A SunCam online continuing education course

Reducing Water Loss in Distribution Systems

by

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Course Outline:

Introduction

Water distributions systems transfer potable water from a water treatment plant (WTP) or water storage facility to individual consumers/customers. See Figure 1 for the main features of a water distribution system. Water loss is when some of the water supplied does not make it to an authorized user. It costs money to treat and pump water, so losing some of it is a financial concern.

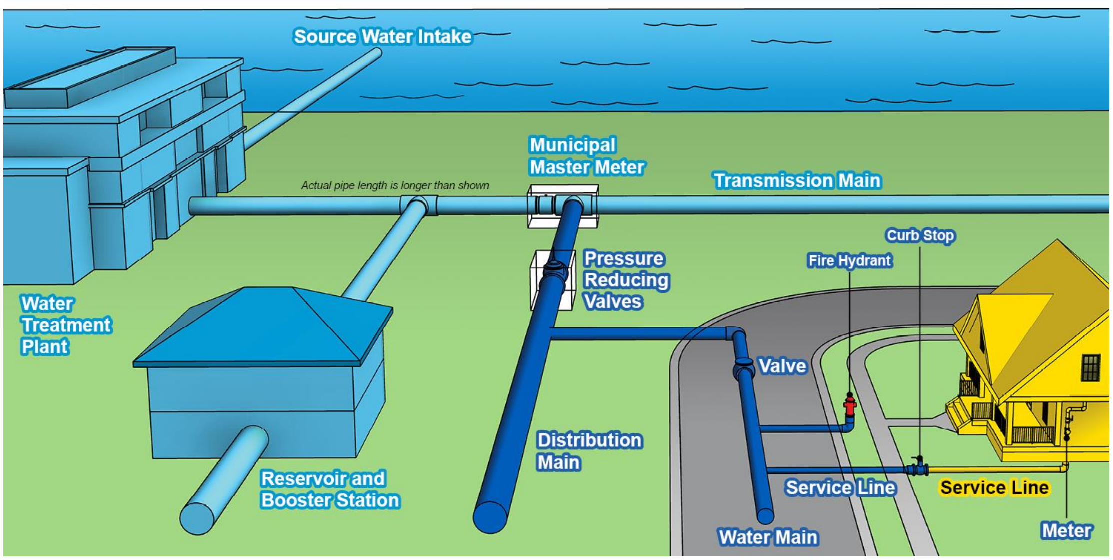


Figure 1: Example distributions system with pipes in shades of blue.
The system starts with the transmission main leaving the WTP and ends at each service line at the property line. The service line in yellow is owned by the customer (in this case a homeowner). The meter should be located at the property line (not at the house) for access and so the metered flow includes any leaks on private property.

Source: Great Lakes Water Authority

Distribution systems have always experienced some loss of treated/supplied water. The concern has become more urgent in the twenty-first century for the following reasons:

- Aging infrastructure with increased pipe leakage,
- Cost of water treatment has increased,
- Scarcity of water sources in many areas, and
- Water conservation awareness and funding.

Water loss control is the active management and reduction of water loss by a water utility agency/company. The following are common water loss control approaches:

- Creating a water balance,
- Plotting and reviewing water supply and consumption data,
- Performing a water audit,
- Benchmarking with key performance indicators (KPIs),
- Reviewing and upgrading billing and accounting software,
- Taking measures to better account for unmetered authorized consumption, such as pipe flushing and fire flow,
- Reducing water meter inaccuracies, including meter calibration and replacement,
- Identifying and removing unauthorized connections,
- Streamlining data management,
- Pressure management,
- Creating district metered areas (DMAs) to identify high losses,
- Regular and targeted leak detection efforts, and
- Pipe replacement based on pipe age, material, leak history, DMA results, etc.

This course will explain these approaches and provide examples for how to apply them.

Water loss can be defined as the amount of supplied water that does not reach customers or other authorized users. The most common cause of water loss is pipe leakage, although other causes include unauthorized connections, water meter inaccuracies, and errors in data management.

Water loss can be calculated in three ways:

1. Water supplied minus authorized consumption (billed and unbilled).
2. Non-revenue water (supplied but not billed) minus unbilled authorized consumption (flushing, fire flow, sampling, etc).
3. Sum of real losses (pipe leakage) and apparent losses (unauthorized connections, meter inaccuracies, and data errors).

Water Balance

A water balance is a breakdown of water consumption and water loss for a distribution system. See the water balance in Table 1 to understand the relationship of water loss terms. It is common to create a water balance table with values for each cell to gain an overall understanding of the distribution system and as part of a water audit.

Table 2 shows an example of a water balance with flow rates in red, in units of million gallons a day (MGD). A water balance can also be done with water volumes, such as million gallons (MG).

For the example in Table 2, the City of Timber Forks has a WTP that discharges 10 MGD with only 8 MGD being billed to customers. Based on this, one may assume the water loss is 2 MGD, however, that is incorrect. 2 MGD is the *non-revenue water* which is slightly different from the term *water loss*.

The difference is that water loss does not include unbilled authorized consumption, such as pipe flushing operations, fire flow from fire hydrants, or water sampling. Per Table 2, there is 0.5 MGD of unbilled authorized consumption, so the water loss is 10 MGD – 8 MGD – 0.5 MGD = 1.5 MGD. This equates to a percent water loss of 1.5 MGD / 10 MGD *100 = 15%.

Here are the equations used in this example:

Water loss = Water Supplied – Billed Authorized – Unbilled Authorized

Percent Water Loss = Water Loss / Water Supplied * 100

Other, similar equations can be made by looking at the columns in Table 1.

Continuing the example in Table 2, pipe leaks are the biggest source of water loss. There is 1.2 MGD of pipe leakage of the 1.5 MGD of water loss (80%). It is common for pipe leaks to be the main source of water loss. This course will explain how to identify areas of a distribution system with high leakage and how leak detection services can b utilized to find and repair the leaks.

<table>
<tr><td colspan="10">Table 1: Water Balance Terms for a Distribution System with Water Loss Categories in Green</td></tr>
<tr><td colspan="10">Water Supplied</td></tr>
<tr><td colspan="4">Authorized Consumption</td><td colspan="6">Water Loss</td></tr>
<tr><td colspan="2">Billed Authorized</td><td colspan="2">Unbilled Authorized</td><td colspan="3">Apparent Losses</td><td colspan="3">Real Losses</td></tr>
<tr><td>Billed Metered</td><td>Billed Unmetered</td><td>Unbilled Metered</td><td>Unbilled Unmetered</td><td>Meter Inaccuracies</td><td>Unauthorized Consumption</td><td>Data Errors</td><td>Leaks & Overflows at Tanks</td><td>Leakage on Mains</td><td>Leakage at Service Lines</td></tr>
<tr><td colspan="2">Revenue Water</td><td colspan="8">Non-Revenue Water</td></tr>
</table>

<table>
<tr><td colspan="10">Table 2: Water Balance Example for City of Timber Forks
Flow Rates in Red</td></tr>
<tr><td colspan="10">Water Supplied
10 MGD</td></tr>
<tr><td colspan="4">Authorized Consumption
8.5 MGD</td><td colspan="6">Water Loss
1.5 MGD</td></tr>
<tr><td colspan="2">Billed Authorized
8.0 MGD</td><td colspan="2">Unbilled Authorized
0.5 MGD</td><td colspan="3">Apparent Losses
0.25 MGD</td><td colspan="3">Real Losses
1.25 MGD</td></tr>
<tr><td>Billed Metered
7.8 MGD</td><td>Billed Unmetered
0.2 MGD</td><td>Unbilled Metered
0.3 MGD</td><td>Unbilled Unmetered
0.2 MGD</td><td>Meter Inaccuracies
0.05 MGD</td><td>Unauthorized Consumption
0.15 MGD</td><td>Data Errors
0.05 MGD</td><td>Leaks & Overflows at Tanks
0.05 MGD</td><td>Leakage on Mains
0.8 MGD</td><td>Leakage at Service Lines
0.4 MGD</td></tr>
<tr><td colspan="2">Revenue Water
8.0 MGD</td><td colspan="8">Non-Revenue Water
2.0 MGD</td></tr>
</table>

Example Problem 1

Best Water Company (BWC) is operating a distribution system and needs to better understand the water consumption and losses. They have collected the following water data over 24 hours on January 12. Create a water balance table, calculate the unauthorized consumption, and determine the percent water loss.

Category	Volume (MG)	Notes
Water Supplied	5.0	
Billed, metered	4.2	Customers
Billed, unmetered	0.1	Reclaim tank filled each week
Flushing, metered	0.1	
Flushing, unmetered	0.05	Estimated by operations staff
Fire flow, unmetered	0.05	Estimated by Fire Dept.
Meter Inaccuracies	-	Assume 1% of billed, metered
Data errors	-	Assume 1% of water supplied
Storage tank losses	0	Based on holding and testing
Leakage in pipes	0.3	Assume 50/50 split for water mains versus service lines

Solution:

A water balance is created in Table 3 using the above volumes. Note that the unbilled unmetered volume (0.1 MG) is the sum of the flushing, unmetered (0.05 MG) plus the fire flow, unmetered (0.05 MG).

The unauthorized consumption is calculated as follows:

Unauthorized consumption = Water Supplied – Authorized Consumption – Real Losses – Meter Inaccuracies – Data Errors
= 5.0 – 4.5 – 0.3 – 0.042 – 0.05 = **0.108 MG**

The percent water loss is calculated as follows:

Water Loss = Water Supplied – Authorized Consumption = 5.0 – 4.5 = 0.5 MG

Percent Water Loss = Water Loss / Water Supplied * 100 = 0.5 / 5.0 = **10%**

Table 3: Example Problem 1, Water Balance for BWC for January 12
with Volumes in Red

Water Supplied 5 MG									
Authorized Consumption 4.5 MG				Water Loss 0.5 MG					
Billed Authorized 4.3 MG		Unbilled Authorized 0.2 MG		Apparent Losses 0.2 MG			Real Losses 0.3 MG		
Billed Metered 4.2 MG	Billed Unmetered 0.1 MG	Unbilled Metered 0.1 MG	Unbilled Unmetered 0.1 MG	Meter Inaccuracies 0.042 MG	Unauthorized Consumption 0.108 MG	Data Errors 0.05 MG	Leaks & Overflows at Tanks 0 MG	Leakage on Mains 0.15 MG	Leakage at Service Lines 0.15 MG
Revenue Water 4.3 MG		Non-Revenue Water 0.7 MG							

Plotting Water Data

Water loss can be tracked and plotted over time as shown in Figures 2 and 3. Figure 2 shows a very efficient distribution system with non-revenue water (NRW) of less than 10%. The water loss would be even less, after subtracting any unbilled authorized consumption.

