Advanced Validation Methods & Technical Assistance: Supply Meter Testing

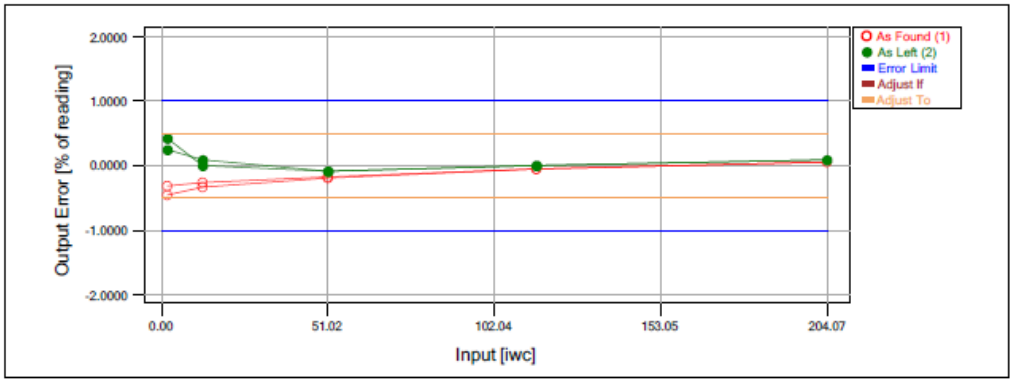
What is a Meter Test?

- *In-situ*
- *Volumetric comparison*
- *Using a known volume*

Meter Test Misconceptions

- *"Got a certificate"*
- *"We have redundant meters"*
- *"Guaranteed it would be accurate"*
- *"Only needs calibration"*

Meter Calibration



1. As Found **PASSED**

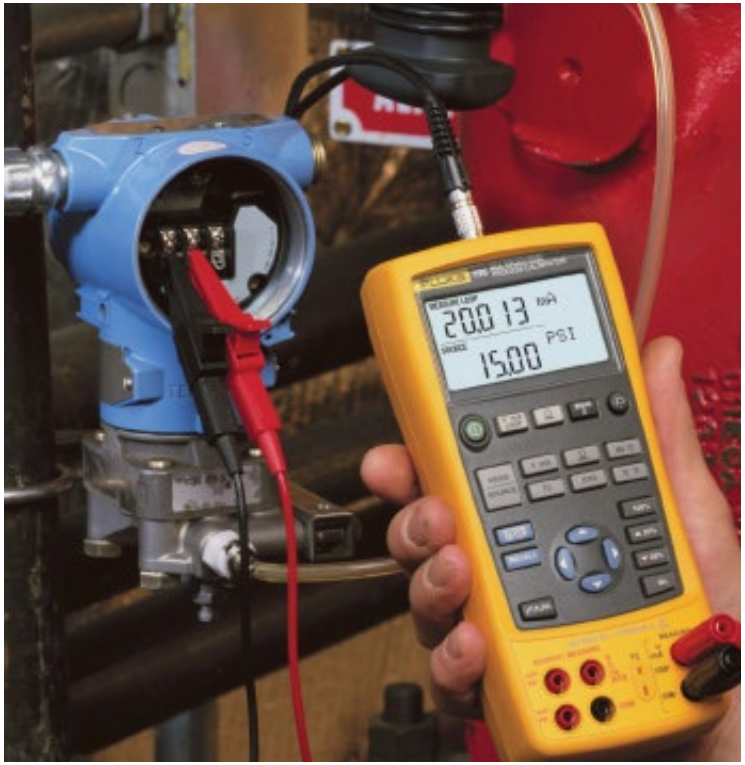
Max Error: -0.46 % of reading

Nominal Input [iwc]	Actual Input [iwc]	Nominal Output [mA]	Actual Output [mA]	Found Error [% of reading]
2.04	2.05	5.60	5.5776	-0.4647
12.75	12.76	8.00	7.9748	-0.3260
51.02	51.04	12.00	11.9782	-0.1963
114.79	114.80	16.00	15.9923	-0.0516
204.07	204.06	20.00	20.0107	0.0555
114.79	114.80	16.00	15.9928	-0.0485
51.02	51.00	12.00	11.9779	-0.1728
12.75	12.76	8.00	7.9803	-0.2572
2.04	2.06	5.60	5.5902	-0.3094

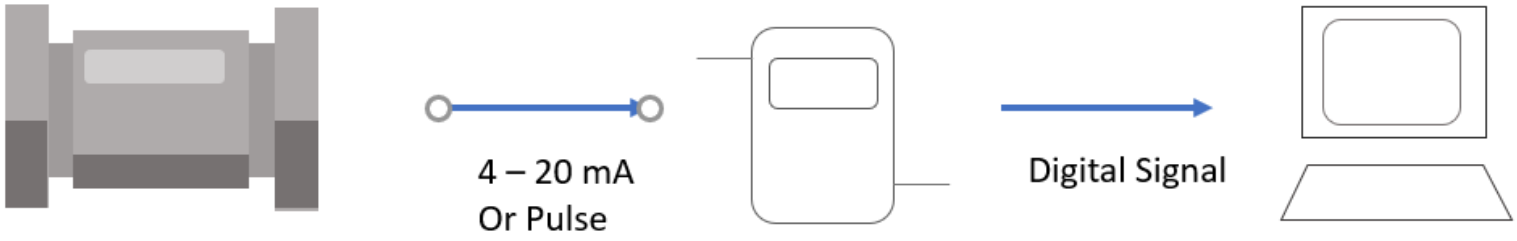
2. As Left **PASSED**

Max Error: 0.42 % of reading

Nominal Input [iwc]	Actual Input [iwc]	Nominal Output [mA]	Actual Output [mA]	Found Error [% of reading]
2.04	2.08	5.60	5.6288	0.2398
12.75	12.72	8.00	8.0016	0.0875
51.02	51.03	12.00	11.9905	-0.0873
114.79	114.77	16.00	15.9988	-0.0012
204.07	204.04	20.00	20.0158	0.0849
114.79	114.78	16.00	16.0002	0.0043
51.02	51.03	12.00	11.9908	-0.0848
12.75	12.76	8.00	8.0015	0.0077
2.04	2.05	5.60	5.6270	0.4168



Primary and Secondary Devices



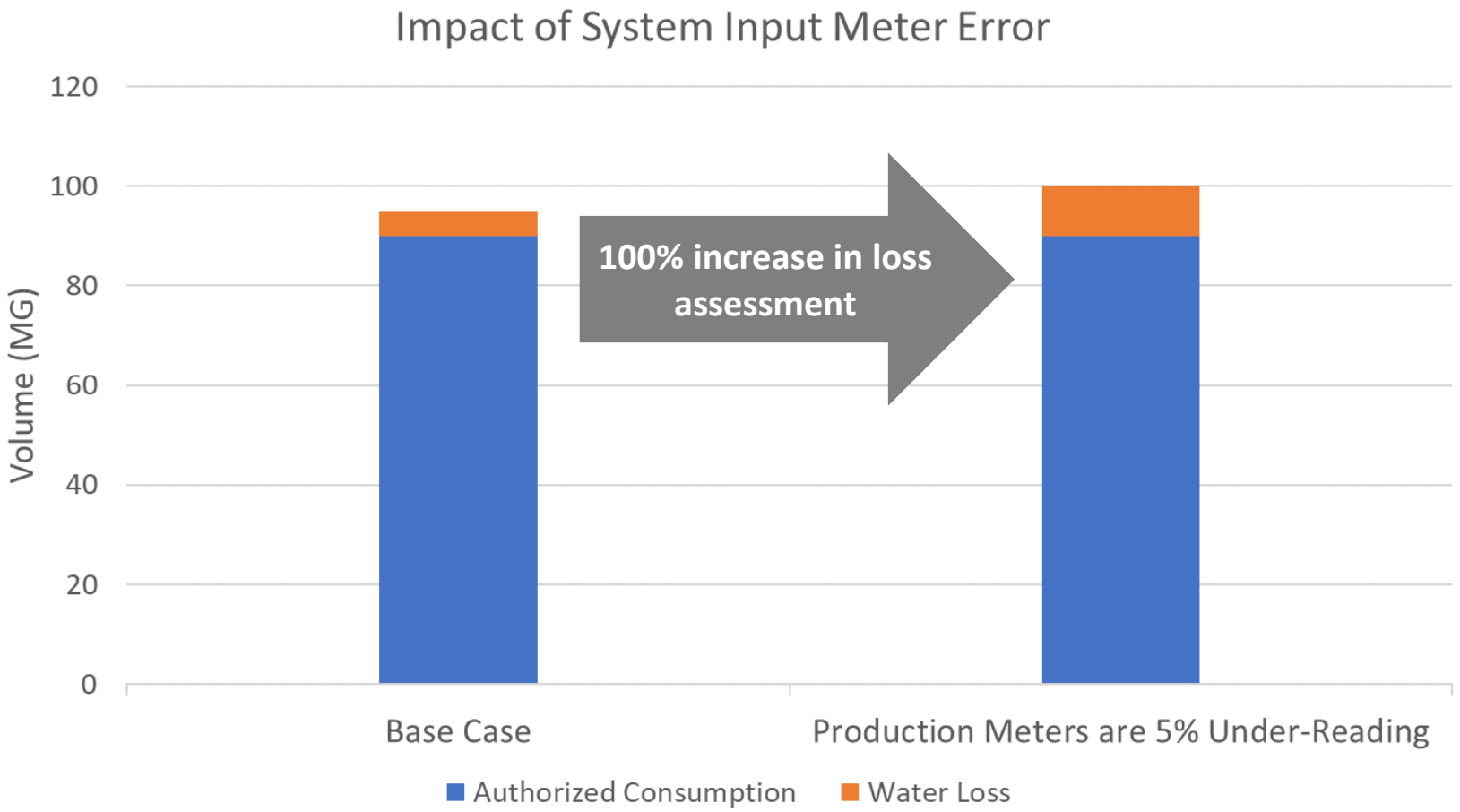
Measurement Element Secondary Electronics* SCADA System

*Calibration

Why Perform Meter Tests?

- *Only way to verify performance*
- *Protect your investment*
- *Improve water balance*
- *Improve data validity score*

Why Perform Meter Tests?

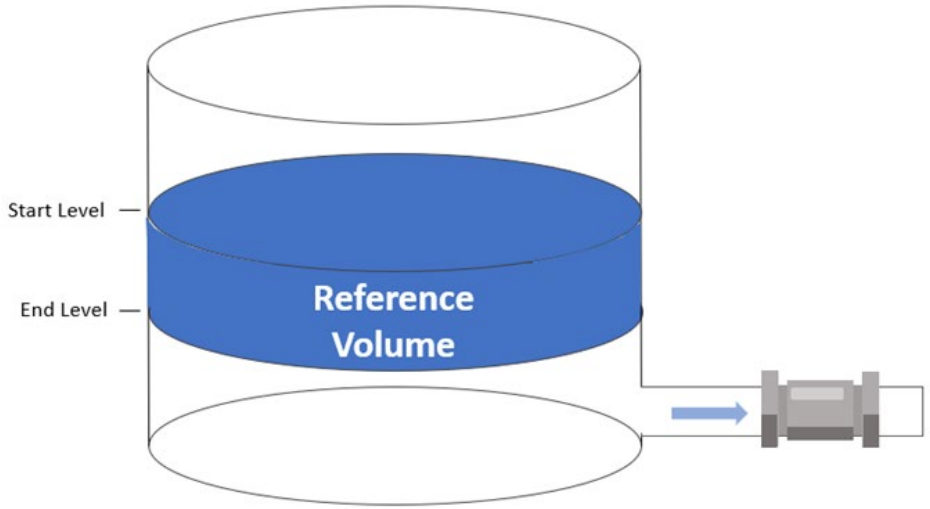


How to Test a Meter

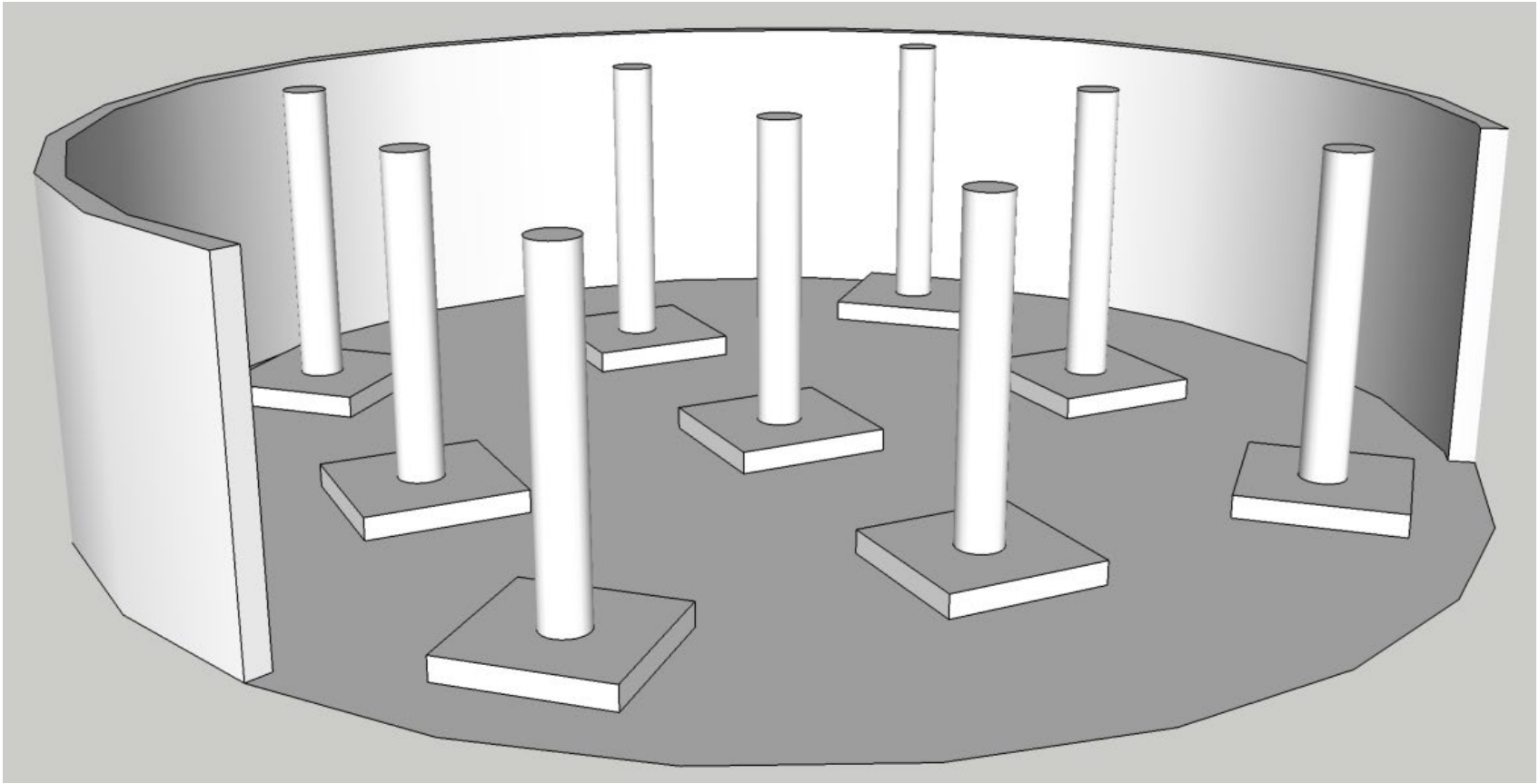
- Use a known volume
- Use a meter of known accuracy
- Consider flow conditions and pipe configuration

Testing with a known volume

- *Preferred Method*
- *Use Tank or Clearwell*
- *Measure Level Change*
- *Requires Accurate Gal/Ft*



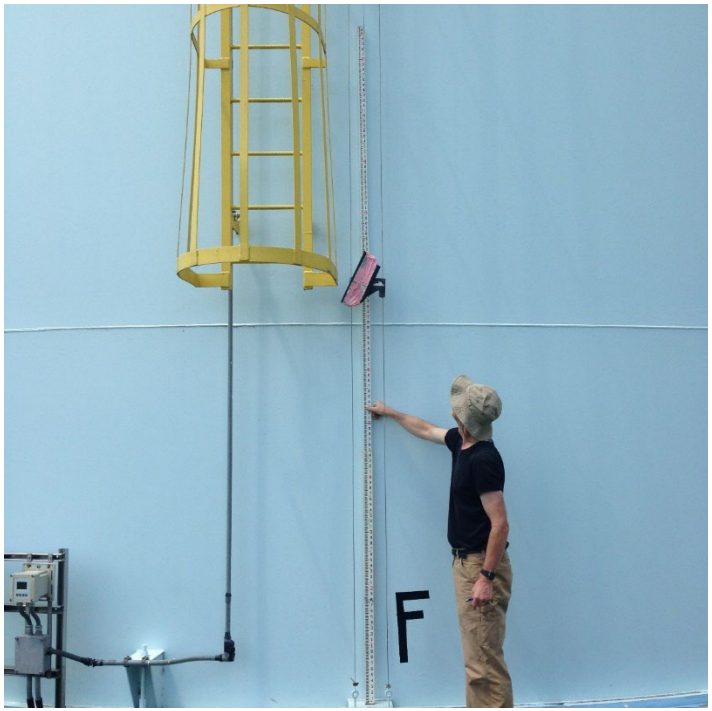
Testing with a known volume



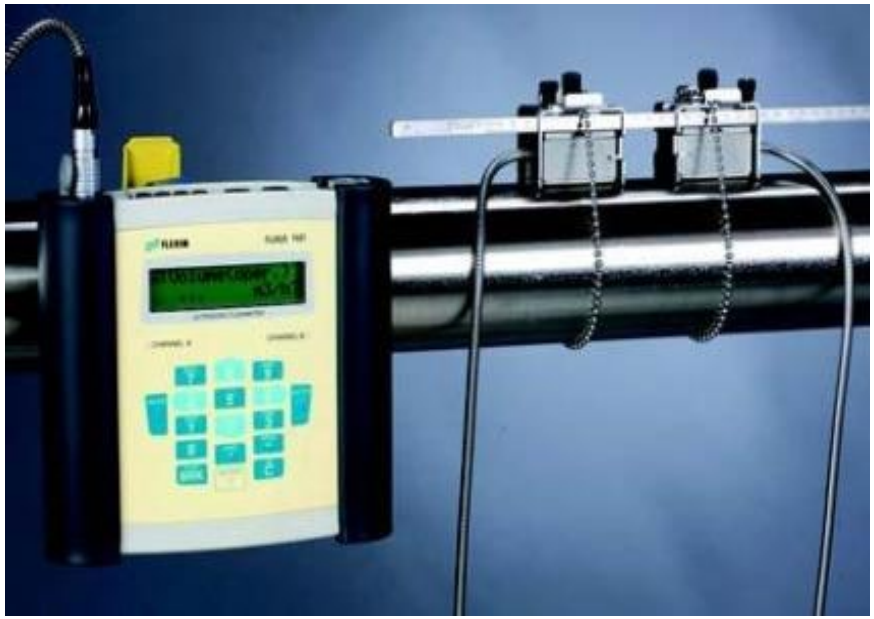
Testing with a known volume

Testing Requirements:

- Tank
- Accurate Measurement or Drawing
- Ability to isolate for extended period
- Way to accurately measure water level

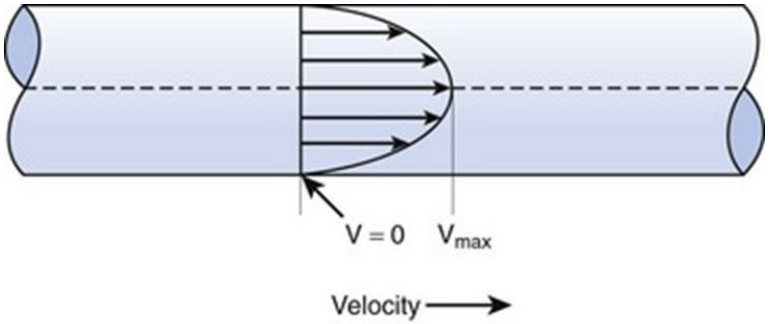


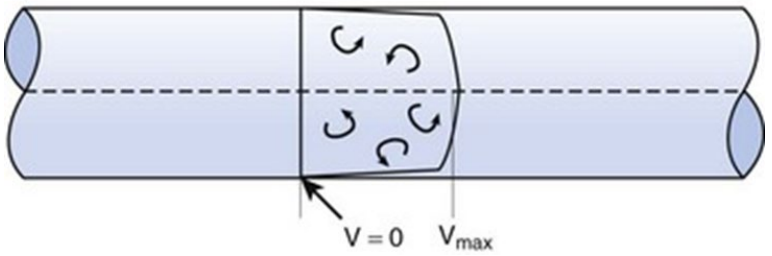
Testing with a Reference Meter

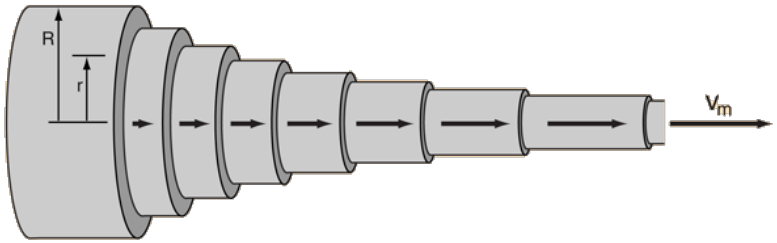


Velocity Profiles

- "Laminar Flow"
- Turbulent Flow
- Fully Developed Flow Profile

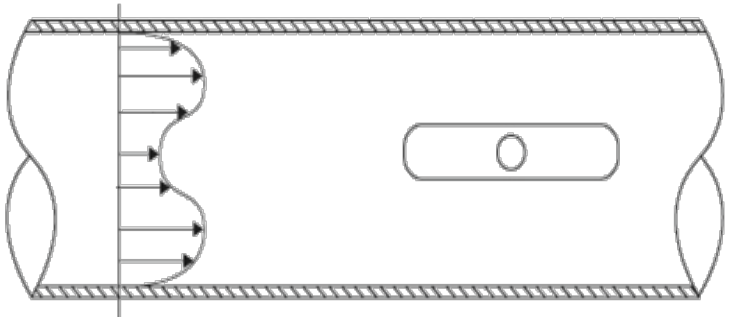




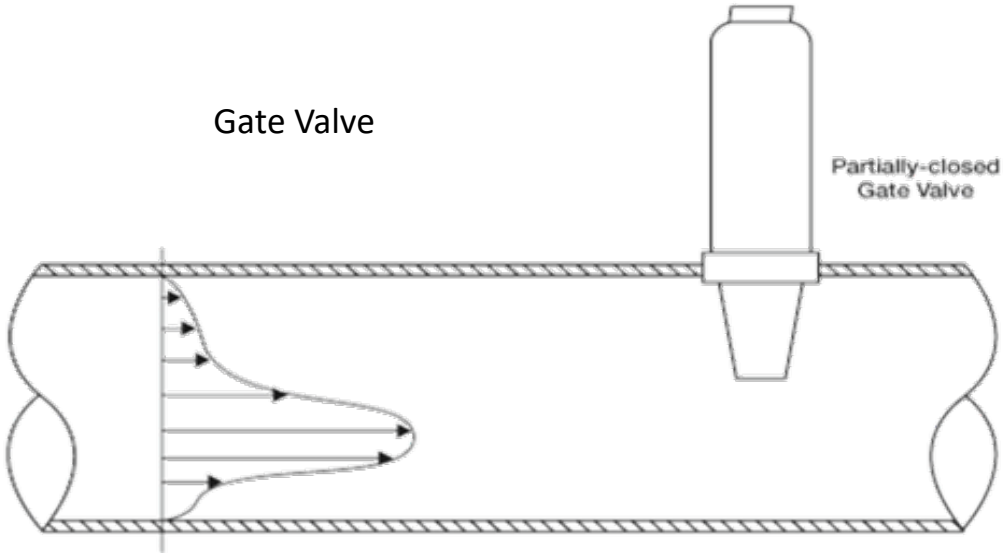


Velocity Profiles

Butterfly Valve

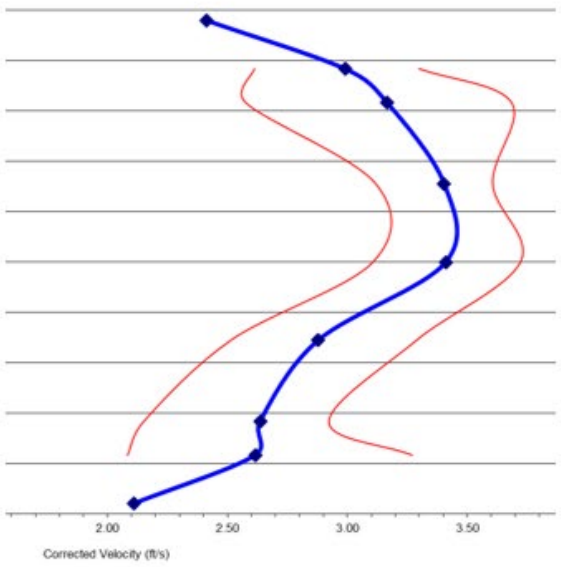


Gate Valve

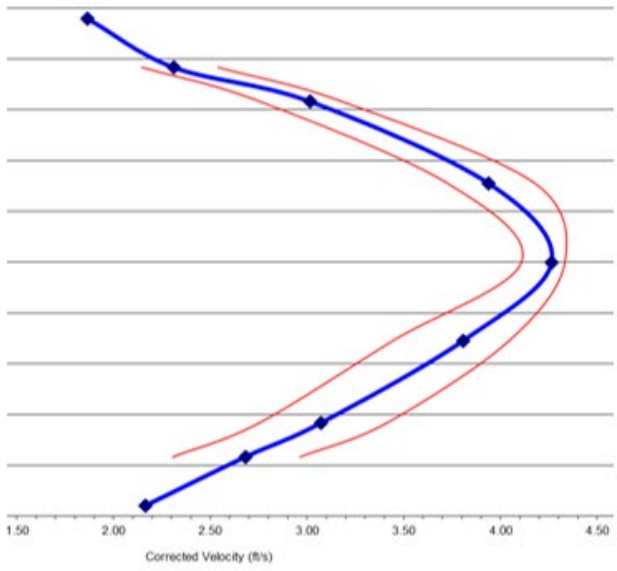


Velocity Profiles

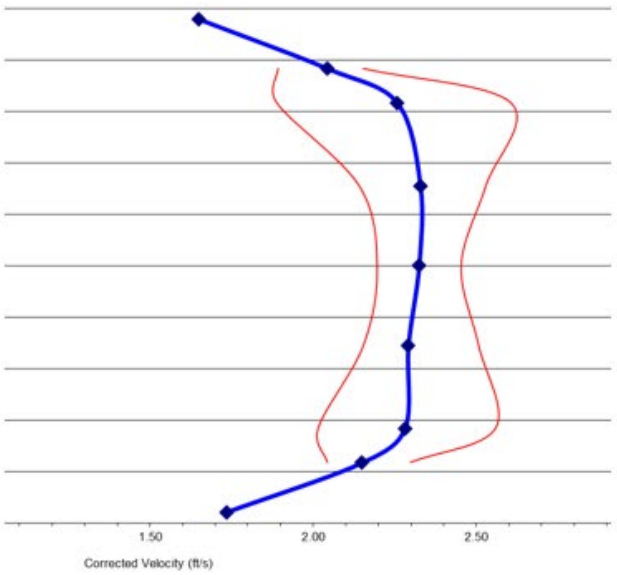
Insufficient Straight Pipe



Pipe build up

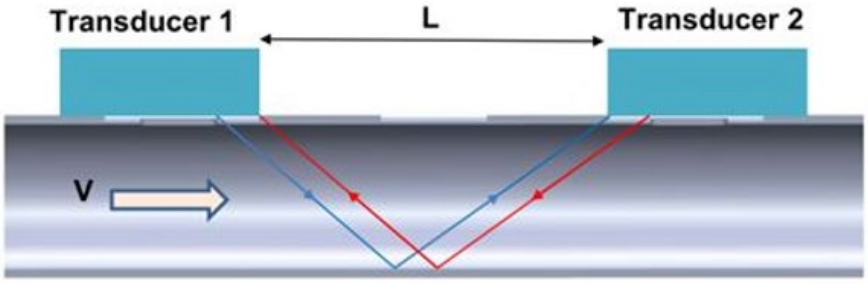


Fully Developed



Ultrasonic Meters

- Transit Time Ultrasonic measures time difference of sound pulses between transducers
- Requires Pipe Information
- Does not use velocity profile



