Indiana Water Loss Audit
Guidance Manual

November 2021, 2nd edition

Acknowledgments

The Indiana Finance Authority would like to acknowledge Water Systems Optimization ("WSO") as the author of the *California Department of Water Resources: Water Audit Manual* (WSO, 2016) upon which the first edition of this manual is based. We appreciate the California Department of Water Resources for sharing this important resource with Indiana utilities.

The IFA would also like to acknowledge the Indiana Section of the American Water Works Association ("AWWA"), Indiana Rural Water Association, Indiana Rural Community Assistance Program, M.E. Simpson Co., Inc., and Wessler Engineering for further developing the materials, and the AWWA for its development of the Free Water Audit Software ("software") and Manual 36, Water Audits and Loss Control Programs.

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Preface

In 2015, Indiana utilities produced an estimated 50 billion gallons of water that did not generate revenue, resulting in a loss of approximately $54.6 million (IFA, 2016). To better understand Indiana's non-revenue water, the Indiana Legislature enacted Senate Enrolled Act 4 (2019). The resulting state statute, IC 8-1-30.8, obligates water utilities to complete annual water audits. In addition, in every even-numbered year, on August 1, the legislation requires these water loss audits to be validated by a certified, third-party water audit validator ("Certified Validator"). Water utilities must then submit these validated water loss audits to the Indiana Finance Authority ("IFA") for compilation into a biennial report to the Indiana General Assembly. The next validated water audit is due on August 1, 2022.

This guidance was prepared specifically as a reference for Indiana water utilities to provide guidance on preparing a water loss audit in accordance with the American Water Works Association ("AWWA") Manual 36 Water Audits and Loss Control Programs ("M36") (AWWA, 2016). While useful, this guide is not a substitute for M36. The release of the AWWA Free Water Audit Software version 6.0 ("software") is the main reason for this second edition.

Water loss audits are a valuable tool in maintaining the managerial, financial, and technical integrity of a water utility. Implementing a water loss audit program can improve the efficiency of water production and delivery for all water suppliers.

Contents

1 INTRODUCTION

1.1 What is a Water Audit?

The water audit is an accounting exercise that is conceptually like a financial audit. Whereas a financial audit tracks all sources and uses of funds for an organization, a water audit tracks all sources and uses of water within a water system over a specified period. By answering the following questions, the exercise can help reveal and clarify inefficiencies in water delivery and revenue generation:

- How much water entered the system?
- How much water was used?
- For what purposes was water used?
- How much water was lost?
- What types of water loss occurred?
- What was the financial cost of water losses?
- What was the volume of *non-revenue* water?
- What was the financial cost of *non-revenue* water?

Key concepts:

Non-Revenue Water: Water that fails to generate revenue for the water supplier for any reason. Non-Revenue Water includes Apparent Losses (paper losses), Real Losses (leakage), and Unbilled Authorized Consumption. See Glossary of Terms on page 63.

Most utility operators recognize leakage as a form of water loss. Less widely appreciated are water losses due to metering inaccuracies, unauthorized consumption, and data handling errors, which are collectively termed "**Apparent Losses**," also known as paper losses.

"**What about Unaccounted-for-Water**?" The concept of unaccounted-for-water has been formally abandoned by AWWA as an effective tool for managing system losses due to its unreliable application and inconsistent definition. As you will see throughout the process of completing the AWWA water audit, you can account for all volumes of water, including water losses. Upon doing so, you can refer to valuable performance indicators that more accurately describe system performance. These are discussed in detail in Section 6.

1.2 Why Perform a Water Audit?

1.2.1 Utility Motivations

An AWWA audit is an excellent way to understand your water losses. Once you understand your water losses, you can devise and implement strategies that result in the following improvements:

- Water resources management—by reducing water waste, thereby maximizing the value of existing sources and reducing the need for new sources.
- Financial performance—by optimizing revenue recovery, improving ratepayer equity, reducing wasteful operating expenses, and reducing the need for costly capital expansion.
- Operational performance—by improving understanding of the distribution system, reducing service disruptions, and generating reliable performance data.

Performance indicators from the audit can be helpful in tracking changes over time and serving as benchmarks in comparison with other utilities.

1.2.2 Statewide Context

Beyond the internal reasons to perform a water audit, there is a regulatory requirement to complete an audit.

- **Senate Enrolled Act 347** (2016) required all public water utilities in the State of Indiana to provide the IFA with a Non-Revenue Water Audit, as identified in the AWWA M36. The act also required the IFA to conduct a study and analysis of infrastructure needs for all water utilities in the State of Indiana. The final report, representing 552 utilities, discovered over 50 billion gallons of annual non-revenue water loss valued at approximately $54.6 million. The report is available at the IFA website.
- **Senate Enrolled Act 4** (2019) requires all community water systems that supply water to its users via meters to complete an annual water audit. In addition, in every even-numbered year, starting in 2020, SEA 4 requires water audits to be validated by a certified, third-party water audit validator and submitted to the IFA by August 1 for compilation into a biennial report to the General Assembly. The next validated water audit is due on August 1, 2022.

1.3 How to Use This Manual

This manual is intended to help Indiana drinking water utilities complete the AWWA Water Audit. The manual proceeds as follows:

- Chapter 2 introduces the water balance.
- Chapter 3 gives an overview of the AWWA Water Audit Software (“software”).
- Chapter 4 shows you how to complete the water audit using the software.
- Chapter 5 provides information on how to interpret the results of the water audit, including performance indicators.

This manual also includes the following Appendices to supplement water audit work:

- Appendix A: Understanding Percentile and Median
- Appendix B: Correcting for Misalignment Between Meter Reading/ Billing Cycles and Audit Period
- Appendix C: Calculating Your Own Systematic Data Handling Errors ("SDHE")
- Appendix D: Conducting Random Meter Tests
- Appendix E: Cost Data Guidance

2 INTRODUCTION TO THE WATER BALANCE

The heart of the water audit is the water balance, which is a graphical and intuitive representation of the water audit. Figure 1 presents a simplified version of the water balance.

Each box represents a specific category, or volume, of water. For example, Water Supplied represents the total volume of water that entered the water system over a particular audit period for use within the distribution system. In the example shown in Figure 1, Water Supplied is 100 million gallons (MG).

Boxes may be summed together to find the total of neighboring boxes. For example, Water Supplied = Authorized Consumption + Water Losses

100 MG = 88 MG + 12 MG.

Similarly, Revenue Water = Billed Metered Consumption + Billed Unmetered Consumption

84 MG = 82 MG + 2 MG.

Boxes need not be next to each other to make comparisons. For example, Water Supplied = Revenue Water + Non-Revenue Water

100 MG = 84 MG + 16 MG.

Keep in mind that the sizes of the boxes in the water balance do not correspond to the actual volumes they represent.

<table>
<tr><td rowspan="8">Water Supplied
100 MG</td><td rowspan="4">Authorized Consumption
88 MG</td><td rowspan="2">Billed Authorized Consumption
84 MG</td><td>Billed Metered Consumption
82 MG</td><td rowspan="2">Revenue Water
84 MG</td></tr>
<tr><td>Billed Unmetered Consumption
2 MG</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
4 MG</td><td>Unbilled Metered Consumption
1 MG</td><td rowspan="6">Non-Revenue Water
16 MG</td></tr>
<tr><td>Unbilled Unmetered Consumption
3 MG</td></tr>
<tr><td rowspan="4">Water Losses
12 MG</td><td rowspan="3">Apparent Losses
4 MG</td><td>Unauthorized Consumption
0.25 MG</td></tr>
<tr><td>Customer Metering Inaccuracies
3.50 MG</td></tr>
<tr><td>Systematic Data Handling Errors
0.25 MG</td></tr>
<tr><td colspan="2">Real Losses
8 MG</td></tr>
</table>

Figure 1. A water balance example.

The exercise below helps you understand the methodology behind the water balance without yet having to consider the complexities of your own system. Answers are below.

> **Exercise:** Based on the information provided in Figure 2, determine the volumes for the missing categories. *(Hint: Water Losses = Water Supplied – Authorized Consumption)*

Water Supplied *40 MG*	**Authorized Consumption** *__ MG*	**Billed Authorized Consumption** *__ MG*	**Billed Metered Consumption** *27 MG*	**Revenue Water** *___ MG*
			Billed Unmetered Consumption *2 MG*	
		Unbilled Authorized Consumption *__ MG*	**Unbilled Metered Consumption** *0 MG*	**Non-Revenue Water** *__ MG*
			Unbilled Unmetered Consumption *1 MG*	
	Water Losses *__ MG*	**Apparent Losses** *__ MG*	**Unauthorized Consumption** *0.50 MG*	
			Customer Metering Inaccuracies *3 MG*	
			Systematic Data Handling Errors *0.50 MG*	
		Real Losses *__ MG*		

Figure 2. Water balance for exercise.

As you may have noticed, some volumes are simply sums of other volumes. For instance, Authorized Consumption is the sum of Billed Authorized Consumption and Unbilled Authorized Consumption. However, Water Losses and Real Losses are derived volumes that are calculated through a process of elimination:

- Water Losses = Water Supplied - Authorized Consumption from.
- Real Losses = Water Losses - Apparent Losses from.
- Since Water Losses and Real Losses are derived volumes, they are not entered by the auditor. The software will automatically calculate them based on the information entered in other portions of the water balance. (The software will be discussed in detail at a later point.)

A primary outcome of the water audit is the determination of the volume of Water Losses and Real Losses. However, since these are derived volumes, they are only as accurate as the accuracy of the other volumes informing the calculation.

For example, the volume of Water Losses and Real Losses in Figure 2 were respectively determined to be 10 MG and 6 MG. However, if the volume of Water Supplied was not 40 MG but actually 42 MG due to source meter inaccuracy, then the respective volumes of Water Losses and Real Losses respectively would be 12 MG and 8 MG.

This is all to say that an accurate determination of Water Losses and Real Losses relies upon the accuracy of the other volumes of the Water Balance.

<table>
<tr><td rowspan="8">Water Supplied
40 MG</td><td rowspan="4">Authorized Consumption
30 MG</td><td rowspan="2">Billed Authorized Consumption
29 MG</td><td>Billed Metered Consumption
27 MG</td><td rowspan="2">Revenue Water
29 MG</td></tr>
<tr><td>Billed Unmetered Consumption
2 MG</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
1 MG</td><td>Unbilled Metered Consumption
0 MG</td><td rowspan="6">Non-Revenue Water
11 MG</td></tr>
<tr><td>Unbilled Unmetered Consumption
1 MG</td></tr>
<tr><td rowspan="4">Water Losses
10 MG</td><td rowspan="3">Apparent Losses
4 MG</td><td>Unauthorized Consumption
0.50 MG</td></tr>
<tr><td>Customer Metering Inaccuracies
3 MG</td></tr>
<tr><td>Systematic Data Handling Errors
0.50 MG</td></tr>
<tr><td colspan="2">Real Losses
6 MG</td></tr>
</table>

Figure 3. Answers to water balance exercise.

3 OVERVIEW OF AWWA WATER AUDIT SOFTWARE

3.1 The AWWA Water Audit Software

The AWWA developed the Free Water Audit Software ("software"), which is based on the principles of the AWWA M36 Water Audit methodology. The software is the drinking water industry standard tool for conducting an annual water audit. It first came out nearly 15 years ago and is now used throughout North America and in other countries around the world. In December 2019, the newest version of the AWWA Free Water Audit Software, version 6.0, was released. To facilitate consistent water auditing practices, Indiana drinking water utilities are to use the AWWA Free Water Audit Software version 6.0 to complete the water audit. The software uses Microsoft Excel and is available at: https://www.awwa.org/Resources-Tools/Resource-Topics/Water-Loss-Control. When you save it, please rename the file, "Your Utility Name INXXXXXXX Water Loss Audit DATE"

Upon opening the software, the user will notice that there are 11 tabs. **Data is only entered in the first three tabs.** The other tabs serve a variety of functions, including presentation of performance indicators, the automatically populated water balance, and helpful background information and definitions. The red box in Figure 4 highlights the location of the tabs.

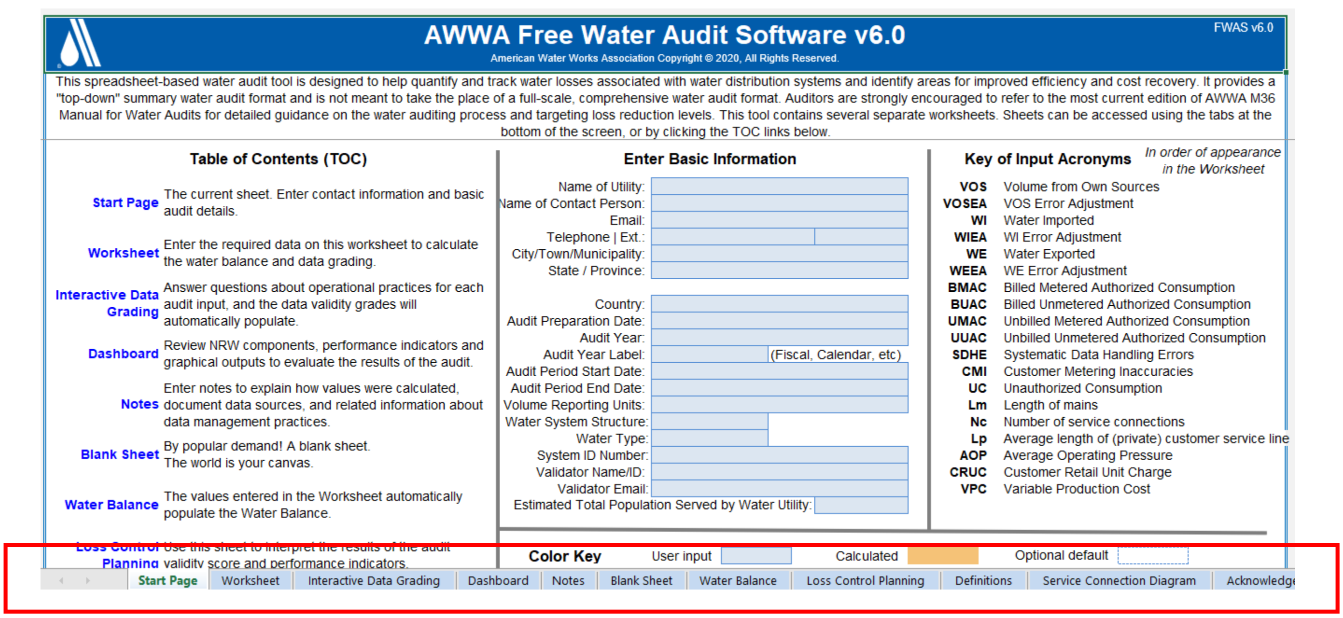


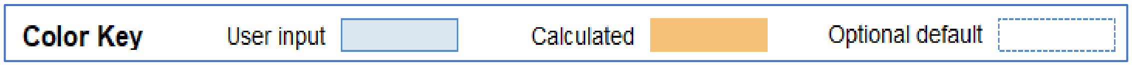
Figure 4. Screenshot of the Start Page Tab.

