

Level 1 Water Audit Validation: Guidance Manual

Project #4639A



Level 1 Water Audit Validation: Guidance Manual



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The Water Research Foundation (WRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research that enables water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

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Level 1 Water Audit Validation: Guidance Manual

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FOREWORD

The Water Research Foundation (WRF) 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. WRF's research agenda is developed through a process of consultation with WRF subscribers and other drinking water professionals. WRF's Board of Directors and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. WRF 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 WRF subscribers. WRF'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. WRF 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. WRF 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 WRF'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 WRF's research are realized when the results are implemented at the utility level. WRF's staff and Board of Directors are pleased to offer this publication as a contribution toward that end.

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OVERVIEW

Hello! Welcome to the world of water audit validation.

This manual will guide you through the process of level 1 water audit validation. It will also highlight the factors that influence water audit data quality and connect you with additional resources.

But first – a little bit of background information.

WHAT IS AN AWWA WATER AUDIT? WHAT IS WATER LOSS CONTROL?

An American Water Works Association water audit – hereafter referred to simply as a “water audit” – accounts for all water introduced into a water distribution system and then consumed in order to estimate volumes of water loss. When a utility understands its volumes of water loss, it can act to cost-effectively reduce water loss.

This practice of assessing water distribution efficiency, evaluating the economic parameters of water loss management, and then acting to reduce water loss to an economically-efficient level is referred to as water loss control.

Effective water loss control offers a host of benefits to a water utility, including:

- Water conservation
- Increased revenue
- Reduced operating costs
- Reduced liability
- Strengthened credibility with stakeholders
- Improved infrastructure management
- Improved data accuracy

WHAT IS WATER AUDIT VALIDATION?

Water audit validation is the process of examining water audit inputs to improve the water audit’s accuracy and document the uncertainty associated with water audit data. Though water audit validation can be conducted at three distinct levels of rigor, all water audit validation efforts share two common goals.

As outlined by Sturm et al. (forthcoming), water audit validation aims to:

1. Identify and appropriately correct for inaccuracies in water audit data and application of methodology
2. Evaluate and communicate the uncertainty inherent in water audit data

In order for a water audit to effectively inform utility management and water loss control programming, it must accurately capture the performance of a distribution system. Water audit reliability, and therefore the data informing water loss management, is improved through water audit validation.

Without a methodical, validated water audit, it is possible that estimations of water loss misrepresent what a utility is actually experiencing. As a result, a water audit that has not been validated can mislead stakeholders, customers, regulators, and utility management in stewarding valuable water and financial resources. Additionally, each of the three levels of validation corresponds to certain goals, outcomes, and limitations.

By validating a water audit, you will deepen your understanding of the water distribution system, the data sources available, and the opportunities presented by water loss control.

Let's get started!

ABOUT THIS MANUAL

This manual has three objectives:

1. Provide step-by-step instruction in level 1 water audit validation.
2. Define a standard of care and documentation for level 1 water audit validation.
3. Highlight the factors that influence water audit data quality.

To accomplish these goals, this manual begins with an explanation of the tools and resources available to compile water audits.

Then, this manual discusses the relationship between data quality and data validation before discussing the role of the validator and the distinct levels of validation.

Finally, this manual guides you step-by-step through level 1 water audit validation and briefly explores higher-level validation activities.

Chapter 1	What is a water audit?
Chapter 2	How does data quality affect a water audit?
Chapter 3	What is water audit validation?
Chapter 4	What defines level 1 water audit validation?
Chapter 5	How do I perform level 1 water audit validation?
Chapter 6	What are advanced validation options?

CHAPTER 1

WHAT IS A WATER AUDIT?

An audit is a systematic examination of records or accounts to confirm their accuracy and ensure the viability of the entity being audited. Audits are common in the world of finance and accounting.

Similar to financial audits, water audits review records and data that trace the flow of water from the point of potable system input, through the distribution system, and to customer delivery.

A water audit accounts for all water introduced into a water distribution system and then consumed in order to estimate volumes of water loss.

Water auditing is often conducted with a worksheet that tallies annual volumes of potable supply, customer consumption, utility operational use, and water losses. A standard water audit also tracks relevant summary costs and calculates a suite of performance indicators to assess the efficiency of the water utility in supplying drinking water.

Through this process of volumetric accounting, a water audit aims to:

1. Account for all volumetric inputs and outputs in a distribution system during an audit period to derive volumes of water loss.
2. Study the reliability and accuracy of water audit data sources to qualify the potential uncertainty of water audit results.
3. Communicate system efficiency with a suite of calculated performance indicators.

WHY SHOULD I PERFORM A WATER AUDIT?

Water auditing provides structured accountability to a water utility's operations.

Additionally, in performing a water audit, the auditor will:

- Assemble and present information in a standardized format for reliable assessment, tracking, and comparison.
- Provide foundational data and metrics to inform water loss control programs, improve water distribution efficiency, increase revenue, and save water and money.
- Meet regulatory requirements in certain US states and Canadian provinces.
- Improve staff knowledge of utility operations and integration between utility departments.

Water suppliers are stewards of the valuable water resources that they manage, but they must also be fiscally responsible to customers, regulatory agencies, and the stakeholders. Water auditing supports these goals.

WHAT TOOLS CAN ASSIST ME IN PREPARING A WATER AUDIT?

The International Water Association publication, *Performance Indicators for Water Supply Services* (Alegre et al. 2000), defined the terms and process of the water audit approach discussed in this guidance manual. Later publications expanded upon the concepts or discussed them in more detail. A handful of software tools and authoritative sources of methodological guidance support water loss control efforts in the drinking water industry. These tools, published by the American Water Works Association (AWWA) and the Water Research Foundation (WRF), promote a standardized, robust approach to water loss assessment and intervention. Because the AWWA and WRF tools are accessible and consistent, a growing number of state, regional, and provincial regulatory agencies have adopted requirements for water auditing that harness these resources.

American Water Works Association Manual M36: Water Audits and Water Loss Control Programs

The American Water Works Association (AWWA) promotes water auditing as the best practice for assessing water losses. To facilitate water auditing that follows a standardized methodology, AWWA publishes guidance manual *M36: Water Audits and Loss Control Programs*. The 3rd edition (and later editions) contain major revisions to the water audit terms and process based on Alegre et al. (2000). At the time of this manual's publication, the most up-to-date version of M36 is the fourth edition.

American Water Works Association Free Water Audit Software and Compiler Software

To support utilities in preparing standardized water audits, the Software Subcommittee of the AWWA Water Loss Control Committee created the AWWA Free Water Audit Software ("AWWA Software"), available for free download from the AWWA Water Loss Control web portal. The AWWA Software is a Microsoft Excel spreadsheet tool that allows users to develop a water balance, access standard definitions, qualify data validity, and calculate performance indicators. At the time of this manual's publication, AWWA Software version 5.0 is the most recent software iteration. As a result, this guidance manual deals specifically with AWWA Software version 5.0, though the philosophy and process of assessing data validity will likely apply to future versions of the Software.

The AWWA Software Subcommittee also publishes a compiler tool available for download from the Water Loss Control web portal to enable utilities and their partners to assess multiple water audits simultaneously. The current iteration of the Microsoft Excel-based AWWA Compiler

Software can combine thousands of individual audits at a time into a single flat spreadsheet. The Compiler Software allows benchmarking among utilities and multi-year performance tracking for the same utility.

Water Research Foundation Leakage Component Analysis Model

A water audit generates an initial estimate of the total volume of Real Losses, but additional leakage data and analysis is necessary to plan cost-effective Real Loss reduction. To determine the most appropriate interventions against leakage, a utility should complete a Component Analysis of Real Losses after preparing a water audit. A Component Analysis of Real Losses divides the total volume of leakage into distinct types of leakage based on how the leakage can be discovered and reduced.

The Water Research Foundation offers a free software tool for utilities to conduct a Component Analysis of Real Losses. The tool, Leakage Component Analysis software, collates and analyzes leak repair and infrastructure data so that the user can plan cost-effective interventions against leakage. Leakage Component Analysis software can be downloaded from the Water Research Foundation's project 4372 webpage.

CHAPTER 2

HOW DOES DATA QUALITY AFFECT A WATER AUDIT?

The accuracy of each data input directly affects the accuracy of the final water audit. Accurate water audits allow for effective water loss control strategies to be planned. Therefore, it's essential that the quality of data that supports a water audit is examined and understood.

By studying the quality of water audit data, a water audit validator will:

- explore and document uncertainty
- minimize inaccuracy

WHAT FACTORS INFLUENCE DATA QUALITY?

To validate water audit data, it's helpful to appreciate how inaccuracy and uncertainty can be introduced into a water audit.

Inaccuracy and uncertainty can be introduced into a water audit at three distinct levels of data production (Sturm et al. forthcoming):

- primary measurement of raw water audit data
- secondary data transfer and summary of primary measurements
- human interaction with data and methodology, including estimation

When validating a water audit, the validator should keep each of these sources of inaccuracy and uncertainty in mind to minimize and document their effects on the overall quality of a water audit.

Primary Measurement of Raw Water Audit Data

Primary measurements – the raw values recorded by instruments that capture volumes, flow rates, pressure, and other essential facets of utility operations – form the foundation of a water audit. Inaccuracies in foundational data cumulatively contribute to overall water audit inaccuracy. In the absence of relevant instruments, water audit data can be estimated, as discussed below in the section on human interaction with water audit data.

Careful investigation of the reliability and efficacy of the instruments that produce raw water audit data is necessary to ascertain the accuracy of a water audit.

The validator should consider the factors that influence instrument accuracy, to the extent aligned with the scope of validation. These factors include:

- maintenance practices
- installation conditions
- accuracy test practices and results
- calibration and programming
- measurement resolution
- sampling and recording frequency

To capture inaccuracies in water audit data resulting from instrument performance, level 2 and/or level 3 water audit validation (described in Chapter 3) should be performed. Level 1 validation typically will not diagnose inaccuracies due to instrument malfunction.

Secondary Data Transfer and Summary of Primary Measurements

Once data has been collected through primary measurement, it is often transferred to permanent storage. Permanent archival can involve data reformatting and multiple data management systems, which can introduce inaccuracy into the final archived data. Therefore, the validator should study the process of data transfer and storage whenever possible and aligned with the scope of validation.

After data has been archived, inaccuracy and uncertainty can also be introduced when data is accessed and summarized for the purposes of the water audit. Documenting utility operations for an entire year produces many individual data points. As a result, working with a year's worth of data describing a wide range of daily operations can be time-intensive. Instead of reckoning with thousands, if not millions, of individual measurements, auditors and validators may instead choose to work with summarized datasets. Additionally, because the AWWA Free Water Audit Software accepts only a handful of inputs to communicate entire system performance, summary of raw data is necessary.

To condense raw data points into a single descriptive value, an auditor may perform a variety of mathematical operations. Furthermore, the programs and data management systems used to collate water audit data may be programmed to automatically perform mathematical operations in producing an output.

The validator should identify how raw data was selected and summarized to confirm that the summary number in the water audit reflects utility operations as accurately as possible. Potential operations performed include:

- averaging
- summing

- interpolating
- extrapolating
- identifying a minimum
- identifying a maximum
- calculating a mode
- calculating a median
- performing a regression

Whether these operations are performed by the auditor or by data management systems (SCADA, billing software, GIS applications, work order platforms, etc.), it is essential that the data selected for summary is indeed the correct data.

Archival and summarizing functions can introduce inaccuracy or uncertainty into a water audit. To the extent required by the level of validation, it is up to the validator to catch inaccuracy and note the potential for uncertainty introduced by data archival, data management systems, and data summary.

Human Interaction with Data and Methodology, Including Estimation

Water auditing often necessitates that an auditor choose sources of data, methods of estimation, and tailored interpretations of general methodology. If the auditor's choices do not accurately capture a utility's audit period performance, the resulting audit is likely to be inaccurate or uncertain.

To identify potential inaccuracy and uncertainty introduced by the auditor, the validator should note the choices that the auditor made in completing the audit. Where possible and aligned with the scope of validation, the outcomes resulting from other choices should be explored, and alternate data sources should be identified.

HOW DOES THE AWWA SOFTWARE ASSESS DATA QUALITY?

Internationally, water audit data quality has been expressed with a range of techniques, from statistical methods that incorporate confidence intervals to qualitative systems that use alphanumeric scales. In North America, the AWWA Free Water Audit Software is recognized as the standard tool for collecting water audit data and qualitatively communicating the data's quality.

In 2010, a data validity grading capability was introduced to the AWWA Free Water Audit Software, version 4. In the AWWA Software system, each input to the Software spreadsheet is assessed for validity on a qualitative, 1-to-10 scale. For some inputs, a grade of N/A may also be selected.

A grade of 1 indicates lowest validity.

A grade of 10 indicates highest validity.

The criteria for grading the validity of each input is unique to that input. This acknowledges that the practices that support data integrity for one volume or data point are often distinct from the practices supporting data integrity for a different volume. For example, it is important to maintain supply meter accuracy to accurately calculate the volumes of Water Supplied, but correctly monitoring and assessing average system pressure requires that attention be paid to pressure models and pressure logging instruments.

To assist both auditors and validators in grading the validity of each input, the AWWA Software includes instructions and a Grading Matrix. The Software user can find the unabridged matrix in the “Grading Matrix” tab of the Software. The Grading Matrix provides two levels of guidance for each water audit data input: criteria for selecting a grade and actions to take to achieve a higher grade in future water audits. Additionally, the criteria for grading each input also appear in a hover box over the data grade input cell in the Reporting tab of the Software.