Insertion Meters

- *Electromagnetic or Paddle-Wheel*
- *Single or Multi-Point Measuring*
- *Requires Accurate Velocity Profile*

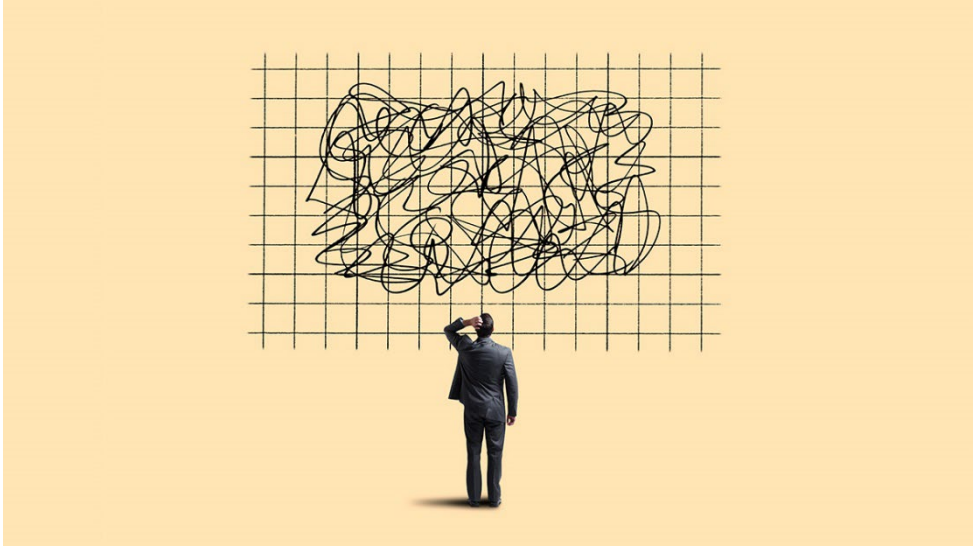
Testing with a Reference Meter

Testing Requirements:

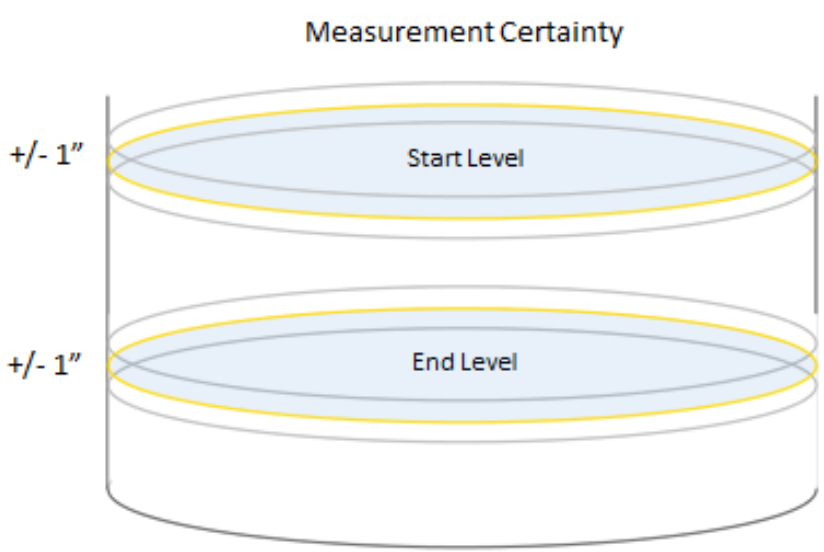
- Exposed Pipe – possibly with tap
- Straight Pipe upstream and downstream of reference meter!!

Measurement Uncertainty

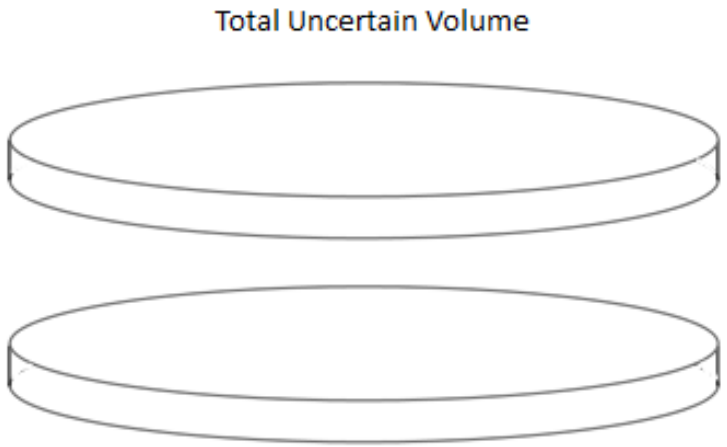
- *Inaccurate Tank Dimensions*
- *Unstable Velocity Profile*
- *Instrument Inaccuracy*
- *Inaccurate Piping Information*
- *Etc.*



Measurement Uncertainty

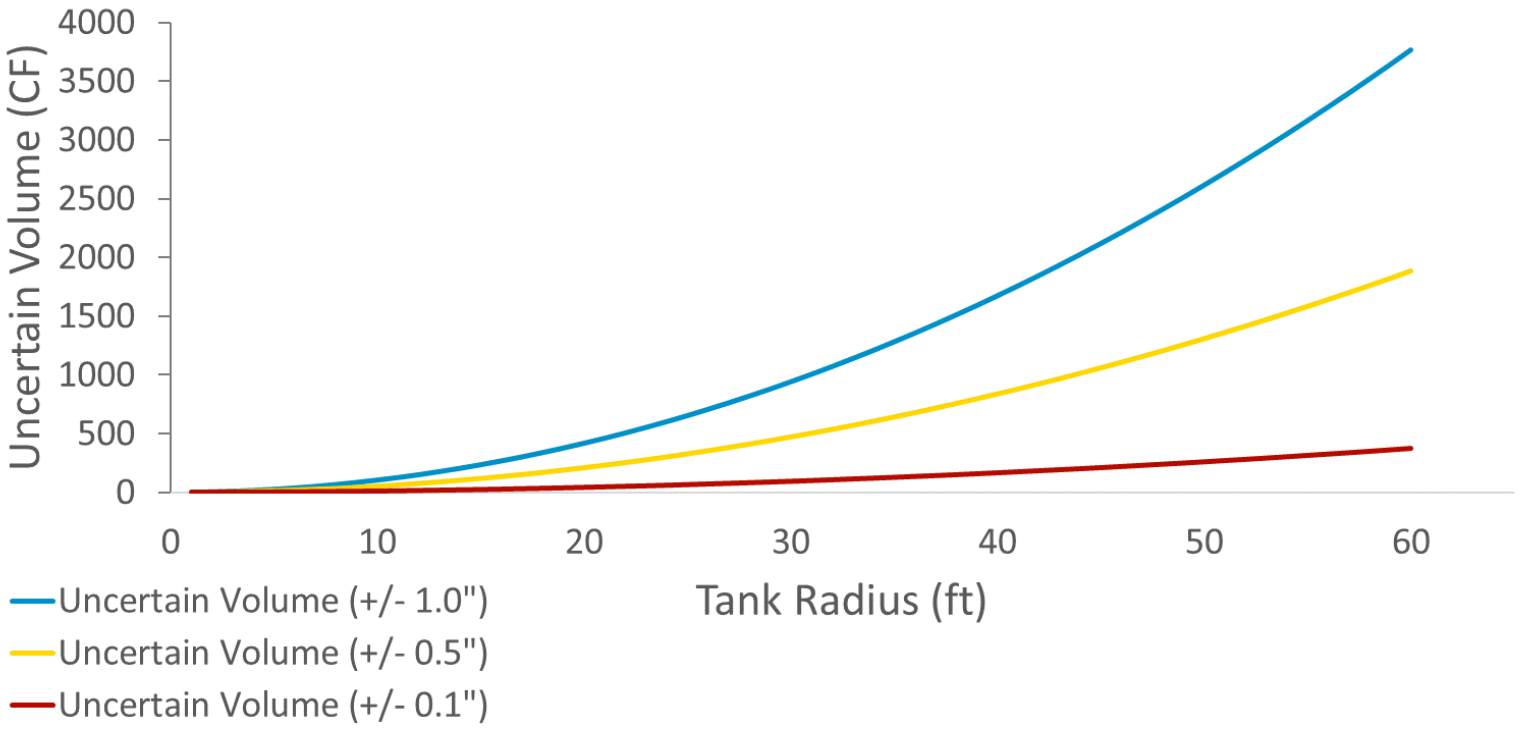


δ = +/- 1”



$$Uncertain\ Volume = (\pi r^2) * (4\delta)$$

Measurement Uncertainty



Measurement Uncertainty

x1,000 gal → 10,000 gal → 10,999 gal / ? / 10,000 gal

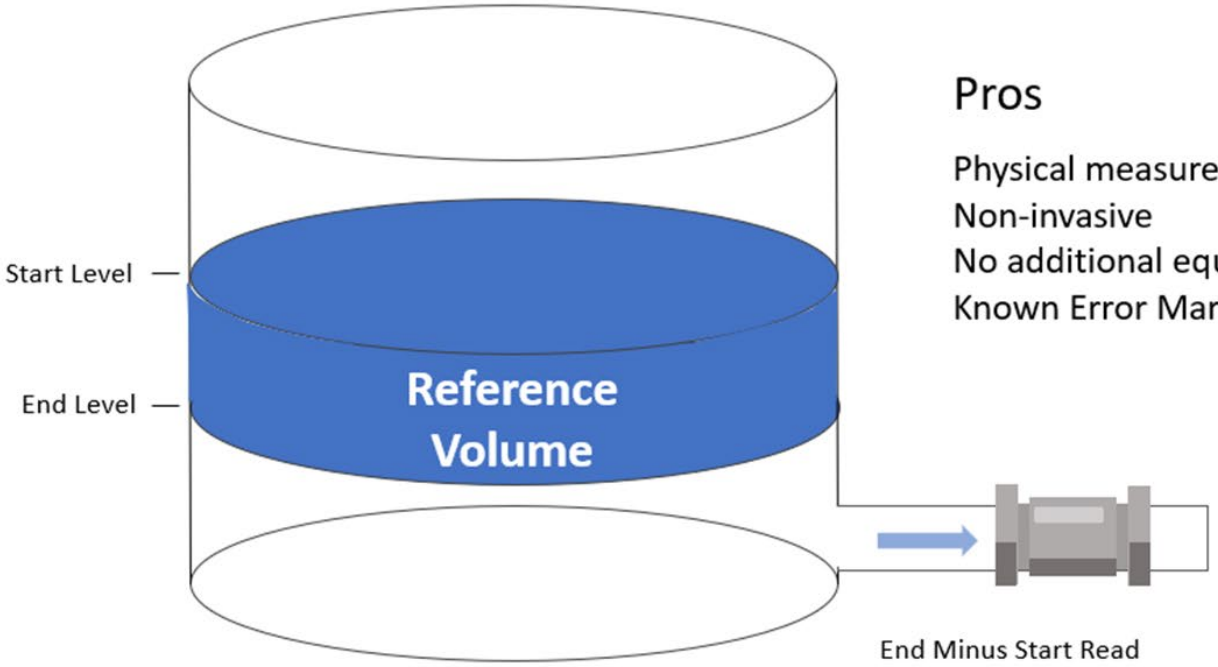
Register Resolution | Physical Reading | Could Be...

$$Uncertain\ Volume = 2 * Register\ Resolution$$

Measurement Uncertainty

- Inherent Meter Accuracy (+/- 2%)
- Pipe Dimensions
- Velocity Profile Uncertainty

Known Volume Test Summary



Pros

Physical measurement
Non-invasive
No additional equipment
Known Error Margins

Cons

Reservoir required
Known geometry
Accurate level sensing
Operational interruption

$$Accuracy = \frac{V_m}{V_r}$$

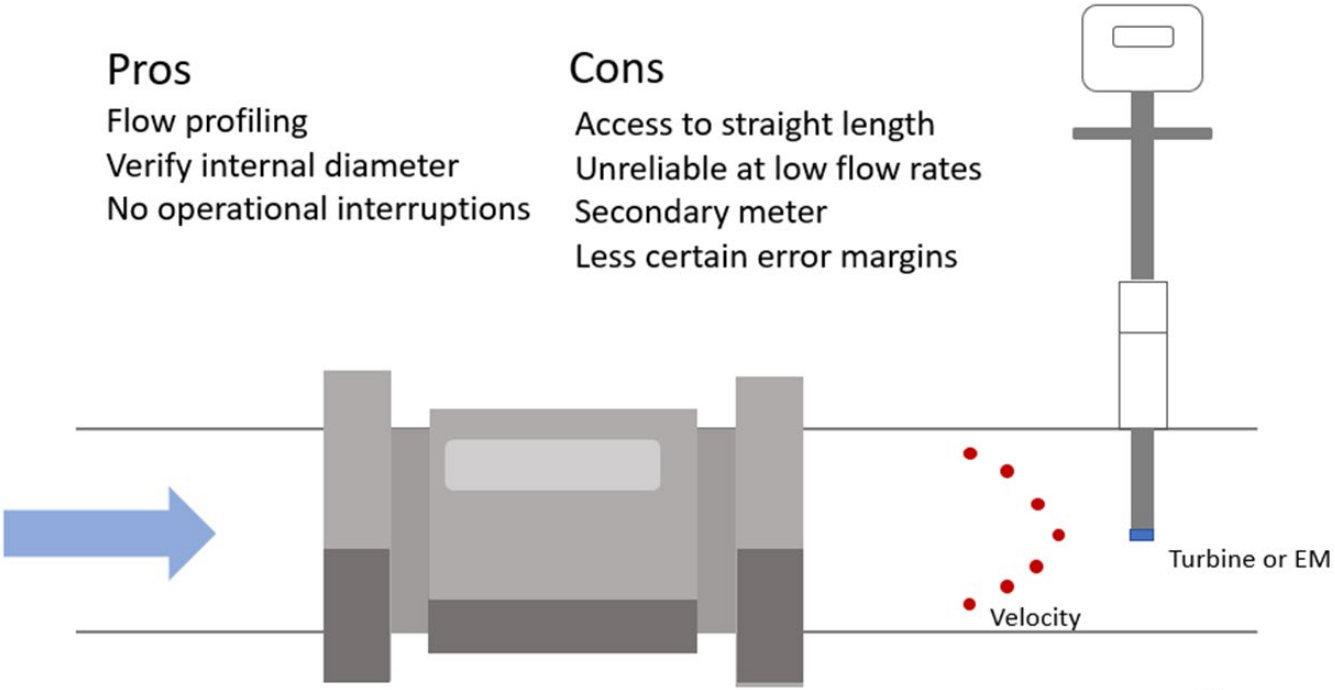
Reference Meter Test Summary

Pros

Flow profiling
Verify internal diameter
No operational interruptions

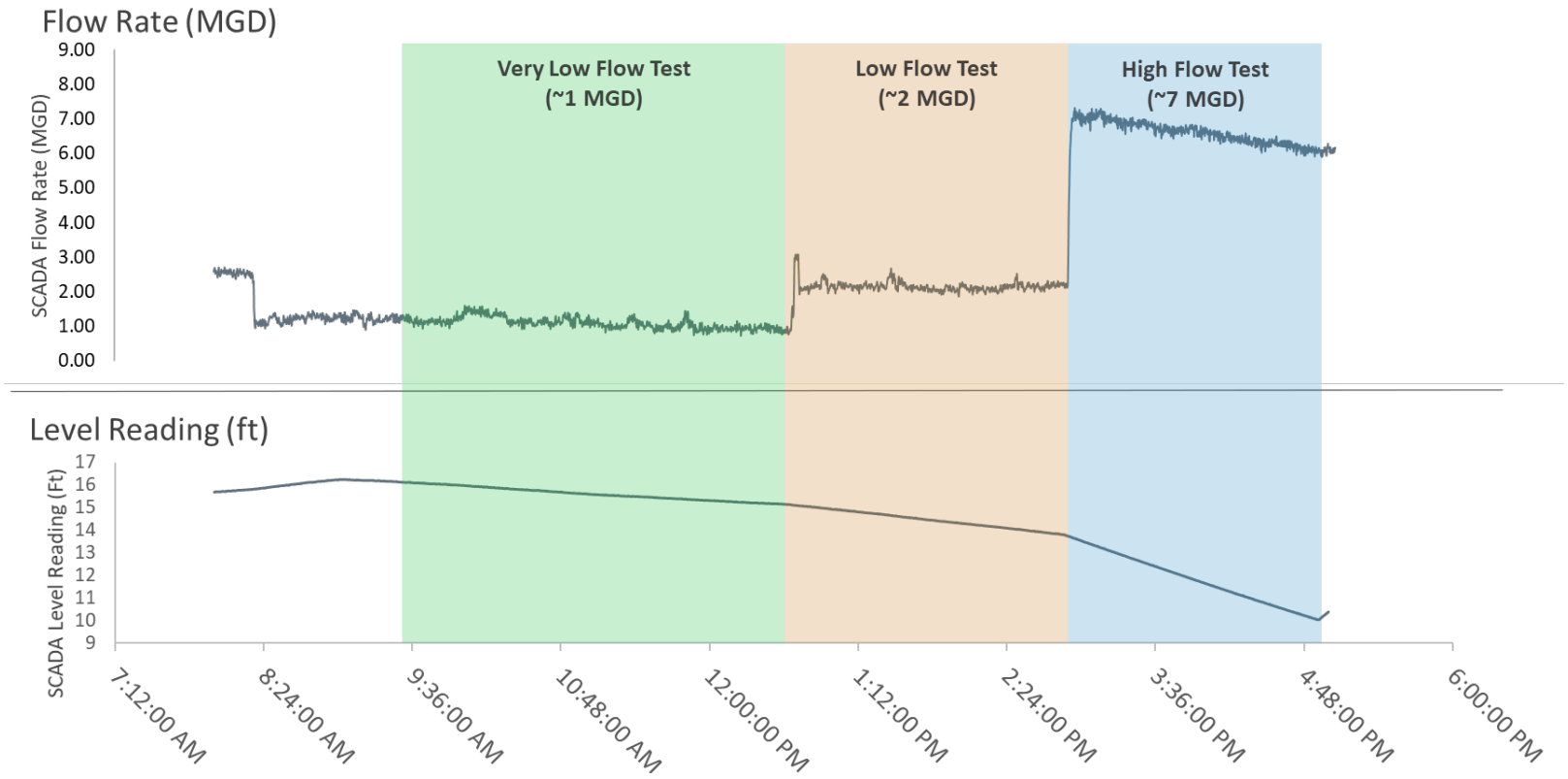
Cons

Access to straight length
Unreliable at low flow rates
Secondary meter
Less certain error margins



$$Accuracy = \frac{V_m}{V_r}$$

Meter Test Results



Use of Test Results

	Meter A	Meter B	Meter C
Volume Supplied	100	1,000	10,000
Meter Accuracy	105.5%	112.6%	99.1%

Weighted Average: (Sum of Volume x Accuracy) / (Sum of Volume)

Example: (100x105.5 + 1,000x112.6 + 10,000x99.1) / (100+1,000+10,000)

= 100.37%

Use of Test Results

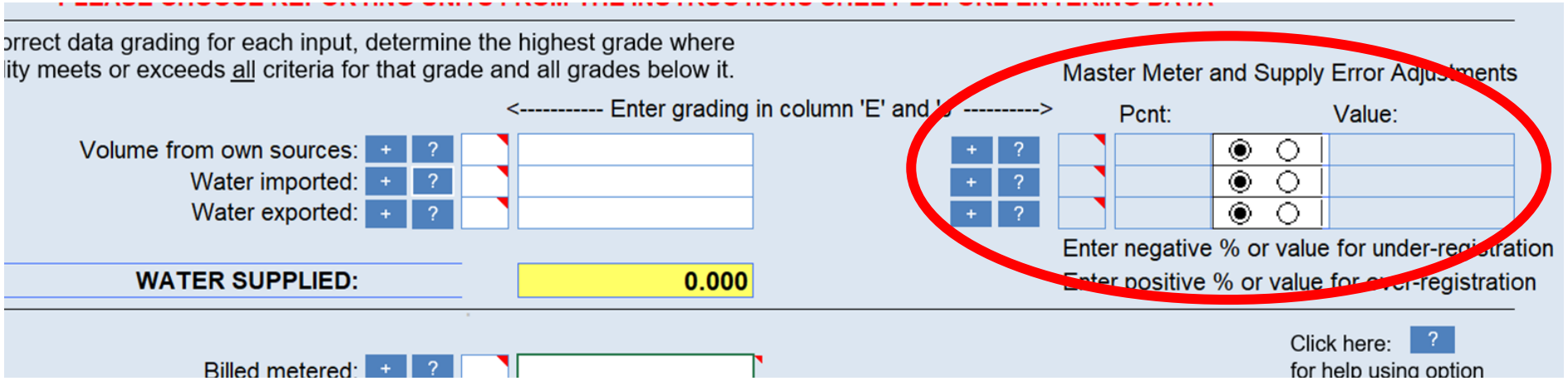
	Meter A	Meter B	Meter C
Volume Supplied	100	1,000	10,000
Meter Accuracy	105.5%	112.6%	99.1%

Comparison of Calculations

- Weighted Average – Average Accuracy = 100.4%
- Simple Average – Average Accuracy = 105.7%

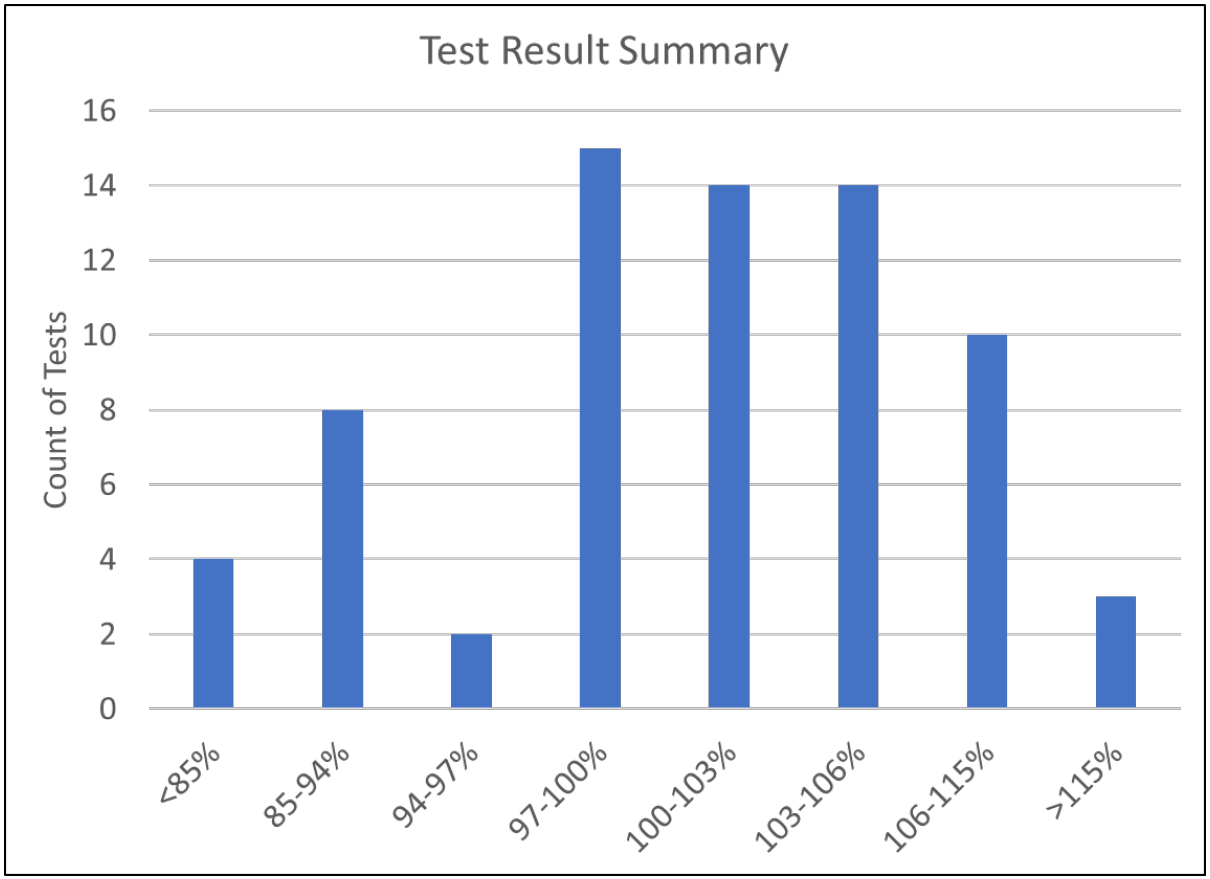
Use of Test Results

- *Adjustment to AWWA Audit Software*
- *Recalibrate/Repair Meter*
- *Leave blank if no test results?*



Use of Test Results

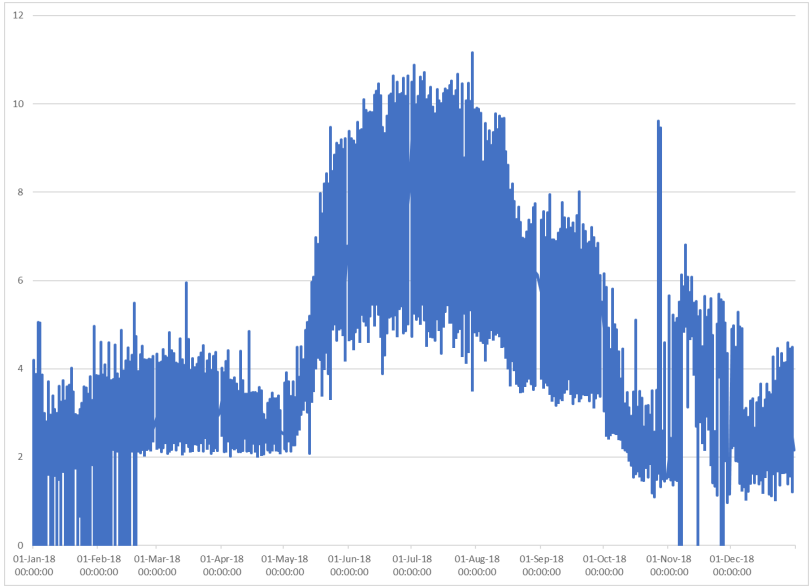
Summary Stats	
Total Tests	70
Min	32.2%
Max	133.6%
Mean	100.3%
Median	101.2%

