Water Loss Management

United Nations Educational, Scientific and Cultural Organization

i-WSSM
International Centre for Water Security and Sustainable Management

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Introduction

Water Loss Management

1. Introduction

UNESCO i-WSSM
United Nations Educational, Scientific and Cultural Organization
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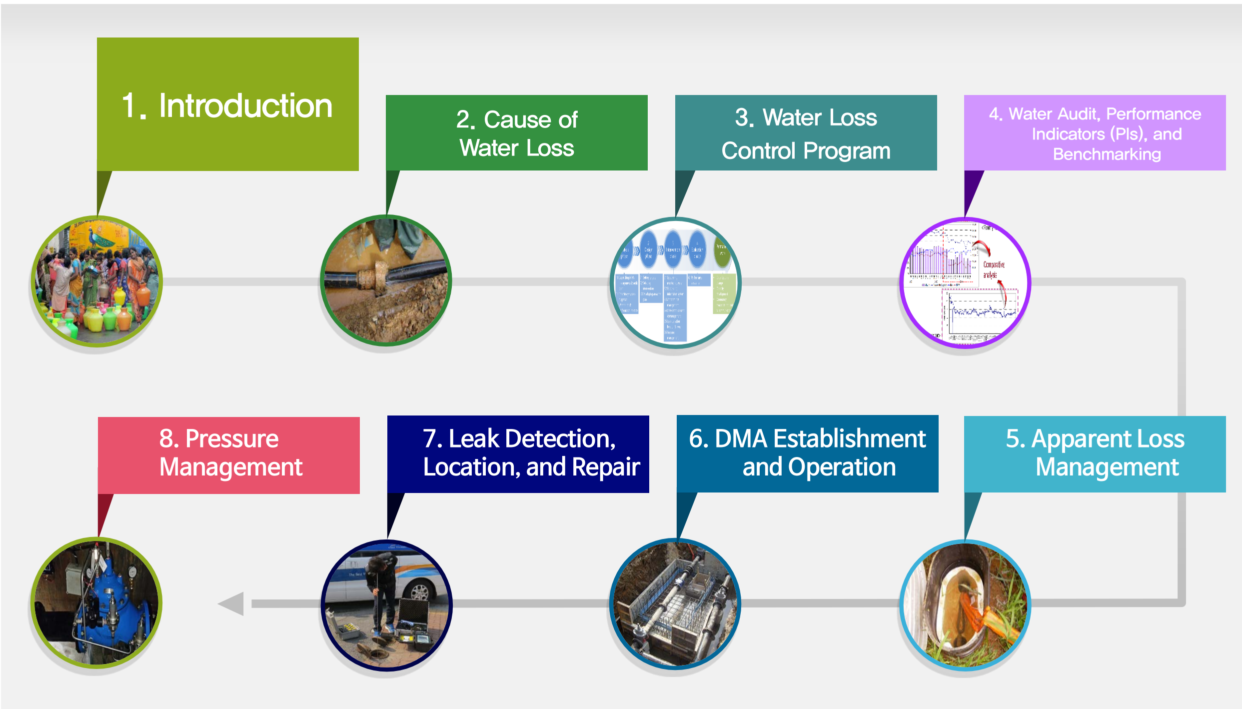
Training Course



Aims & Objectives

- Aims of the course:

  Provide trainees with basic knowledge before proceeding with the course on water loss management

- Objectives: To enhance the trainees' understanding of:

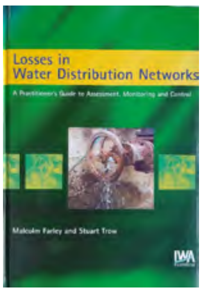
  (1) Vicious and virtuous cycles in water loss management;
  (2) Types of water loss;
  (3) Characteristics of water loss.

References

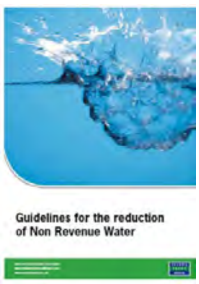
A Manual of DMA Practice
(UKWIR, 1999)

Leakage Detection and Management
(Butler, 2000)

Leakage Management and Control
(Farley, 2001)



Losses in Water Distribution Networks
(Farley & Trow, 2003)



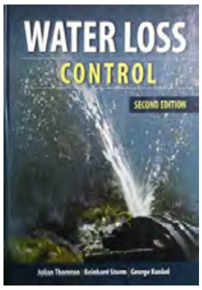
Guidelines for the Reduction of Non-revenue Water (Severn Trent Services, 2005)

Leakage Management Technology (Fanner et al., 2007)

References

Evaluating Water Loss and Planning Loss Reduction Strategies (Fanner et al., 2007)

The Manager's Non-revenue Water Handbook (Farley et al. , 2008)



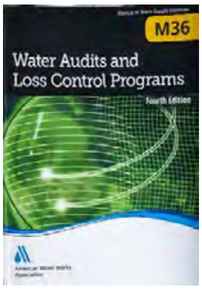
Water Loss Control (Thornton et al., 2008)

Control and Mitigation of Drinking Water Losses in Distribution Systems (AWWA, 2010)

Guidelines for Water Loss Reduction (GIZ, 2011)

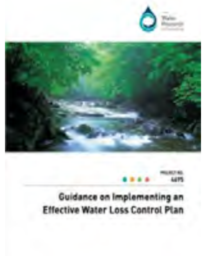
Guidelines for Reducing Water Losses in South African Municipalities (MCKENZIE, 2014)

References

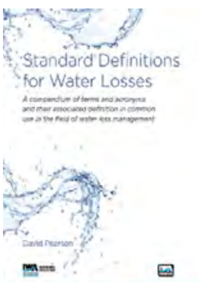


Water Audits and Loss Control Programs (AWWA, 2016)

Active Water Loss Control (EPAL, 2017)

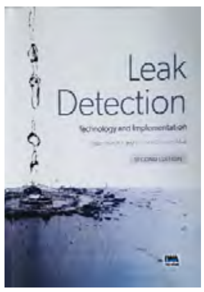


Guidance on Implementing an Effective Water Loss Control Plan (WRF, 2019)



Standard Definitions for Water Losses (Pearson, 2019)

Assessment of Performance Indicators for Non-revenue Water Target Setting and Progress Tracking (AWWA, 2019)



Leak Detection Technology and Implementation (IWA, 2020)

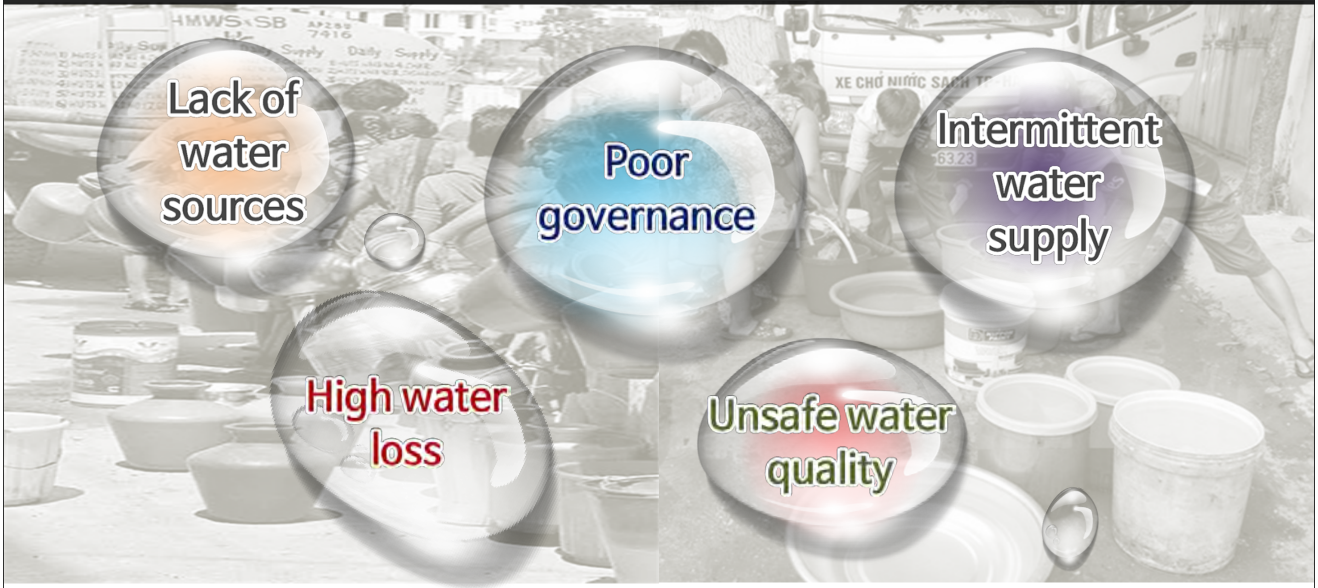
Contents

1. Overview

1.1 Background
1.2 Changes in Perception of Water Loss
1.3 Stakeholders

1.1 Background

- Challenges in water supply: The common water supply problems in several cities are related to the sources and use of raw water, intermittent supply, high water loss, and quality of tap water at the consumers' end



[Challenges in Water Supply]

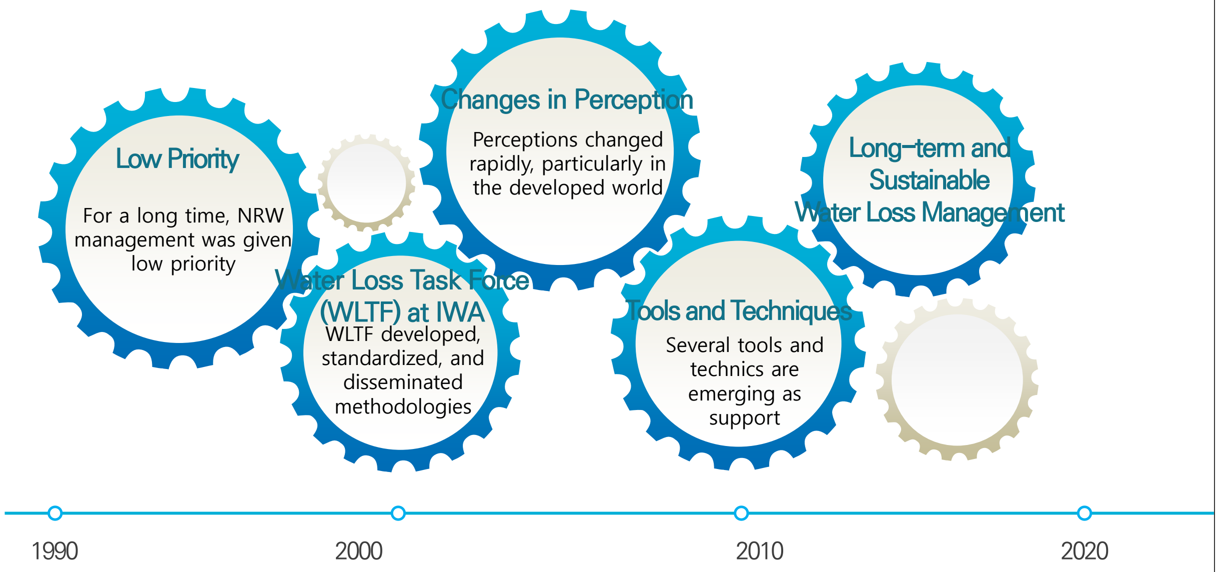
1.1 Background

- Problems of water loss: Water loss remains a major concern for all water supply systems due to wastage, technical burdens, contamination, and revenue losses to water utilities

[Main Problems caused by Water Loss]

1.2 Changes in Perception of Water Loss

- **Changes in Perception: Governments and water utilities have realized that reducing water loss is critical, thus leading to the rapid change in the perception of water loss management**



[Changes in Perception of Water Loss]

1.3 Stakeholders

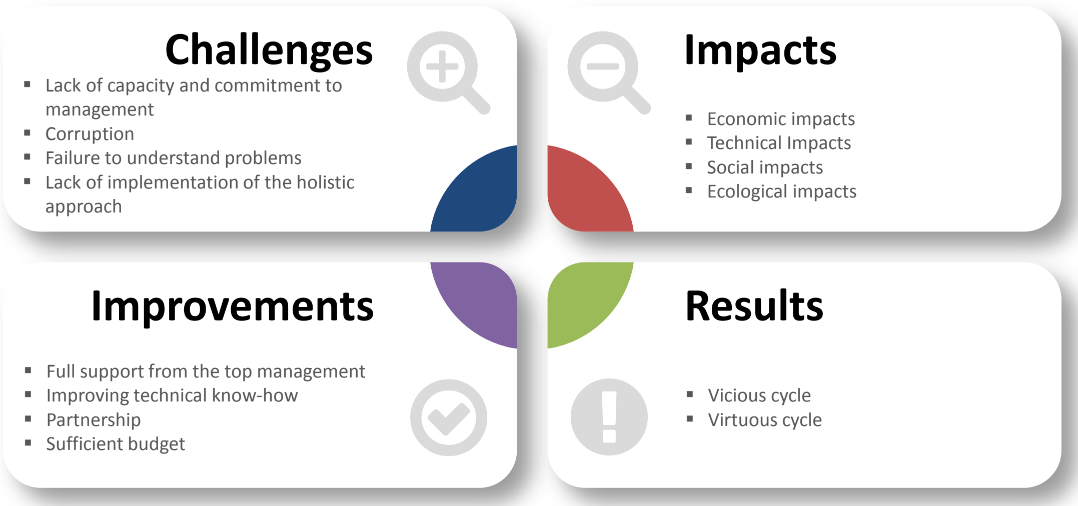
- **Collaborative governance: A water association, individual local water utilities, or the public sector can act as the driving force behind the introduction of water loss control programs**

[Stakeholders in Water Loss Management]