When evaluating data validity grades, the validator must remember that all criteria must be met or exceeded for a given grade and all grades below it in order for that grade to apply.

Once data validity grades have been assigned to all water audit inputs, the AWWA Software calculates a composite Data Validity Score (DVS). The DVS reflects the extent to which the water utility employs best practices in collecting, managing, and analyzing water audit data. The DVS is weighted and normalized to 100, with the most weight given to the largest volumes in the water audit.

Lastly, the AWWA Software also includes a Water Loss Control Planning Guide, a table that evaluates the DVS in five ranked ranges. A DVS falling in lower ranges prompts a utility to implement practices that promote the collection of more reliable data. A DVS in higher ranges indicates that water audit data is reliable enough to serve as the basis for water loss intervention planning.

CHAPTER 3

WHAT IS WATER AUDIT VALIDATION?

Water audits are composed of individual data inputs. If water audit data inputs are inaccurate, the water audit results will also be inaccurate. As a result, simply compiling a water audit does not guarantee accuracy. Primary measurement, secondary data summary, human interpretation of data and methodology, and estimation can introduce inaccuracy and uncertainty into the final water audit.

To determine the potential for inaccuracy and uncertainty in a water audit, the audit should be validated.

According to Sturm et al. (forthcoming), water audit validation is the process of examining water audit inputs in order to:

1. Identify and appropriately correct for inaccuracies in water audit data and application of methodology
2. Evaluate and communicate the uncertainty inherent in water audit data

Additionally, water audit validation helps ensure that water audit data validity grades and the overall Data Validity Score reliably represent the operations and practices of the water utility during the audit year.

Without a methodical, validated water audit, it is possible that estimations of water loss misrepresent what a utility is actually experiencing. As a result, a water audit that has not been validated can mislead stakeholders, customers, regulators, and the utility itself in stewarding valuable water and financial resources.

Furthermore, water audit validation provides a degree of quality control to utility water audit data. While not guaranteeing that the final water audit is free of inaccuracy or uncertainty, the validation process does strengthen water audit results so that utilities can more effectively plan water loss control efforts, track performance, benchmark indicators, and improve future water audits.

WHAT ARE THE LEVELS OF WATER AUDIT VALIDATION?

The depth of water audit validation depends on the utility's goals and resources. At one end of the spectrum of validation, validation can be an introductory assessment of data inputs that looks for evident inaccuracies and correct application of methodology. At the other end of the spectrum, validation can be much more rigorous, involving a complete interrogation of all data sources and field tests of instrument accuracy.

There are three levels of water audit validation that build upon self-reported water audits, each with a distinct aim and level of effort.

The levels of validation below were discussed by WLCC (2015), Sturm et al. (2015) and Sturm et al. (forthcoming). The definitions below have developed throughout these works.

Self-reported water audits have not been validated. Their accuracy and reliability have not been confirmed.

Level 1 validated water audits have been examined for inaccuracies evident in summary data and application of methodology. The data validity grades assigned to inputs accurately reflect utility practices.

Level 2 validated water audits have been corroborated with investigations of raw data and archived reports of instrument accuracy. The best sources of data to inform the water audit have been identified.

Level 3 validated water audits have been bolstered by field tests of instrument accuracy. The water audit's estimate of Real Losses has been confirmed through pilot leak detection, Component Analysis of Real Losses, and/or minimum night flow analysis.

Because validation can be conducted at distinct levels with distinct outcomes, it is necessary to define the purpose and level of validation before starting the validation process.

WHO SHOULD VALIDATE WATER AUDITS?

When selecting a person to validate a water audit, it is important to consider the validator's relationship to the water audit, knowledge of validation methodology, and overall posture toward data quality and validation.

A water audit validator should not be the person who compiled the water audit.

The process of water audit review is made more effective when the validator approaches the water audit with fresh eyes, having not been intimately involved in its assembly. Nonetheless, the validator may be a part of the same organization as the auditor, and a validator may validate the audit of his or her own utility.

The effectiveness of water audit validation hinges on the knowledge and skills of the validator. A validator must:

- Be proficient in current AWWA M36 best practices for water audit preparation and validation
- Have access to the data and people that informed the water audit

- Be gently skeptical of water audit data and data validity grades, as initially submitted
- Ask open-ended questions and listen to the answers
- Document the process and outcomes of water audit validation

In addition to having these technical capacities, a water audit validator must also adopt a posture toward water auditing and validation that furthers the goals of validation.

A water audit validator should be:

- objective in order to appreciate the interplay between instrumentation, data management systems, and utility staff as it affects the water audit
- transparent in order for validation findings to improve the quality of the water audit
- diplomatic in order to appreciate the work that went into compiling the water audit but still uncover inaccuracies
- methodical in order to catch all potential inaccuracies or sources of uncertainty through the validation process
- forward-thinking in order for the recommendations resulting from validation to improve the water audit and water loss control in subsequent years

CHAPTER 4

WHAT DEFINES LEVEL 1 WATER AUDIT VALIDATION?

The levels of water audit validation are defined by distinct goals, outcomes, and limitations. Therefore, to discuss level 1 water audit validation, it's important to enumerate what level 1 validation does and does not do.

Level 1 water audit validation ensures that the data validity grades assigned to data inputs accurately describe utility practices. In addition, the level 1 validation process aims to document and correct for inaccuracies that are evident at the summary level and confirm the correct application of water audit methodology.

WHAT DOES LEVEL 1 WATER AUDIT VALIDATION DO?

As per Sturm et al. (forthcoming) the Level 1 water audit validation aims to:

- confirm the accurate application of AWWA M36 water audit methodology and terminology to the utility-specific situation
- identify evident inaccuracies and correct inaccuracies, where realistic
- verify the selection of correct data validity grades

In meeting these goals, the level 1 validation process results in:

- data validity grades that reflect utility practices
- identification of macroscopic inaccuracies
- recommendations for advanced validation activities

WHAT DOES LEVEL 1 WATER AUDIT VALIDATION NOT DO?

Level 1 water audit validation is the least rigorous level of validation. The effort and time required to complete level 1 validation are relatively small. As a result, a level 1 engagement with data sources and the water audit has limitations.

Level 1 water audit validation does not:

- correct inaccuracies in raw data that may affect summary data and audit inputs
- investigate data processing and handling to identify and correct inaccuracies
- study instrument accuracy through field tests to improve the certainty of the water audit
- corroborate the volume of Real Losses with bottom-up or field investigations of leakage

Given these limitations, anyone who wishes to understand the performance of key water audit instruments and data management systems; study raw data for gaps, redundancies, and inaccuracies; or document the translation of data from measurement to summary should perform higher-level validation activities.

The more rigorous the validation, the more likely the water audit is to be accurate and representative of actual utility performance. As a result, level 1 water audit validation is often only a starting point in the effort to compile reliable water audits. Higher-level validation activities are usually needed to produce and confirm high-quality water audits that inform long-term, cost-effective water loss control.

CHAPTER 5

HOW DO I PERFORM LEVEL 1 WATER AUDIT VALIDATION?

Before a water audit can be validated, it must be prepared. The process of preparing a water audit is distinct from the process of validating a water audit. Though many of the best practices for water audit validation can also apply to water audit preparation, this manual guides validators in performing level 1 water audit validation; it does not address water audit preparation. For an in-depth treatment of water audit preparation, please refer to AWWA Manual M36: Water Audits and Loss Control Programs.

Level 1 water audit validation consists of 5 steps:

1. Receive and review the water audit and supporting documentation.
2. Review performance indicators for evidence of inaccuracy.
3. Review audit inputs and data validity grades and confirm correct application of methodology in a level 1 validation interview. Adjust inputs and data validity grades if necessary.
4. Review performance indicators again for evidence of persisting inaccuracy.
5. Document results.

Each step is described on the following pages.

The validator should keep in mind that the goals of a level 1 validation effort are confirming that the methodology was correctly interpreted, identifying evident inaccuracies, and verifying that data validity grades accurately reflect utility practices. Level 1 validation will not correct – or even identify – all inaccuracies that may be present in a water audit. Nonetheless, the potential for uncertainty in a water audit will be better understood following a level 1 validation.

STEP 1: RECEIVE AND REVIEW THE WATER AUDIT AND SUPPORTING DOCUMENTATION

When preparing to perform level 1 water audit validation, the validator should request and receive the water audit and the documentation necessary to corroborate key water audit inputs, methodology, and data validity grades. Though much data likely supports the water audit, an in-depth examination of water audit data, analyses, and instrumentation is beyond the scope of level 1 validation.

At minimum, the validator should request and receive:

- Completed AWWA Free Water Audit Software
- Volume from Own Sources detailed by month and supply meter

- Water Imported detailed by month
- Water Exported detailed by month
- Supply meter testing and/or calibration documentation (if supply meters are tested and/or calibrated)
- Volume of water sold detailed by month and rate code (e.g. charge status, water type, or customer class)

If the validator does not receive all required supporting documentation, the water audit cannot be level 1 validated.

Additional supporting documentation will improve the level 1 validation process, but such information is not strictly necessary to complete a level 1 water audit validation. Helpful supplemental documentation includes the derivations of Customer Meter Inaccuracy, Average Operating Pressure, Customer Retail Unit Cost, and Variable Production Cost. Additionally, audits from previous years can be collected to examine consistency from one year to the next, if previous audits are available.

Once the validator has received the water audit and supporting documentation, the validator should schedule a conversation with the auditor and other utility staff positioned to describe utility practices.

Level 1 validation consists primarily of an interview between the validator, the auditor, and utility staff.

In the interview, the validator should ask open-ended questions to explore the utility practices that maintain the quality of infrastructure, instruments, data, and general operations.

Because each utility operates uniquely, every interview and the collection of supporting documentation must be tailored to the utility. However, some general questions and lines of inquiry that pertain to water audit inputs and data validity grades are provided in this manual for the third step, reviewing water audit inputs.

Once the validator has collected supporting documentation and scheduled a level 1 validation interview, the validator should examine initial performance indicators for evidence of inaccuracy,

STEP 2: EXAMINE PERFORMANCE INDICATORS FOR EVIDENCE OF INACCURACY

The “Performance Indicators” tab of the AWWA Software lists a suite of performance indicators calculated using the data inputs provided by the auditor. Prior to the level 1 validation interview,

each performance indicator can be checked for feasibility as described below to supply an initial assessment of the overall reliability of the water audit. Additionally, by studying initial performance indicators before examining each audit input in the interview, the validator will be positioned to identify potential audit data inaccuracies contributing to questionable performance indicators.

Non-Revenue Water as a Percent by Cost of Operating System

To calculate Non-Revenue Water as a percent by cost of operating system, the audit software first calculates the value of Apparent Losses using the Customer Retail Unit Cost. Then, the audit software calculates the value of Real Losses and Unbilled Authorized Consumption using either the Variable Production Cost (default) or the Customer Retail Unit Cost, depending on the auditor's selection. Next, the audit software sums the Non-Revenue Water component volume valuations to determine the total value of Non-Revenue Water. Finally, the audit software divides the value of Non-Revenue Water by the total cost of operating the system.

To verify that the results of the audit are technically feasible, this performance indicator should be greater than 0% and less than 100%. A performance indicator in this range communicates that some but not all of the utility's operating budget covers the intrinsic cost of water losses.

- Is Non-Revenue Water as a percent by cost of operating system greater than 0%?
- Is Non-Revenue Water as a percent by cost of operating system less than 100%?

If Non-Revenue Water as a percent by cost of operating system does not pass this check, at least one of the volumetric or cost inputs is inaccurate.

Apparent Losses Per Service Connection Per Day

To calculate Apparent Losses per service connection per day, the audit software divides the total Apparent Loss volume by the count of service connections and the number of days in the audit period. Apparent Losses per service connection per day as a performance indicator is often referred to as "normalized Apparent Losses."

Generally, utilities incur Apparent Losses through theft, meter under-registration, and errors in data handling. As a result, the majority of utilities will have positive values of normalized Apparent Losses.

However, a handful of utilities may experience negative normalized Apparent Losses through meter over-registration and certain errors in data handling, like duplication. However, such a situation is unlikely. Should a utility present negative normalized Apparent Losses, the validator should pay careful attention to the derivation of Apparent Loss volumes.

Real Losses (Normalized)

The AWWA Free Water Audit Software reports Real Losses as a total volume and then calculates a series of normalized Real Loss performance indicators.

For systems with a service connection density equal to or greater than 32 connections per mile of main, the audit software normalizes Real Losses to service connections and to operating pressure. To arrive at Real Losses normalized to service connections, the audit software divides the Real Loss volume by the count of service connections and the number of days in the audit period. Results are presented in gallons per connection per day. The audit software also further normalizes Real Losses to pressure by dividing Real Losses normalized to service connections by the average operating pressure. Results are presented in gallons per connection per day per PSI of pressure.

For systems with a service connection density less than 32 connections per mile of main, the audit software normalizes Real Losses to the length of mains. To arrive at Real Losses normalized to the length of mains, the audit software divides the Real Loss volume by the miles of main and the number of days in the audit period. Results are presented in gallons per mile of main per day.

To verify that the results of the audit are technically feasible, all normalized Real Loss performance indicators should be greater than 0 gallons per day. A normalized Real Loss performance indicator greater than 0 gallons per day indicates that the utility lost some of the volume it supplied to leakage, as is expected.

- Is Real Losses (normalized) greater than 0 gallons?

If normalized Real Losses does not pass this check, at least one of the volumetric inputs is incorrect.