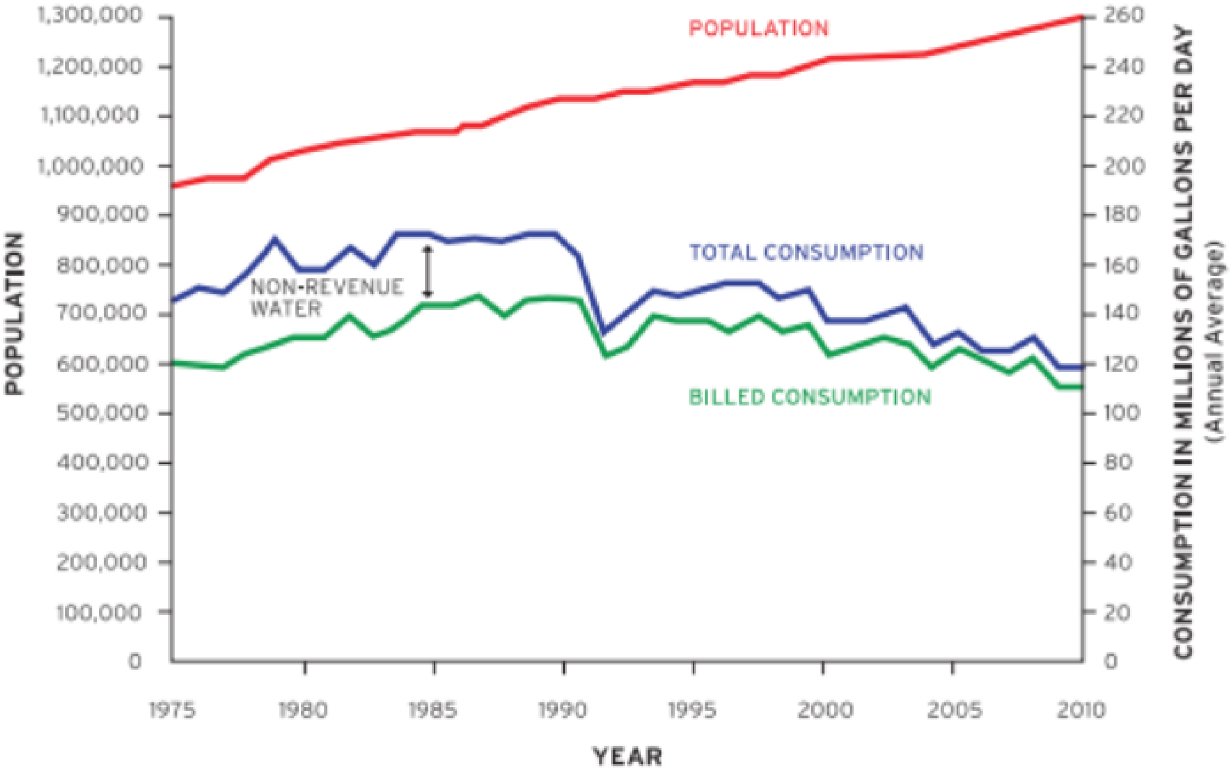


Figure 2: Plot of population, total consumption (water supply), and billed consumption over time for Seattle Public Utilities. Water conservation efforts were started in the early 1990s and have minimized non-revenue water and water loss.

Source: https://www.epa.gov/sites/default/files/2016-12/documents/wc_best_practices_to_avoid_supply_expansion_2016_508.pdf

Figure 3 shows a less efficient distribution system, with water losses ranging from 15% to 25%. These plots over time can indicate if high water losses are tied to events or known system changes.

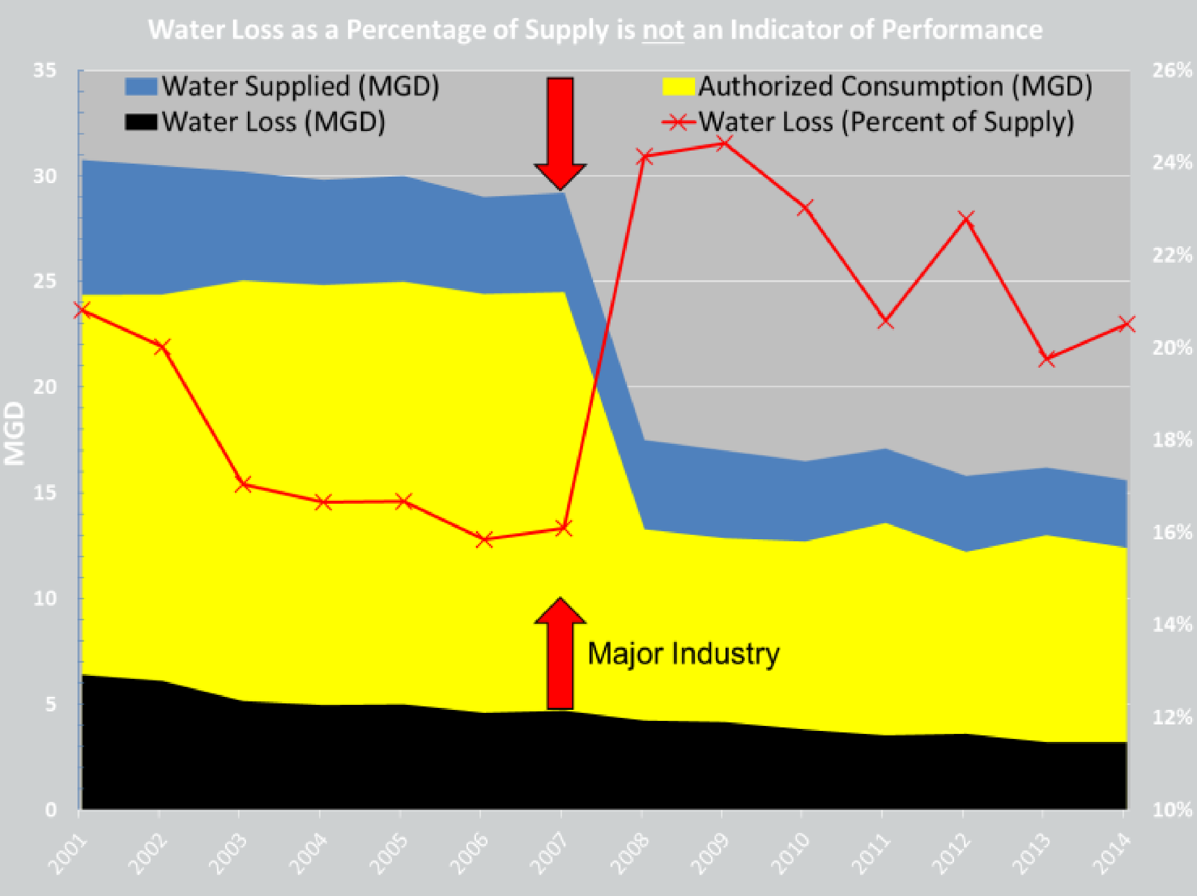


Figure 3: Plot of a distribution system water supply (blue), authorized consumption (billed and unbilled) (yellow), water loss flow rate (black), and water loss percent (red). In 2007 there was a major reduction in industrial consumption, leading to a reduction in water use and water loss flow rate, but an increase in the water loss percent.

Source: https://www.state.nj.us/drbc/library/documents/WMAC/022020/AWWA_NRW_kunkel.pdf (public domain)

A diurnal (24-hour) plot, as shown in Figure 4, can be helpful to identify suspected sources of water loss based on the following logic:

- Pipe leaks tend to be higher at night when pressures are higher due to lower flows. If water loss is higher at night, suspect pipe leakage as the main cause.
- Unauthorized connections tend to produce spikes in the water supply at regular times. If there are industrial unauthorized connections, there will be spikes during production hours. If residential, there will be increased water loss through the daytime hours, especially in the morning and evening due to showers, dishwashers, and laundry. If there are irrigation connections, there will be increased water loss when irrigation is most common or at night.