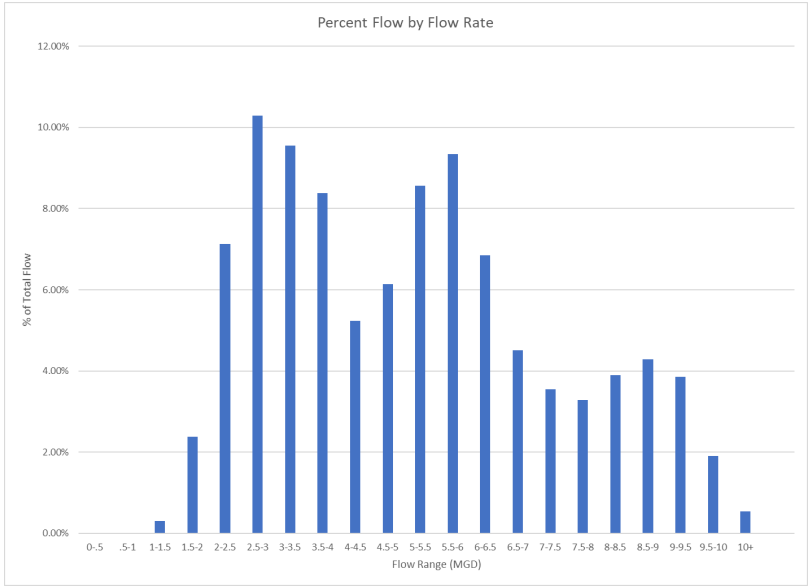


Data Request for Meter Testing

- Meter Make/Model
- Meter Size
- Flow History
- Upstream & Downstream Straight Pipe

- Piping Configuration
- Proximity to Tank/Clearwell
- Previous Test/Calibration Results





Advanced Validation Methods & Technical Assistance: Billing Data Analysis

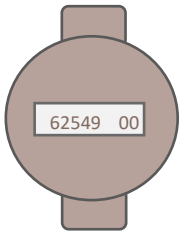
Why perform Consumption Data Analysis

- Confirm consumption volumes
  - Both metered and unmetered
  - Differentiate billed vs. unbilled
- Identify practices that may contribute to water losses
- Identify lost revenue or new sources of revenue
- Analysis and validation can be done from a volume perspective and from a revenue perspective

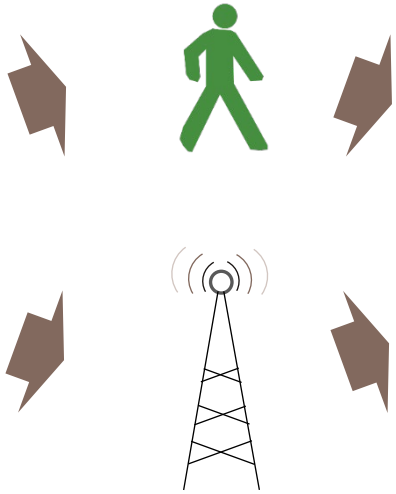
Why perform Consumption Data Analysis

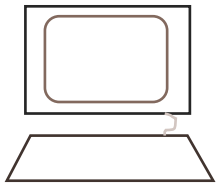
Meter Reading and Billing System

Volume Recorded



Meter Readings Collected



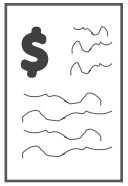


Data Processed

read.p	read.c
62549	62549
62549	62549
62549	62549

meterID	Meter Multiplier
13576	10
198604	100
B23487	10

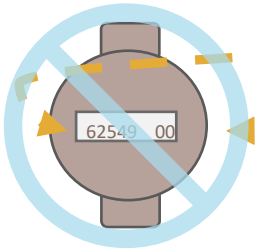
Billing, Reporting, and Archiving



Month	Billings
Jan	$ 324,568
Feb	$ 431,243
Mar	$ 501,387

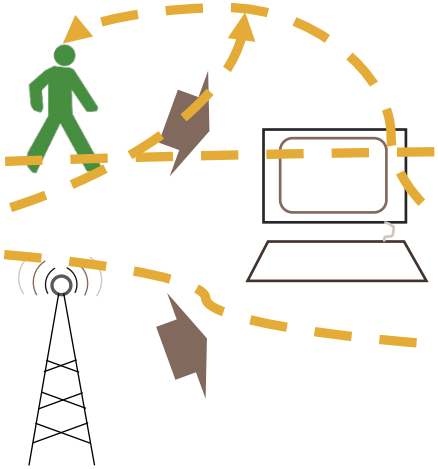
Why Analyze Billing Data?

Volume Recorded



- X Meter malfunction
- X Inaccurate meters
- X Incorrect meter or customer data

Meter Readings Collected



- X Missed or Incorrect reads
- X Failed data transmission
- X Incomplete data stored

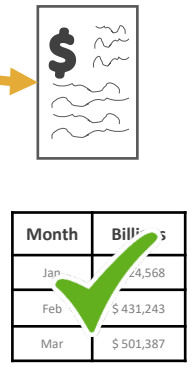
Data Processed

read.p	read.c
62549	62549
62549	62549
62549	62549

meterID	Meter Multiplier
13576	10
198604	100
B23487	10

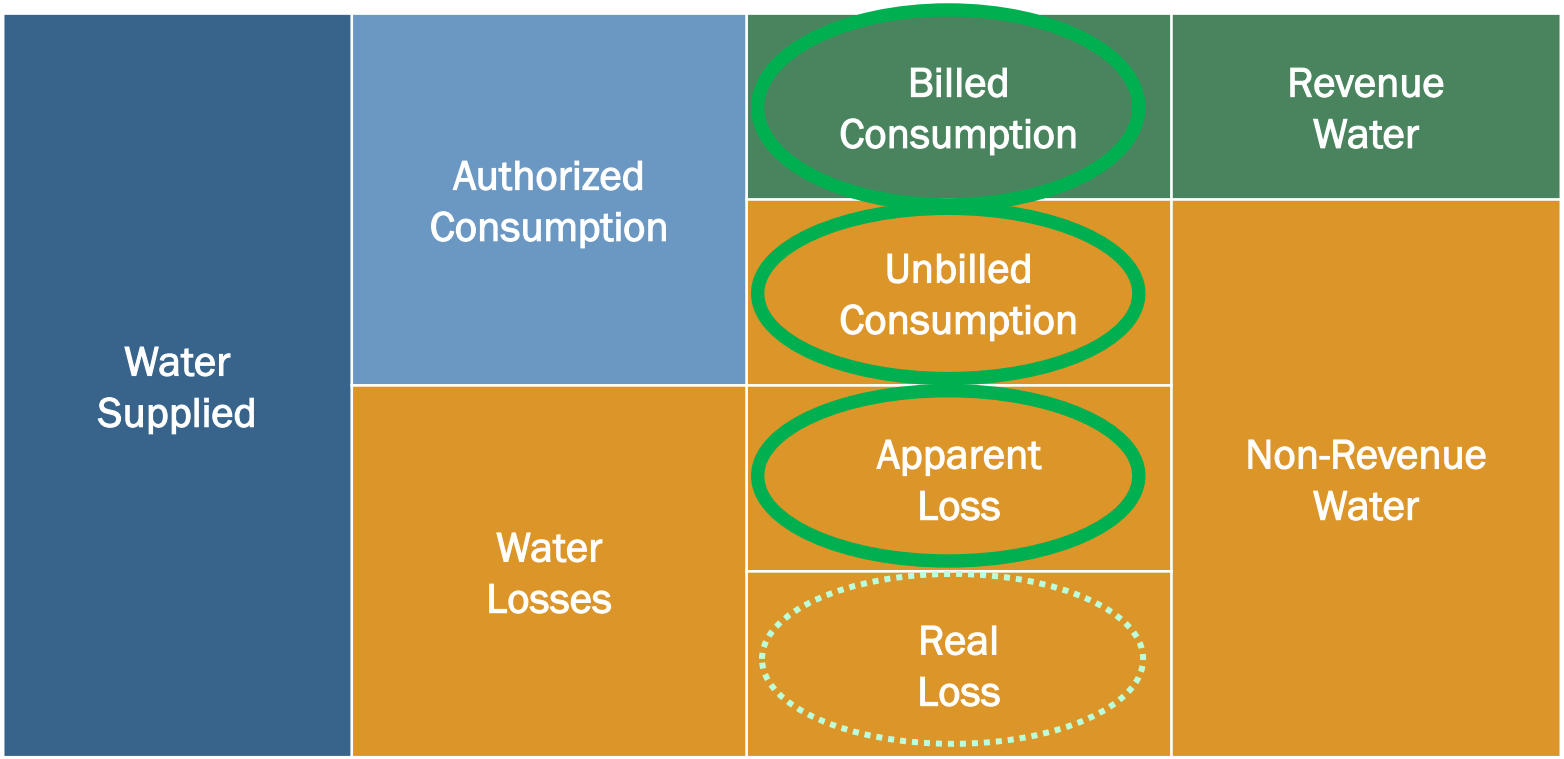
- X Duplicate records
- X Consumption adjustments
- X Meter rollovers
- X Consumption estimates
- X Re-read

Billing, Reporting, and Archiving



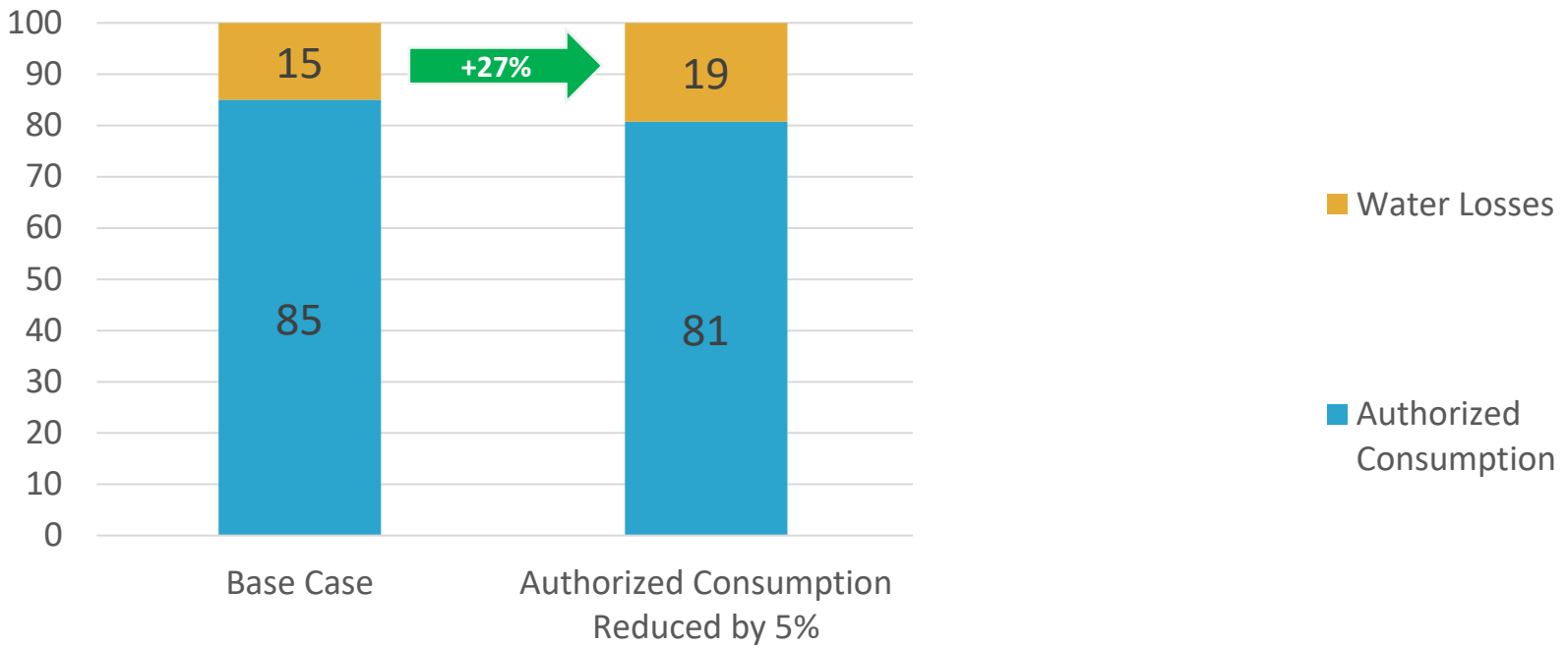
- X Reporting for financial purposes
- X Bill adjustments
- X Archive quirks

Why perform Consumption Data Analysis

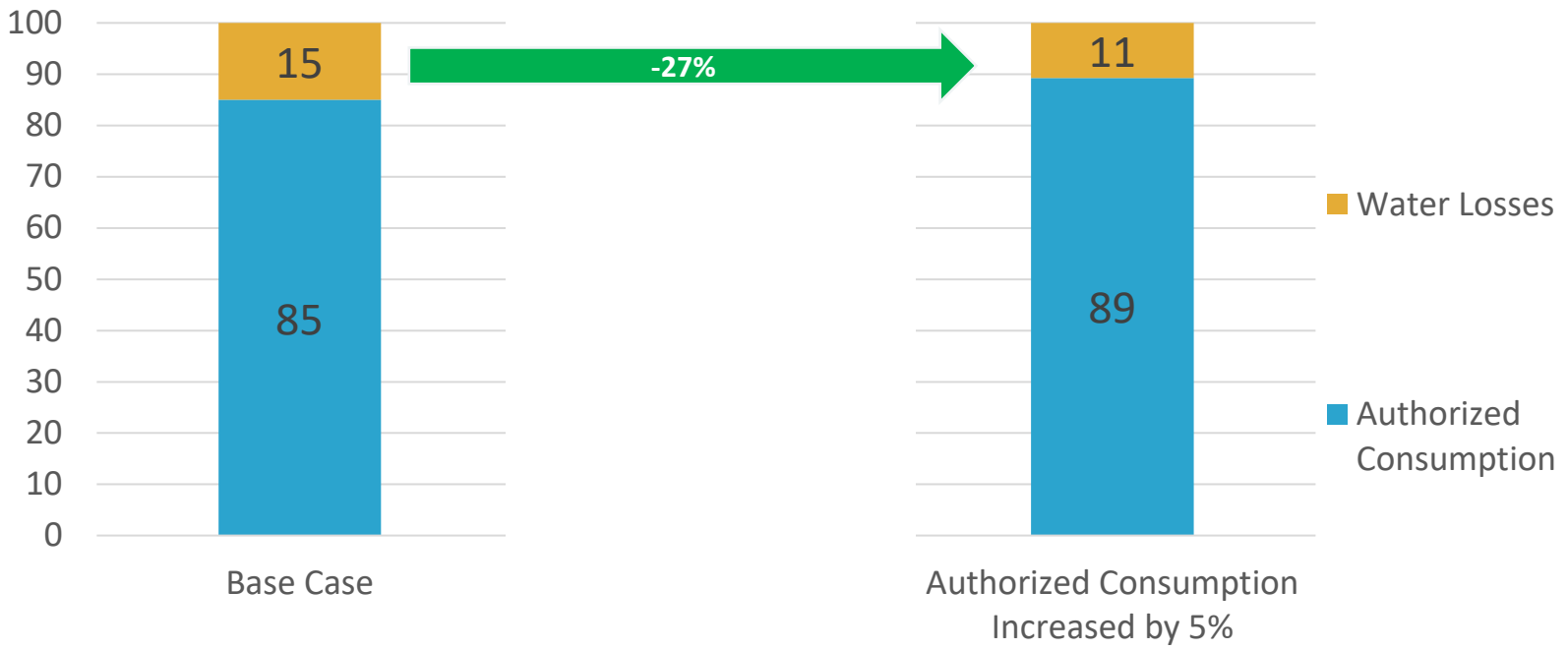


Confirm Consumption Volume

Confirm Consumption Volume



Confirm Consumption Volume

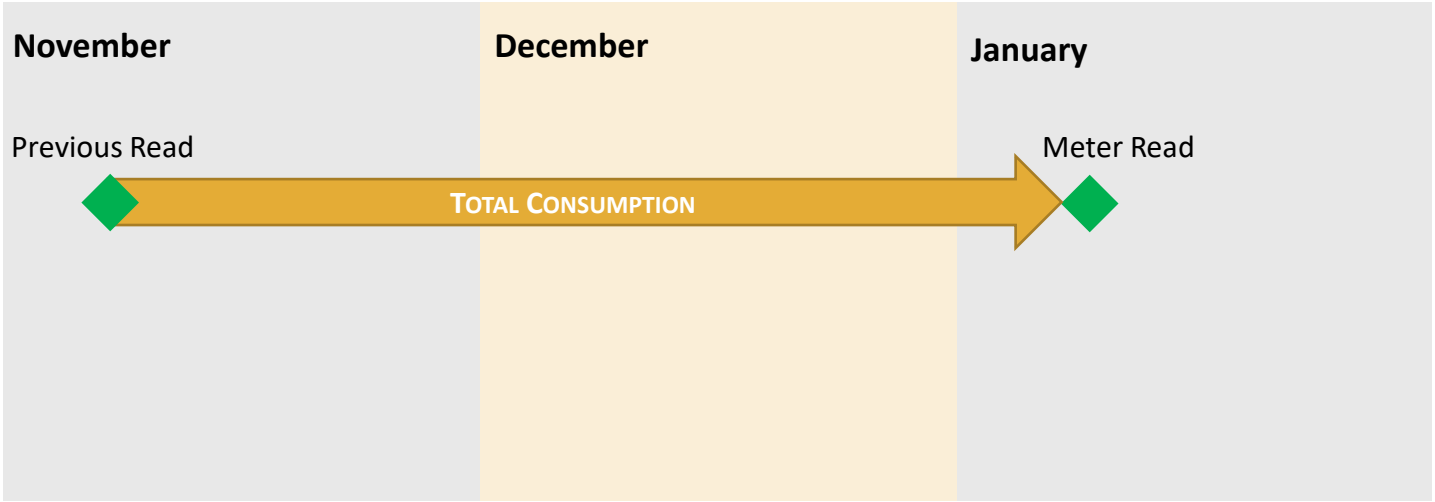


Basic checks – Volumes

- Relevant to **potable water** audit
  - ✓Include potable water services
  - ✓Include potable water uses that may be tracked in a different system – wholesale, hydrant sales, temporary meters, construction meters
  - ✓Exclude raw, recycled or other types of non-potable water

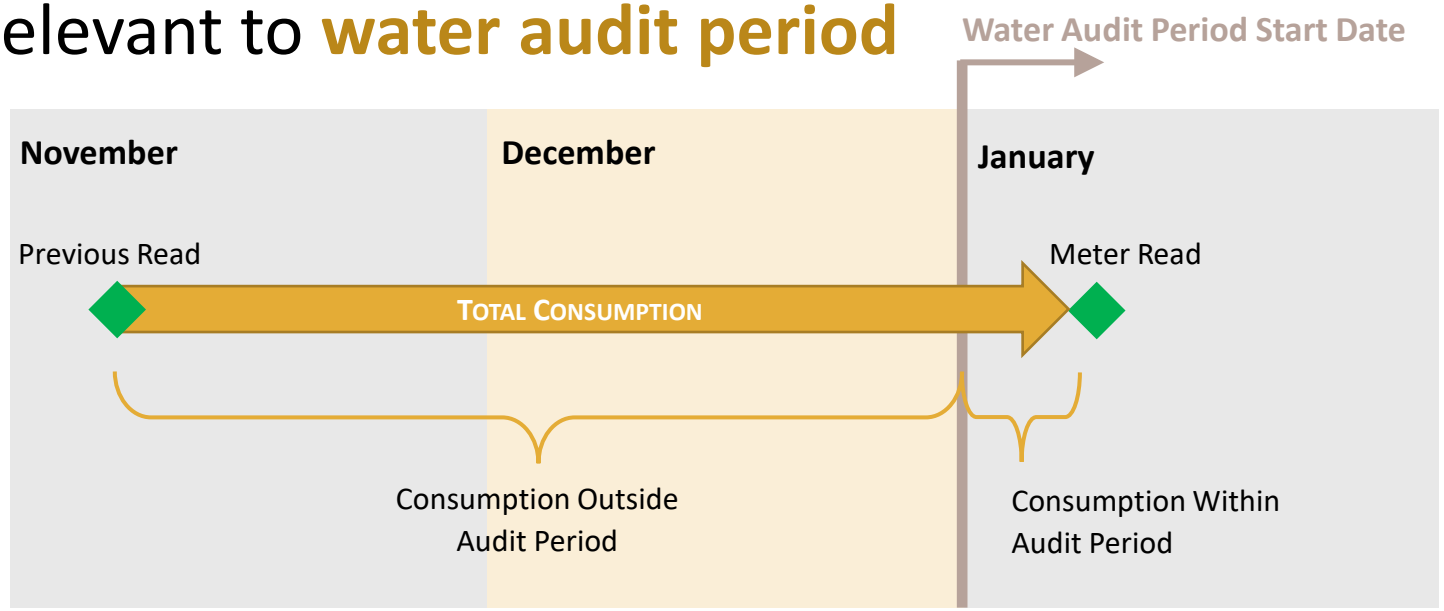
Basic checks – Volumes

- Relevant to **water audit period**



Basic checks – Volumes

- Relevant to **water audit period**



Basic checks – Volumes

- Relevant to **water audit period**
  - ✓Lag time analysis

12-month period	Total Consumption (MG)	Difference with Audit Period
Audit Period	25,648	--
Shifted by 1 month	25,635	-0.05%
Shifted by 2 months	25,800	0.60%

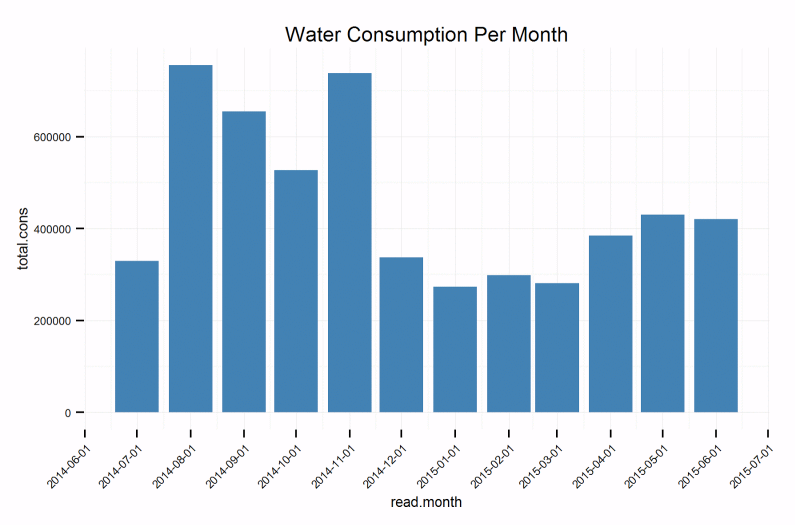
Basic checks – Volumes

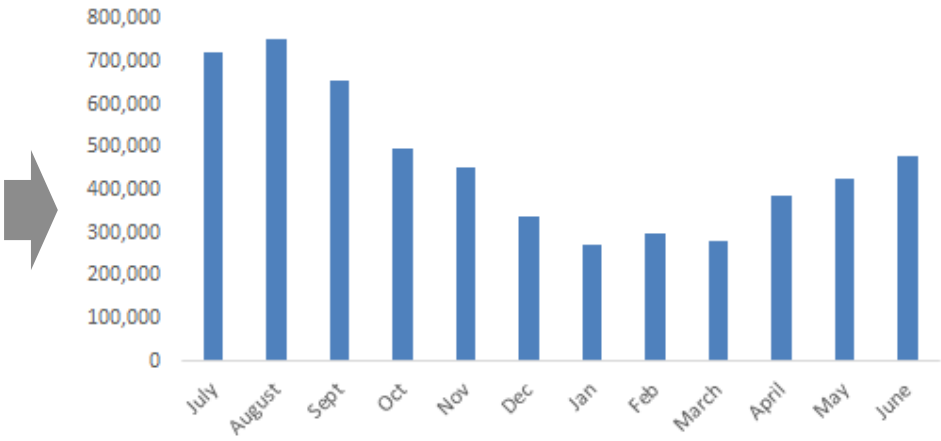
- Relevant to **water audit period**
  - ✓Lag time analysis

12-month period	Total Consumption (MG)	Difference with Audit Period
Audit Period	578.9	-
Shifted by 1 month	575.8	- 0.50%
Shifted by 2 months	549.6	- 4.75%

Basic checks – Volumes

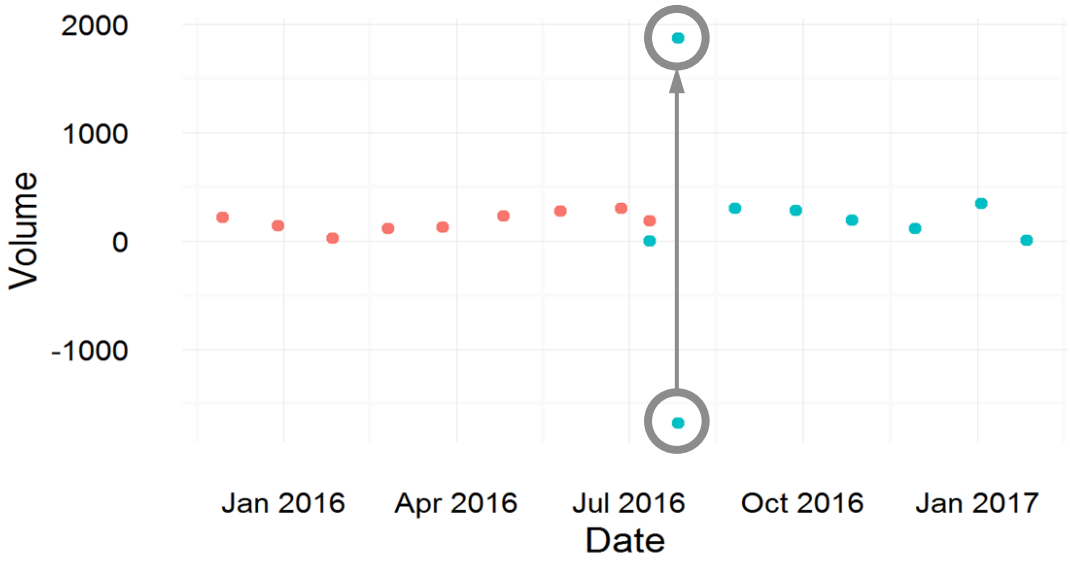
- Relevant to **water audit period**
  - ✓Prorating Consumption





