# Water Audits in the United States: A Review of Water Losses and Data Validity

PDF Report #4372b

Subject Area: Infrastructure

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# Water Audits in the United States: A Review of Water Losses and Data Validity

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# FOREWORD

The Water Research Foundation (Foundation) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help drinking water utilities respond to regulatory requirements and address high-priority concerns. The Foundation's research agenda is developed through a process of consultation with Foundation subscribers and other drinking water professionals. The Foundation's Board of Trustees and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. The Foundation sponsors research projects through the Focus Area, Emerging Opportunities, and Tailored Collaboration programs, as well as various joint research efforts with organizations such as the U.S. Environmental Protection Agency and the U.S. Bureau of Reclamation.

This publication is a result of a research project fully funded or funded in part by Foundation subscribers. The Foundation's subscription program provides a cost-effective and collaborative method for funding research in the public interest. The research investment that underpins this report will intrinsically increase in value as the findings are applied in communities throughout the world. Foundation research projects are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. The Foundation provides planning, management, and technical oversight and awards contracts to other institutions such as water utilities, universities, and engineering firms to conduct the research.

A broad spectrum of water supply issues is addressed by the Foundation's research agenda, including resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide a reliable supply of safe and affordable drinking water to consumers. The true benefits of the Foundation's research are realized when the results are implemented at the utility level. The Foundation's staff and Board of Trustees are pleased to offer this publication as a contribution toward that end.

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# EXECUTIVE SUMMARY

## OBJECTIVES

This Water Research Foundation project aimed to assess the adoption of American Water Works Association (AWWA) water audit methodology and evaluate the levels of distribution-system water loss occurring in five regions. To this end, the research team investigated the reporting frameworks of regions that track water loss and collected AWWA-methodology water audits from the California Urban Water Conservation Council (CUWCC), the Delaware River Basin Commission (DRBC), the Georgia Department of Natural Resources (GA DNR), the Tennessee Comptroller of the Treasury (TN COT), and the Texas Water Development Board (TWDB) to assemble a composite water audit data set. Audits submitted to these entities were completed by water utilities and capture distribution system performance.

Using both the results of the research into regional water loss reporting requirements and the composite data set, this report addresses the following questions:

- What are the reporting frameworks of states that track water loss?
- Is the data submitted in water audits reasonable?
- Has audit data quality changed with repeated auditing?
- Have reported water loss volumes and relevant metrics changed with repeated auditing?
- What trends in both water loss and cost figures can be observed in the composite data set?
- How is the quality of audit data affected by reporting requirements and validation?

The findings of this project are relevant to water utilities, regulatory and reporting entities, legislators considering reporting and validation programs, water efficiency and conservation groups, and water loss control industry professionals.

## BACKGROUND

As of the publication of this report, five regional entities in the United States require water loss reporting concordant with AWWA methodology. The CUWCC, DRBC, GA DNR, and TN COT collect water audits periodically using AWWA Free Water Audit Software. The TWDB also collects audits but uses a unique submission form that adheres to AWWA methodology. AWWA methodology is employed in order to avoid the term “unaccounted-for” water and instead promote the division of water losses into distinct volumes, as prescribed by AWWA manual *M36: Water Audits and Loss Control Programs*. The entities report that they collect water loss data to track improvements in efficiency, evaluate utility performance, and promote water loss control. Also, all five entities provide water utilities with training in audit methodology, to varying degrees. An additional three entities (the New Mexico Office of the State Engineer, the Washington Department of Health, and the Wisconsin Public Services Commission) collect some water loss information but do not fully employ AWWA methodology and/or administer comprehensive auditing programs.[1]

Most audits collected by the entities studied in this project are self-reported and have not been through a formal validation process. However, all Georgia audits were reviewed by a third party as part of the state reporting program. In this program, the data sources informing the water audit were examined to identify potential sources of inaccuracy and to grade data quality accordingly (see Chapter 3 for more information on levels of data validation). More rigorous audit validation is occasionally pursued by individual utilities in order to produce accurate audit results, but no entity currently has a higher-level validation program in place due to the financial and human resources necessary for such an effort.

Because most of the audits collected for this research have not been validated, the calculated regional and composite water loss statistics must necessarily be qualified as indicative of potential patterns but not exact values. Additionally, even validated audits have margins of error. Nonetheless, the regional and composite data sets still present an opportunity to examine the relationships between water auditing requirements, data validity, and water loss performance.

## RESEARCH METHODOLOGY

To evaluate the validity of water audit data and calculate water loss performance indicators, the research team collected a total of 4,575 AWWA-methodology water audits from five reporting entities, spanning a five-year period from 2010 to 2014 (see Table ES.1).

**Table ES.1 Counts of audits collected by regional entities**

| ENTITY | AUDITS COLLECTED | YEARS | TOOL |
|---|---|---|---|
| CUWCC | 300 | 2010-2012 | AWWA Software |
| DRBC | 517 | 2012-2013 | AWWA Software |
| GA DNR | 452 | 2012-2013 | AWWA Software |
| TN COT | 630 | 2010-2014 | AWWA Software |
| TWDB | 2,646 | 2010, 2013 | own form (AWWA methodology) |
| **TOTAL** | **4,575** | **AWWA-methodology audits** | |

Then, to accurately calculate the water loss statistics specific to each region and for the composite data set as a whole, the research team identified and removed unrealistic audits using the series of filters listed in Table ES.2. This "filtering" process reviewed the self-reported audit data validity on a high level; the rigor and individualized attention of level 1 audit validation was not applied. Audits passing the filtering process contributed to the calculation of median performance indicators.

[1] The Colorado Water Conservation Board (CWCB) began collecting water loss date in 2014 from retail water providers who sell 2,000 acre feet or more of water annually, as mandated by Colorado General Assembly HB10-1051 (Colorado Water Conservation Board 2014). Through a unique online data entry portal, the CWCB collects information about distribution system characteristics, water demand, conservation efforts, and water losses. However, the data are not necessarily pursuant to AWWA methodology. Because the program began in 2014 and is therefore outside the scope of this report, the CWCB reporting program will not be discussed further.

**Table ES.2 Filters used to exclude audits**

| | METRIC | CRITERIA FOR EXCLUSION |
|---|---|---|
| *volumetric* | Infrastructure Leakage Index | < 1.0 |
| | | > 20.0 |
| | Real Losses | < 0 (negative) |
| | cost of Non-Revenue Water | > 100% of system operating costs |
| | incomplete audit | key fields not filled out |
| *financial* | Customer Retail Cost | more than 2 orders of magnitude off of the data set's median |
| | Variable Production Cost | more than 2 orders of magnitude off of the data set's median |

Upon calculation, median performance indicators were examined for trends through time and between regions.

## RESULTS

Performance indicators calculated for the composite data set (the most recent audits from each of the five regions) are provided below in Table ES.3. In order to generate the median and average performance indicators, the composite data set was filtered for plausibility using the filters presented previously in Table ES.2. The number of audits passing the various filters and contributing to median and average performance indicators is given in Table ES.3.

Of note is the median Infrastructure Leakage Index (ILI) of 2.48, indicating that 50% of audits report water losses that exceed the technical minimum volume by a factor of at least 2.48. Additionally, the filtering process excluded 21.1% of the audits in the composite data set from the calculation of performance indicator statistics, indicating that more than 1 out of every 5 audits presents an implausible water loss scenario. This suggests that the data used to populate the excluded water audits may not be accurate.

**Table ES.3 Composite water audit data set median performance indicators**

| | PERFORMANCE INDICATOR | MEDIAN | AVERAGE | UNIT | *n* | FILTERS |
|---|---|---|---|---|---|---|
| *financial* | **customer retail unit cost** | **$4.67** | $8.33 | $ / 1,000 gallons | *1,545* | passes customer retail unit cost check |
| | **variable production cost** | **$950.00** | $2,085.28 | $ / million gallons | *1,489* | passes variable production cost check |
| | **NRW as % of operating cost** | **7.8%** | 10.2% | % of operating cost | *630* | passes both cost checks<br>passes volumetric validity checks<br>does not come from Texas (operating cost not reported) |
| *operational* | **Apparent Losses** | **5.73** | 14.88 | gallons / serv conn / day | *1,290* | passes volumetric validity checks |
| | **Real Losses (serv conn)** | **39.88** | 51.81 | gallons / serv conn / day | *812* | passes volumetric validity check<br>service connection density ≥ 32 conn / mile of main |
| | **Real Losses (mains)** | **785.54** | 1,132.42 | gallons / mile of main / day | *478* | passes volumetric validity checks<br>service connection density < 32 conn / mile of main |
| | **Real Losses (pressure)** | **0.59** | 0.79 | gallons / serv conn / day / PSI | *812* | passes volumetric validity checks<br>service connection density ≥ 32 conn / mile of main |
| | **ILI** | **2.48** | 3.12 | *(dimensionless)* | *644* | passes basic volumetric validity checks<br>UARL calculation applies – (32 x $Lm$) + $Nc \geq$ 3,000 |
| | **data validity score** | **73.1** | 71.7 | points out of 100 | *679* | passes basic volumetric validity checks<br>does not come from Texas |

Other notable findings are presented below.

- In all of the regional data sets reviewed, audits were excluded from further analysis due to implausible data. Table ES.4 presents the total number and percentage of audits excluded from each region's data set. Georgia and Tennessee — the regions with the highest levels of training to support reporting requirements — have the fewest excluded audits.

**Table ES.4 Excluded audits by region for all audits to date**

| ENTITY | CA | DRBC | GA | TN | TX |
|---|---|---|---|---|---|
| Total Audits Submitted | 300 | 517 | 452 | 629 | 5,646 |
| # of Audits Excluded | 100 | 130 | 74 | 122 | 1065 |
| *% Of Excluded Audits* | *33%* | *25%* | *16%* | *19%* | *40%* |

- Utilities whose audit results were not plausible tended to grade their data validity notably higher than utilities that submitted audits with realistic data. Audits excluded from the calculation of summary statistics for reporting unreasonable results had a median self-reported data validity score of 77.1, whereas audits included in the calculation of summary statistics had a median self-reported data validity score of 73.1. Additionally, the lowest data validity scores are seen in Georgia, where the most rigorous data validation is pursued. These findings indicate that utility self-scoring of data validity does not actually capture true data validity. As a result, third-party validation of audit data tends to produce lower (but more accurate) data validity scores.
- All regional data sets show an increasing Real Losses per service connection per day over time. Given the changing level of accuracy and consistency with which these audits are completed, the research team cannot confirm that this trend in the data absolutely reflects an increasing volume of Real Losses. It is possible it also reflects more accurate reporting over time.
- Examining correlations in the composite data set revealed a number of valuable findings:
    - Systems with the highest variable production cost tend to have the lowest levels of normalized Real Losses.
    - Real Losses increase as average operating pressure increases.
    - No significant relationships were found in comparing Real Losses with customer retail cost or Real Losses with system size.

## CONCLUSION AND RECOMMENDATIONS

An impressive number of utilities are assessing and reporting their water losses in partnership with regional entities. As the first step in developing a water loss control strategy, the growing adoption of the AWWA Free Water Audit Software signals increased attention being paid to supply-side efficiency in water management. Additionally, the use of AWWA methodology to quantify distinct water loss volumes instead of the obsolete "unaccounted-for" water volume is essential for devising targeted and effective water loss reduction programs. However, in order for water audits to inform water loss control programs, they must accurately represent the types and magnitudes of water loss occurring in a system. This research project suggests that many audits do not reflect the actual water losses of reporting utilities, evidenced by the high number of audits (21%) that do not pass basic checks of plausibility.

In reviewing the largest compilation of AWWA Software and AWWA-methodology audits to date, it is clear that more training and education is needed to improve confidence in regional water loss reporting. Additionally, more rigorous audit validation will be required to produce audits that truly capture reality. Currently, the only region to require audit validation is Georgia, where all audits are subject to level 1 validation (see "Levels of Data Validation" in Chapter 3 for definitions of level 1, level 2, and level 3 validation efforts). The Georgia data set produced the fewest unrealistic audits, thereby providing evidence that third-party audit validation improves audit quality. More rigorous validation at levels 2 and 3 could further improve audit quality and perhaps even eliminate all unreasonable audits.

Until the number of implausible audits decreases, it will be difficult to discuss typical levels of water loss without qualification of the accuracy of the data set. In the meantime, this study highlights general but noteworthy trends, such as the connections between Real Losses and pressure and the relationship between Real Losses and production cost. The research team is optimistic that as the reliability of regional data sets improves, more insight into appropriate and effective water loss control programs will surface.

# CHAPTER 1: INTRODUCTION

For Water Research Foundation Project #4372 Part A: *Real Loss Component Analysis – A Tool for Economic Water Loss Control*, the research team developed a software tool ("the Model") to advance utilities' understanding of the types of leakage in their systems. To inform the development of the Model, the research team studied AWWA Free Water Audit Software ("AWWA Software"), the most widely-adopted software tool used to assess water losses. This report, Water Research Foundation Project #4372 Part B, is an extension of that study.

Here, the research team examines the adoption of AWWA Software and methodology in select regions. Recent water audit data sets were collected from regional entities that track the water losses of their member water utilities. Audits submitted to the entities were completed by water utilities and capture distribution system performance. The data sets were individually considered by regional entity, and a "composite data set" of the most recent water audits was compiled. The composite data set is the largest group of AWWA Software and AWWA-methodology water loss audits reviewed and analyzed to date.

The entities whose audit data sets are studied in this report employ a range of educational and outreach programs and structured validation in supporting their water loss reporting requirements. Only the State of Georgia requires comprehensive data validation, considered level 1 validation. The AWWA Water Audit Data Initiative (WADI) validates a small set of utility audits every year but was not included in this study due to the fact that WADI audits are not submitted to a state or regional entity.

The research team tackled two main areas of investigation: the quality of the AWWA-methodology water audits and the levels of water loss reported. Of course, these two areas of interest are linked, as the quality of audit data directly influences the calculation of water losses. The AWWA-methodology water audits examined here are largely self-reported and feature some level of inaccuracy. Therefore, it is important to stress that all discussion of water loss levels in this report must be qualified by uncertainty.

Acknowledging the imperfect nature of the AWWA-methodology water audits collected, the research team posits that the composite data set still presents interesting patterns and findings. This report aims to address the following questions:

- What are the reporting frameworks of states that track water loss?
- Is the data submitted in water audits reasonable?
- Has audit data quality changed with repeated auditing?
- Have reported water loss volumes and relevant metrics changed with repeated auditing?
- What trends in both water loss and cost figures can be observed in the composite data set?
- How is the quality of audit data affected by reporting requirements and validation?

In Chapter 2, the AWWA Software is introduced and the regulatory requirements for each regional entity are examined. Chapter 3 presents the methodology used to filter and analyze data sets. Chapter 4 presents each region's data set separately, and Chapter 5 presents the composite data set. The research team presents the water loss data collected to highlight both the successful adoption of the AWWA Software and auditing methodology and the remaining challenges in attaining reliable, insightful water loss reporting.