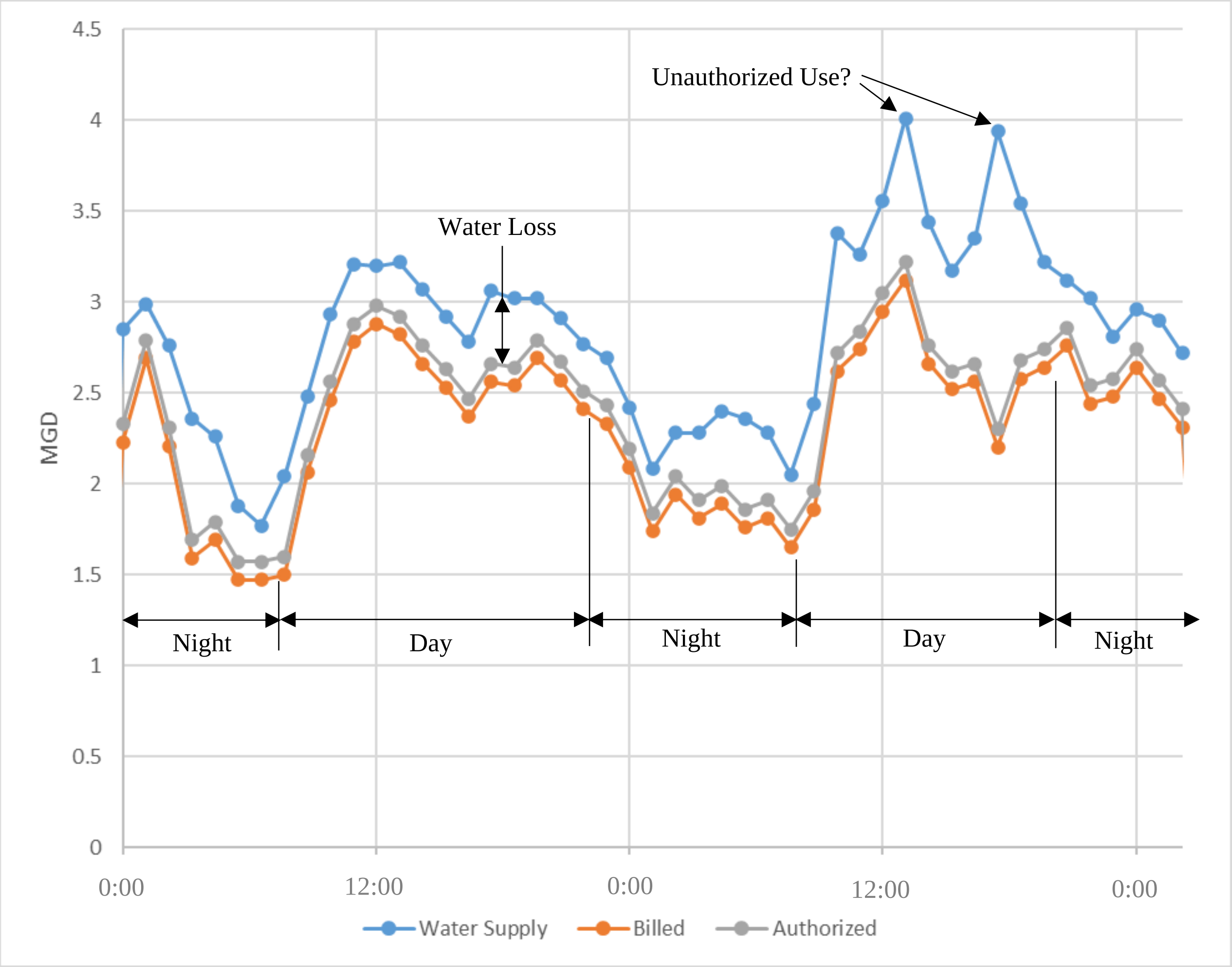


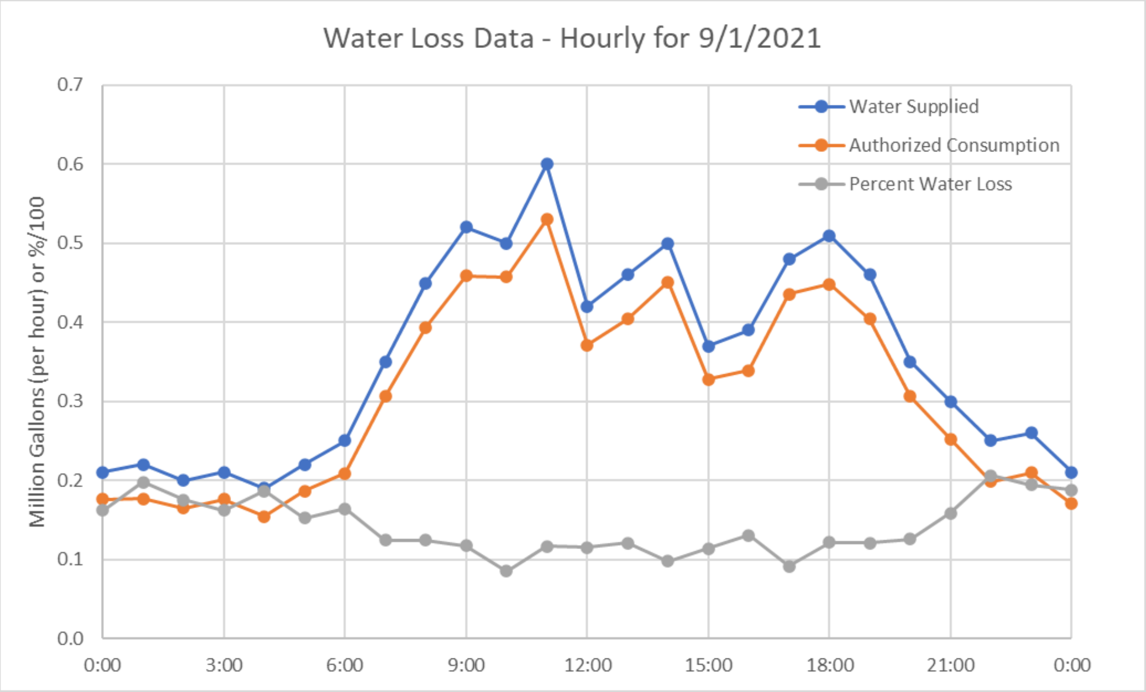
Figure 4: Diurnal plot over 2 days. The water loss is the difference between the water supply (blue) and authorized use (grey). The average water loss is 20% during the day, 13% at night, and 16% total. There are two water supply spikes during the second day to be investigated for unmetered consumption or unauthorized connections.

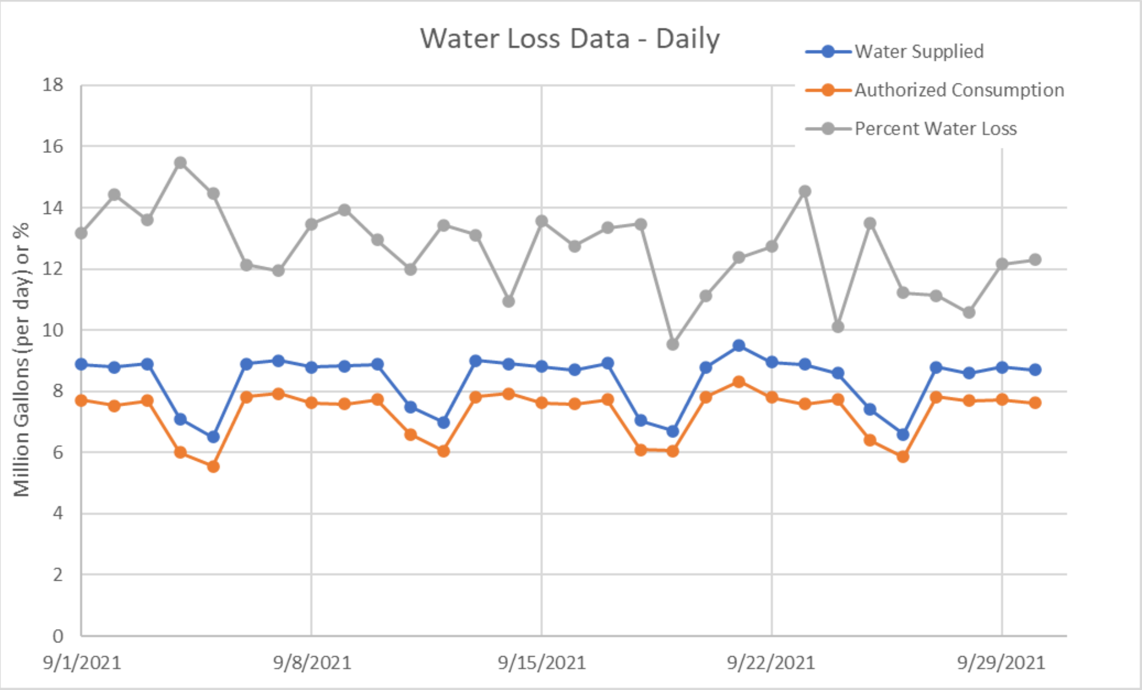
Source: Author

Sometimes diurnal plots are misleading due to the operation of water storage tanks in the distribution system. Most storage tanks are operated by filling at night and draining during the day. If the data is not modified to account for this, it will appear the water loss is high at night and low during the day. There are two approaches to account for the additional "storage flow" in (positive) and out (negative) of a storage tank:

1. Add storage flow to the authorized consumption data to make a modified authorized curve.
2. Subtract storage flow from the water supply data to make a modified supply curve.

See the software that comes with this course for a template for entering and plotting water data. Below are example plots for hourly and daily water data.





Water Audit

A water audit is the process of quantifying consumption and losses (such as a water balance) and reviewing the management and accounting procedures for a particular water distribution system. The purpose of a water audit is to understand the water balance of the distribution system, how it benchmarks against other systems, and to identify areas of improvement to reduce water loss.

Common tasks for a water audit include the following:
- Gather data from meters, billing systems, and operations,
- Perform a water balance,
- Grade/score the data validity based on meter type, reading frequency, calibration frequency, how records are maintained, etc.,
- Calculate key performance indicators (KPIs),
- Benchmark comparisons, and
- Set goals for water loss reduction.

The American Water Works Association (AWWA) has developed an excel-based software called *AWWA Free Water Audit Software* ©. Version 6 was released in 2021. The software is available here:

https://www.awwa.org/Resources-Tools/Resource-Topics/Water-Loss-Control/Free-Water-Audit-Software

This software is by far the most commonly used in the water industry. The approaches and terms in this AWWA Audit Software will be covered in this course.

The AWWA Audit Software includes the following nine excel tabs:

1. Start Page:
    - Enter basic information like name, location, date, units, water type, and population.

2. Worksheet:
    - Enter volumes for water supplied, authorized consumption, apparent losses, and real losses.
    - Enter distribution system data for the length of mains, number of service connections, operating pressure, retail cost, and production cost.

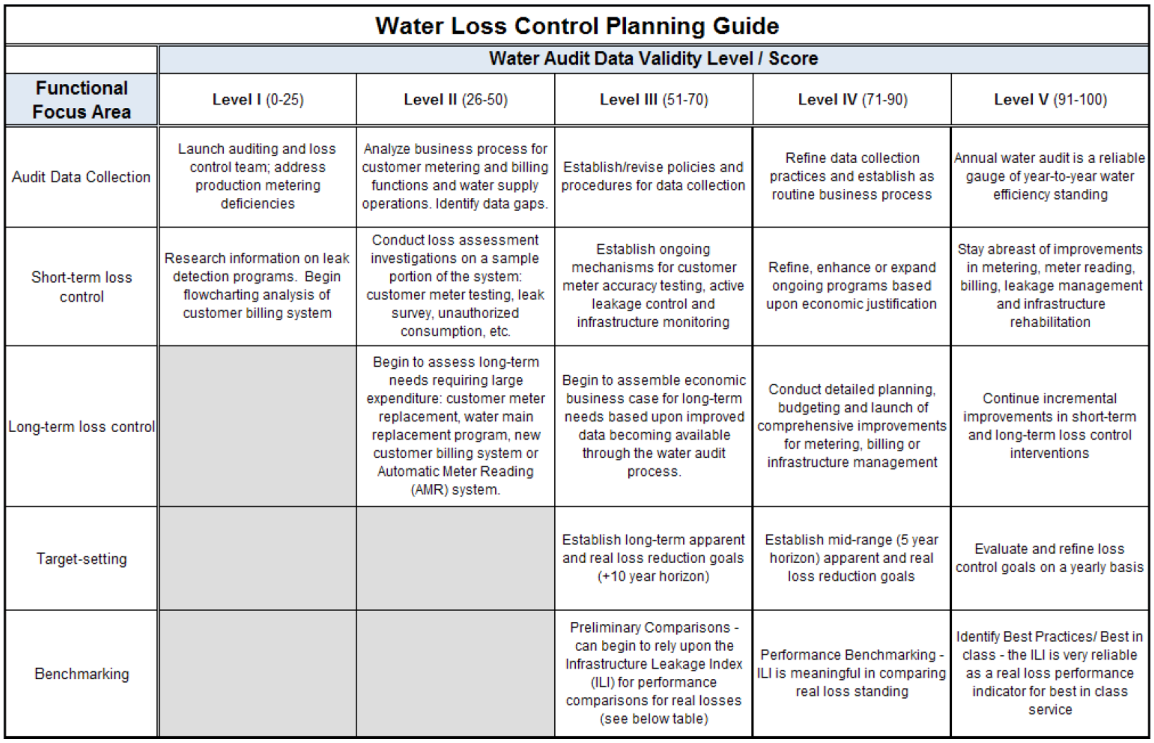
3. Interactive Data Grading:
    - Answer questions about the validity and confidence of the data entered on the worksheet tab.
    - Example questions:
        - What is the frequency of electronic flow meter calibration?
        - Is the most recent electronic calibration document available for review?
        - What are the results (in percent) of in-situ flow accuracy testing?
        - What is the frequency of finished water meter readings?
        - Are daily changes in stored water volumes in distribution system tanks included in the daily volume from own sources quantity?
        - For billed metered accounts, what % of bills are estimated?
        - How often does the utility read its customer meters?
        - When was the billing data reviewed by someone independent of the utility billing process?
        - What portion of billed accounts are unmetered?
        - How many unbilled metered accounts exist?
        - How often is each unbilled customer meter read?
        - How often are unbilled metered volumes reviewed for accuracy?
        - Which best describes the policy for new service accounts to ensure no lapse between the start of customer water usage and the start of measurement/billing?
        - For small-size customer meters, which best describes the frequency of proactive testing?
        - To what extent does meter replacement occur and for which meters?
        - Are hydrant laterals included in the length of distribution system piping?
        - Which best describes how the water mains inventory (GIS, ledger, etc) is kept up to date?
        - What is the count of service lines based on?
        - Which best describes how the customer service line mapping is validated to what is in the field?
        - Which best describes how continuous pressure data is collected?
        - Choose the option that best describes how the water treatment costs were calculated.