Infrastructure Leakage Index

To calculate the Infrastructure Leakage Index (ILI), the audit software divides the derived volume of Real Losses by the volume of Unavoidable Annual Real Losses (UARL). The UARL is modeled using the length of mains, count of service connections, average length of customer service lines, and average operating pressure. The ILI is a dimensionless ratio that compares a utility's Current Annual Real Losses (CARL) volume to its calculated technical minimum volume of leakage. (Alegre et al. 2000)

To verify that the results of the audit are technically feasible, this performance indicator should be greater than 1.0. An ILI greater than 1.0 indicates that the utility lost a volume of leakage greater than its calculated technical minimum volume of leakage.

- Is the ILI greater than 1.0?

If the ILI does not pass this check, it is likely that at least one of the volumetric inputs, infrastructure inputs, or average system pressure is incorrect.

However, a handful of very efficient utilities have reported and defended ILIs less than 1.0. Such remarkable performance suggests that the modeling assumptions underlying the calculation of the ILI need to be adjusted to apply to this subset of systems. Should a utility present an ILI less than 1.0, the validator should pay careful attention to all audit inputs and explore the utility’s infrastructure maintenance and renewal programs. For a water utility to have a valid ILI close to or below 1.0, the utility must have extensive and verifiable leakage policies and practices in place.

Summary

Initial performance indicator checks are condensed in Table 1. Should the performance indicator fail the check, the validator should pay particular attention to the contributing inputs in the process of level 1 validation.

**Table 1
Performance indicator checks**

CATEGORY	PERFORMANCE INDICATOR	CHECK	CONTRIBUTING INPUTS
NRW	Non-Revenue Water as a percent by cost of operating system	$0\% < \text{NRW (cost)} \% < 100\%$	volumetric inputs, cost inputs
Real Losses	Real Losses / service connection / day	Real Losses > 0 gal	volumetric inputs
	Real Losses / length of main / day		
	Real Losses / service connection / day / PSI pressure		
ILI	Infrastructure Leakage Index	$\text{ILI} > 1.0$	volumetric inputs, infrastructure inputs, average system operating pressure

Once the validator has examined initial performance indicators, he or she should proceed to assessing the validity of each water audit input and data validity grade. If the performance indicator review suggests that the water audit is likely inaccurate, the validator should remain alert to this fact when reviewing the relevant contributing inputs.

STEP 3: VALIDATE AUDIT INPUTS, CONFIRM CORRECT APPLICATION OF METHODOLOGY, AND CHANGE INPUTS AS NECESSARY

After examining performance indicators for technical feasibility, the validator should explore the derivation of each audit input and systematically assess data validity grade selections. The data

validity grading themes are unique for each input, so this manual elucidates the important considerations for the assignment of each grade. Additionally, this manual identifies the common errors associated with each input and provides examples of the data validity scoring process.

The AWWA Free Water Audit Software contains 20 data inputs. For each audit input, the validator should ask the following broad questions:

- How did the auditor arrive at the water audit input?
- How did the auditor interpret general methodology and definitions to apply to the specifics of the system?
- How did the auditor select a data validity grade?
- How does the audit input compare to previous years (if applicable)?

In evaluating the data validity grade for each input, the validator should keep in mind that all criteria must be met or exceeded for a given grade and all grades below it in order for that grade to apply. The AWWA Software grading matrix does provide flexibility in assigning grades by permitting the user to select odd numbers (3, 5, 7, and 9), which exist without descriptive criteria but fall between even grades.

The example data validity grading scenarios presented in the following pages use grading criteria extracted from AWWA Software version 5.0.

Volume from Own Sources

Volume from Own Sources is the volume of water withdrawn from water resources (rivers, lakes, wells, etc.) controlled by the utility and treated for potable water distribution (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Volume from Own Sources input depends on:

- the extent of production metering
- the frequency and results of calibration of the meters' related instrumentation
- the frequency and results of meter volumetric accuracy testing

To grade the validity of the Volume from Own Sources input the validator will have to answer the following questions.

- How many distinct own-source distribution inputs are there?
 - How many inputs are metered?
 - Are any of the meters in series?
 - Do the meters capture raw water or potable water?
 - How are unmetered inputs estimated?
- Which own-source meters are calibrated? How often are calibrations performed?
 - What were the results of the calibrations closest to the audit period?
- Which own-source meters are volumetrically tested? How often are tests conducted?
 - What were the results of the volumetric accuracy tests closest to the audit period?

Common Errors

In validating the Volume from Own Sources input, it is important to maintain a distinction between meter calibration and meter volumetric accuracy testing.

Meter calibration pertains to a meter's secondary instrumentation. Meter calibration ensures the accurate communication and conversion of electronic signals.

Meter volumetric accuracy testing studies a meter's primary measuring mechanism. In volumetric testing, a meter's registered volume is compared to a known reference volume.

Meter calibration and volumetric accuracy testing each relate to a distinct aspect of meter performance. As a result, a meter's accuracy is best understood when both maintenance

practices are jointly employed. Achieving a high data validity grade requires that a utility calibrate and volumetrically test meters; mid-range grades require either calibration or volumetric accuracy testing.

Additionally, it is important that the Volume from Own Sources consist exclusively of potable water. If a utility does not meter all potable water and instead meters raw water prior to the treatment process, the validator will need to investigate the estimations employed to arrive at a volume of potable water. A minor volume of water is usually consumed in the treatment process, resulting in a potable water volume slightly smaller than the raw water volume.

Example Data Validity Grade Selection

A utility meters all potable water that it produces and inputs into the distribution system. The utility calibrates all meters annually, and calibrations during the audit period indicated deviations of less than 1% for all meters. However, the utility does not conduct any volumetric accuracy testing of input meters. Production volumes are reviewed weekly by staff to identify anomalies in data.

What data validity grade should this utility receive for Volume from Own Sources?

To receive a grade of 6,

At least 75% of treated water production sources are meters, or at least 90% of the source flow is derived from metered sources. Meter accuracy testing and/or electronic calibration of related instrumentation is conducted annually. Less than 25% of tested meters are found outside of $\pm 6\%$ accuracy.

To receive a grade of 7,

Conditions between 6 and 8.

To receive a grade of 8,

100% of treated water production sources are metered, meter accuracy testing and electronic calibration of related instrumentation is conducted annually, less than 10% of meters are found outside of $\pm 6\%$ accuracy (WLCC 2014)

This utility exceeds the criteria for a grade of 6. However, the utility does not meet all the criteria for a grade of 8. The utility does not perform annual calibration and volumetric testing, even though all other criteria for a grade of 8 are met.

Therefore, the appropriate grade is 7, indicating conditions between 6 and 8.

Volume from Own Sources – Master Meter and Supply Error Adjustment

Volume from Own Sources is adjusted for meter inaccuracy with a Master Meter and Supply Error Adjustment (MMEA). The auditor may choose to adjust for Master Meter and Supply Error using either a percentage input into the audit software or a volume that is then added or subtracted from the Volume from Own Sources. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Volume from Own Sources MMEA input depends on:

- the technology and frequency of data collection
- the frequency of data review
- the incorporation of change in stored volume

To grade the validity of the Volume from Own Sources MMEA input, the validator will have to answer the following questions.

- How are own-source production volumes sampled and recorded?
- How often is own-source production data reviewed?
 - Under what conditions is own-source production data adjusted?
- Are changes in stored volume incorporated?
 - If so, how?

Common Errors

Utility technicians may conduct calibration and maintenance of production meter instrumentation periodically. This work typically interrupts the signal from the production meter to the SCADA system for several hours, and SCADA may log zero-flow readings despite normal pumping and treatment operations. Unless the utility regularly reviews this data and adjusts recorded values to capture missed flow, the archived pumped or treated volume for the day of calibration will be understated, therefore introducing inaccuracy into the data.

Additionally, data validity grades above 3 require that a utility tracks daily changes in storage and that the change in stored volume over the course of the audit year is incorporated. If this volume is not included in the water audit, the utility cannot receive a data validity grade higher than 3 for the Volume from Own Source Master Meter Error Adjustment.

Example Data Validity Grade Selection

A utility records production data continuously with a recently-upgraded SCADA system. Summary SCADA data is reviewed on Friday each week to identify anomalous values and gaps in data; errors and gaps are corrected whenever reasonably possible. The utility does not archive stored volumes in its SCADA system, and as a result the stored volume on the first day of the audit period and the last day of the audit period is not known.

What data validity grade should this utility receive for Volume from Own Sources Master Meter Error and Supply Adjustment?

To receive a grade of 2,

No automatic datalogging of production volumes; daily readings are scribed on paper records without any accountability controls. Flows are not balanced across the water distribution system; tank or storage elevation changes are not employed in calculating the Volume from Own Sources component, and archived flow data is adjusted only when grossly evident data error occurs.

To receive a grade of 3,

Conditions between 2 and 4.

To receive a grade of 4,

Production meter data is logged automatically in electronic format and reviewed at least on a monthly basis with necessary corrections implemented. Volume from own sources tabulations include estimate of daily changes in tanks/storage facilities. Meter data is adjusted when gross data errors occur, or occasional meter testing deems this necessary. (WLCC 2014).

Though this utility logs production data automatically and reviews the data weekly, the volume in storage is not considered in the estimation of Volume from Own Sources. Therefore, because all criteria for a given grade must be met for that grade to apply, this utility does not qualify for a grade of 4. Nonetheless, the utility exceeds the criteria for a grade of 2.

Therefore, the appropriate grade is 3.

Water Imported

Water Imported is the volume of bulk water purchased to supply the distribution system. Typically, Water Imported is purchased from a neighboring water utility or regional water authority and is metered at a point of interconnection between the two utilities. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Water Imported input depends on:

- the extent of import metering
- the frequency and results of calibration of the import meters' related instrumentation
- the frequency and results of import meter volumetric accuracy testing

To grade the validity of the Water Imported input, the validator will have to answer the following questions.

- How many distinct import connections are there?
 - How many import connections are metered?
 - Are any of the meters in series?
 - Do the meters capture raw water or potable water?
 - How are unmetered imports estimated?
- How often are import meters calibrated? Which meters are calibrated?
 - What were the results of the calibrations closest to the audit period?
- How often are import meters tested for volumetric accuracy? Which meters are volumetrically tested?
 - What were the results of the volumetric accuracy tests closest to the audit period?

Common Errors

In validating the Water Imported input, it is important to maintain a distinction between meter calibration and meter volumetric accuracy testing, especially for the assignment of higher data validity grades. For more information about the difference between calibration and volumetric accuracy testing, please reference the preceding section about validating the Volume from Own Sources input.

It is also important that the volume of Water Imported consist exclusively of potable water. If a utility imports raw water and then treats imported water itself without metering after the

treatment process, the validator will need to investigate the estimations employed to arrive at a volume of potable Water Imported.

Finally, if a utility imports water through emergency interconnections that are not always active, this imported volume should still be included in the water audit. The auditor and validator will need to note the tracking mechanisms that document emergency imports and inform the water audit.

Example Data Validity Grade Selection

A utility has four interconnections with a regional water wholesaler. Historically, all four connections are metered and see approximately equal volumes of throughput. However, one of the import meters was offline during the audit period for meter vault reconstruction. To maintain the connection, the wholesaler constructed an unmetered diversion around the meter vault to continue the supply. Because the diversion was not metered, the wholesaler billed the utility based on historical import volumes. Additionally, the wholesaler performs meter calibration every six months on all four meters, though the wholesaler did not calibrate the offline meter during the audit period. All recent calibrations have determined meters to electronically deviate no more than 4%.

What data validity grade should this utility receive for Water Imported?

To receive a grade of 4,

50% - 75% of imported water sources are metered, other sources estimated. Occasional meter accuracy testing conducted.

To receive a grade of 5,

Conditions between 4 and 6.

To receive a grade of 6,

At least 75% of imported water sources are metered, meter accuracy testing and/or electronic calibration of related instrumentation is conducted annually for all meter installations. Less than 25% of tested meters are found outside of $\pm 6\%$ accuracy.
(WLCC 2014)

Ordinarily all water that the utility imports is metered. However, during this particular audit period, only 75% of imported water was metered due to meter vault reconstruction. Additionally, all meters are calibrated at least annually but not volumetrically tested.

Given these factors, the utility exceeds the criteria for a grade of 4. However, the utility does not satisfy the criteria for a grade of 6.

Therefore, the appropriate grade is 5, indicating conditions between 4 and 6. In future years when all imported water is metered, the utility will qualify for a higher data validity grade for Water Imported, assuming all other import considerations remain the same.

Volume Imported – Master Meter and Supply Error Adjustment

Volume Imported is adjusted for meter inaccuracy with a Master Meter and Supply Error Adjustment (MMEA). The auditor may choose to adjust for Master Meter Error using either a percentage input into the audit software or a volume that is then added or subtracted from the Volume Imported. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Water Imported MMEA input depends on:

- the technology and frequency of data collection
- the frequency of data review
- the documentation and clarity of interagency import-export agreement

To grade the validity of the Water Imported MMEA input, the validator will have to answer the following questions.

- How are Water Imported volumes recorded?
 - How often are Water Imported volumes captured?
- How often is Water Imported data reviewed?
 - Under what conditions is Water Imported data adjusted?
- What documentation is available to describe the interagency import-export agreement?

Example Data Validity Grade Selection

A utility imports water from a regional wholesaler through a single meter. The terms of the import-export agreement are recorded in written materials and revisited once a decade. The meter is owned by the wholesaler, who is contractually obligated to volumetrically test and calibrate the meter annually. However, the wholesaler was unable to produce any documentation when asked for the most recent test and calibration records.

The wholesaler also operates a SCADA system that continually logs the transferred volume, and production data is reviewed daily for errors and gaps. Corrections to archived data are made as appropriate and thoroughly documented.