# CHAPTER 2: WATER LOSS REPORTING GUIDELINES

## INTRODUCTION

Throughout the country, some state and regional water utility regulatory bodies require water loss reports from member utilities. These reporting programs aim to evaluate regional water loss, encourage utilities to proactively pursue water loss control, and defensibly allocate financial and educational resources. Water loss reporting requirements vary from stand-alone reported water loss totals to annual submission of complete American Water Works Association (AWWA) audits. This chapter describes the primary tool available to utilities to comply with reporting requirements and the reporting frameworks of eight entities that collect water loss reports.

## WATER LOSS REPORTING TOOL

Most entities included in this report require audit submissions using the free Water Audit Software published by AWWA. As the most prevalent reporting tool, the AWWA Software is described in detail below. However, a handful of entities have their own water balance reporting forms. Entity-specific forms often use AWWA terminology and definitions in their reporting framework, although this is not always the case.

### AWWA Free Water Audit Software

The AWWA Free Water Audit Software was developed by the AWWA Water Loss Control Committee (WLCC) and features ten worksheets in a Microsoft Excel spreadsheet file. The most recent iteration of AWWA Software is version 5.0. However, most audits included in this data set were submitted using version 4.2, the version that was current at the time that the water audits were prepared and submitted to the state entity.

The AWWA Software prompts the user to enter water balance volumes (e.g. Volume Supplied from Own Sources, Billed Metered Authorized Consumption, Customer Metering Inaccuracies, etc.) and choose a unit of volume from a short list of options. Recognizing that some utilities do not tabulate all of the data necessary to complete a water balance, the software permits the user to supply either measured or estimated volumes. For certain volumes (for example, Unauthorized Consumption) estimates can be calculated using software-supplied default percentages, if desired. Additionally, the quality of each data input must be graded for validity on a scale of 1 to 10, and guidelines are provided for assigning validity scores.

Once all data entry fields are populated, the software calculates a series of performance indicators, identifies three volumes for priority attention to improve audit accuracy, and produces an IWA/AWWA water balance. AWWA's current standard water balance is provided below in Figure 2.1. Please note that while the water balance lists sources of Real Loss – leakage on mains, leakage and overflows at storage tanks, and leakage on service connections (italicized in Figure 2.1) – AWWA Software does not calculate these Real Loss component volumes.

For Real Losses to be broken down further, a utility must complete a component analysis of Real Losses, also known as a "bottom-up" approach to Real Loss quantification. The research team developed a tool to pursue a component analysis of Real Losses in WRF #4372 Part A, which is fully detailed in the report titled *Real Loss Component Analysis: A Tool for Economic Water Loss Control*.

<table>
<tr><td rowspan="8">Volume from Own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported (corrected for known errors)</td><td colspan="3">Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Water Imported (corrected for known errors)</td><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the point of Customer Metering</td></tr>
</table>

*Source*: AWWA 2016.

**Figure 2.1 Standard AWWA water balance**

AWWA Software is available for free online, uses standardized IWA/AWWA terminology, can be quickly compiled using Microsoft Excel-based software for the creation of an audit database, and comes with many tutorials and online resources to promote accessibility and utility.

## REGIONAL WATER LOSS REPORTING REQUIREMENTS

The research team identified eight entities that require some level of water loss reporting.[2] The California Urban Water Conservation Council, the Delaware River Basin Commission, the Georgia Department of Natural Resources, the New Mexico Office of the State Engineer; and the Tennessee Comptroller of the Treasury require submission using AWWA Software. The Texas Water Development Board uses AWWA terminology and water balance methodology but has its own specific form. The Washington State Department of Health and the Wisconsin Public Services Commission each have unique reporting forms derived from AWWA methodology but are less rigorous in the amount of data they require and the data validity information they collect. The entities responsible for collecting audits and basic audit program information are supplied in Table 2.1. The following sections describe each of the entities' mandates, reporting framework, and training programs in more detail.

[2] The Colorado Water Conservation Board (CWCB) began collecting water loss data in 2014 from retail water providers who sell 2,000 acre feet or more of water annually, as mandated by Colorado General Assembly HB10-1051 (Colorado Water Conservation Board 2014). Through a unique online data entry portal, CWCB collects information about distribution system characteristics, water demand, conservation efforts, and water losses. However, the data are not necessarily pursuant to AWWA methodology. Because the program began in 2014 and is therefore outside the scope of this report, the CWCB reporting program will not be discussed further.

**Table 2.1 Summary of regional water loss reporting requirements and frequency**

| ENTITY | TOOL | PARTICIPATION | FREQUENCY | START | LEVEL OF VALIDATION |
|---|---|---|---|---|---|
| **California Urban Water Conservation Council** | AWWA Software | all signatories | two years of data submitted every two years | 2010 | self-reported |
| **Delaware River Basin Commission** | AWWA Software | all utilities | annual | 2012 | self-reported |
| **Georgia Department of Natural Resources** | AWWA Software | utilities serving a population greater than 3,300 | annual | 2012 | level 1 |
| **New Mexico Office of the State Engineer** | AWWA Software | permit applicants | variable | 2005 | self-reported |
| **Tennessee Office of the Comptroller** | AWWA Software | all utilities | annual | 2013 | self-reported |
| **Texas Water Development Board** | own form | all utilities | annual to every five years | 2005 | self-reported |
| **Washington State Department of Health** | own form | all utilities | annual | 2007 | self-reported |
| **Wisconsin Public Services Commission** | own form | all utilities | annual | 1997 | self-reported |

## California Urban Water Conservation Council

The California Urban Water Conservation Council (CUWCC) is a membership organization that brings together urban water utilities, public interest organizations, governmental bodies, and private entities to promote urban water efficiency in California. The CUWCC is committed to integrating technology, effective public policy, research, and education to improve the management of California's water resources. To this end, the CUWCC has outlined water efficiency goals in a Memorandum of Understanding (MOU). Currently the CUWCC has more than 400 members, of which 250 are utility signatories of the MOU (California Urban Water Conservation Council 2015).

The MOU, first adopted in 1991, contains 14 Best Management Practices (BMPs) organized into 5 categories. MOU signatories commit to implementing the BMPs voluntarily. As a result, the CUWCC does not penalize noncompliant utilities. BMPs categorized as "Utility Operations" or "Education" are considered "foundational" and are therefore expected to be implemented on an ongoing basis (California Urban Water Conservation Council 2008). Among these foundational BMPs is BMP 1.2: Water Loss Control. BMP 1.2, as revised in September of 2009, outlines the requirements of a water loss control program and provides a 10-year implementation schedule. The first half of the 10-year program focuses on data validation and water loss accounting. The second phase of the program establishes water loss benchmarks and assists utilities in achieving water loss reduction goals (California Urban Water Conservation Council 2009).

Annual submission of a water audit using AWWA Software is mandatory under BMP 1.2. This requirement and other tenets of BMP 1.2 are described in Table 2.2 below.

**Table 2.2 CUWCC implementation framework for BMP 1.2**

| PROGRAM COMPONENT | DESCRIPTION | FREQUENCY/ TIMING |
|---|---|---|
| standard water audit & water balance | Complete AWWA Software to quantify the volumes and costs of Real and Apparent Losses. | Annually |
| validation | Follow AWWA methods to improve the validity of the data used for water balance to achieve an AWWA data validity score of 66 and later satisfy data validity Level IV (data validity score of 71). By the 2nd year of implementation, test all source import and production meters annually. | 4 years allotted for attainment of a data validity score of 66; by 5th year, Level IV |
| economic values | Determine the economic value of Real Loss recovery, using the guidelines outlined in the Council's Avoided Cost Model. | Annually |
| component analysis | Conduct a component analysis to break Real Losses down into volumes categorized by cause. | At least once every 4 years |
| interventions | Reduce Real Losses to the extent cost-effective, repairing all reported and unreported leaks as dictated by economic analysis. By the second year of implementation, maintain a record-keeping system for repair of reported leaks. | Continuous |
| customer leaks | Alert and advise customers when leaks appear on customer's side of the meter. | Continuous |

*Source:* Adapted from California Urban Water Conservation Council 2008

Utilities signing the MOU prior to December 31, 2008 were required to submit their first BMP 1.2 report by December 1, 2010 for years 2008-2009 and 2009-2010. Utilities signing the MOU after December 31, 2008 are required to implement BMP 1.2 by July 1st of the year following signing and report on the first report period after implementation (California Urban Water Conservation Council 2008).

As BMP 1.2 was implemented and new utilities became signatories of the MOU, the CUWCC provided eleven two-day workshops for member utilities between July of 2009 and April of 2011. Additionally, a three-hour webinar workshop was offered in November of 2012. The workshops were designed to train signatories on AWWA methodology and Water Audit Software, data validation, and CUWCC reporting requirements. Additionally, the CUWCC has a three-hour workshop recording available to stream to help utilities meet BMP 1.2 requirements.

### Delaware River Basin Commission

The Delaware River Basin Commission (DRBC), established in 1961, manages the Delaware River Basin, which covers parts of New York, Pennsylvania, New Jersey, and Delaware. The Commission is tasked with equitably allocating water supply, protecting water quality, managing droughts and floods, and protecting environmental interests Delaware River Basin Commission 2015).

Prior to 2009, the DRBC required reporting on annual volumes of "unaccounted-for water." However, these volumes were not informative or reliable enough to serve as effective planning or regulatory tools. To improve the quality of information available to both utilities and regulators, the DRBC revised its Comprehensive Plan and Water Code in 2009. The revision required the "owners of water supply systems serving the public with sources or service areas located in the Delaware River Basin [to] implement an annual calendar year water audit program," starting in 2012 (Delaware River Basin Commission 2013). From 2009 to 2011, submission of water audits was voluntary but encouraged. The audit requirement applies to suppliers who have been approved to withdraw greater than an average of 100,000 gallons per day of water in any 30-day period (Alliance for Water Efficiency 2014). All audits are to comply with AWWA Water Audit Methodology as a best management practice in water loss control.

The first round of audits were submitted in March of 2013. In preparation for the first round of submissions, the DRBC conducted several outreach efforts. The commission offered a full-day training and workshop to prepare utilities for the water auditing process and familiarize users with AWWA terminology and methodology (Sayers 2012). Additionally, the DRBC published guides to its requirements and AWWA audit procedure on its website, including proceedings of the training workshops and a list of frequently-asked questions.

### Georgia Department of Natural Resources

In 2010, the Georgia Senate enacted the Georgia Water Stewardship Act (GWSA) to encourage a culture of water conservation throughout the state (Kiepper and Evans 2011). One key component of the GWSA was to require public water providers to complete annual AWWA water audits. The state emphasized the need for minimum standards and best practices in monitoring and improving the efficiency of public water systems and the effectiveness of water conservation. The state highlighted water audits and incremental implementation of water loss abatement programs.

The Environmental Protection Division (EPD) of the Department of Natural Resources (DNR) was tasked with collecting audits, employing a categorization system for utilities by size and service population, and developing a technical assistance program to provide guidance (Georgia Senate 2010). In order to stagger initial audit submissions, the GWSA required the first round of submissions from systems serving more than 10,000 individuals in March, 2012. In March of 2013, systems serving between 3,300 and 10,000 individuals submitted their first audits.

To aid utilities in fulfilling audit requirements, the EPD partnered with the Georgia Environmental Finance Authority (GEFA) and the Georgia Association of Water Professionals (GAWP) to develop a technical assistance manual. In addition, the GAWP sponsored five full-day training sessions in 2011 for large water systems (before the first round of submissions) to provide training in audit methodology and AWWA Software. The following year, the Georgia Rural Water Association (GRWA) provided a similar training for smaller water systems prior to their first audit. This training was offered six times for a full day each time.

In order to ensure that audits submitted to the EPD were not only complete but also reasonable and insightful, Georgia chose to conduct third-party independent audit validation. Consultants versed in AWWA water audit methodology interviewed utility auditors to assess the accuracy of data validity grading assignments. Any audits identified as incorrectly-graded were returned to their respective utilities for revision and resubmission (Alliance for Water Efficiency 2014). As a result of this third-party review process, the research team describes Georgia audits as level 1 validated, according the definitions of data validity review provided in the section titled "Levels of Data Validation" (Chapter 3).

Survey feedback provided to the EPD suggests that the implementation schedule and AWWA Software posed challenges for some Georgia water utilities. To maximize participant success, submission deadline extensions and technical support were provided whenever necessary. Additionally, training workshops and continued technical assistance were provided in anticipation of 2014 submissions (Georgia Association of Water Professionals 2014).

### New Mexico Office of the State Engineer

The New Mexico Office of the State Engineer (NMOSE) has not established a state-wide program for water loss accounting but has implemented AWWA methodology to assess Real Losses, revenue losses, and conservation potential. While the NMOSE does not have a legal mandate requiring submissions, the NMOSE affirms that water loss accounting is a growing state focus. In its *water Conservation Planning Guide for Public Water Suppliers – Technical Report 53* (TR 53), the NMOSE encourages water suppliers to evaluate the efficiency of their systems using AWWA Software (Office of the State Engineer 2013).

Furthermore, the NMOSE considers water loss performance when evaluating a utility's new water appropriation application, change-of-place application, or purpose-of-use application. Application approval is generally conditional on submission of an AWWA audit within one year (Vogel 2012). Additionally, in order to qualify for 2015 Water Trust Board (WTB) funding, applicants diverting more than 500 AF per year were required to submit a conservation plan prepared in accordance with TR 53 and therefore complete an AWWA audit.

As a result of these application procedures and WTB requirements the NMOSE has received twenty-one AWWA audits and is currently working with other utilities on water conservation and AWWA Software use. However, the NMOSE has not yet provided training services on AWWA methodology to utilities.

### Tennessee Comptroller of the Treasury

In 2007, the General Assembly of the State of Tennessee passed House Bill No. 743 containing Public Chapter No. 243 to assure "the provision and preservation of adequate water" (General Assembly of the State of Tennessee 2007). The legislation required that public water systems submit an annual unaccounted-for water loss percentage and the calculation steps leading to the volume. Unaccounted-for water percentages were then subject to review by the Comptroller of the Treasury (COT), and any utilities exceeding a threshold deemed "excessive" were referred to the Utility Management Review Board (UMRB) or the Water and Wastewater Financing Board (WWFB). The initial threshold for excessive water loss was 35%, calculated according to the manner prescribed by the COT. Utilities with excessive unaccounted-for water percentages could be subject to legal action requiring water loss reduction or the removal of commissioners from office.

That same year, the Tennessee Association of Utility Districts (TAUD) recommended the standardized use of AWWA water audit methodology. Shortly thereafter, the UMRB and the WWFB chose to adopt the AWWA audit method for financial reports. The UMRB and the WWFB also assumed responsibility for defining the threshold for "excessive" water loss and the appropriate methodology for quantifying water loss (Leauber 2011). When AWWA methodology requirements went into effect in 2013, the evaluated performance indicator became Non-Revenue Water (NRW) as a percent of operating cost (Alliance for Water Efficiency 2014).