4. <u>Dashboard</u>:
   - Graphically shows rankings for the following:
     - Data validity ranked from Tier I (worst) to Tier V (best)
     - Volume and cost of non-revenue water
     - Key performance indicators (KPIs):
       - Total loss cost rate ($/conn/year)
       - Apparent loss cost rate ($/conn/year)
       - Real loss cost rate ($/conn/year)
       - Unit total losses (gal/conn/day)
       - Unit apparent losses (gal/conn/day)
       - Unit real losses (gal/conn/day)
       - Infrastructure leakage index (ILI)
       - Unit real losses (gal/mile/day)

5. <u>Notes</u>:
   - Users can add notes for each input and grading category

6. <u>Water Balance</u>:
   - A volume-based water balance is populated based on Worksheet tab inputs. The AWWA water balance looks similar to Table 3 although the rows and columns are inverted.

7. <u>Loss Control Planning</u>:
   - A table is provided to describe the state of the utility based on the data validity scores (Tier I to V) for the following focus areas:
     - Audit data collection
     - Short-term loss control
     - Long-term loss control
     - Target-setting
     - Benchmarking
   - See Figure 5 for an older version of the table.



Water Loss Control Planning Guide

	Water Audit Data Validity Level / Score				
Functional Focus Area	**Level I** (0-25)	**Level II** (26-50)	**Level III** (51-70)	**Level IV** (71-90)	**Level V** (91-100)
Audit Data Collection	Launch auditing and loss control team; address production metering deficiencies	Analyze business process for customer metering and billing functions and water supply operations. Identify data gaps.	Establish/revise policies and procedures for data collection	Refine data collection practices and establish as routine business process	Annual water audit is a reliable gauge of year-to-year water efficiency standing
Short-term loss control	Research information on leak detection programs. Begin flowcharting analysis of customer billing system	Conduct loss assessment investigations on a sample portion of the system: customer meter testing, leak survey, unauthorized consumption, etc.	Establish ongoing mechanisms for customer meter accuracy testing, active leakage control and infrastructure monitoring	Refine, enhance or expand ongoing programs based upon economic justification	Stay abreast of improvements in metering, meter reading, billing, leakage management and infrastructure rehabilitation
Long-term loss control		Begin to assess long-term needs requiring large expenditure: customer meter replacement, water main replacement program, new customer billing system or Automatic Meter Reading (AMR) system.	Begin to assemble economic business case for long-term needs based upon improved data becoming available through the water audit process.	Conduct detailed planning, budgeting and launch of comprehensive improvements for metering, billing or infrastructure management	Continue incremental improvements in short-term and long-term loss control interventions
Target-setting			Establish long-term apparent and real loss reduction goals (+10 year horizon)	Establish mid-range (5 year horizon) apparent and real loss reduction goals	Evaluate and refine loss control goals on a yearly basis
Benchmarking			Preliminary Comparisons - can begin to rely upon the Infrastructure Leakage Index (ILI) for performance comparisons for real losses (see below table)	Performance Benchmarking - ILI is meaningful in comparing real loss standing	Identify Best Practices/ Best in class - the ILI is very reliable as a real loss performance indicator for best in class service

Figure 5: Loss Control Planning Guide from the AWWA Audit Software

Source: https://www.epa.gov/sites/default/files/2016-12/documents/
wc_best_practices_to_avoid_supply_expansion_2016_508.pdf

8. Definitions:
    - Key terms and acronyms are defined

9. Service Connection Diagram:
    - Diagrams of the following typical service connection arrangements and length of customer service line on private property (Lp):
        1. Meter at curb stop (best arrangement) (Lp=0)
        2. Meter inside property (Lp = distance from curb stop to meter)
        3. Unmetered (Lp = distance from curb stop to point of first use)

The AWWA Audit Software uses a top-down approach, which is a recommended starting point for water loss control efforts. A bottom-up approach uses targeted field investigations to gain detailed insights. Some utilities will perform top-down audits annually and bottom-up audit activities on an ongoing basis.

A comparison of the two approaches is summarized here:

1. Top-down approach
   - Initial desktop audit including gathering information, water balance, performance indicators, target setting, and benchmarking
   - Focuses on the overall distribution system
   - Relatively fast
   - Examples:
     - AWWA Audit Software
     - Water balance

2. Bottom-up approach
   - Validates top-down results with actual field measurements
   - Focuses on targeted areas of the distribution system
   - Often takes months for field investigations
   - Can be an ongoing process over multiple years
   - Examples:
     - Review customer meter data for anomalies
     - Compare Geographic Information System (GIS) and Customer Information System (CIS) databases to identify missing accounts or inaccurate locations (see Figure 6 for an example)
     - Compare consumptive use and well permits to a list of properties without water accounts, for potential unauthorized connections
     - Flow verification tests of water supply and DMA meters
     - Field or bench accuracy tests for a sample of customer meters
     - Field confirm inactive accounts are not directly piped with open valves
     - Field confirm bypass pipes on large meters have closed valves
     - Create and monitor district metered areas (DMAs)
     - Utilize flow meters on fire hydrant connections to monitor for authorized unmetered flows such as flushing and fire flow
     - Install pressure sensors and identify areas and times of high or low pressure
     - Create maps with break complaints, break repairs, and leak detection results

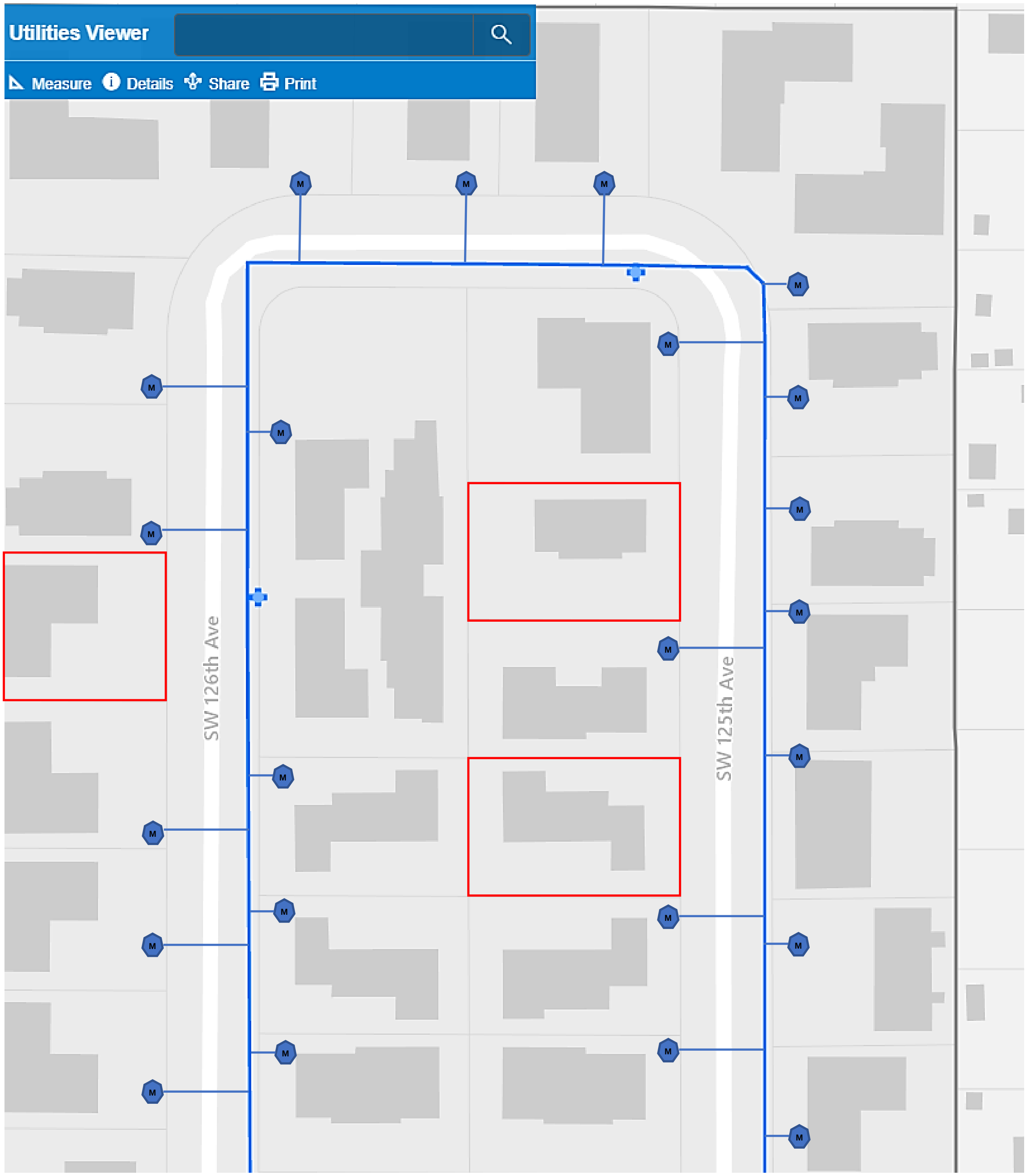


Figure 6: GIS screenshot with customer meters in blue. The properties boxed in red do not have a water meter shown in GIS.

Source: https://www.beavertonoregon.gov/2311/Utility-Maps (public domain)

Performance Indicators

Performance indicators allow for a realistic overall understanding of the losses occurring in a distribution system. Performance indicators are often compared to other similar utilities and industry averages. This helps in target-setting and benchmarking efforts.

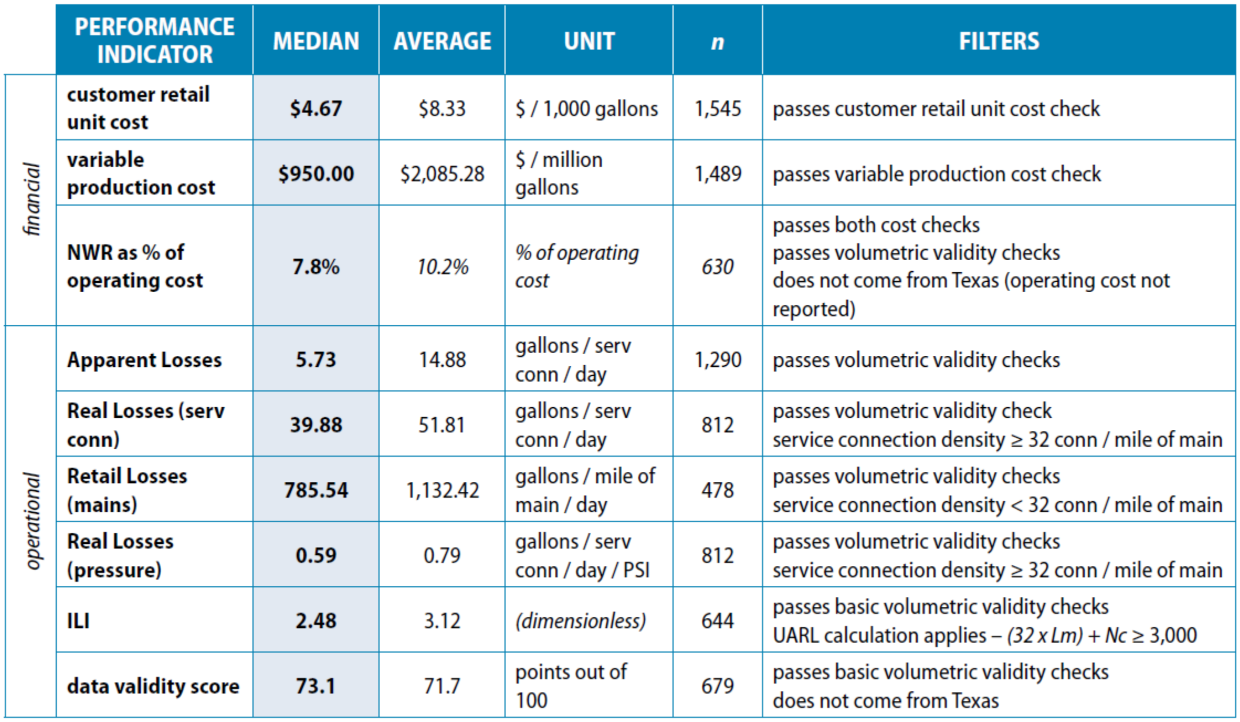
The following are basic performance indicators, which provide very little insight:

- Percent water loss
  - Percent water loss = water loss / water supplied * 100
  - The red line in Figure 3 is an example of percent water loss
- Percent non-revenue water (NRW)
  - Percent NRW = NRW / water supplied * 100

The following are key performance indicators (KPIs) from AWWA Audit Software:

- Total loss cost rate ($/conn/year)
- Apparent loss cost rate ($/conn/year)
- Real loss cost rate ($/conn/year)
- Unit total losses (gal/conn/day)
- Unit apparent losses (gal/conn/day)
- Unit real losses (gal/conn/day)
- Infrastructure leakage index (ILI) (unitless)
- Unit real losses (gal/mile/day)

Figure 7 shows a list of water loss performance indicators with common values. Many of these indicators differ slightly in name or calculation from the KPIs in the latest AWWA Audit Software.



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

Figure 7: Median and average performance indicator values from 2015.
The column *n* represents the number of water utilities reporting values.

Source: https://www.epa.gov/sites/default/files/2016-12/documents/wc_best_practices_to_avoid_supply_expansion_2016_508.pdf

The infrastructure leakage index (ILI) is the most common indicator for target-setting and benchmarking. It is calculated as the ratio of the Current Annual Real Loss (CARL) and Unavoidable Annual Real Loss (UARL). UARL represents the theoretical lowest leakage that would exist in a distribution system with maximum water loss control efforts being applied. The ILI formula is as follows:

$$ILI = \frac{CARL}{UARL}$$

$$CARL = Water\ Losses - Apparent\ Losses$$

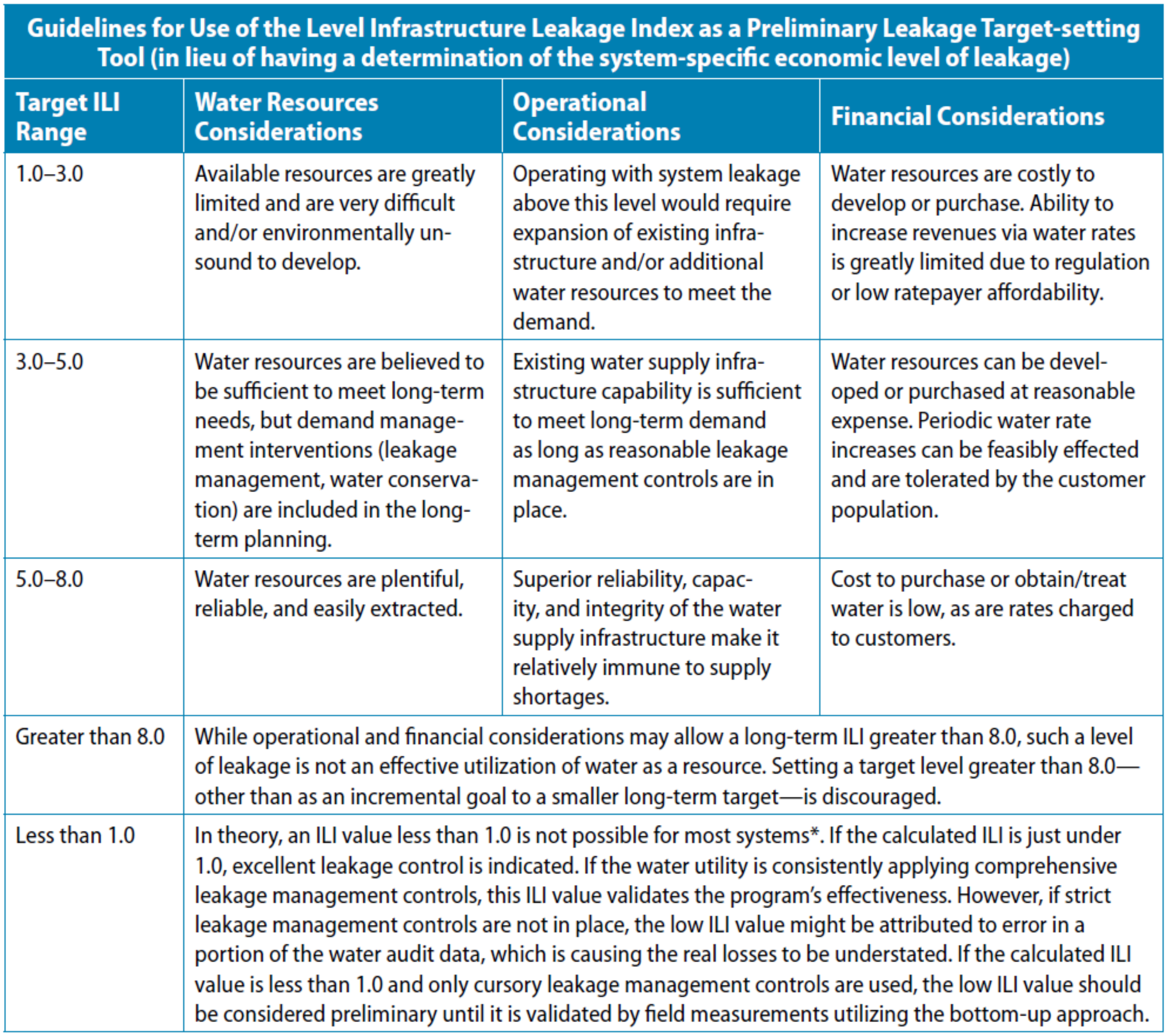
$$UARL\ (gal) = (5.4L_m + 0.15Nc + 7.5Lc)\ \times\ P\ \times\ 365\ d/yr$$

where:

Lm = length of water mains, including hydrant lead length (miles)

Nc = number of customer service connections
Lc = total length of customer service connection lines (miles)
P = average operating pressure in the system (psi)

The AWWA Manual M36 provides specific guidance on setting a target ILI based on the water resources available, existing infrastructure, and billing rates. See Figure 8 for ILI target-setting guidelines.



Guidelines for Use of the Level Infrastructure Leakage Index as a Preliminary Leakage Target-setting Tool (in lieu of having a determination of the system-specific economic level of leakage)

Target ILI Range	Water Resources Considerations	Operational Considerations	Financial Considerations
1.0–3.0	Available resources are greatly limited and are very difficult and/or environmentally unsound to develop.	Operating with system leakage above this level would require expansion of existing infrastructure and/or additional water resources to meet the demand.	Water resources are costly to develop or purchase. Ability to increase revenues via water rates is greatly limited due to regulation or low ratepayer affordability.
3.0–5.0	Water resources are believed to be sufficient to meet long-term needs, but demand management interventions (leakage management, water conservation) are included in the long-term planning.	Existing water supply infrastructure capability is sufficient to meet long-term demand as long as reasonable leakage management controls are in place.	Water resources can be developed or purchased at reasonable expense. Periodic water rate increases can be feasibly effected and are tolerated by the customer population.
5.0–8.0	Water resources are plentiful, reliable, and easily extracted.	Superior reliability, capacity, and integrity of the water supply infrastructure make it relatively immune to supply shortages.	Cost to purchase or obtain/treat water is low, as are rates charged to customers.
Greater than 8.0	While operational and financial considerations may allow a long-term ILI greater than 8.0, such a level of leakage is not an effective utilization of water as a resource. Setting a target level greater than 8.0—other than as an incremental goal to a smaller long-term target—is discouraged.		
Less than 1.0	In theory, an ILI value less than 1.0 is not possible for most systems*. If the calculated ILI is just under 1.0, excellent leakage control is indicated. If the water utility is consistently applying comprehensive leakage management controls, this ILI value validates the program's effectiveness. However, if strict leakage management controls are not in place, the low ILI value might be attributed to error in a portion of the water audit data, which is causing the real losses to be understated. If the calculated ILI value is less than 1.0 and only cursory leakage management controls are used, the low ILI value should be considered preliminary until it is validated by field measurements utilizing the bottom-up approach.		

Figure 8: Guidelines for target-setting of the ILI performance indicator.

Source: https://www.epa.gov/sites/default/files/2016-12/documents/wc_best_practices_to_avoid_supply_expansion_2016_508.pdf

Reducing Apparent Losses

Apparent losses are when water is delivered to a user but is not measured or accounted for correctly. Apparent losses often result in a loss of revenue. If left undiscovered, large apparent losses may be assumed to be real losses (pipe leakage) which can lead to poor decisions for addressing real losses.

Apparent losses can be grouped into three categories: 1) meter inaccuracies, 2) unauthorized consumption, and 3) data errors. Each of these is discussed below.

Meter Inaccuracies

Customer meter accuracy is influenced by the following factors:

1. Meter type: There are many types of water meters. Displacement meters are common for sizes less than 1”, such as residential connections. For larger meters, options include turbine, compound, single-jet, propeller, ultrasonic, and electromagnetic meters. The selected meter type should maintain accuracy through the full flow range. For applications where there are periods of low flow, a meter type should be chosen that maintains accuracy with low velocities.
2. Meter size: Meters that are oversized result in lower accuracy readings at low flows. Some meters stop reading if the velocity drops below a set value. This results in under-estimating the water consumption. Conversely, if a meter is undersized, the regular high velocities will wear the internal parts and increase inaccuracy.
3. Proper installation: Each meter manufacturer provides unique installation instructions to be followed. In general, customer meters should be installed horizontally in weather protection boxes with space on each side per the manufacturer’s recommendations.
4. Testing and replacement program: Utilities should own, install, test, and replace customer meters as part of an ongoing meter program. See AWWA Manual M6 entitled “Water Meters – Selection, Installation, Testing, and Maintenance” for sound meter management practices.

The following technologies are available for controlling apparent losses:

- *Automatic meter reading* (AMR) systems gather customer meter readings every month via a one-way communications device (handheld or vehicle patrols).
- *Advanced metering infrastructure* (AMI) uses a fixed communication network (cellular technology or similar) to provide two-way communication to obtain meter

readings multiple times a day (4-hour intervals is common), receive alarm signals, and give the meters commands such as closing a shut-off valve.

AMI technology is particularly helpful for controlling both apparent and real losses. For example, if a 24-hour flow test is performed for a district metered area, it is helpful to obtain the meter readings as soon as possible to evaluate the results and repeat the test if needed. For AMI meters, the readings will be available no later than the following day. See Figure 9 for a depiction of an AMI meter and communication system.

Figure 9: Left: Water meter with AMI communications device in white. Often these radio communications devices will look like hockey pucks on the lid of the meter box. Right: Basic components of an AMI communications system.

