Values ($)
Unauthorized Consumption	198.352	$1,465,200
Meter Inaccuracy (Large)	451.000	$3,118,109
Meter Inaccuracy (Small)	667.206	$5,263,911
Data Handling Errors	155.906	$1,139,936
Total Apparent Loss	1,472.465	$10,987,156

Figure 4 – Apparent Loss Component Analysis Breakdown – Aggregate CWWMG (CY2017)

The following charts show all Non-Revenue Water Components and Subcomponents broken down by volume and by value for the aggregate CWWMG water utility membership.

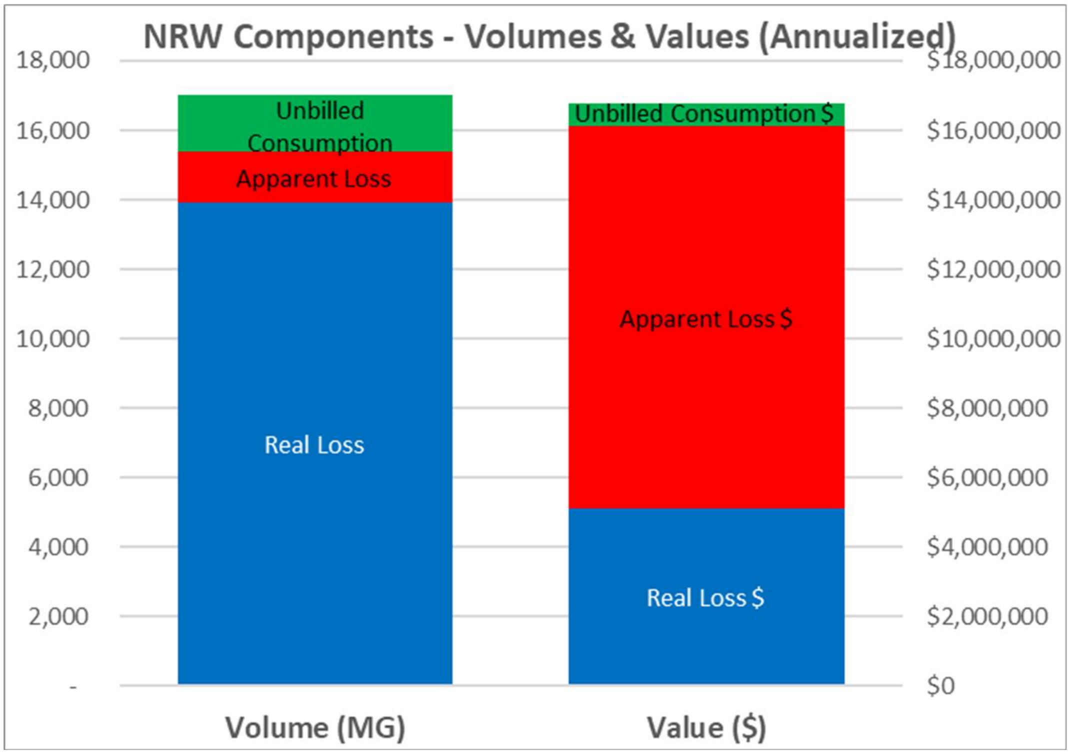


Figure 4 – Total Non-Revenue Water Volumes and Values by Component

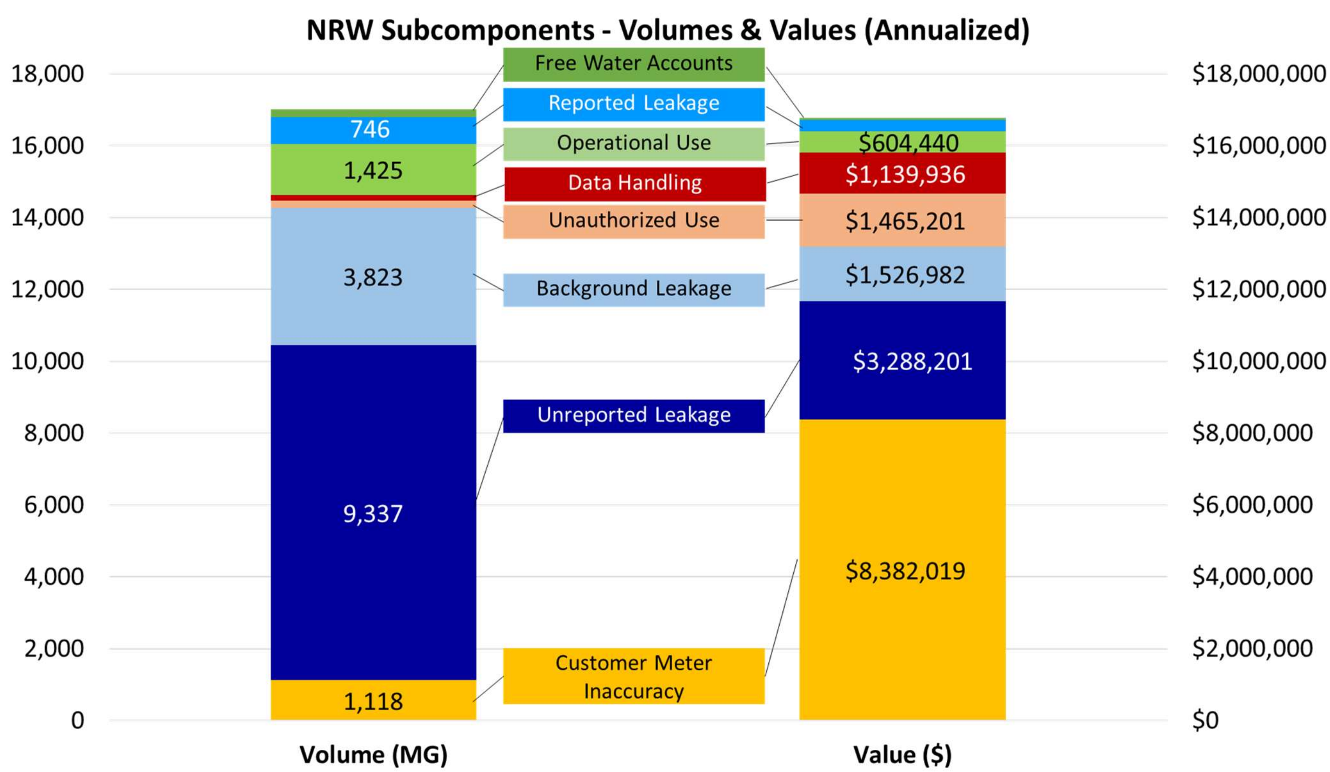


Figure 5 – Total Non-Revenue Water Volumes and Values by Sub-Component

AWWA M36 Standard Terminology

Data Validity

A measure of the reliability of the audit input data, and therefore the reliability of the audit output. Data Validity is quantified on a 1 – 100 scale.

Statistical Confidence Interval

An interval that will contain a population parameter a specified proportion of the time. The confidence interval can take any number of probabilities, with the most common being 95% or 99%. 95% confidence interval is referred to as 'margin of error' in this report.

Water Losses

The difference between water supplied and authorized consumption. Water loss consists of apparent loss plus real loss.

Apparent Losses

Losses in customer consumption and associated revenue occurring as customer metering inaccuracy, systematic data handling error and unauthorized consumption (theft). Apparent losses represent 'paper losses' or 'commercial losses' that result in uncaptured revenue for the water utility and distortion of customer consumption data. Apparent losses are valued at the retail rate.

Real Losses

Physical losses, largely leakage from the infrastructure: mains, valves, service lines, and tank overflows. Leakage occurrences are categorized as "reported" events, "unreported" events and background leakage. Real losses are often valued at the variable production rate, but may also be valued at the customer retail rate if the source water resources are greatly constrained, such that any water saved in leakage control could be sold to an expanding customer base.