In 2012, the WWFB and the UMRB approved an order requiring utilities to achieve both a certain minimum data validity score and NRW as a percent of operating cost below an identified threshold. The specific scores and thresholds become more stringent as utilities learn audit procedure, as outlined in Table 2.3 below. Any utility that does not meet the standards is required to submit a plan for improvement, while utilities who do not comply with submission requirements will be referred to the appropriate board (Comptroller of the Treasury 2015). Additionally, the term "unaccounted-for" water was removed from relevant legislation and replaced instead with more precise definitions of water loss.

**Table 2.3 Tennessee reporting thresholds requiring improvement plan submission**

| DATE EFFECTIVE | DATA VALIDITY SCORE | NRW AS % OF OPERATING COST |
|---|---|---|
| 1/1/2013 | 65 or lower | 30% or greater |
| 1/1/2015 | 70 or lower | 25% or greater |
| 1/1/2017 | 75 or lower | 20% or greater |
| 1/1/2019 | 80 or lower | 20% or greater |

TAUD has provided a series of trainings on how to perform an AWWA audit and comply with COT requirements (Alliance for Water Efficiency 2014). Additional trainings are planned during 2015.

### Texas Water Development Board

In 2003, the Texas Legislature enacted House Bill 3338 in order to conserve the state's water resources by quantifying and reducing utility water losses. Bill 3338 requires that retail public utilities file standardized water audits with the Texas Water Development Board (TWDB). Although the TWDB is not a regulatory agency, failure to comply with submission requirements results in barred access to TWDB funding. Initial submissions were scheduled to occur once every five years. In 2011, House Bill 3090 was passed to require utilities with an outstanding loan from the TWDB to submit audits annually. In 2013, House Bill 857 was passed to require utilities with more than 3,300 connections to submit audits annually.

In response to audit requirements, the TWDB developed an audit form soliciting data typically required for an internal, top-down water audit. Most of the data can be compiled from water consumption and water loss reports commonly completed by water utilities (Mathis et al. 2008). The first round of audits were collected in 2005 and found to contain suspect data. To improve the utility of the audits and acknowledge the possible range of data quality, the second iteration of the audit form required users to grade the validity of data inputs. The updated *Water Loss Audit Manual for Texas Utilities* (2008) provides guidance for assigning data validity scores ranging from 1 (low) to 5 (high). This rating scheme is similar to but not directly comparable to the data validity assignments in AWWA Software. The *Water Loss Audit Manual* also encourages all utilities to submit audits annually.

In addition to the *Water Loss Audit Manual*, the TWDB has developed online resources to instruct utilities on best management practices and AWWA methodology. The TWDB also offers staff consultation and an outreach program for water utilities.

### Washington State Department of Health

The Washington Administrative Code (WAC) 246-290-820 requires that all state water municipalities determine their distribution system leakage volume annually by submitting a System Input Volume and an Authorized Consumption Volume and then calculating the difference. In agreement with AWWA definitions, System Input Volume is defined as the sum of all metered water from both utility-owned sources and purchased water. Authorized Consumption is considered all metered customer use plus authorized unmetered uses. Additionally, the WAC requires that utilities achieve a distribution leakage percentage of less than 10%, calculated as a three-year running average (Washington State Legislature 2008).

The Department of Health (DOH) sponsors water loss reporting through an online submission form. Once every six years, water loss figures are calculated as part of comprehensive water system plans. If a utility fails to meet the 10% water loss standard, they must create and implement a water loss control strategy and reporting annual progress (Dexel 2012). While this reporting process and focus on utility accountability encourage water loss control, DOH methodology does not meet best practices as established by the IWA and AWWA, especially in the evaluation of data validity. However, the DOH permits the use of AWWA tools and procedures in complying with state requirements, as long as the distribution system leakage volume can be calculated in line with WAC instructions (Washington State Department of Health 2011).

To assist utilities in fulfilling reporting requirements, the DOH has conducted or contracted out training since 2007. Over 50 training events have been held, focusing on clear explanation of legal requirements and the importance of water loss accounting in utility operations. The DOH has also published a manual to its Water Use Efficiency regulations and uploaded supplemental literature to its website.

### Wisconsin Public Services Commission

The Wisconsin Public Service Commission (PSC) regulates 582 water utilities, including both municipal and investor-owned systems (Public Services Commission 2013). In 1997, the PSC updated its operating requirements to establish water loss standards and incorporated them into annual financial reporting requirements that every utility must meet. Systems losses, calculated as the difference between metered system input and metered authorized consumption, must be less than 25% of system losses for small systems (fewer than 14,000 customers) and less than 15% for mid-size and large systems (more than 14,000 customers). Additionally, all utilities are required to submit an annual water audit listing the following volumes (Public Services Commission 1997).

- Water purchased or pumped from all sources
- Water used in treatment or production processes
- Water entering the distribution system
- Water sold, including both metered and unmetered sales
- Water not sold but used for utility-authorized purposes, including flushing mains, fire protection, freeze prevention, and other authorized system uses
- Water loss
- Unknown or unaccounted-for water

While the PSC still tabulates "unaccounted-for" water volumes and therefore does not comply with AWWA best practices, much of the language in the Wisconsin State Administrative Code was updated in 2012 to reflect AWWA terminology. Utilities are now expected to calculate their percentages of NRW and water losses and implement a water loss control plan if NRW is greater than 30% of system input or if water losses exceed the aforementioned thresholds (Public Services Commission 1997). Nonetheless, utilities are not currently required to reflect on the validity of the data contributing to their reports and water loss figures. However, proposed Administrative Code changes, in the comment and review phase at the time of publication of this report, include a requirement that utilities submit a water audit using AWWA Software. For the 2015 reporting year, audit data submission through AWWA Software is optional.

The PSC has published a guide to water loss terminology and control on its website in addition to guidance filling out the state reporting form. Furthermore, PSC employees are available to answer any questions that may arise during the auditing and reporting process. While formal training sessions are not frequently offered, a pilot training program is scheduled for fall of 2015, with plans to expand the training in 2016 and subsequent years (Schmidt 2015).

## SUMMARY AND SYNTHESIS

The research team examined the auditing requirements of eight proactive entities that mandate some level of utility water loss reporting. Five of the eight entities employ AWWA Software; the other three entities have their own forms based to varying degrees on AWWA methodology. Six of the eight entities require annual audit submissions. The New Mexico Office of the State Engineer requires audit submissions as part of new project applications. The Texas

Water Development Board mandates submissions every five years. However, Texas systems with more than 3,300 service connections and systems with active financial engagements with the Board must submit audits every year. The entities studied herein report that they collect water loss data to track improvements in efficiency, evaluate utility performance, and promote water loss control.

For water audits to be useful in devising water loss control strategies, they must accurately represent the types and magnitudes of water loss occurring in a system. Because audits involve a process of repeated subtraction to reach final water loss volumes, the accuracy of each data input affects the ultimate calculation of water losses. As a result, the best practices promoted by the AWWA include a standardized data validity grading system to acknowledge sources of potential inaccuracy. Therefore, entities employing AWWA Software automatically collect data validity grades. However, the degree to which data validity is emphasized varies among the entities studied in this report. The Washington State Department of Health and the Wisconsin Public Services Commission do not allow for the quality of data inputs to be graded. In contrast, the Georgia Department of Natural Resources contracts with third-party consultants to externally verify the validity scores of audits through a phone-call interview process. Most entities discussed in this report provide some level of audit training to regulated utilities.

As they focused on water auditing requirements, most entities transitioned from collecting data about “unaccounted-for” water to a more precise approach that quantifies distinct water loss volumes. The five entities that employ AWWA Software collect Apparent Loss and Real Loss volumes. The Texas Water Development Board also requires the calculation of both Real Losses and Apparent Losses in its unique reporting form. The Washington State Department of Health, on the other hand, calculates a “distribution system leakage” volume that is composed of both Apparent Losses and Real Losses, and the Wisconsin Public Services Commission collects unaccounted-for water figures. While requiring utilities to track their water loss volumes annually can reveal general trends in water loss and prompt intervention, a detailed breakdown of Water Losses into component volumes is necessary for targeted and effective water loss reduction.

In evaluating utility performance with collected audit data, most entities use a version of water losses as a percent of input volume. This usually takes the form of Non-Revenue Water as a percent of System Input Volume or Non-Revenue Water as a percent of Operating Costs. Percent of Water that is “Unaccounted-for” is no longer considered a valid performance indicator by AWWA. While Non-Revenue Water as a Percent of System Input Volume is a standard performance indicator calculated by AWWA Software, there are other performance indicators that may serve as more reliable metrics of efficiency. Non-Revenue Water as a Percent of System Input Volume is unduly influenced by System Input Volume; if water losses are consistent year-to-year but System Input Volume changes, this performance indicator will also change. Therefore, the research team recommends that regional entities consider more resilient metrics like the Infrastructure Leakage Index and Real Losses per Service Connection per Day as better measures of system performance, particularly when designing strategies for leakage loss reduction and financing efficiency improvements.

A water audit describes the unique water loss profile of a utility. As a result, water audits can serve utilities and regulators alike by equipping each with the data necessary to inform water loss control efforts at the utility and state levels. Only by appreciating the types and magnitudes of water losses can utilities and their regulatory partners cost-effectively target the distinct forms of water loss. Each of the eight entities described above has recognized the value of water loss assessment by requiring audit completion and submission on a regular basis. Auditing programs can be improved by following AWWA standardized methodology, focusing on data validation as an essential audit component, increasing outreach and education efforts to improve the quality of water audits, and tracking data from year-to-year to identify trends and prioritize intervention.

# CHAPTER 3: RESEARCH METHODOLOGY

## INTRODUCTION

In order to discuss the accuracy of audit data sets and determine typical water loss performance, the research team defined levels of data validity, filtered data sets for implausible audits, and chose to describe the center of data sets with median values rather than averages. Each of these data handling considerations is described in detail below.

## LEVELS OF DATA VALIDATION

Audits are most useful when the water loss volumes they report capture reality. To this end, audit data is graded for validity. Each validity grading describes the accuracy of the estimation or data source. Beyond the basic data scoring required by AWWA Software, a more in-depth review of data validity is possible, ranging from a brief assessment of the technical plausibility of audit volumes to a thorough third-party review and testing of all contributing data sources. This report will employ the terms “self-reported,” “filtered,” “level 1 validated,” “level 2 validated,” and “level 3 validated” according to the definitions below.

- Self-reported audits have not been subject to in-depth review. The utility auditor has assigned a data validity grade to each data input based on his or her understanding of the reliability of the contributing data sources and the data validity assignment guidelines presented in AWWA Software.
- Filtered audits have been checked for technical plausibility by the research team based on simple, broad criteria below in the section titled “Data Filtering Steps.” Beyond a check on whether or not the audit presents a realistic scenario, the accuracy of contributing data sources has not been investigated. Filtered audits will be either included in or excluded from calculations based on their technical plausibility.

Third-party data validation improves data validity beyond self-reporting and simple filtering. Third-party validation can be performed at one of three levels depending on available time and resources, as described below. Definitions have been adapted from a working document prepared by the AWWA Water Loss Control Committee – Software Subcommittee (Water Loss Control Committee – Software Subcommittee 2015).

- Level 1 validated audits have been subject to third-party “desktop review” of data that is immediately available, like supply reports, consumption reports, and testing reports. Third-party validators have interviewed utility staff, usually in an hour-long phone call, in addition to spending time preparing for the interview and documenting results. Interview questions were focused on outlining organizational practices to make sure that data validity scores have been assigned correctly and consistently. Anomalies were discussed and either confirmed, corrected, or noted as needing further investigation.
- Level 2 validated audits have been third-party reviewed with a deeper “desktop” analysis. To inform the validation, utility data sources have been thoroughly recruited for analysis of non-revenue water components, and available data (including the production database and reports from the SCADA system) have been dissected to identify gaps or overlaps in

the data chain. The billing system has been investigated to confirm and clean consumption data, thereby removing redundancies, duplicates, and lag-time effects. In addition, third-party reviewers have verified the exclusion of non-potable volumes from the audit, and any available meter test results have been applied to volume calculations. Finally, 95% confidence limits have been calculated for all water balance volumes. However, no field testing has been performed to confirm instrument accuracy, and no new data has been gathered to inform analysis.

- Level 3 validated audits have been third-party reviewed using both "desktop analysis" (as described in level 2 validation) and field investigations. Supply meters have been tested for accuracy, and in-field verification of SCADA data chain transfer from instrument to transmitter to database system has been performed. Customer meters have been tested through representative and random sampling, pressure data has been collected and studied, and night-time flows have been recorded and analyzed for leakage.

## DATA FILTERING STEPS

In order to accurately calculate the water loss statistics specific to each region and for the composite data set as a whole, the research team identified and removed unrealistic audits using the series of filters listed in Table 3.1 and detailed below. This "filtering" process reviewed audit data validity beyond self-reporting but without the rigor of true audit validation. For definitions of the levels of audit data validation, please refer to the section titled "Levels of Data Validation" (Chapter 3).

**Table 3.1 Filters used to exclude audits**

| | METRIC | CRITERIA FOR EXCLUSION |
|---|---|---|
| *volumetric* | Infrastructure Leakage Index | < 1.0 |
| | | > 20.0 |
| | Real Losses | < 0 (negative) |
| | cost of Non-Revenue Water | > 100% of system operating costs |
| | incomplete audit | key fields not filled out |
| *financial* | Customer Retail Cost | more than 2 orders of magnitude off of the data set's median |
| | Variable Production Cost | more than 2 orders of magnitude off of the data set's median |

## Infrastructure Leakage Index (ILI)

The Infrastructure Leakage Index (ILI) is a dimensionless number used to compare leakage occurring in systems regardless of differences in size, infrastructure, or input volume. The ILI is calculated by dividing the Current Annual Real Loss (CARL) volume by the Unavoidable Annual Real Loss (UARL) volume to get a ratio. The UARL is the technical minimum level of leakage losses achievable for a system using all applicable water loss control best practices. The UARL is determined using an internationally-standardized formula that incorporates a variety of system-specific characteristics affecting Real Losses, including operating pressure, length of mains, and number of service connections. It is important to note that the UARL is only calculated when the number of service connections plus 32 times the length of main in the system is equal to or greater than 3,000 (AWWA 2009). Written mathematically, this requirement is:

$$(32 \times Lm) + Nc \geq 3{,}000$$

where

$Lm$ is the length of mains in miles
$Nc$ is the count of service connections

If a utility does not meet this threshold, the UARL and ILI are not calculated. If this is the case, these fields are completed with "N/A" in audit forms. Audits with incalculable ILIs are not automatically excluded from the composite data set.