Source: https://www.sherwoodoregon.gov/utilitybilling/page/advanced-metering-infrastructure

Unauthorized Consumption

Unauthorized consumption is when water is taken from the distribution system without being authorized by the utility. Examples include:

- Illegal connections to water mains, laterals, service lines (upstream of the meter), or hydrant laterals
- Unauthorized temporary hydrant connections (see Figure 10),
- Unauthorized hydrant use,
- Open bypasses at large meters,
- Buried or obscured manual meters (see Figure 11),
- Vandalized meters, and
- Re-opening closed service lines without meters.

Figure 10: An authorized fire hydrant connection with a flow meter and backflow prevention device. This is an example of unbilled, metered, authorized consumption.

Source: https://commons.wikimedia.org/wiki/File:Tool_to_extract_water_from_fire_hydrant.JPG (public domain)

Figure 11: A buried manual water meter. The meter box should be Cleanout out to allow taking a meter reading.

Source: https://commons.wikimedia.org/wiki/File:Southern_California_water_meters_-_2.jpg, RightCowLeftCoast, CC-BY-SA-4.0

Approaches to controlling unauthorized consumption include the following:

1. Detection: Detect unauthorized consumption events by using DMAs, field inspections, meter data reviews, GIS to CIS comparisons, well permit reviews, consumptive use permit reviews, and water balances.
2. Policy: Create and promote policies that define authorized versus unauthorized water use. Policies should exist to cover the wide spectrum of activities that occur in providing water service.
3. Enforcement: Maintain the authority to stop unauthorized water use and enforce appropriate penalties.

Example Problem 2

Which of the following are considered unauthorized consumption?

1. Open bypass around a large meter.
2. Open bypass while staff replaces a meter.
3. Fire sprinkler line without a meter.
4. Tee connection upstream of a meter for an irrigation system.
5. Tee connection downstream of a meter for an irrigation system.
6. Straight piped connection after meter removed and service stopped.
7. Operations opening a hydrant for pipe flushing.
8. Water quality sample taken from a sampling station without a meter.
9. Contractor connecting to a hydrant to obtain water for construction without a permit.
10. Temporary service line to a construction job trailer with a permit.

Solution:

The following are considered unauthorized consumption since they are unmetered and not authorized or permitted by the utility:

1. Open bypass around a large meter.
4. Tee connection upstream of a meter for an irrigation system.
6. Straight piped connection after meter removed and service stopped.
9. Contractor connecting to a hydrant to obtain water for construction without a permit.

The remainder is considered unbilled authorized consumption, since they were done by staff, downstream of a meter, with a permit, or for fire protection:

2. Open bypass while staff replaces a meter.
3. Fire sprinkler line without a meter.
5. Tee connection downstream of a meter for an irrigation system.
7. Operations opening a hydrant for pipe flushing.
8. Water quality sample taken from a sampling station without a meter.
10. Temporary service line to a construction job trailer with a permit.

Data Errors

Often there are errors in the collection or processing of meter data. These errors often add up to a sizable volume of water and a high percentage of the total authorized flow. Common causes and potential solutions are as follows:

- Obtaining water meter readings:
    - Manual read meters have human errors such as misreads which can be avoided by replacing them with AMR or AMI meters.
    - Check the conversion of units such as cubic feet to gallons. Reading in gallons is more accurate since it is more granular (smaller) than cubic feet.

- Data transfer errors:
    - Manual readings are prone to errors in data entry and transposition. Recommend replacement with AMR or AMI meters.
    - AMR equipment can have failures that are not realized for months. AMI meters have two-way communication so alarms can be seen quickly.
    - Improper setup of units, truncation factors, or flow cut-off values in meters. These values can be audited to confirm they are correct.
    - Mix-up of meter type in a system with a combination of manual, AMR, and AMI technology. Improve management and documentation of new meters to avoid mix-ups.

- Data analysis errors:
    - Manual entry of assumed volumes for meters with errors. Meters should be fixed or replaced quickly to avoid poor estimates.
    - Poor adjustment of meter readings for customer credits.
    - Closing or transferring of accounts is not done properly.
    - Summing of meter readings and billed volumes not done properly. To perform a water balance, the billed metered, unbilled metered, and billed unmetered values are obtained by summing individual volumes. Care must be taken when summing the readings for a particular time period since meter readings are taken at different times of the day or month. Meter reading units should be double-checked. Meters with errors should be identified and removed from the aggregate volumes.

- Policy and procedure issues:
  - Often municipal-owned facilities are authorized to utilize water without a meter, with water use estimated. This opens the door to errors.
  - Some customers are allowed to enter an “unbilled” status which can remove them from the list when summing the meter readings.
  - Procedures leading to delays in taking readings for new accounts.

- Customer billing system:
  - Billing systems are set up for financial accounting purposes, not overall water accounting purposes. Program adjustments can more easily allow viewing and downloading of water usage data.
  - An interface between GIS and the billing system can be helpful, especially when defining DMA boundaries, listing the customer meters within the DMA, and downloading the relevant water consumption data.
  - Software security features are needed to ensure customer data is not manipulated by unauthorized users.

Reducing Real Losses

Real losses are from the leakage of water throughout the distribution system, including at tanks, fire hydrants, and up to customer meters. For most utilities, pipe leaks are the biggest contributor to water loss and non-revenue water. Finding and fixing these leaks can quickly pay off.

Leaks and Overflows at Storage Tanks

Water storage tanks include ground storage tanks, elevated tanks (water towers), and standpipes. Storage tanks are designed to be essentially leak-free. During startup, tanks are tested by letting water sit for at least 24 hours and measuring the change in water surface elevation. A small elevation change is allowed due to evaporation. Over time, hairline cracks form in concrete, tank settling can cause cracks and joint separation, metal components may corrode, weather damage may occur, and coatings degrade. So it is not unusual to have some leakage in an older tank.

Tank leakage can be measured by taking the tank offline and holding it full of water for approximately 24 hours. Measure the elevation change. A properly sealed tank should not lose more than 0.05% of the tank volume over 24 hours. If the tank is losing more water, consider a condition assessment and lining of the tank interior.

Tank overflows, as shown in Figure 12, are more common than people assume. Since it is potable water, the spill may not need to be reported or of great concern. Operators may consider it a watering of the lawn. The volume of water lost in an overflow event can be estimated by multiplying the tank rise rate (or influent flow rate) times the period of the event. If the tank has a level transmitter, the `rise rate and time of overflow can be obtained from the historically level readings around the time of the event.

Overall, tank leaks and overflows should be assessed, but are likely to be much less than pipe leakage in the system.

Figure 12: A ground storage tank with an overflow pipe and ice buildup leaving evidence of a recent overflow event.

Source: commons.wikimedia.org/wiki/File:Ice_From_Water_Tank_Overflow_dyeclan.com_-_panoramio.jpg, The Dye Clan, CC-BY-SA-3.0

Leakage on Mains and Service Lines

Reducing pipe leaks should be a central focus of a water loss control program. Efforts spent to find and repair leaks are the most likely to result in a measurable decrease in water loss.

Common causes of leaks are as follows:

- External corrosion due to aggressive soils, groundwater, or stray electric current. This is most common in aged metallic pipes.
- Internal corrosion caused by parameters such as excess chlorine, pH changes, oxygen level changes, etc. This is most common in aged metallic pipes.

- Defective pipe materials or joints (see Figure 13). This includes pipe that was sitting too long in the sun before installation.
- Poor pipe bedding or support.
- Poor installation methods, such as excessive joint deflections, sharp rocks under the pipe, inadequate backfill methods or materials, joints not tightened, etc.
- Excessive pressures or forces due to slamming closed valves, starting and stopping of pumps, etc.
- Weather-induced stresses due to frost loading, soil expansion, extreme temperature events, or expansion and contraction from water temperature versus ground temperature differential.
- Previous repair was done poorly.
- Construction activity or heavy traffic loading.
- Tree roots hugging the pipe and prying at the joints for water (see Figure 13).

Figure 13: Left: tree roots stressing a pipe. Upper right: Slow leak at a defect in a joint. Lower right: Large leak on a water main with an unknown cause.

Sources: commons.wikimedia.org/wiki/File:Leak_in_rusted_pipe_side_view.jpg, Shamrock Lee, CC-BY-4.0
www.pflugervilletx.gov/city-government/public-works/water-leaks (public domain)

Approaches for reducing pipe leakage include the following:

- Encourage customers to report leaks, breaks, water flowing in a street, or low pressure. Improve the management of customer reports and the response time for fixing reported leaks.
- Ongoing acoustic leak detection with field crews.
- Identify pipes with a high likelihood of leakage through the use of pipe condition assessments, risk ranking software, break history maps, pipe age maps, pipe material maps, etc.
- Create district metered areas (DMAs) to find areas of high water loss.
- Monitor pressures to identify pipes with unusually low pressures.
- Perform a satellite survey for potable water presence in the ground near pipes.
- Reduce pressure during the night and in areas of the system with excessive pressures, such as at low elevations.
- Keep up with the latest technology for leak detection.

Pressure Management

The higher the water pressure, the greater the flow through leaks. As a rule of thumb, the percent increase in pressure will produce the same percent increase in leakage. For example, a 10% increase in pressure will result in a 10% increase in the leakage flow rate. Conversely, a 10% drop in pressure will result in a 10% drop in leakage flow.

Distribution systems must maintain a minimum pressure of 35 psi, per the *Ten States Standards* (see Helpful References) and many state standards. A maximum pressure is not specified, although a range of 60 to 80 psi is recommended. Pressures over 100 psi are considered to be excessive due to the potential for water hammer, appliance damage, pipe and joint stresses, and increased leakage. The average pressure for water utilities in North America is 76 psi, per AWWA M36, Table 6-1. In general, utilities should consider dropping the overall distribution system pressure to reduce leakage.

For utilities with great elevation changes, the pressures at the lower elevations can be reduced to decrease water loss. See Figure 14 for an example. The water pressure change due to the elevation change of water pipes is calculated as follows, based on Bernoulli's principle:

$$\Delta p = \frac{\Delta EL * sg}{2.31} = 0.43 * \Delta EL$$

where:
$p = \text{water pressure (psi)}$
$\Delta EL = \text{elevation change of water pipes (feet)}$
$sg = \text{specific gravity of the fluid (1.0 for water)}$

Pressure can be reduced by installing a pressure-reducing valve at each branch feeding the low elevation area. These valves can also have flow controllers or timers so that the pressure is only decreased during low flows or the night hours.