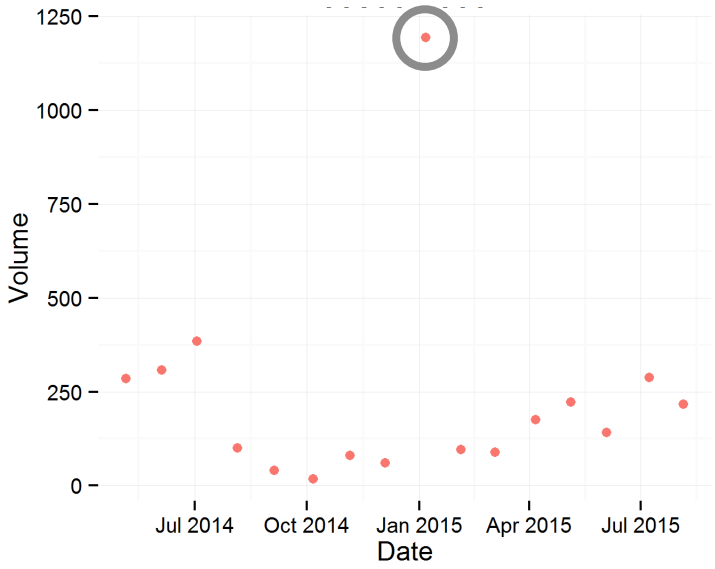
Basic checks – Volumes

- Correct
  - ✓Duplicates
  - ✓Negatives
    - Adjustments
    - Meter Changes
    - Meter Rollovers



Basic checks – Volumes

- Correct
  - ✓Duplicates
  - ✓Negatives
    - Adjustments
    - Meter Changes
    - Meter Rollovers
  - ✓Outliers



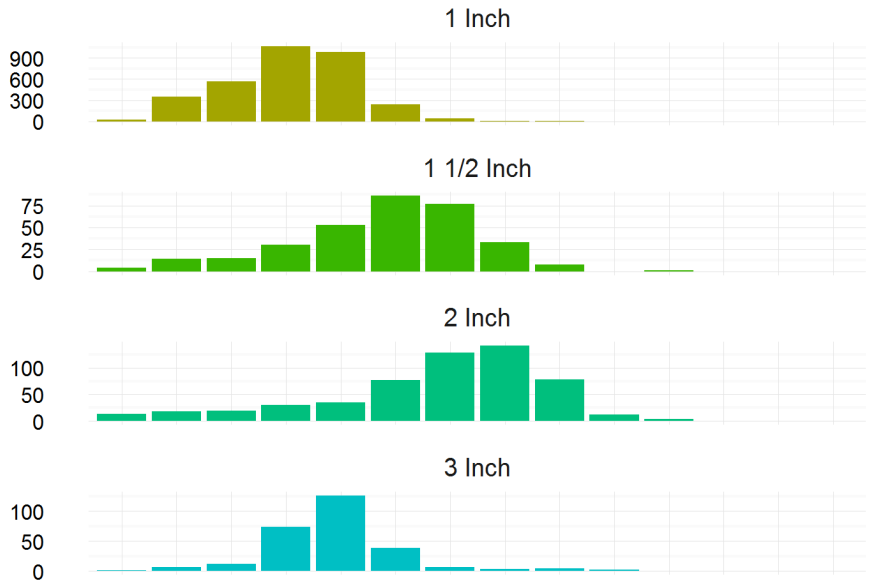
Basic checks – Volumes

- Correct
  - ✓Duplicates
  - ✓Negatives
    - Adjustments
    - Meter Changes
    - Meter Rollovers
  - ✓Outliers
  - ✓Units and Multipliers

Comparing Meter Model, Size, and Multiplier				
Size	Model	Multiplier (0.01)	Multiplier (0.1)	Multiplier (1.0)
3/4 Inch	35	3988	-	2
3/4 Inch	70	1	-	-
3/4 Inch	PF-170	1	-	-
3/4 Inch	PF-35	2000	1	-
1 Inch	35	1	-	-
1 Inch	70	6586	-	-
1 Inch	PF-170	1	-	-
1 Inch	PF-70	5325	1	1
1.5 Inch	120	-	371	-
1.5 Inch	PF-120	1	213	-
1.5 Inch	PF-170	-	1	-
2 Inch	170	2	258	-
2 Inch	PF-170	-	120	-
4 Inch Comp	70	-	1	-
6 Inch	170	-	1	-

Other checks – Revenues

- Correct customer and meter data
  - ✓Customer type
  - ✓Service type

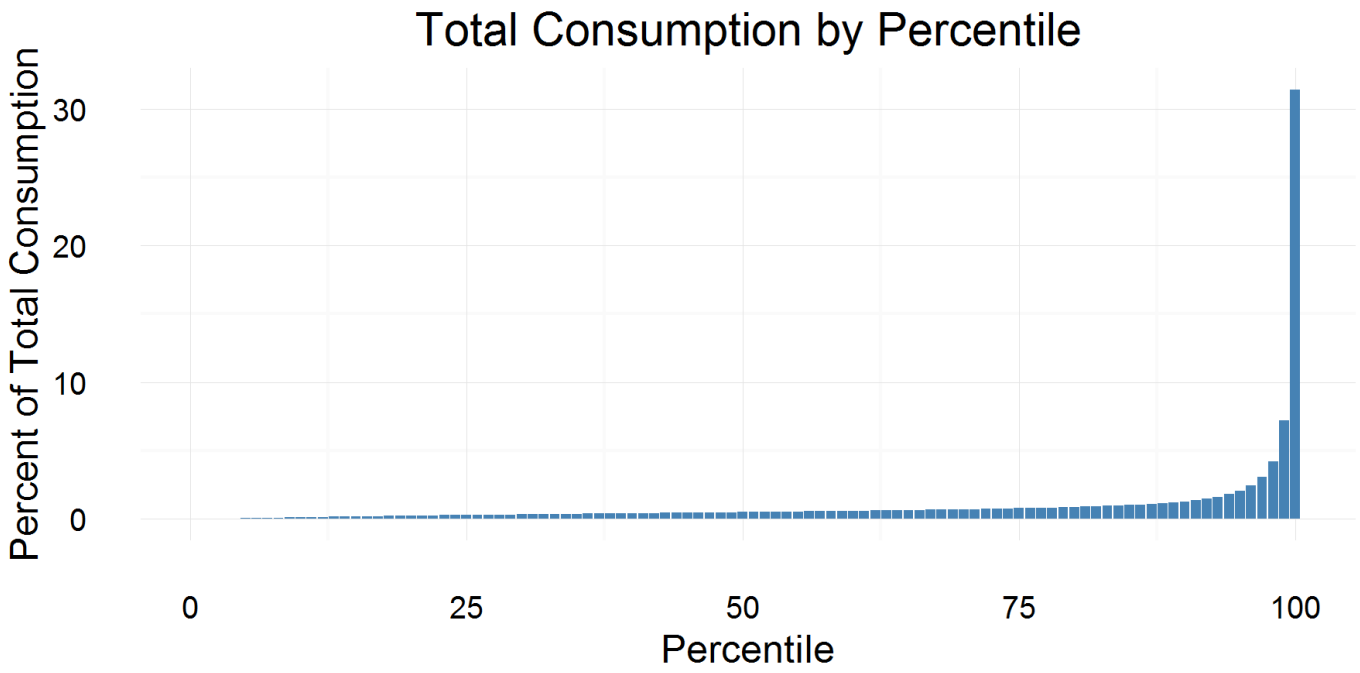


Other checks – Revenues

- Correct customer and meter data
  - ✓ Customer type
  - ✓ Service type
  - ✓ Meter size
    - Size in field matches size in system
    - Appropriate for consumption volumes
- Account status
  - ✓ Active or Inactive
- Other utility specific regulation
  - ✓ Separate fire suppression system requirement
  - ✓ Irrigation restrictions
  - ✓ Volume adjustment for fire uses

Other checks – Revenues

- Knowing your largest consumers



In summary

- Meter reading and billing systems are a invaluable tool for any water utility – not just for it's primary purpose – but also to:
  - ✓ Assure correct volumes are billed and recorded
  - ✓ Track utility processes that may impact water losses and revenue
  - ✓ Complement effective NRW reduction strategies

- These checks can have a significant impact on a water audit which in turn will shape the selection of cost-effective strategies for the reduction of NRW

Data Request for Billing Data Analysis

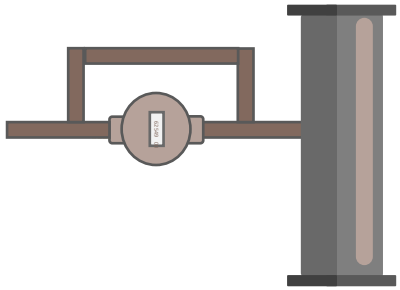
Billing Data Analytics (Integrity Review & Anomaly Flagging)

- Timeframe for the data requested unless noted otherwise: Calendar 2020 plus 2 months on the front and back end (so 16 months total). In order to perform this analysis, we will need to receive raw billing data or meter read data in a specific format. We will need data in a single file in **.csv format** with a **single record for each bill**. Each record should include the following fields (variables), if you have them available.

REQUESTED BILLING DATA FIELDS		
1	**Location ID**	*a unique identifier for a parcel or service connection in the water system, similar to an address*
2	**Customer ID**	*a unique identifier for a customer at a given location*
3	**Meter ID**	*a unique identifier for a meter at a given location*
4	**Meter Size**	*indication of meter size*
5	**Meter Installation Date**	*The installation date for the meter body, ideally including meters that have been replaced.*
6	**Meter Total Lifetime Throughput**	*The total volume of water that has passed through the meter, accounting for meter rollovers.*
7	**Service or Account Type**	*identifying fields that indicate what type of service is provided (e.g., "residential")*
8	**Read Date**	*the date on which the meter was read*
9	**Previous Read Date**	*the date on which the meter was last read*
10	**Read Volume**	*the raw totalizer volume from the meter on the read date*
11	**Previous Read Volume**	*the raw totalizer volume from the meter on the previous read date*
12	**Units**	*the units that the read volumes are recorded in*
13	**Billed Consumption**	*the actual volume the customer was billed for during the billing period*
14	**Adjustment or Estimate Flags**	*any flags that indicate the billed consumption was adjusted or estimated during the billing period.*

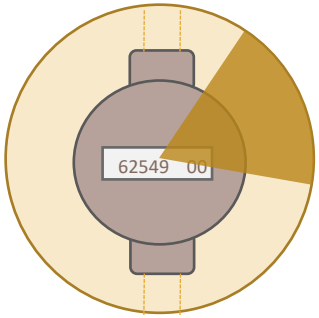
Advanced Validation Methods & Technical Assistance: Customer Meter Test Design And Results Analysis

Types of Apparent Losses



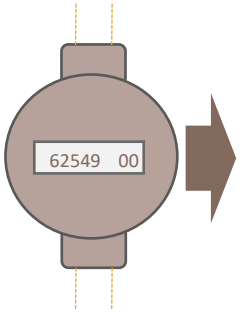
Unauthorized Consumption

Theft!



Metering Inaccuracy

Customer meter under registration



read.p	read.r
62549	62549
62549	62549
62549	62549

Data Handling Errors

Reporting or other clerical errors during the handling of meter reading data

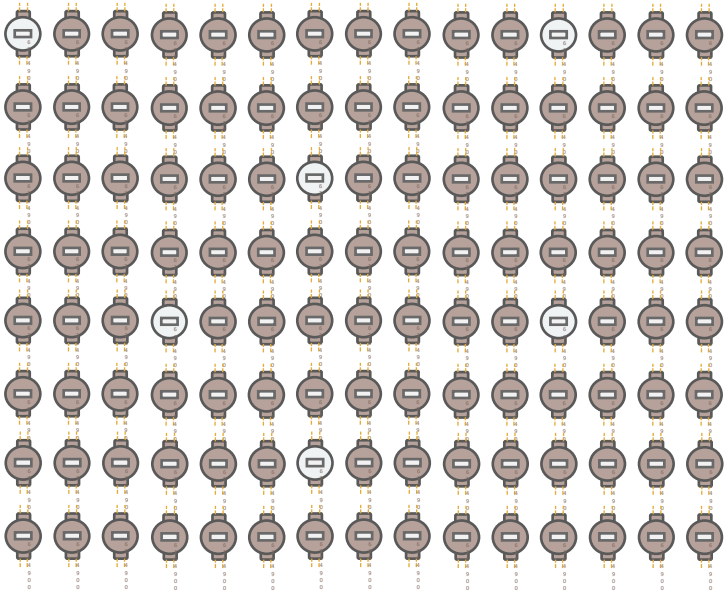
Apparent Loss: Customer meter testing

Many meters, **small** volumes

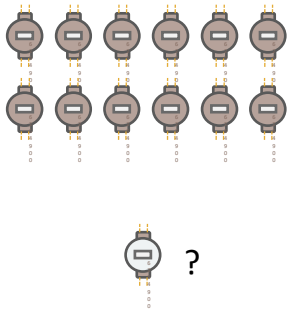
Few meters, **large** volumes

Estimating Customer Metering Inaccuracy

Meter Population



Sample



Customer Meter Testing Process

1 **Design Testing Strategy**
Determine goals of testing program and agree upon a sampling strategy and number of meters to sample.

2 **Meter Sample Selection**
Evaluate meter inventory or billing data to generate a list of meters and alternates based on the agreed test design.

3 **Retrieve & Replace Meters**
Pull and test small meters identified in meter sample.

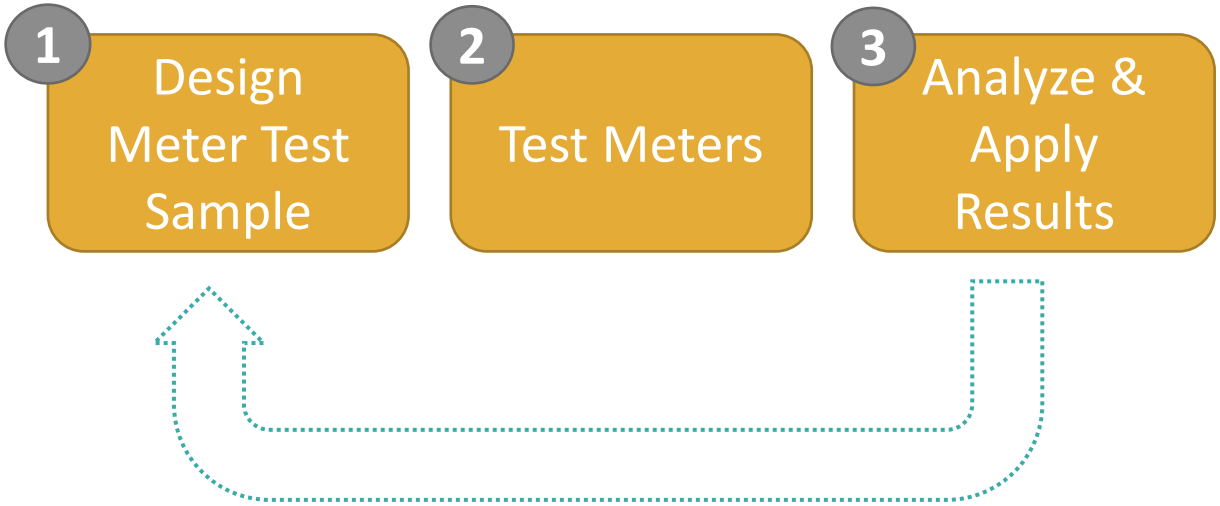
4 **Meters Tested**
Meter testing contractor tests meters and documents results thoroughly (tabular electronic format is preferred).

4 **Results Analyzed**
Provide meter test results for analysis.

Small Meter Testing Strategy

How many small customer meters do you need to test?

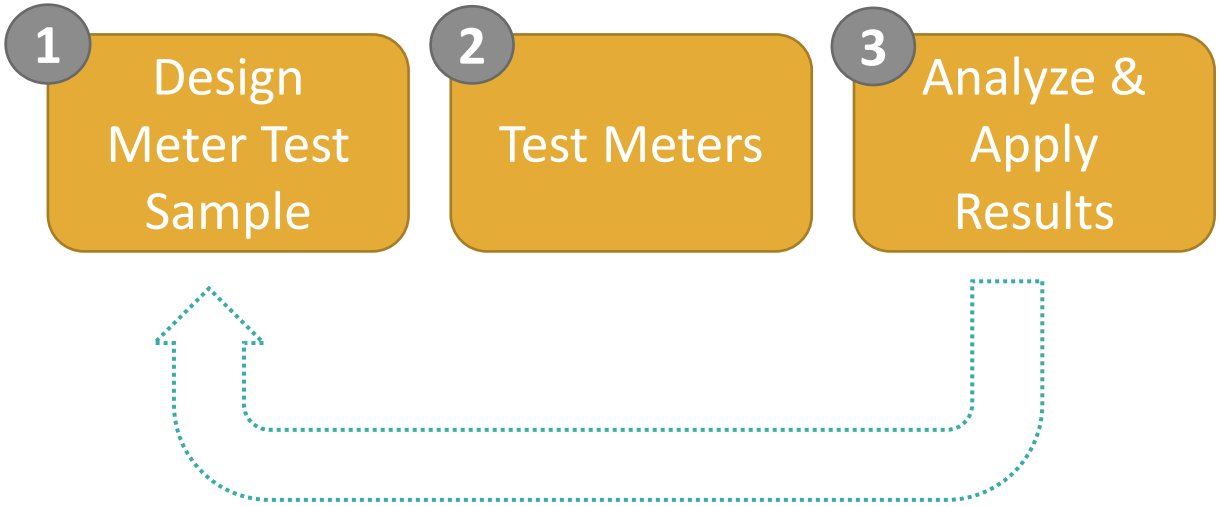
1. Evaluate the level of certainty required to meet management objective.
2. Select a sample size that provides the required level of certainty.

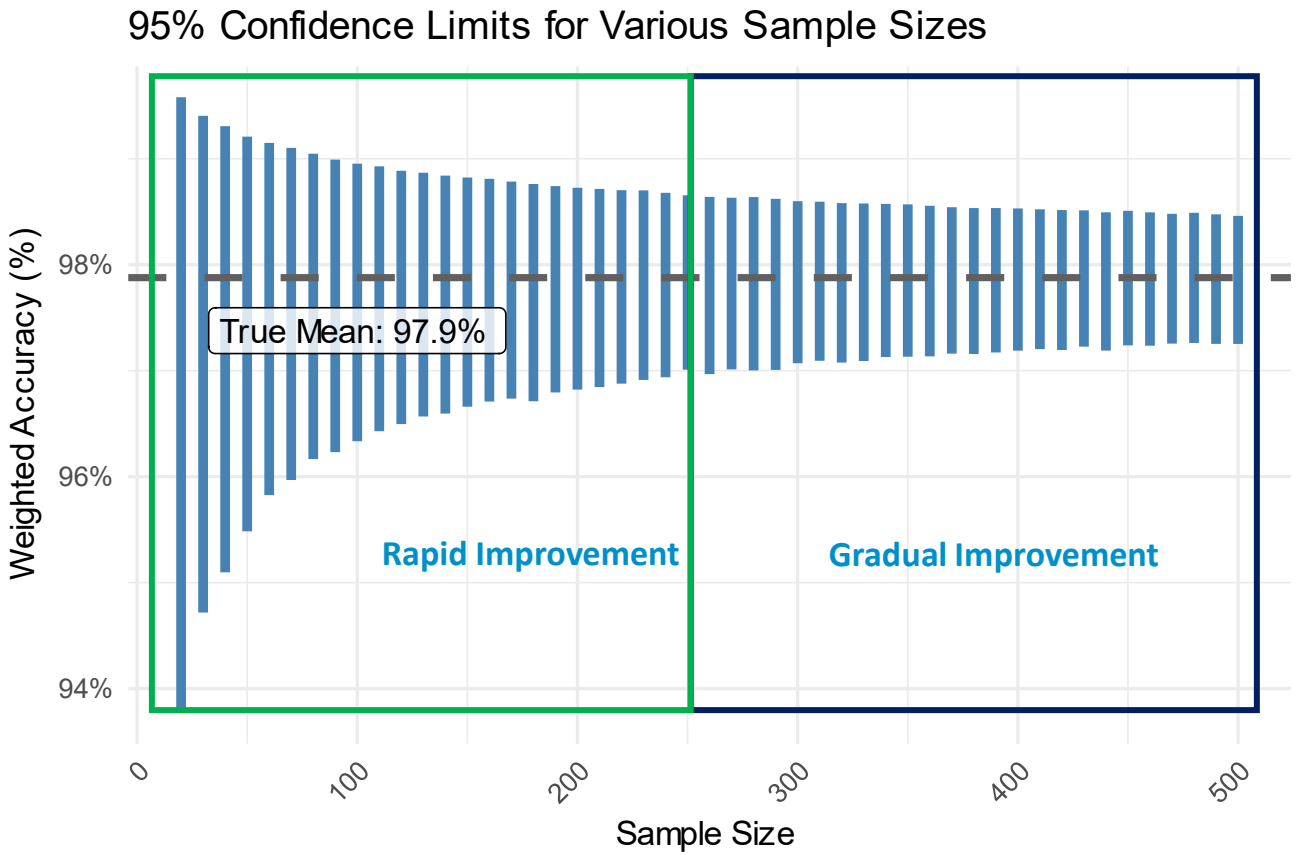


Small Meter Testing Strategy

How many small customer meters do you need to test?

1. It depends…..




95% Confidence Limits for Various Sample Sizes
Weighted Accuracy (%)
98%
96%
94%
True Mean: 97.9%
Rapid Improvement
Gradual Improvement
0
100
200
300
400
500
Sample Size

Small Customer Meter Sample Design

1 Design Meter Test Sample

- Representative and random meter sample → *remember our goal is to appreciate the accuracy of the **whole population***
- What sample size is big enough?

Small Customer Meter Testing

2 Test Meters

- Careful with meter transport
- Test at low, medium, and high flows
- Document thoroughly
  - include reference volume, testing flow rate, meter totalizer reads, all meter information
  - compile data in analysis-friendly format

Weighting Factors

Time-Based (AWWA M36 4th Edition)

Customer meters spend 15% of the ***time*** at low flows, 70% at medium flows, and 15% at high flows—need to convert to volume-based weights.

Test Flow Rate (gpm)	Percent of Time Spent at Each Flow Rate	Volume Recorded in 1 Hour at Each Flow Rate (gal)	Percent of Total Volume Recorded at Each Flow Rate
0.5	15%	4.5	**1.3%**
3	70%	126	**35.4%**
25	15%	225	**63.3%**

Volume-Based (AWWA M6)

Customer meters see 15% of the ***volume*** at low flows, 70% at medium flows, and 15% at high flows—no conversion needed.

2016 Residential End Use Study Weighting (pending publication)

The most recent research on the percent of volume recorded at various flow rates suggests that about 13% of the ***volume*** is recorded at low flow rates, 55% at medium rates, and 32% at high flow rates—no conversion needed.

Weighting Factors

How do weighting factors overall accuracy?

Overall inaccuracy may be inappropriately biased by low flow inaccuracy when using simple mean

Weighting Method	All Results (2011-18) 3,873 records
M36 Weighted Mean	98.36%
M6 Weighted Mean	97.43%
2016 REU Weighted Mean	97.59%
None (simple mean)	96.67%

Small Customer Meter Analysis

3

Analyze & Apply Test Results

- Organize all test results
- Analyze accuracy findings
- Consider confidence limits
- Calculate Apparent Loss Volumes

Small Customer Meter Analysis

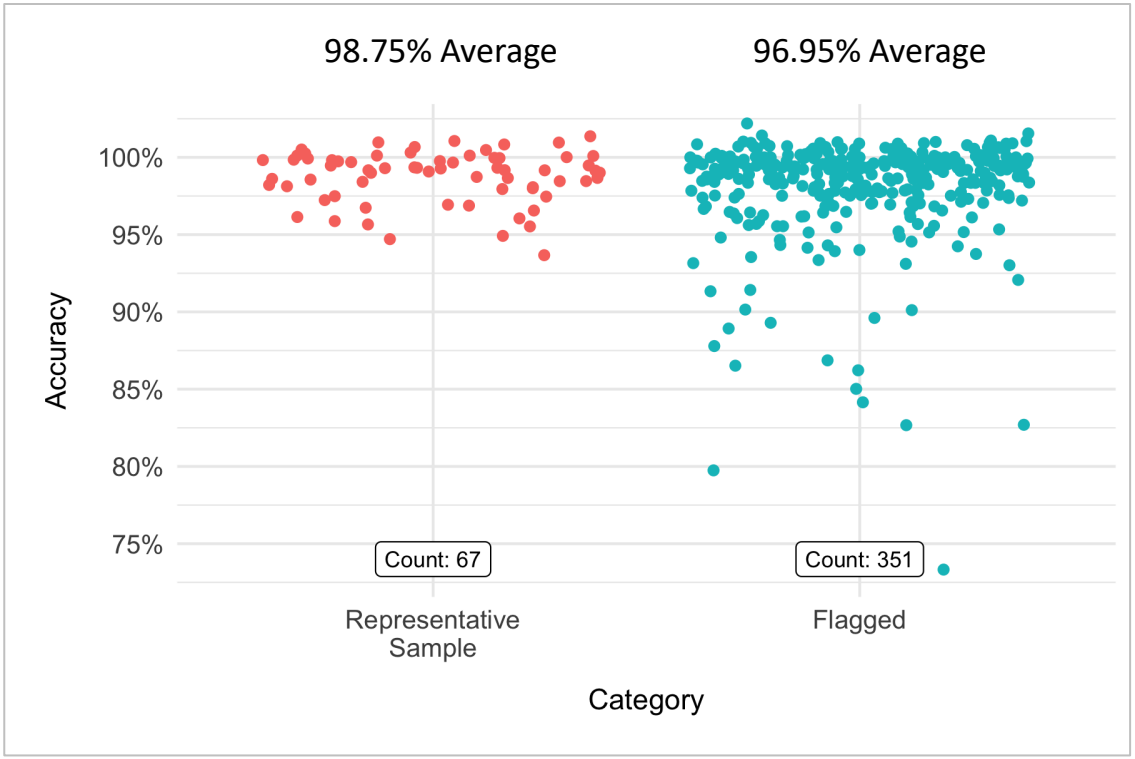
3 Analyze & Apply Test Results

Accuracy Results Analysis Considerations

- Averaging across flow rate results
  - time-weighting
  - volume-weighting and consumption profiling
- Handling stuck meters

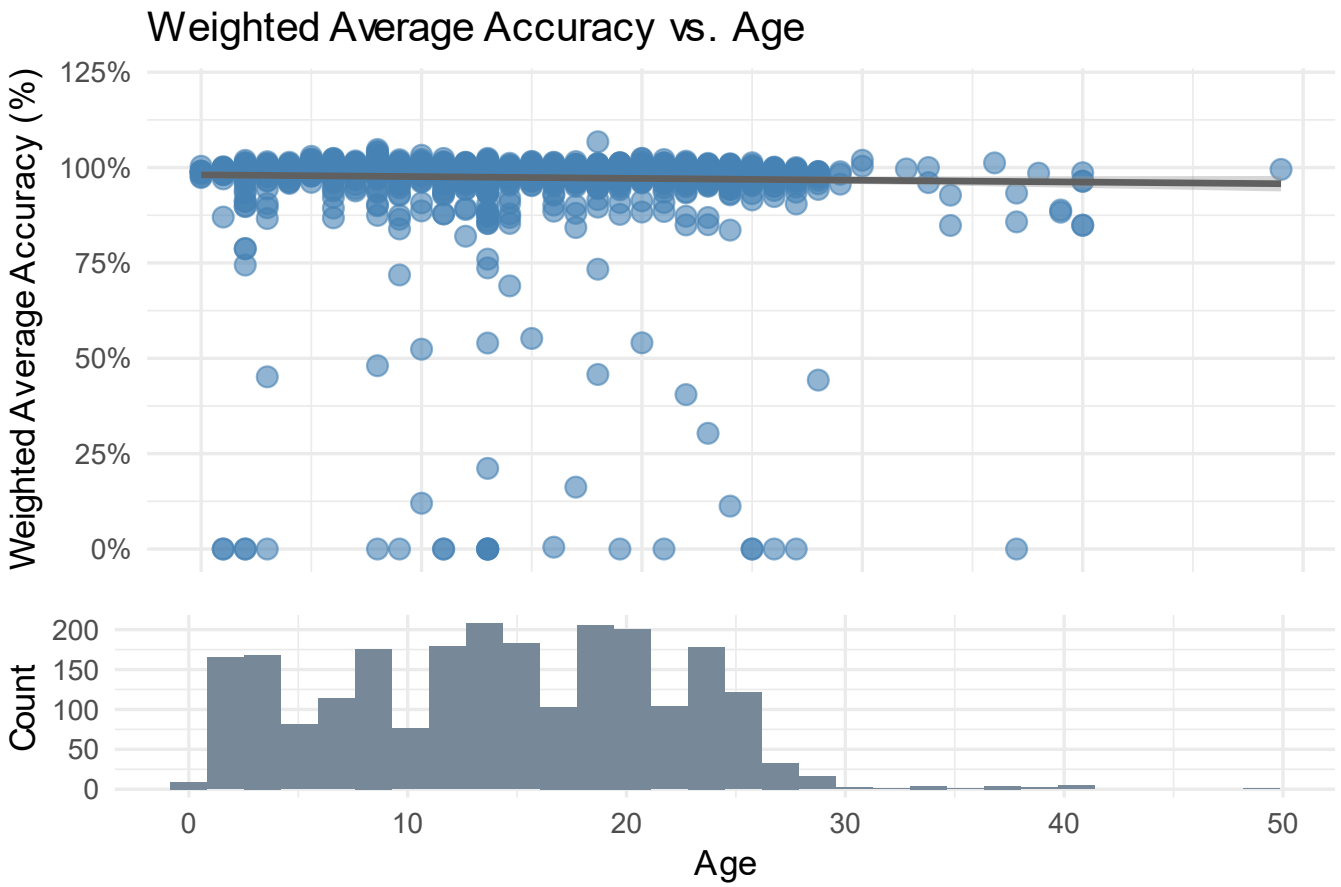
Small Meters (2018) – Flagged vs. Random

3/4” and 1” Results (2018)



WSO determined to a 95% confidence level that the mean accuracy for the random sample meters is somewhere **between 0.7% and 2.0% higher** than the flagged meters in the case of 3/4” and 1” meters.