An ILI of 1.0 indicates that the current losses are equal to the technical minimum. As such, an ILI less than 1.0 indicates that losses are below the technical minimum, which is implausible. Audits with an ILI of less than 1.0 most likely contain suspicious data inputs and as a result were not incorporated in data set summary statistics. However, some water utilities with excellent leakage management practices have questioned the derivation of the UARL formula and believe that with the UARL formulated as it currently is, an ILI value below 1.0 is achievable. Nonetheless, water utilities in North America with such highly sophisticated leakage management in place are extremely rare, and it has been found that the vast majority of water utilities reporting an ILI below 1.0 are found to have questionable data.

Additionally, audits with an ILI greater than 20.0 were eliminated because few, if any, systems in the United States lose more than 20 times their technical minimum.

### Negative Real Losses

It is possible that the ILI is not calculated for a utility (given the limitations of the ILI formula discussed above) but that utility's audit still reports negative Real Losses. Negative Real Losses are technically impossible.[3] Therefore, the research team excluded audits reporting negative Real Losses in the absence of ILI values.

### Non-Revenue Water

In AWWA water balance methodology, Non-Revenue Water (NRW) is the sum of Unbilled Authorized Consumption, Apparent Losses, and Real Losses (see Figure 3.1). NRW is all water supplied to a system that does not generate revenue. To calculate the volume of NRW, Billed Authorized Consumption is subtracted from Water Supplied.

[3] The AWWA Software includes a number of built-in checks, and one of these checks flags negative Real Losses and alerts the auditor by displaying a message asking the auditor to reassess their input data. It is curious that some auditors nonetheless submit an AWWA Software water audits with a negative Real Loss value, despite being alerted to this implausibility by the software.

<table>
<tr><td rowspan="8">Volume from Own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported (corrected for known errors)</td><td colspan="3">Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Water Imported (corrected for known errors)</td><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the point of Customer Metering</td></tr>
</table>

*Source*: AWWA 2016.

**Figure 3.1 Standard AWWA water balance, non-revenue water highlighted**

To determine the monetary value of NRW, component volumes are valued at either customer retail cost (in the case of Apparent Losses and Unbilled Authorized Consumption) or variable production cost (in the case of Real Losses). The values of these component volumes are then summed to calculate the value of NRW. Therefore, the accuracy of NRW valuation depends on reliable volume calculations in tandem with accurate entry of variable production cost and customer retail cost.

Comparing the value of NRW to system operating costs can serve as a measure of system efficiency. NRW Water as a Percent of System Operating Costs is a standard performance indicator calculated by AWWA Software. NRW as a Percent of System Operating Costs can vary from only a couple of percentage points to more than half of a system’s operating costs. However, NRW valued in excess of total operating costs (i.e. greater than 100%) indicates an invalid audit. Such a utility could not maintain financial solvency. As a result, audits reporting NRW as a Percent of System Operating Costs greater than 100% are excluded from the calculation of data set statistics.

## Incomplete Audits

Audits missing key fields – those fields used to calculate performance indicators – were excluded from data set summary statistics and the composite data set as a whole.[4]

[4] As is the case for negative Real Losses, AWWA Software includes a built-in check alerting the auditor when certain key data is not complete. The submittal of an incomplete water audit from an auditor using AWWA Software is therefore unusual.

### Cost Figures

In order to calculate financial performance indicators like NRW as a Percent of System Operating Costs, a utility must report a variable production cost and a customer retail unit cost. Incorrect calculation of either cost can skew financial performance indicators but will not affect volumetric performance indicators. Therefore, the audits of utilities reporting suspicious cost figures were excluded from calculation of average financial performance indicators but included in calculating average volumetric performance indicators. To identify errant cost figures, the research team first calculated the median variable production cost and median customer retail cost for each regional data set. The research team then identified audits whose reported cost figures were two orders of magnitude (i.e. 100 times) greater than or less than the median.

Errors in reported costs are often attributable to auditors incorrectly converting units. Most data in AWWA Software is inputted in units of million gallons (MG) or acre-feet (AF). However, customer retail cost must be reported either in units of dollars per thousand gallons ($/1000 gal) or dollars per one hundred cubic feet ($/CCF). In contrast, variable production cost is inputted in units of MG or AF. This change in units often prompts order-of-magnitude and conversion errors in cost reporting. The Texas Water Development Board has avoided this potential source of inaccuracy by requiring that *all* volumes and costs are reported only in units of gallons.

## PERFORMANCE INDICATORS

The International Water Association (IWA) and AWWA have developed a series of standardized performance indicators to evaluate utility water loss performance and identify areas for improvement. Performance indicators can be categorized as either financial or operational. Performance indicators can also be sorted by the amount of data required to calculate the indicator (the "level" of the indicator in Table 3.2). Key performance indicators and descriptions are presented in Table 3.2 on the following page. Data set medians of each of the performance indicators listed in Table 3.2 will be calculated for each region, where possible.

The research team has chosen to exclude Fi36 (NRW as a percent of Water Supplied), even though it is calculated by the current version of AWWA Software, because the AWWA WLCC has decided that this performance indicator is obsolete. Because NRW as a percent of Water Supplied is primarily influenced by the volume of Water Supplied, rather than the volume of NRW, comparisons between utilities and years using this performance indicator are not informative. The WLCC reports that in future versions of AWWA Software, this performance indicator will not be calculated.

Table 3.2 IWA/AWWA performance indicators

| INDICATOR | CODE | LEVEL | CALCULATION AND UNITS | DESCRIPTION |
|---|---|---|---|---|
| **Operational** | | | | |
| Apparent Losses (normalized) | Op23 | 1 – basic | gallons / service connection / day | Basic but meaningful performance indicator for Apparent Losses. Easy to calculate once Apparent Losses are quantified. |
| Real Losses (normalized) | Op24 | 1 – basic | gallons / service connection / day<br>(service connection density ≥ 32/mile of main)<br>*or*<br>gallons / mile of main / day<br>(service connection density < 32/mile of main) | Useful for target setting. Limited use for comparisons between systems. |
| Real Losses (normalized, including pressure) | Op24 | 2 - intermediate | gallons / service connection / day / pressure unit<br>*or*<br>gallons / mile of main / day / pressure unit | Useful for comparisons between systems operating at different average pressures. |
| Unavoidable Annual Real Losses | UARL | 3 – detailed | UARL (gallons) = (5.41Lm + 0.15 Nc + 7.5Lc) x P<br>*where*<br>Lm = length of mains (miles)<br>Nc = number of service connections<br>Lc = total length of customer service connection piping (miles)<br>P = average operating pressure (PSI) | A theoretical reference value representing the technical low limit of leakage that could be achieved if all of today's best technology were to be successfully applied. UARL is a key variable in calculating the ILI. The calculation for UARL is not valid for systems whose service connection count added to 32 times the length of main is less than 3000. |
| Infrastructure Leakage Index (ILI) | Op25 | 3 – detailed | dimensionless | Ratio of Real Losses volume to UARL. Best indicator for comparisons between systems. |
| **Financial**[5] | | | | |
| Non-Revenue Water (cost) | Fi37 | 3 – detailed | value of NRW as percent of system operating cost | Incorporates different unit costs for non-revenue components. Good financial indicator. In calculating the cost of NRW, Apparent Losses and Billed Unmetered volumes are usually valued at customer retail cost, while Real Losses are valued at variable production cost. |
| **Other** | | | | |
| Data validity | - | - | sum of all data validity scores, normalized to 100<br>ranges from 1 to 100 | Individual data entries are graded on a scale from 1 to 10 for validity, based on a scoring guide. Broadly indicates the reliability of the data entries. |

*Source*: adapted from AWWA 2015.

[5] The research team has chosen to exclude performance indicator Fi36 (NRW as a percent of Water Supplied) from this study because the AWWA WLCC has deemed this performance indicator uninformative and therefore obsolete.

## STATISTICAL INTERPRETATION

The majority of audits collected by the research team are self-reported. AWWA Software requires that data inputs are graded for validity using a standardized scale, but the data validity scores are also self-reported and subject to error. Additionally, scoring data validity does not actually correct errors. Instead, the process only acknowledges the potential for inaccuracy.

Since the accuracy of audits assessed in this study is unverifiable, the research team cannot comment on the performance of any single utility. However, compiled data sets can be analyzed for relative patterns, as the error from a single audit is diluted by the size of the data set. Of course, it must still be acknowledged that the data set is imperfect, and summary statistics are not conclusive or absolute. Instead, the values presented in this report, particularly those describing the center of each data set, are intended to demonstrate relationships between water loss metrics and the potential magnitude of water loss.

The research team employed a filtering process in order to eliminate clearly erroneous audits. The filtering process excludes audits based on implausible or technically impossible reported results. While this step improves the reliability of summary statistics, it also makes the comparison of multiple years in each state data set an imperfect process. Filtering can eliminate a specific water audit, but not necessarily all audits from that utility. Therefore, the utilities contributing to annual state data sets are different from year to year. However, the number of audits included year to year is approximately constant. Therefore, this report discusses the center of each data set (using statistics like medians and averages), rather than individual utilities, under the assumption that excluded audits fall equally above and below the center of the data set and so do not affect center values. While this assumption is not ideal, it permits the research team to qualify the results presented in this report and navigate the uncertainty of self-reported audits.

In order the measure the center of each data set, the research team used median values rather than averages. The median is defined as the midpoint of a frequency distribution where 50% of values fall below and 50% fall above. A median value therefore minimizes the skew that outlying data points might introduce to the average.

## NOTE ON COST FIGURES

In order to value Water Losses, AWWA Software requires submission of two unit cost figures:

- customer retail unit cost ($/1,000 gal or $/CCF): the charge that customers pay for water service, often calculated by dividing total potable water revenue by the number of units sold or by determining a weighted average cost using the customer rate structure. Customer retail unit cost should include additional charges for sewer, stormwater, and biosolids processing, but only if these charges are linked to the volume of potable water consumed.
- variable production cost ($/MG or $/AF): the cost to produce and distribute the next unit of water. This is usually composed of bulk water purchasing rates and the cost of water treatment and pumping. Variable production cost can also include other appropriate miscellaneous costs included in providing the next unit of water.

The calculation of cost figures is specific to each utility, as the customer rates and water production costs of each utility are unique. Currently, AWWA Software does not collect information on the expenses included in determining customer retail unit cost and variable production cost. Therefore, the research team cannot confirm that customer retail unit costs and variable production costs are directly comparable between utilities. However, the state of Georgia encourages utilities to exclude sewer, stormwater, and biosolids charges when calculating customer retail unit cost so that this cost can be compared from utility to utility and represents only the rates applied to potable water consumption.

While side-by-side consideration of cost figures may not be an “apples-to-apples” comparison, when cost figures are viewed as a valuation of Water Losses, comparison becomes more practical. Viewed this way, cost figures represent the financial boundaries and economic potential of water loss recovery, making comparison between audits and data sets a fruitful practice.

# CHAPTER 4: REGIONAL WATER AUDIT DATA SETS

## INTRODUCTION

To assemble regional water audit data sets and create a larger composite data set, the research team collected audits submitted over the past five years to the state entities that use the AWWA methodology. Audits from the California Urban Water Conservation Council, the Delaware River Basin Commission, the Georgia Department of Natural Resources, the Tennessee Comptroller of the Treasury, and the Texas Water Development Board were examined.

Counts of audits collected and years represented are presented below in Table 4.1. This data set will inform an assessment of water loss performance in each of these states or regions, with an understanding that the data set is primarily composed of self-reported and unscrutinized audits. Audits adhering to AWWA methodology will contribute to a calculation of national water loss statistics.

**Table 4.1 Count of audits collected by regional entities**

| ENTITY | AUDITS COLLECTED | YEARS | TOOL |
|---|---|---|---|
| CUWCC | 300 | 2010-2012 | AWWA Software |
| DRBC | 517 | 2012-2013 | AWWA Software |
| GA DNR | 452 | 2012-2013 | AWWA Software |
| TN COT | 630 | 2010-2014 | AWWA Software |
| TWDB | 2,646 | 2010, 2013 | own form (AWWA methodology) |
| **TOTAL** | **4,575** | **AWWA-methodology audits** | |

## WATER LOSS STATISTICS BY REGION

The following sections present the water loss statistics for each region by summarizing the count of audits submitted, the count of audits that passed the aforementioned data filtering tests, and the average water loss statistics of the filtered data set.

### California Urban Water Conservation Council

The research team received 300 audits from the CUWCC. The audits covered reporting periods from 2009 to 2013, with the majority of the audits reflecting 2010, 2011, and 2012 data. Counts of audits collected and filtered are presented below in Table 4.2.

**Table 4.2 Number of California (CUWCC) audits by year**

| YEAR | 2009 | 2010 | 2011 | 2012 | 2013 | ALL YEARS |
|---|---|---|---|---|---|---|
| **INCLUDED AUDITS** | 4 | 59 | 67 | 68 | 2 | 200 |
| **EXCLUDED AUDITS** | 2 | 21 | 36 | 41 | 0 | 100 |
| ***% EXCLUDED*** | *33%* | *26%* | *35%* | *38%* | *0%* | *33%* |
| **TOTAL AUDITS** | **6** | **80** | **103** | **109** | **2** | **300** |

Due to the low number of audits from 2009 and 2013, the research team focused exclusively on 2010, 2011, and 2012 in presenting water loss statistics for California. A summary of performance indicators for these years is provided in Table 4.3.

**Table 4.3 California (CUWCC) water loss statistics**

| | STATISTIC | 2010 (n = 59) median | 2011 (n = 67) median | 2012 (n = 68) median | UNIT |
|---|---|---|---|---|---|
| *financial* | customer retail unit cost | $3.38 | $3.52 | $3.70 | $ / 1,000 gallons |
| | variable production cost | $1,562.52 | $1,313.48 | $1,448.40 | $ / million gallons |
| | NRW as % of operating cost | 3.4% | 3.6% | 4.1% | % of operating cost |
| *operational* | Apparent Losses | 5.24 | 6.09 | 6.95 | gallons / serv conn / day |
| | Real Losses (service connections) | 35.40 | 35.68 | 36.57 | gallons / serv conn / day |
| | Real Losses (mains) | 11,532.72 | 4,538.43 | 3,979.32 | gallons / mile of main / day |
| | Real Losses (pressure) | 0.49 | 0.52 | 0.51 | gallons / serv conn / day / PSI |
| | ILI | 2.08 | 2.10 | 2.12 | *(dimensionless)* |
| | data validity score | 73.5 | 73.8 | 74.3 | points out of 100 |

***Observations***

- The number of audits excluded from the data set by the filtering process increases from 2010 to 2012. In 2010, only 26% of audits were excluded, whereas in 2012, 38% of audits were excluded.
- Data validity score increases from 2010 to 2012. Utilities reported higher confidence in their data, as demonstrated by the increase in the data validity score.
- Water loss increases from 2010 to 2012. Normalized Apparent Losses increase from 5.24 gallons per service connection per day in 2010 to 6.95 gallons per service connection per day in 2012. The Real Loss metrics – ILI, normalized Real Losses, and NRW as percent of input and operating cost – all increase as well.
- Customer retail cost increases from 2010 to 2012. Median customer retail unit cost grows by nearly 10% from 2010 to 2012, though variable production cost does not display the same trend.