3.2 Start Page

The tab titled "Start Page" provides a general orientation to the software. This is also where basic audit information should be entered. Some notes:

- Please enter name of utility without the words "Town of/City of" at the beginning.
- Contact person is the name of the person who should be contacted for questions about the audit.
- Audit Year is the four-digit year of the data that will be analyzed.

- Hover over cells for more information about what is being requested.
- System ID Number: Each audit should reference a single PWSID but, if your system has special circumstances and needs to include multiple PWSIDs, multiple PWSIDs may be entered.
- Enter your validator's name, certification number, and email. Or have them do it when they complete their validation.
- Cells that require data entry are blue, auto generated ones are orange.



3.3 Worksheet Tab

This worksheet tab is where you should complete the water audit. The worksheet follows the general flow of the water balance methodology. If you aren't sure what a word means, most text is a hyperlink to a definition.

There are three categories of data to enter:

a. **Basic water, system, and cost data:** this includes parameters such as water supplied, authorized consumption, system data, length of mains, operating pressure, and cost data.

b. **Error adjustments:** no system is perfect, and the spreadsheet is set up to account for typical water supplied errors. You can use the "default" or enter a custom number that you believe is more representative.

c. **Data validity grades:** this is measurement of how confident you are in the data that you are providing. The data validity score describes the level of accuracy and reliability of each data entry contributing to the audit.

This screenshot shows where basic water data, such as Water Supplied/Volume from Own Sources and Authorized Consumption/Billed Metered data, is entered.

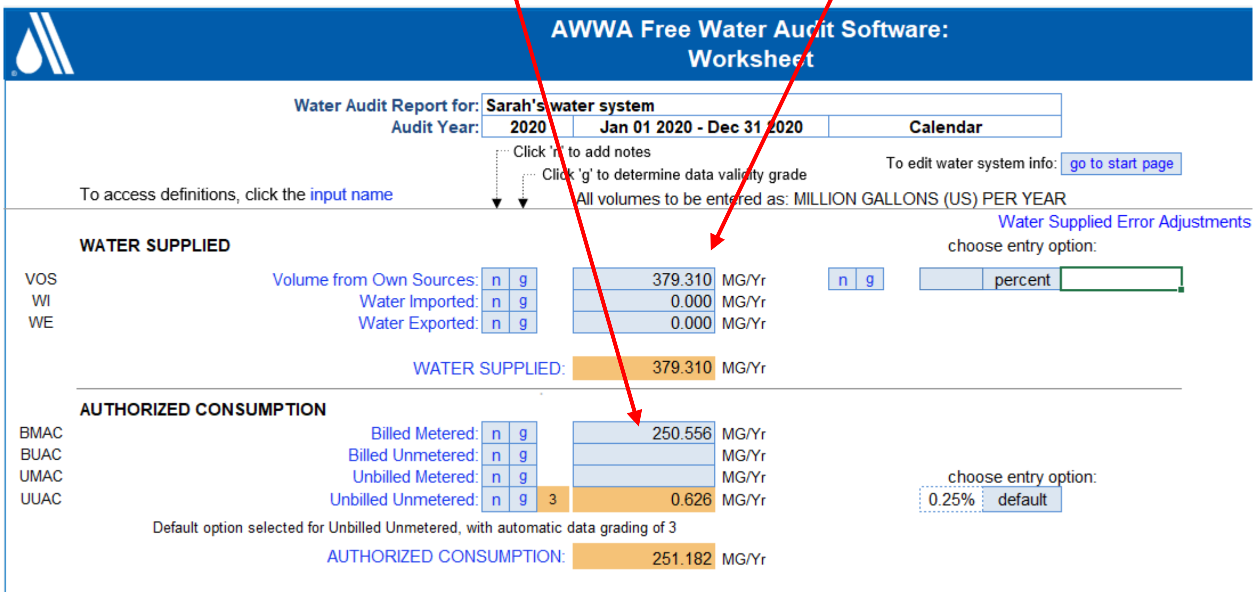


Figure 5. Screenshot of where to enter Water Supplied and Authorized Consumption.

This screenshot shows where to enter error adjustments, such as Water Supplied/Volume from Own Sources error adjustment and Authorized Consumption/Unbilled Unmetered error default value. Error boxes are usually set off to the right of the main data entry cells.

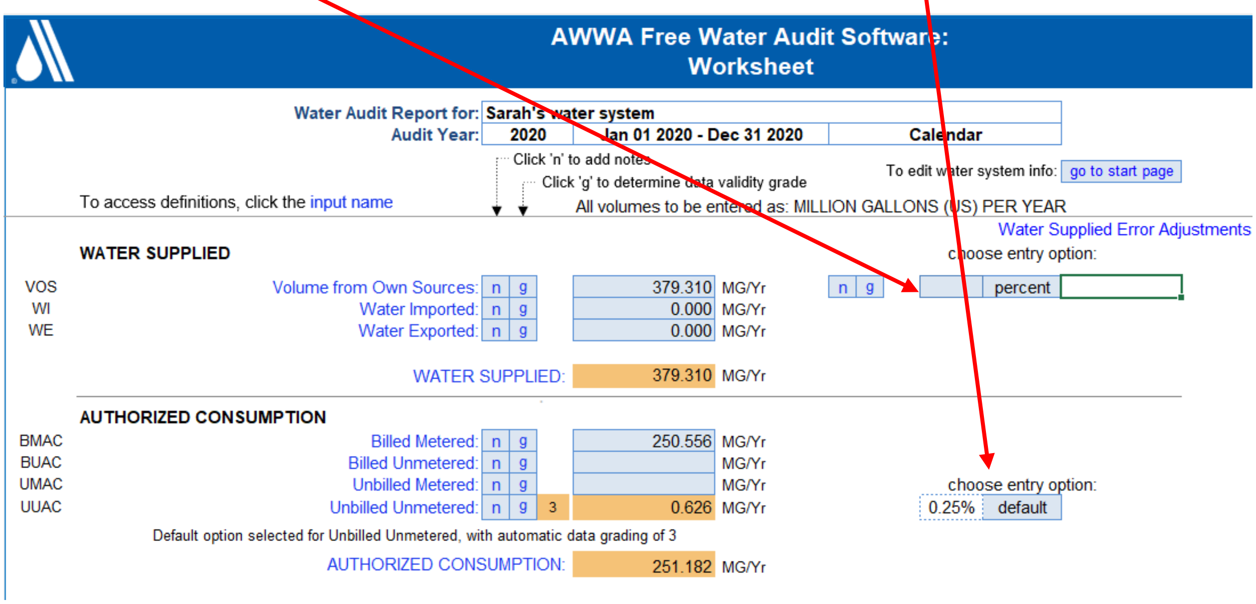


Figure 6. Screenshot of where to enter error adjustments and default values.

This screenshot shows where to click (on the lower case "g") to enter the data validity grade for Water Supplied/Volume from Own Sources. When you click on the "g", the spreadsheet takes you to the Interactive Data Grading Tab. Here you will answer questions that will help determine the data validity grade for most of the main data that you enter.

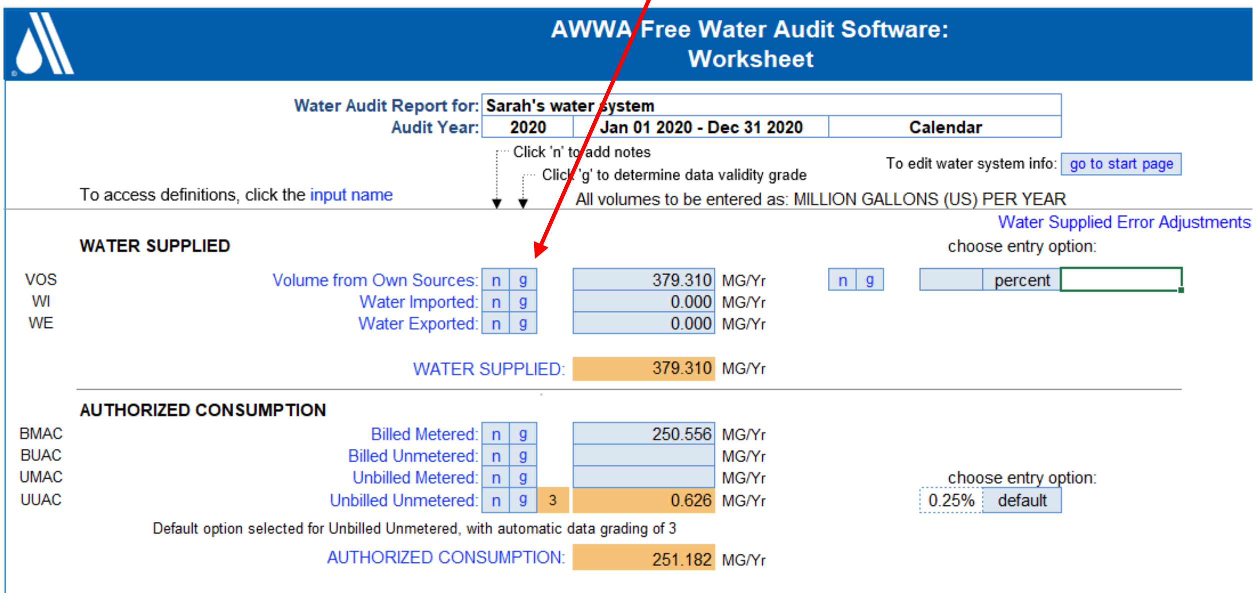


Figure 7. Screenshot of where to enter data validity grades.

3.4 Interactive Data Grading Tab

The Interactive Data Grading tab is where the software helps you determine the data validity grade. There are 19 categories with a handful of questions related to each one. The cells at the top will turn from white (incomplete) to orange (complete) and a final data grade will appear when all the questions are answered.

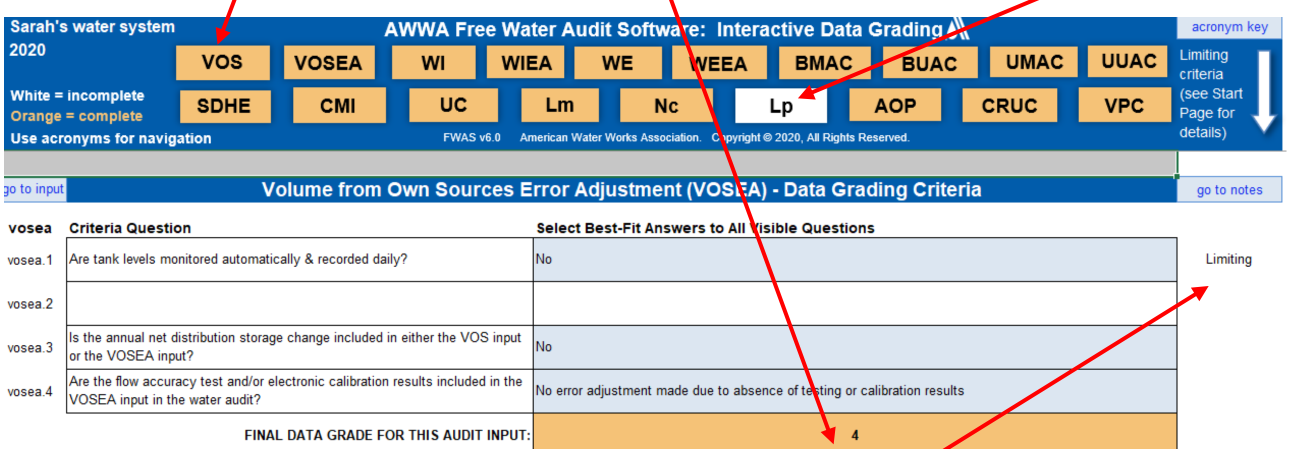


Figure 8. Screenshot of Interactive Data Grading Tab.

If the grade is 9 or less, the limiting criteria will be identified.

The separate document titled, AWWA Free Water Audit Software v6.0 Interactive Data Grading Matrix is helpful in explaining how the grades are derived and how to improve the data grade.

When you click back to the Worksheet tab you will see that the grade has been assigned.

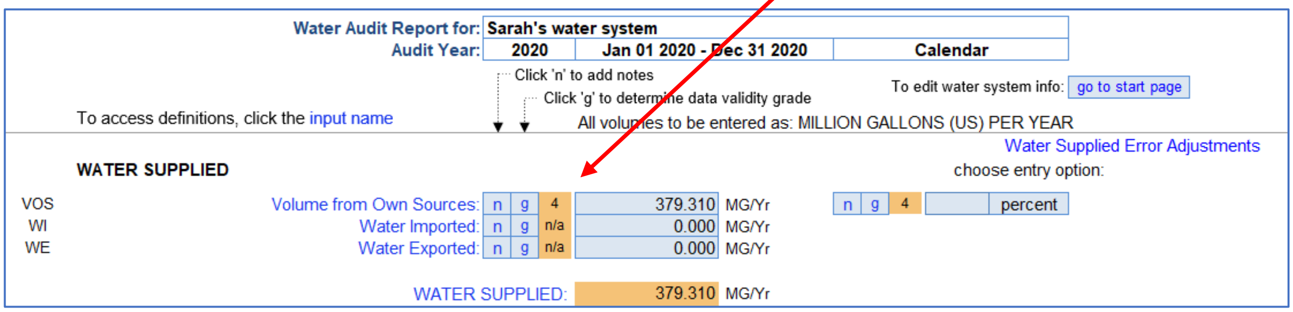


Figure 9. Screenshot of Worksheet tab with data grade entered.