2. Challenges, Impacts, Results, and Improvement

2.1 Challenges, Impacts, Results, and Improvements

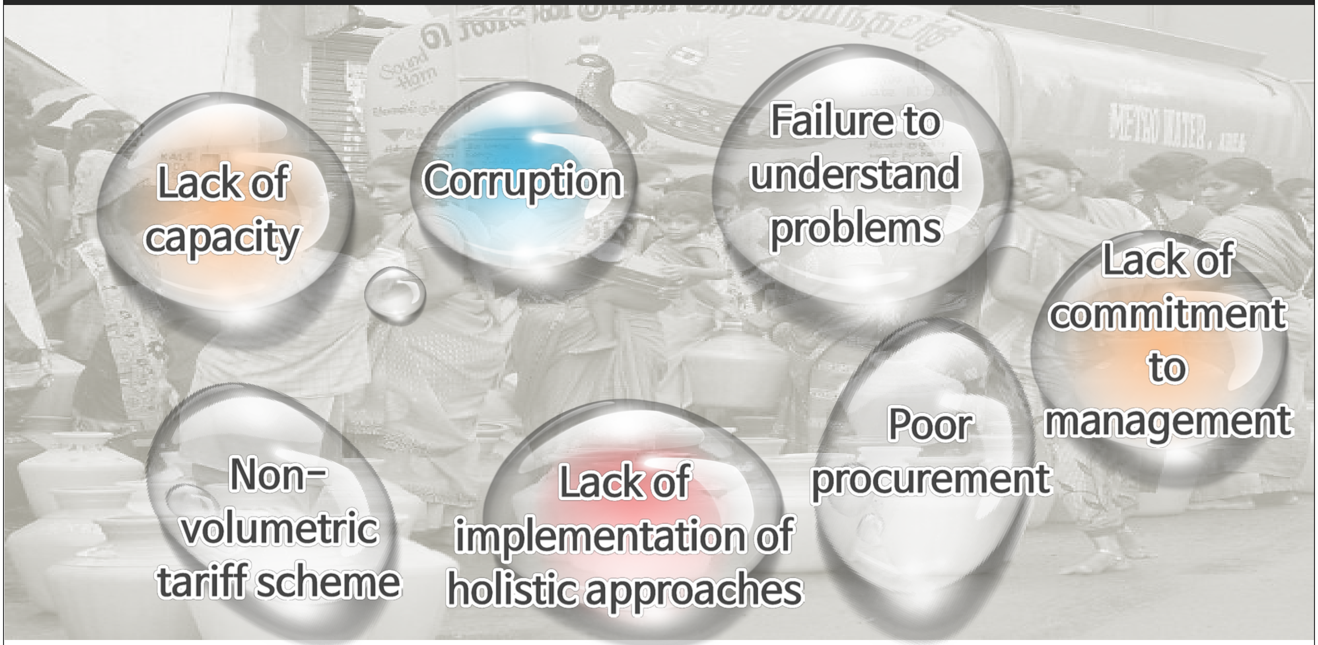
- **Effect of water loss: Many challenges lead to negative impacts, which result in a vicious cycle. To shift to a virtuous cycle, several improvements are required.**



[Challenges, Impacts, Results, and Improvement From the Water Loss Point of View]

2.2 Challenges in Water Loss Management

- **Challenges: Complex reasons can explain the struggle of utilities in controlling NRW**



[Challenges in Water Loss Management]

2.3 Impacts of Poor Water Loss Management

- **Impacts: In the operation of water supply systems, water losses are a clear obstacle to sustainability, as evidenced by the following potential impacts**
  - NRW exerts a serious impact on the financial viability of water utilities through loss of revenue, loss of water resources, and increased operational costs

Economic Impacts
- Increased production and maintenance costs
- Loss of revenue and increased tariff
- Damage to infrastructure
- Reduced reinvestment

Technical Impacts
- Reduced coverage
- Increased unstable (intermittent) water supply
- High head loss
- Increased loading on wastewater systems

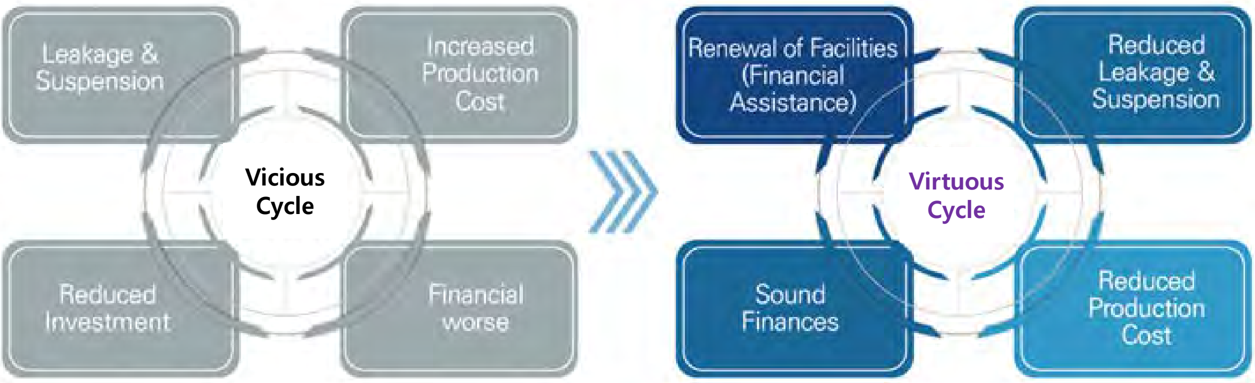
Social Impacts
- Increased dissatisfaction and complaints
- Decreased willingness to pay
- Inequity
- Increased health risks

Ecological Impacts
- Increased water extraction

[Negative Impacts of Poor Water Loss Management]

2.3 Results of Poor Water Loss Management

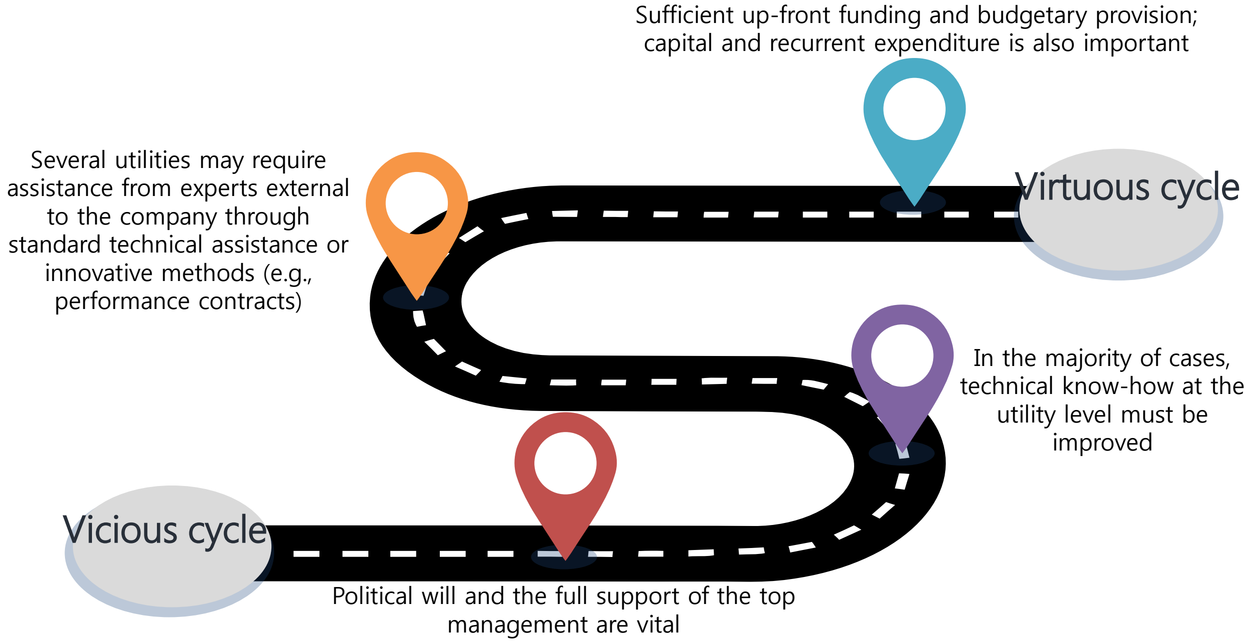
- **Vicious cycle: Water collection, treatment, and distribution costs increase, whereas water sales decrease with the loss of a utility's product (treated water). Moreover, substantial capital expenditure programs are frequently promoted to meet the ever-increasing demand. In other words, the utility enters a vicious cycle that does not address the core problem**



[Vicious Cycle vs. Virtuous Cycle]

2.4 Improvement in Poor Water Loss Management

- **Shifting from a vicious to a virtuous cycle: Many actions are required to enable this transformation**



[Shifting from a Vicious to a Virtuous Cycle]

3. Types of Water Loss

3.1 Terminology
3.2 Classification of Real Loss
3.3 Classification of Apparent Loss

3.1 Terminology

- **Terms: Standardized terminologies are a precondition for water loss management**
  - Terminologies are well explained and defined in Standard Definitions for Water Losses (Pearson, 2019)

Water loss
Total water loss pertains to the difference between the amount of water produced and amount billed or consumed

Leakage
Leakage is one of the components of the total water loss in a network and comprises physical losses from pipes, joints, and fittings and from overflowing service reservoirs

Water waste
Deliberate waste (e.g., standpipe vandalism and tap left "open" permanently in areas with intermittent supply to fill vessels when supply returns, which then overflows)

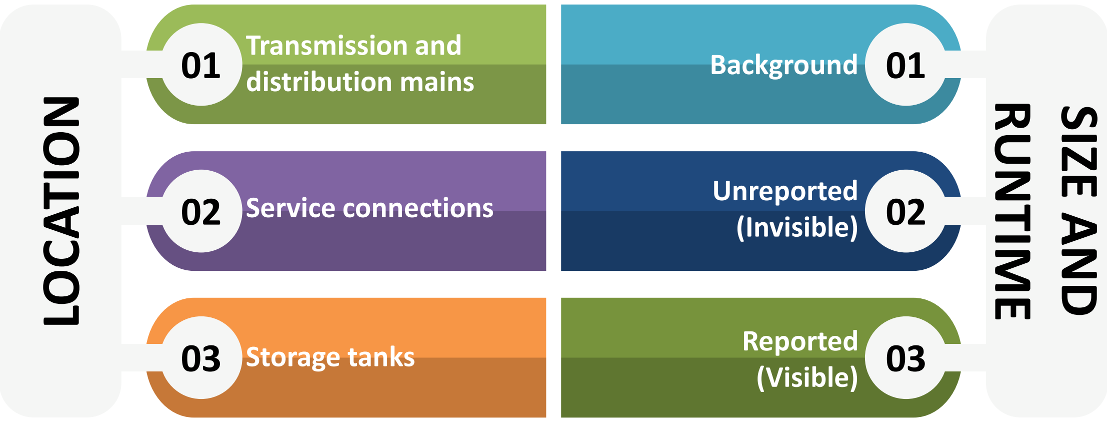
Real loss
Real loss denotes loss from the pressurized system and from the utility's service reservoirs to the point of supply

Apparent loss
Apparent loss includes all types of inaccuracies associated with customer metering, data handling errors, and unauthorized consumption

[Definition of Terminologies in Water Loss Management]

3.2 Classification of Real Loss

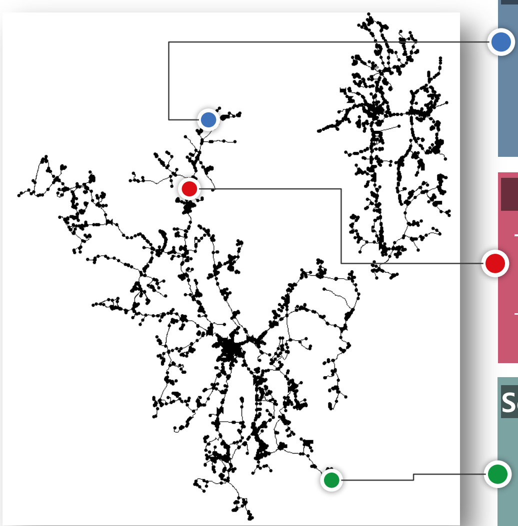
- **Classification of real loss: Real losses can be classified according to location within the system or size and runtime**



[Classification of Real Loss]

3.2 Classification of Real Loss

- **Location: This classification is typically used when the IWA water balance is calculated**



Storage tanks
- Water loss is caused by deficient or damaged level controls
- Seepage may occur from masonry or concrete walls that are not watertight
- Water losses from tanks are frequently underestimated and, although easy to detect, repair is elaborate and expensive

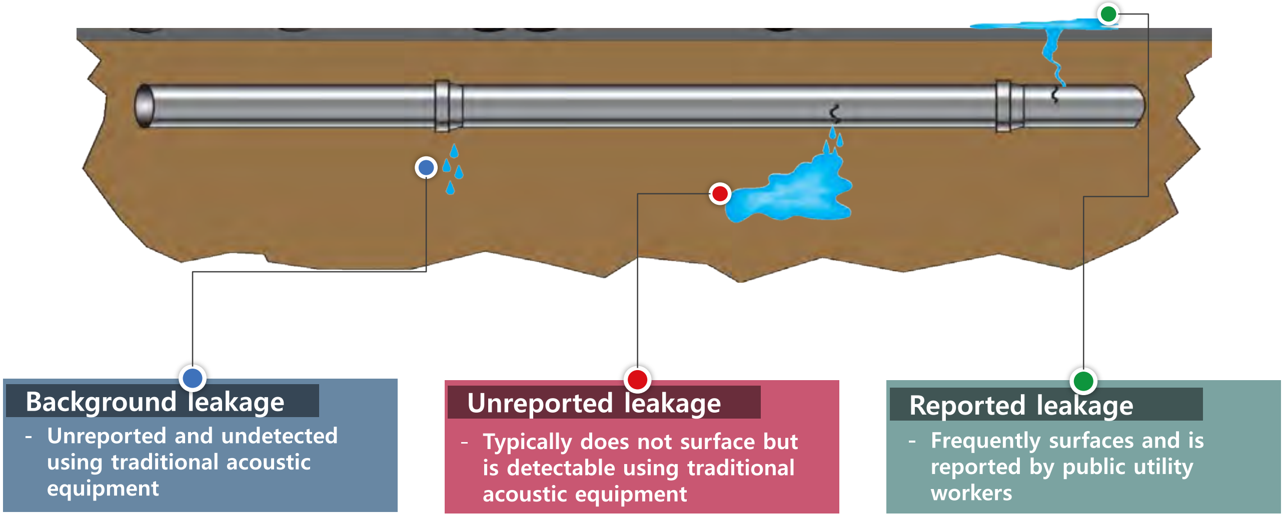
Transmission and distribution mains
- Water loss may occur in pipes (bursts due to extraneous causes or corrosion), joints (disconnection and damaged gaskets), and valves (operational or maintenance failure)
- Water loss typically reaches medium to high flow rate and short to medium runtime

Service connections
- Water loss is in the form of leakage from service connections up to the point of the customer meter
- Service connections are oftentimes referred to as the weak points of water supply networks because their joints and fittings exhibit high failure rates

[Classification of Real Loss Based on Location]

3.2 Classification of Real Loss

- **Size and runtime: This classification is used when minimum night flow analysis is implemented**



[Classification of Real Loss based on Size and Runtime]

3.2 Classification of Real Loss

- **Background leakage: Background leaks are basically extremely small leaks that tend to run unnoticed, which can last for years and may not create any problems until they eventually grow into large leaks**

Background Leakage

Sharing: "Background leaks frequently make up the major proportion of real water loss due to their great number and long runtimes."