What data validity grade should this utility receive for Water Imported Master Meter Error and Supply Adjustment?

To receive a grade of 8,

Continuous Imported supply metered flow data is logged automatically and reviewed each business day by the Exporter. Data is adjusted to correct gross error from detected meter or instrumentation equipment malfunction and/or results of meter accuracy testing. Any data errors or gaps are detected and corrected on a daily basis. A data trail exists for the process to protect both the selling and the purchasing Utility.

To receive a grade of 9,

Conditions between 8 and 10.

To receive a grade of 10,

Computerized system (SCADA or similar) automatically records data which is reviewed each business day by the Exporter. Tight accountability controls ensure that all errors and data gaps that occur in the archived flow data are quickly detected and corrected. A reliable data trail exists and contract provisions for meter testing and data management are reviewed by the selling and purchasing Utility at least once every five years. (WLCC 2014)

Because data is logged continuously and reviewed daily and documentation of the import-export agreement exists, this utility exceeds a grade of 8. However, because the exporter was unable to produce a “reliable data trail” for meter test and calibration results, the utility does not qualify for a grade of 10. Furthermore, the terms of the import-export agreement are only reviewed once every ten years, rather than once every five years as the criteria for a grade of 10 require.

Therefore, the appropriate grade is 9.

Water Exported

Water Exported is the volume of bulk water conveyed and sold by a water utility to a neighboring system(s) that exists outside the utility's service area. Typically, Water Exported is metered at a point of interconnection between the two water utilities, and usually the meter(s) is owned by the utility that sells the water. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

It is important to note that the Water Exported volume is sold in bulk to agencies who are normally charged a wholesale rate. Wholesale rates tend to differ from retail rates charged to customers within a utility's own service territory. As a result, it is important to differentiate Water Exported from Billed Metered Authorized Consumption and avoid double-counting the volume of Water Exported. (WLCC 2014).

Data Validity Themes

The validity of the Water Exported input depends on:

- the extent of export metering
- the frequency and results of export meter calibration
- the frequency and results of export meter volumetric accuracy testing

To grade the validity of the Water Exported input, the validator will have to answer the following questions.

- How many distinct export connections are there?
 - How many export connections are metered?
 - Are any of the meters in series?
 - Do the meters capture raw water or potable water?
 - How are unmetered exports estimated?
- How often are export meters calibrated? Which meters are calibrated?
 - What were the results of the calibrations closest to the audit period?
- How often are export meters tested for volumetric accuracy? Which meters are volumetrically tested?
 - What were the results of the volumetric accuracy tests closest to the audit period?

Common Errors

In validating the Water Exported input, it is important to maintain a distinction between meter calibration and meter volumetric accuracy testing, especially for the assignment of higher data validity grades. For more information about the difference between calibration and volumetric

accuracy testing, please reference the preceding section about validating the Volume from Own Sources input.

Additionally, if a utility exports water through emergency interconnections that are not always active, this exported volume should still be included in the water audit. The auditor and validator will need to note the tracking mechanisms that document emergency exports and inform the water audit.

Utilities who sell bulk water as a wholesale export must be careful to categorize this water as Water Exported and not double-count it as Billed Metered Authorized Consumption. Wholesale exports are commonly tracked in the billing database, so the auditor and validator alike should confirm that wholesale export volumes have been extracted from billing summaries and included in the volume of Water Exported.

Example Data Validity Grade Selection

The criteria for grading the validity of the Water Exported volume is identical to the criteria for grading the validity of the Water Imported volume, only applied in reference to an export meter(s) and the corresponding contractual arrangement. Therefore, for an example of the grading process as it pertains to volumes of Water Imported and Water Exported, please refer back to the section on Water Imported.

Volume Exported – Master Meter and Supply Error Adjustment

Volume Exported is adjusted for meter inaccuracy with a Master Meter and Supply Error Adjustment (MMEA). The auditor may choose to adjust for Master Meter Error using either a percentage input into the audit software or a volume that is then added or subtracted from the Volume Imported. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Water Exported MMEA input depends on:

- the technology and frequency of data collection
- the frequency of data review
- the documentation and clarity of interagency import-export agreement

To grade the validity of the Water Exported MMEA input, the validator will have to answer the following questions.

- How are Water Exported volumes recorded?
 - How often are Water Exported volumes captured?
- How often is Water Exported data reviewed?
 - Under what conditions is Water Exported data adjusted?
- What documentation is available to describe the interagency import-export agreement?

Example Data Validity Grade Selection

The criteria for grading the validity of the Water Exported Master Meter and Supply Error Adjustment is identical to the criteria for grading the validity of the Water Imported Master Meter and Supply Error Adjustment, only applied in reference to an export meter(s) and the corresponding contractual arrangement. Therefore, for an example of the grading process as it pertains to volumes of Water Imported MMEA and Water Exported MMEA, please refer back to the section on Water Imported MMEA.

Billed Metered Authorized Consumption

Billed Metered Authorized Consumption (BMAC) is water delivered to metered customers who receive a bill and generate revenue for a utility. All billed and metered customer groups are incorporated in the total Billed Metered Authorized Consumption volume, including domestic, commercial, industrial, potable irrigation, and agricultural users. However, bulk water exported is not considered a component of Billed Metered Authorized Consumption. Instead, Water Exported is a component of the System Input Volume used to calculate Water Supplied. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the BMAC input depends on:

- the prevalence of customer metering
- the technology and success of customer meter read collection
- the frequency of customer meter replacement
- the prevalence and purpose of customer meter testing
- the technology of customer data management
- the frequency of customer meter data review

To grade the validity of the Billed Metered Authorized Consumption input, the validator will have to answer the following questions.

- What portion of customers are metered?
- How are customer meter reads collected?
 - What is the success rate of meter read collection?
- When are customer meters replaced?
- How many customer meters are tested annually? Why?
- How are customer bill records maintained?
 - How often are customer bill records audited? By whom?

Common Errors

The guidance provided for BMAC data validity grading incorporates three broad but distinct components of customer billing and metering: the prevalence of metering, the technology of meter read collection and management, and the policies surrounding meter replacement and testing. It is important that both the auditor and validator keep all three contributing factors in mind in selecting the grade for which all criteria are met. For the BMAC input, it is particularly

important that the validator strictly adhere to the requirement that a utility meet or exceed all criteria for a grade and all grades below it for that grade to legitimately apply.

For example, a utility may benefit from a fully-metered system with successful advanced metering infrastructure (AMI). However, if meters are only replaced upon complete failure, the utility cannot qualify for a data validity grade above 4.

Additionally, it will be important to confirm that the BMAC volume does not contain non-potable water, include unbilled authorized uses, or double-count volume already categorized as Water Exported.

Example Data Validity Grade Selection

A utility aims to meter all billed customers, and a recent study concluded that more than 99% of billed customers indeed have a radio-read (AMR) meter. The study also audited portions of the billing system and determined that introduction of error into the billing process is likely minimal, but structured or regular billing system audits are infrequently conducted. Furthermore, the utility maintains a customer meter replacement program in which meters are replaced 18 years after installation. It is utility policy that meters are tested only in response to customer requests.

What data validity grade should this utility receive for Billed Metered Authorized Consumption?

To receive a grade of 4,

At least 75% of customers with volume-based billing from meter reads; flat or fixed rate billing for remaining accounts. Manual meter reading is conducted with at least 50% meter read success rate; consumption for accounts with failed reads is estimated. Purchase records verify age of customer meters; only very limited meter accuracy testing is conducted. Customer meters are replaced only upon complete failure. Computerized billing records exist, but only sporadic internal auditing conducted.

To receive a grade of 5,

Conditions between 4 and 6.

To receive a grade of 6,

At least 90% of customers with volume-based billing from meter reads; consumption for remaining accounts is estimated. Manual customer meter reading gives at least 80% customer meter reading success rate; consumption for accounts with failed reads is estimated. Good customer meter records exist, but only limited meter accuracy testing is conducted. Regular replacement is conducted for the oldest meters. Computerized billing records exist with annual auditing of summary statistics conducted by utility personnel.
(WLCC 2014)

Though this utility maintains a population of automatic meter reading (AMR) meters that are regularly replaced and has completely audited its billing process, the utility does not perform significant customer meter accuracy testing. Meter accuracy testing is purely reactive and therefore very limited. Furthermore, this utility does not regularly audit its entire billing system; as a result, auditing is considered sporadic.

As a result, the appropriate grade is 4.

Billed Unmetered Authorized Consumption

Billed Unmetered Authorized Consumption (BUAC) is water delivered to unmetered customers who nonetheless receive a bill and generate revenue for the utility. Generally, billed unmetered customers pay a flat rate, even though consumption may be variable. As a result, Billed Unmetered Authorized Consumption volumes must typically be estimated for the purposes of the water audit. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the BUAC input depends on:

- the prevalence of customer meter installation
- the method of consumption estimation
- the clarity and comprehensiveness of utility metering policy

To grade the validity of the Billed Unmetered Authorized Consumption input, the validator will have to answer the following questions.

- What are utility policies regarding which customers must be metered?
 - Are metering policies clear?
 - Are metering policies consistently implemented?
- How is unmetered consumption estimated?

Common Errors

In assessing the validity of the BUAC input, the validator will need to study utility policy on customer metering exemptions and determine how effectively utility policy is implemented. While a utility may aim to meter all customers in accordance with written policy, it is possible that a significant portion of customers may nonetheless be unmetered due to unusual circumstances or incomplete customer data management.

Additionally, the BUAC volume pertains to volume that is unmetered due to utility policy. It does not include volume passed through meters that are installed but not functioning properly. Missed volume, whether partial or complete, is a form of Apparent Loss.

Example Data Validity Grade Selection

A utility has historically operated an unmetered system. However, three years ago the utility adopted a policy to meter all customers. Since the policy was adopted, meters were installed on a majority of service connections. As the meter installation program nears completion, the utility is conducting a census of all customer accounts to identify those that remain unmetered.

Preliminary results indicate that approximately 90% of customers now have a meter. To account for the consumption seen on the remaining unmetered accounts, the utility multiplied typical residential customer consumption by the estimated count of unmetered accounts.

What data validity grade should this utility receive for Billed Unmetered Authorized Consumption?

To receive a grade of 6,

Water utility policy does require metering and volume based billing but established exemptions exist for a portion of accounts such as municipal buildings. As many as 15% of billed accounts are unmetered due to this exemption or meter installation difficulties. Only a group estimate of annual consumption for all unmetered accounts is included in the annual water audit, with no inspection of individual unmetered accounts.

To receive a grade of 7,

Conditions between 6 and 8.

To receive a grade of 8,

Water utility policy does require metering and volume based billing for all customer accounts. However, less than 5% of billed accounts remain unmetered because meter installation is hindered by unusual circumstances. The goal is to minimize the number of unmetered accounts. Reliable estimates of consumption are obtained for these unmetered accounts via site specific estimation methods. (WLCC 2014)

The utility is nearing complete customer metering. Nonetheless, an unknown minority of customers remain unmetered, perhaps 10% of all customers. Therefore, it is prudent to select a data validity grade that acknowledges this uncertainty. Additionally, the utility used a single estimation to account for unmetered consumption, rather than site-specific estimates.

As a result, the appropriate grade is 7.

Unbilled Metered Authorized Consumption

Unbilled Metered Authorized Consumption (UMAC) is water delivered to metered customers but deemed by utility policy to be unbilled and therefore not revenue-generating (Alegre et al. 2000, AWWA 2009, WLCC 2014). This could include metered water consumed by the utility itself in treatment or distribution operations or metered water provided to a civic institution free of charge.

Data Validity Themes

The validity of the UMAC input depends on:

- the enforcement of billing policies
- the frequency of meter reading
- the precision of the count of unbilled metered connections

To grade the validity of the Unbilled Metered Authorized Consumption input, the validator will have to answer the following questions.

- What are utility policies regarding which customers are metered but unbilled?
 - Are billing exemption policies clear?
 - Are billing exemption policies consistently implemented?
- How often are unbilled meters read?
 - How is unbilled metered consumption estimated in the absence of a recent meter read?

Common Errors

Meter reading for unbilled customers and consumptive utility operations is generally a lower priority than collecting reads of revenue-generating meters. As a result, read frequency for unbilled customers or utility meters can be infrequent. Therefore, though an unbilled customer or utility operation may be metered, the meter may not have been read frequently enough to fully inform the audit, requiring the auditor to estimate some portion of UMAC.

Even though UMAC consumption may be estimated, it is important to maintain the categorization of the volume as metered, given that more accurate measurements of consumption could be achieved with more frequent meter reading.

Example Data Validity Grade Selection

A utility meters but does not bill treatment plant use, water utility office building consumption, and city park irrigation, as laid out in city contracts and operating protocols. In total, there are twelve unbilled metered accounts, a count the utility is confident about but has not audited this year. The utility has been short-staffed the past couple of years, so meter reading for unbilled accounts occurs only a few times annually.

What data validity grade should this utility receive for Unbilled Metered Authorized Consumption?

To receive a grade of 8,

Written policy identifies the types of accounts granted a billing exemption. Customer meter management and meter reading are considered secondary priorities, but meter reading is conducted at least annually to obtain consumption volumes for the annual water audit. High level auditing of billing records ensures that a reliable census of such accounts exists.

To receive a grade of 9,

Conditions between 8 and 10.