Accuracy and Age



Small Customer Meter Testing

Meter Size	Meter Population	Registered Consumption Volume (MG)	Volume-Weighted Average Accuracy	Unregistered Consumption Volume (MG)
5/8”	13,548	2,225	92.0%	194
3/4”	1,392	203	98.5%	3
1”	2,145	274	96.9%	9
1-1/2”	311	57	94.0%	4
2”	391	78	97.6%	2

$$Accuracy = \frac{Registered\ Consumption\ Volume}{Total\ Registered\ Volume}$$

the more consumption, the more important accuracy!

Large Customer Meter Testing

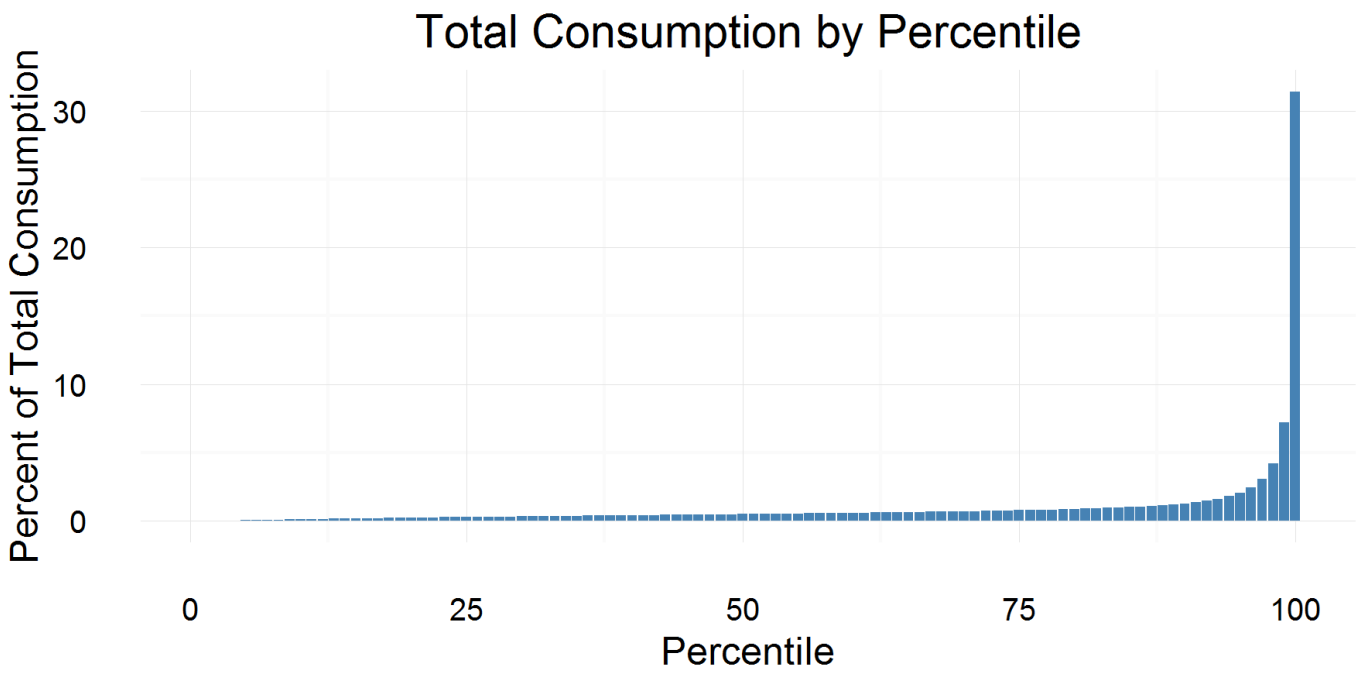
- Fewer, more important meters!
- Individual assessment
- Prioritize by consumption
- Flow profiling is key

1. Design Meter Test Sample
2. Test Meters
3. Analyze & Apply Results

Large Customer Meter Testing

1 Design Meter Test Sample

- Critical for revenue monitoring and recovery
- Significant factor in apparent loss assessment



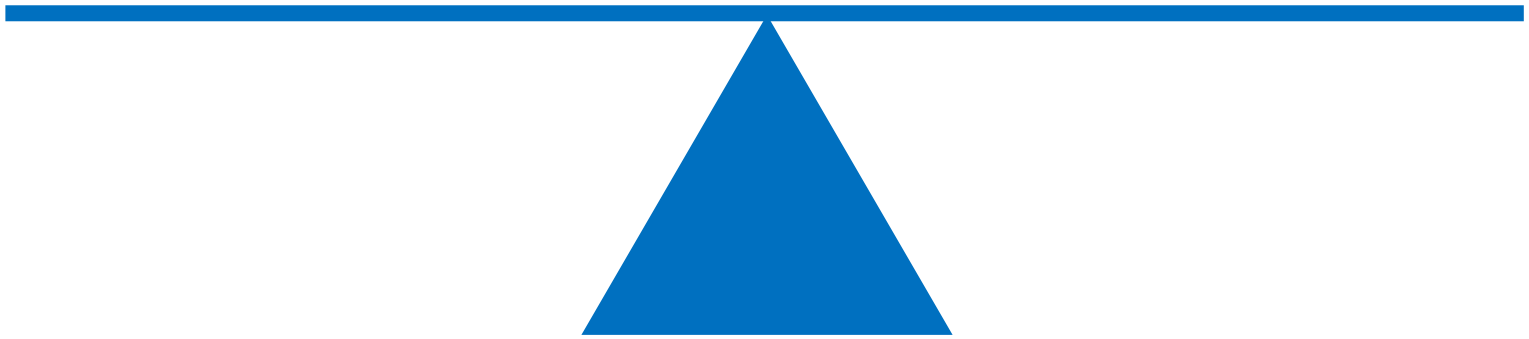
Balancing the costs of testing a large customer meter

Cost of Inaccuracy:

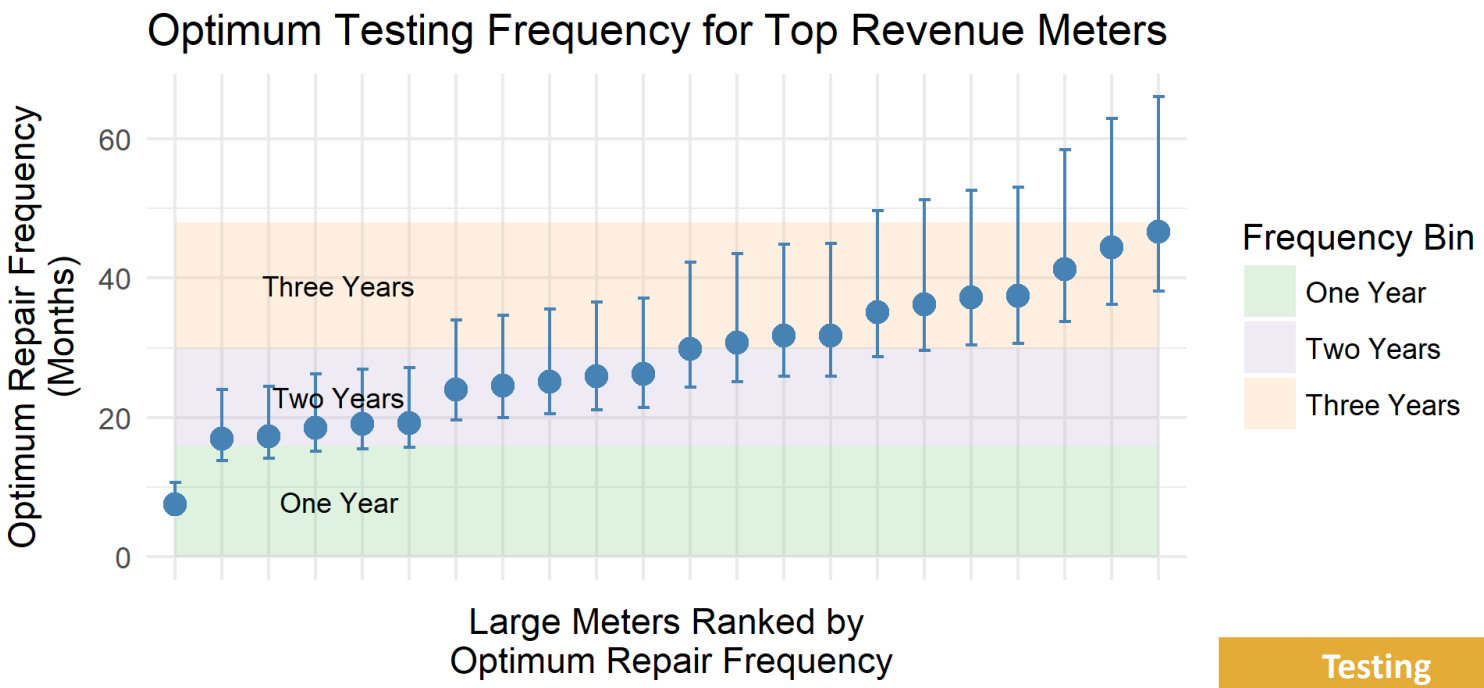
- Reduced Volume Recorded
- Retail Value of Water Sold
- Inaccurate water loss estimates

Cost of Testing and Repair:

- Expected Cost of Test and Repair



Overall Schedule



Testing Frequency	Count of Meters
1 year	1
2 years	10
3 years	11
Regular Testing	36
Total	**58**

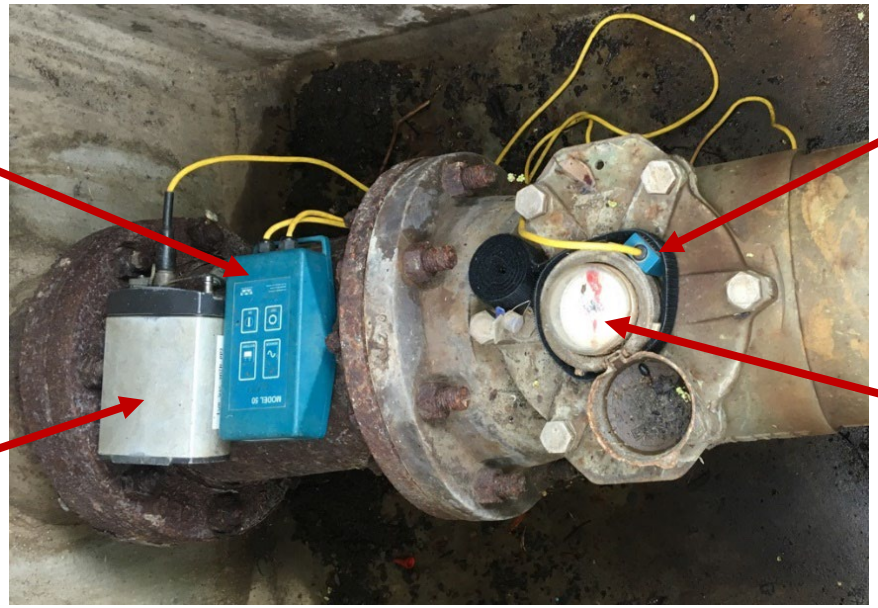
Customer Meter Profiling

Flow Sensor

Meter-Master Model 50

Data Logger

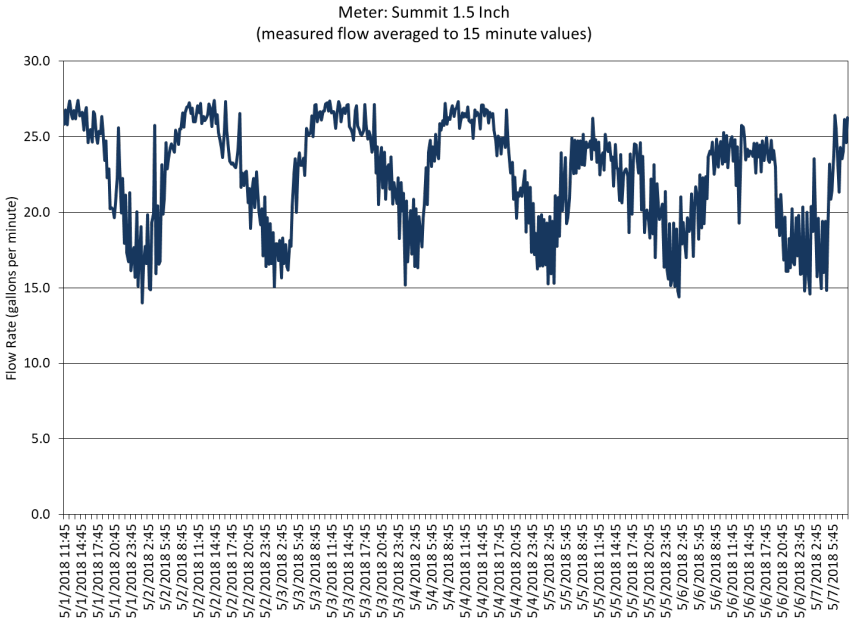
Primelog 2i

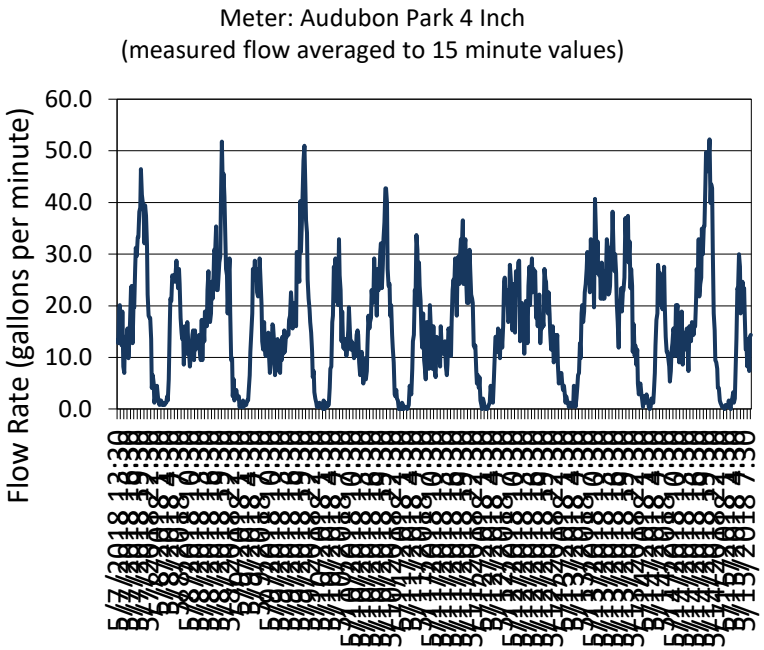


Flow sensor's magnetic pad strapped to meter body

Meter register

Customer Meter Profiling



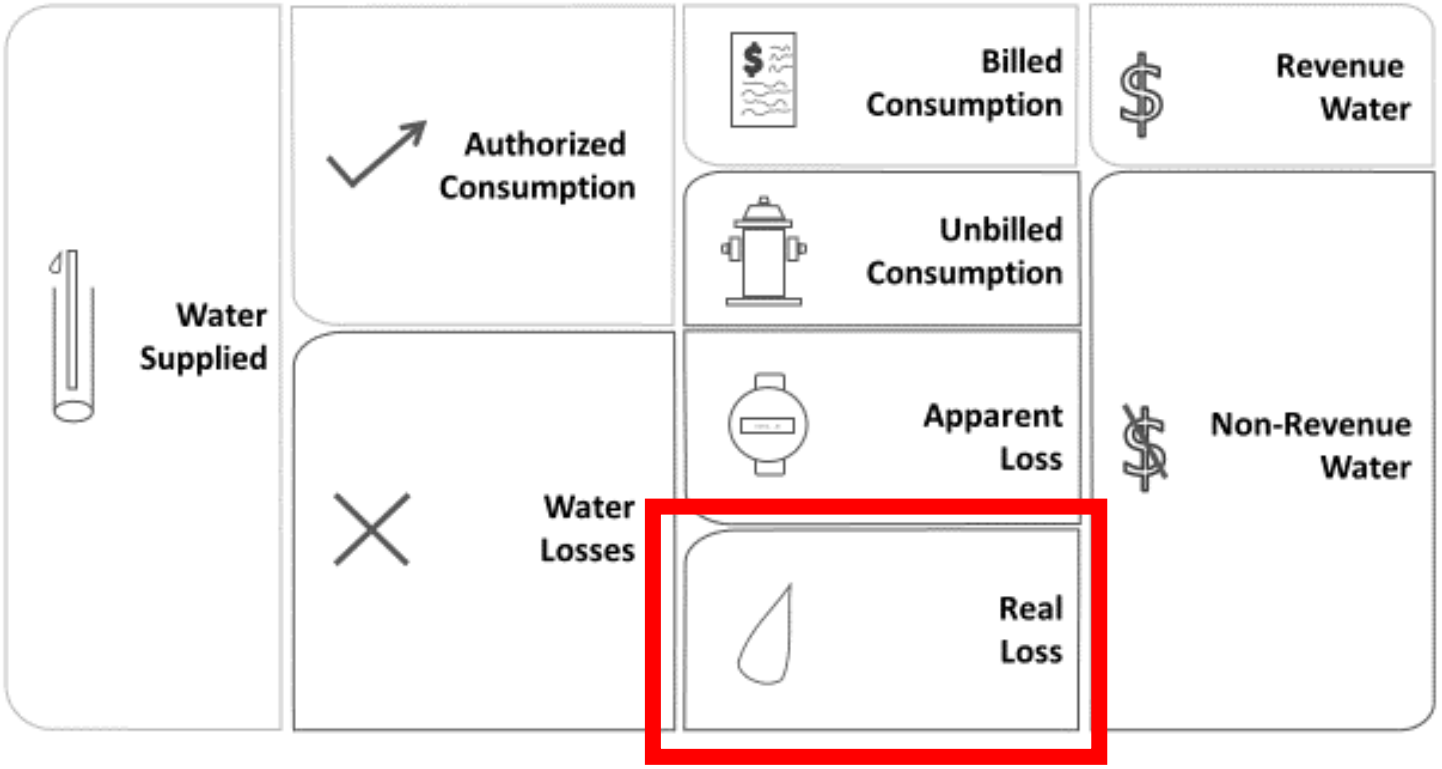


Customer Meter Accuracy Test

- Small and Large meters should have different testing strategies
  - Small meter test samples based on random sampling
  - Large meter test samples based on consumption volume (& revenue generation)
- Meters should be tested at low, medium, and high flow and test results weighted for averaging
- Add layer of consumption volume to calculate Apparent Losses due to meter inaccuracy
- Data request is at a minimum an inventory of customer meters – including age and throughput
  - Additional data may be requested depending on testing objectives

Advanced Validation Methods & Technical Assistance: Real Loss Component Analysis

Methods: AWWA Water Balance



Real Losses

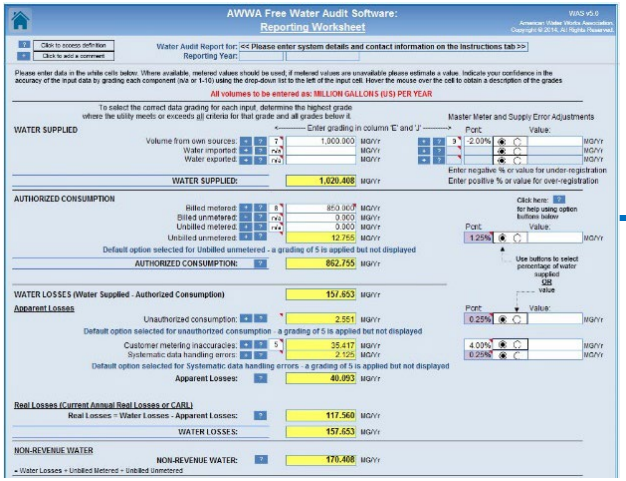
- Leaks from the water mains, valves, hydrants, service lines
- Leaks and overflows from water tanks

Why Component Analysis?

Different types of leakage should be addressed… Differently!