3.5 Other Tabs

The Dashboard tab displays key performance indicators, and the Loss Control Planning tab offers suggestions for improving them. The Water Balance tab displays your data according to the Water Balance categories. The Definitions tab and Service Connection Diagram are helpful resources. It is highly recommended to use the Notes tab to identify sources of data and track of calculations to help complete future audits.

4 COMPLETING THE WATER AUDIT

4.1 Water Supplied

The determination of Water Supplied is the first step and the foundation of the water balance.

Water Supplied: The volume of treated and pressurized water input to the retail water distribution system. Mathematically:

Water Supplied = System Input Volume – Water Exported

System Input Volume: The volume of water that is introduced to the water distribution system over the audit period. Mathematically:

System Input Volume = Volume from Own Sources + Water Imported +/- the Change in Storage

Water Exported ("WE"): Bulk water sold to neighboring water systems that exist outside the service area.

Water Imported ("WI"): Bulk water typically purchased from a neighboring water utility or regional water authority, which is metered at the custody transfer point of interconnection between the two utilities. Water Imported is also known as import, purchased or wholesale water.

Volume from Own Sources ("VOS"): The volume of water withdrawn from water resources (rivers, lakes, wells, etc.) controlled by the water utility and then treated for potable water distribution.

Changes in Storage: *The annual volumetric change in stored water that is located within the bounds of the water audit.*

It is advised that you collect Water Supplied data from meters that are located immediately at or prior to entry into the distribution system. For example, if faced with the choice of using flow data from either a water treatment plant influent or effluent meter, the effluent meter would be preferable (insofar as it is in good working order, because the effluent meter captures only the water that enters the distribution system whereas the influent meter may also capture water used for operational purposes at the treatment plant, which is upstream of the distribution system).

An excerpt of the water balance is presented in Figure 10 below to illustrate the relationship between Water Supplied and other key volumes. Water Supplied is highlighted.

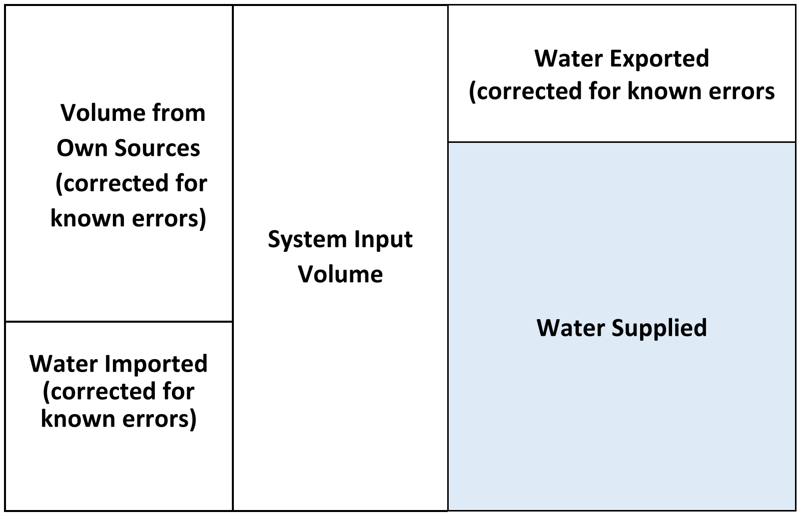


Figure 10: Water Balance highlighting Water Supplied.

Figure 11 shows the setup of a fictious water system named the Green Country Water District ("GCWD"). GCWD's potable water comes from two wells, surface water, and treated imported water. Well water and surface water go to the water treatment plant prior to entering the distribution network. Flow volumes are metered as effluent from the treatment plant. Imported water enters the distribution network directly and is metered at the interconnection between the GCWD system and the neighboring system. GCWD exports some water to a neighboring utility, which is metered at the system interconnection.

As such, Volume from Own Sources consists of water from wells and surface water, which is cumulatively metered as treated effluent at the water treatment plant. Water Imported consists of imported water. Water Exported consists of export water to the neighboring utility. GCWD's auditor collected data for the audit period from the three relevant meters, indicated by the letter "M."

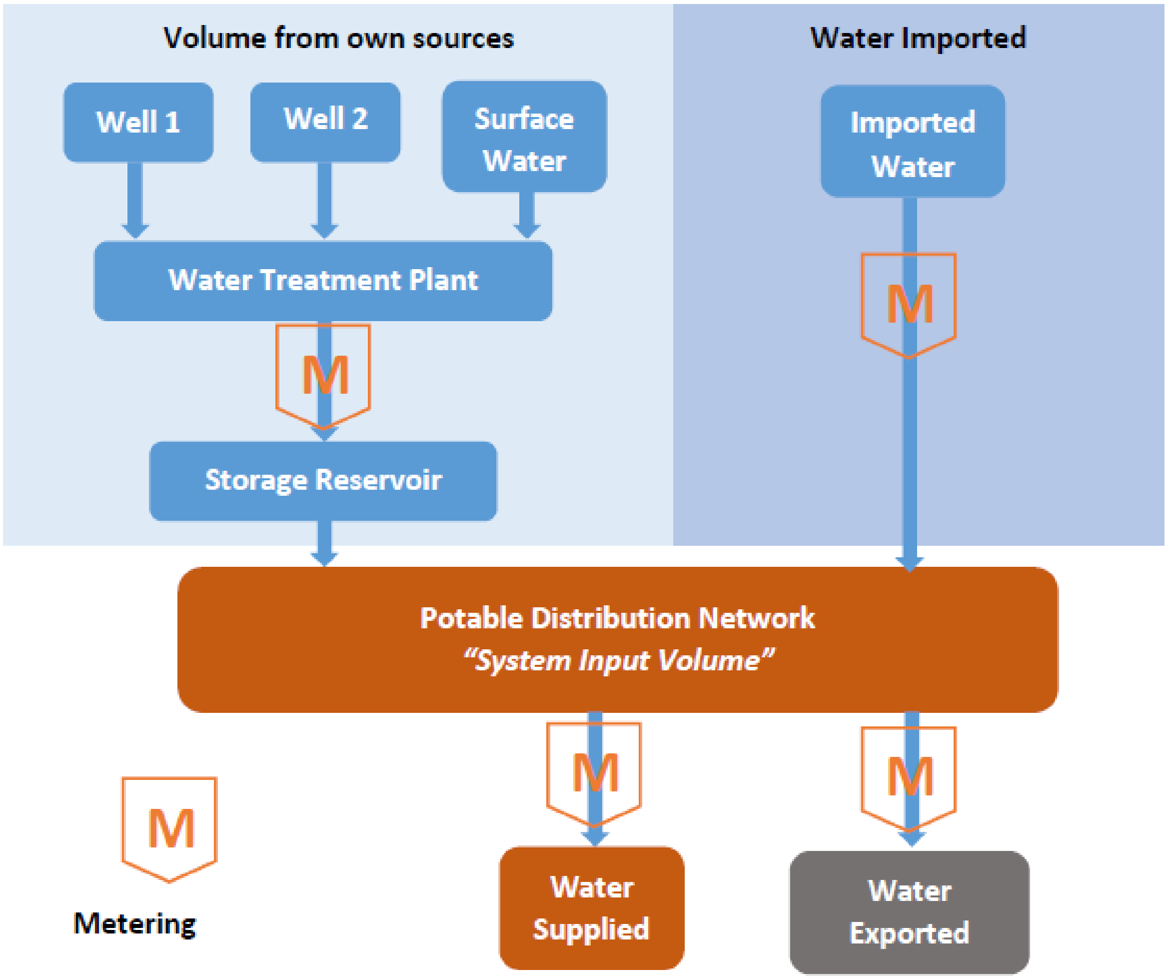


Figure 11: Green Country Water District water system.

You may turn to a number of different sources for Water Supplied data. For example, your utility may have information from any number of the following sources:

- Monthly water purchases on bills from wholesalers
- Monthly groundwater extraction volumes on statements from groundwater-regulating agencies
- Manual meter readings
- SCADA meter readings

Ultimately, you will need to determine which data sources most accurately reflect the actual volume of water entering the distribution system and leaving as exports.

Every water system is unique, so you will have to consider the distinct setup of your own system when determining how to appropriately calculate Water Supplied. Nonetheless, this checklist can help you make sure that Water Supplied is accurately calculated:

- ✓ Did you account for all sources of water?
- ✓ Did you ensure that no water was mistakenly double-counted?
- ✓ Did you account for all exports of water?
- ✓ Did you make sure to exclude all non-potable water?
- ✓ Did you properly incorporate changes in storage, if applicable?

4.1.1 Accounting for Change in Storage

A best practice is to account for changes in reservoir storage levels over the course of the audit period. If the volume of stored water increased between the first and last day of the audit period, then the change in storage represents a withdrawal of water from the distribution system. In other words, the increase in storage represents water that was supplied into the system but then temporarily withheld from customer use. In this case, the absolute value of the volumetric change should be ***subtracted*** from the calculation of Water Supplied. The inverse is similarly true: if stored volume decreased between the first and last day of the audit period, then the change represents an additional supply of water to distribution system, and the absolute value of the volumetric change should be ***added*** to the calculation of Water Supplied.

Change in Storage should only be accounted for if storage is located downstream of the metering points that are relied upon for Water Supplied data. If storage is upstream of those meters, then changes in storage will already be accounted for by the meters and will not need to be accounted for separately.

The software does not provide a separate field for Change in Storage. As such, Change in Storage can be applied in one of three places:

- Volume from Own Sources
- Water Imported, if applicable
- Water Supplied Error Adjustment, using the volume method is easiest. More on Water Supplied Error Adjustment in the next section.

In the below example, Green County Water District storage was calculated to have decreased by -0.825 MG between the first and last days of the audit period based on tank levels. Therefore, the auditor should ***add*** 0.825 MG to Volume from Own Sources (or Water Imported, as applicable) since it represents an additional supply to the distribution system. It is important to make a note of the specific volume of Changes in Storage that was applied to Volume from Own Sources, using the Comments feature in the software.

Some utilities keep monthly records of changes in storage, in which case the storage changes over the course of the year-long audit period can be added together. Make sure that "+" and "–" signs are properly taken into account.

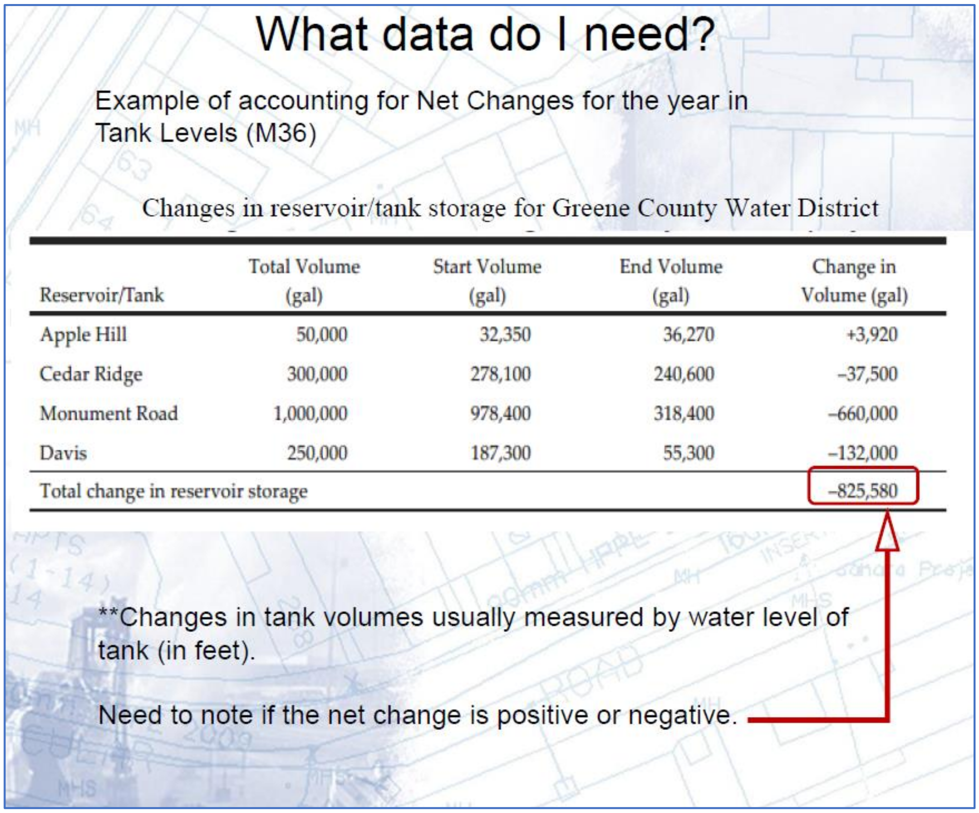


Figure 12: Tank level changes for year.