To receive a grade of 10,

Clearly written policy identifies the types of accounts given a billing exemption, with emphasis on keeping such accounts to a minimum. Customer meter management and meter reading for these accounts is given proper priority and is reliably conducted. Regular auditing confirms this. Total water consumption for these accounts is taken from reliable readings from accurate meters.
(WLCC 2014)

Though the utility operates with clear policies about customers granted billing exemptions and maintains a count of the number of exemptions, meters are not read nor audited frequently.

As a result, the appropriate grade is 8.

Unbilled Unmetered Authorized Consumption

Unbilled Unmetered Authorized Consumption (UUAC) is any form of Authorized Consumption that is neither billed nor metered and must therefore be estimated. Unbilled Unmetered Authorized Consumption typically includes water used for fire-fighting, water and sewer main flushing, street cleaning, and fire flow tests (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Users may select a default value (1.25% of Water Supplied) to estimate UUAC. Employing the default value automatically assigns a data validity grade of 5 to UUAC. Should the auditor choose instead to input a UUAC volume, the auditor will have to select an appropriate data validity grade.

Data Validity Themes

The validity of the UUAC input depends on:

- clarity of and adherence to documentation policies
- the method of consumption estimation

To grade the validity of the Unbilled Unmetered Authorized Consumption input, the validator will have to answer the following questions.

- What uses are unmetered and unbilled?
 - Are utility policies on unmetered and unbilled use clear?
- How are unmetered, unbilled uses documented?
 - How is consumption for each use estimated?

Common Errors

Water lost to leakage is not considered an authorized use and should therefore not be included in Unbilled Unmetered Authorized Consumption. However, water used for leak repair (for example, in post-repair flushing) is indeed authorized and should be categorized as Unbilled Unmetered Authorized Consumption.

Example Data Validity Grade Selection

A utility initially selects the default option to estimate UUAC. The utility then conducts a high-level census of UUAC volumes and determines that some uses, like sewer flushing, are easy to estimate because field operators reliably record flow rates and event durations. Other uses, like fire-fighting and post-repair flushing, are undocumented. Upon comparing the default volume to the utility's own estimates of UUAC, the utility notices that the default value grossly overestimates the probable volume of UUAC. Therefore, the utility chooses a more conservative assumption of 0.25% of Water Supplied to account for UUAC.

What data validity grade should this utility receive for Unbilled Unmetered Authorized Consumption?

To receive a grade of 2,

Clear extent of unbilled, unmetered consumption is unknown, but a number of events are randomly documented each year, confirming existence of such consumption, but without sufficient documentation to quantify an accurate estimate of the annual volume consumed.

To receive a grade of 3,

Conditions between 2 and 4.

To receive a grade of 4,

Extent of unbilled, unmetered consumption is partially known, and procedures exist to document certain events such as miscellaneous fire hydrant uses. Formulae is used to quantify the consumption from such events (time running multiplied by typical flowrate, multiplied by number of events).
(WLCC 2014)

Because the utility chose not to use the AWWA Software-supplied default value, the utility should choose a data validity grade other than 5 to describe the UUAC input. The utility maintained detailed records of some uses but no records of other uses. The UUAC records are not random, as a grade of 2 indicates. The utility does use formulae to quantify the uses from some events, but these formulae were used only to corroborate a simple percentage estimate of UUAC.

Therefore, the appropriate grade is 3.

Unauthorized Consumption

Unauthorized Consumption is water that an end user consumes illegitimately. This includes water illegally withdrawn from fire hydrants, illegal connections, bypasses around customer consumption meters, and other methods of extraction intended to circumvent the utility's ability to collect revenue. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Unauthorized Consumption tends to be a small volume, and discovering instances of Unauthorized Consumption is often resource-intensive. Nonetheless, some volume of Unauthorized Consumption is expected in all systems. As a result, the auditor may choose to select a value of 0.25% of Water Supplied to estimate Unauthorized Consumption. If an auditor has not yet gather detailed data capturing occurrences of Unauthorized Consumption, it is recommended that the auditor select the default value.

Data Validity Themes

The validity of the Unauthorized Consumption input depends on:

- insight into the extent of Unauthorized Consumption
- the method of Unauthorized Consumption estimation

To grade the validity of the Unauthorized Consumption input, the validator will have to answer the following questions.

- What instances of Unauthorized Consumption have been documented?
 - What information is captured in records of Unauthorized Consumption?
- How are unmetered, unbilled uses documented?
 - How is consumption for each use estimated?
- Are documented volumes of Unauthorized Consumption thorough enough to replace the default estimate?

Common Errors

Most users select the default value to estimate Unauthorized Consumption. Users are discouraged from inputting a value of zero, since a small volume of Unauthorized Consumption is expected for all systems.

Example Data Validity Grade Selection

A utility records occasional instances of discovered water theft, but most instances are not documented. During this audit period, the auditor found six reports of illegal connections and

three reports of intentional meter tampering. A loss volume was calculated for each discovered instance of theft, resulting in a total estimated loss of 0.7 acre-feet. Because the information describing Unauthorized Consumption appeared incomplete, the auditor chose to use the default value of 0.25% of Water Supplied, which produced an estimate of 1.5 acre-feet of Unauthorized Consumption.

What data validity grade should this utility receive for Unbilled Unmetered Authorized Consumption?

To receive a grade of 4,

Procedures exist to document some Unauthorized Consumption such as observed unauthorized fire hydrant openings. Use formulae to quantify this consumption (time running multiplied typical flowrate, multiplied by number of events).

To receive a grade of 5,

Default value of 0.25% of volume of Water Supplied is employed.

To receive a grade of 6,

Coherent policies exist for some forms of unauthorized consumption (more than simply fire hydrant misuse) but others await closer evaluation. Reasonable surveillance and recordkeeping exist for occurrences that fall under the policy. Volumes quantified by inference from these records.
(WLCC 2014)

Though some information is available to describe Unauthorized Consumption using per-event estimates, the auditor did not deem the information complete. Instead, the auditor selected the default value to estimate Unauthorized Consumption.

Therefore, the appropriate grade is 5. Upon selecting the default, the AWWA Software will automatically assign a data validity grade of 5. Even though the utility has data available to describe some instances of Unauthorized Consumption, that data did not ultimately inform the water audit input for Unauthorized Consumption.

Customer Metering Inaccuracies

Customer Metering Inaccuracies are a form of Apparent Loss that results from collective meter under-registration. Most meters gradually wear with cumulative throughput, causing the meters to register volumes smaller than the volumes that actually passed through the meters (Alegre et al. 2000, AWWA 2009, WLCC 2014). All metered systems feature a degree of inaccuracy.

In acknowledging meter inaccuracy in the AWWA software, the auditor may input either an inaccuracy percentage to describe bulk under-registration or a volume of Apparent Loss resulting from calculation performed outside the AWWA Software.

Data Validity Themes

The validity of the Customer Metering Inaccuracy input depends on:

- the quality and technology of customer meter recordkeeping
- the frequency and design of customer meter replacement
- the frequency and purpose of customer meter testing
- the method of Customer Metering Inaccuracies estimation

To grade the validity of the Customer Metering Inaccuracies input, the validator will have to answer the following questions.

- How are customer meter records managed?
- What is the make-up of the customer meter population? Is it homogenous or varied?
- How many meters are replaced annually?
 - How are meters selected for replacement?
- How many meters are tested annually? Why?
 - Were test results used for Customer Metering Inaccuracies calculation? How?

Common Errors

Prior to using customer meter test results to estimate Customer Metering Inaccuracies, it is essential that the auditor identify the purpose of the tests. Because the Customer Metering Inaccuracies percentage input describes the performance of a typical meter in a utility's meter stock, test results used to calculate this figure should also capture a typical meter.

Many utilities primarily test meters suspected of malfunction. Tests conducted to diagnose poor performance, while useful for maintaining customer meter accuracy, do not accurately inform

water audits. Instead, meters should be selected randomly and representatively to increase the statistical likelihood that sample test results capture average meter performance.

Lastly, meter age does not always correspond to meter accuracy. Research over the past decade has indicated that age is not a reliable predictor of meter accuracy. Variables like meter installation conditions, water hardness, consumption patterns, and climate also affect meter accuracy. Even new meters can under-register. Therefore, while an older meter population is likely to register more inaccurately than a newer meter population, meter age alone does not always provide sufficient insight for calculating Apparent Losses due to Customer Metering Inaccuracies.

Example Data Validity Grade Selection

A utility conducted a customer meter accuracy study five years ago, and the study indicated that an average meter in the utility’s meter stock registered with 98.2% accuracy. Since the conclusion of the study, the utility has replaced a quarter of its meter stock to improve revenue generation. No follow-up assessments of meter accuracy have been performed. However, customer meters are tested upon customer request.

Additionally, the utility maintains a thorough electronic customer meter inventory. For the purposes of this audit, the utility has estimated Customer Metering Inaccuracy to be 1.5%, a slight improvement over the 1.8% inaccuracy calculated five years ago prior to meter replacement.

What data validity grade should this utility receive for Customer Metering Inaccuracies?

To receive a grade of 2,

Poor recordkeeping and meter oversight is recognized by water utility management who has allotted staff and funding resources to organize improved recordkeeping and start meter accuracy testing. Existing paper records gathered and organized to provide cursory disposition of meter population. Customer meters are tested for accuracy only upon customer request.

To receive a grade of 3,

Conditions between 2 and 4.

To receive a grade of 4,

Reliable recordkeeping exists; meter information is improving as meters are replaced. Meter accuracy testing is conducted annually for a small number of meters (more than just customer requests, but less than 1% of inventory). A limited number of the oldest meters are replaced each year. Inaccuracy volume is largely an estimate, but refined based upon limited testing data. (WLCC 2014)

The utility maintains reliable meter information and has tested meters in the past, but for this audit period, no temporally-relevant test data was available to describe the accuracy of the meter population. Meters are only tested upon customer request.

Therefore, the appropriate grade is 2. Should the utility randomly and representatively test customer meters in the future, the data validity grade for Customer Metering Inaccuracies will increase.

Systematic Data Handling Errors

Systematic Data Handling Errors can cause Apparent Losses through accounting omissions, errant computer programming, gaps in policy and procedure, and other data lapses that result in understated customer consumption (AWWA 2009, WLCC 2014).

The auditor may choose to select a default value of 0.25% of Billed Metered Authorized Consumption to estimate Systematic Data Handling Errors. If an auditor has not yet gathered detailed data capturing occurrences of Systematic Data Handling Errors, it is recommended that the auditor select the default value, since some degree of error is likely.

Data Validity Themes

The validity of the Systematic Data Handling Errors input depends on:

- the quality and frequency of review of billing policies and procedures
- the technology that manages billing data
- the frequency and extent of billing data review
- the method used in volume estimation

To grade the validity of the Systematic Data Handling Errors input, the validator will have to answer the following questions.

- What policies govern billing processes and account management?
 - How effectively are these policies implemented?
- What technologies are used in read collection and billing processes?
- How often are billing processes and billing data audited?
 - Who performs the auditing?
 - What checks and functions are built into billing data management to minimize error?
- How was the volume of Systematic Data Handling Errors estimated?

Common Errors

While each utility's read collection practices and billing technology is susceptible to unique lapses and errors, it is common to encounter zero reads and negative reads that affect summaries of billed volumes.

Consecutive zero consumption recordings may legitimately indicate no consumption, perhaps due to property vacancy or seasonal occupation. However, it is also possible that consecutive zeroes result from meter reading errors, read transmission failure, meter failure, or billing system lapses, all of which should be investigated in order to determine the volume of Apparent Loss due to Systematic Data Handling Errors.

Negative reads may result from billing system algorithms that adjust recorded volumes to generate financial credits. Such data manipulation may delete record of legitimate consumption and cause the volume of metered consumption to be understated. In these cases, bill adjustment procedures should be reviewed to determine the volume that is potentially missing from summaries of Authorized Consumption.

In the absence of a detailed investigation of meter reading and bill generation processes, a utility does not have the basis to report a Systematic Data Handling Errors volume of 0. Should a utility not have an estimate available for Apparent Losses due to Systematic Data Handling Errors, the default value should be selected.

Example Data Validity Grade Selection

A utility reviews its billing policies and procedures every five years. The utility manages meter read collection and bill generation processes with a new computerized system. The system incorporates checks on consumption and includes flags for flat-lined consumption, unexpectedly high or low consumption, and missing reads. However, the volume attributable to errant reads, stuck meters, and other shortcomings of the billing process is difficult to quantify, so the utility can only calculate an approximate volume that is qualified by some assumptions made in the calculation.

What data validity grade should this utility receive for Systematic Data Handling Errors?

To receive a grade of 4,

Policy and procedures for new account activation and oversight of billing operations exist but needs refinement. Computerized billing system exists, but is dated or lacks needed functionality. Periodic, limited internal audits conducted and confirm with approximate accuracy the consumption volumes lost to billing lapses.

To receive a grade of 5,

Conditions between 4 and 6.

To receive a grade of 6,

Policy and procedures for new account activation and oversight of billing operations is adequate and reviewed periodically. Computerized billing system is in use with basic reporting available. Any effect of billing adjustments on measured consumption volumes is well understood. Internal checks of billing data error conducted annually. Reasonably accurate quantification of consumption volume lost to billing lapses is obtained.
(WLCC 2014)

The utility does use a computerized system that identifies certain types of data handling errors. Policies and procedures are reviewed periodically. However, the utility is at this time only able to approximate the volume lost to Systematic Data Handling Errors.

Therefore, the appropriate grade is 5. Should the utility be able to quantify the volume lost to Systematic Data Handling Errors with greater certainty in the future, the data validity grade for Systematic Data Handling Errors will increase.