Difficult to repair: "Even if background leaks could be detected, repairing them would not be cost effective because the costs involved would be orders of magnitude higher than the value of the water that could be saved."

Control: "Although background leakage can never be eliminated completely, it can be controlled to a certain extent through pressure management or, as a last resort, by pipe replacement"

[Background Leakage]

3.2 Classification of Real Loss

- **Burst leakage (unreported & reported): The normally accepted definition of burst leakage is that they amount to more than 250 l/h at a 50-m pressure**

Reported and unreported leakage

Leakage amount: "Burst leakage occurs on mains and connections. Such leaks on mains tend to be spectacular and can range in size from below 2 m^3/h to more than 1,000 m^3/h, although the average leak in mains is likely between 2 m^3/h and 4 m^3/h."

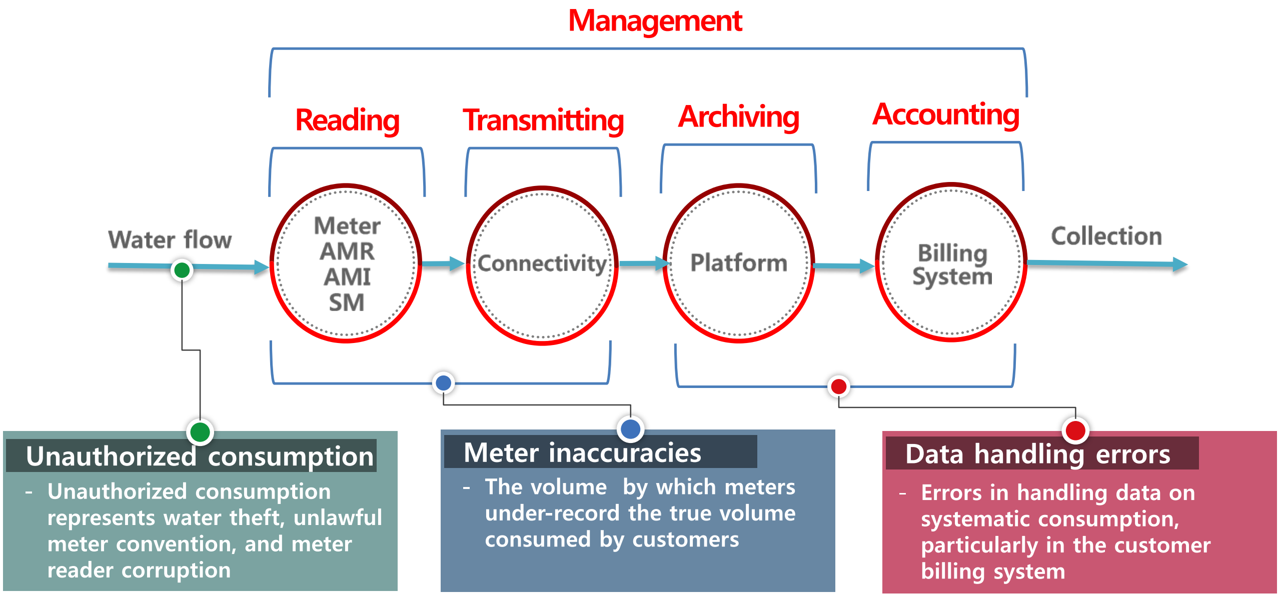
Definition: "By definition, unreported or hidden leaks have flow rates greater than of 250 l/h at 50 m pressure but do not appear at the surface due to unfavorable conditions."

Methods for detection: "Methods for leak detection primarily aim to locate unreported leakage, which accounts for the majority of water loss due to leakage in many water distribution systems."

[Reported and Unreported Leakage]

3.3 Classification of Apparent Loss

- **Classification of apparent loss: Apparent loss consists of three main elements, namely, meter inaccuracies, data handling errors, and unauthorized consumption**

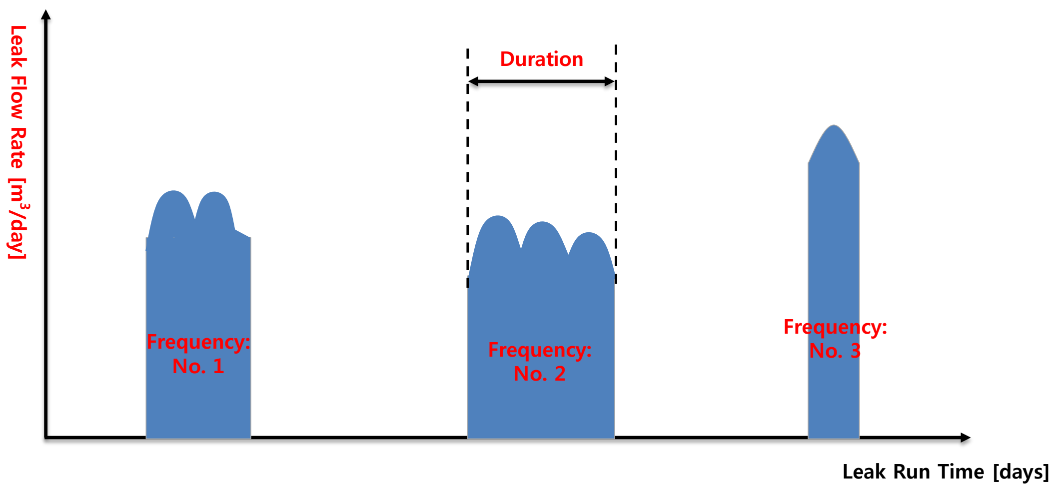


[Classification of Apparent Loss]

4. Volume of Water Loss

4.1 Influencing Factors

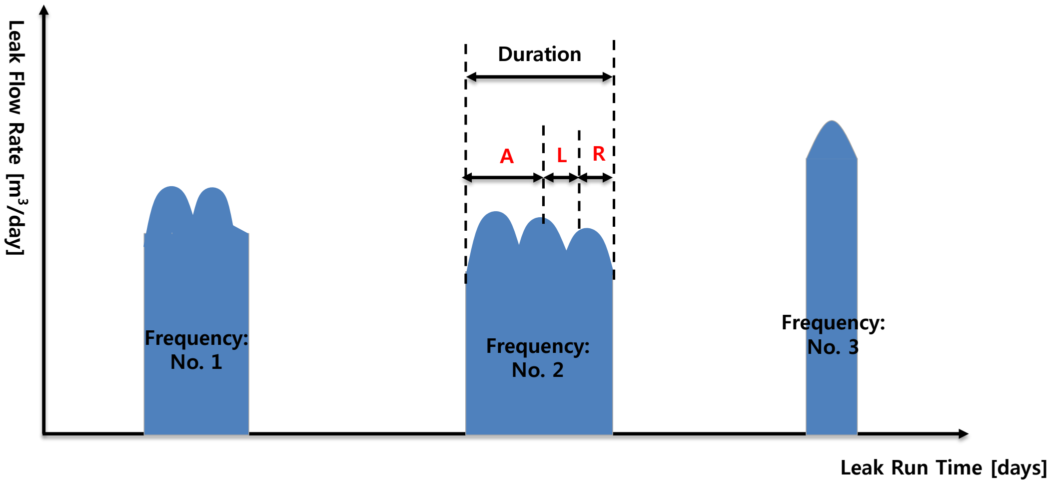
- **Influencing factors: Leak flow rate, duration, and burst frequency influence the volume of water loss**
  - Therefore, the volume of water loss is mainly dependent on the characteristics of the pipe network and leak detection and repair policies practiced by a company



[Factors that Influence Total Water Loss]

4.2 Duration: ALR Time Concept

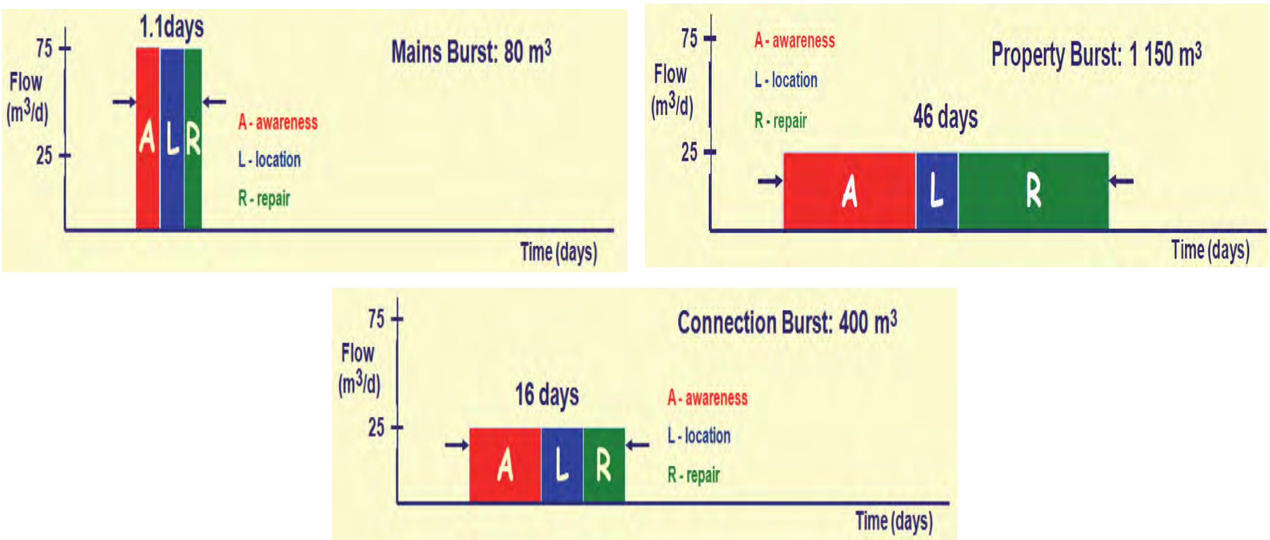
- **ALR concept: Leak duration (runtime) consists of three time components:**
  - Awareness: time until the utility becomes aware of the existence of a leak
  - Location: time spent to precisely locate the leak to enable the issuance of a repair job order
  - Repair: time between the issuance of the repair job order and completion of the repair



[Time Concept of ALR]

4.2 Duration: ALR Time Concept

- **ALR difference: If awareness time largely determines the volume of water loss from a pipe burst, then utilities should implement a strategy for reducing awareness time**

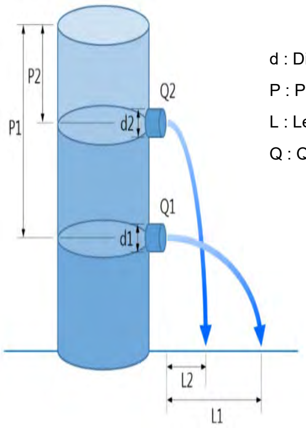


[ALR Difference According to Burst Location]

Source: Mckenzie (2014)

4.3 Leak Flow Rate

- **Pressure versus flow rate: The flow rate typically increases with the exponential growth in pressure**
  - Leakage discharge tests show that water loss from a single circular hole with a diameter of 6 mm in a distribution pipe with a 50-m pressure equals 1.8 m^3/h (1,300 m^3/month)



d : Diameter (㎜); d1 = d2
P : Position head (m)
L : Length (m)
Q : Quantity (㎥)

[Hydraulic Relation Between Pressure and Flow]

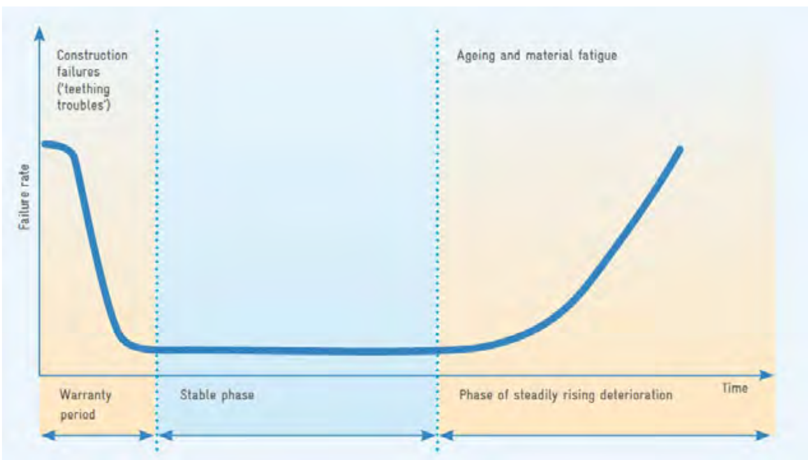
	Orifice		Leakage flow rate		
	[mm]	[l/min]	[l/hour]	[m^3/day]	[m^3/month]
	0.5	0.33	20.00	0.48	14.40
	1.0	0.97	58.00	1.39	41.60
	1.5	1.82	110.00	2.64	79.00
	2.0	3.16	190.00	4.56	136.00
	3.0	8.15	490.00	11.75	351.00
	4.0	14.80	890.00	21.40	640.00
	5.0	22.30	1,340.00	32.00	690.00
	6.0	30.00	1,800.00	43.20	1,300.00
	7.0	39.30	2,360.00	56.80	1,700.00

[Leakage Flow Rate for Circular Holes at a 50-m Pressure]

Source: GIZ (2011)

4.4 Burst Frequency

- **Linear relation: The amount of leakage is linearly related to burst frequency. Experience shows that failures accumulate at the beginning (construction failure) and end (i.e., material fatigue and corrosion) of the useful life of discrete pipe sections, such as a bathtub curve**



[Typical Behavior of Failure Rate in Pipes]

Source : GIZ (2011)

5. Visible and Invisible Leakage

5.1 Visible and Invisible Leaks

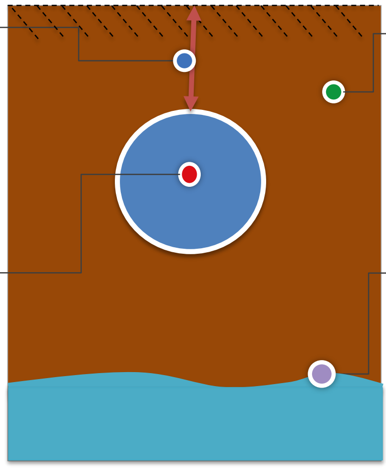
- *Visible leakage* **will appear as clear water on the surface. If pipes are pressurized, then water bubbling up to the surface may be detectable.**
  - A possible scenario is that visible leaks have been running for a relatively long time, and vegetation may indicate the presence of a leak despite the absence of water on the surface.
- **Controversial subject: The actual distinction between visible and invisible leaks is a debatable point and may vary according to area**
- **Active leak control (ALC) for detecting invisible leaks: If invisible leaks are dominant, then active leakage policies should be implemented.**

5.2 Influencing Factors

- **Influencing factors of visibility: To understand why some leaks are visible on the surface, whereas others remain underground and invisible, the following factors should be considered.**

Depth
- The most important possible factor is the depth in which the pipe has been buried

Average pressure
- If the water pressure is high, then the chance of a leak surfacing is greater than that for cases where the system pressures are very low



Soil type
- In certain types of soil, such as clay, water from underground leaks may be visible on the surface relatively quickly, whereas similar leaks in chalk or sandy soil can continue indefinitely without showing

Ground water level
- If the ground water is close to the surface, even if a leak will come to the surface, it may be confused with normal groundwater and therefore be difficult to detect from visual inspection

[Influencing Factors of Leak Visibility]

5.3 Two Perspectives on Invisible Leakage

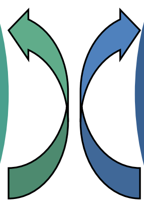
- **Two perspectives: Major water distribution experts hold two major views on how the problem should be considered**
- **Confirmation: The only method for determining leaks is to undertake a pilot study in a small area before embarking on a city-wide leak location exercise**

Visible leak: dominant

"In general, approximately 90% of water physically lost from leaks are not visible on the surface."