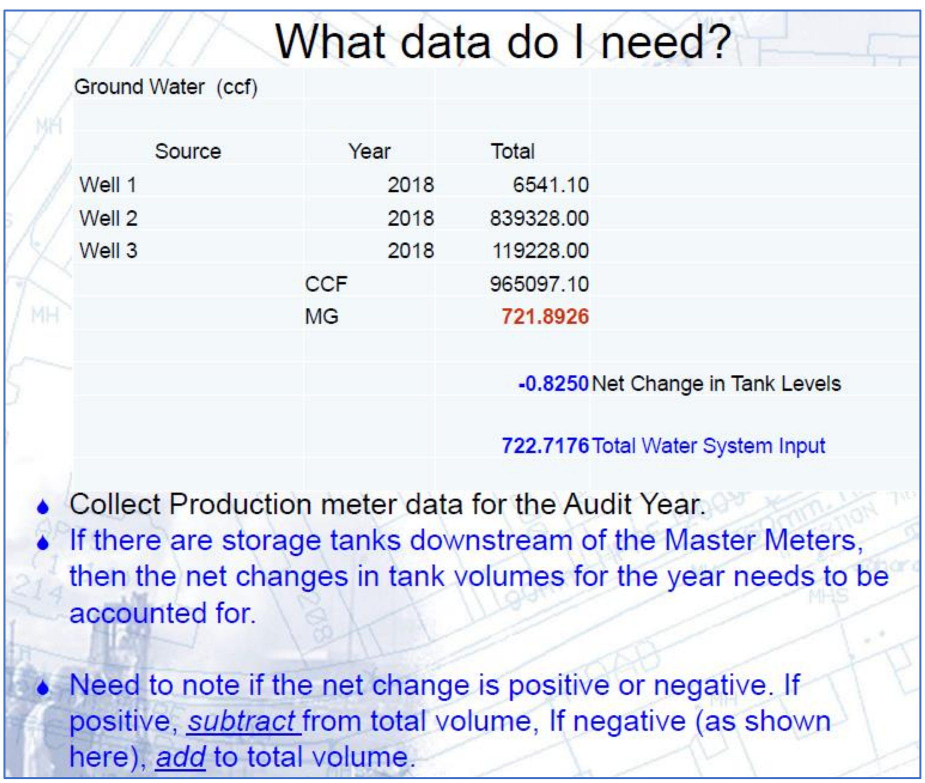


Figure 13. Tank level changes effect Volume from Own Sources.

The GCWD auditor filled out the Reporting Worksheet accordingly:

	WATER SUPPLIED									Water Supplied Error Adjustments choose entry option:				
VOS	Volume from Own Sources:	n	g	4	721.893	MG/Yr	n	g	4	volume	0.825	MG/Yr	under-registration	VOSEA
WI	Water Imported:	n	g	4		MG/Yr								WIEA
WE	Water Exported:	n	g	n/a		MG/Yr								WEEA
	WATER SUPPLIED:				722.718	MG/Yr								

4.1.3 Water Supplied Error Adjustments (“VOSEA”, “WIEA” and/or “WEEA”)

This is where you should account for any known errors in master meters. Sources of error include meter error (under- or over-registration) and data transfer error of the meter instrumentation.

1. **Meter error:** measurement inaccuracy in the meter(s) used to derive the input volume, typically identified through in-situ flow accuracy testing. Applicable for Volume from Own Sources, Water Imported, and Water Exported. If no such testing has been performed, adjustment for meter error is not typically recommended.
2. **Data transfer error:** inaccuracy in archived volumes, typically due to gaps in data, programming errors impacting unit conversions, and/or programming errors impacting totalization of measured volumes over the audit period. Applicable for Volume from Own Sources, Water Imported, and Water Exported. These errors are typically identified through electronic calibration to verify data transfer at the secondary device (i.e., conversion to mA, meter transmitter or similar instrumentation) and/or the tertiary device (i.e., SCADA, historian, or other computerized archival system).

There is no uniform method for calculating master meter and supply error because every utility has a unique combination of master metering setup, testing and calibration procedures, and data management processes. The person completing the audit will have to use their best judgment based on the information available.

Derivation Guidance:

If an Error Adjustment input is being calculated as a volume, each source of error (described above) may be separately calculated, with careful consideration of under- vs over-registration, then added together to determine the composite volume to input. The composite input should be entered on the Worksheet as a positive number, then under- or over-registration selected on the adjacent dropdown.

If an Error Adjustment input is being calculated as a percent, some very general guidance for calculating each error source (described above) is provided below. The auditor is again cautioned that each specific water supply setup needs to be evaluated closely as noted in the Disclaimer. Refer to the latest AWWA M36 Manual for additional discussion and guidance on this matter.

1. **Meter error:** If in-situ flow accuracy testing has been performed, and inherent testing method error is understood, first the meter accuracy % may be determined as follows:

meter accuracy % = System input meter(s) volume / Reference volume

Then, the meter error % may be determined as follows:

meter error % = meter accuracy % - 100%

2. **Data transfer error:** If electronic calibration at the secondary device (i.e., device that converts to mA, meter transmitter or similar instrumentation) and/or tertiary device (i.e., SCADA, historian, or other computerized archival system) has been performed, first the data transfer accuracy % may be determined as follows:

data transfer accuracy % = Tertiary device volume / Reference volume (typically at Secondary device)

Then, the data transfer error % may be determined as follows:

data transfer error % = data transfer accuracy % - 100%

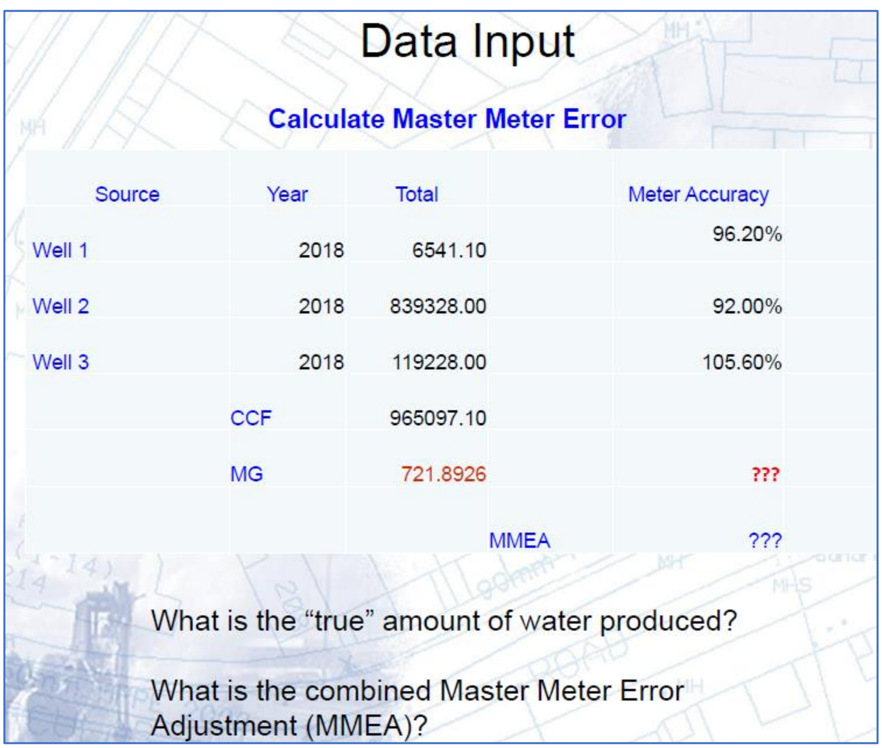
If no error is identified, if electronic calibration has not been performed, or if no secondary or tertiary devices exist, a data transfer error % adjustment is not typically recommended.

The final step is to add meter error % and data transfer error %:

Error Adjustment % = meter accuracy % + data transfer error %

If the total Error Adjustment % calculates out as a negative number, it represents an under-registration. Vice versa, if positive. The composite input should be entered on the Worksheet as a positive number, then under- or over-registration selected on the adjacent dropdown.

An example is provided:



Source	Year	Total		Meter Accuracy
Well 1	2018	6541.10		96.20%
Well 2	2018	839328.00		92.00%
Well 3	2018	119228.00		105.60%
	CCF	965097.10		
	MG	721.8926		???
			MMEA	???

Figure 14. Water Supplied Error, step 1.

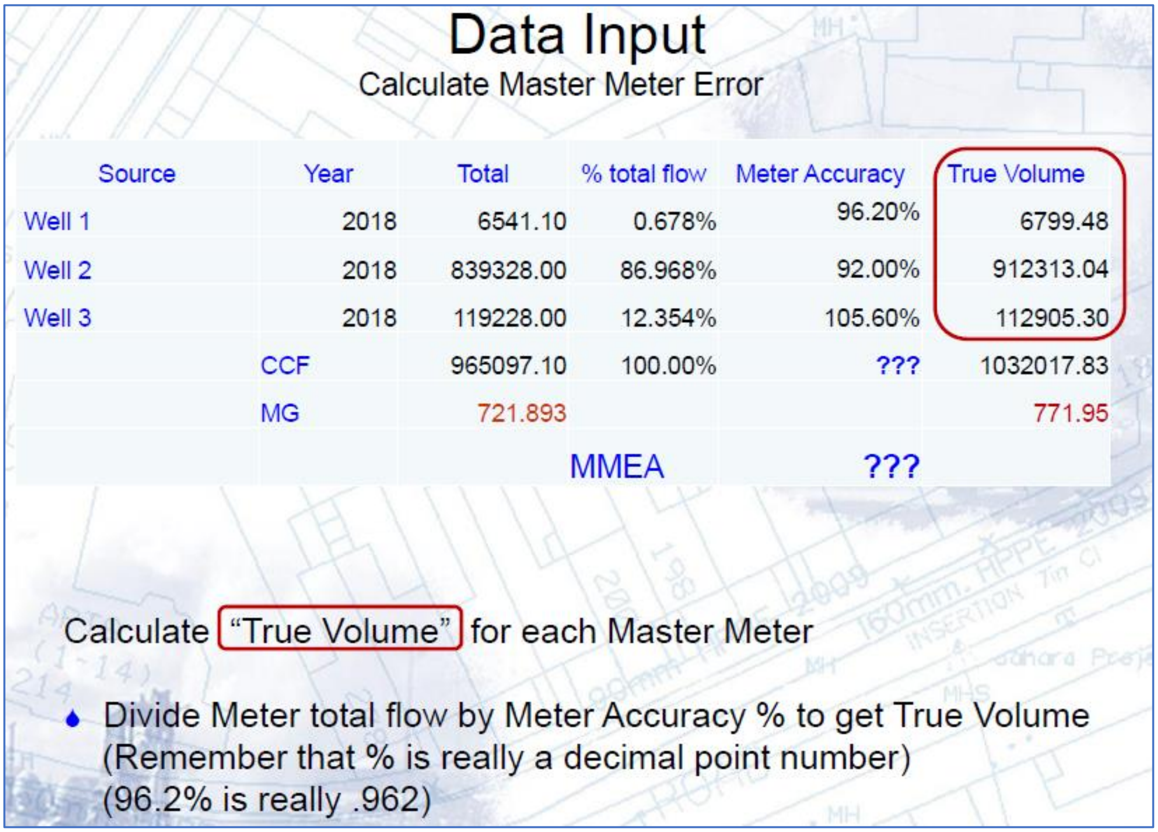


Figure 15. Water Supplied Error, step 2.

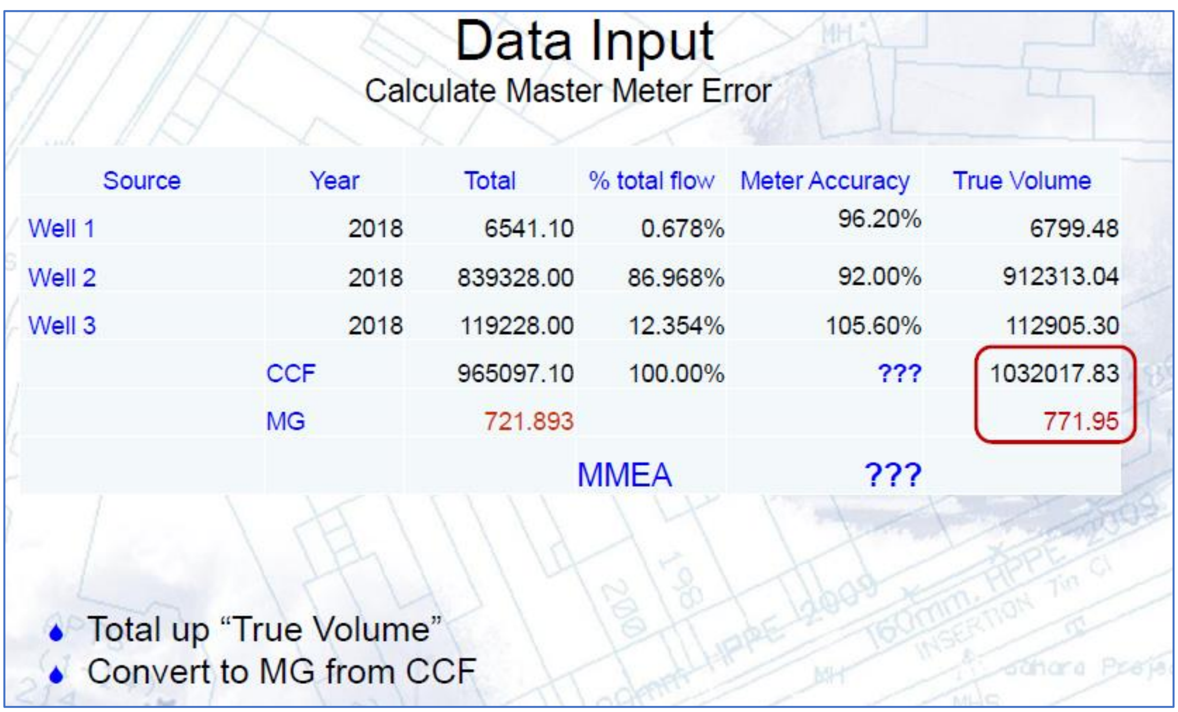


Figure 16. Water Supplied Error, step 3.