Length of Mains

For the purposes of the water audit, the Length of Mains is the length of all pipelines (except service connections) in a system, measured from the point of input metering to encompass only the infrastructure that transmit potable water. The Length of Mains includes the total length of fire hydrant lead pipe and laterals. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Length of Mains input depends on:

- the policies that direct asset installation and documentation
- the technology used for asset data management
- the method and frequency of asset data review

To grade the validity of the Length of Mains input, the validator will have to answer the following questions.

- What is the utility policy for installing and documenting new infrastructure?
 - How effectively are these policies implemented?
- How are pipe assets tracked?
- How often are asset records validated with field data?

Common Errors

The Length of Mains for a utility should include not only standard transmission and distribution piping, but also the total length of fire hydrant laterals. However, the Length of Mains does not include service connection piping. When selecting a data source to inform the Length of Mains calculation, the auditor will need to identify what types of potable water pipe are included in the data source.

To include the length of fire hydrant laterals, the auditor may either sum the lengths of individual hydrants laterals (if such data is available) or multiply the estimated average lengths of a hydrant lateral by the count of hydrants in the system.

Example Data Validity Grade Selection

A utility is building a GIS system to manage asset data after using paper records for decades. Because the GIS system is still coming online, the paper records are maintained as a system back-up. It is utility policy that all new installations are recorded in the GIS system within 48 hours of project completion. However, no field validation of the GIS system has yet been performed. The

GIS systems is almost finished and can easily be queried to determine a comprehensive length of transmission and distribution pipe. However, fire hydrant laterals are not yet incorporated in the database, even though each hydrant has a unique GIS tag in the database.

The utility estimates that the average hydrant lateral length is 6 feet and multiplies this length by the count of hydrants drawn from the GIS system. The utility adds this total to the length of mains drawn from the GIS system to determine the audit input for the Length of Mains.

What data validity grade should this utility receive for Length of Mains?

To receive a grade of 6,

Sound written policy and procedures exist for permitting and commissioning new water mains. Highly accurate paper records with regular field validation; or electronic records and asset management system in good condition. Includes system backup.

To receive a grade of 7,

Conditions between 6 and 8.

To receive a grade of 8,

Sound written policy and procedures exist for permitting and commissioning new water mains. Electronic recordkeeping such as a Geographical Information System (GIS) and asset management system are used to store and manage data.
(WLCC 2014)

The utility does indeed work with a GIS system, though the system is not yet complete and has not been field validated. Policies are sufficient to support accurate asset recordkeeping, and in the transition from a paper system to an electronic system, the paper records are maintained as back-up.

Therefore, the appropriate grade is 7, indicating conditions between 6 and 8.

Number of Active and Inactive Service Connections

The Number of Active and Inactive Service Connections is the total count of pressurized customer service connections extended from the water main to supply water to customers (WLCC 2014). This figure should include the number of distinct pressurized connections, including fire connections, regardless of whether connections are metered or unmetered. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Number of Active and Inactive Service Connections input depends on:

- the policies and procedures that direct service connection permitting and installation
- the technology used for service connection data management
- the potential error in the total count
- the frequency of field verification

To grade the validity of the Number of Active and Inactive Service Connections input, the validator will have to answer the following questions.

- What is the utility policy for permitting, installing and documenting new service connections?
 - How effectively are these policies implemented?
- How are service connections tracked?
 - How is service connection documentation field verified?
- What margin of error does the auditor assign to the estimate of the Number of Active and Inactive Service Connections?

Common Errors

As the name implies, the Number of Active and Inactive Service Connections should indeed include connections that are inactive, unmetered, and/or unbilled in addition to standard billed and metered connections, as long as the service connection piping is full and pressurized. The Number of Active and Inactive Service Connections is used to calculate a utility's Unavoidable Annual Real Losses (UARL), and so each point of connection to the main pipe is allocated a technical-minimum leakage allowance.

This may be distinct from the number of active and inactive accounts. The audit input for the Number of Active and Inactive Service Connections is strictly concerned with infrastructure, not accounting or customer service designations. Therefore, the auditor will have to choose a data

source carefully to inform the Number of Active and Inactive Service Connections, as the utility's billing database likely does not contain all relevant service connections.

Example Data Validity Grade Selection

A utility tracks service connections associated with active accounts in its billing software. A rough census of unbilled and/or unmetered accounts is kept in an Excel spreadsheet in the utility's shared cloud drive. The spreadsheet is updated quarterly, though no recent field verification has been performed.

Utility staff report that they are unfamiliar with the policies that guide decommissioning service connections and retiring accounts, and each employee follows an individual protocol for interacting with inactive accounts and service connections. Therefore, staff report that there is likely to be significant error in the total count of active and inactive service connections.

What data validity grade should this utility receive for the Number of Active and Inactive Service Connections?

To receive a grade of 2,

General permitting policy exists but paper records, procedural gaps, and weak oversight result in questionable total for number of connections, which may vary 5-10% of actual count.

To receive a grade of 3,

Conditions between 2 and 4.

To receive a grade of 4,

Written account activation policy and procedures exist, but with some gaps in performance and oversight. Computerized information management system is being brought online to replace dated paper recordkeeping system. Reasonably accurate tracking of service connection installations & abandonments; but count can be up to 5% in error from actual total.
(WLCC 2014)

The utility tracks service connections with a pair of electronic systems. Neither utility employees nor the validator can determine the extent to which the two systems (billing database and Excel spreadsheet) capture all of the utility's infrastructure, given that policies guiding decommissioning and documentation are not standardized. As a result, the potential maximum error cannot be reliably determined.

Therefore, the appropriate grade is 2, because in conservative assessment this utility's count of service connections could be up to 10% in error.

Average Length of Customer Service Line

The Average Length of Customer Service Line is the average length of the customer service line owned and maintained by the customer from the point of ownership transfer to the customer water meter or building line, if the customer is unmetered (Alegre et al. 2000, AWWA 2009, WLCC 2014). This parameter accounts for unmetered service line infrastructure that may leak on customer property but will not be captured by the customer's water meter.

The audit software prompts the user to indicate whether customer meters are typically located at the curbstop or property line. If meters are typically located at the curbstop or customer property line, the auditor should select "Yes" from the appropriate drop-down box. If the auditor selects "Yes", the option to indicate the Average Length of Customer Service Line will disappear, and the audit input will be assigned a data validity grade of 10.

If the auditor selects "No," the input will need to be graded for data validity.

Data Validity Themes

The validity of the Average Length of Customer Service Line input depends on:

- the policies and procedures that determine ownership delineation and meter placement
- the method used to estimate
- the frequency of installation review

To grade the validity of the Average Length of Customer Service Line input, the validator will have to answer the following questions.

- Where does utility policy dictate that ownership transfer occurs?
- Where does utility policy dictate that meters are installed?
- How is meter installation and asset ownership information tracked?
 - How is recorded information field verified?
- How is the average length of service connection pipe estimated?

Example Data Validity Grade Selection

A utility locates meters in customer basements as clear utility policy dictates, rather than at the curbstop or property line. Therefore, the utility selects "No" from the drop-down menu and is prompted to indicate the average length of customer service lines.

The utility does not have this information stored in GIS or in paper records, nor are staff able to visit a representative selection of properties to measure a sample of average lengths. Staff agree that customer service line length to the meter ranges widely from 10 feet to more than 100 feet, and field staff guess that the average length of customer service line is around 50 feet.

To receive a grade of 1,

Vague policy exists to define the delineation of water utility ownership and customer ownership of the service connection piping. Curb stops are perceived as the breakpoint but these have not been well-maintained or documented. Most are buried or obscured. Their location varies widely from site-to-site, and estimating this distance is arbitrary due to the unknown location of many curb stops.

To receive a grade of 2,

Policy requires that the curb stop serves as the delineation point between water utility ownership and customer ownership of the service connection pipe. The pipe from the water main to the curb stop is the property of the water utility; and the piping from the curb stop to the customer building is owned by the customer. Curb stop locations are not well documented and the average distance is based upon a limited number of locations measured in the field.

(WLCC 2014)

Though utility policy on the location of ownership delineation and meter installation is clear, the average length of customer service lines is unknown. As a result, the audit input is a guess and has not been informed by any field measurements.

Therefore, the appropriate grade is 1.

Average Operating Pressure

The Average Operating Pressure should be calculated for the potable water distribution infrastructure that is the subject of the water audit (Alegre et al. 2000, AWWA 2009, WLCC 2014). The exact calculation of Average Operating Pressure is utility-specific, but generally the pressure in areas with more infrastructure should be given greater weight.

Data Validity Themes

The validity of the Average Operating Pressure input depends on:

- the technologies that monitor pressure, manage pressure and separate zones
- the success of pressure regulation
- the frequency and purpose of pressure data collection
- the process of average operating pressure estimation

To grade the validity of the Average Operating Pressure input, the validator will have to answer the following questions.

- How does the utility manage system pressure?
 - Does the utility employ pressure zones?
 - How are pressure zones defined and separated?
 - Are pressure zones discrete?
- How does pressure vary throughout the system?
- How and where is pressure data collected?
- How was average system pressure determined?

Common Errors

When validating average operating pressure, the validator should explore the data sources that informed the audit input. Use of a fully calibrated, current hydraulic model can provide a detailed calculation of average pressure. A utility can also use field pressure measurements to calculate average system pressure, as long as pressure zones, infrastructure density, and topography are taken into consideration. In either case, the reliability of the average pressure calculation relies upon obtaining accurate and representative field measurements to calibrate the hydraulic model or input in weighted calculations.

Furthermore, it is advised that infrastructure density is incorporated in *weighting* discrete pressure measurements or nodes when calculating average pressure for the entire system.

Additionally, the validator should investigate how pressure measurements or nodes relate to the geography and topography of the distribution system. For example, pressures logged at pump station inlets likely represent minimum local pressure and should not be the sole data source used to describe average operating pressure.

Example Data Validity Grade Selection

A utility operates three discrete pressure zones. One pressure zone is gravity-fed from a treatment plant. The other two zones are fed from the gravity zone by pump stations. The utility continuously logs pressure at pump outlets and the outlet of the treatment plant using a SCADA system. Additionally, pressures are sporadically collected during fire hydrant flushing and when low pressure complaints arise. The utility has a hydraulic model, though it has not been updated in seven years.

To calculate average system pressure, the utility chose to use recorded pressures at the treatment plant and pump station outlets and logged hydrant pressures closest to pump station inlets. Additionally, pressures were weighted by the portion in each zone of the total mileage, which distribution staff were able to estimate roughly.

To receive a grade of 4,

Effective pressure controls separate different pressure zones; moderate pressure variation across the system, occasional open boundary valves are discovered that breach pressure zones. Basic telemetry monitoring of the distribution system logs pressure data electronically. Pressure data gathered by gauges or dataloggers at fire hydrants or buildings when low pressure complaints arise, and during fire flow tests and system flushing. Reliable topographical data exists. Average pressure is calculated using this mix of data.

To receive a grade of 5,

Conditions between 4 and 6.

To receive a grade of 6,

Reliable pressure controls separate distinct pressure zones; only very occasional open boundary valves are encountered that breach pressure zones. Well-covered telemetry monitoring of the distribution system (not just pumping at source treatment plants or wells) logs extensive pressure data electronically. Pressure is gathered by gauges or dataloggers at fire hydrants and buildings when low pressure complaints arise, and during fire flow tests and system flushing. Average pressure is determined by using this mix of reliable data.
(WLCC 2014)

The utility logs some pressures with an electronic telemetric system (SCADA), but this form of pressure monitoring is not geographically comprehensive. The utility's understanding of pressure is deepened by hydrant pressure sampling, though this program is also not comprehensive and captures pressures only during the day.

Therefore, the appropriate grade is 4. The criteria for a grade of 4 are met but not exceeded, so a grade of 5 does not apply.

Total Annual Cost of Operating Water System

The Total Annual Cost of Operating Water System includes costs for operations, maintenance, and any annually incurred costs for upkeep of the drinking water supply and distribution system. Both daily costs and long-term financing (e.g. capital bond repayment, infrastructure expansion and rehabilitation projects) should be incorporated, in addition to employee salaries and benefits, materials, equipment, insurance, and other administrative costs. Depreciation costs may also be included, depending on utility policy (Alegre et al. 2000, AWWA 2009, WLCC 2014). It is important that all costs pertain specifically to the potable water system.

Data Validity Themes

The validity of the Total Annual Costs of Operating Water System input depends on:

- the extent of operational cost tracking
- the technology that manages utility accounting
- the frequency of financial auditing
- the relationship of the financial auditor to the utility

To grade the validity of the Total Annual Cost of Operating System input, the validator will have to answer the following questions.

- How thoroughly are costs tracked?
 - Are any relevant costs not tracked?
- What technology manages cost, budget, and other financial data?
- How frequently are operating costs audited? By whom?

Common Errors

The Total Annual Cost to Operate System should only include costs relevant to the potable system. If a utility also operates reclaimed water, recycled water, or sewer system in addition to a potable system, total operating costs should be parsed to reflect the approximate allocation of expenses, time, and resources to the potable system.

Example Data Validity Grade Selection

A utility tracks all relevant costs with a newly-installed, electronic accounting system. Utility employees audit their budgets and expenditures every month. Every other year, a third-party CPA is hired to audit all financial records. During the most recent audit, the CPA confirmed that

all relevant costs had been included and all relevant costs had been excluded in the Total Annual Cost to Operate System.

To receive a grade of 8,

Reliable electronic, industry-standard cost accounting system in place, with all pertinent water system operating costs tracked. Data audited at least annually by utility personnel, and at least once every three years by third-party CPA.

To receive a grade of 9,

Conditions between 8 and 10.