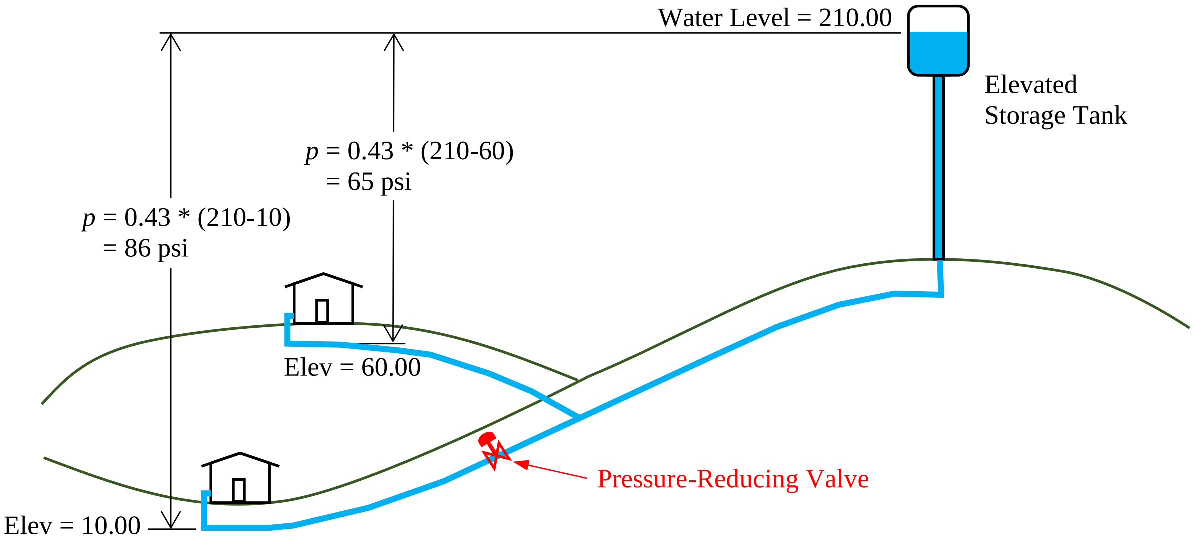


Figure 14: Water pressure (*p*) calculated at the lowest and highest elevations in a community. A pressure-reducing valve (in red) can be added to decrease the pressure from 86 psi to 65 psi, which may correspondingly reduce pipe leakage by 24%.

Leaks can also form or grow from temporary spikes in pressure, also called surges or transients. Surge control techniques include pump speed control (VFD or soft start), cushioned check valves, bladder tanks, pressure relief valves, vacuum valves, and high-pressure discharge or recirculation arrangements.

Tools for pressure management include the following:

- Pressure transmitters located throughout the distribution system. Placing them near sewer lift stations provides a means for remote communications.
- Pressure-reducing, pressure sustaining, or pressure relief valves.
- Altitude valves at storage tanks.
- Transient/surge control techniques.

District Metered Areas

Distribution systems are built up over many years, often involving acquisitions or merges with neighboring water utilities or private communities. Water pipes were installed to different standards by different Contractors in different time periods. This variation means that most of the pipe leakage could be occurring in only a small portion of the system. If these areas of high leakage are found, a significant reduction in water loss can be achieved with minimal investment.

A way to find areas of high leakage is to sectorize the distribution system into logical zones, called district metered areas (DMAs). Creating DMAs requires metering the flow into the zone by installing water meters on all the active water mains at the zone boundary. The formula for calculating the water loss is as follows:

$$\text{Water loss} = \sum \text{zone meters} - \sum \text{billed authorized} - \sum \text{unbilled authorized}$$

Installing meters on buried water mains in the distribution system can be expensive, so typically valves are closed to force all the flow through one or two water mains so fewer meters are required. See Figures 15 and 16 for an example in which four DMAs are created with different combinations of meters and closed valves.

For water mains and other large pipes, flow meters are commonly installed in vaults or above ground on concrete pads with isolation valves and a bypass pipe. However, for temporary DMA purposes, there are more economical meter solutions, such as a portable strap-on ultrasonic meter or an insertion meter, as shown in Figure 17.

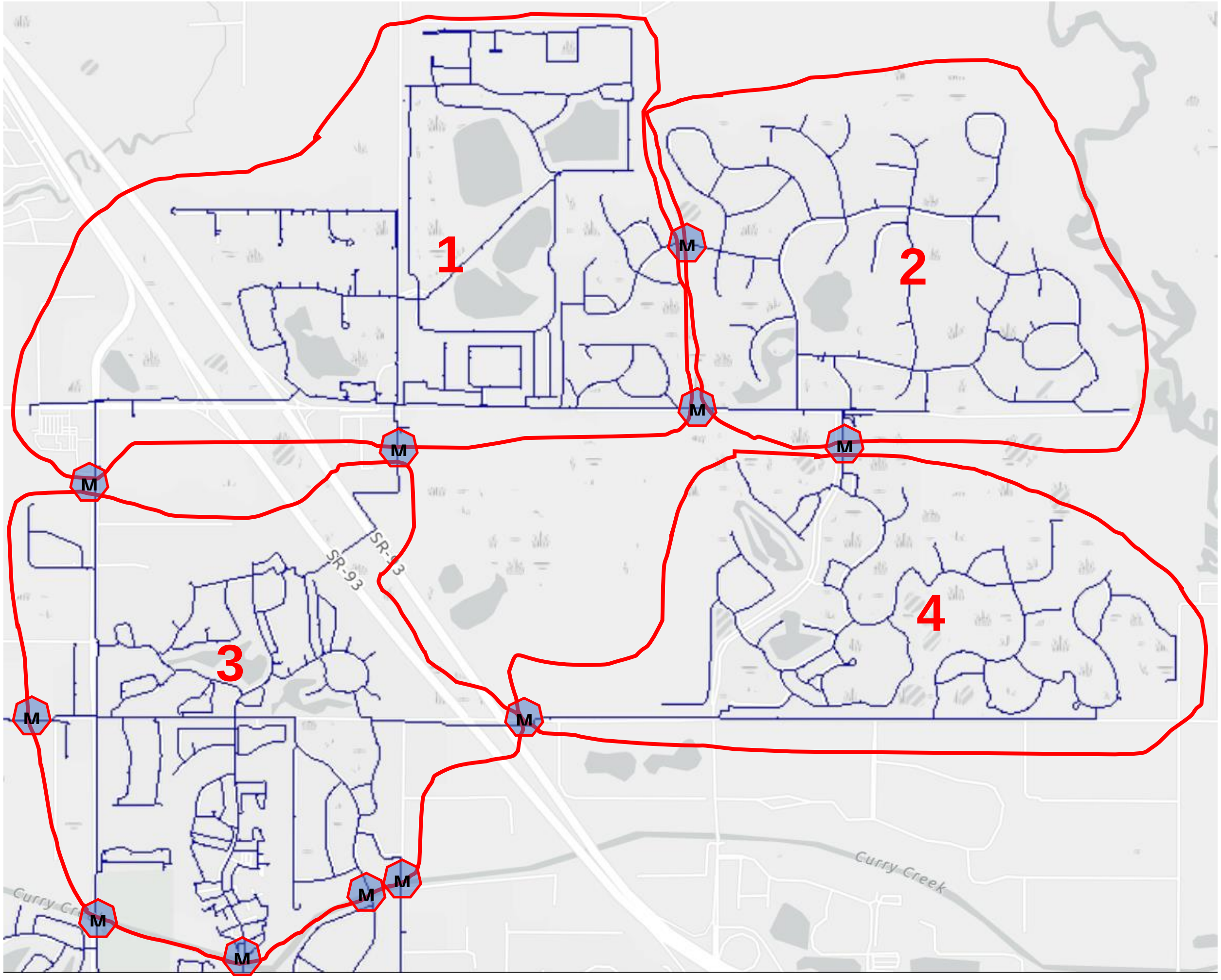


Figure 15: GIS screenshot with 4 DMAs created with 11 zone meters.

Source: www.venicegov.com/services/utilities/geographic-information-systems-gis-mapping, modified (public domain)

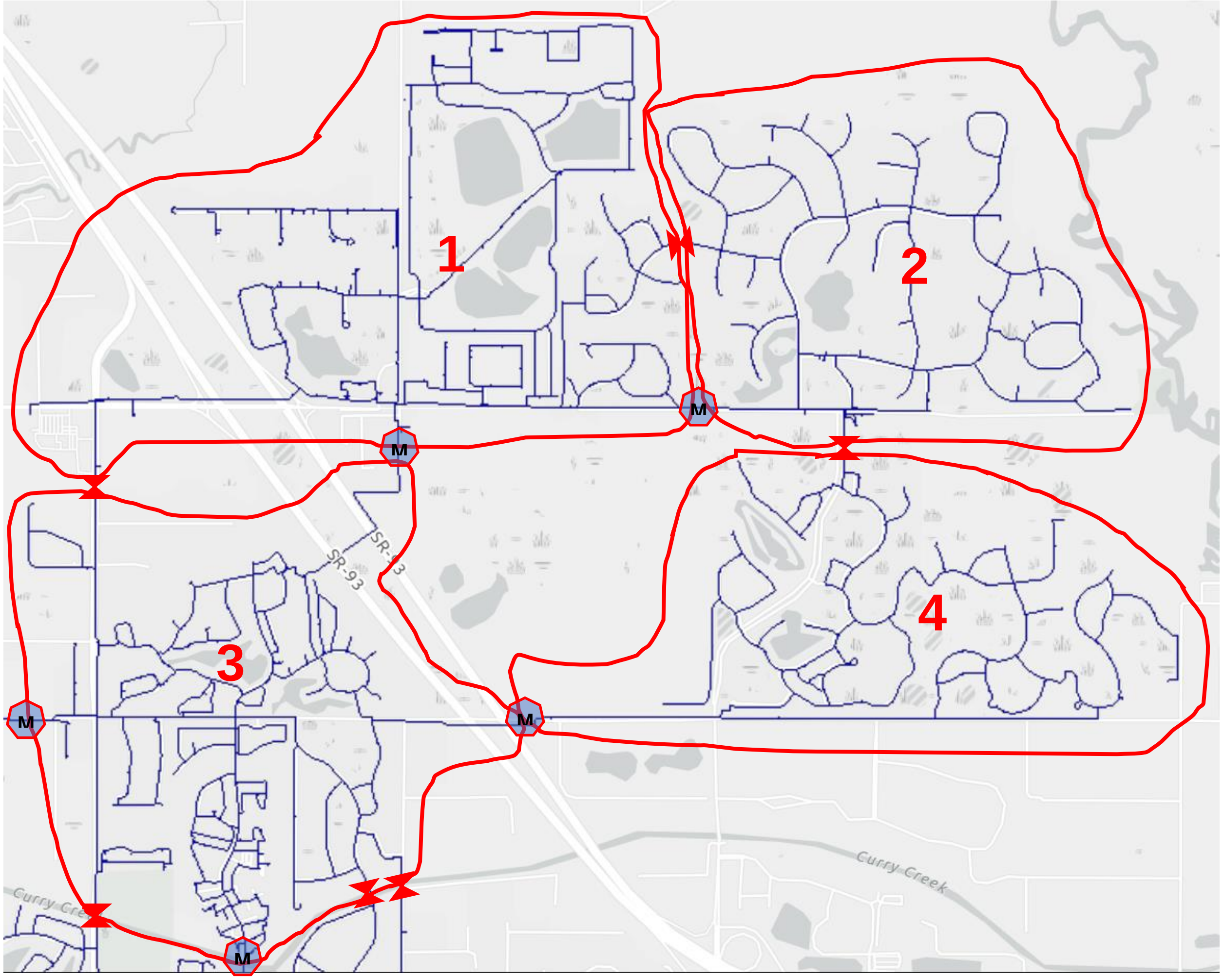


Figure 16: GIS screenshot with 4 DMAs created with 5 zone meters and 6 closed valves. Closing valves is more economical than using all flow meters.