"Oftentimes, undetected leaks can be relatively large, such as those that run directly into a sewer or a drain."

"Water loss from large-diameter pipes can be significant in low-pressure systems, where leaks may not be visible on the surface and remain unnoticed for many years ."



Invisible leak: dominant

"Although the breakdown of visible and invisible leaks may be appropriate for many parts of the world, it may be inappropriate for other parts."

"The ratio between visible and invisible leaks is not 10 to 90. In many cases, the virtual opposite appears to be true."

"This opinion will draw considerable criticism especially from those selling leak-location equipment."

[Two Views on Invisible Leak]

5.3 Two Perspectives on Invisible Leakage

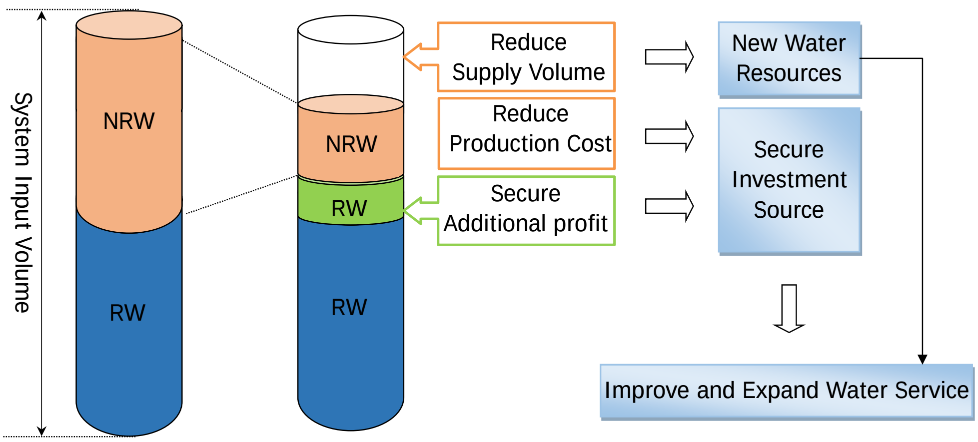
[Cases of Visible Leakage]

Courtesy of K-water

6. Concept of Water Loss Management

6. Concept of Water Loss Management

- **Water loss management: By reducing NRW, water utility services can reduce the supply volume and secure additional profit**
  - Reducing excessive real water loss results in the greater amount of water available for consumption and postpones the need for investing in new sources
  - Similarly, reducing commercial losses generates additional revenues with a short payback period



[Concept of Water Loss Management]

Cause of Water Losses

Water Loss Management

2. Causes of Water Losses

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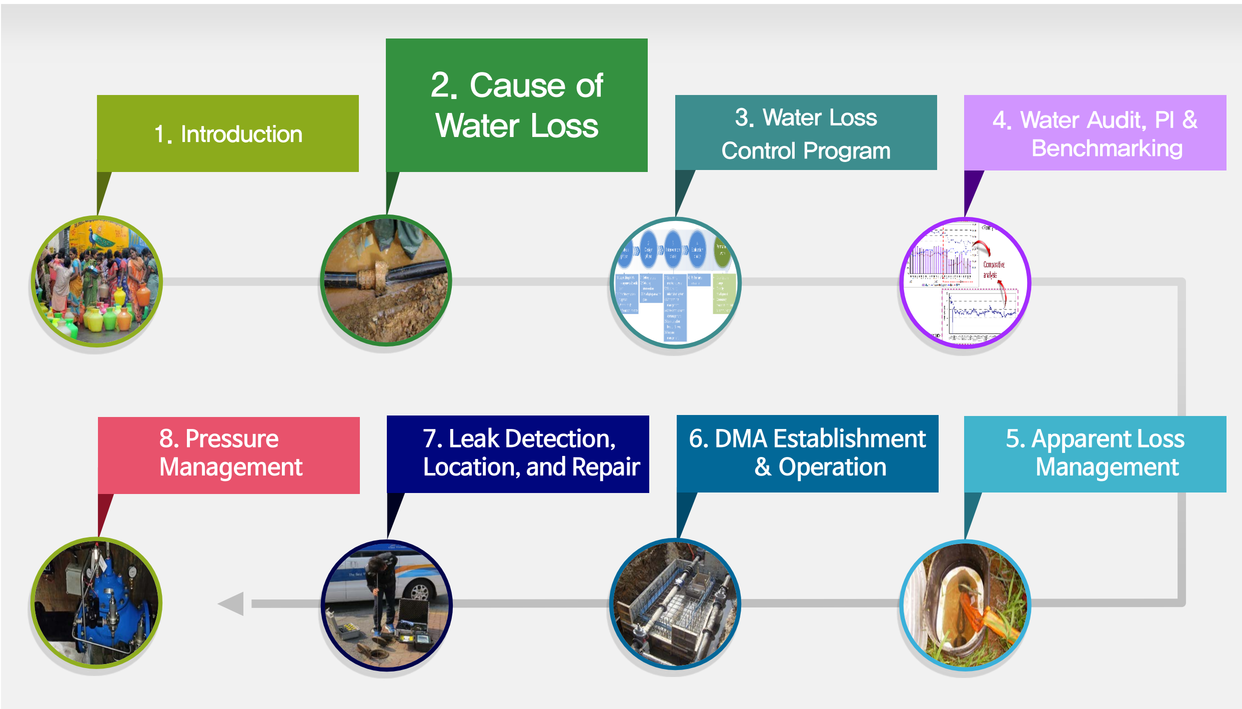
Training Course



Aims & Objectives

- The aims of the course are to:

(1) Promote among trainees a good understanding of the causes of water loss according to the types
(2) Enable trainees to identify the main leakage causes of their system

- The objectives are that trainees will understand:

(1) Causes of real loss
(2) Causes of apparent loss

Contents

1. Overview

1.1 Backgrounds

1.1 Backgrounds

- (Need understanding before intervention) Before deciding which intervention methods are appropriate in water loss management, a water utility has to understand which causes attribute to the water loss in their water supply systems

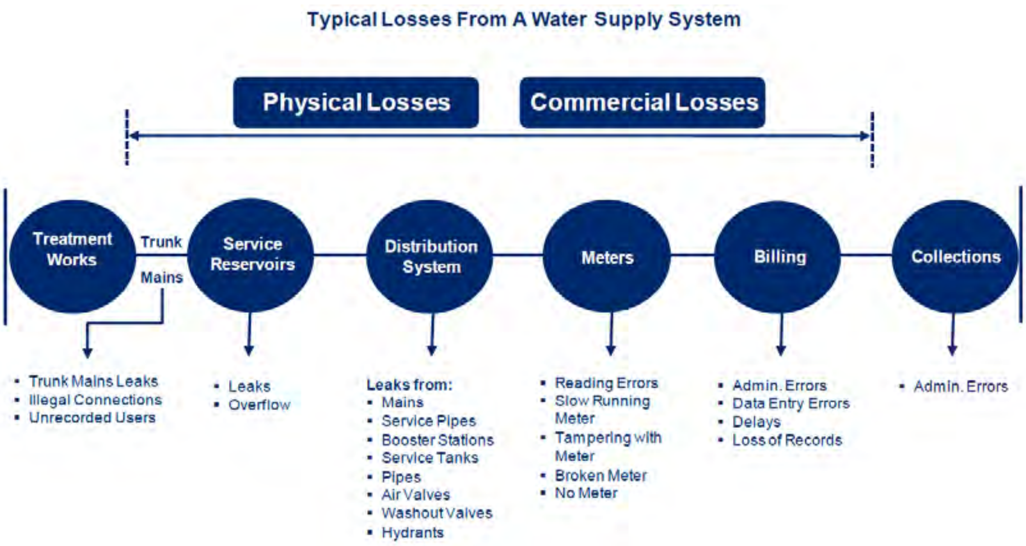
- (Systematic or technical) The causes of real loss and apparent loss can be mainly classified into systematic reason and technical reason

- (Compound influence) It is evident that various causes have a complex effect on the leakage of the system

- (Limitation of elimination) While apparent losses can be nearly totally eliminated, a certain level of real losses (i.e. unavoidable real losses) will always remain in any water supply system

1.1 Backgrounds

- **(Water losses location) Real losses are highly related with water supply pipeline and apparent losses are mainly related with billing process**



[Chart to Help Staff Understand NRW Components]

Source : Farley et al. (2008)

1.1 Backgrounds

- **(Dominant part in water losses) In developed countries, real losses usually represent the most important component of water losses**
  - However, in developing and emerging countries losses due to illegal connections, metering and accounting errors (i.e. apparent losses) may often be of major significance to water utilities

- **(Misconception) When people think about leakage, they normally think of big and spectacular pipe burst**
  - They often cause a lot of damage but are insignificant in volume compared to all the other leaks that do not come to the surface
  - Normally most of real loss can not be seen on the surface

- **(Overlooking apparent losses) In contrast to real losses, the apparent losses are not visible, which lead many water utilities to overlook apparent losses and concentrate instead on real losses**

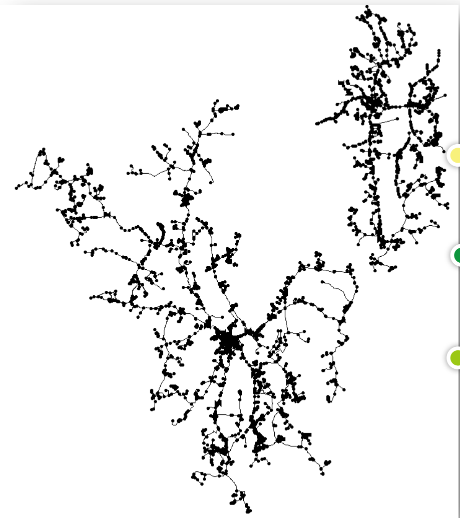
2. Causes of Real Losses

2.1 Causes of Real Losses
2.2 Pipe Deterioration Mechanism
2.3 Real Losses at Pipes & Joints, Valves, & Fittings
2.4 Real Losses at Reservoirs, Storage Tanks & Pumps

2.1 Causes of Real Losses

- (Causes of real losses) The multitude of active and passive interactions between water network component and their environment frequently lead to damage and leaks

Water Network Components | **Environment**



Design, installation, and workmanship

- ✓ Design, stock management
- ✓ Laying of pipes, bedding, backfill & compaction, execution of pipe joints
- ✓ Poor material, inappropriate use of material
- ✓ Repair & replacement

Operation & maintenance

- ✓ External & internal corrosion
- ✓ Aging problem
- ✓ High & low pressure

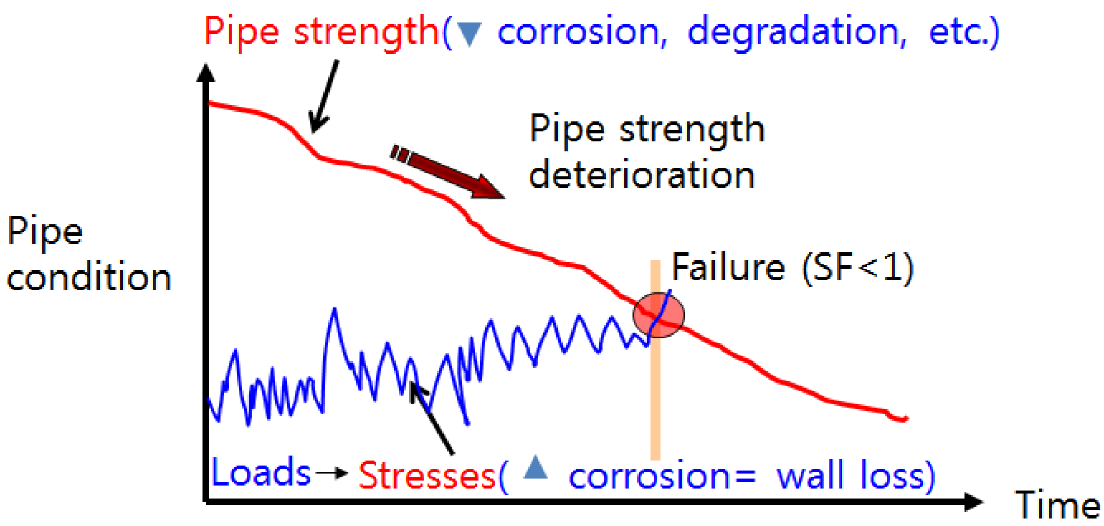
External Stress

- ✓ Soil and ground water
- ✓ Traffic
- ✓ Third-party influence

[Causes of Real Losses]

2.2 Pipe Deterioration Mechanism

▪ (Pipe deterioration) Over time, pipe strength are reduced due to corrosion or degradation, it will be resulted in physical failure



[Pipe Deterioration and Failure]