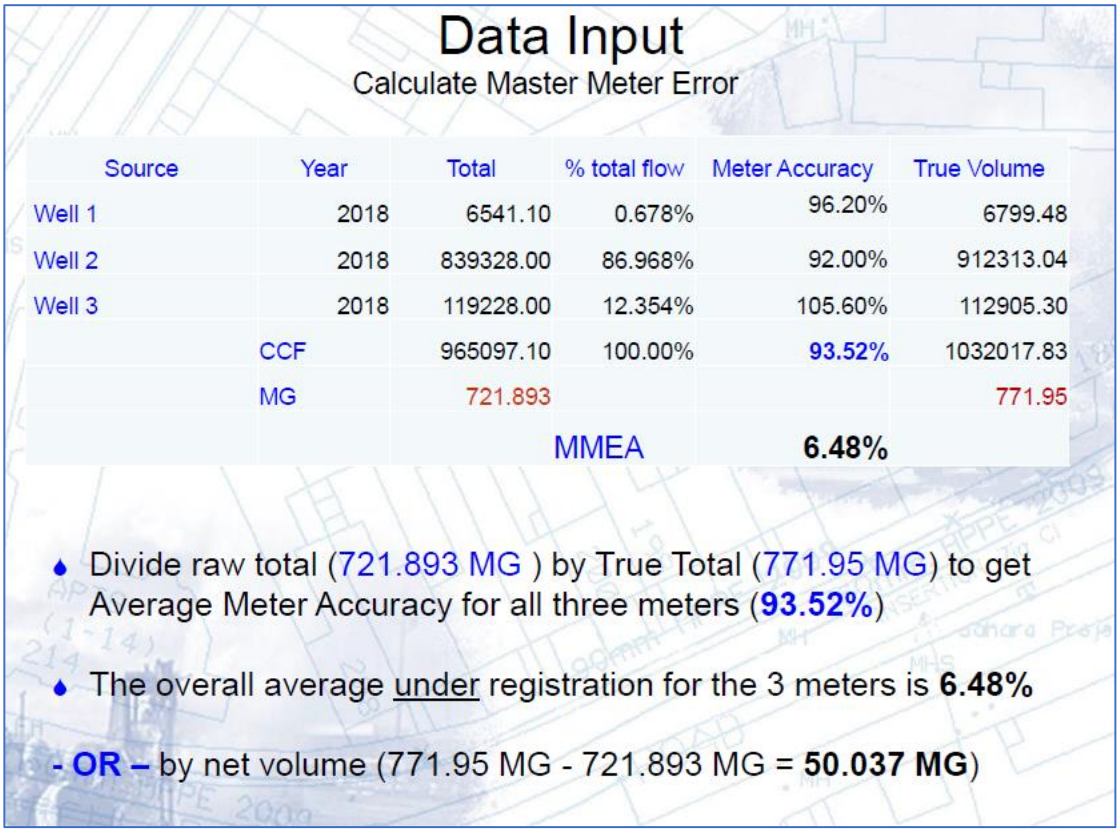
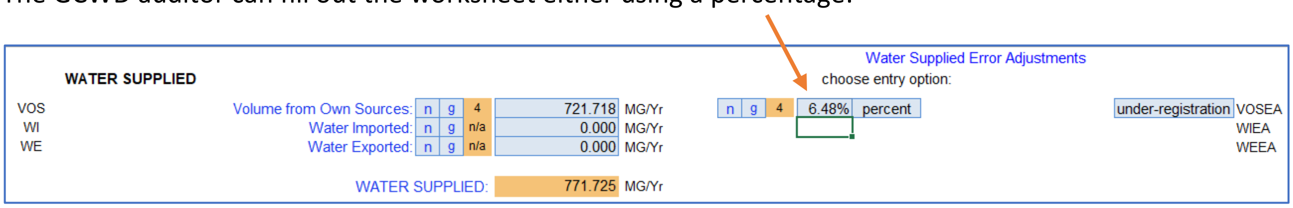
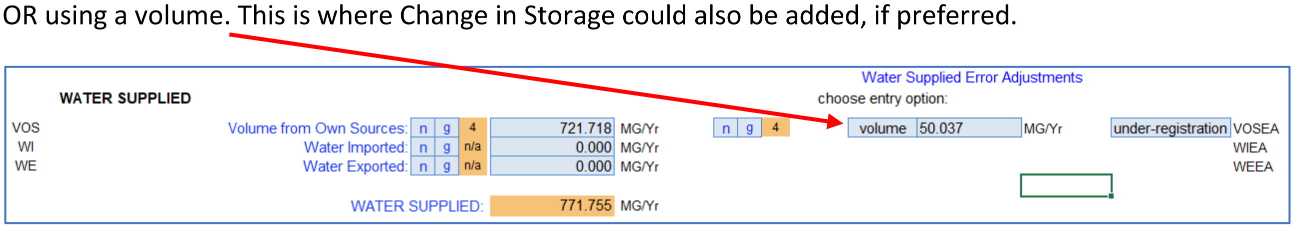


Figure 17. Water Supplied Error, step 4.

The GCWD auditor can fill out the worksheet either using a percentage:



OR using a volume. This is where Change in Storage could also be added, if preferred.



4.1.4 Primary, Secondary, and Tertiary Metering Devices

Some notes about meter testing and calibration on the Interactive Data Grading tab:

1. There is a notable difference between accuracy testing of the primary metering device and calibration of related instrumentation (e.g., a pressure differential cell). A meter test compares the test meter reading to either a reference meter or a fixed volume, while instrument calibration ensures accurate communication of the electronics of certain types of meters. While calibration of instrumentation is critical, it does not guarantee meter accuracy.

2. In-situ flow accuracy testing = a test process that confirms the flow metering accuracy of the primary device (e.g., the main meter), in its installed location, using an independent reference volume.

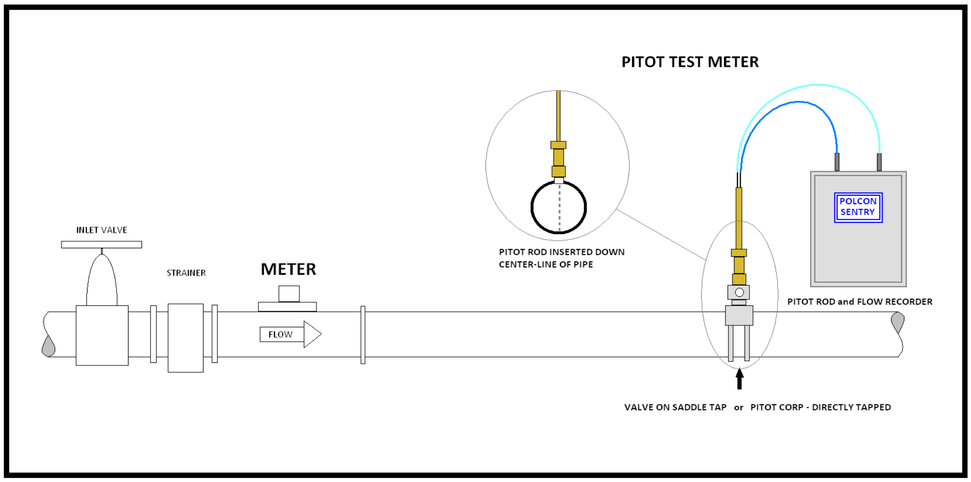


Figure 18. An "in-situ" test, where the primary device, the meter, is being tested.

3. Electronic calibration = a process that checks for error in the metering secondary device(s) and/or the tertiary device(s).

4. Secondary device = another meter that could include conversion to mA, meter transmitter or similar instrumentation.

5. Tertiary device = another meter that could include SCADA or other computerized archival system.

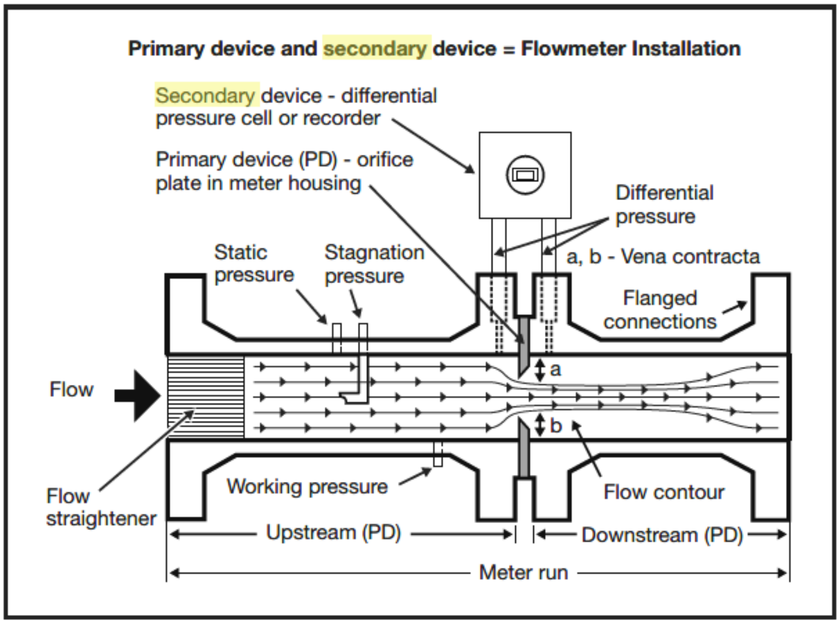


Figure 19. Primary and secondary metering devices.

4.2 Authorized Consumption

The determination of the volume of Authorized Consumption is the second major component of the AWWA water balance.

Authorized Consumption: The volume of metered and/or unmetered water taken by registered customers, the water supplier, and others who are authorized to do so.

Figure 10 below shows the position of Authorized Consumption and its sub-components within the simplified water balance. (This manual uses the term "simplified water balance" to refer to the portion of the water balance that begins with Water Supplied, thereby excluding the presentation of Water Exported.)

As shown below, Authorized Consumption consists of Billed Authorized Consumption and Unbilled Authorized Consumption, which can be further divided into the following components:

Billed Metered Consumption*:* Consumption that generates revenue, the volume of which is determined by a water meter.

Billed Unmetered Consumption*:* Consumption that generates revenue, the volume of which is determined by estimation or is not known.

Unbilled Metered Consumption: Consumption that does not generate revenue, the volume of which is determined by a water meter.

Unbilled Unmetered Consumption: Consumption that does not generate revenue, the volume of which is determined by estimation or is not known.

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

Figure 20. The Authorized Consumption portion of the AWWA water balance.

It is important to accurately distinguish amongst these categories because they directly inform your utility's understanding of revenue and non-revenue water. Additionally, the process of categorization can lead to valuable insights as to how to improve the reliability of data.

This guide proceeds by describing how to calculate the volumes associated with the four types of Authorized Consumption and provides examples to clarify how particular uses of water should be categorized.

4.2.1 Billed Metered Consumption ("BMAC")

Billed metered consumption consists of all uses that generate revenue and are metered. In a utility where most of or all customers are metered, consumption by retail customers will comprise the majority of billed metered consumption, so it is imperative that you be thorough in the determination of this volume. Any errors introduced at this step will have a relatively large impact on the accuracy of the water balance and the calculation of real losses.

> It is best practice to keep track of the particular parameters and procedures that are followed to generate data, so that you can replicate the process year-to-year.

Work with your billing department to generate a customer consumption report that includes all classes of potable customers that provide revenue to the utility. It is important to include temporary meters that generate revenue, such as meters used for construction sites. Make sure that the parameters of the report are established such that the consumption data best reflects consumption as it actually occurred within the audit period, so that your comparison of "water in" from source meters to "water out" to customers makes sense. Although every utility conducts billing in a unique manner, here are some guidelines that most utilities will find applicable:

1. If your billing system utilizes Advanced Metering Infrastructure ("AMI"), you probably have access to actual daily consumption data, which allows you to very accurately capture consumption over the audit period. This is ideal.
2. If your billing system does not utilize AMI—if your utility uses either Automatic Meter Reading or manual readings—then run a consumption report in which the meter read date falls within the audit period.
3. If your billing system does not allow you to run a report by meter read date, then run a report in which the bill date falls within the audit period. For the purpose of capturing consumption as it actually occurred in the audit period, this method is less accurate than using meter read date because bills are sent out later than the meter read date and less accurately reflect the actual timing of customer consumption.

Do not confuse exports to other agencies with billed metered consumption, even if such volumes are billed and metered! Exports should be treated as Water Exported in the determination of Water Supplied. Some customer billing systems include records of sales to outside agencies—if so, make sure to exclude them from the calculation of Authorized Consumption.

The following checks can help ensure that the consumption report accurately reflects the parameters of the water audit:

- ✓ Does the data include all billed metered customers and exclude unbilled metered customers such as non-paying municipal accounts (or at least identify those accounts so that you may account for them separately)?
- ✓ Did you make sure that any sales to outside agencies were excluded (or at least identified so that you may account for them separately)?
- ✓ Did you make sure that any non-potable water sales were excluded (or at least identified so that you may exclude them yourself)?
- ✓ Are you sure that the consumption data reflects actual volumetric use, and not changes that may have been made to billed consumption for the sole purpose of making financial adjustments to the bill?

4.2.1.1 Consistency of Units

Make sure that volumetric units within the billing database are consistent. Some utilities have meters that are read in different units—some may be read in CCF (hundred cubic feet), while others may be read in KGAL (thousand gallons). If the billing database features more than one volumetric unit, make sure to make the necessary conversions to standardize the data.

4.2.1.2 Correct for Misalignment between Billing Period and Audit Period

If you used Option 2 or 3 above to generate a consumption report, it is best practice to correct for the misalignment between the meter reading / billing cycles and the audit period. This is applicable when meter reading / billing cycles do not perfectly coincide with the audit period.

The following example introduces the concept of correcting for misalignment in a simple situation—where customer meters are read on a single day every month. However, the exercise can become quite complex with utilities that have a high number of meter reading / billing cycles. The example below does not show the specific calculations that were performed to make the corrections for misalignment. Those calculations are presented in Appendix B: Correcting for Misalignment between Meter Reading / Billing Cycles and Audit Period.

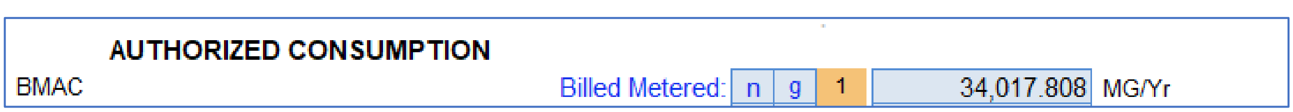
> Correcting for billing period misalignment using the pro-rating method is especially important in utilities that bill at less frequent intervals, such as on a bi-monthly or quarterly basis.

Green Country Water District reads customer meters on the same day every month. The GCWD auditor compiled billed metered sales data relevant to the audit period (01/01/2019 - 12/31/2019), as detailed in Table 1 below, plus an extra meter read on either side of the audit period to correct for misalignment. This data is shown in the column titled "Customer Sales." The final column of Table 1 shows the volume of sales after correcting for misalignment.