**Delaware River Basin Commission**

The research team received 517 audits from the DRBC. The audits capture data from 2012 and 2013. Counts of audits collected and filtered are presented below in Table 4.4.

**Table 4.4 Number of DRBC audits by year**

| YEAR | 2012 | 2013 | ALL YEARS |
|---|---|---|---|
| **INCLUDED AUDITS** | 194 | 193 | 387 |
| **EXCLUDED AUDITS** | 64 | 66 | 130 |
| ***% EXCLUDED*** | *25%* | *25%* | *25%* |
| **TOTAL AUDITS** | **258** | **259** | **517** |

A summary of performance indicators for the DRBC is provided in Table 4.5.

**Table 4.5 DRBC water loss statistics**

| | STATISTIC | 2012 (*n = 194*) *median* | 2013 (*n = 193*) *median* | UNIT |
|---|---|---|---|---|
| *financial* | customer retail unit cost | $5.33 | $5.69 | $ / 1,000 gallons |
| | variable production cost | $532.16 | $520.00 | $ / million gallons |
| | NRW as % of operating cost | 6.7% | 7.2% | % of operating cost |
| *operational* | Apparent Losses | 3.54 | 3.40 | gallons / serv conn / day |
| | Real Losses (service connections) | 31.41 | 35.71 | gallons / serv conn / day |
| | Real Losses (mains) | 503.23 | 746.74 | gallons / mile of main / day |
| | Real Losses (pressure) | 0.48 | 0.55 | gallons / serv conn / day / PSI |
| | ILI | 2.39 | 2.52 | *(dimensionless)* |
| | data validity score | 75.1 | 75.4 | points out of 100 |

***Observations***

- The percentage of audits excluded by the filtering process is 25% in both 2012 and 2013. The count of excluded audits increases from 64 to 66, but because the total number of audits also increases, the rounded percentage of excluded audits does not change.
- Water Losses increase from 2012 to 2013. Apparent Losses decrease nominally, while all Real Losses and Non-Revenue Water performance indicators increase.
- The median data validity score increases marginally from 2012 to 2013, from 75.1 to 75.4.
- Customer retail unit cost increases from 2012 to 2013, but variable production cost decreases.

**Georgia Department of Natural Resources**

The research team received 452 audits from the GA DNR. The audits capture 2012 and 2013 data. Counts of audits collected and filtered are presented below in Table 4.6.

**Table 4.6 Number of Georgia (DNR) audits by year**

| YEAR | 2012 | 2013 | ALL YEARS |
|---|---|---|---|
| **INCLUDED AUDITS** | 190 | 188 | 378 |
| **EXCLUDED AUDITS** | 36 | 38 | 74 |
| ***% EXCLUDED*** | *16%* | *17%* | *16%* |
| **TOTAL AUDITS** | **226** | **226** | **452** |

A summary of performance indicators for Georgia is provided in Table 4.7.

**Table 4.7 Georgia (DNR) water loss statistics**

| | STATISTIC | 2012 (*n = 190*) *median* | 2013 (*n = 188*) *median* | UNIT |
|---|---|---|---|---|
| *financial* | customer retail unit cost | $4.13 | $4.27 | $ / 1,000 gallons |
| | variable production cost | $415.47 | $426.65 | $ / million gallons |
| | NRW as % of operating cost | 6.7% | 6.6% | % of operating cost |
| *operational* | Apparent Losses | 6.56 | 5.96 | gallons / serv conn / day |
| | Real Losses (service connections) | 42.98 | 51.57 | gallons / serv conn / day |
| | Real Losses (mains) | 1,678.00 | 1,729.82 | gallons / mile of main / day |
| | Real Losses (pressure) | 0.66 | 0.75 | gallons / serv conn / day / PSI |
| | ILI | 2.34 | 2.50 | *(dimensionless)* |
| | data validity score | 57.3 | 59.4 | points out of 100 |

***Observations***

- The percentage of audits excluded increases from 16% in 2012 to 17% in 2013. All Georgia audits were reviewed by a third party for data validity grading accuracy and are therefore level 1 validated. This validation process and the rigorous training provided prior to audit submittal may have caused fewer Georgia audits being excluded than in other regions. However, it is important to note that level 1 validation does not correct inaccurate inputs; instead, level 1 validation acknowledges and qualifies the inaccuracy.
- Customer retail unit cost and variable production cost increase in tandem from 2012 to 2013.
- The median data validity score increases from 2012 to 2013. All Georgia audits were subject to third party review of data validity scores and appropriate use of the audit software, so the increase in self-reported data validity may indeed reflect more valid data. Notably, this review cannot correct for the poor meter performance, lack of data resolution, and insufficient tracking. These factors may still result in the submission of an audit that would be excluded from the research team's analysis. See Table 4.6 for a count of excluded audits.
- All metrics of Real Losses increase from 2012 to 2013, while normalized Apparent Losses decrease.

**Tennessee Comptroller of the Treasury**

The research team received 629 audits from the TN COT. The audits capture data from 2011 through 2014. Counts of audits collected and filtered are presented below in Table 4.8. Audits representing financial years instead of calendar years were assigned to whichever year the majority of the financial year covered. In cases where the financial year ran from July to June (therefore covering six months of each year), the second year was designated the primary year for categorization. As a result, the 2014 audit data set is incomplete; audits covering FY13-14 were received and filed as 2014 audits, but calendar-year 2014 audits had not been filed at the time of this report's writing.

**Table 4.8 Count of Tennessee (COT) audits by year**

| YEAR | 2011 | 2012 | 2013 | 2014 | ALL YEARS |
|---|---|---|---|---|---|
| **INCLUDED AUDITS** | 7 | 126 | 226 | 148 | 507 |
| **EXCLUDED AUDITS** | 2 | 37 | 58 | 25 | 122 |
| ***% EXCLUDED*** | *22%* | *23%* | *20%* | *14%* | *19%* |
| **TOTAL AUDITS** | **9** | **163** | **284** | **173** | **629** |

A summary of performance indicators for Tennessee is provided in Table 4.9.

**Table 4.9 Tennessee (COT) water loss statistics**

| | | **2012 (*n = 126*)** | **2013 (*n = 226*)** | **2014 (*n = 148*)** | |
|---|---|---|---|---|---|
| | **STATISTIC** | *median* | *median* | *median* | **UNIT** |
| *financial* | customer retail unit cost | $7.52 | $7.25 | $6.97 | $ / 1,000 gallons |
| | variable production cost | $1,081.41 | $1,163.57 | $966.92 | $ / million gallons |
| | NRW as % of operating cost | 11.2% | 11.7% | 12.0% | % of operating cost |
| *operational* | Apparent Losses | 7.27 | 6.22 | 5.57 | gallons / serv conn / day |
| | Real Losses (service connections) | 58.49 | 61.25 | 65.76 | gallons / serv conn / day |
| | Real Losses (mains) | 1,062.04 | 1,091.84 | 1,162.88 | gallons / mile of main / day |
| | Real Losses (pressure) | 0.84 | 0.81 | 0.78 | gallons / serv conn / day / PSI |
| | ILI | 1.93 | 2.19 | 2.17 | *(dimensionless)* |
| | data validity score | 76.6 | 79.7 | 80.7 | points out of 100 |

***Observations***

- The percentage of audits excluded through filtering decreases from 2012 to 2014. It is possible that the combination of auditor training and practice with reporting enhanced audit quality.
- Median customer retail unit cost decreases with time, while variable production cost does not display a trend.
- Real Losses normalized to service connections increase from 2012 to 2014, but Real Losses normalized to service connections and pressure decreases during the same time period. This indicates that the increase in reported system pressure perhaps contributes to the increase in Real Losses, but the increase in pressure is proportionally greater than the increase in Real Losses.
- Apparent Losses decrease from 2012 to 2014, a trend observed in most of the regional data sets.
- The quality of data submitted in audits improves from 2012 to 2014. Data validity scores consistently improve, and the percentage of audits excluded via the research team's filtering decreases.

**Texas Water Development Board**

The research team received 2,646 audits from the TWDB. The water audits were submitted using a unique form which adheres to AWWA methodology. The audits capture data from 2010 and 2013. Counts of audits collected and filtered are presented below in Table 4.10. 2010 was a standard reporting year, so all Texas utilities were required to submit an audit. 2013 was an off year, so only larger systems and systems with an active financial engagement with the TWDB were required to submit an audit. As a result, less than one-third the number of audits submitted in 2010 were submitted in 2013.

**Table 4.10 Number of Texas (TWDB) audits by year**

| YEAR | 2010 | 2013 | ALL YEARS |
|---|---|---|---|
| **INCLUDED AUDITS** | 966 | 615 | 1,581 |
| **EXCLUDED AUDITS** | 930 | 135 | 1,065 |
| ***% EXCLUDED*** | *49%* | *18%* | *40%* |
| **TOTAL AUDITS** | **1,896** | **750** | **2,646** |

A summary of performance indicators for Texas is provided in Table 4.11. Texas does not require that utilities report an annual operating cost, so NRW as a percent of operating cost does not apply as a performance indicator. Additionally, the Texas reporting form utilizes a different data validity scoring scale than the AWWA Software, so data validity score is also not considered an applicable performance indicator in comparing Texas performance to the composite data set.

**Table 4.11 Texas (TWDB) water loss statistics**

| | STATISTIC | 2010 (n = 966) median | 2013 (n = 615) median | UNIT |
|---|---|---|---|---|
| *financial* | customer retail unit cost | $3.10 | $3.83 | $ / 1,000 gallons |
| | variable production cost | $1,750.00 | $1,400.00 | $ / million gallons |
| | NRW as % of operating cost | N/A | N/A | % of operating cost |
| *operational* | apparent losses | 6.86 | 5.78 | gallons / serv conn / day |
| | real losses (service connections) | 38.10 | 32.80 | gallons / serv conn / day |
| | real losses (mains) | 943.93 | 484.68 | gallons / mile of main / day |
| | real losses (pressure) | 0.64 | 0.54 | gallons / serv conn / day / PSI |
| | ILI | 2.51 | 2.83 | *(dimensionless)* |
| | data validity score | N/A | N/A | points out of 100 |

### *Observations*

The Texas data set must be interpreted with caution because the 2010 and 2013 data sets are comprised of different samples pools and sample sizes.

- The percentage of audits excluded by the filtration process decreases from 49% in 2010 to 18% in 2013. The 2013 audits primarily represent large utilities, while the 2010 audits represent a range of system sizes. The TWDB requires annual audit submission from large utilities, which suggests that frequent audit submission improves data validity and/or that larger utilities submit audits of higher validity.
- Median customer retail unit cost increases from 2010 to 2013, but variable production cost decreases.
- Normalized Real Losses decrease from 2010 to 2013.

- Median ILI increases. This must be interpreted with caution, as utilities reporting in 2013 are on average larger. Therefore, the ILI applies as a performance indicator to proportionally more utilities in the 2013 data set than the 2010 data set.

## COMPARISON BETWEEN REGIONS

Regional data sets must be compared to each other with caution. Performance indicators are useful for benchmarking the water loss levels of systems and regions but do not acknowledge the regulatory, historic, meteorological, and financial contexts in which utilities operate. With this caveat in mind, the following sections juxtapose and discuss state and regional median performance indicators. The most recent audit year's filtered data serves as the snapshot of each state or region's performance, as highlighted below in Table 4.12. Additionally, only those states or regions employing AWWA methodology and requiring a significant number of utilities to submit audits are included in these comparisons.

**Table 4.12 Count of audits from most recent complete year**

| STATE or REGION | California (CUWCC) | DRBC | Georgia (DNR) | Tennessee (COT) | Texas (TWDB) | TOTAL |
|---|---|---|---|---|---|---|
| **most recent year** | 2012 | 2013 | 2013 | 2013 | 2013 | |
| **count of audits** | 68 | 193 | 188 | 226 | 615 | **1,290** |

### Customer Retail Unit Cost and Variable Production Cost

Figure 4.1 below displays the customer retail unit costs ($/MG) and variable production costs ($/MG) for each region. Cost figures for each region are also tabulated in Table 4.13. Regions with higher variable production costs tend to report lower customer retail unit costs. Conversely, regions with lower variable production costs tend to report higher customer retail unit costs. For example, California has both the highest median variable production cost and the lowest customer retail unit cost. In contrast, the Delaware River Basin has the second lowest variable production cost and the second highest customer retail unit cost. However, please note that the exact expenses contributing to utilities' calculations of the cost figures are not known. Additionally, Georgia's customer retail unit costs likely do not contain sewer, stormwater, and biosolids charges. For more information on the calculation and comparison of cost figures, please refer back to the "Note on Cost Figures" in Chapter 3.

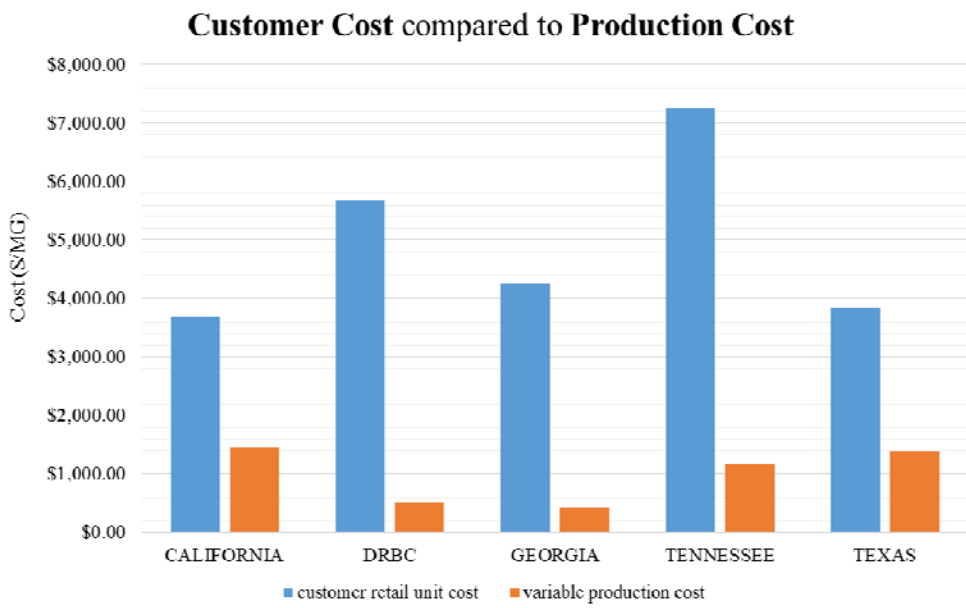


**Figure 4.1 Customer retail unit cost compared to variable production cost**

**Table 4.13 Customer retail unit cost compared to variable production cost**

| STATE or REGION | California (CUWCC) | DRBC | Georgia (DNR) | Tennessee (COT) | Texas (TWDB) |
|---|---|---|---|---|---|
| **median customer retail unit cost ($ / 1,000 gal)** | $3.70 | $5.69 | $4.27 | $7.25 | $3.83 |
| **median variable production cost ($ / MG)** | $1,448.40 | $520.00 | $426.65 | $1,163.57 | $1,400.00 |
| **median customer retail unit cost ($ / MG)** | $3,696.27 | $5,685.00 | $4,270.00 | $7,250.00 | $3,830.00 |
| ***customer retail unit cost as a multiple of variable production cost*** | *2.6* | *10.9* | *10.0* | *6.2* | *2.7* |

## Customer Retail Unit Cost and Normalized Real Losses

Figure 4.2 below displays the customer retail unit costs ($/1,000 gallons) and normalized Real Losses (gallons/service connection/day) for each region. Please note that two distinct vertical axes provide different scales, one for cost and the other for Real Losses volume. Table 4.14 displays this information in tabular form. Higher customer costs tend to correlate with greater Real Losses. The inverse is also true – lower customer costs tend to correlate with lower levels of Real Losses. Tennessee has both the highest customer cost and the highest level of normalized Real Losses. Conversely, Texas and California have the lowest customer retail unit costs and two of the lowest levels of Real Losses. Further research into the revenue generation tools and justification of rate structures could investigate the relationship between inefficiency and customer rates. Additionally, clarification of the costs included in customer retail cost (e.g. sewer costs) would need to be clarified. For more information on the calculation and comparison of cost figures, please refer back to the "Note on Cost Figures" in Chapter 3.