2.2 Pipe Deterioration Mechanism

(1) Unlined CIP/ DCIP

Inside

Local internal corrosion

Hole / crack / burst

Outside

Local external corrosion

Hole / crack / burst

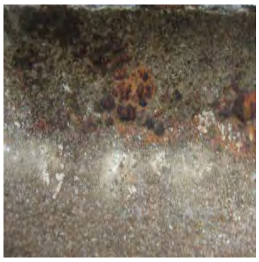
2.2 Pipe Deterioration Mechanism

(2) CML-DCIP

Inside

CML neutralization

CML is changed to sand



100% CML neutralization
Local internal corrosion

Hole / crack/ burst

Outside

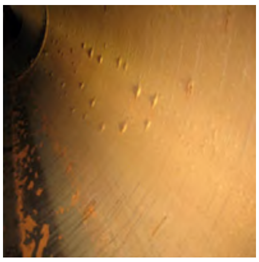
Local external corrosion

Hole / crack / burst

2.2 Pipe Deterioration Mechanism

(3) SP

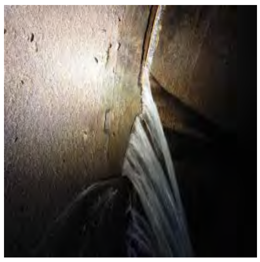
Inside



Void

Coating partial stripping

Exfoliation corrosion



Hole / burst

Outside

Coating damage

Local external corrosion

Hole / burst

2.2 Pipe Deterioration Mechanism

(4) Plastic (PE, PVC) Pipe

Inside & Outside

Deformation

Degradation

Burst

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

- **(Design, installation, and maintenance workmanship) Inappropriate design, installation and maintenance workmanship can cause the real losses in the water network**

Causes & factors influencing water losses		Details
Main	Sub	
Design, installation, and workmanship	Design	- Mistakes made during the planning phase may influence leakage from pipes, such as the incorrect material choice, insufficient dimensioning for the actual pressure, inadequate corrosion protection measures or incorrect alignment

[Pipe Burst caused by Two Pipes Contact]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage in Exposed pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage in Unorganized Service Connection]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
Design, installation, and workmanship	Storage of pipes	- Improper storage may damage pipes even before installation * Grass roots can penetrate the bituminous coating of steel pipes * Dragging PE pipes over concrete surfaces or stones will cause chambers which are more susceptible to future leakage * Extended sunlight exposure causes PE pies to become brittle
	Laying of pipes	- The quality of workmanship when laying the pipes is one of the most important factors influencing the leakage
	Bedding	- The selection of inappropriate material for pipe bedding is a frequent cause of damage * Coarse or rocky bedding material spoil external coatings on steel or cast iron pipes and support corrosion * Longitudinal and spiral cracks may appear in PE and PVC pipes as a result of stony bedding materials

[Leaks Caused By Inappropriate Bedding]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
Design, installation, and workmanship	Backfill & compaction	- Insufficient backfill and compaction of the pipe trench may cause subsidence * These uncontrolled soil movements can also trigger socket disconnection or pipe rupture

[Damage Caused by Casting Concrete above the Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage Caused by Bad Backfill]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
Design, installation, and workmanship	Improper installation of pipe and accessories	- Unprofessional execution of pipe joints is a further reason for leakage * Welded steel pipes often lack proper internal and external corrosion protection along the weld seam * If unskilled or poorly trained workers execute the butt fusion in PE pipes, it frequently contains defects due to insufficient heating and pressing of the pipe ends * Leakage can also occur if socket pipes exceed the maximum permitted angular bending or if water hammer and high pressure affect joints that are not force locked

[Leakage Caused by Bad Finish]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage at the Unproperly Deformed Pipe using Heat in the Field]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Improper Joint Connection]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage Caused by Excessive Joint Deflection]

Courtesy of K-water

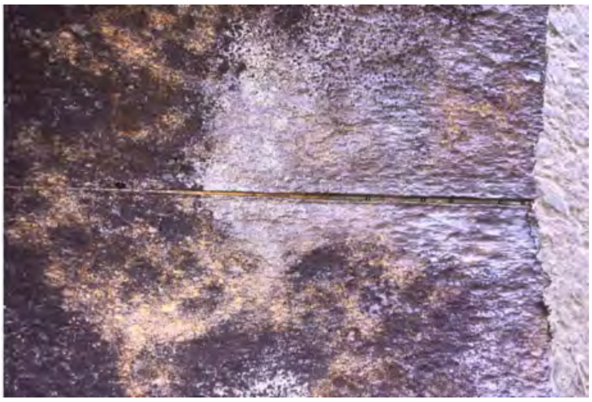
2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
Design, installation, and workmanship	Poor material	- Material failures can be happen because of manufacturing defects * Insufficient wall thickness * Poor internal and external protection (lining and coating) * Unreliable materials of pipes, joints, fittings, etc.
	Inappropriate use of certain material (suitability, cement neutralization)	- There is a great variation in the suitability of service and supply pipe materials (lead, galvanized iron, cooper, polyethylene, etc.) * Soft water with a high carbonic acid (CO2) content and low calcium concentrations, or with high sulphate concentrations are known to affect concrete aggressively

[Unreliable Casting Materials in DCIP]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Poor Welding in SP]

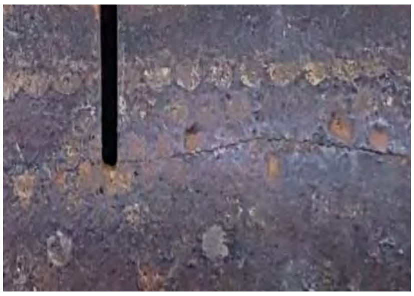
Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting



[Pipe Burst Caused by Poor Material DCIP and Stress Concentration]

Courtesy of K-water



[Pipe Burst Cased by Poor Material in DCIP]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Poor PE Joints]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
Design, installation, and workmanship	Inappropriate repair and replacement	- If improper repair or replacement of failure pipes or fittings can cause another leakages

[Improper Repair Using Tape]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Improper Repair Using a Wooden Needle]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Improper Repair Using a String or Rubber Band]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

- **(Operation & maintenance) The use of poor material, corrosion, infrastructure aging problem, and high & negative pressure causes real losses**

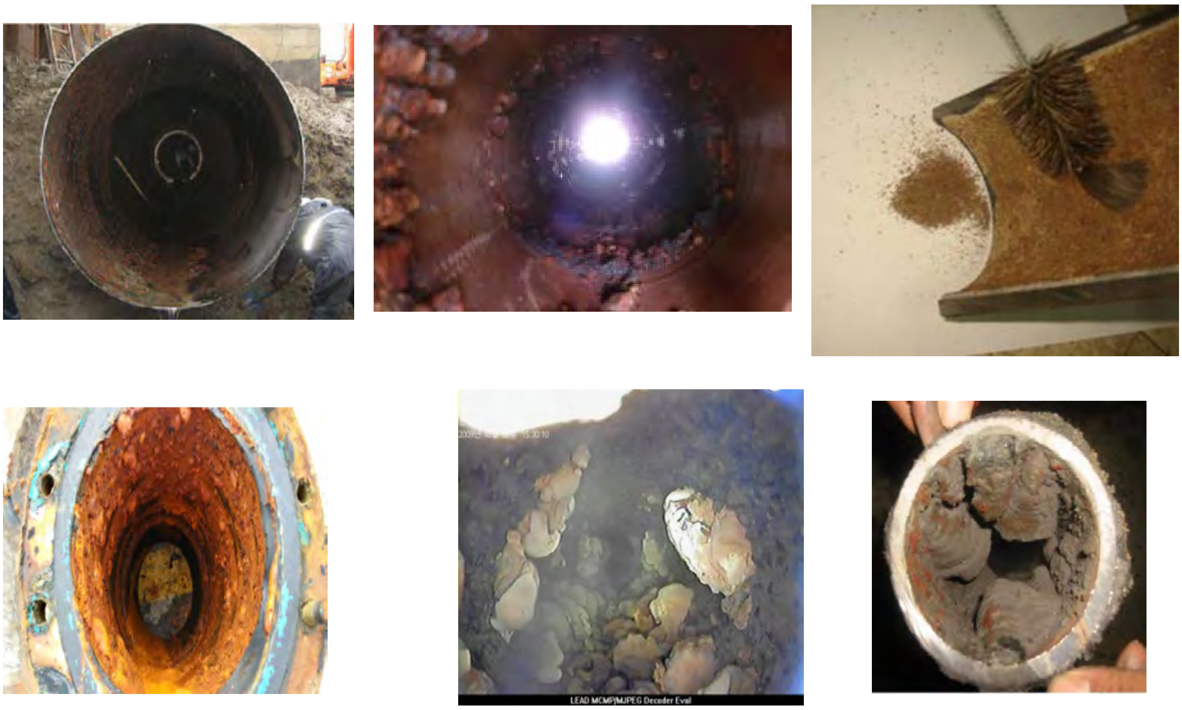
Causes & factors influencing water losses		Details
Main	Sub	
O&M	Condition (external & internal corrosion)	- All metallic pipes are exposed to physical and electro-chemical corrosion and it will reduce the wall thickness and decrease the pipe's ability to withstand water pressure and external stress - The most common causes of corrosion are aggressive water and soil as well as stray current * Internal corrosion is usually more sever in soft (acidic) waters from upland sources * Aggressive soils may cause external corrosion because of differing level of dissolved salts, oxygen, moisture, pH, and bacterial activity, leading to corrosion currents in the metal

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage Caused by Corrosion in Metallic Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting



[Internal Damaged Coating and Lining, Tubercle, and Scale in Metallic Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Internal Corrosion in Metallic Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Internal Hole, Crack, and Burst in Metallic Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[External Damaged Coating and Taping in Metallic Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[External Corrosion in Metallic Pipe]

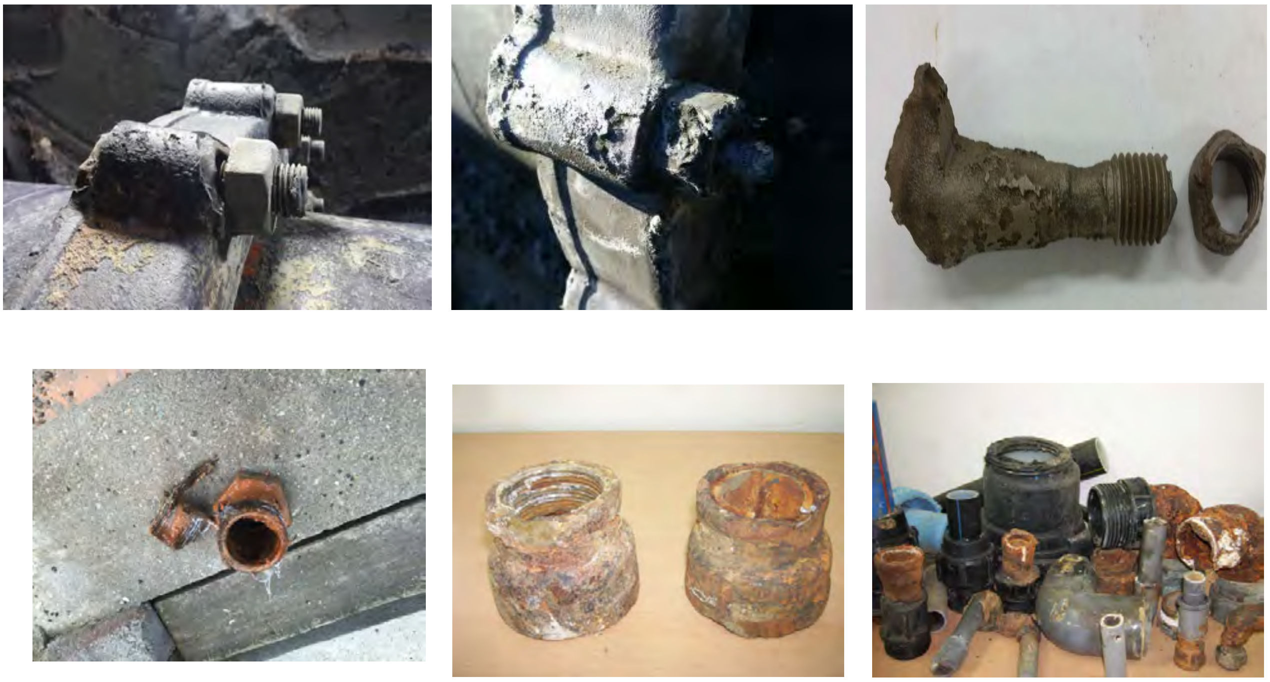
Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[External Hole, Crack, and Burst in Metallic Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting



[Corrosion of Pipe Accessories]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
O&M	Aging Problems	- Many factors influencing leakage are age-dependent - Consequently, the age of a pipe section can appear to be the most significant factor for leakage - Nevertheless, age is not necessarily a factor, if the pipe has been carefully designed and installed, maintenance is carried out at regular intervals and external conditions are favorable

[Leakage in the Aged Pipe #1]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage in the Aged Pipe #2]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Broken Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage in the Aged Joint #1]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage in the Aged Joint #2]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting






[Leakage at the Aged Valve #1]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting





[Leakage at the Aged Valve #2]

Courtesy of K-water

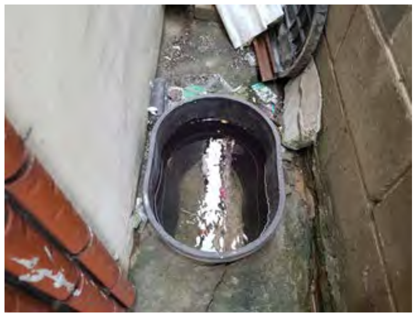
2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Closing the Leaking Valve]

[Leakage at the Air Valve]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting



[Leakage at the Meter Box]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage at the Saddle]

Courtesy of K-water

[Leakage at the Flange End Cap]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Leakage in the Bridge Crossing Pipe]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
O&M	Pressure: high Pressure	- Increasing pressure will result in a higher flow rate from existing leaks - High pressure will increase the pipe burst frequency

[High Leak Flow Rate in High Pressure]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Damages Caused by High Pressure]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
O&M	Pressure: low pressure	- Low pressure may complicate leak detection efforts because the water is less likely to reach the surface - Decreased noise levels from the leak in low pressure impede acoustic leak detection and may cause longer leak awareness time
	Pressure: pressure cycling	- Pressure cycling in the network due to bad operation may lead to material fatigue and thus to leakage, mainly in plastic pipes
	Pressure: water hammer	- Pressure surge (water hammer) can happen when a pump is tripped, or a valve is opened or closed too quickly - This can cause pipe fractures, disconnect joints and damage valves and fittings, move thrust blocks, or damage the socket hence leading to leakage - There is also some evidence that surge can cause pipes to flex and move against rocks, resulting in local stress concentrations, and sometimes pipe failure

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

- **(External load) External load caused by soil, ground water, and traffic can damage the pipes**
  - Unfortunately, water utilities can not control the weather, geologic conditions, or even traffic to any great extent

Causes & factors influencing water losses		Details
Main	Sub	
External force	Soil and groundwater : soil aggressiveness	- Cohesive soil may negatively affect the external corrosion of metallic pipes due to differing levels of dissolved salts, oxygen, moisture, pH and bacterial activity * Most non-cohesive soils are not aggressive
	Soil and groundwater : soil movement	- Soil movement may cause pipe joints to disconnect and pipes to rupture, or result in localized stress concentrations within the pipe leading to failure - Soil movement is caused by changes in the temperature and moisture content, heavy frost as well as subsidence prompted by incorrect pipe bedding, mining activities or earthquakes - Construction work, increased surface loads or pipe repair work may also trigger soil movement