Table 1: GCWD Correcting for Billing Period Misalignment Example

Read Date	Customer Sales (MG)	Customer Sales – Corrected for Misalignment (MG)
12/10/2018	2,418.661	0
1/10/2019	2,278.897	735.128
2/10/2019	2,233.471	2,233.471
3/10/2019	2,278.897	2,278.897
4/8/2019	2,877.013	2,877.013
5/10/2019	2,952.724	2,952.724
6/9/2019	3739.260	3,739.260
7/10/2019	3,471.978	3,471.978
8/10/2019	3,439.905	3,439.905
9/11/2019	3,068.071	3,068.071
10/12/2019	2,865.882	2,865.882
11/10/2019	2,460.604	2,460.604
12/10/2019	2,422.748	2,422.748
1/10/2020	2,281.797	1,472.127
Total	**34,089.450**	**34,017.808**

The GCWD auditor filled out the Reporting Worksheet accordingly:



The example above shows the value of correcting for misalignment. Without doing so, billed metered consumption would have been 33,642.876 MG, which is 1.1% less than the corrected volume. If left uncorrected, this 1.1% difference would have been carried through the remaining steps of the water balance and been accounted for as real losses. The resulting volume of real losses would have been calculated to be 3,244 MG instead of 2,858 MG – overstated by 13.5**%. In other words, make sure to get this step right, because it will impact your understanding of water losses, real losses, revenue and non-revenue water, and the resulting performance metrics for your system.**

4.2.2 Billed Unmetered Consumption ("BUAC")

Billed unmetered consumption consists of consumption that generates revenue but is not metered. These accounts are often referred to as flat rate or flat fee customers, since they are assessed a fixed charge based on an estimated volume of use.

There are several means by which consumption can be estimated, such as using a sample of *metered* accounts similar in characteristics (e.g., customer category, meter size) and extrapolating consumption habits from those accounts to the non-metered population. However, even such an approach contributes a great deal of uncertainty to the determination of consumption volumes. Because of the difficulty in accurately determining consumption through estimation, the AWWA M36 manual highly recommends that all customers be properly metered, read, and archived.

In the example of GCWD, all customers are metered, except for some unmetered condominium developments. These unmetered accounts are billed an assumed monthly usage of 8 CCF per housing unit, which is based on an approximate average monthly consumption for metered multi-family housing units. These accounts are included in the customer billing database and uniquely identified as flat fee. The total audit period consumption for these accounts was 29.872 MG. When calculating *billed metered* authorized consumption, the auditor made sure to exclude those accounts.

The GCWD auditor filled out the Reporting Worksheet accordingly:

	AUTHORIZED CONSUMPTION					
BMAC	Billed Metered:	n	g	1	34,017.808	MG/Yr
BUAC	Billed Unmetered:	n	g	n/a	29.872	MG/Yr

4.2.3 Unbilled Metered Consumption ("UMAC")

Unbilled metered consumption includes all uses that are metered but do not generate revenue for the utility. In Indiana, such use is typically associated with metered operational uses by the water utility, such as flushing programs that utilize temporary meters to track usage. Unbilled metered uses may be tracked in the billing system, on operational records, or a combination of the two, depending on utility practices. Keep in mind that consumption volumes that are *calculated* rather than *metered*—such as the filling of a fixed-volume water truck—should be categorized as unbilled unmetered consumption, as described in the next section.

The auditor for GCWD has identified the following unbilled metered uses and consumption volumes for the audit period, and performed the appropriate lag time correction:

Table 2: GCWD Unbilled Unmetered Use

Type of Use	CY19 Pro-rated Consumption (MG)
Water Utility Facilities – Indoor	41.464
Water Utility Facilities – Irrigation	2.588
Total Unbilled Metered Consumption	44.052

The GCWD auditor can fill out the Reporting Worksheet using a percentage:

AUTHORIZED CONSUMPTION

BMAC	Billed Metered:	n	g	1	34,017.808	MG/Yr
BUAC	Billed Unmetered:	n	g	n/a	29.872	MG/Yr
UMAC	Unbilled Metered:	n	g	n/a	44.052	MG/Yr

4.2.4 Unbilled Unmetered Consumption ("UUAC")

Unbilled unmetered consumption consists of those uses that are neither metered nor revenue-generating. Most often, this includes operational uses by the water utility. Because the volumes associated with these forms of consumption can be challenging to compile and accurately quantify, AWWA provides a default value that can be used until better information within the utility becomes available. The default value equates to 0.25 of the Billed Authorized Consumption (BMAC + BUAC). Of note, the default UUAC volume is not intended as a long-term (or even medium-term) substitute for a system specific UUAC estimate. As it is recommended for water utilities to begin estimating their UUAC volumes in the short-term, the statistical representativeness of a UUAC default volume becomes less important.

The GCWD auditor used the default percentage because GCWD does not keep thorough documentation of unbilled unmetered consumption, as shown below. However, the auditor suspects that the actual consumption volume is less than the default value and has initiated a utility-wide review of all unbilled unmetered uses so that future audits can more accurately estimate consumption.

AUTHORIZED CONSUMPTION

BMAC	Billed Metered:	n	g	1	34,017.808	MG/Yr	
BUAC	Billed Unmetered:	n	g	n/a	29.872	MG/Yr	
UMAC	Unbilled Metered:	n	g	n/a	44.052	MG/Yr	choose entry option:
UUAC	Unbilled Unmetered:	n	g	3	85.119	MG/Yr	0.25% default

Default option selected for Unbilled Unmetered, with automatic data grading of 3

If you choose to quantify unbilled unmetered uses rather than use the default value, the following types of uses commonly fall into this category:

- Reservoir/tank draining
- Water use at water utility facilities (if unmetered)
- Water quality testing
- Water treatment plant operations (if within boundaries of water audit, i.e., downstream of the source meters relied upon for Water Supplied data)
- Flushing water mains (hydrant flushing), storm inlets, culverts, and sewers
- Firefighting and training
- Fire flow tests performed by the utility
- Street cleaning
- Landscaping/irrigation in public areas
- Construction sites (should be billed metered, but sometimes not enforced by utilities)

4.3 Water Losses

Water Losses consists of Apparent Losses and Real Losses, as shown in Figure 21. First, you will determine the volume of Apparent Losses, which will in turn determine the volume of Real Losses— which is simply the remainder after the volume of Apparent Losses has been subtracted from the volume of Water Losses.

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

Figure 21. The different types of water losses on the water balance.

4.3.1 Apparent Losses

Apparent losses are the nonphysical losses that occur when water is successfully delivered to the customer but is not measured or recorded accurately.

As shown in Figure 22, Apparent Losses consists of Unauthorized Consumption, Customer Metering Inaccuracies, and Systematic Data Handling Errors:

Systematic Data Handling Errors: Errors caused by accounting omissions, errant computer programming, data gaps, and data entry; inaccurate estimates used for accounts that fail to produce meter readings; billing adjustments that manipulate billed consumption so as to generate a rightful financial credit in such a way that billed consumption does not reflect actual consumption.

Customer Metering Inaccuracies: Inaccuracies in registering water consumption by retail customer meters.

Unauthorized Consumption: Consumption that is not explicitly or implicitly authorized by the utility, commonly known as water theft.

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

Figure 22. Apparent Losses and its sub-components within the simplified water balance.

Controlling Apparent Losses can offer substantial opportunities for revenue recovery, since such water is valued at the customer retail cost. In other words, Apparent Losses represent water that is being delivered but not being billed for—the recovery of which can have significant financial benefits.

It is important to develop an accurate understanding of Apparent Losses because its relationship with Real Losses is zero-sum, due to the deduced determination of Real Losses. Any under-estimation of Apparent Losses will result in an over-estimation of Real Losses, and vice versa.

This guide proceeds by describing how to calculate the volumes associated with the three types of Apparent Losses.

4.3.1.1 Systematic Data Handling Errors ("SDHE")

Systematic Data Handling Errors refer to a type of apparent losses caused by accounting omissions, errant computer programming, gaps in policy, procedure, and permitting/activation of new accounts or any type of data lapse that results in under-counting of customer water consumption in summary billing reports. Systematic Data Handling Errors result in a direct loss of revenue potential. Water utilities can find "lost" revenue by focusing on this component.

If the water auditor has not yet gathered detailed data or assessment of systematic data handling error, it is recommended that the auditor apply the default value of 0.25% of the Billed Authorized Consumption volume. However, if the auditor has investigated the billing system and its controls and has well validated data that indicates the volume from systematic data handling error is substantially higher or lower than that generated by the default value, then the auditor should enter a quantity that was derived from the utility investigations and select an appropriate grading. Negative or zero values are not allowed for this audit component.

For suggestions on how to calculate your own Systematic Data Handling Errors, see Appendix C.

4.3.1.2 Customer Metering Inaccuracies ("CMI")

Customer metering inaccuracies account for the fact that all meter populations feature a certain degree of inaccuracy in registering customer consumption volumes. Inaccuracies typically reflect meter under-registration due to wear-and-tear and inappropriate meter sizing (usually over-sizing).

The auditor has two options for entering data for this component of the audit. The auditor can enter a percentage under-registration (typically an estimated value), this will apply the selected percentage to the two categories of metered consumption to determine the volume of water not recorded due to customer meter inaccuracy. Note that this percentage is a composite average inaccuracy for all customer meters in the entire meter population. The percentage will be multiplied by the sum of the volumes in the Billed Metered and Unbilled Metered components. Alternatively, if the auditor has substantial data from meter testing activities, he or she can calculate their own loss volumes, and this volume may be entered directly.

Note that a value of zero will be accepted but is not recommended, as all metered systems tend to have some degree of inaccuracy. A positive value should be entered. A value of zero in this component is generally valid only if the water utility does not meter its customer population.

The formula for calculating a volume of CMI from a percentage input is as follows:

CMI volume = (BMAC+UMAC)/(1-CMI%)-(BMAC+UMAC)

For guidance on how to conduct random meter testing, see Appendix D.

4.3.1.1 Unauthorized Consumption ("UC")

Unauthorized consumption, also known as water theft, can include:

- Illegal connections
- Open bypasses
- Buried or otherwise obscured meters
- Misuse of fire hydrants and fire-fighting systems
- Vandalized or bypassed consumption meters (meter tampering)
- Tampering with meter reading equipment
- Illegally opening intentionally closed valves or curb stops on customer service piping that has been discontinued or shut off for nonpayment.

While Unauthorized Consumption varies from system to system, the total volume of water lost is typically a very small portion of the volume of Water Supplied. AWWA has found a default estimate of 0.25% of Billed Authorized Consumption to be suitable in most cases. However, if the auditor has investigated unauthorized occurrences, and has well validated data that indicates the volume from unauthorized consumption is substantially higher or lower than that generated by the default value, then the auditor should enter a quantity that was derived from the utility investigations. Note that a value of zero will not be accepted since all water utilities tend to have some volume of unauthorized consumption occurring in their system.

4.3.2 Real Losses

At this point, you have entered all the necessary information to be able to determine the volume of Real Losses (leakage). As discussed in Section 2.1.1, in a top-down water audit such as this one, Real Losses are derived using a process of deduction or process of elimination. Now that you have calculated the volume of Water Supplied, Authorized Consumption, and Apparent Losses, the volume of Real Losses is simply what is left over.

In addition, you have also calculated Revenue Water and Non-Revenue Water; you now have a complete *water balance* in place. At this point, you do not quite yet have a complete *water audit*—the following sections discuss the necessary pieces of system information and cost data that are necessary to complete the water audit, which provides useful performance metrics beyond the water balance itself.

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

Figure 23. Real Losses = Water Losses - Apparent Losses.

4.4 System Data

To complete a water audit, it is essential to provide physical information about the water system to which the audit pertains: length of mains, number of service connections, location of customer meters, and operating pressure. This information informs the calculation of key performance metrics.

4.4.1 Length of Mains (“Lm”)

This is the total length of transmission and distribution pipelines in the potable water system to which the audit pertains. It does not include the length of service lines, but it does include fire hydrant lateral pipe—the segment of pipe between the water main and the hydrant. If the actual length of fire hydrant lateral pipe is not known, an average length can be estimated, and then multiplied by the number of hydrants in the system.

Total length of mains can therefore be calculated as:

Length of Mains, miles = (total pipeline length, miles) + [{(average fire hydrant lead length, ft) x (number of fire hydrants)} / 5,280 ft/mile]

4.4.2 Number of Service Connections (“Nc”)

This includes the total number of active and inactive customer service connection laterals, which are located between the water main and the customer. It does not include fire hydrant lateral pipe, which should be accounted for in “Length of Mains.” It is important to note that this statistic reflects distinct piping connections, including fire connections, regardless of whether the respective account is active or inactive. This number may be different from the number of customers or accounts.

4.4.3 Are Customer Meters Typically Located at the Curbstop/Property Line? ("Lp")

This field requires a yes/no response. The point of this question is to determine the length of customer-owned pipe that is upstream of the meter. If your customer meters are located at the curbstop then this length is zero, and you should select "Yes." However, if your customer meters are typically located some distance away from the curb stop, you will need to select "No," and then estimate the average length of customer service line. If most of your customers are unmetered, then you should select "No" and estimate the average length of customer service line between the point of ownership transfer and the building line.

In Indiana, most utilities' customer meters are located at the curbstop/property line (typically on or adjacent to the sidewalk). If the auditor selects "Yes", then this distance is set to zero and the data grading score for this component is set to 10.

For a helpful visual display of the various metering setups, refer to the "Service Connection Diagram" tab in the software.

4.4.4 Average Operating Pressure

The average operating pressure for the potable distribution network plays a critical role in determining the leakage allowance volume (Unavoidable Annual Real Losses). Thus, it is important to be as thorough as possible in determining this value.