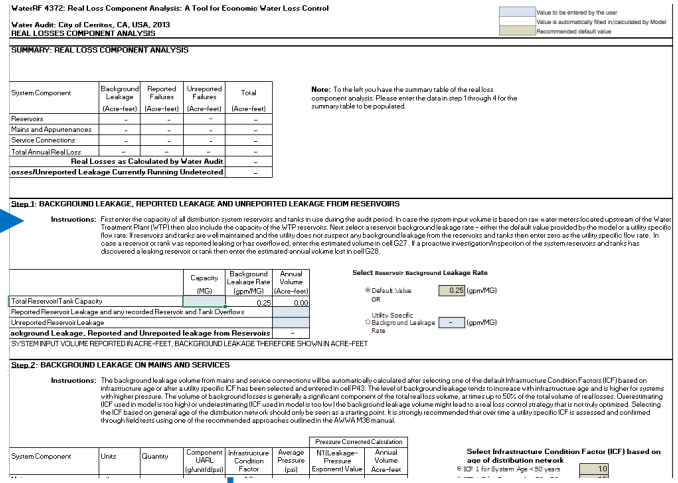
From Water Audit To Component Analysis

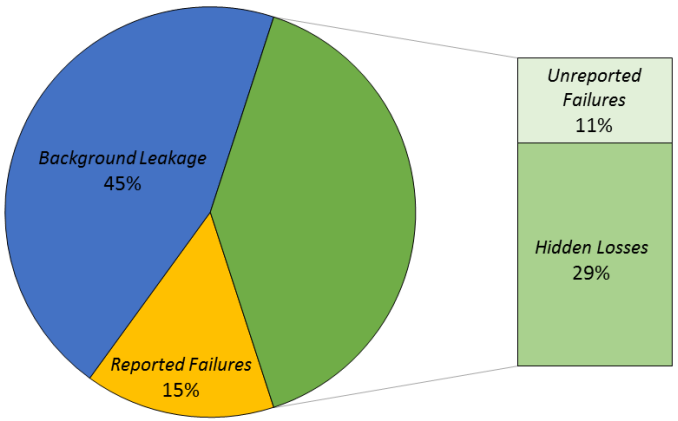
1 AWWA Audit Model



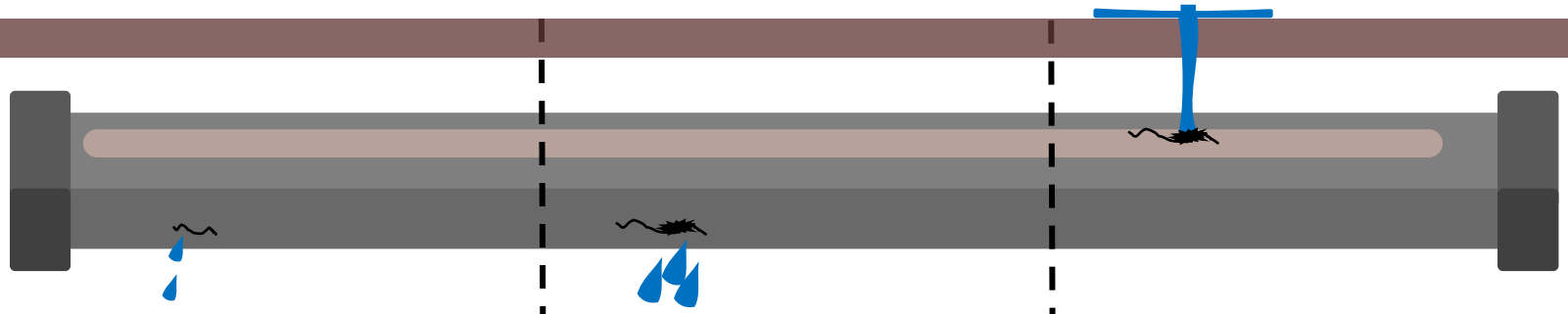
Total Real Losses

2 Component Analysis Model





Types of Real Losses



Background Leakage

Unreported and un-detectable using traditional acoustic equipment

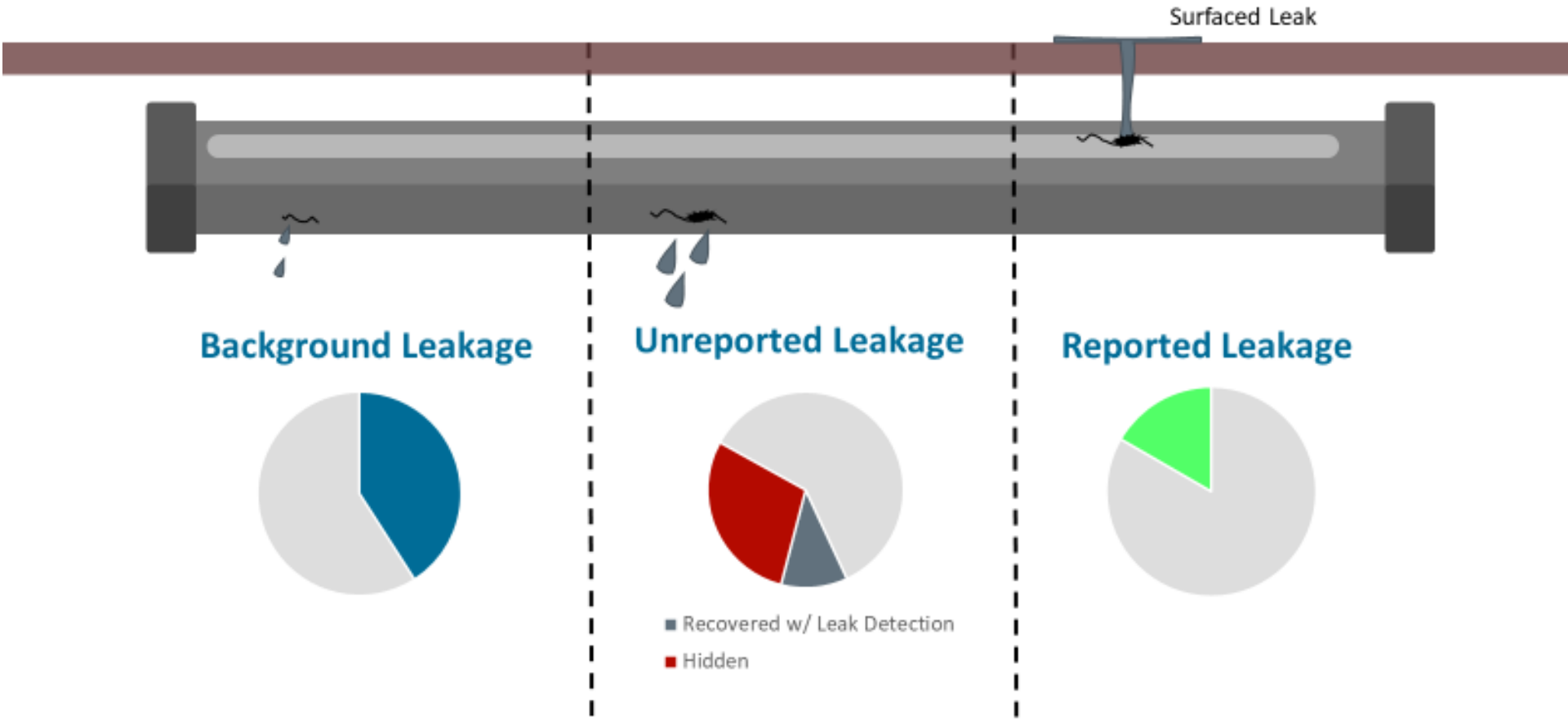
Unreported Leakage

Unreported and able to be detected using traditional acoustic equipment

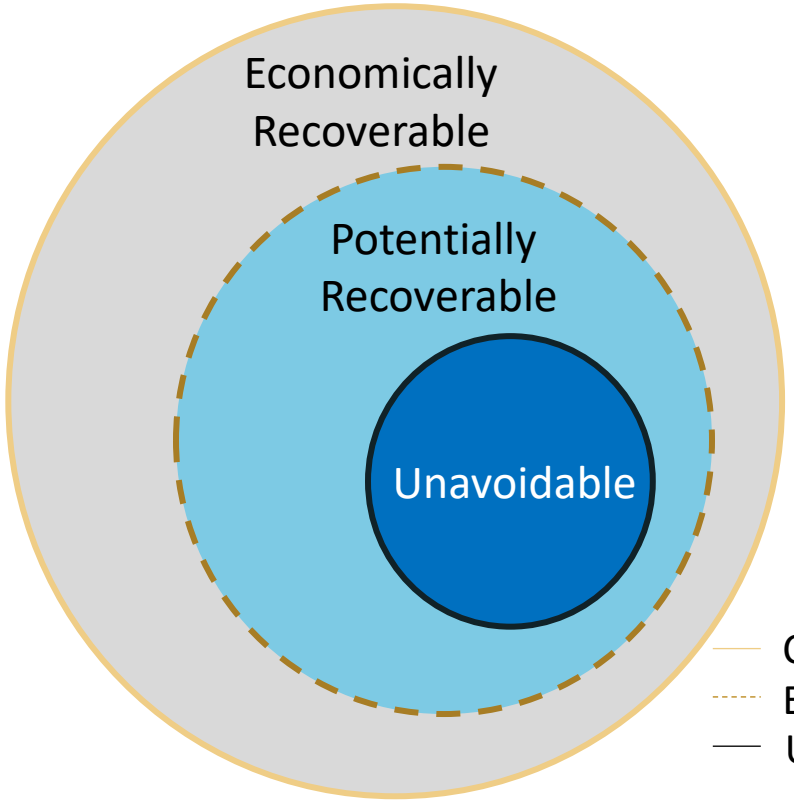
Reported Leakage

Surfaced and reported by public or utility staff

Types of Real Losses

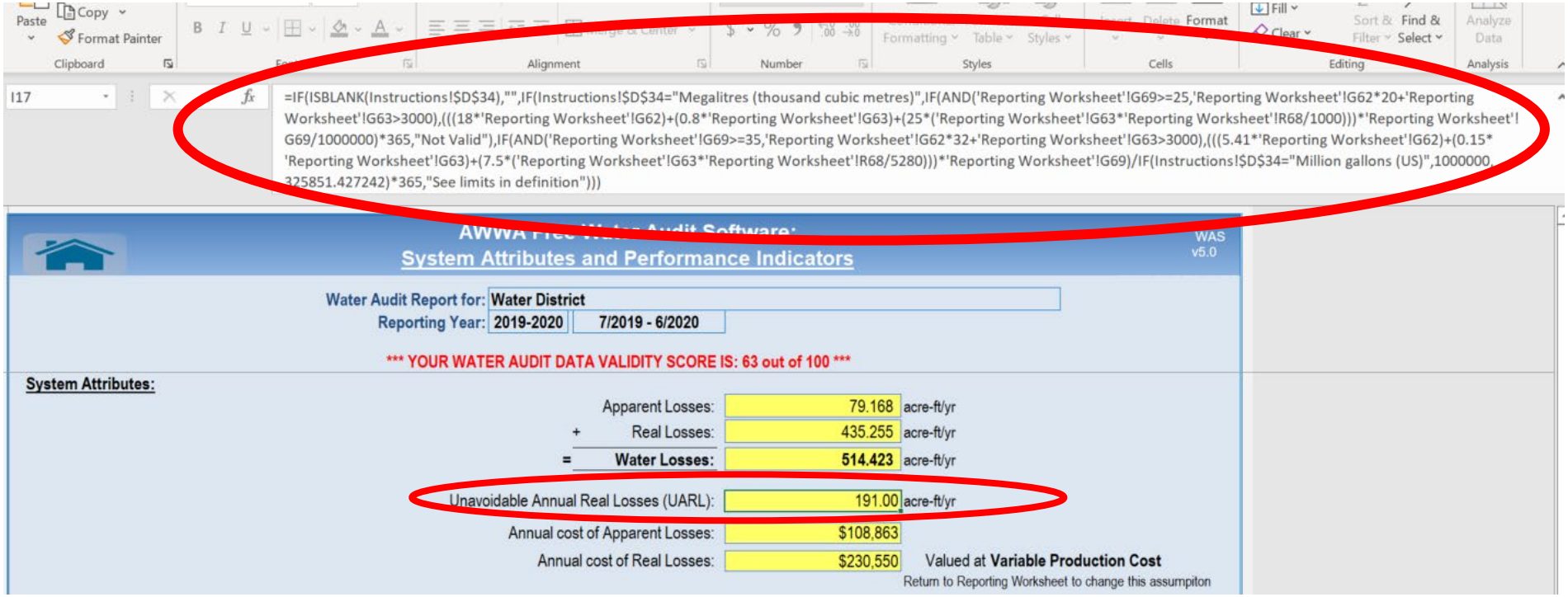


Recoverability of Real Losses



The AWWA audit software will model the **technical minimum** level of real loss based on system infrastructure data.

AWWA Technical Minimum Leakage



I17

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AWWA Free Water Audit Software: WAS v5.0

System Attributes and Performance Indicators

Water Audit Report for: Water District
Reporting Year: 2019-2020 7/2019 - 6/2020

*** YOUR WATER AUDIT DATA VALIDITY SCORE IS: 63 out of 100 ***

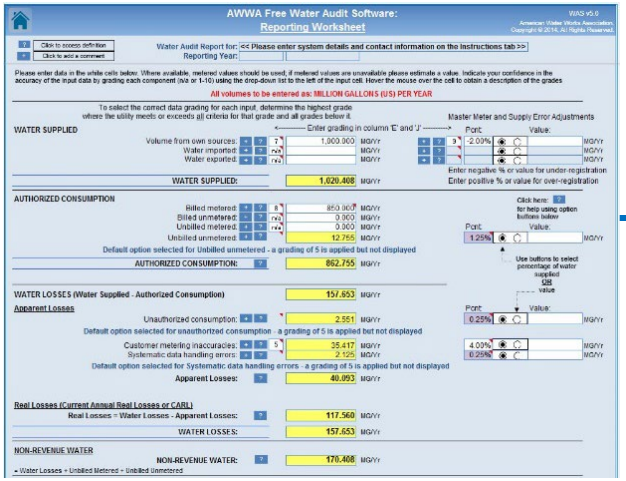
System Attributes:

	Apparent Losses:	79.168	acre-ft/yr
+	Real Losses:	435.255	acre-ft/yr
=	**Water Losses:**	**514.423**	acre-ft/yr
	Unavoidable Annual Real Losses (UARL):	191.00	acre-ft/yr
	Annual cost of Apparent Losses:	$108,863	
	Annual cost of Real Losses:	$230,550	Valued at **Variable Production Cost**

Return to Reporting Worksheet to change this assumpiton

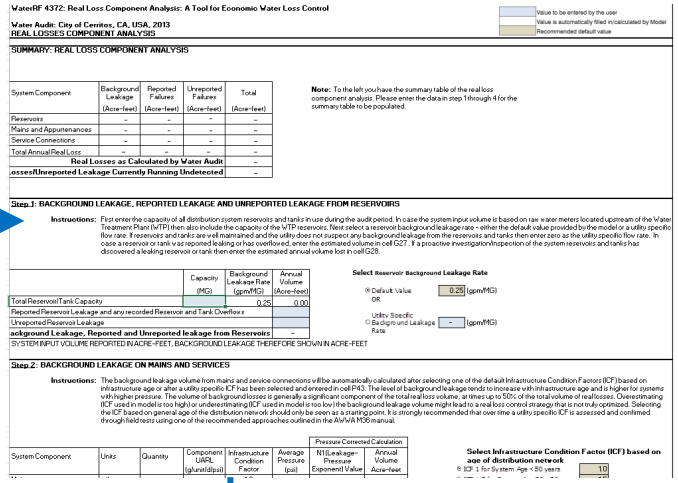
From Water Audit To Component Analysis

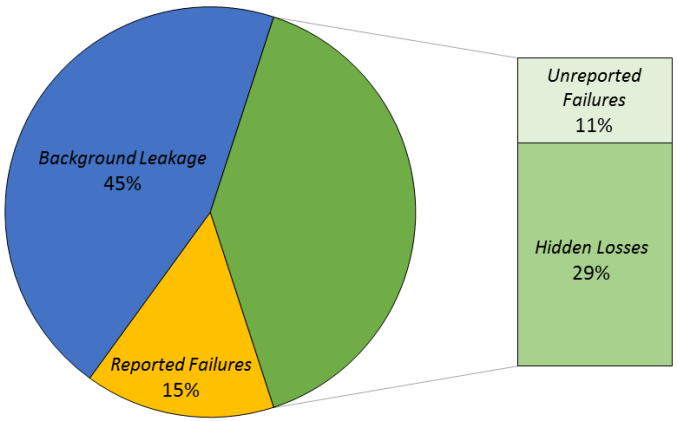
1 AWWA Audit Model



Total Real Losses

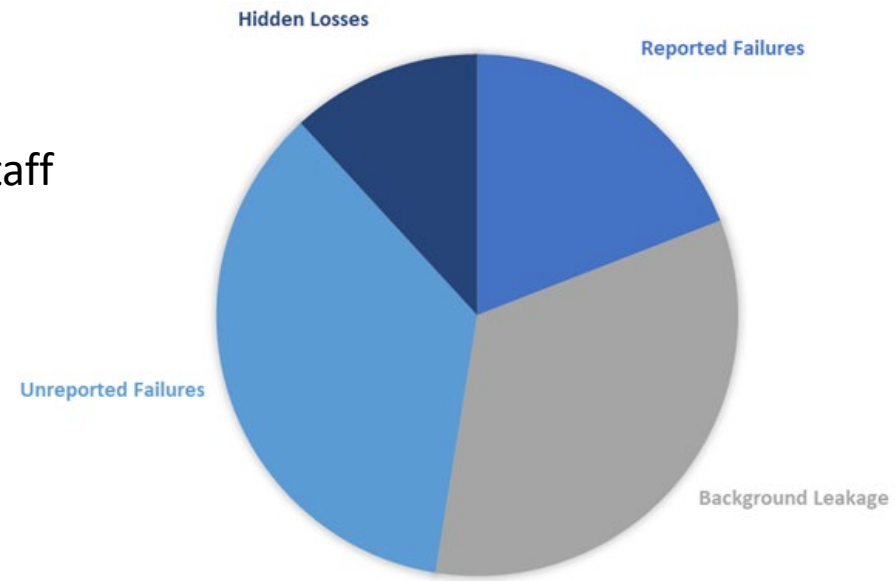
2 Component Analysis Model





Component Analysis Model - WRF 4372

- ***Background***
  - Modeled from Infrastructure Data
- ***Reported Failures***
  - Leaks called in by customers or utility staff
  - Noticeable without leak equipment
- ***Unreported Failures***
  - Discovered through leak detection
- ***Hidden Losses***
  - Difference between Audit results and known failure volume



Component Analysis Model - WRF 4372

WATER SUPPLIED		
WATER SUPPLIED:	3,600.000	Acre-feet/Yr
AUTHORIZED CONSUMPTION		
Billed Metered:	3,000.000	Acre-feet/Yr
Billed Unmetered:	-	Acre-feet/Yr
Unbilled Metered:	-	Acre-feet/Yr
Unbilled Unmetered:	10.000	Acre-feet/Yr
AUTHORIZED CONSUMPTION:	3,010.000	Acre-feet/Yr
WATER LOSSES:	590.000	Acre-feet/Yr
APPARENT LOSSES:	80.000	Acre-feet/Yr
REAL LOSSES:	510.000	Acre-feet/Yr
NON REVENUE WATER:	600.000	Acre-feet/Yr
SYSTEM DATA		
Length of mains:	150.0	miles
Number of active AND inactive service connections:	9,000	service connections
Service connection density:	60.0	conn./mile main
Average length of customer service line*:	-	feet
Average operating pressure:	80.0	PSI
	*Note: pipe length between curb stop and customer meter or point of first use fo	
COST DATA	metered service connections	

Component Analysis Model - WRF 4372

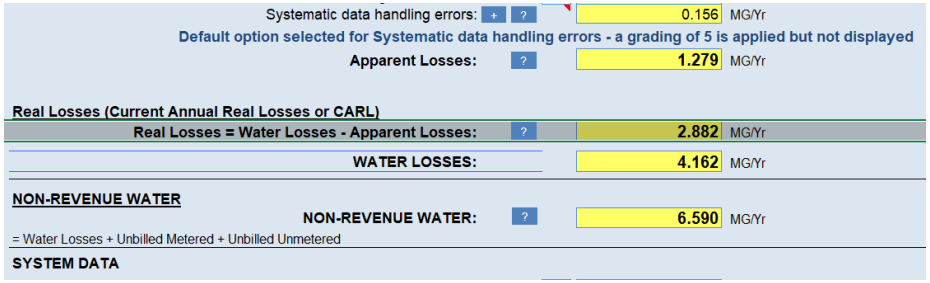
Mains by Size	Number of Leaks & Failures per Year	Length of Main (miles)	Failure Frequency (number / 100miles / yr)	Average Failure Flow Rate @ 70psi (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration			Average Annual Loss per Failure (MG)	Total Annual Loss (MG)
							Average Awareness Duration (days)	Average Duration for Location and Repair/Shutoff Failure (days)	Total Duration (days)		
Diameter 2"	4	17.0	24	13.90	66.0	1.00	2.00	4.00	6.00	0.11	0.45
Diameter 3"	8	38.0	21	13.90	66.0	1.00	2.00	6.00	8.00	0.15	1.21
Diameter 4"	4	61.0	7	44.00	66.0	1.00	1.00	6.00	7.00	0.42	1.67
Diameter 6"	14	52.0	27	92.00	66.0	1.00	1.00	10.00	11.00	1.37	19.24
Diameter 8"	3	2.0	150	92.00	66.0	1.00	0.50	6.00	6.50	0.81	2.44
Diameter 10"				92.00	66.0	1.00					

System Appurtenances by Type	Number of Failures per Year	Total Number of Appurtenances	Failure Frequency Number of Failures per 1000 Appurtenances	Average Failure Flow Rate @ 70psi (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration			Average Annual Loss per Failure Acre-feet	Total Annual Loss Acre-feet
							Average Awareness Duration (days)	Average Duration for Location and Repair/Shutoff Failure (days)	Total Duration (days)		
Hydrants	4	200	20	3.50	80.0	1.00	10.00	5.00	15.00	0.27	1.06
Valves	5	1,000	5	6.90	80.0	1.00	15.00	10.00	25.00	0.87	4.36
Meters	8	10,000	1	0.25	80.0	1.00	25.00	20.00	45.00	0.06	0.45
Other (e.g. Blow-offs, etc.)	-	-	-	-	80.0	1.00	-	-	-	-	-
									SUB-TOTAL REPORTED LEAKS ON SYSTEM APPURTENANCES		**5.87**

Component Analysis Model - WRF 4372

Data Required:

- Real Losses from Water Audit
- System Infrastructure Data
- Detailed Leak Repair Information



Systematic data handling errors: + ?	0.156	MG/Yr
Default option selected for Systematic data handling errors - a grading of 5 is applied but not displayed		
Apparent Losses: ?	1.279	MG/Yr
Real Losses (Current Annual Real Losses or CARL)		
Real Losses = Water Losses - Apparent Losses: ?	2.882	MG/Yr
WATER LOSSES:	4.162	MG/Yr
NON-REVENUE WATER		
NON-REVENUE WATER: ?	6.590	MG/Yr
= Water Losses + Unbilled Metered + Unbilled Unmetered		
SYSTEM DATA		

Mains by Size	Number of Leaks & Failures per Year	Length of Main miles	Failure Frequency (number / 100miles / yr)	Average Failure Flow Rate @ 70psi (gpm)	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration			Average Annual Loss per Failure (MG)	Total Annual Loss (MG)
							Average Awareness Duration (days)	Average Duration for Location and Repair/Shutoff Failure (days)	Total Duration (days)		
Diameter 2"	4	17.0	24	13.90	66.0	1.00	2.00	4.00	6.00	0.11	0.45
Diameter 3"	8	38.0	21	13.90	66.0	1.00	2.00	6.00	8.00	0.15	1.21
Diameter 4"	4	61.0	7	44.00	66.0	1.00	1.00	6.00	7.00	0.42	1.67
Diameter 6"	14	52.0	27	92.00	66.0	1.00	1.00	10.00	11.00	1.37	19.24
Diameter 8"	3	2.0	150	92.00	66.0	1.00	0.50	6.00	6.50	0.81	2.44
Diameter 10"				92.00	66.0	1.00					

Component Analysis Model - WRF 4372

		Unique ID# for failure or work order
Minimum Required Information	Failure Event Type	*Reported - from complaints* *Unreported - from proactive leak detection*
	Service Connection Ownership Where Service Leak Occurred	*Utility Maintained Section* *Customer Maintained Section*
	General Location of Failure Event	*For Example - House Address*
	Size Information	*Service Connection Size*
	Failure Event Reported	*Date*
		Time
	Failure Event Pinpointed	*Date*
		Time
	Failure Event Contained/Valve-off/Repaired	*Date*
		Time

Component Analysis Model - WRF 4372

WaterRF 4372: Real Loss Component Analysis: A Tool for Economic Water Loss Cont

REAL LOSSES COMPONENT ANALYSIS

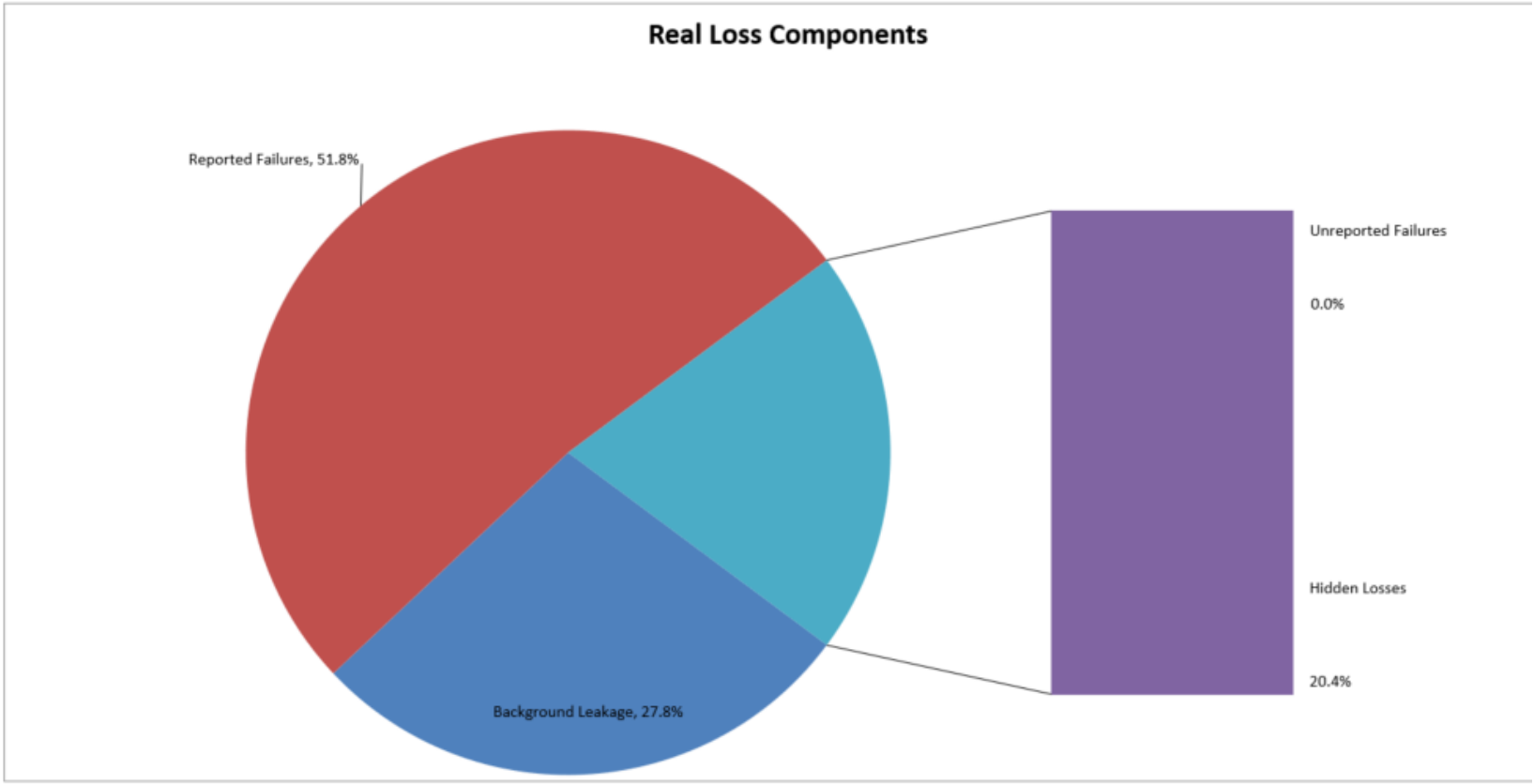
SUMMARY: REAL LOSS COMPONENT ANALYSIS

System Component	Background Leakage (Acre-feet)	Reported Failures (Acre-feet)	Unreported Failures (Acre-feet)	Total (Acre-feet)
Reservoirs	4.03	-	-	**4.03**
Mains and Appurtenances	41.24	238.19	-	**279.44**
Service Connections	96.56	26.14	-	**122.70**
Total Annual Real Loss	**141.84**	**264.33**	**-**	**406.17**
Real Losses as Calculated by Water Audit				**510.00**
Hidden Losses/Unreported Leakage Currently Running Undetected				**103.83**

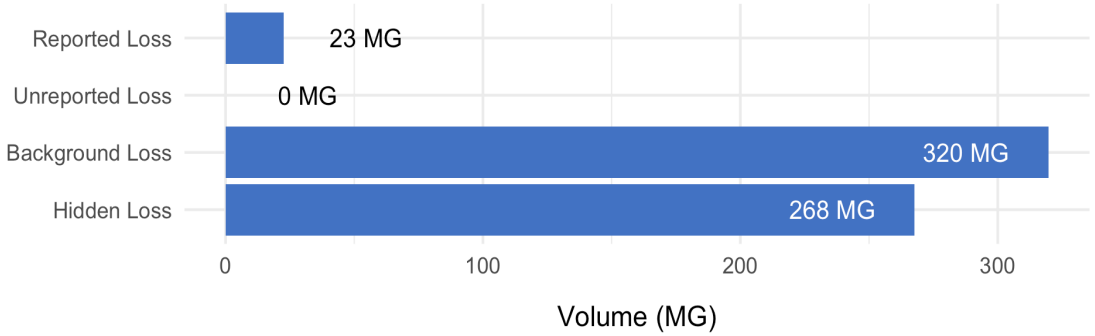
Component Analysis Model - WRF 4372

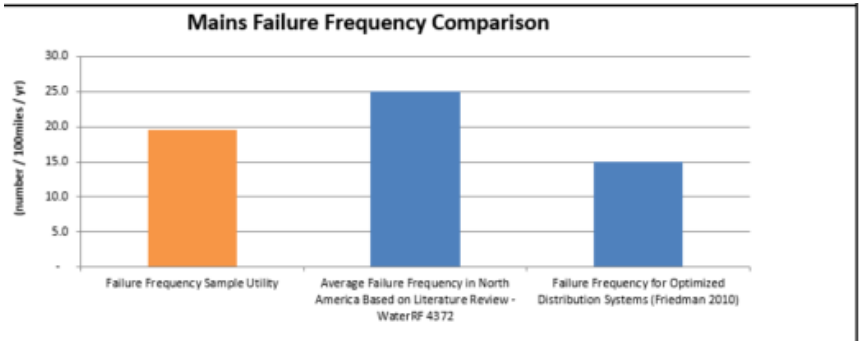
WaterRF 4372: Real Loss Component Analysis: A Tool for Economic Water Loss Control