To receive a grade of 10,

Reliable electronic, industry-standard cost accounting system in place, with all pertinent water system operating costs tracked. Data audited annually by utility personnel and annually also by third-party CPA.
(WLCC 2014)

The utility meets all conditions for a grade 10 except the requirement for annual auditing by a third party CPA, since the utility's financed are audited by a third-party CPA only every other year.

Therefore, the appropriate grade is 9, indicating conditions between 8 and 10.

Customer Retail Unit Cost

The Customer Retail Unit Cost is the average rate that customers pay for a unit of water. The Customer Retail Unit Cost is used to value Apparent Losses, since improvements in customer meter accuracy and billing data handling will result in increased revenues at retail rates. Most utilities bill customers with a tiered rate structure that incorporates ranges of use and/or distinct customer classes. In valuing Apparent Losses, it is recommended that a composite average customer retail rate is used, rather than any single rate tier or customer class rate. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

If sewer revenues collected by the water utility are volumetrically linked to potable water use, the Customer Retail Unit Cost can also incorporate sewer rates since improvements in meter accuracy will increase both water revenue and sewer revenue.

In regions of source water scarcity, water utilities may also choose to value Real Losses at the Customer Retail Unit Cost by selecting a check box next to the Customer Retail Unit Cost input in the water audit software.

Data Validity Themes

The validity of the Customer Retail Unit Cost input depends on:

- the quality of the customer rate structure
- the consistency of rate application
- the process of customer retail cost estimation
- the frequency of rate structure review

To grade the validity of the Customer Retail Unit Cost input, the validator will have to answer the following questions.

- What is the utility's rate structure?
 - When was the rate structure last studied or updated?
 - How consistently is the rate structure applied?
- How was the Customer Retail Unit Cost determined?
 - Have all rate tiers and account classes been incorporated?
- How frequently is the rate structure reviewed by a party knowledgeable in AWWA water audit methodology?

Common Errors

It is important that the Customer Retail Unit Cost represents a weighted average of all customer rate classes and tiers. A simple average of all individual rates will likely over-value Apparent Losses; conversely, selection of the lowest or most commonly applied rate will likely under-value Apparent Losses. To calculate an appropriately weighted average, the total volumetric revenue collected during the audit period should be divided by the total volume registered as sold. If a utility is unable to calculate a weighted-average Customer Retail Unit Cost, the utility will receive a low data validity grade for this audit input.

Additionally, the Customer Retail Unit Cost should only include relevant commodity charges. All fixed, flat, or readiness-to-serve costs should be excluded. Sewer rates that are proportional to the volume of water consumed should be included.

Example Data Validity Grade Selection

A utility tracks all revenues with an up-to-date customer billing system. Customers are billed based on account class (residential, commercial, industrial, and agricultural) with a progressive tiered rate structure. The rate structure was updated last year, and given its complexity, the auditor chose to divide total revenue earned by total volume sold to determine the Customer Retail Unit Cost. The auditor was careful to exclude all fixed fees, and the utility does not operate a sewer system. The utility hires a third-part expert to study the effectiveness of the rate structure at least every four years, but the expert is unfamiliar with water auditing.

To receive a grade of 8,

Effective water rate structure is in force and is applied reliably in billing operations. Composite customer rate is determined using a weighted average composite consumption rate, which includes residential, commercial, industrial, institutional (CII), and any other distinct customer classes within the water rate structure.

To receive a grade of 9,

Conditions between 8 and 10.

To receive a grade of 10,

Current, effective water rate structure is in force and applied reliably in billing operations. The rate structure and calculations of composite rate - which includes residential, commercial, industrial, institutional (CII), and other distinct customer classes - are reviewed by a third party knowledgeable in the M36 methodology at least once every five years. (WLCC 2014)

Though the utility calculated the Customer Retail Unit Cost in alignment with prescribed methodology and incorporated only relevant costs, the rate structure expert that the utility hires is not proficient in M36 methodology.

Therefore, the appropriate grade is 9, indicating conditions between 8 and 10.

Variable Production Cost

The audit input for Variable Production Cost is used to value Real Losses. Therefore, the auditor may choose to value Real Losses at strict Variable Production Cost (the average cost of producing one unit of water) or use a higher value that incorporates costs relevant to marginal production (the production of the next unit of water), the most expensive source of water, avoided expenditures, or other indirect expenses. (Alegre et al. 2000, AWWA 2009, WLCC 2014).

Data Validity Themes

The validity of the Variable Production Cost input depends on:

- the technology used for and completeness of production cost tracking
- the process used for cost estimation
- the frequency and nature of production cost review

To grade the validity of the Variable Production Cost input, the validator will have to answer the following questions.

- How thoroughly are production costs tracked?
 - Are any relevant production costs not tracked?
- What technology manages production cost tracking?
- How was Variable Production Cost estimated?
- How frequently are production costs audited? By whom?

Common Errors

It is important that the Variable Production Cost or an alternate Real Loss valuation exclude fixed costs related to the current production of water. For example, the salaries of treatment plant operators are not directly related to the volumes of water that they produce at the treatment plant. Therefore, operator salaries should not be included in the Variable Production Cost. The exception to this rule is when new fixed costs will be incurred in marginal supply development. If reducing Real Losses results in deferred supply development (and the capital and other fixed costs associated with development), then these costs can be incorporated in the valuation of Real Losses.

Example Data Validity Grade Selection

To supply its system, a utility imports raw water and then treats the water itself. The imported water cost is known, as it is the same for every unit. Additionally, the utility has record of its chemical purchases during the audit period. However, the utility is unable to identify the portion of total power costs that resulted from the production of water, in contrast to the costs that maintained other operations (like administrative buildings). Asset depreciation relevant to the volumetric production of water cannot be identified in current depreciation schedules. Therefore, the utility chooses to include only imported water and chemical costs plus an estimated 25% of power expenditures in its Variable Production Cost calculation. The utility recognizes that this likely under-values Real Losses.

Additionally, a CPA audits all utility financial statements every year, though the CPA is not versed in water auditing and water loss control. Financial statements and utility-wide expenditures are tracked with a standard electronic accounting system.

To receive a grade of 2,

Reasonably maintained, but incomplete, paper or electronic accounting provides data to roughly estimate the basic operations costs (pumping power costs and treatment costs) and calculate a unit variable production cost.

To receive a grade of 3,

Conditions between 2 and 4.

To receive a grade of 4,

Electronic, industry-standard cost accounting system in place. Electric power and treatment costs are reliably tracked and allow accurate weighted calculation of unit variable production costs based on these two inputs and water imported purchase costs (if applicable). All costs are audited internally on a periodic basis.
(WLCC 2014)

The utility incorporates import, treatment, and pumping costs in its assessment of Variable Production Cost, though the allocation of pumping costs is rough and therefore does not meet the criteria for a grade of 4. Because the utility hires a third-party auditor annually, the utility exceeds the criteria for a grade of 2.

Therefore, the appropriate grade is 3, indicating conditions between 2 and 4.

After examining inputs, the validator should work with the auditor to incorporate changes to data validity grades and audit inputs in order to improve the accuracy of the audit before re-examining performance indicators.

STEP 4: RE-EXAMINE PERFORMANCE INDICATORS FOR EVIDENCE OF PERSISTING INACCURACY

Completing a level 1 validation of water audit inputs confirms that data validity grades have been correctly selected, that water audit methodology has been appropriately applied to the utility's situation, and that evident inaccuracies have been identified and corrected, if possible. After examining inputs, the validator should recommend changes to data validity grades and audit inputs in order to improve the accuracy of the audit.

Once recommended changes have been made, the validator should check performance indicators again for feasibility. Should any performance indicators not pass the standard checks outlined below in Table 2 and previously in Step 2, it is likely that inaccuracy persists in the water audit. Discovering these buried inaccuracies is beyond the scope of level 1 validation. However, the validator can indicate where he or she suspects inaccuracy is introduced and suggest next steps for validation and future water audit improvements.

Table 2
Performance indicator checks

CATEGORY	PERFORMANCE INDICATOR	CHECK	CONTRIBUTING INPUTS
NRW	Non-Revenue Water as a percent by cost of operating system	0% < NRW (cost) % < 100%	volumetric inputs, cost inputs
Real Losses	Real Losses / service connection / day	Real Losses > 0 gal	volumetric inputs
	Real Losses / length of main / day		
	Real Losses / service connection / day / PSI pressure		
ILI	Infrastructure Leakage Index	ILI > 1.0	volumetric inputs, infrastructure inputs, average system operating pressure

If inaccuracies reside in raw data, analyses, and data management systems, they will likely be identified and resolved by a level 2 validation.

If inaccuracies are attributable to instrument performance, they will likely be identified and resolved by a level 3 validation.

After re-examining performance indicators, the validator should proceed to documenting the results of the level 1 validation.

STEP 5: DOCUMENT RESULTS

The validator should document the results of the level 1 validation in the “Comments” tab of the AWWA Software or in a comparable format. At minimum, the validator should provide the following information:

- Validator name and contact information
- Results of initial performance indicator review
- Summary of level 1 interview, particularly related to water audit input derivation and data validity grade selection
- Recommended changes to data validity grades and rationale
- Recommended changes to water audit inputs and rationale
- Results of follow-up performance indicator review
- Overall impressions, including the consistency of performance indicators with system conditions and water loss management practices
- Recommendations for advanced validation and water audit improvements

While some uncertainty may persist in the water audit, the water audit is more reliable for having been level 1 validated.

CHAPTER 6

WHAT ARE ADVANCED VALIDATION OPTIONS?

Level 1 validation is often only the initial step in pursuing accurate and consistent water audits. After level 1 validation, gross inaccuracies, incorrect application of methodology, incomplete data, and misleading data validity grades should no longer be issues. However, minimizing obvious inaccuracies and misinterpretation of methodology does not guarantee accurate water audits. Errors can still exist in the data, instrumentation, and analyses that support the water audit.

Persisting inaccuracies may or may not produce unfeasible performance indicators, depending on the nature of the inaccuracies and the balance of water audit data inputs.

For example, if a utility is approaching an ILI of 1.0 (its technical minimum volume of leakage), any inaccuracies in water audit data may produce an ILI below 1.0. In contrast, comparable inaccuracies for a utility with a higher true ILI may inaccurately lower the ILI, but not below a threshold that arouses suspicion.

To further address the potential for uncertainty and inaccuracy in water audits, higher-level validation activities are encouraged. Level 2 validation investigates inaccuracy in raw water audit data and data management systems. Level 3 validation investigates inaccuracy in instrumentation and corroborates water audit results with other investigations of Real Loss.

Level 2 water audit validation and level 3 water audit validation need not be conducted sequentially or concurrently. A utility may choose the higher-level validation activities that most directly address the probable sources of inaccuracy and uncertainty in that utility's water audit.

Establishing water audit reliability tends to require effort over multiple years. It is recommended that level 1 validation of a water audit be conducted every year. The more detailed activities of level 2 and level 3 validation may occur over a period of years, with validation activities focusing on one or two components of the water audit at a time.

WHAT ARE EXAMPLES OF LEVEL 2 WATER AUDIT VALIDATION?

As discussed in WLCC (2015), Sturm et al. (2015), and Sturm et al. (forthcoming), level 2 water audit validation aims to:

- Study the accuracy of data translation from primary measurement to water audit input
- Identify anomalies, gaps, and redundancies in raw data and correct inaccuracies, where possible
- Stratify and apply available customer meter test data to water audit calculations

- Confirm the average operating pressure calculation

To meet these aims, potential level 2 validation activities include:

- Investigation of SCADA data archival and retrieval fidelity
- Analysis of raw billing and consumption data to confirm consistency, completeness, and relevance
- Pro-rating of billing and consumption data to temporally aligned volumes of production and consumption
- Analysis of existing customer meter test results to incorporate statistical considerations like demographic stratification, flow rate and consumption profiles, and margin-of-error assessment
- Detailed average system pressure calculation to weight infrastructure density and geography of pressure measurements or model nodes

WHAT ARE EXAMPLES OF LEVEL 3 WATER AUDIT VALIDATION?

As discussed in WLCC (2015), Sturm et al. (2015), and Sturm et al. (forthcoming), level 3 water audit validation aims to:

- Measure supply meter accuracy
- Confirm 4-20 mA signal conversion accuracy from meter transmitter to SCADA archive
- Improve the understanding of Apparent Losses with meter tests
- Confirm the Real Loss volume through bottom-up or field investigation
- Field verify average system pressure

To meet these aims, potential level 3 validation activities include:

- Volumetric accuracy testing of supply meters using a reference volume or comparative meter
- Calibration of supply meter electronics
- 4-20mA signal tracking
- Customer meter testing that randomly and representatively investigates small meters and studies the most influential large meters
- Component Analysis of Real Losses to determine the system's Real Loss profile
- Pilot leak detection to explore the prevalence and types of leaks
- Minimum night flow analysis to establish zonal leakage budgets
- Pressure logging that studies pressure dynamics throughout the system

WHAT SHOULD I DO AFTER VALIDATING MY WATER AUDIT?

The process of water loss control begins with a validated water audit, but more information and analyses are necessary to direct resources to the most cost-effective water loss interventions. A water loss control program typically consists of seven steps as discussed in Alegre et al. (2000), AWWA (2009), and others.

The first three steps evaluate water losses and the opportunities presented by water loss control.

The next three steps cost-effectively intervene against water losses.

The last step supports the monitoring and tracking mechanisms necessary to institutionalize water distribution efficiency.