Source: www.venicegov.com/services/utilities/geographic-information-systems-gis-mapping, modified (public domain)

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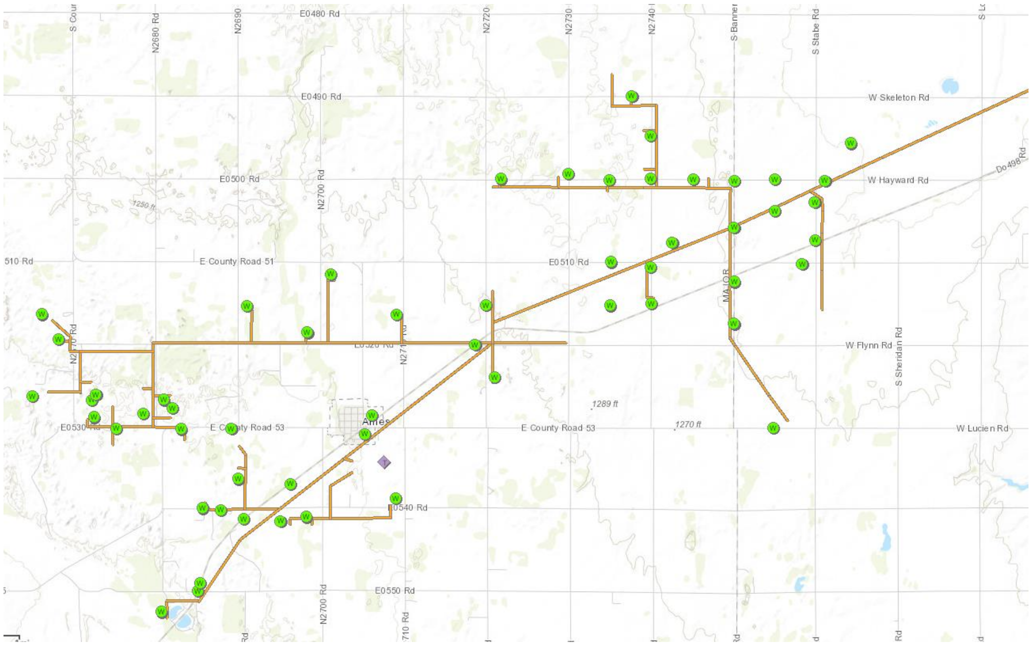
Figure 17: Examples of a strap-on ultrasonic flow meter (left) and a magnetic insertion meter (right), both installed on existing water mains.

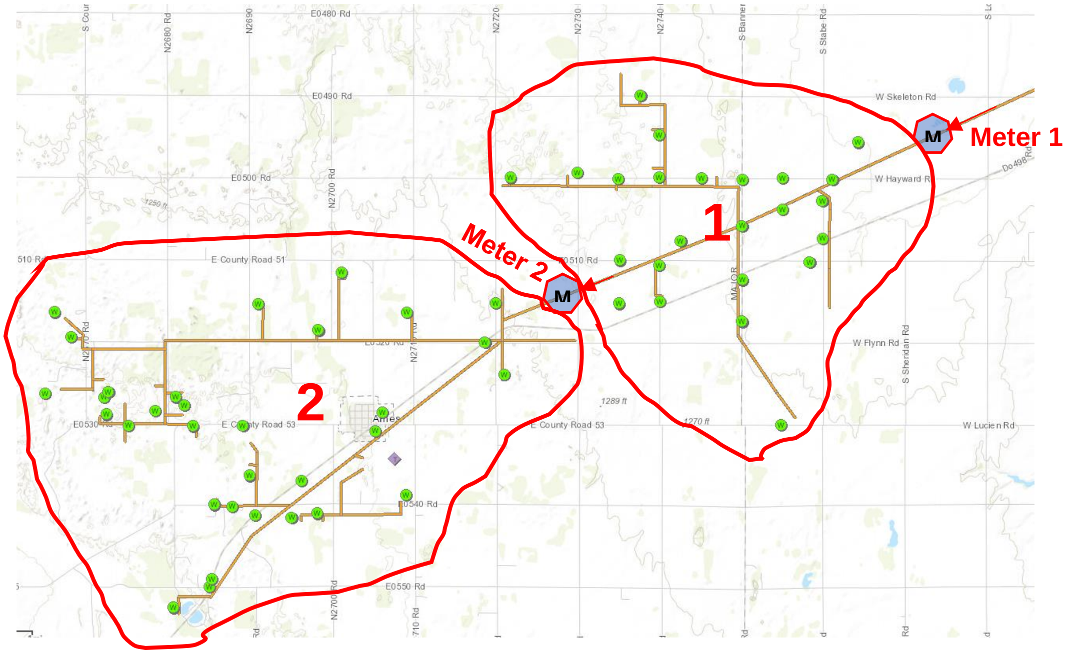
Example Problem 3

Engineer Phil is tasked with creating two DMAs for the below water distribution system in brown. He is to identify the meter locations, any closed valves, and circle the DMAs.



Solution:

Phil uses two meters to create the following two DMAs. No closed valves are needed.



Example Problem 4

Continuing with Example Problem 3, Phil obtains the below water data over 24 hours for the two DMAs. Calculate the percent water loss for each DMA and indicate which DMA is best for starting leak detection activities.

	Volume (MG)	
Category	DMA 1	DMA 2
Zone Meter 1	5.0	-
Zone Meter 2	2.8	2.8
Billed, metered	1.6	2.3
Billed, unmetered	0.1	0
Flushing, metered	0.1	0
Flushing, unmetered	0	0.1

Solution:

Phil starts with DMA 1 and calculates the water loss (MG and %). Note that the sum of the flow into DMA 1 is Meter 1 minus Meter 2 since Meter 2 records the flow that exits the DMA.

$$\begin{aligned}\text{Water loss}_{\text{DMA1}} &= \sum \text{zone meters} - \sum \text{billed authorized} - \sum \text{unbilled authorized} \\ &= (5 - 2.8) - (1.6 + 0.1) - (0.1 + 0) = 0.4\ \text{MG}\end{aligned}$$

$$Percent\ Loss_{DMA1} = \frac{0.4\ MG}{(5.0-2.8)MG} = \mathbf{18.2}\%$$

$$\begin{aligned}\text{Water loss}_{\text{DMA2}} &= \sum \text{zone meters} - \sum \text{billed authorized} - \sum \text{unbilled authorized} \\ &= 2.8 - (2.3 + 0) - (0 + 0.1) = 0.4\ \text{MG}\end{aligned}$$

$$Percent\ Loss_{DMA2} = \frac{0.4\ MG}{2.8\ MG} = \mathbf{14.3}\%$$

The percent loss is higher in DMA 1 (18.2%). Therefore, DMA 1 appears to have more leakage and should be the first for leak detection activities.

Leak Detection Techniques

Leak detection is an essential part of water loss control. It is often the most rewarding as you can physically see the water loss being stopped when a leak is found and the pipe is repaired. It can also be frustrating when a pipe break is reported on a pipe that was recently investigated with a leak detection technique with no leaks found. Common techniques to locate leaks are summarized below.

Manual Acoustic Leak Detection

Acoustic leak detection has been used for decades around the world and remains the most common method of finding leaks. It involves listening to sounds coming from the pipe wall or the nearby soil. Leaks produce a signature noise as the water sprays out from the pipe. When a leak noise is identified, the technician will pinpoint the location and mark it for excavation.

Contact points are used to pick up vibrations in the pipe wall. Examples of convenient access points are fire hydrants, curb stops, valve nuts, or touching the pipe in a meter box. A probe rod can also be used to push through the soil and touch the top of the pipe.

The following are acoustic leak detection methods:

- Ground-microphone method: The technician uses a monophonic or stereophonic microphone to listen for noise at ground level directly above the pipe. See Figure 18 for an example on a paved surface.
- Correlator method: This uses a device called a leak noise correlator unit, which has a receiver, processor, and two sensors (transducer or hydrophone). The sensors communicate by radio to the receiver. Each sensor is placed on a contact point such as a valve or hydrant, typically a few hundred feet apart. The distance, pipe material, and diameter are entered into the correlator. The device compares the vibrations in the two sensors to identify a leak signature and estimate the distance from each sensor. See Figure 18 for an example.
- Probe method: The technician uses a t-handle probe rod to touch the top of the pipe and listen for a leak. A small hole may need to be drilled through the pavement and compacted fill for the probe rod to get to the pipe.
- Inline leak detection sensor: An acoustic sensor is inserted into a large diameter water main and allowed to float down the pipe. The sensor may be a free-flowing ball that can be retrieved at a predetermined location. Or the sensor can be

tethered with a long cable. Tethered sensors may include a camera for CCTV viewing of the pipe wall and visual confirmation of leaks.

- Automated leak detection: Acoustic sensors can be mounted at contact points and left to collect data for days or months. Some automated acoustic devices have batteries and radio communications systems to allow for the real-time collection of data. A benefit to an automated device is that it can listen for leaks during very low flows and peak flows. However, the range is only a few hundred feet on PVC pipes, and installing many devices is expensive.

Figure 18: Technician using a correlator (left) and ground-mic (right).

Source: https://concordma.gov/1647/Water-Main-Leak-Detection (public domain)

Satellite Survey

Special satellite images can be used to identify areas on the ground with a high likelihood of having a potable water leak. Potable water has water quality parameters, such as the dielectric constant, that differ from groundwater, surface water, or saltwater. Satellite images can be studied along the route of water pipes to find evidence of leaks that are saturating the ground and giving off the signature of potable water. After identifying potential areas, an acoustic technician can listen for leaks in those areas and pinpoint the leak location.

Tracer Gas Method

Hydrogen or helium gas is injected into a water main through a standard tap or fire hydrant. The gas moves with the flow of water and escapes out any leaks. Once out of the pipe, the gas rises to the surface since it is very light. The escaped gas can be detected by gas sensing instruments carried by a technician, thereby pinpointing the leak location.

Ground-penetrating Radar

Ground-penetrating radar (GPR) is commonly used to locate buried pipes. It can also find pipe leaks if the soil around the leak creates a void in the soil. A transmitter sends short-duration pulses of high-frequency electromagnetic energy down into the ground. Buried objects, voids, and anomalies reflect a signal to the receiver. GPR is not commonly used for leak detection work, however, leaks are often inadvertently discovered during pipe locate services.

Thermography

The ground surface near an active leak is likely cooler or warmer than the surrounding soil as the potable water temperature typically differs from groundwater or surface temperatures. An infrared radiation image can capture this temperature differential. A high-resolution commercial infrared camera is required. Drones can be equipped with infrared cameras for this purpose.

Pressure Testing

Hydrostatic testing is done during pipe installation to confirm there are no leaks. These same procedures can be repeated on sections of existing buried piping. However, if the pressure does not hold in a section of existing pipe, the valves may not be sealing. New isolation valves would need to be installed or temporary pipe plugs installed. For this reason, pressure testing is not often done on existing piping.

Pressure Monitoring

Another approach using pressure is to record the pressure changes when isolation valves are closed. In a sealed pipe, when an isolation valve is closed quickly, there will be a pressure transient through the pipe. In a pipe with significant leakage, when an isolation valve is closed quickly, the pressure transient will be less as pressurized water will escape out the leaks. A pressure transmitter can be installed on the section of the pipe to record the pressure changes when valves are closed and help determine if a leak is present.

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