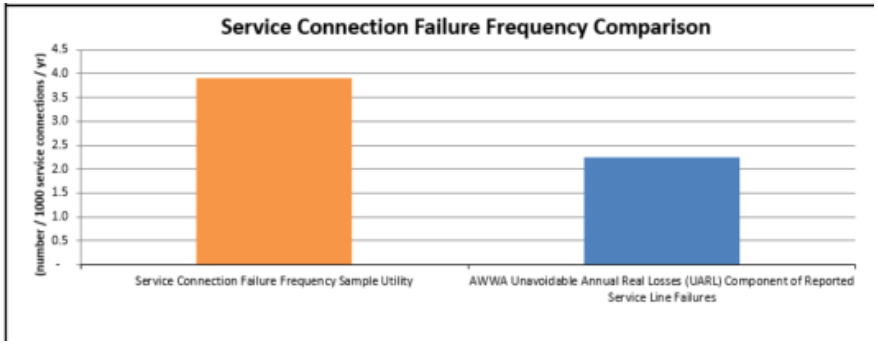
REAL LOSSES COMPONENTS CHART



Component Analysis Model - WRF 4372

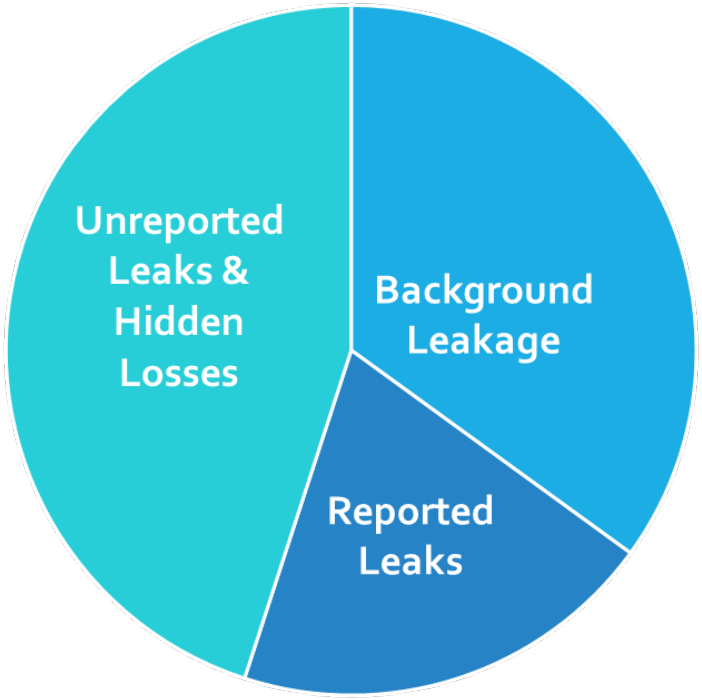




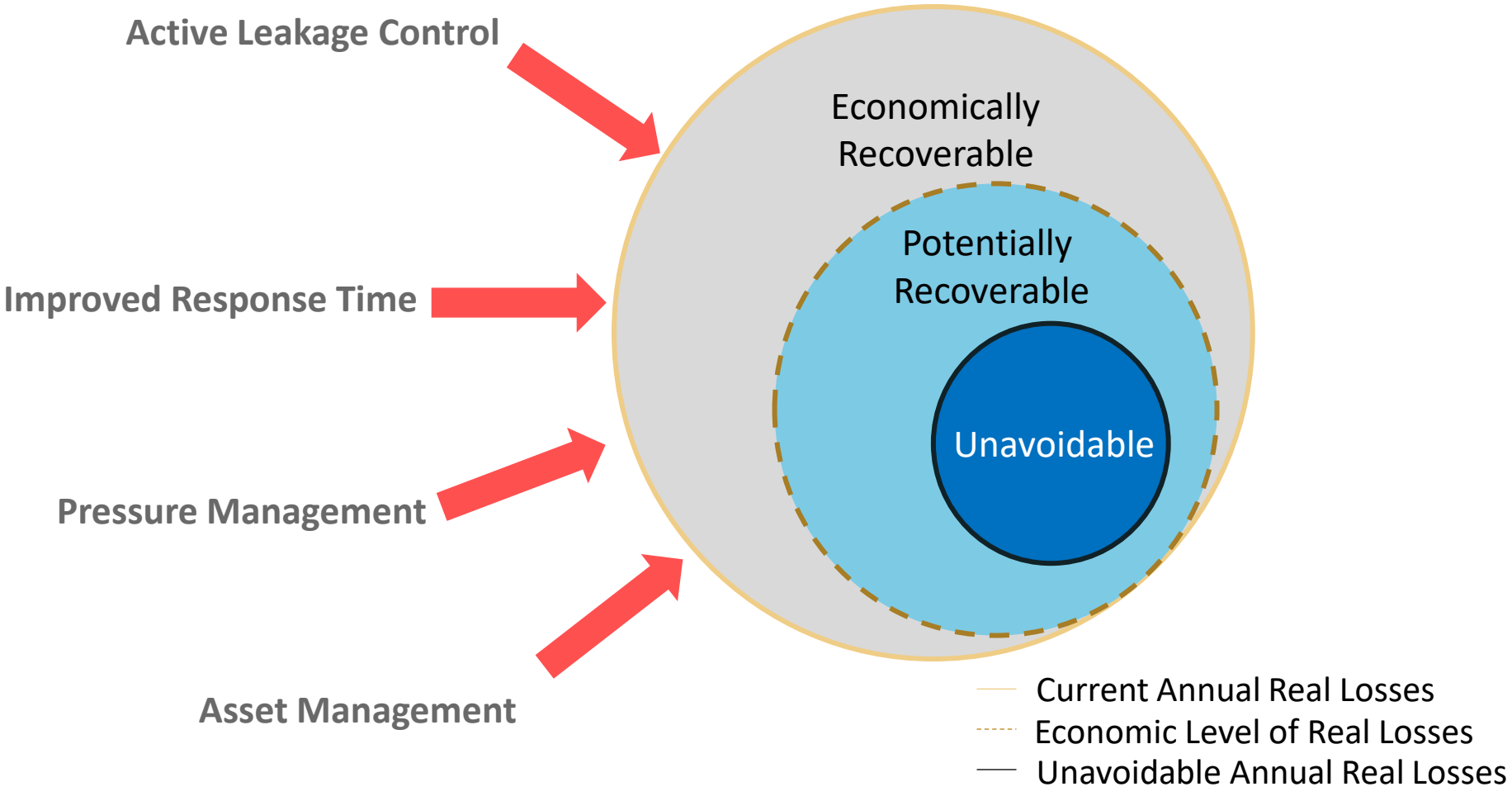


Managing Real Losses

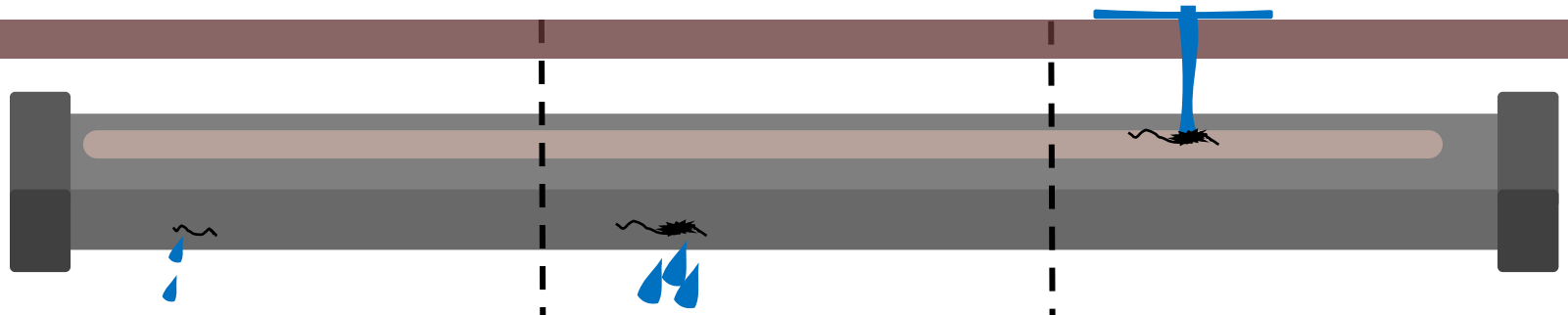
- Based on types of leakage in the system
- Based on value of recoverable leakage
- Based on cost of leakage reduction interventions
- Determine implementation strategy



Intervention Strategies



Managing Real Losses



Background Leakage

- Pressure management
- Main & service replacement
- Reduce # of joints and fittings

Unreported Leakage

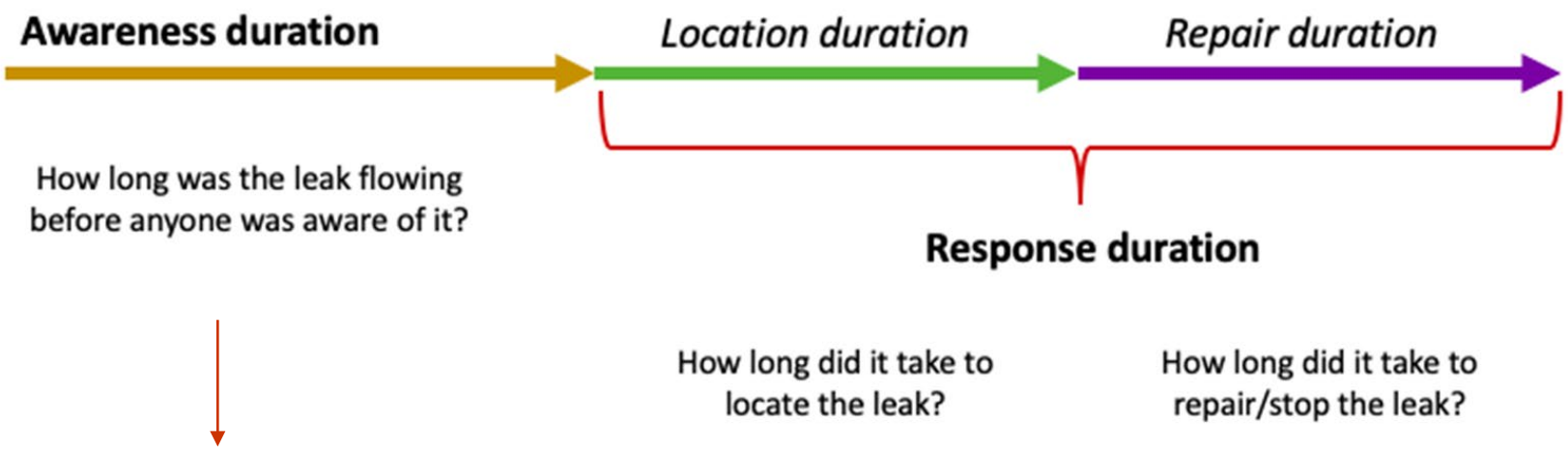
- Pressure management
- Main & service replacement
- Reduce # of joints and fittings
- Proactive leakage program
- Optimized repair time

Reported Leakage

- Pressure management
- Main & service replacement
- Optimized repair time

Managing Real Losses

Improved Response Time



Can be improved with active leakage control

Component Analysis Model - WRF 4372

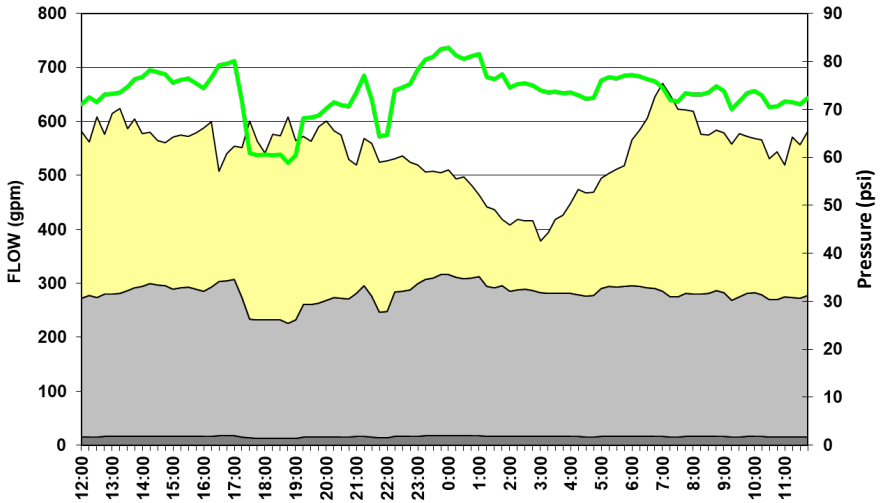
Improved Response Time

Reported and Unreported Failure Events			
Failures on Mains	***Reported***	***Unreported***	
Total Failures on Mains	25	-	
Average location and repair duration	10.0	-	days
Total Volume lost (stemming from location and repair duration)	116.2	-	Acre-feet
Total Cost of Volume lost (stemming from location and repair duration)	$ 58,081	$ -	
What IF Location and Repair Duration is Reduced to	5		days
Percent Reduction	50%	0%	
Potential Related Savings in Leakage Volume	58.1	-	Acre-feet
Potential Related Savings in Leakage Volume Cost	$ 29,040	$ -	
Service Line Failures	***Reported***	***Unreported***	
Total Number of Failures on Service Connections	30	-	
Average location and repair duration	10.0	-	days
Total Volume lost (stemming from location and repair duration)	10.5	-	Acre-feet
Total Cost of Volume lost (stemming from location and repair duration)	$ 5,227	$ -	
What IF Location and Repair Duration is Reduced to	5		days
Percent Reduction	50%	0%	
Potential Related Savings in Leakage Volume	5.2	-	Acre-feet
Potential Related Savings in Leakage Volume Cost	$ 2,614	$ -	
Failures on System Appurtenances	***Reported***	***Unreported***	
Total Number of Failures on System Appurtenances	17	-	
Average location and repair duration	13.5	-	days
Total Volume lost (stemming from location and repair duration)	2.3	-	Acre-feet
Total Cost of Volume lost (stemming from location and repair duration)	$ 1,149	$ -	

Managing Real Losses

Active Leakage Control

- Proactive Leak Detection
- Leak Noise Loggers
- DMA Measurements



Component Analysis Model - WRF 4372

Active Leakage Control

	Variable Cost of Real Losses		
CV	Variable Production cost (applied to Real Losses):	1.53	$/per kgal
		500.00	$/Acre-ft
CI	Cost of comprehensive leak detection survey (excluding leak repair cost)	300.00	$/per mile
		45,000	$/for entire system
RR	Average Rate of Rise of Unreported Leakage	0.30	kgal/mile of mains/day in a year
		0.14	AF/day in a year
	CI/CV	195.5	kgal/mile
EIF	Economic Intervention Frequency [0.789 * (CI/CV)/RR] ^0.5	22.7	months
		689.7	days
	Economic Intervention Frequency - Average Leak Run Time	344.9	days
	Economic Percentage of System to be Surveyed per Year	53	%
ABI	Average Annual Budget for Intervention (Proactive Leak Detection)	23,814	$/year
EUL	Economic Unreported Real Losses	15,520	kgal/year
		47.6	AF/year
	Economic Infrastructure Leakage Index (ILI)	2.6	

Managing Real Losses

Pressure Management

Managing Real Losses

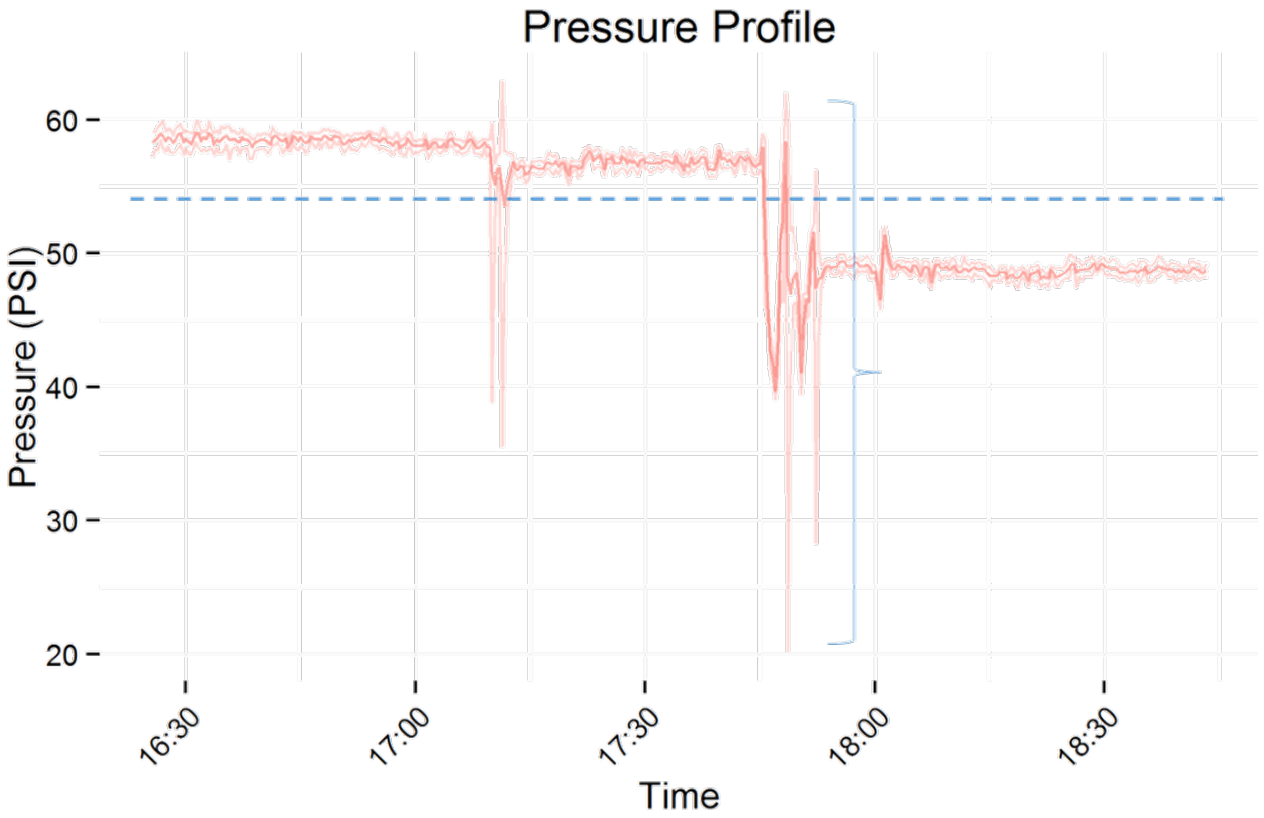
Pressure Management

Managing Real Losses

Pressure Management

Managing Real Losses

Pressure Management



Component Analysis Model - WRF 4372

Pressure Management

Pressure Management Opportunities

	Existing Pressure Management Policy	
Current Average System Pressure	80.0	PSI
Total Annual Real Losses	510.0	Acre-feet/Yr
Value of Real Losses	255,000	$/year

FAVAD N1 Value Used for Calculation of Real Loss Reduction Due to Reduction of Average System Pressure

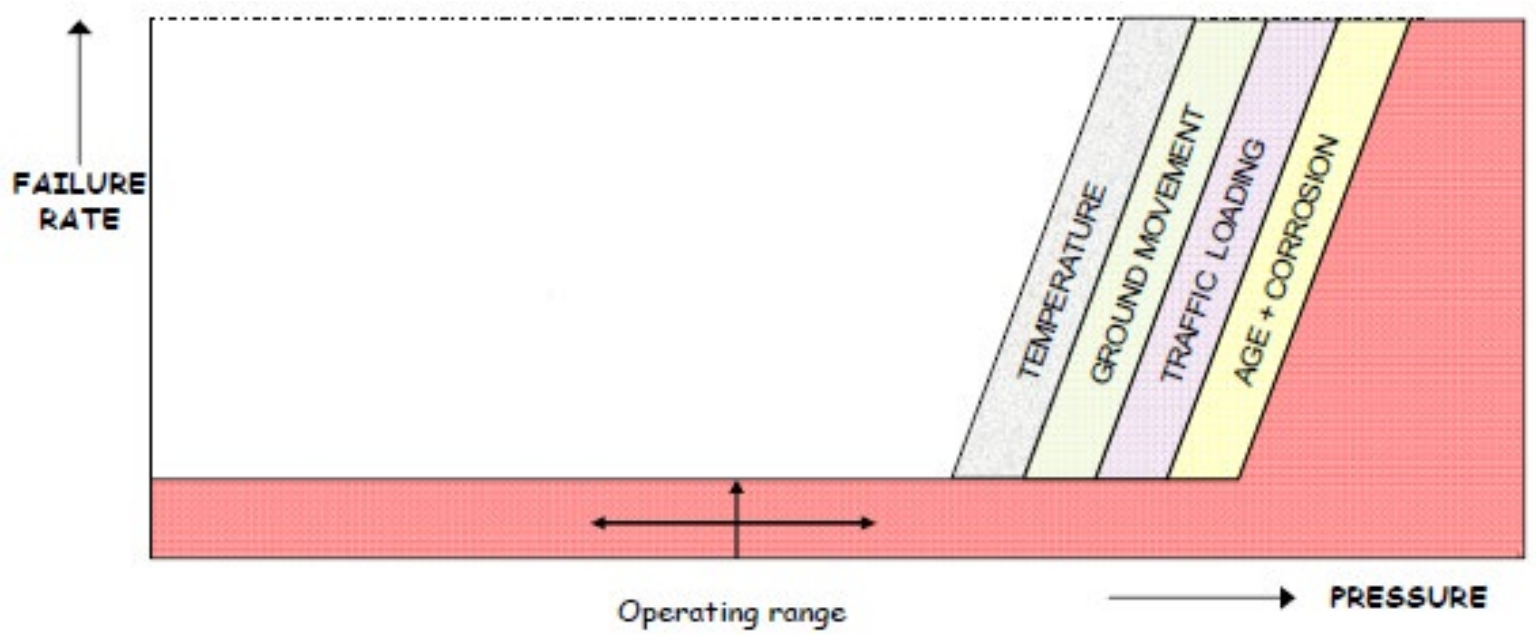
	○ Use Default N1	1.0
	◉ Use System Specific N1	1.2
Enter % of rigid pipes and service connections in system	40%	
ILI	2.6	

	Alternative Pressure Management Policy	
Assumed Reduction in Average System Pressure	5.0	PSI
Assumed % Reduction in Average System Pressure	6%	
Real Loss Volume Saved Through Alternative Pressure Management Policy	38.0	Acre-feet/Yr
Value of Real Loss Volume Saved Through Alternative Pressure Management Policy	18,984	$/Year
Enter Estimated Cost of Implementing Alternative Pressure Management Policy	20,000	$
Simple Payback Period for Implementing Alternative Pressure Management Policy	1.1	Years

Managing Real Losses

Asset Management

- Create Inventory by Age, Size, Material, Etc.
- Failure Rates Affected by Multiple Factors



Source: Lambert, A. 2013 "Relationships between pressure, bursts and infrastructure life"

Real Loss Program Development

Calculate Water Losses

- AWWA Water Audit Model
- Real Losses v. Apparent Losses

Breakdown Leakage Volumes

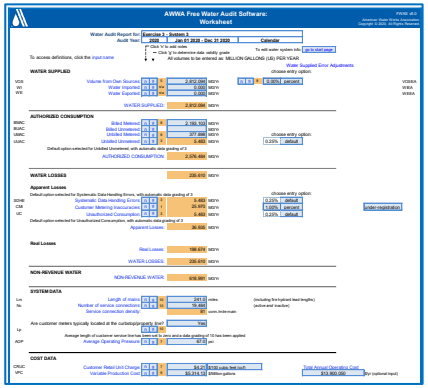
- Background
- Reported
- Hidden
- Unreported

Economic Analysis

- Value Lost Water
- Evaluate Cost of Intervention

Implement Interventions

- Leak Detection
- Pressure Management
- Repair Time
- Infrastructure Management



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Failures on System Appurtenances	*Reported*	*Unreported*	
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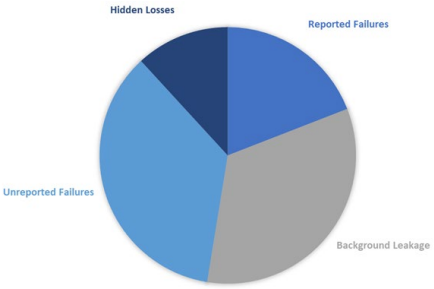


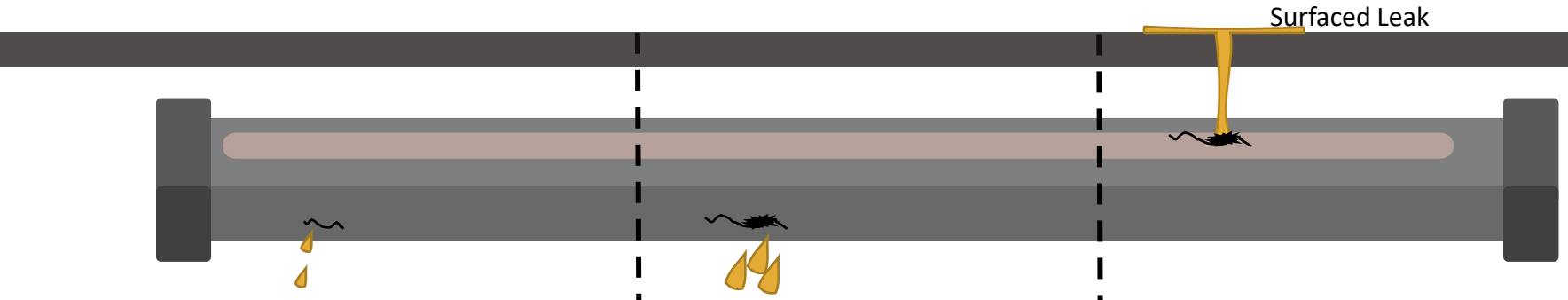
Data Request for Component Analysis

- Completed Water Audit Software
- Reported Leak Repair Data
- Unreported Leak Repair Data
- Additional Infrastructure Data (# Valves, hydrants, etc)

		Unique ID# for failure or work order
Minimum Required Information	Failure Event Type	*Reported - from complaints* *Unreported - from proactive leak detection*
	Service Connection Ownership Where Service Leak Occurred	*Utility Maintained Section* *Customer Maintained Section*
	General Location of Failure Event	*For Example - House Address*
	Size Information	*Service Connection Size*
	Failure Event Reported	*Date*
		Time
	Failure Event Pinpointed	*Date*
		Time
	Failure Event Contained/Valve-off/Repaired	*Date*
		Time