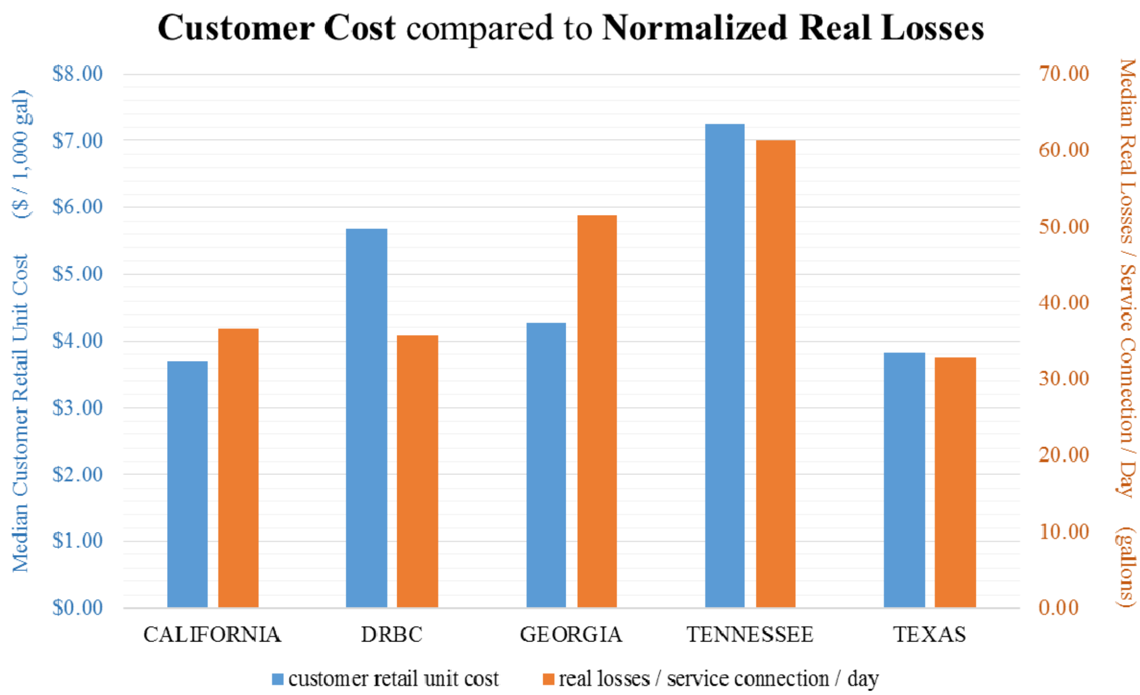


**Figure 4.2 Customer retail unit cost compared to normalized real losses**

**Table 4.14 Customer retail unit cost compared to normalized real losses**

| STATE or REGION | California (CUWCC) | DRBC | Georgia (DNR) | Tennessee (COT) | Texas (TWDB) |
|---|---|---|---|---|---|
| **median customer retail unit cost ($ / 1,000 gal)** | $3.70 | $5.69 | $4.27 | $7.25 | $3.83 |
| **median normalized Real Losses (gallons / service conn / day)** | 36.57 | 35.71 | 51.57 | 61.25 | 32.80 |

## Variable Production Cost and Normalized Real Losses

Figure 4.3 below displays the variable production costs ($/MG) and normalized Real Losses (gallons/service connection/day) for each region. Please note that two distinct vertical axes provide different scales, one for cost and the other for Real Losses volume. These values for each region are also tabulated in Table 4.15. Variable production cost does not display a clear relationship with normalized Real Losses. California and Texas have the highest variable production costs and two of the lowest Real Losses levels. Similarly, Georgia has the lowest variable production cost but the second-highest Real Losses value. However, the DRBC has the lowest variable production cost and one of the lowest levels of Real Losses. Additionally, Tennessee has the highest normalized volume of Real Losses and a relatively high variable production cost. In comparing median regional variable production costs and normalized real losses, it appears that higher costs of production do not correspond with lower levels of Real

Losses, as would be expected were higher production costs to effectively incentivize Real Losses recovery.

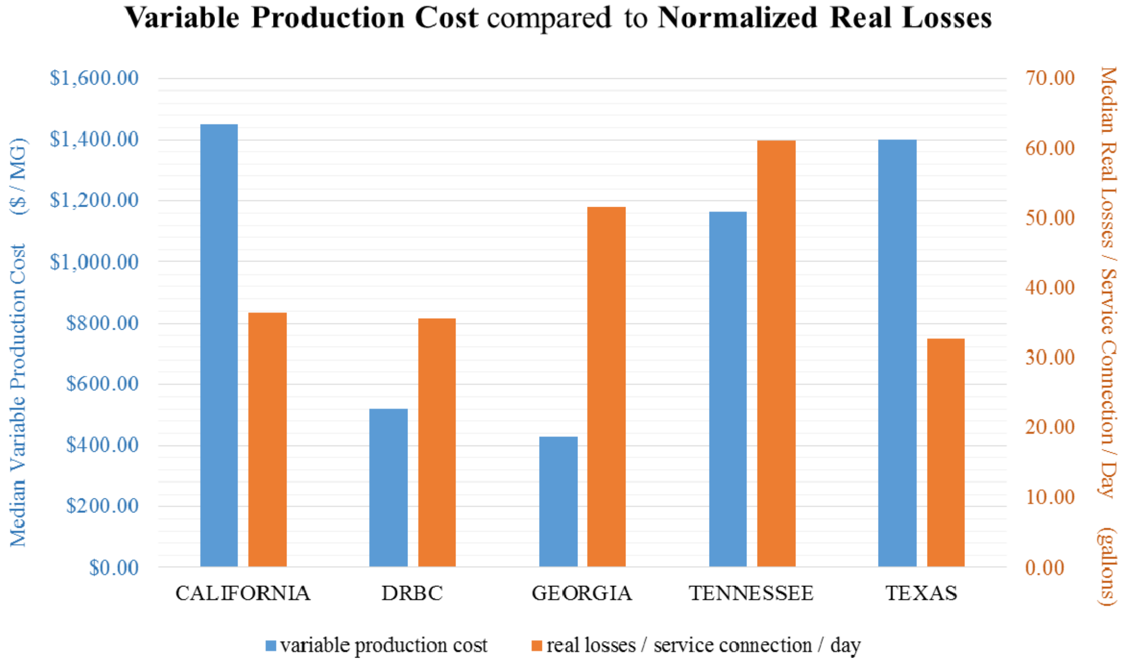


**Figure 4.3 Variable production cost compared to normalized real losses**

**Table 4.15 Variable production cost compared to normalized real losses**

| STATE or REGION | California (CUWCC) | DRBC | Georgia (DNR) | Tennessee (COT) | Texas (TWDB) |
|---|---|---|---|---|---|
| **median variable production cost ($ / MG)** | $1,448.40 | $520.00 | $426.65 | $1,163.57 | $1,400.00 |
| **median normalized Real Losses (gallons / service conn / day)** | 36.57 | 35.71 | 51.57 | 61.25 | 32.80 |

# CHAPTER 5: COMPOSITE WATER AUDIT DATA SET

## INTRODUCTION

State and regional water audit data sets capture valuable snapshots of water loss and regulatory practices in parts of the United States. When combined to form a single composite data set, the audits can provide an insight into the relationships between infrastructure, pressure, and water losses. To create a composite water audit data set, the research team selected the most recent audit period with complete data from each state or region. All audits – regardless of the filters for reasonable results as discussed earlier - were included in the data set to allow for discussion of data validity. However, only the audits that passed the filtering tests described in the previous section titled "Data Filtering Steps" contributed to the calculation of median performance indicators. Counts of audits in the composite data set and the year they describe are given by region in Table 5.1. The full data set consisted of 1,636 audits, capturing 2012 for California and 2013 for all other regions.

**Table 5.1 Composite water audit data set composition**

| STATE or REGION | California (CUWCC) | DRBC | Georgia (DNR) | Tennessee (COT) | Texas (TWDB) | TOTAL |
|---|---|---|---|---|---|---|
| **most recent year** | 2012 | 2013 | 2013 | 2013 | 2013 | |
| **count of audits** | 109 | 259 | 226 | 292 | 750 | **1,636** |

It is important to again note that the data set is composed primarily of self-reported audits. Only audits from Georgia have been subjected to level 1 validation. Therefore, interpretations of data and trends should be viewed with caution, as descriptive of potential patterns but not absolute values.

## DATA FILTERING

The research team examined the basic plausibility of the composite audit data set by filtering audits through the same data filtering checks used to examine the regional data sets. Please reference the previous section titled "Data Filtering Steps" for details on this process. The basic data filtering checks are reproduced below in Table 5.2. It is important to note that data failing the cost checks (Customer Retail Unit Cost and Variable Production Costs) were excluded from the calculation of median financial performance indicators but not median volumetric performance indicators. Audits failing a volumetric check or composed of incomplete data were excluded from the calculation of all median volumetric performance indicators.

**Table 5.2 Criteria used to exclude audits**

| | METRIC | CRITERIA FOR EXCLUSION |
|---|---|---|
| *volumetric* | **Infrastructure Leakage Index** | < 1.0 |
| | | > 20.0 |
| | **Real Losses** | < 0 (negative) – *if ILI does not apply* |
| | **cost of Non-Revenue Water** | > 100% of system operating costs |
| | **incomplete audit** | key fields not filled out |
| *financial* | **Customer Retail Unit Cost** | more than 2 orders of magnitude off of the regional median |
| | **Variable Production Cost** | more than 2 orders of magnitude off of the regional median |

### Excluded Audits and Self-Reported Data Validity Scores

The median self-reported data validity score of all included audits (those passing the aforementioned volumetric filtering checks) is 73.1 out of 100. In contrast, the median self-reported data validity score of all excluded audits (those failing the aforementioned volumetric filtering checks) is 77.1. Audits excluded for reporting technically-impossible situations tended to have higher self-reported validity scores than audits reporting plausible water balances. A breakdown of the number of excluded audits by reason for exclusion and the median self-reported data validity score of each group is given in Table 5.3. Texas audits are included in the counts presented in Table 5.3. However, the TWDB submission form uses a unique data validity grading scheme that makes comparison with AWWA Software data grading impractical. Therefore, Texas data does not contribute to the validity scores listed in the right-most column of Table 5.3.

**Table 5.3 Counts of excluded audits by reason for exclusion**

| REASON FOR EXCLUSION | COUNT | % OF COMPOSITE DATA SET | MEDIAN VALIDITY SCORE |
|---|---|---|---|
| ILI < 1 | 284 | 17.4% | 77.0 |
| ILI > 20 | 10 | 0.6% | 81.7 |
| Negative Real Losses | 35 | 2.1% | 84.0 |
| NRW > 100% operating cost | 8 | 0.5% | 62.1 |
| Incomplete | 9 | 0.6% | 84.5 |
| **TOTAL** | **346** | **21.1%** | **77.1** |

Figure 5.1 below displays box plots that describe the range and density of self-reported audit validity scores. The plots display the minimum and maximum scores reported (shown as the end points of the lines to the left and right of the boxes). The middle 50% of the data set is contained within the boxes (the bounds of the boxes show the first and third quartiles). The medians are marked by the lines in the center of the boxes. Again, please note that this figure excludes audits from Texas, as Texas uses a unique data validity grading system.

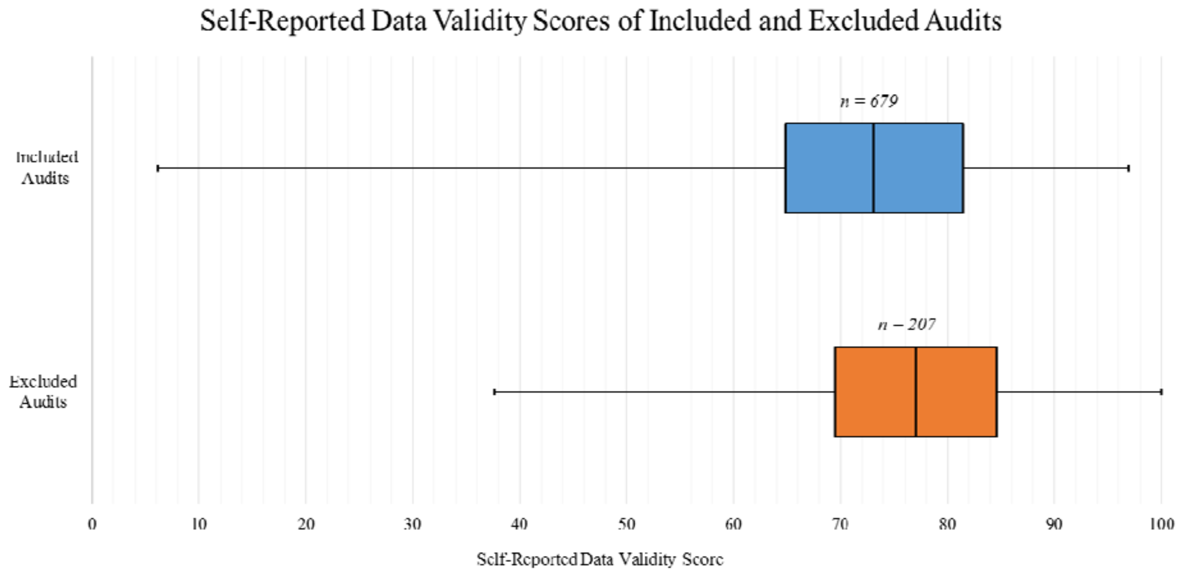


**Figure 5.1 Comparison of self-reported validity scores of included and excluded audits**

Presentation of data in this format shows that the validity scores reported in included audits (those kept in the composite data set) are lower in all five descriptive statistics – minimum, maximum, and the three quartiles – than the scores reported in excluded audits. Utilities whose audit results were not plausible tended to grade their data validity notably higher that utilities that submitted audits with realistic data. This indicates any of the following possible conclusions.