2.2 Real Losses at Pipes, Joints, Valves, and Fitting



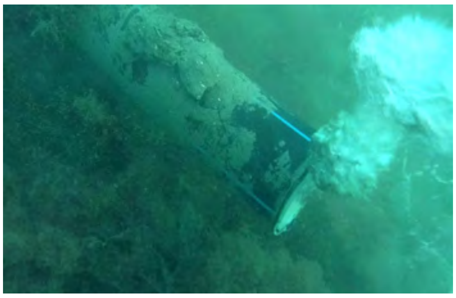
[Loss and Restoration of Pipelines due to Heavy Rain]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

Causes & factors influencing water losses		Details
Main	Sub	
External force	Traffic load	- More vehicles and the high loading trucks place an additional burden on the pipes
	Pavement	- The visible leaks may appear far away from the damage due to concrete and asphalt pavements, thus hampering leak location efforts
	Stray current	- Stray currents aggravate the external corrosion of metallic pipes
	Accidental or deliberate damage	- Accidents may be happen during the construction or other utilities installation if workers have wrong information on water pipelines





[Leakage from Pipe Broken by External Force]

Courtesy of K-water

2.2 Real Losses at Pipes, Joints, Valves, and Fitting

[Pipe Broken by External Force]

[Outside and Inside of Pipe Broken by External Force]

Courtesy of K-water

2.3 Real Losses at Reservoirs, Storage Tanks & Pump Stations

- **(Underestimation) Even though it is easy to detect and repair, water losses from reservoirs or tanks are often underestimated and left unattended**

Causes & factors influencing water losses		Details
Main	Sub	
Reservoir, Storage tanks & pumps	Reservoir and tank overflows	- Most overflows occur at night when demands are low and pumping schedule is not correct

[Overflow at Distribution Reservoir]

Courtesy of K-water

2.3 Real Losses at Reservoirs, Storage Tanks & Pump Stations

Causes & factors influencing water losses		**Details**
Main	Sub	
Reservoir, Storage tanks & pumps	Structure damage of reservoirs and tanks	- Structural damage involves cracks, holes or delamination at reservoir(or tank) walls or floors, leakage due to inferior concrete quality, as well as sealings and pie penetrations that are not watertight

[Delamination and Leakage at Distribution Reservoir Wall]

Courtesy of K-water

2.3 Real Losses at Reservoirs, Storage Tanks & Pump Stations

Causes & factors influencing water losses		**Details**
Main	Sub	
Reservoir, Storage tanks & pumps	Defective pump	- Water losses from pumps are usually caused by defective pump shaft seals - The amount of leakage is negligible in most cases, but flooding pump chambers and electric equipment is a nuisance and should be avoided by undertaking proper maintenance

[Leakage at the Valve and joint in Pump Station]

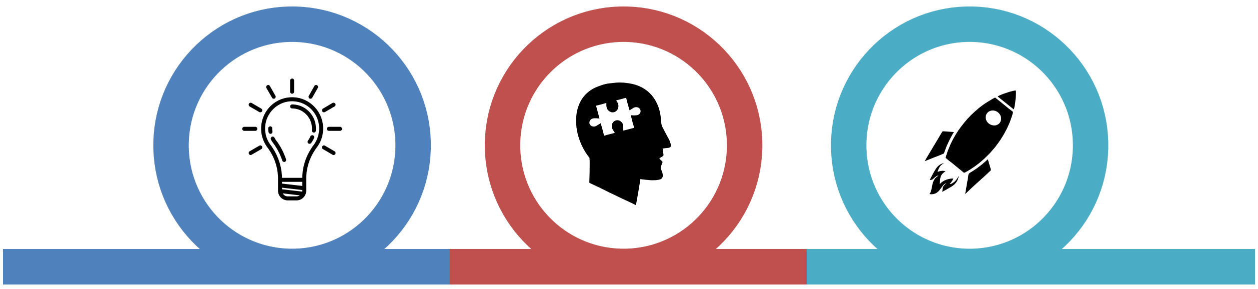
Courtesy of K-water

3. Causes of Apparent Losses

3.1 Causes of Apparent Losses
3.2 Metering Inaccuracies
3.3 Systematic Data Handling Error
3.4 Unauthorized Consumption

3.1 Causes of Apparent Losses

- **(Apparent losses) Apparent losses includes meter inaccuracy, data handling error, and unauthorized consumption**



Meter Inaccuracy

- Lack of meter maintenance
- Registering error
- Improper meter selection
- Incorrect installation
- Deterioration

Data Handling error

- Administrative error
- Meter reading error
- Data transfer error
- Distorted customer consumption
- Estimated volume
- Poor customer account management
- Poor billing system

Unauthorized Consumption

- Illegal connection
- Meter by-passing
- Meter tampering
- Theft at hydrants or fountains
- Corruption of meter reader

[Main Causes of Three Apparent Losses Types]

3.2 Metering Inaccuracies

- **(Meter inaccuracies) Inaccurate meters tend to under-register water consumption which reads to reduced sales and therefore reduced revenue**

Causes & factors influencing water losses		Details
Main	Sub	
Lack of periodic meter testing and maintenance	Lack of periodic meter testing and maintenance	- Contributing to poor meter problem is the lack of good quality meter testing facilities, especially when it comes to larger diameter meters, and the lack of experience in how to best utilize such facilities
Registering error (physical capacity error)	Under-registering: aging (wear out)	- It is recognized that mechanical meters tend to have a gradual tendency for under-registration throughout their life cycle
	Under-registering: faulty meter	- Water volume can not exactly measured in stopped or faulty meter
	Under-registering, Low flow	- Under-recording can occur when flow rate is below the at low flows such as when a flow rate is below the minimum flow (Q1) - Turbine meters are designed to capture continuous moderate and high flows, but if the user has periodic lower flows, exact flow rate can not be measured
	Over-registering, Air	- If a fluid other than water(e.g., air) occupies part of the volume in the metering chamber, the metering error can be quite severe and rapid wear of moving parts may occur - In intermittent water supply, customer meters will register a certain volume of air when the water supply is first turned on

3.2 Metering Inaccuracies

[Stopped Bulk Meter]

Courtesy of K-water

3.2 Metering Inaccuracies

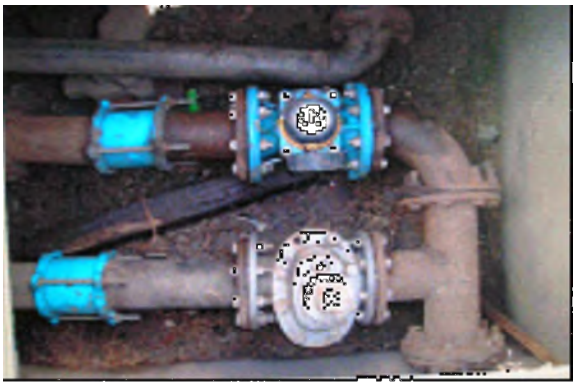
Causes & factors influencing water losses		Details
Main	Sub	
Improper meter (intrinsic error)	Size	- Sometimes, the selection of water meter size is based on availability of meters in stock and the size of the service pipe rather than on a customer's consumption pattern - In the past, it was common to size customer service connections and meters based on the peak flow rates that the meter was expected to encounter - Oversized meters tend to under-register under low flow conditions and may lead to larger differences between the recorded volume and the water that is actually consumed
	type	- Utilities should seek to select appropriate meter types and prepare tailored specifications * This can prove difficult, especially where procurement laws and regulations encourage purchasing the cheapest products on the market

[Improper Meter Size]

Courtesy of K-water

3.2 Metering Inaccuracies

Causes & factors influencing water losses		Details
Main	Sub	
Incorrect installation of water meters		- There are various requirement regarding the length of straight pipe before and after each type of meter * The supplier will provide details of these requirements for each meter - When meter readers identify the meter, it should be easy to determine which meter belongs to which properties - All meter should be installed above ground and located where they can be audited easily, including by the meter readers during their regular rounds



[Improper Meter Installation]

Courtesy of K-water

3.2 Metering Inaccuracies

[Difficulty in Finding Correct Customer Meter]

Courtesy of K-water

3.2 Metering Inaccuracies

[Difficulty in Assessing Customer Meter]

Courtesy of K-water

3.2 Metering Inaccuracies

Causes & factors influencing water losses		Details
Main	Sub	
Deterioration	Harsh environmental condition	- Extreme heat or cold affecting water meters
	Suspended particles	- Water quality and suspended particles (sedimentation) can greatly degrade water meter accuracy * In some cases, it produce a blockage of the meter * Because suspended particles often enter the distribution system during repair work

[Debris at Strainer or Rotating Part]

Courtesy of K-water

3.2 Metering Inaccuracies

Causes & factors influencing water losses		Details
Main	Sub	
Deterioration	Poor maintenance	- Poor maintenance will not only encourage inaccuracy but may shorten the life span of the meter

[Deteriorated Water Meter]

Courtesy of K-water

3.3 Systematic Data Handling Error

- **(Data handling) Data handling errors include reading, transmitting, archiving, and reporting error**
- **(Data transferring process) The typical method of data handling and billing requires a meter reader to visit each property and read the customer meter**
  - The data is then recorded by hand on a form, taken back to the office, given to the billing department, and typed into a billing system
  - A bill is then printed and mailed to the customer

Causes & factors influencing water losses		Details
Main	Sub	
Data handling error:	Meter reading error	- Errors can be easily negligence, laziness, or aging meters during the process of reading the meters and billing customers * Sometimes lazy meter reader records estimated value and use it as a reading value * Dirty dials, faulty meters, and jammed meters can also contribute to meter reading errors - Incompetent or inexperienced meter readers may read the meter incorrectly or make simple errors, such as placing a decimal in the wrong place
	Data transfer error	- Errors during transferring written data to the office, AMR equipment failure, and data entry errors during meter change-outs can make the wrong data

3.3 Systematic Data Handling Error

Causes & factors influencing water losses		Details
Main	Sub	
Billing system error	Distorted customer consumption	- There are many day-to-day processes in operating a billing system that have the potential to corrupt the integrity of the consumption data, depending on the design of the billing system - It is important that water utility managers understand the working of the customer billing system with regard to consumption data integrity * Most billing systems are not designed to retain the integrity of consumption data and they are designed to deliver accurate bills to customers and correctly account for the bills
	Estimated volume	- It may not be serious problem to correct estimated volume in billing system for billing purpose, however, it can cause a significant effect on water loss calculation
	Poor customer account management	- Unregister customer can contribute the distorted water audit results * Sometimes connections are made legally, but the billing department is not notified of the new connection, therefore the customer is never billed * Some accounts may not be activated, lost, or transferred erroneously

3.4 Unauthorized Consumption

- **(Unauthorized consumption) Unauthorized consumption includes illegal connections, meter by-passing, meter tempering, illegal water withdrawal from hydrants, and corruption of meter reader**

Causes & factors influencing water losses		Details
Main	Sub	
Illegal use	Illegal connection	- Illegal connections involve the physical installation of a connection to water distribution pipelines without the knowledge and approval of the water utility - Illegal connections can occur during the installation of a new supply connection, or sometimes the customer's supply is cut off after non-payment and the customer cannot afford, or does not water to pay, to be reconnected - Water theft can occur from large pipes as well as from household water connections

[Illegal Connection]

Courtesy of K-water

3.4 Unauthorized Consumption

Causes & factors influencing water losses		Details
Main	Sub	
Illegal use	Meter by-passing	- Some customers try to reduce their water bill by using a meter bypass, which is an additional pipe installed around the meter * Sometimes, this bypass pipe is buried and very difficult to detect * Meter by-passing is usually committed by agricultural, industrial, or commercial purpose
	Meter tampering	- People sometimes temper with their meter to lower the measured volume * Customers may insert pins or other objects into the meter to disturb its moving parts * Some try to affect the readings of metal meters by attaching a strong magnet to it * In other cases, customers have boiled plastic meters trying to melt the internal plastic parts

[An Illegal By-pass at a Water Meter]

Courtesy of K-water

3.4 Unauthorized Consumption

[An Illegal By-pass for Irrigation]

Courtesy of K-water

[An Illegal By-pass for Construction]

Courtesy of K-water

3.4 Unauthorized Consumption

Causes & factors influencing water losses		Details
Main	Sub	
Illegal use	Theft at hydrants or community fountains	- People can use them illegally to fill tankers (normally at night) or as water supply connections to construction sites * The only legal use of fire hydrants is for fire fighting - These high flows are not only incidences of illegal use, but also a detriment to the pipe network and water quality, which affects the service to the customer
	Corruption of meter reader	- Corrupt meter readers can create a large impact on the monthly billed consumption - Corrupt meter readers will record lower meter readings in exchange for a monetary incentive

[Theft at Hydrant]

Courtesy of K-water


Thank you very much

Water Loss Control Program

Water Loss Management

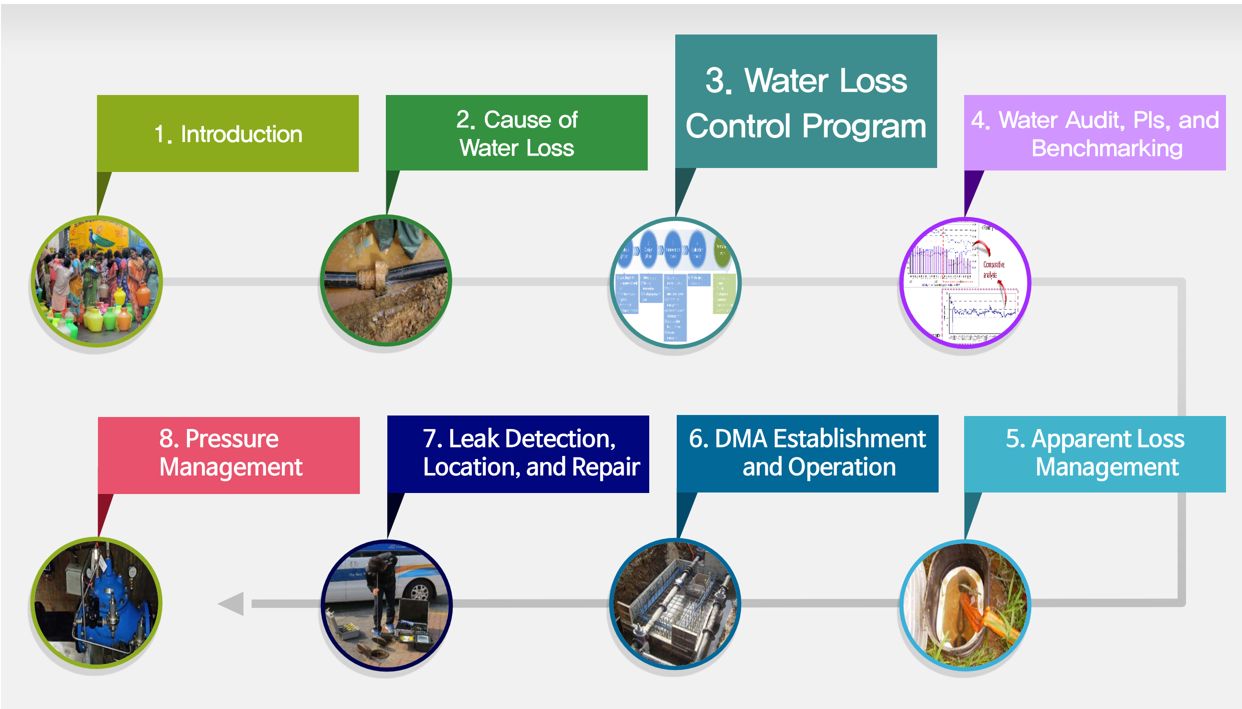
3. Water Loss Control Programs

공동개발기관마크

United Nations Educational, Scientific and Cultural Organization

International Centre for Water Security and Sustainable Management

Training Course



Aims & Objectives

- The course aims to:

  (1) Provide trainees with an overview of the general process of water loss control programs;
  (2) Enable trainees to design a program for reducing water loss for the water network system at the end of this course;

- The objectives are that trainees will understand the following:

  (1) General strategies for controlling real and apparent loss
  (2) Activities for controlling water loss;
  (3) Interventions in analysis, design, intervention, and evaluation

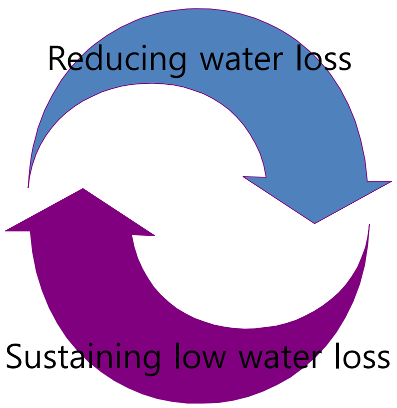
Contents

1. Overview

1.1 Background
1.2 Appropriate Objectives
1.3 Holistic Approach
1.4 Flexible and Customized Plans
1.5 Understanding the Current Status
1.6 Establishing Clear Procedures
1.7 Sustained Commitment: Long-term plans
1.8 Systematic Support from the Organization

1.2 Appropriate Program Objectives

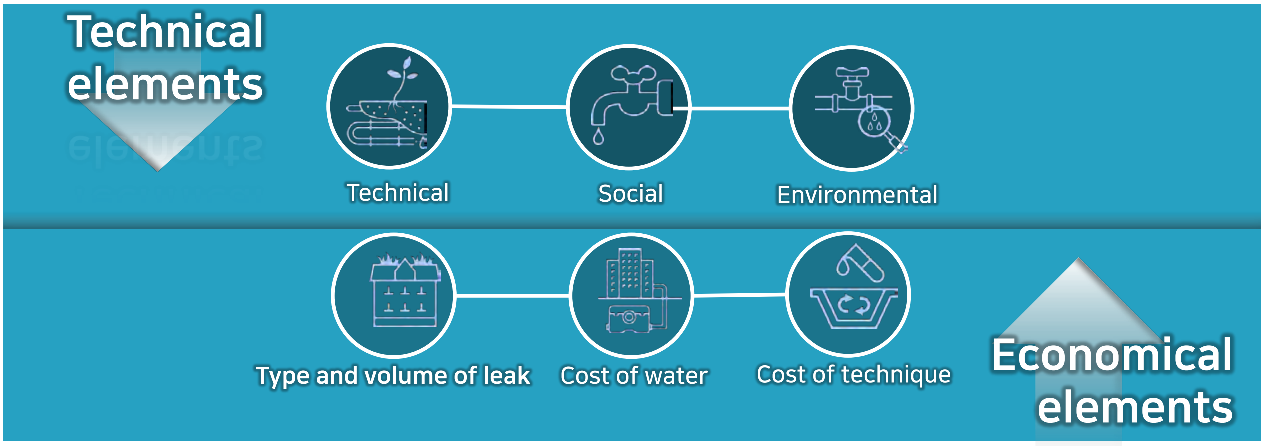
- **Two main objectives: Water loss reduction activities should be designed to reduce the existing apparent and real losses to economic levels and sustain optimum levels**
- **Realistic goals: When setting goals, water utilities should be realistic and consider the difficulties of the environment in operation**



[Two Main Objectives of Water Loss Control Programs]

1.1 Background

- **Technical elements: Water utilities should consider the technical, social, and environmental aspects of water loss control programs**
- **Economical elements: Effective water loss control programs can be developed by identifying the types and volumes of water loss, cost of water, and costs of appropriate techniques for reducing the specific components of leakage**



[Considerations for Developing Water Loss Control Programs]

1.3 Holistic Approach

- **Diagnostic approach: This approach is reinforced by implementing practical and achievable solutions, which can be applied to the development of strategies for water loss management**
  - The diagnostic approach firstly identifies problems, then uses available tools to reduce or eliminate such problems
- **Limitation of a single task: Water utilities should note that a single project or task cannot resolve NRW reduction**
  - Water loss control activities have been grouped into modules based on the types of professionals involved in their execution and the characteristics and level of development of the water distribution network
- **Holistic approach: A combination of various methods will constitute the most efficient and economical instrument for water loss reduction, which is dependent on the local situation**

1.4 Flexible and Customized Plans

- **Flexible and customized plans: A water loss control program should be flexible and tailored to the specific needs and characteristics of a water supply system**

- **Site-specific plans: Leak management plans should be specific to the water company and supply areas within the company**
  - Each company should adopt a strategy for water loss control that suits their reality and improve the quality of service to its customers

- **Modified best practices: Many utilities can implement good practices from other utilities with little modification**

1.5 Understanding the Current Status

- **Assessing water loss: Current water loss should be understood and assessed using a top-down and bottom-up audit before an appropriate strategy for water loss reduction can be developed**
  - Before deciding which intervention methods are appropriate, a water utility thus should understand the factors that contribute to the real loss in its particular system

- **Identifying the causes: To understand the reasons why, how, and where water is being lost, the managers should perform an appraisal of the physical characteristics of the network and current operational practices**

- **Understanding the system: Considering a series of conditions and actions to be implemented is imperative to the network that requires prior profound network knowledge, such as characteristics and operation**

1.6 Establishing Clear Procedures

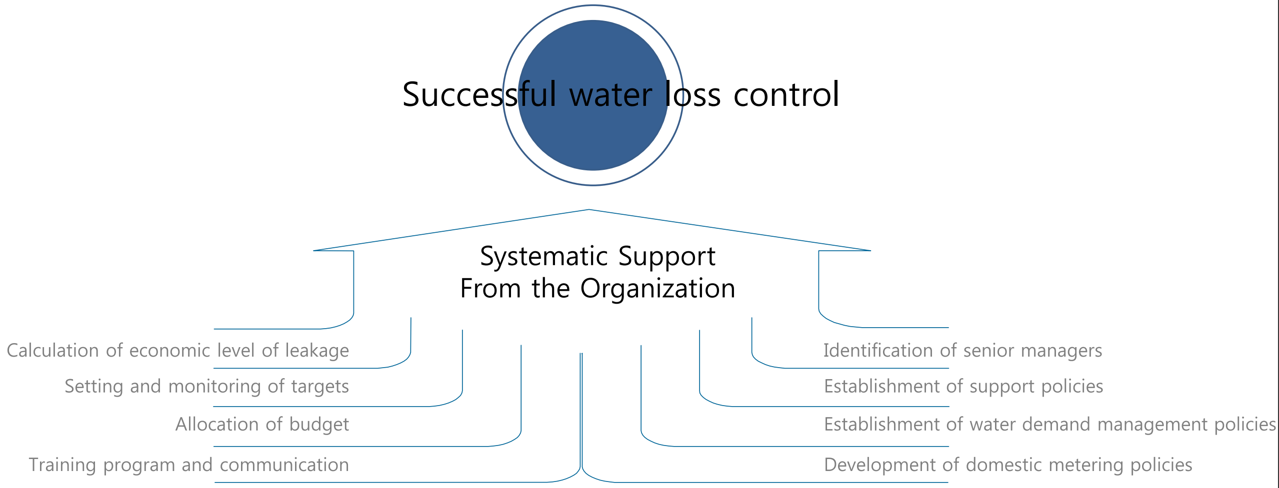
- **Establishing guidelines: Water loss control programs should be designed to provide systematic guidelines, such as a set of procedures, flowcharts, worksheets, and forms**
  - Utility managers, engineers, and operations staff can adopt such guidelines for planning and implementing activities
- **Role of specialists: Specialists on water loss reduction should determine suitable policies, procedures, and suggestions from the guidelines to enable the staff to initiate a systematic reduction in NRW regardless of the infrastructure, resource, or financial situation experienced by the utility**
- **General process: It usually includes the following aspects:**
  - Understanding the components of water loss and their relative significance
  - Developing action plans to address each cause of the loss
  - Transference of training and skills to ensure the sustainability of good leakage management

1.7 Sustained Commitment: Long-term Plan

- **Long-term project: It must be clearly understood that the introduction of a water loss control program must be viewed as a long-term project, which should continue until the economic level of leakage is reached and sustained**
  - Immediate savings cannot be expected and water utilities should rather plan for a 5-year or preferably 10-year program
  - The savings will be difficult to achieve, and possibly more difficult to sustain
- **Reorganization for sustainability: To achieve permanent results, management procedures associated with a utility's organization, procedures, and human resources should be modified**
- **Focus on real and apparent losses: Many programs for the reduction of NRW have failed in the long run because they focus on real loss without sufficient attention being paid to apparent loss**

1.8 Systematic Support from the Organization

- **Support from utilities: The introduction of a strategy must be supported, managed, and constantly reviewed by a senior utility management team, who must establish the infrastructure, procedures, policies, and motivation**

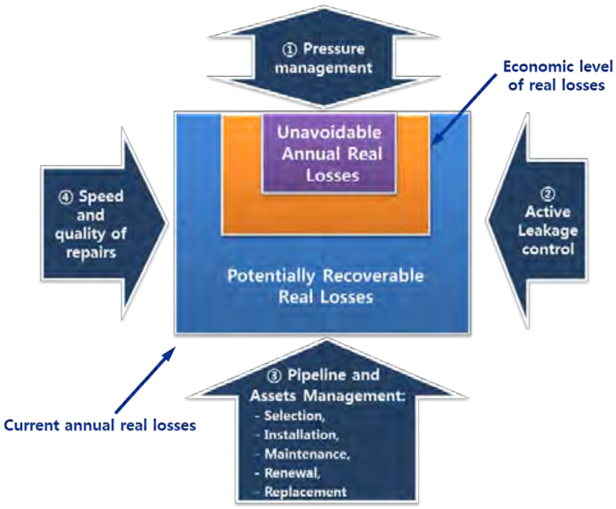


2. General Strategies for Real Loss Management

2.1 Four Principal Methods for Managing Real Loss
2.2 Pressure Management
2.3 Active Leakage Control
2.4 Asset Management
2.5 Speed and Quality of Repairs

2.1 Four Principal Methods for Managing Real Loss

- **Major intervention methods: In 2003, the IWA Water Loss Task Force defined the four principal intervention methods for reducing real loss**
  - This chart, which can be found in every book on NRW management, illustrates the entire real loss management issue

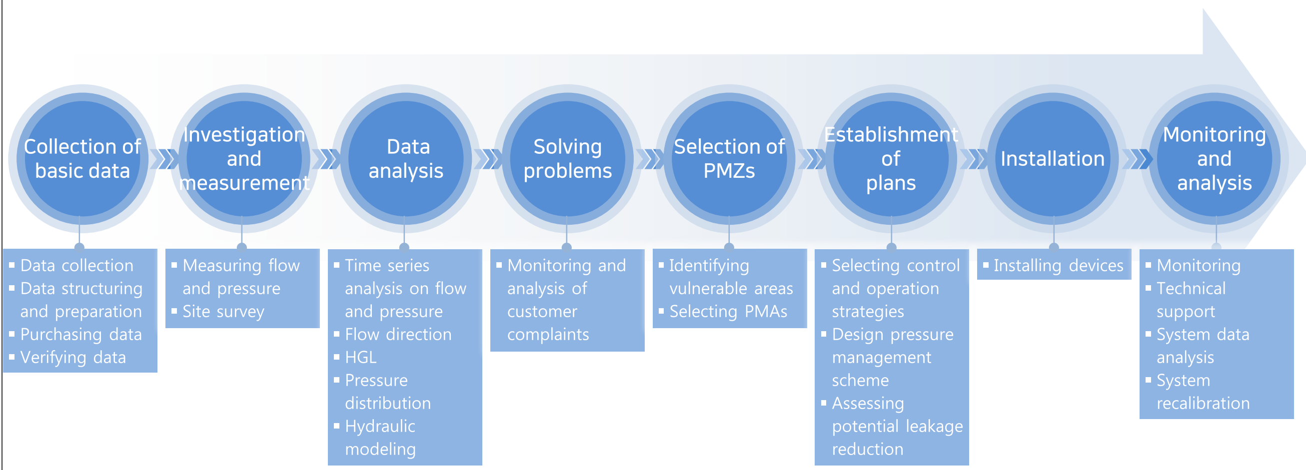


[Four Major Intervention Methods for Reducing Real Loss]

Source: IWA Water Loss Task Force (2003)