Advanced Validation Methods & Technical Assistance: Leak Detection Survey

Types of Real Losses & Intervention Strategies



Background Leakage

- Pressure reduction
- Main & service replacement
- Reduce # of joints and fittings

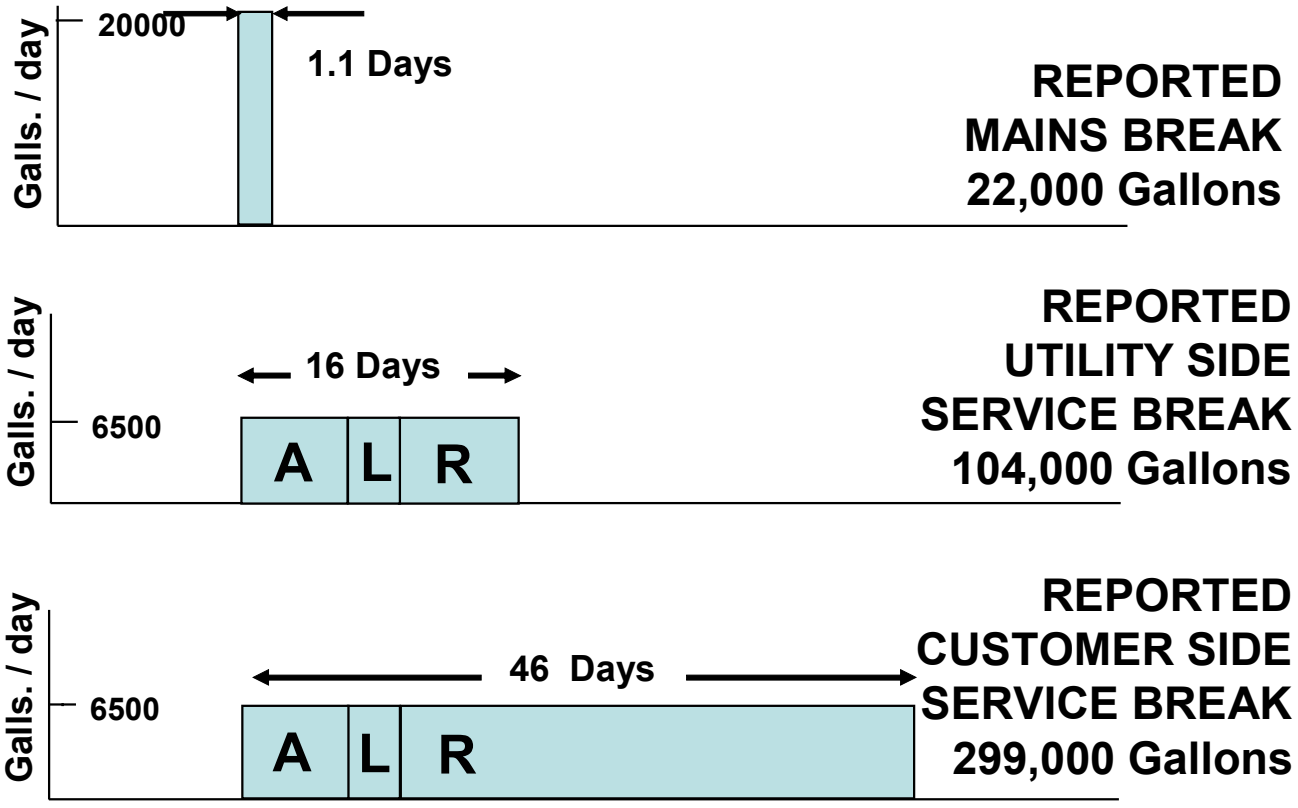
Unreported Leakage

- Pressure reduction
- Main & service replacement
- Reduce # of joints and fittings
- Proactive leak detection

Reported Leakage

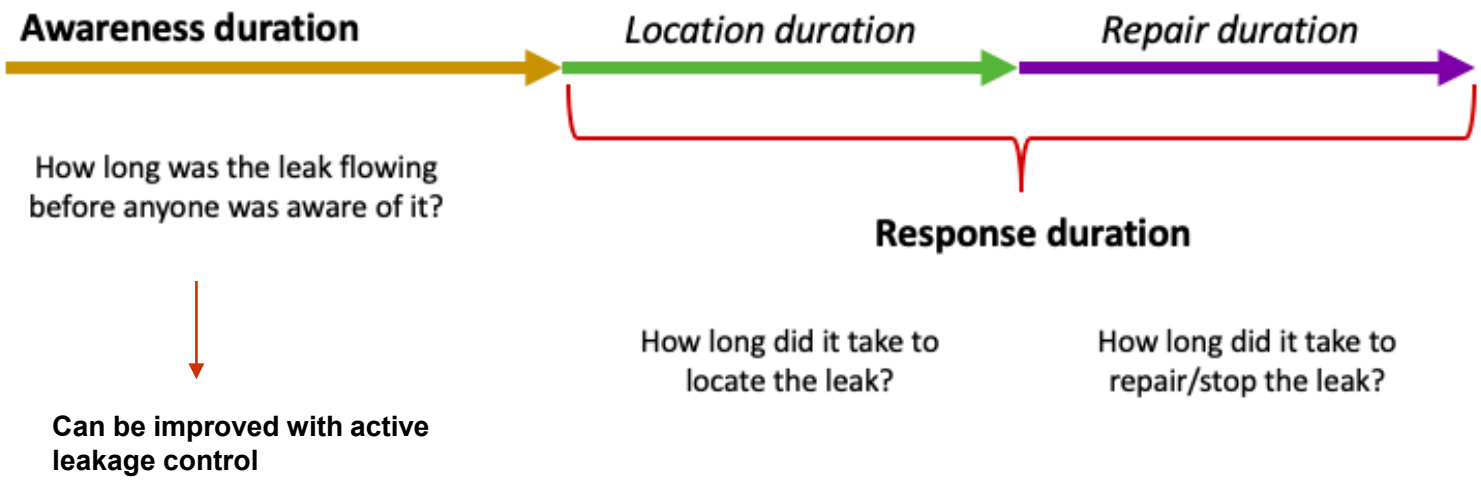
- Pressure reduction
- Main & service replacement
- Optimized repair time

The Impact of Leak Run Times



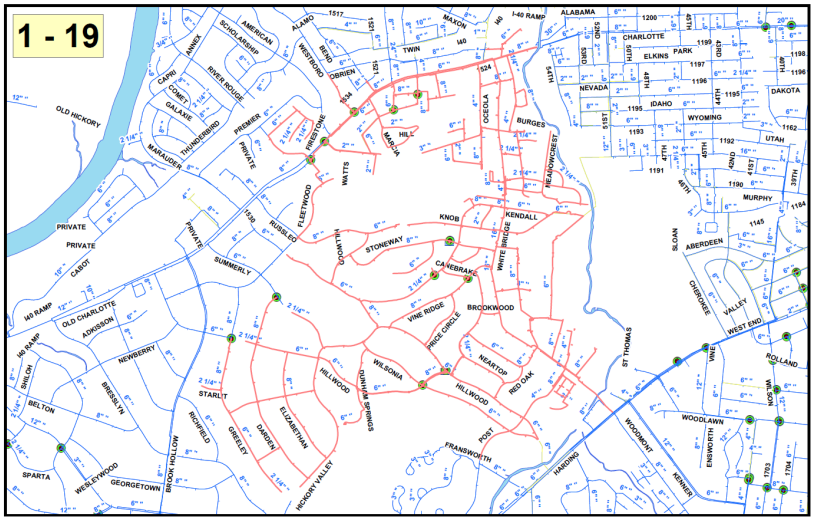
Real Loss Management Strategies

Improved Response Time



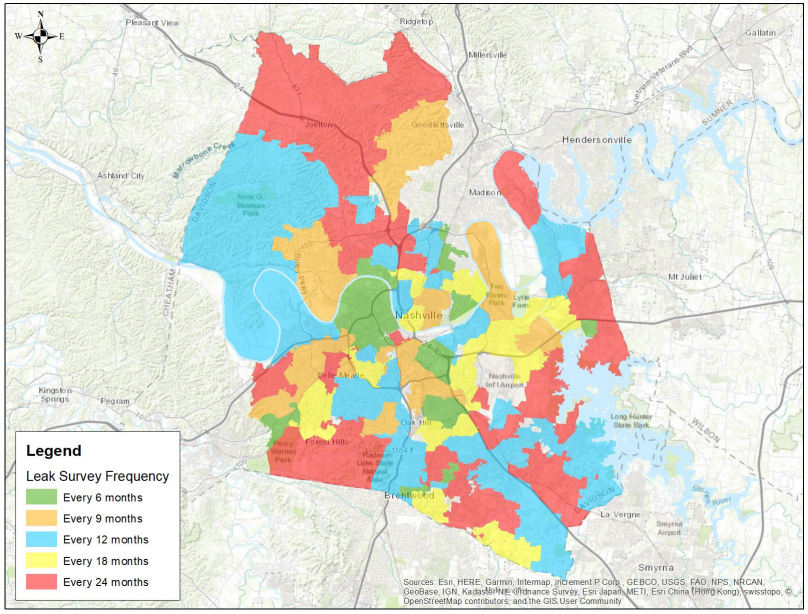
Leak Survey

- Type of field investigation that uses specialized acoustic equipment to survey the water distribution system to locate non-surfacing leaks
- Select a portion or whole distribution system to check for leaks
  - Where to survey
  - How frequently
- During the survey, technicians listen to meters, service connections, hydrants, and valves throughout the water distribution system
- Depending on the complexity, other equipment or technologies may be employed to confirm and pinpoint the leak



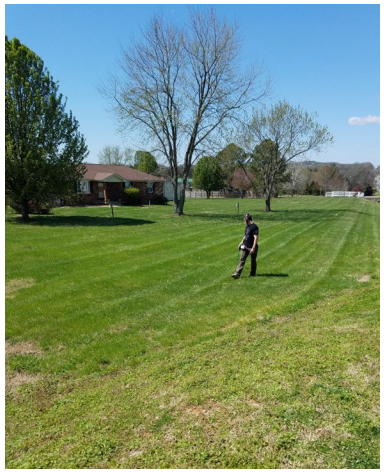
Leak Survey

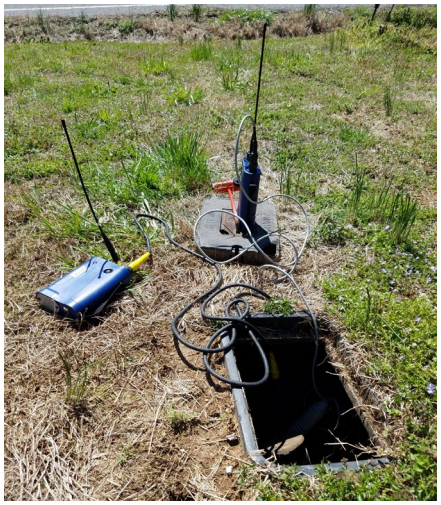
- Where to survey
  - If first survey, select areas based on operational knowledge:
    - Reported leak events
    - Older parts of the system
    - Low pressure reports
    - Unexplained bodies of water
    - Questionable contractor work
  - If previous surveys have been conducted
    - Areas not previously surveyed
    - Analysis of previous leak surveys
- How frequently
    - Depends on system condition and economics – costs of water lost and costs of intervention
    - Perform a component analysis of real losses
    - Analysis of results from leak surveys



Acoustic Leak Detection

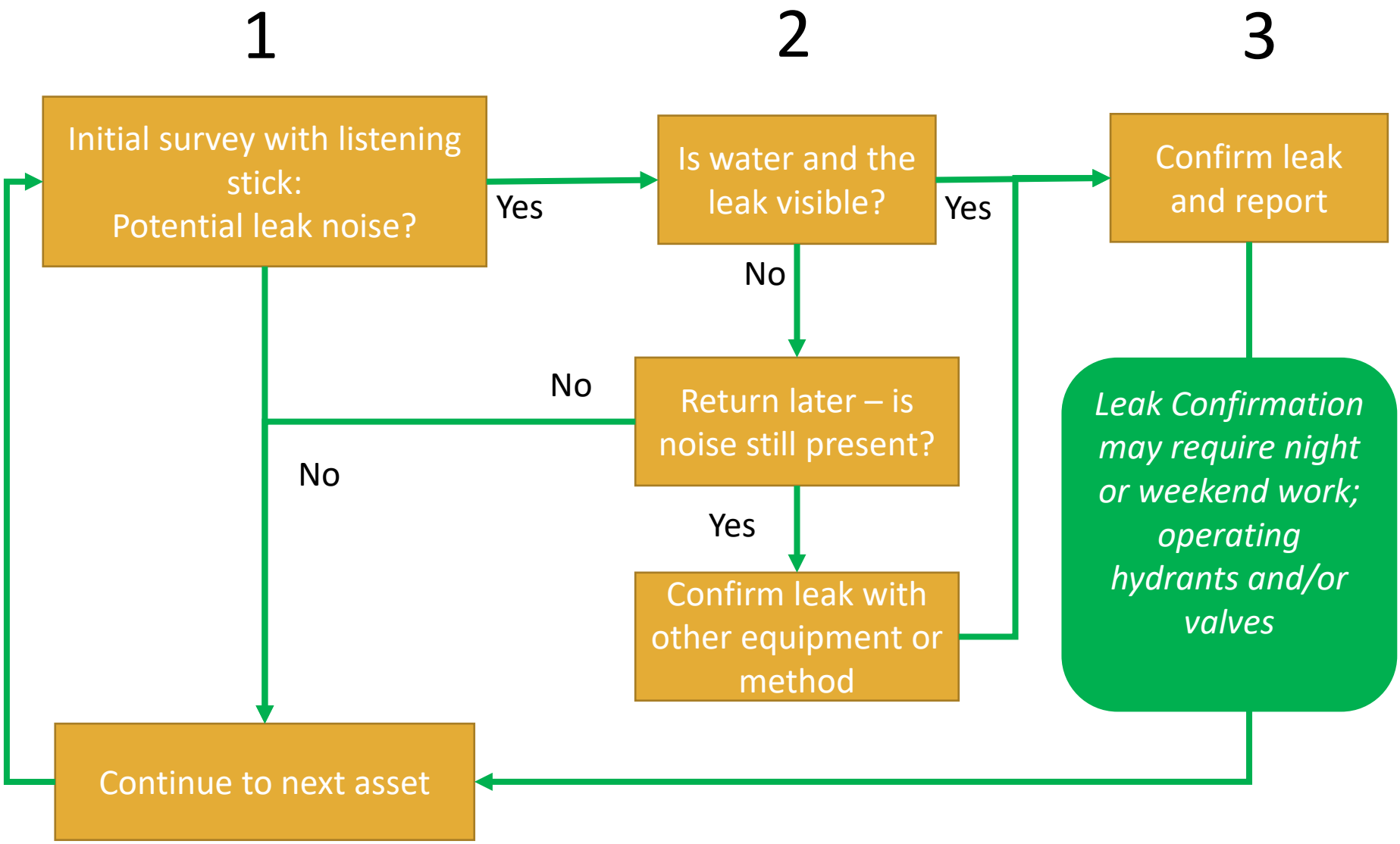
- Walking survey with listening device
  - Listening Stick
  - Geophone
  - Electronic Sounding Instrument
- Leak noise correlators & hydrophones
- Noise loggers
- Line locators
- Metal detectors





- Leak Sound Characteristics:
  - Pipe Wall – higher frequency, shorter travel
  - “Escaping” Water – lower frequency, travels farther
  - Impact – lower frequency, water impacting cavity walls and rocks circulating in cavity
  - Continuous – leak sound is continuous unlike transient ambient noises
- Factors Affecting Leak Sound:
  - System Pressure
  - Pipe Material & Size
  - Background Noise
  - Type Of Leak
  - Surface Covering Pipes

- Sources Of Interference
  - Traffic & Other Equipment Noise
  - Variation of Soil Moisture & Water Table
  - Variation of Surface Materials
  - Variation of Depth
  - Variation of Soil Properties
  - Variation in Pipe Bedding Materials
  - Low Pressure in Pipe
  - Radio Frequency Interference
- Non-Leak Sound Sources ("False Positives"):
  - Gas lines
  - Repair couplings
  - PRVs
  - Force mains
  - Consumption
  - Meter noise
  - Partially closed or broken valves
  - Active blow-offs


1
2
3
Initial survey with listening stick:
Potential leak noise?
Yes
Is water and the leak visible?
Yes
Confirm leak and report
No
No
Return later – is noise still present?
No
Yes
Confirm leak with other equipment or method
Leak Confirmation may require night or weekend work; operating hydrants and/or valves
Continue to next asset

- Methods to verify leaks
  - Visible water
  - Chlorine test
  - Shut-off water service (for leaks suspected on service line or customer meter)
  - Operating hydrants or valves
  - Leak noise correlation
  - Excavation
- We make every effort possible to find the exact location of the leak. However, unknow conditions underground may cause the leak to appear to be some distance from the real location. Marked leak locations may have a margin of error of 5-8 feet.
- If during the excavation, the utility is having trouble locating a reported leak, WSO technicians can assist during the excavation

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

Colorado Water Loss Initiative

Office 615.451.3922 Office: 615.457.5790

LEAK REPORT

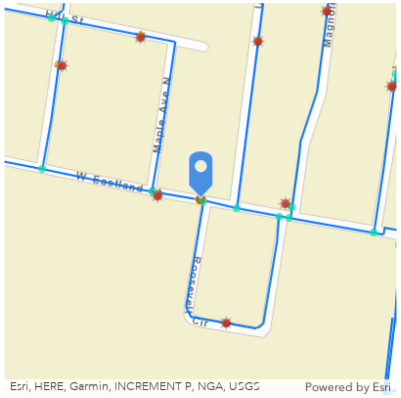
Date: October 15, 2021 **Report #: 51**

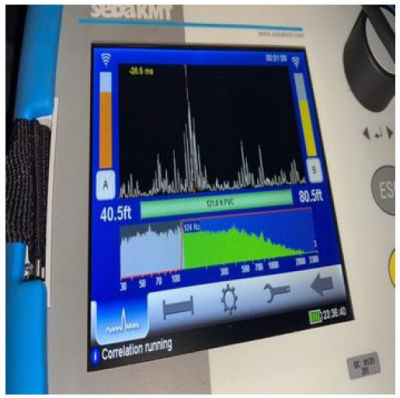
Survey ☑ Recheck ☐ Location Error ☐ Request ☐

LOCATION	
Address: 570 W Eastland St, Gallatin, Tennessee, 37066	
Cross Street: Roosevelt cir	*Grid Map: 47*

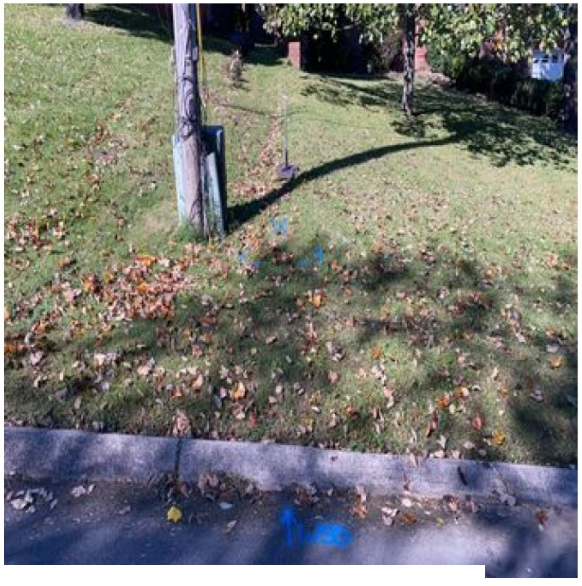
DETAILS	
ESTIMATION: GPM 10	PRIORITY:
COVER: Asphalt	TECHNICIAN: U Navarro, C Bracy
COMMENT S: Correlation: Sensor A (valve 113-O-15) to Sensor B (valve 113-O-16)	

Suspected On: Main **Indication:** Sonic, Correlation, Visual Water **ID:**





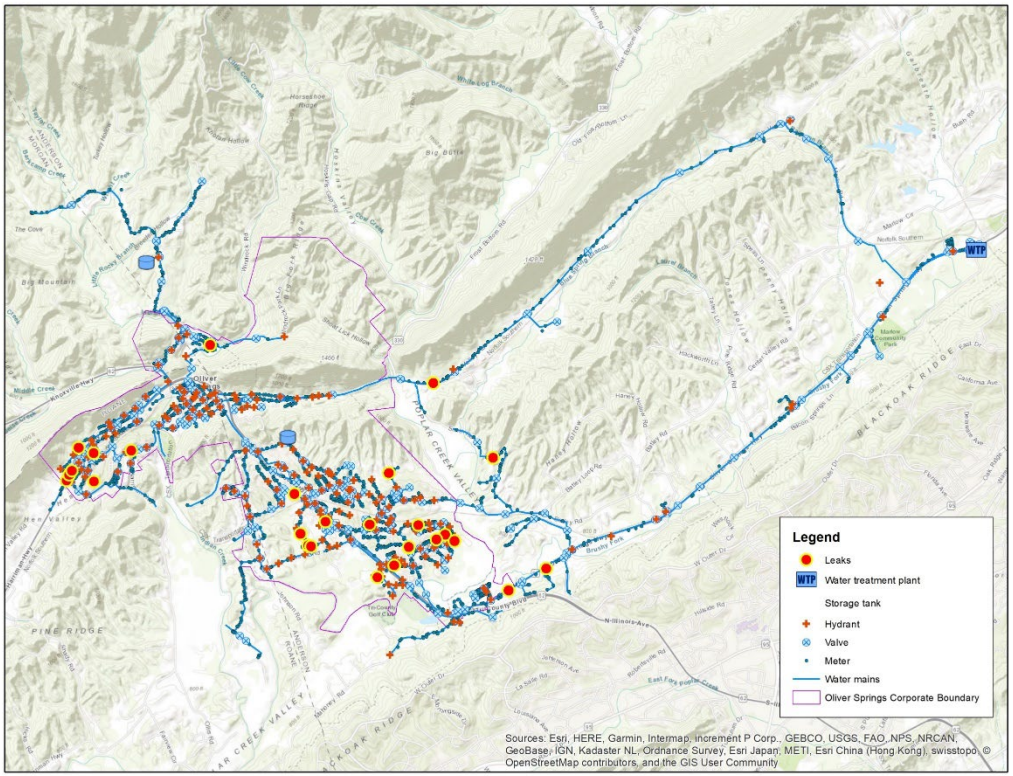
Leak Report



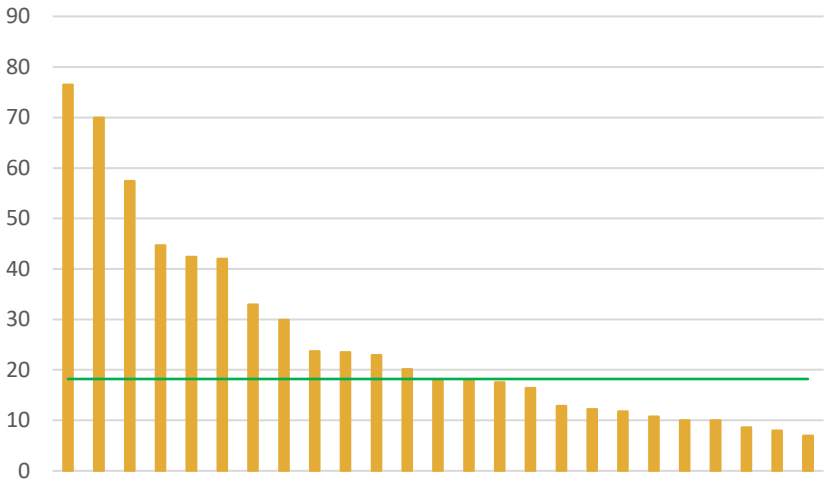
Leak Reports

Results of recent survey ~65 miles

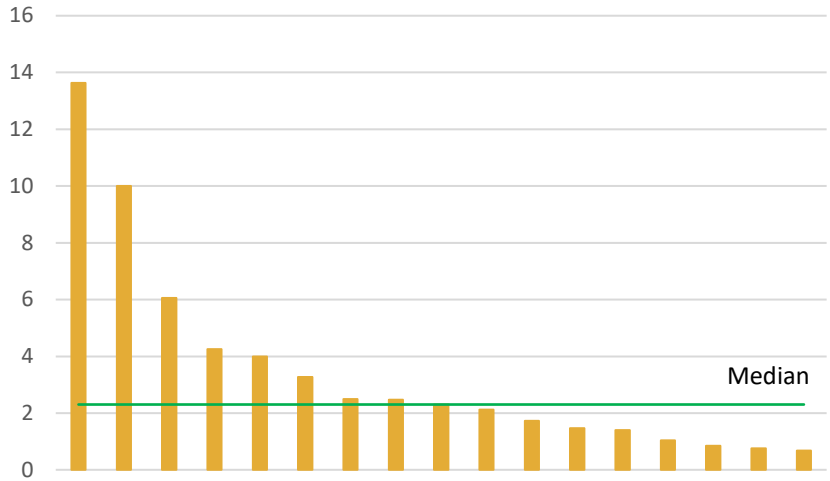
Infrastructure Type	Count of Leaks	% of Total Leaks	Estimated Flow Rate (GPM)	% of Total Flow Rate
Main	5	18%	33	31%
Service	12	43%	38	36%
Meter	5	18%	6	6%
Hydrant	6	21%	30	28%
Total	**28**	**100%**	**107**	**100%**



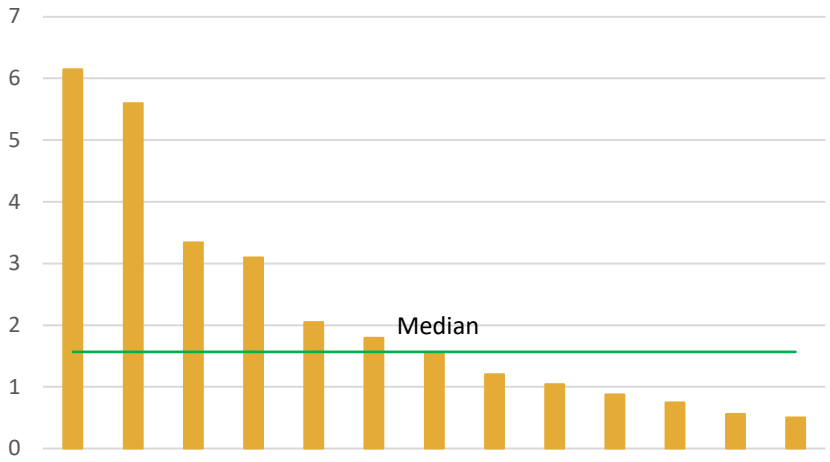
All Leaks/100 miles of main



Main Leaks/100 miles of main



Service & Meter Leaks/1,000 customers



Leak Survey Data Request

GIS files or maps:

- Pipe Material
- Size
- Asset Type