A significant portion of auditors:

- require further training and assistance with the water balance methodology
- require further training and assistance on how to accurately use the Water Audit Software
- require further training and assistance on how to accurately assign data validity scores
- did not verify the feasibility of their results upon completing a water balance
- require further training and assistance in how to interpret performance indicators

The gap between self-assessment of validity and the research team's filtering for reasonable water balances suggests that merely collecting audits is insufficient in promoting utility accountability and proactive water loss control. Fortunately, utility reporting of data accuracy can be improved to better reflect operational reality, promote transparent evaluation, and anchor effective water loss intervention strategies. Audit workshops, educational outreach, and provision of guides and auditing materials can aid auditors in becoming familiar with AWWA methodology and accurately completing water audits and data validity assessment. This is evidenced by the high percentage of reasonable audits from Georgia and Tennessee, where the most training is offered. Additionally, third-party review of audits and technical assistance programs, as has been performed in Georgia, can improve the quality of audits. The percentage of audits excluded by the filtering process is lowest in Georgia, likely due to third-party validation, trainings, and technical assistance.

## PERFORMANCE INDICATOR STATISTICS

Table 5.4 on the following page lists the composite data set performance indicators, the count of data points contributing to each indicator, and the filters applied to the calculation of each indicator. A total of 1,636 audits compose the data set. Of those audits,

- 1,290 audits (78.9%) pass all volumetric validity checks
- 1,463 audits (89.4%) pass all financial validity checks

Both median performance indicator values and average performance indicator values are provided. The median is considered a more robust measure of central tendency when a data set is skewed or populated by asymmetric extreme values. Therefore, the research team will present composite water loss performance in terms of median values. Average values are provided to give a sense of the direction and magnitude of skew.

### Observations

- The median ILI is 2.48. Therefore, half of systems report losing between the technical minimum volume of Real Losses (UARL) and 2.48 times the UARL. The other half of systems report losing more than 2.48 times the UARL.
- Average indicators of Water Loss are higher than median values. This indicates that Water Losses are positively skewed (skewed toward higher values). A minority of unusually-high reported Water Loss volumes pull the average above the median.

### Table 5.4 Composite water audit data set median performance indicators

| | PERFORMANCE INDICATOR | MEDIAN | AVERAGE | UNIT | *n* | FILTERS |
|---|---|---|---|---|---|---|
| *financial* | **customer retail unit cost** | **$4.67** | $8.33 | $ / 1,000 gallons | *1,545* | passes customer retail unit cost check |
| | **variable production cost** | **$950.00** | $2,085.28 | $ / million gallons | *1,489* | passes variable production cost check |
| | **NRW as % of operating cost** | **7.8%** | 10.2% | % of operating cost | *630* | passes both cost checks<br>passes volumetric validity checks<br>does not come from Texas (operating cost not reported) |
| *operational* | **Apparent Losses** | **5.73** | 14.88 | gallons / serv conn / day | *1,290* | passes volumetric validity checks |
| | **Real Losses (serv conn)** | **39.88** | 51.81 | gallons / serv conn / day | *812* | passes volumetric validity check<br>service connection density ≥ 32 conn / mile of main |
| | **Real Losses (mains)** | **785.54** | 1,132.42 | gallons / mile of main / day | *478* | passes volumetric validity checks<br>service connection density < 32 conn / mile of main |
| | **Real Losses (pressure)** | **0.59** | 0.79 | gallons / serv conn / day / PSI | *812* | passes volumetric validity checks<br>service connection density ≥ 32 conn / mile of main |
| | **ILI** | **2.48** | 3.12 | *(dimensionless)* | *644* | passes basic volumetric validity checks<br>UARL calculation applies – (32 x *Lm*) + *Nc* ≥ 3,000 |
| | **data validity score** | **73.1** | 71.7 | points out of 100 | *679* | passes basic volumetric validity checks<br>does not come from Texas |

## COMPOSITE DATA SET CORRELATIONS

To discuss correlations between Real Losses and other performance indicators and operational variables, the research team isolated the 812 audits in the composite data set for which Real Losses normalized to service connections were calculated (see Table 5.4). The count of audits contributed by each region is provided in Table 5.5. Please note that values presented in these correlations are medians.

**Table 5.5 Composition of composite data set**

| STATE or REGION | California (CUWCC) | DRBC | Georgia (DNR) | Tennessee (COT) | Texas (TWDB) | TOTAL |
|---|---|---|---|---|---|---|
| **most recent year** | 2012 | 2013 | 2013 | 2013 | 2013 | |
| **count of audits** | 66 | 179 | 133 | 82 | 352 | **812** |

### System Size and Real Losses

The research team sorted systems into size categories based on the number of service connections. Small systems have between 0 and 3,000 service connections; medium-sized systems have between 3,001 and 30,000 service connections; and large systems have more than 30,000 service connections. The number of utilities captured by each size range is provided in Figure 5.2.

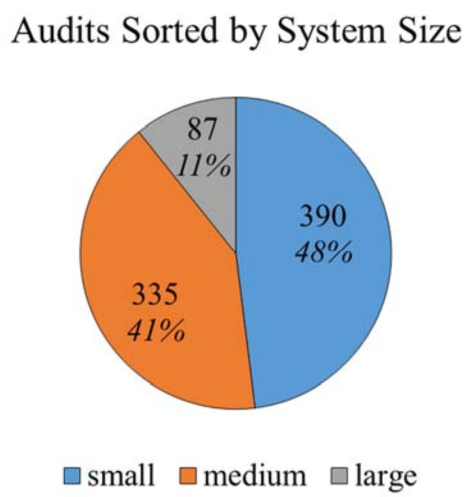


**Figure 5.2 Audits included in the composite data set by system size**

The median Real Losses volume per service connection per day was then calculated for each size range. The results are displayed below in Figure 5.3.

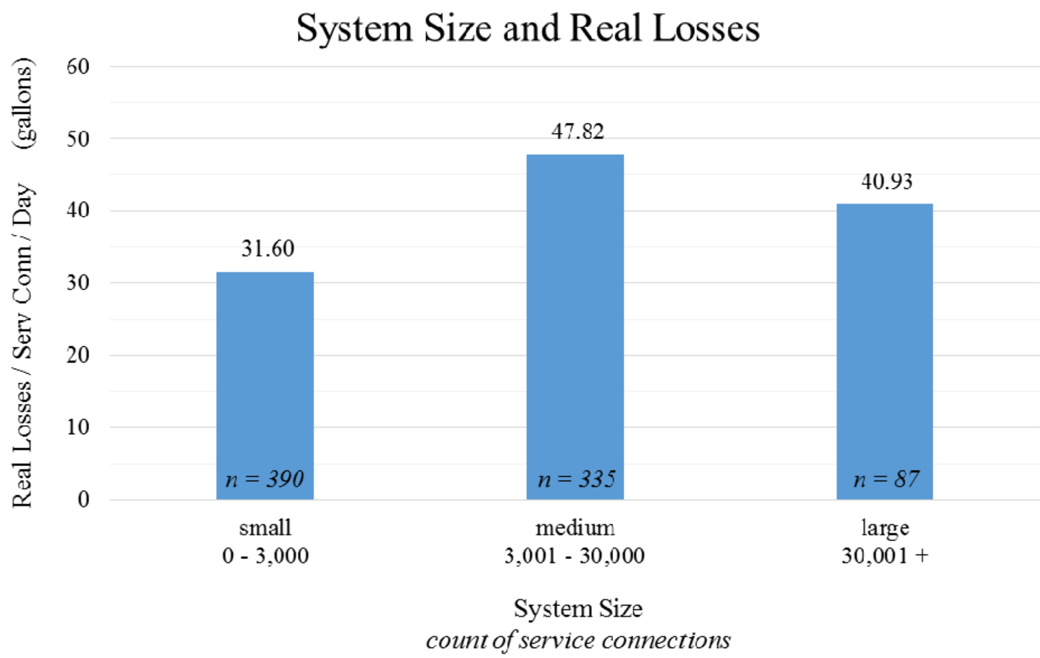


**Figure 5.3 Correlation between system size and normalized real losses**

In this analysis, Real Losses do not correlate with system size as measured by the number of service connections. Of course, the boundaries selected to define size ranges are arbitrary. As a result, choosing alternate boundaries might reveal a different pattern. Previous studies have determined that larger systems tend to lose more water (Chastain-Howley et al. 2013), but this analysis shows that for the composite audit data set, large systems have higher Real Losses than small systems but lower Real Losses than mid-sized systems.

### Operating Pressure and Real Losses

To consider the relationship between average operating pressure and Real Losses, the research team divided audits into categories of low, medium and high pressure. Low-pressure systems operate at an average pressure of 50 PSI or less, medium-pressure systems between 50 PSI and 80 PSI, and high-pressure systems greater than 80 PSI. A correlation between pressure and Real Losses is presented below in Figure 5.4.

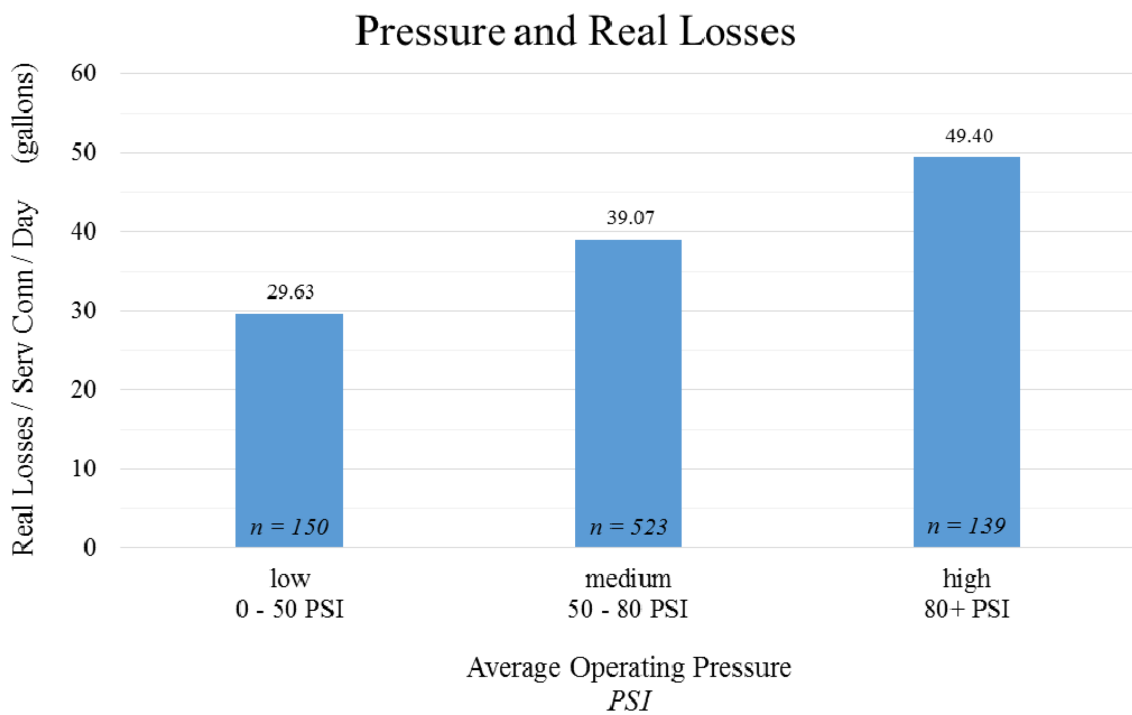


**Figure 5.4 Correlation between average operating pressure and normalized real losses**

As expected, Real Losses increase as average operating pressure increases. Previous studies have demonstrated that higher pressures result in greater leakage. This pressure-leakage relationship is incorporated in the UARL formula to acknowledge that systems operating at higher pressures have higher thresholds for the technical minimum level of Real Losses (see the discussion of UARL and ILI in Chapter 3 for the specific calculation).

Also of note is the fact that the majority of systems (64%) in the composite audit data set operate at mid-range pressures between 50 PSI and 80 PSI.

## Import Volume and Real Losses

The research team next examined the composite data set by looking at the relationships between percent of water imported, normalized Real Losses, and variable production cost. To this end, audits were divided into categories of "little" water imported (0% to 25% of System Input Volume), "some" water imported (25% to 75% of System Input Volume), and "most" water imported (75% to 100% of System Input Volume). System Input Volume is the volume of potable water inputted into the distribution system and is composed of imported water and water produced from utility-owned sources. The specific language of the AWWA definition for System Input Volume can be found in the AWWA Software. The results of these comparisons are presented below in Figure 5.5.

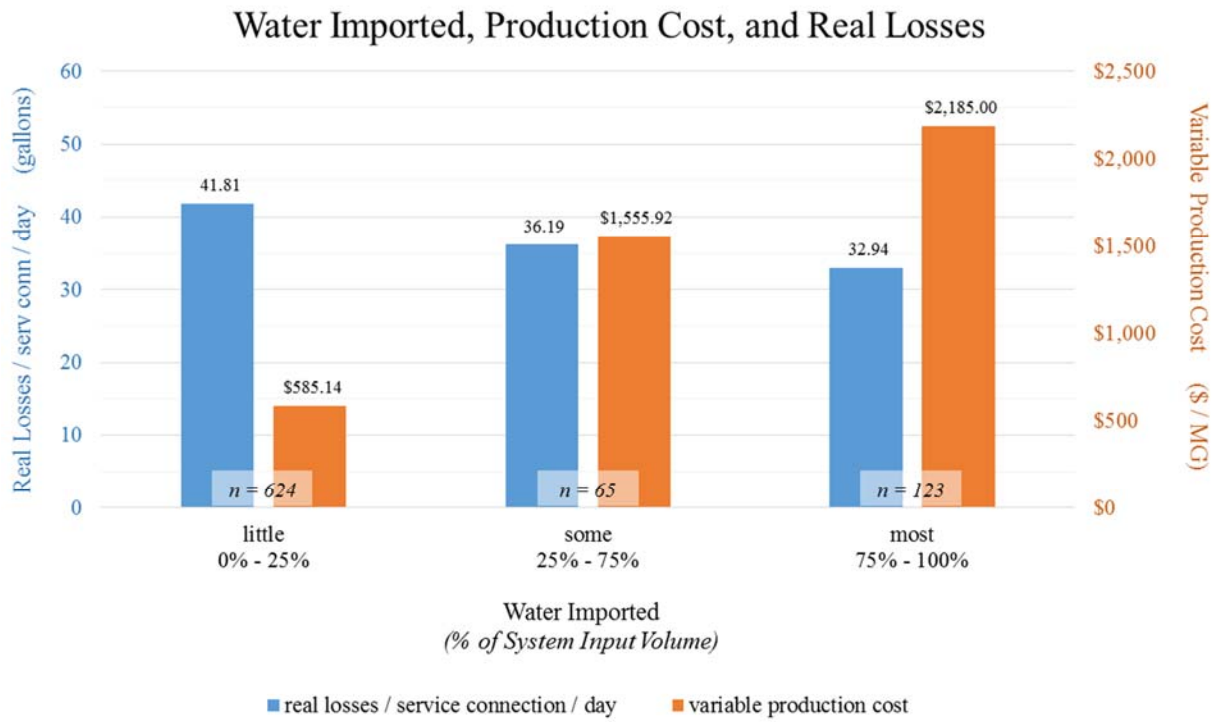


**Figure 5.5 Correlations among water imported, normalized real losses, and variable production cost**

As the percent of SIV composed of imported water increases, variable production cost increases and Real Losses decrease. It appears that greater percentages of imported water lead to higher variable production costs, thereby incentivizing efficiency in the form of lower levels of Real Losses. Additionally, most systems (77%) import less than 25% of total supply.