There are several ways to determine this value:

- If your utility utilizes a hydraulic model, an average of the nodes can be taken. Ensure that the model has been recently calibrated with actual field pressures and that the nodes are geographically distributed throughout the system.
- If you do not have a calibrated hydraulic model, use one of the following three methods:
    - If the water distribution system is relatively flat and/or consists of a single pressure zone, you should take a representative sample of pressure readings, and then simply average those values.
    - If the water distribution system features significant elevation changes, and/or consists of multiple pressure zones, the average pressures for each zone should be taken, and then weighted according to either the number of service connections or miles of mains within each zone, depending on the following:
        - If there are >32 service connections per mile of main for the entire system, use number of service connections as the basis for weighting.
        - If there are ≤ 32 service connections per mile of main for the entire system, use miles of main as the basis for weighting.
- If you are compiling the audit for the first time and do not have the ability to conduct such testing, the average pressure can be approximated, but with a low data validity grading.

Regardless of which method is used above, do your best to gain a representative sample of average system operating conditions. Consider the level of demand throughout the day—it would not be advisable to use pressure data from the middle of the night, when demand is at its lowest and pressure is highest, or in the early morning, when demand peaks and pressure is at its lowest. Also consider tank operations and how they impact pressure throughout the day.

4.5 Cost Data

A water audit provides more than just an accounting of water over a given period. It also provides meaningful financial information that can inform forward-looking management decisions.

The software provides financial performance indicators based on three different pieces of information entered by the auditor, discussed in the following sections.

You can find additional guidance on calculating cost data in Appendix E: Cost Data Guidance.

4.5.1 Total Annual Operating Cost

The Total Annual Operating Cost was a required entry in past versions of the software but became an optional entry in version 6. However, it is useful for the water utility to track annual costs of operations as related to the water loss in its system. For that reason, the State recommends that utilities continue to include this data in their audit.

The total cost of operating the potable water system, including, but not limited to:

- Salaries and benefits
- Supplies and equipment
- Electricity
- Purchased water costs
- Equipment rental
- Chemicals
- Loan repayments and debt service
- Insurance and administrative costs
- Depreciation

Make sure to include only costs pertaining to the potable water system. Costs associated with wastewater, biosolids, and recycled water should be excluded.

4.5.2 Customer Retail Unit Cost (“CRUC”)

The Customer Retail Unit Cost is the average price a customer pays for a unit of water. The CRUC does not include fixed charges. Determining the CRUC helps put a cost on the amount of water a customer receives but is not billed for due to metering errors. This difference between the amount billed and the amount received is part of the utility system’s apparent losses.

Because every utility has a unique rate structure, often featuring a mix of fixed service fees, variable use charges, tiers, and base allocations, you will have to come up with the most reasonable way to determine a composite cost for the audit period. A simple approach would be to divide total volume-based revenues by the total volume of potable water delivered. Or compute a volume-weighted average of water sold at each unique rate to determine a single composite charge that is entered into this cell. The weighted average charge should also include additional charges for sewer, storm water, and biosolids processing, but only if these charges are based upon the volume of potable water consumed.

Appendix E provides a detailed example of how to calculate the CRUC.

4.5.3 Variable Production Cost ("VPC")

The Variable Production Cost is the cost to produce one more additional unit of water than you are producing right now. The Variable Production Cost puts a value on the real water losses in your system (i.e., the water lost through leaks/breaks/theft).

This cost is determined by calculating the summed unit costs for ground- and surface water treatment and all power used for pumping from the source to the customer. It may also include other miscellaneous unit costs that apply to the production of drinking water. If applicable, it should also include the unit cost of bulk water purchased as an import.

It is common to apply the VPC unit cost to the volume of Real Losses. However, if water resources are strained and the ability to meet future drinking water demands is in question, then the water auditor may be justified in applying the Customer Retail Unit Charge to the Real Loss volume, rather than applying the Variable Production Cost.

As an example of a starting point, you can add up the direct variable costs associated with water production and wholesale purchases, and then divide by the total volume of Water Supplied (if applicable to your utility).

The following costs should be included, where known:

- Treatment costs (chemicals)
- Energy costs for pumping, treatment
- Wholesale (i.e., bulk or import) purchase costs

Appendix E provides a detailed example of how to calculate the VPC.

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Senate Enrolled Act 4, Indiana General Assembly, (2019 Session).

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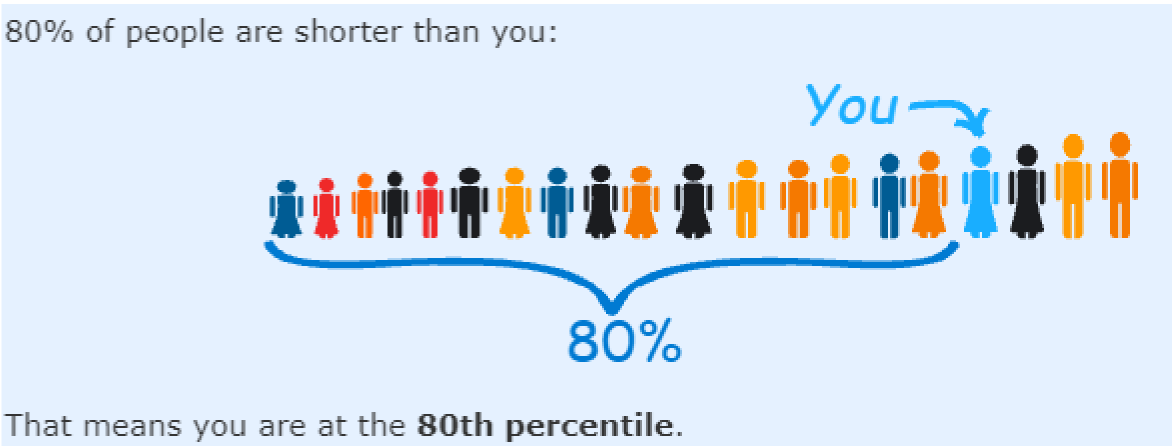
APPENDIX A: UNDERSTANDING PERCENTILE AND MEDIAN

In statistics, a percentile is a score **below which** a given percentage, 80% for example, of scores in its frequency distribution falls. Percentile is used when the frequency, or the number of, the scores is important.

For example, if you are in the 80th percentile, it means 80% of people are shorter than you. It also means that 20% of people are taller than you.



The median is the middle number in a sorted list of numbers. If the median height of a group of people is 5’7”, that means that 50% of people are shorter than 5’7” and 50% of people are taller than 5’7”. The median is not affected by extreme scores, like the average might be.

APPENDIX B: CORRECTING FOR MISALIGNMENT BETWEEN METER READING/ BILLING CYCLES AND AUDIT PERIOD

To properly correct for misalignment between meter reading/billing cycles and the audit period, the auditor should first determine billed metered consumption for every meter reading cycle (by date). For small utilities, there may be just a few meter-reading cycles; for large utilities, there could be many.

The example below introduces the concept with a very simple meter reading schedule: where meters are read on the same day each month.

Green Country Water District staff read customer meters on the same day every month. The GCWD auditor compiled billed metered sales data relevant to the audit period (1/1/19 - 12/31/19), as detailed in Table 1 below, plus an extra meter read on either side of the audit period in order to correct for misalignment.

Table 1: GCWD Monthly Sales Example

Read Date	Customer Sales (MG)
12/10/2018	2,418.661
1/10/2019	2,278.897
2/10/2019	2,233.471
3/10/2019	2,278.897
4/8/2019	2,877.013
5/10/2019	2,952.724
6/9/2019	3,739.260
7/10/2019	3,471.978
8/10/2019	3,439.905
9/11/2019	3,068.071
10/12/2019	2,865.882
11/10/2019	2,460.604
12/10/2019	2,422.748
1/10/2020	2,281.797
Total CY19	**34,089.450**

The auditor then made adjustments to billed metered sales on both ends of the audit period, based on the pro-rated share of consumption actually falling within the audit period. This is shown in Table 2.

Table 2: GCWD Prorated Consumption Example

	Read Date	1/10/2019	1/10/2020
	Previous Read Date	12/10/2018	12/10/2019
A	Customer Sales	3,471.98	4,169.55
B	Days in Audit Period	10	21
C	Days of Consumption	31	31
D = A * (B/C)	**Customer Sales - Corrected**	**1,119.993**	**2,824.533**

Table 3 below shows monthly customer sales after correcting for misalignment. The shaded cells indicate which dates were added to calculate the total calendar year value.

Table 3: GCWD Monthly Misalignment Example

Read Date	Customer Sales (MG)	Customer Sales - Corrected for Misalignment (MG)
12/10/2018	2,418.661	0.000
1/10/2019	2,278.897	735.128
2/10/2019	2,233.471	2,233.471
3/10/2019	2,278.897	2,278.897
4//2019	2,877.013	2,877.013
5/10/2019	2,952.724	2,952.724
6/9/2019	3,739.260	3,739.260
7/10/2019	3,471.978	3,471.978
8/10/2019	3,439.905	3,439.905
9/11/2019	3,068.071	3,068.071
10/12/2019	2,865.882	2,865.882
11/10/2019	2,460.604	2,460.604
12/10/2019	2,422.748	2,422.748
1/20/2020	2,281.797	1,472.127
Total CY 19	**34,089.450**	**34,017.808**

In reality, most utilities have more complex reading cycles. Therefore, a meter lag correction should be used for each meter reading route. This will require that the auditor determine the volume of billed consumption for each meter reading route, and then making the correction in the manner as described above.

APPENDIX C: CALCULATING YOUR OWN SYSTEMATIC DATA HANDLING ERRORS ("SDHE")

If you choose to determine the volume yourself, rather than rely upon the default estimate, the paragraphs below can help get you started.

1. **Meter Reading**
   Meter reading can introduce errors or inaccuracies into the billing system in a number of ways. Regardless of the type of meter reading system employed (manual reads, AMR, AMI), a certain number of reads will fail to successfully register. The frequency of failed reads (the positive equivalent would be the meter read success rate) should be investigated, particularly in settings where meters are read manually.

   When a successful read is not obtained, estimates are typically made. The frequency of estimates should be evaluated, as well as the volumetric impact of such reads (e.g., 2.5% of volumetric sales were associated with estimated reads.) Additionally, you should look into the means by which consumption is estimated and assess whether such methodology is appropriate. Sometimes estimates are based on outdated information that poorly reflects actual consumption.

   "Zero reads"—reads where consumption is zero—should be investigated. Sometimes these reads will reflect genuine zero-consumption—for example, on an account where the customer has been on extended vacation—but other times they can indicate failed reads, meter tampering or theft, or a stuck meter. Accounts that feature strings of consecutive zero reads should be given close attention.

2. **Billing Adjustments**
   Billing adjustments, which are made in order to resolve financial concerns, can sometimes interfere with the accurate calculation of consumption. Many utilities will modify billed consumption volumes to trigger a financial adjustment, in the process distorting consumption data. Ideally, utilities will either issue financial adjustments without changing consumption volumes or will keep two distinct fields for customer consumption: one for registered consumption (actual water use), and another for billed consumption. In the absence of such practices, you as the auditor would need to thoroughly review adjustments to get a sense of their volumetric impact. One place to start would be to examine negative billed consumption volumes, which would presumably reflect a credit issued to the customer.

3. **Policy and Procedure Shortcomings**
   Policy and procedure shortcomings can contribute to Apparent Losses, including but not limited to:
   a. Inefficiencies or delays in permitting, metering, or billing.
   b. Allowing water use to occur without proper tracking.
   c. Poor customer account management, such as accounts that were not initiated, lost, or transferred erroneously.

APPENDIX D: CONDUCTING RANDOM METER TESTS

It is simply not practical to inspect and test every single customer meter. Large, high-revenue meters are typically associated with industrial, commercial, and agricultural customers that produce a much larger share of revenue per account than small meters, which tend to be associated with residential uses. As such, it is recommended that the utility annually inspect and test high-revenue meters and a random sample of small meters.

The purpose of this section is to introduce key concepts with respect to the determination of customer metering error. For a more comprehensive guide for meter testing, refer to the AWWA Manual M6, *Water Meters— Selection, Installation, Testing, and Maintenance.*

What is a random meter sample?

A random meter sample means that meters are selected entirely by chance and not for any particular reason. This can be achieved by labeling all of the meters with a unique ID code and using a random-number generator such as that offered by Microsoft Excel. Here are a few examples of samples that are not random:

a. Test results from meters that were removed due to customer complaints
b. Test results from meters that were removed due to age
c. Test results from meters located in a particular geographic area

Testing before installation

Best practice is to inspect and test all large meters prior to use. While this is practical for large meters, it would be practicably challenging to test every meter in a large set of small meters, so it is advised that the utility test a random sample of meters (stratified by relevant criteria, such as meter age, manufacturer, model, and size) prior to installation.

Small Meter Testing

Utilities should test a random sample of small meters (see sidebar on the meaning of random). Ideally, the utility would stratify its small meter population into different groups, based on any combination of manufacturer, model, and size, and randomly test meters within each group. Information on meter age and/or total throughput (cumulative water volume passed through the meter over its lifespan) could be included for additional analysis. Keep in mind that any given sample of a particular meter group should be sufficiently large to be meaningful—for example, three tests of 3/4” Badger meters is not sufficiently large to confidently represent the actual performance of the entire population of 3/4" Badger meters. The level of specificity to which the analysis goes should be informed by your utility’s capacity to test meters and perform data analysis.

Small meters are typically tested at a number of flow rates because meter accuracy varies with flow rate.

Table 4 summarizes test results for GCWD, which randomly selected 100 small meters for testing.

Table 4: GCWD Meter Testing Example

Test Flow Rate	Mean Accuracy
Low (0.25 gpm)	94.60%
Medium (2.0 gpm)	97.20%
High (15.0 gpm)	99.20%

The next step is to identify the volume of consumption registered at different flow rates. Sometimes, utilities will have system-specific data showing the breakdown of consumption by flow rates, but this is rare. For utilities that do not have such information at hand, it is advised that the AWWA volume-weighted standards be applied. These values are shown in Table 5, under column A. The GCWD auditor used the combination of AWWA volume-weighted standards, consumption data, and meter test results to calculate meter error, as detailed in Table 5. The determination of customer meter error applies to metered consumption only, so any unmetered consumption should be excluded from this analysis.

Stuck meters, or "dead" meters—where the register does not turn at all when water is passed through—should be excluded from this analysis insofar as there are policies and procedures in place to identify dead meters promptly, to replace them, and to bill the customer accordingly.