1. Compile and thoroughly validate a water audit.
2. Perform a Component Analysis of Real Losses.
3. Evaluate the costs and benefits of intervention against component volumes of Real and Apparent Losses.
4. Implement interventions to the extent cost-effective.
5. Evaluate the efficacy of interventions.
6. Refine interventions against water loss.
7. Continue to monitor water losses through annual validated water audits and Component Analyses of Real Losses while improving the accuracy and reliability of key data sources.

Water audits and water loss control activities are most effective when they are ongoing and incorporated into standard utility business practices.

APPENDIX A

LEVEL 1 VALIDATION CHECKLIST

STEP 1: RECEIVE AND REVIEW THE WATER AUDIT AND SUPPORTING DOCUMENTATION

At minimum, the validator should request and receive:

- Completed AWWA Free Water Audit Software
- Volume from Own Sources detailed by month and supply meter
- Water Imported detailed by month
- Water Exported detailed by month
- Supply meter testing and/or calibration documentation (if supply meters are tested and/or calibrated)
- Volume of water sold detailed by month and rate code (e.g. charge status, water type, or customer class)

Additional supporting documentation will improve the level 1 validation process

- Derivations of Customer Meter Accuracy
- Derivations of Average Operating Pressure,
- Derivations of Customer Retail Unit Cost,
- Derivations of Variable Production Cost.
- Audits from previous years

STEP 2: EXAMINE PERFORMANCE INDICATORS FOR EVIDENCE OF INACCURACY

Prior to the level 1 validation interview, each performance indicator can be checked for feasibility as described below to supply an initial assessment of the overall reliability of the water audit.

Table 1
Performance indicator checks

CATEGORY	PERFORMANCE INDICATOR	CHECK	CONTRIBUTING INPUTS
NRW	Non-Revenue Water as a percent by cost of operating system	$0\% < \text{NRW (cost)} \% < 100\%$	volumetric inputs, cost inputs
Real Losses	Real Losses / service connection / day	Real Losses > 0 gal	volumetric inputs
	Real Losses / length of main / day		
	Real Losses / service connection / day / PSI pressure		
ILI	Infrastructure Leakage Index	$\text{ILI} > 1.0$	volumetric inputs, infrastructure inputs, average system operating pressure

STEP 3: VALIDATE AUDIT INPUTS, CONFIRM CORRECT APPLICATION OF METHODOLOGY, AND CHANGE INPUTS AS NECESSARY

The AWWA Free Water Audit Software contains 20 data inputs. For each audit input, the validator should ask the following broad questions:

- How did the auditor arrive at the water audit input?
- How did the auditor interpret general methodology and definitions to apply to the specifics of the system?
- How did the auditor select a data validity grade?
- How does the audit input compare to previous years (if applicable)?

Volume from Own Sources

To grade the validity of the input the validator will have to answer the following questions.

- How many distinct own-source distribution inputs are there?
- How many inputs are metered?
- Are any of the meters in series?
- Do the meters capture raw water or potable water?

- How are unmetered inputs estimated?
- Which own-source meters are calibrated? How often are calibrations performed?
 - What were the results of the calibrations closest to the audit period?
- Which own-source meters are volumetrically tested? How often are tests conducted?
 - What were the results of the volumetric accuracy tests closest to the audit period?

Volume from Own Sources – Master Meter and Supply Error Adjustment

To grade the validity of the input the validator will have to answer the following questions.

- How are own-source production volumes sampled and recorded?
- How often is own-source production data reviewed?
 - Under what conditions is own-source production data adjusted?
- Are changes in stored volume incorporated?
 - If so, how?

Water Imported

To grade the validity of the input the validator will have to answer the following questions.

- How many distinct import connections are there?
 - How many import connections are metered?
 - Are any of the meters in series?
 - Do the meters capture raw water or potable water?
 - How are unmetered imports estimated?
- How often are import meters calibrated? Which meters are calibrated?
 - What were the results of the calibrations closest to the audit period?
- How often are import meters tested for volumetric accuracy? Which meters are volumetrically tested?
 - What were the results of the volumetric accuracy tests closest to the audit period?

Volume Imported – Master Meter and Supply Error Adjustment

To grade the validity of the input the validator will have to answer the following questions.

- How are Water Imported volumes recorded?
 - How often are Water Imported volumes captured?
- How often is Water Imported data reviewed?
 - Under what conditions is Water Imported data adjusted?
- What documentation is available to describe the interagency import-export agreement?

Water Exported

To grade the validity of the input the validator will have to answer the following questions.

- How many distinct export connections are there?
 - How many export connections are metered?
 - Are any of the meters in series?
 - Do the meters capture raw water or potable water?
 - How are unmetered exports estimated?
- How often are export meters calibrated? Which meters are calibrated?
 - What were the results of the calibrations closest to the audit period?
- How often are export meters tested for volumetric accuracy? Which meters are volumetrically tested?
 - What were the results of the volumetric accuracy tests closest to the audit period?

Volume Exported – Master Meter and Supply Error Adjustment

To grade the validity of the input the validator will have to answer the following questions.

- How are Water Exported volumes recorded?
 - How often are Water Exported volumes captured?

- How often is Water Exported data reviewed?
- Under what conditions is Water Exported data adjusted?
- What documentation is available to describe the interagency import-export agreement?

Billed Metered Authorized Consumption

To grade the validity of the input the validator will have to answer the following questions.

- What portion of customers are metered?
- How are customer meter reads collected?
 - What is the success rate of meter read collection?
- When are customer meters replaced?
- How many customer meters are tested annually? Why?
- How are customer bill records maintained?
 - How often are customer bill records audited? By whom?

Billed Unmetered Authorized Consumption

To grade the validity of the input the validator will have to answer the following questions.

- What are utility policies regarding which customers must be metered?
 - Are metering policies clear?
 - Are metering policies consistently implemented?
- How is unmetered consumption estimated?

Unbilled Metered Authorized Consumption

To grade the validity of the input the validator will have to answer the following questions.

- What are utility policies regarding which customers are metered but unbilled?
 - Are billing exemption policies clear?
 - Are billing exemption policies consistently implemented?

- How often are unbilled meters read?
- How is unbilled metered consumption estimated in the absence of a recent meter read?

Unbilled Unmetered Authorized Consumption

To grade the validity of the input the validator will have to answer the following questions.

- What uses are unmetered and unbilled?
- Are utility policies on unmetered and unbilled use clear?
- How are unmetered, unbilled uses documented?
- How is consumption for each use estimated?

Unauthorized Consumption

To grade the validity of the input the validator will have to answer the following questions.

- What instances of Unauthorized Consumption have been documented?
- What information is captured in records of Unauthorized Consumption?
- How are unmetered, unbilled uses documented?
- How is consumption for each use estimated?
- Are documented volumes of Unauthorized Consumption thorough enough to replace the default estimate?

Customer Metering Inaccuracies

To grade the validity of the input the validator will have to answer the following questions.

- How are customer meter records managed?
- What is the make-up of the customer meter population? Is it homogenous or varied?
- How many meters are replaced annually?
- How are meters selected for replacement?
- How many meters are tested annually? Why?

- Were test results used for Customer Metering Inaccuracies calculation? How?

Systematic Data Handling Errors

To grade the validity of the input the validator will have to answer the following questions.

- What policies govern billing processes and account management?
 - How effectively are these policies implemented?
- What technologies are used in read collection and billing processes?
- How often are billing processes and billing data audited?
 - Who performs the auditing?
 - What checks and functions are built into billing data management to minimize error?
- How was the volume of Systematic Data Handling Errors estimated?

Length of Mains

To grade the validity of the input the validator will have to answer the following questions.

- What is the utility policy for installing and documenting new infrastructure?
 - How effectively are these policies implemented?
- How are pipe assets tracked?
- How often are asset records validated with field data?

Number of Active and Inactive Service Connections

To grade the validity of the input the validator will have to answer the following questions.

- What is the utility policy for permitting, installing and documenting new service connections?
 - How effectively are these policies implemented?
- How are service connections tracked?
 - How is service connection documentation field verified?

- What margin of error does the auditor assign to the estimate of the Number of Active and Inactive Service Connections?

Average Length of Customer Service Line

To grade the validity of the input the validator will have to answer the following questions.

- Where does utility policy dictate that ownership transfer occurs?
- Where does utility policy dictate that meters are installed?
- How is meter installation and asset ownership information tracked?
 - How is recorded information field verified?
- How is the average length of service connection pipe estimated?

Average Operating Pressure

To grade the validity of the input the validator will have to answer the following questions.

- How does the utility manage system pressure?
 - Does the utility employ pressure zones?
 - How are pressure zones defined and separated?
 - Are pressure zones discrete?
- How does pressure vary throughout the system?
- How and where is pressure data collected?
- How was average system pressure determined?

Total Annual Cost of Operating Water System

To grade the validity of the input the validator will have to answer the following questions.

- How thoroughly are costs tracked?
 - Are any relevant costs not tracked?
- What technology manages cost, budget, and other financial data?
- How frequently are operating costs audited? By whom?

Customer Retail Unit Cost

To grade the validity of the input the validator will have to answer the following questions.

- What is the utility's rate structure?
 - When was the rate structure last studied or updated?
 - How consistently is the rate structure applied?
- How was the Customer Retail Unit Cost determined?
 - Have all rate tiers and account classes been incorporated?
- How frequently is the rate structure reviewed by a party knowledgeable in AWWA water audit methodology?

Variable Production Cost

To grade the validity of the input the validator will have to answer the following questions.

- How thoroughly are production costs tracked?
 - Are any relevant production costs not tracked?
- What technology manages production cost tracking?
- How was Variable Production Cost estimated?
- How frequently are production costs audited? By whom?

STEP 4: RE-EXAMINE PERFORMANCE INDICATORS FOR EVIDENCE OF PERSISTING INACCURACY

**Table 2
Performance indicator checks**

CATEGORY	PERFORMANCE INDICATOR	CHECK	CONTRIBUTING INPUTS
NRW	Non-Revenue Water as a percent by cost of operating system	0% < NRW (cost) % < 100%	volumetric inputs, cost inputs
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	Real Losses / length of main / day		
	Real Losses / service connection / day / PSI pressure		
ILI	Infrastructure Leakage Index	ILI > 1.0	volumetric inputs, infrastructure inputs, average system operating pressure

STEP 5: DOCUMENT RESULTS

The validator should document the results of the level 1 validation in the “Comments” tab of the AWWA Software or in a comparable format. At minimum, the validator should provide the following information:

- Validator name and contact information
- Results of initial performance indicator review
- Summary of level 1 interview, particularly related to water audit input derivation and data validity grade selection
- Recommended changes to data validity grades and rationale
- Recommended changes to water audit inputs and rationale
- Results of follow-up performance indicator review
- Overall impressions, including the consistency of performance indicators with system conditions and water loss management practices
- Recommendations for advanced validation and water audit improvements

REFERENCES AND RESOURCES

REFERENCES

- Alegre, H., H. Hirner, J.M. Baptista, and R. Parena. 2000. *Performance Indicators for Water Supply Services – IWA Manual of Best Practice*. London, UK: IWA Publishing.
- AWWA (American Water Works Association). 2009. *M36 Water Audits and Loss Control Programs*. Third Edition. Denver, Colo.: American Water Works Association.
- Sturm, R., L. Andrews, K. Gasner, W. Jernigan, S. Cavanaugh, and G. Kunkel. Forthcoming. “Utility Water Audit Validation: Principles and Programs.” Project #4639. Denver, Colo.: Water Research Foundation.
- Sturm, R., K. Gasner, and L. Andrews. 2015. *Water Audits in the United States: A Review of Water Losses and Data Validity*. Project #4372b. Denver, Colo.: Water Research Foundation.
- WLCC (Water Loss Control Committee). 2014. *AWWA Free Water Audit Software* (version 5.0). Microsoft Excel. Denver, CO: American Water Works Association.
- WLCC (Water Loss Control Committee – Software Subcommittee). 2015. *Validation Level Summary*. Unpublished working document. Denver, Colo: American Water Works Association.

RESOURCES

Additional resources are available to anyone who wishes to learn more about water auditing and water loss control. This manual builds upon decades of water loss control research and establishment of best practices. A selection of definitive resources is listed below.

- AWWA (American Water Works Association). 2016. *M36 Water Audits and Loss Control Programs*. Fourth Edition. Denver, Colo.: American Water Works Association.
- Sturm, R. K. Gasner, T. Wilson, S. Preston and M.A. Dickinson. 2014. *Real Loss Component Analysis: A Tool for Economic Water Loss Control*. Project #4372. Denver, Colo.: Water Research Foundation.
- WLCC (Water Loss Control Committee). 2015. *AWWA Water Audit Software Compiler* (version 5.0). Microsoft Excel. Denver, CO: American Water Works Association.

ABBREVIATIONS

The world of water auditing is replete with acronyms and abbreviations. The acronyms and abbreviations used in this guidance manual are defined below.

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
AWWA	American Water Works Association
AWWA Software	American Water Works Association Free Water Audit Software, version 5.0
BMAC	Billed Metered Authorized Consumption
BUAC	Billed Unmetered Authorized Consumption
CPA	Certified Public Accountant
DVS	Data Validity Score
gal	gallon(s)
GIS	Geographic Information System
ILI	Infrastructure Leakage Index
mA	milliamp
MMEA	Master Meter and Supply Error Adjustment
N/A	not applicable
NRW	Non-Revenue Water
PSI	pounds per square inch
SCADA	Supervisory Control and Data Acquisition
UARL	Unavoidable Annual Real Losses
UMAC	Unbilled Metered Authorized Consumption
UUAC	Unbilled Unmetered Authorized Consumption
WRF	Water Research Foundation