### Retail Cost and Real Losses

To further investigate the relationship between cost of water and Real Losses, the research team compared customer retail unit cost to normalized Real Losses. Customer retail unit cost was divided into terciles so that each tercile contained approximately one-third of the audits in the entire audit data set (with invalid customer retail cost figures removed). The first tercile – “low” customer retail unit cost – ranged from $0.00 per 1,000 gallons to $3.30 per 1,000 gallons. “Medium” customer retail unit cost ranged from $3.31 per 1,000 gallons to $5.55 per 1,000 gallons. “High” customer retail unit cost was considered above $5.56 per 1,000 gallons. These terciles and associated median customer retail unit costs are presented in Figure 5.6.


**Figure 5.6 Correlation between customer retail unit cost and normalized real losses**

This basic analysis indicates that there is no correlation between customer retail cost and Real Losses. However, the highest customer retail cost (greater than $5.56 per 1,000 gallons) corresponds to the greatest volume of normalized Real Losses. A similar phenomenon was observed when comparing customer cost and Real Losses on a regional basis (see Table 4.14). While customer retail unit cost reflects both the regulatory pricing parameters and the operational expenses unique to each system, this analysis suggests that for those utilities with the highest volumes of Real Losses normalized to service connections, the cost of real losses may manifest in customer pricing. However, please note that the exact expenses (e.g. sewer cost) included in utilities' reported customer retail costs are not known. For more information on the calculation and comparison of cost figures, please refer back to the "Note on Cost Figures" in Chapter 3.

**Variable Production Cost and Real Losses**

To examine the relationship between variable production cost and normalized Real Losses without incorporating import percent, the research team sorted audits into variable production cost terciles. The lowest tercile ranged from $0.00 per MG to $500.00 per MG, and the middle tercile ranged from $500.01 per MG to $1,600.00 per MG. The highest tercile was composed of any audits reporting a variable production cost higher than $1,600.01 per MG.

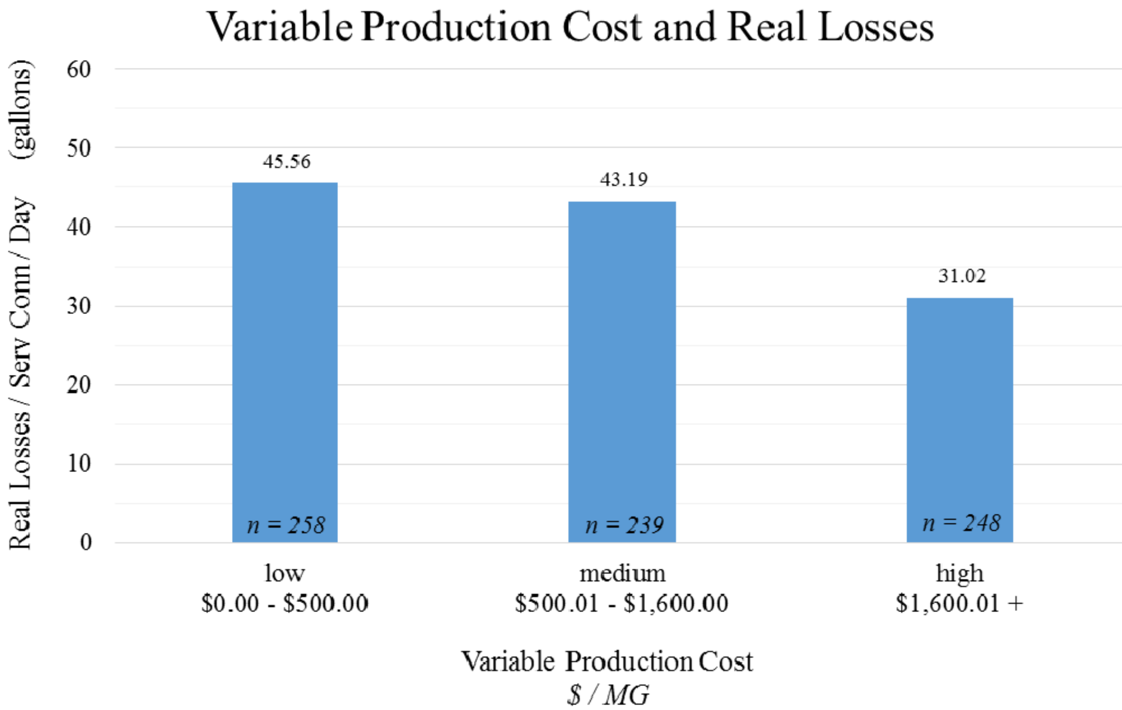


**Figure 5.7 Correlation between variable production cost and normalized real losses**

As observed in the previous comparisons between import percent, variable production cost, and Real Losses, systems with the highest variable production cost tend to have the lowest levels of normalized Real Losses. This relationship is displayed above in Figure 5.7. When divided into terciles based on production cost, systems with the lowest variable production cost lose 50% more water per service connection than systems with the highest variable production cost.

## TOTAL WATER AND FINANCIAL LOSSES

The composite audit data set provides a unique opportunity to quantify water losses and financial losses at a multi-state level. The 1,290 valid audits capturing the most recent audit period in California, the Delaware River Basin, Georgia, Tennessee, and Texas record 355,906 MG of Water Losses (both Real Losses and Apparent Losses), conservatively valued at $556,752,484. This equates to an average of 275.9 MG of audit-period Water Losses per utility, conservatively valued at $431,591.

To determine the volume of Water Losses reflected in the audits, the research team summed the Apparent Loss volume and Real Losses volume reported in each audit. To then quantify the financial losses associated with these Water Losses, the median retail unit cost of the full data set was applied to Apparent Losses, and the median variable production cost was applied to Real Losses. Using median values allowed the research team to incorporate the financial losses of systems that reported invalid cost figures but valid volumetric data. Additionally, the research team also calculated financial losses using average cost figures. A minority of unusually high reported costs pulled average values significantly above median values. Therefore, employment of median cost figures produces more conservative estimates of financial losses. Total data set Water Losses and financial losses are presented below in Table 5.6.

**Table 5.6 Calculation of total water losses and financial losses**

| | VOLUME OF LOSSES (MG) | MEDIAN COST | COST OF LOSSES (median) | AVERAGE COST | COST OF LOSSES (average) |
|---|---|---|---|---|---|
| **Apparent Losses** | 58,774.78 | $4.67 / 1,000 gal | $274,478,228 | $8.33 / 1,000 gal | $489,483,725 |
| **Real Losses** | 297,130.80 | $950.00 / MG | $282,274,256 | $2,085.28 / MG | $619,602,300 |
| **TOTAL WATER LOSSES** | **355,905.58** | – | **$556,752,484** | – | **$1,109,086,025** |

While these audits are primarily self-reported, this analysis nonetheless suggests that the median utility in the data set lost a volume of water valued at nearly half a million dollars during a single audit period. These losses occurred as both Apparent Losses and Real Losses, with each audit presenting a unique loss profile.

The data set suggest that much of the Real Losses volume (and therefore the expenses associated with Real Losses) is technically recoverable, as the median ILI value in the data set is 2.48 – approximately two and a half times the technical minimum level of leakage. The amount of water that is economically recoverable depends on the distinct financial and operational profile of each utility. The volumes of Apparent Losses that might be technically recoverable and economically recoverable depend on the distinct forms of Apparent Loss and each utility's revenue generation framework.

# CHAPTER 6: CONCLUSIONS

An impressive number of utilities are assessing and reporting their water losses. As the first step in developing a water loss control strategy, the growing adoption of the AWWA Water Audit Software and audit methodology signals increased attention being paid to supply-side efficiency in water management. The research team examined both the quality of the AWWA-methodology audits from state entities across the country and the levels of water loss reported. The following findings summarize the trends observed in the data sets and suggest areas for focus and improvement.

- In all of the regional data sets reviewed, audits were excluded from further analysis due to implausible data. Table 6.1 presents the total number and percentage of audits excluded from each region's data set based on a series of filters (see "Data Filtering Steps" in Chapter 3).

**Table 6.1 Excluded audits by region for all audits to date**

| ENTITY | CA | DRBC | GA | TN | TX |
|---|---|---|---|---|---|
| Total Audits Submitted | 300 | 517 | 452 | 629 | 5,646 |
| # of Audits Excluded | 100 | 130 | 74 | 122 | 1065 |
| *% Of Excluded Audits* | *33%* | *25%* | *16%* | *19%* | *40%* |

It is notable that the regions with the fewest audit exclusions – Georgia and Tennessee, with 16% and 19% of audits excluded, respectively – have the highest levels of training to support their reporting requirements.

- Utilities whose audit results were not plausible tended to grade their data notably higher than the utilities that submitted audits with realistic data. Audits excluded from the calculation of summary statistics for reporting unreasonable results had a median self-reported data validity score of 77.1, whereas audits included in the calculation of summary statistics had a median self-reported data validity score of 73.1. This indicates that utility self-scoring of data validity does not actually capture true data validity. The gap between self-assessment of validity and the research team's filtering for reasonable water balances suggests that merely collecting audits is insufficient in promoting utility accountability. Fortunately, inaccuracy in data validity assessment can be corrected by audit validation, as defined in the section titled "Levels of Data Validation" in Chapter 3. Validation tends to result in lower data validity scores that better reflect true data validity, as seen in Georgia.
- The trend in number of audits excluded over time differs between regions. For Georgia and the DRBC, the number of audits that were excluded from the reasonable data sets remained consistent from year to year. In Tennessee's data set, fewer audits were excluded from year to year, whereas in California, more audits were excluded from year to year. Texas data is primarily composed of a single year, so temporal trends were not examined.
- The research team observed that all regional programs collect audits that require improvement in order to be informative. As a result, data validity is a worthwhile subject for trainings and other education and outreach programs. Given the number of excluded water audits, this kind of training is a critical first step before more reliable insight into national water loss statistics is possible.

- After exclusions of implausible audits, the composite data set – composed of the most recent audits from each regional data set – has a median ILI of 2.48. Therefore, half of systems report losing between the technical minimum volume of Real Losses (UARL) and 2.48 times the UARL. The other half of systems report losing more than 2.48 times the UARL.
- Looking a bit more closely at the data reveals that the average indicators of Water Loss are higher than median values. This indicates that normalized Water Losses are positively skewed (skewed toward higher values). A minority of unusually high reported Water Loss volumes pull the average above the median. See Chapter 4 for further analysis of the composite data set. Further investigation is required to determine whether these outliers reflect a reality of high losses or are the result of data integrity or data entry issues.
- All regional data sets show an increasing median value of Real Losses per service connection per day over time. Given the changing levels of accuracy and consistency with which these audits are completed, the research team cannot confirm that this trend in the data actually reflects an increasing volume of Real Losses. It is possible it also reflects more accurate reporting over time.
- Examining correlations in the composite data set revealed a number of valuable findings:
    - Systems with the highest variable production cost tend to have the lowest levels of normalized Real Losses.
    - Real Losses increase as average operating pressure increases.
    - No significant relationships were found in comparing Real Losses with customer retail cost or Real Losses with system size.

In reviewing the largest compilation of AWWA-methodology audits to date, it is clear that more training and education would be worthwhile to improve confidence in regional water loss reporting. Additionally, more rigorous audit validation will be required to produce audits that truly reflect reality. Currently, the only region to require audit validation is Georgia, where all audits are subject to level 1 validation (see Chapter 3 for definitions of audit validation levels). The Georgia data set produced the fewest unrealistic audits, thereby providing evidence that third-party audit validation improves audit quality. More rigorous validation at levels 2 and 3 could further improve audit quality and perhaps even eliminate all unreasonable audits.

Until the number of implausible audits decreases, it will be difficult to discuss typical levels of water loss without qualification of the accuracy of the data set. In the meantime, this study highlights general but noteworthy trends, such as the connections between Real Losses and pressure and the relationship between Real Losses and production cost. The research team is optimistic that as the reliability of regional data sets improves, more insight into appropriate and effective water loss control programs will surface.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AF | acre-feet |
| AWWA | American Water Works Association |
| BMP | Best Management Practices |
| CARL | Current Annual Real Losses |
| CCF | hundred cubic feet |
| COT | Comptroller of the Treasury |
| CUWCC | California Urban Water Conservation Council |
| CWCB | Colorado Water Conservation Board |
| DNR | Department of Natural Resources |
| DOH | Department of Health |
| DRBC | Delaware River Basin Commission |
| EPD | Environmental Protection Division |
| gal | gallons |
| GAWP | Georgia Association of Water Professionals |
| GEFA | Georgia Environmental Finance Authority |
| GWSA | Georgia Water Stewardship Act |
| ILI | Infrastructure Leakage Index |
| IWA | International Water Association |
| MG | million gallons |
| MOU | Memorandum of Understanding |
| NMOSE | New Mexico Office of the State Engineer |
| NRW | Non-Revenue Water |
| PI | performance indicator |
| PSC | Public Services Commission |
| serv conn | service connection |
| SIV | System Input Volume |
| TAUD | Tennessee Association of Utility Districts |
| UARL | Unavoidable Annual Real Losses |
| UMRB | Utility Management Review Board |
| VPC | variable production cost |

| | |
|---|---|
| WAC | Washington Administrative Code |
| WADI | Water Audit Data Initiative |
| WLCC | Water Loss Control Committee |
| WRF | Water Research Foundation |
| WTB | Water Trust Board |
| WUE | Water Use Efficiency |
| WWFB | Water and Wastewater Financing Board |