Table 5: GCWD Meter Testing: AWWA Volume-Weighted Standards Example

	A	**B**	**C = A * B**	**D**	**E = (C/D) - C**
Flow Rate	Consumption Volume Distribution[1]	GCWD CY19 Small Meter Total Consumption (MG)[2]	GCWD CY19 Small Meter Consumption at Flow Rate (MG)	Mean Accuracy	Meter Error (MG)[3]
Low (0.5 – 1.0 gpm)	2.0%	26,946.454	538.929	94.60%	30.763
Medium (1 – 10 gpm)	63.8%	26,946.454	17,191.838	97.20%	495.238
High (10 - 15 gpm)	34.2%	26,946.454	9,215.687	99.20%	74.320
Total	**100.0%**	**26,946.454**	**26,946.454**	**97.82%**[4]	**600.322**

[1]In other words, an estimated 2.0% of total consumption by small meters is registered at low flows.
[2]Based on sales data.
[3]The formula for meter error produces a value of opposite sign to the formula that was used to calculate meter error for source meters in Section 5.1.3. That is because the AWWA software is set up such that negative values mean under-registration for source meter error, while negative values mean over-registration for customer meters.
[4]The total mean accuracy of 97.82% is a composite accuracy calculated by comparing the total uncorrected volume of small meter consumption to the total corrected volume [(26,946.454 / (26,946.454 + 600.322)].

Large Meters

A similar analysis described above for small meters above can be performed for large meters. However, there is no reliable industry standard for consumption volume distribution by flow rate, since large meter use is much more unpredictable and variable. If your utility has reliable information on the breakdown of large meter consumption volumes by flow range, that is ideal. If such information is not available, then you can equally weight accuracy at all flows by utilizing a simple average. Table 6 shows large meter accuracy results for GCWD from tests that were performed during the audit period. GCWD tests approximately half of its large meters every year.

Table 6: GCWD Large Meter Test Example

	Test Flow Rate	Mean Accuracy
A	Low	91.40%
B	Medium	96.90%
C	High	99.90%
(A + B + C)/3	Average	96.07%

The GCWD auditor used the average accuracy of 96.07% and billing data to calculate large meter error, as shown in Table 7.

Table 7: GCWD Large Meter Error Example

A	**B**	**C = (B / A) - B**
Meter Accuracy	GCWD CY19 Large Meter Total Consumption (MG)	Meter Error
96.07%	7,071.354	289.528

For GCWD, total customer metering inaccuracies for CY19 were 889.95 MG, as shown in Table 8.

Table 8: GCWD Total Customer Metering Inaccuracies Example

	Meter Error (MG)
Small Meters	600.322
Large Meters	289.528
Total	**889.850**

APPENDIX E: COST DATA GUIDANCE

This guide provides additional information about:

1. Total Annual Operating Cost
2. Customer Retail Unit Cost
3. Variable Production Cost

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1. Total Annual Operating Cost

What is the Total Annual Operating Cost?

- The Total Annual Operating Cost includes all expenses related to keeping the water system up and running.

Why is this number important?

- Estimating annual operating expenses has many practical uses. Utility staff and other stakeholders can better plan budgets and manage rates when they know all the costs involved in running the utility. Additionally, evaluating water loss costs as related to the total operating cost helps prioritize financial investments.

How do I find the Total Annual Cost of operating a drinking water System?

- The Total Annual Cost includes all expenses related to operating only the drinking water system. It does not include any costs associated with wastewater or other non-drinking water systems.

Costs may include, but are not limited to:

Employee salaries and benefits	Facility rent and mortgage
Supplies and equipment	Insurance
Electricity	Chemicals and analysis
Purchased water costs	Loan repayments
Equipment rental and repair	Legal fees
Phone and internet	Depreciation transfers

Example 1: Calculating Total Annual Cost of Operating a Drinking Water System

Expense Categories	**2018 Year End Expended**
Salaries & Wages	$ 225,978
Employee Benefits	$ 78,314
Power Purchase	$ 10,528
Water Purchase	$ 333,828
Materials & Supplies	$ 71,963
General & Misc.	$ 169,011
Contract Services	$ 116,460
New Equipment	$ 37,040
Depreciation Transfers	$ 15,616
Capital Improvements	$ 5,272
Bond & Loan Transfers	$ 74,041
Total Annual Cost of Operating a Drinking Water System	$1,138,051

2. Customer Retail Unit Cost

What is the Customer Retail Unit Cost?

- The Customer Retail Unit Cost (CRUC) is the average price a customer pays for a unit of water.

Why is this number important?

- Determining the Customer Retail Unit Cost helps put a cost on the amount of water a customer receives but is not billed for due to metering errors. This difference between the amount billed and the amount received is part of the utility system's apparent losses.

How do I find the Customer Retail Unit Cost?

- A utility can use several methods to find the Customer Retail Unit Cost. One option is as follows:

$$CRUC = \frac{variable\ (volume\ based)\ revenue}{total\ volume\ billed}$$

Where do these numbers come from?

- Volume based revenue (e.g., income from selling water) can be found by subtracting fixed revenue (e.g., meter charges) from total revenue:

Total revenue = fixed revenue + variable revenue

- The total volume billed is the amount of water the utility billed customers.

What if I cannot separate out fixed revenues?

- If your billing system does not allow you to separate out fixed revenues, you can estimate based on the number of meters and the meter size rate schedule.

Other Tips:

- Make sure you track the units your billing software provides (e.g., gallons or 1,000 gallons or million gallons).

- Average range of Customer Retail Unit Costs is $4 - $18. If you are outside of this range, double-check your math or sources to verify your result.

- If you do not remove fixed costs, indicate this on your notes/documentation.

Example 2: Calculating Customer Retail Unit Costs

Total revenue = fixed revenue + variable revenue

Variable revenue = total revenue – fixed revenue

$$CRUC = \frac{variable\ (volume\ based)\ revenue}{total\ volume\ billed} = \frac{\$}{1000\ gallons}$$

Code	Meter count	Annual Rate by Meter Size 5/8"	Annual Rate by Meter Size 1"	Fixed Annual Revenue ($)	Annual Units (gallons)	Annual Units (1000 gallons)	Variable Annual Revenue ($)	Total Annual Revenue
	Fixed Revenue				*Variable Revenue*			
Residential	1,095	$ 89.40	$ -	$ 97,870.65	58,075,000	58,075	$ 949,231.25	$ 1,047,101.90
Shop	67	$ 89.40	$ -	$ 6,027.05	3,244,000	3,244	$ 53,791.05	$ 59,818.10
Commercial	103	$ 89.40	$ -	$ 9,193.30	36,080,000	36,080	$ 550,226.42	$ 559,419.72
Government	23	$ -	$ 135.72	$ 3,132.87	5,942,000	5,942	$ 77,401.49	$ 80,534.36
School	11	$ -	$ 135.72	$ 1,436.37	4,666,000	4,666	$ 64,981.73	$ 66,418.10
Religious	17	$ 89.40	$ -	$ 1,519.80	704,000	704	$ 13,895.93	$ 15,415.73
Total	1,316			$ 119,180.04	108,711,000	108,711	$ 1,709,527.85	$ 1,828,707.89

CRUC = $15.73 per thousand gallons

3. Variable Production Cost

What is Variable Production Cost?

- The Variable Production Cost is the cost to produce one more additional unit of water than you are producing right now.

Why is this number important?

- The Variable Production Cost puts a value on the real water losses in your system (i.e. the water lost through leaks/breaks/theft).

How do I find the Variable Production Cost?

- You can find the Variable Production Cost by adding all the costs to treat and pump water, and then dividing that sum by the total annual volume of water treated and sent into the distribution system. If purchasing (importing) water, include the purchase cost in the numerator and the volume purchased in the denominator.

  Note: the total volume of water pumped will be different from the total volume of water billed (the volume used in Example 2: Customer Retail Unit Cost).

$$\text{Variable Production Cost:}$$

$$= \frac{electricity + chemicals + purchased\ water + residuals\ disposal}{annual\ volume\ of\ water\ treated\ and\ sent\ into\ distribution\ system}$$

Other Tips:

- Utilities supplying their own water will likely be in the $200 - $800 range. Utilities purchasing most of their water may have higher variable production costs, up to the $4,000 range.

Example 3: Calculating Variable Production Cost

$$\text{Variable Production Cost} = \frac{electricity + purchased\ water}{annual\ volume\ of\ treated\ water}$$

$$= \frac{\$10{,}528 + \$333{,}828}{112.309 \text{ million gallons}}$$

$$= \$3{,}066 \text{ per million gallons}$$

(Cost data comes from expense reports as seen in Example 1. Volume data comes from utility meter records)

GLOSSARY OF TERMS

Apparent Losses: The nonphysical losses that occur when water is successfully delivered to the customer but is not measured or recorded accurately. Apparent Losses can result from customer metering inaccuracies, unauthorized consumption (theft), and systematic data handling error. Often referred to as “paper losses.” Note: over estimation of Apparent Losses results in under-estimation of Real Losses and vice versa.

Authorized Consumption: The volume of metered and/or unmetered water taken by registered customers, the water supplier, and others who are authorized to do so.

Billed Metered Consumption (BMAC): Water that is taken for authorized purposes that is both metered and generates revenue for the water supplier.

Billed Unmetered Consumption (BUAC): Water that is taken for authorized purposes that is not metered and generates revenue for the water supplier.

Changes in Storage: The net distribution storage change is the difference between end of audit period and beginning of audit period for total finished water stored, downstream of the system input meter(s). This volume is typically derived by comparing distribution storage tank water levels at end and beginning of the water audit period and using approximate tank geometry to convert levels to volumes.

Current Annual Real Losses (CARL): The volume of water lost to all forms of leakage or spillage. The ratio of the CARL to the Unavoidable Annual Real Losses (UARL) is the Infrastructure Leakage Index (ILI).

Customer Metering Inaccuracies (CMI): is a type of Apparent water losses caused by the collective under-registration of customer water meters. Many customer water meters gradually wear as large cumulative volumes of water are passed through them over time. This causes the meters to under-register the flow of water.

Customer Retail Unit Charge (CRUC): The Customer Retail Unit Cost is the average price a customer pays for a unit of water. The CRUC does not include fixed charges. Determining the CRUC helps put a cost on the amount of water a customer receives but is not billed for due to metering errors.

Infrastructure Leakage Index (ILI): A performance indicator that assesses a distribution system’s Real Losses (leakage), taking into account its key characteristics, namely the length of water mains, number of service connections, and pressure. Mathematically, it is the ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL).

Median: the middle most value in an ordered sequence of data. Its calculation is not affected by outliers, which is what makes it different from the mean, or average, which is the sum of the numbers divided by the amount of numbers.

Non-Revenue Water: Water that fails to generate revenue for the water supplier for any reason. Non-Revenue Water includes Apparent Losses (paper losses), Real Losses (leakage), and Unbilled Authorized Consumption.

Percentiles: is the value below which a percentage of data falls.

Real Losses: Physical loss of water from the system as a result of leaks, breaks, or spillage that occurs prior to the point of customer consumption (the customer meter in metered systems; in unmetered systems, it is the point of transfer of responsibility). Customer-side leaks are not considered Real Losses. Note: over estimation of Real Losses results in under-estimation of Apparent Losses and vice versa.

Revenue Water: Water that generates revenue for the utility. It consists of Billed Authorized Consumption (and Billed Water Exported in the expanded version of the Water Balance).

System Input Volume: The volume of water that is introduced to the water distribution system over the audit period. It is equal to the water produced by the water supplier's own source waters (Volume from Own Sources), plus Water Imported, plus or minus the net change in applicable water storage (Changes in Storage).

Systematic Data Handling Errors (SDHE): A type of Apparent Loss that can be caused by accounting omissions, errant computer programming, data gaps, and data entry; inaccurate estimates used for accounts that fail to produce meter readings; and billing adjustments that manipulate billed consumption so as to generate a rightful financial credit in such a way that billed consumption does not reflect actual consumption.

Unauthorized Consumption (UC): Any water that is taken in an unauthorized fashion; water theft. This may include "unpermitted water withdrawn from fire hydrants, illegal connections, bypasses to customer meters, meter or meter reading equipment tampering, or similar actions." A type of Apparent Loss.

Unavoidable Annual Real Losses (UARL): The UARL is a theoretical reference value representing the technical low limit of leakage that could be achieved if all of today's best technology could be successfully applied, given the pipeline mileage, service connection density, and average operating pressure of the system. It serves as the denominator in the ratio that determines the Infrastructure Leakage Index.

The formula for calculating the UARL is:

UARL (gallons/day) = $(5.41Lm + 0.15Nc + 7.5Lc) \times P$

Where *Lm* is the length of mains in miles

Where *Nc* is the number of active and inactive service connections

Where *Lc* is the average length of customer piping

Where *P* is the average system operating pressure

Multiply the result by 365 to determine the annual volume.

Unbilled Metered Consumption (UMAC): Water that is used for authorized purposes that is metered and does not generate revenue for the water supplier.

Unbilled Unmetered Consumption (UUAC): Water that is used for authorized purposes that is not metered and does not generate revenue for the water supplier- e.g., system flushing.

Variable Production Cost (VPC): the cost to produce and supply the next unit of water. It puts a value on the real water losses in your system.

Volume from Own Sources (VOS): The volume of water withdrawn from water resources (rivers, lakes, wells, etc.) controlled by the water utility, and then treated for potable water distribution.

Water Exported (WE): Bulk water sold to neighboring water systems that exist outside the service area.

Water Imported (WI): Bulk water typically purchased from a neighboring water utility or regional water authority, which is metered at the custody transfer point of interconnection between the two utilities. Also known as "import," "purchased," or "wholesale" water.

Water Losses: Consists of Real Losses (leakage) plus Apparent Losses (paper losses). Can also be derived by subtracting Authorized Consumption from Water Supplied.

Water Supplied: The volume of treated and pressurized water input to the retail water distribution system.

Water Supplied Error Adjustments (VOSEA, WIEA, WWEA): Sources of error include meter error (under- or over-registration) and data transfer error of the meter instrumentation. Changes in storage adjustments can also be made here.