Unbilled Consumption

Any authorized consumption occurring in the water system for which no bill is issued and no revenue collected. This includes unbilled metered consumption, such as municipal buildings, and also includes unbilled unmetered consumption, such as flushing and fire-suppression.

Non-Revenue Water (NRW)

NRW equals real loss plus apparent loss plus authorized unbilled consumption.

Unavoidable Annual Real Loss (UARL)

UARL is the lowest real loss technically achievable in a water utility based on its key characteristics. The derivation of the UARL calculation is based on leakage data gathered from well-maintained and well-managed systems. Equations for calculating UARL for individual systems were developed and tested by the International Water Association's Water Loss Task Force and published in 2000. The equations take into account measured frequencies, flow rates and durations of background losses, reported leaks and unreported leaks, as well as the pressure-leakage relationship (assumed to be linear for most large systems). Note: The UARL is strictly a reference value used in calculating performance indicators; it is not an actual component of leakage.

Infrastructure Leak Index (ILI)
The ratio of the CARL to the UARL. The ILI can be an effective performance indicator for comparing (benchmarking) the performance of utilities in operational management of real losses, once all justifiable pressure management measures have been undertaken. If rigorous leakage control existed such that the CARL was equal to the UARL, the ILI would then equal a value of “1”. However, such low leakage levels are rarely possible or economically justified for most water utilities. An ILI value less than “1” is highly unlikely and typically indicative of embedded data inaccuracies in the water audit.