2.2 Pressure Management

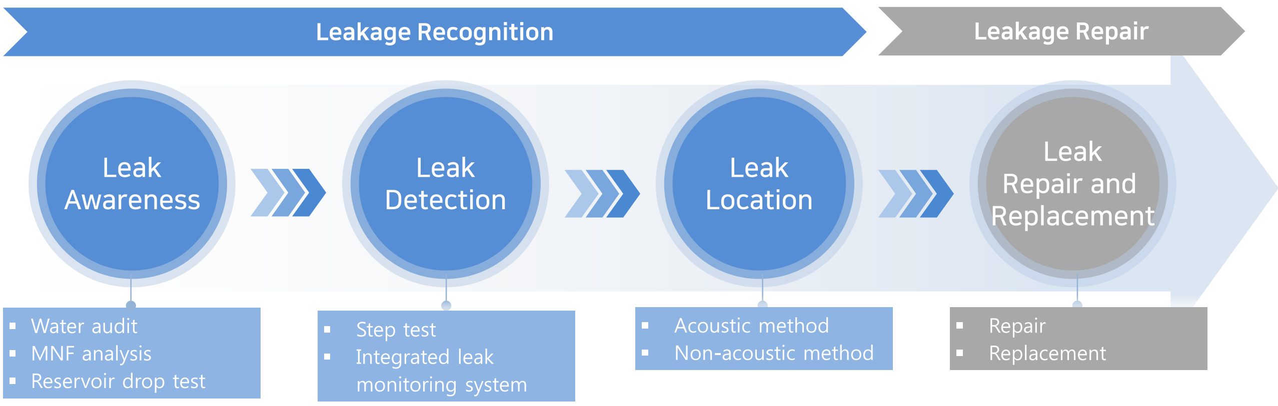
- **Most effective method: Leakage levels can be improved or worsened solely by changes in the level of operating pressure**
- **Sole solution: Pressure management is represented by a solely bidirectional arrow because it is the only solution for the reduction of unavoidable annual real loss**



[Pressure Management Process]

2.3 Active Leakage Control

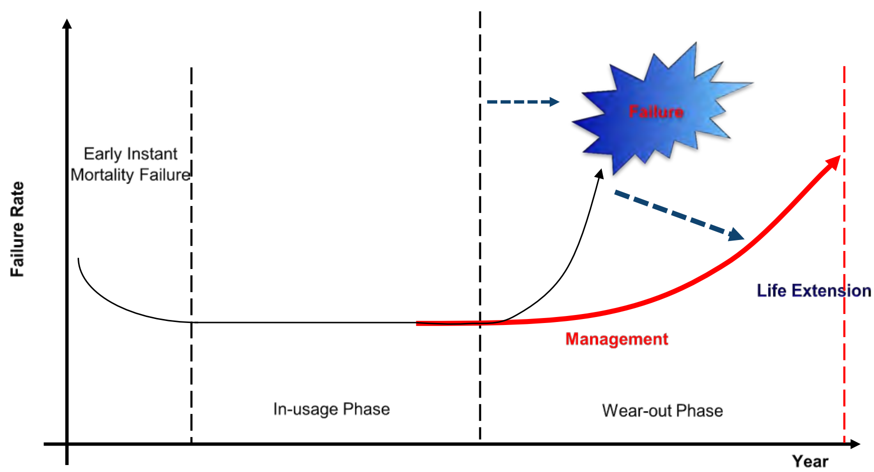
- **ALC must be introduced to detect all unreported and invisible leaks**
  - To Identify and quantify existing leakage in a distribution system; activities for leak awareness, detection, and location are performed in DMAs



[Activities for Active Leakage Control During Leakage Recognition and Repair Processes]

2.4 Asset Management

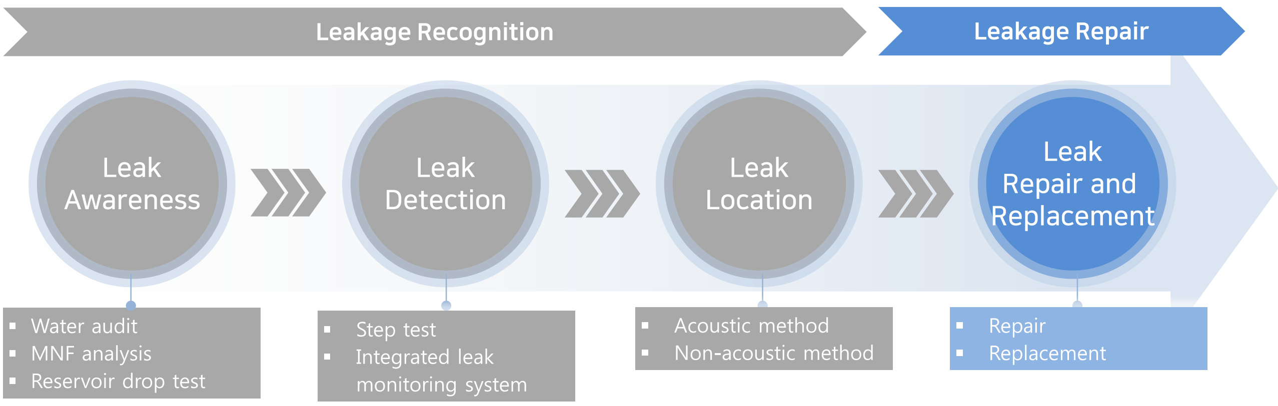
- **In the long run, pipes should be rehabilitated or replaced using good quality materials and installation**
  - All pipeline assets eventually reach the end of their shelf life and should be rehabilitated or replaced if they are to continue to provide service



[Rehabilitation and Replacement to Extend Life Span]

2.5 Speed and Quality of Repairs

- **Identified leaks should be repaired as soon as possible to maintain low leak running times. The good quality of the repairs will render the efforts sustainable**
  - Ensuring timely and long-lasting repairs is critical to the success of the leakage management program
  - Even visible leaks are frequently overlooked by poorly run water utilities



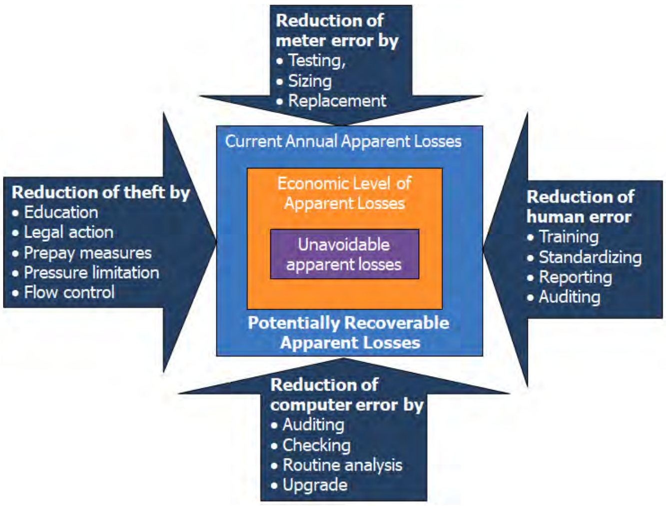
[Leak Repair and Replacement During Leakage Recognition and Repair Processes]

3. General Strategies for Apparent Loss

3.1 Four Principal Methods for Managing Apparent Loss
3.2 Reducing Customer Meter Inaccuracies
3.3 Improving Data Handling and Billing Systems
3.4 Reducing Unauthorized Consumption

3.1 Four Principal Methods for Managing Apparent Loss

- **Major intervention methods: The methodologies for controlling apparent loss require carefully managing water meters, implementing control policies for unauthorized consumption, reducing data handling errors, and optimizing the billing system**



[Four Major Intervention Methods for Reduce Apparent Loss]

Source: Thornton (2002)

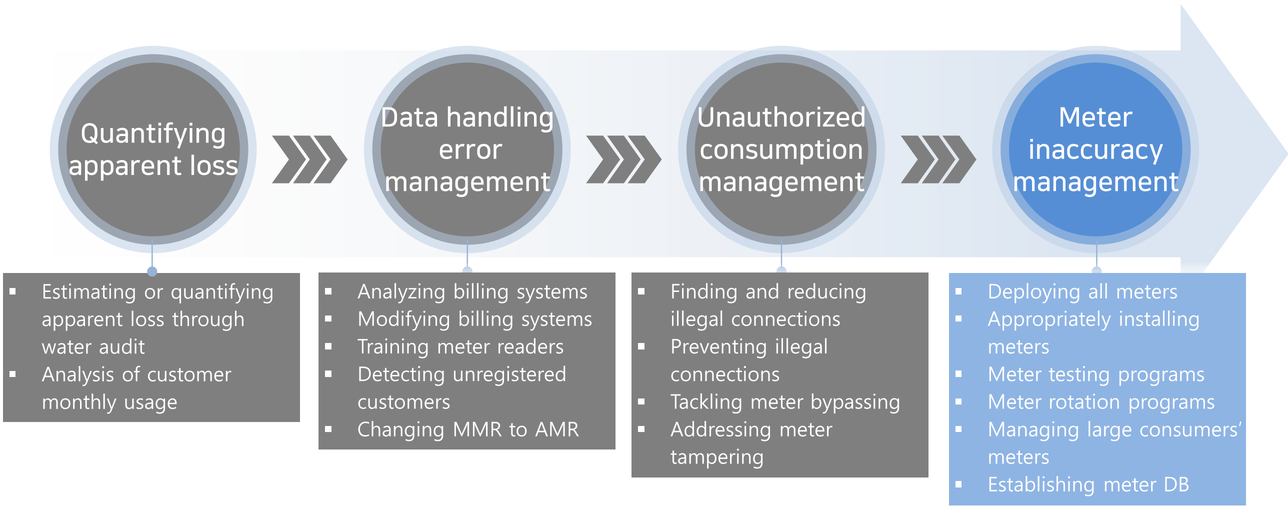
3.1 Four Arrows for Managing Apparent Loss

- **Intervention order #1: Reducing data handling error is typically the first step in apparent loss management**
  - A general recommendation is that billing system analysis be performed as the initial step because gaps in the process could influence data used in the other steps

- **Intervention order #2: Meter replacement is the last option in apparent loss management**
  - Many water utilities tend to assume that their system's apparent loss is solely caused by inaccuracy in the customers' meter and that meter replacement of the entire customer population is the best option
  - Implementing a comprehensive customer meter changeout is a very expensive and inefficient proposition if the bulk of the apparent loss cases is in fact caused by data errors in the billing system or unauthorized consumption

3.2 Reduction of Customer Meter Inaccuracies

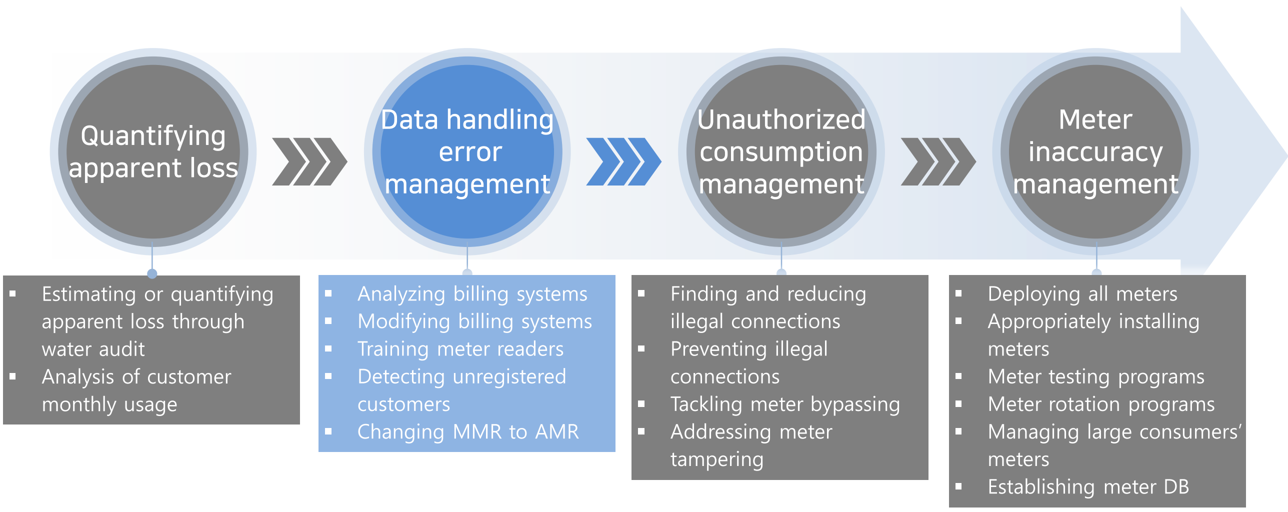
- **Management of meter inaccuracy: The tasks include deploying all meters, appropriately installing meters, meter testing programs, meter rotation programs, managing large consumers' meter, and establishing a meter database**



[Meter Inaccuracy Management and Related Tasks During the Apparent Loss Management Process]

3.3 Improvement of Data Handling and Billing Systems

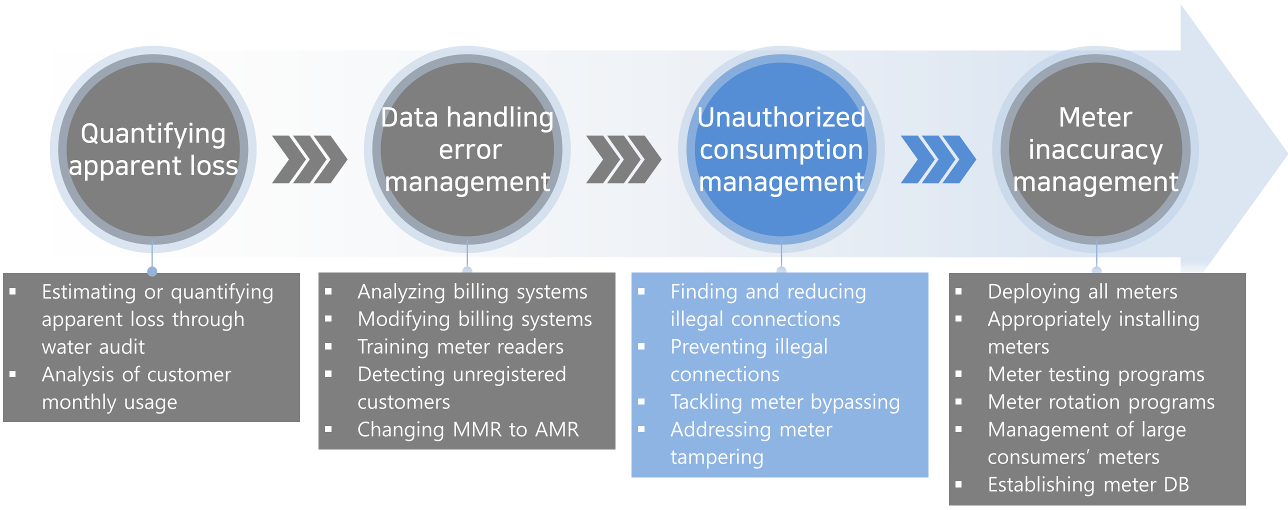
- **Data handling management: The tasks for the management of data handling errors include analyzing and modifying the billing system, training meter readers, detecting unregistered customers, and shifting from manual meter reading to automatic meter reading**



[Management of Data Handling and Billing System Errors and Related Tasks During the Apparent Loss Management Process]

2.4 Reduction of Unauthorized Consumption

- **The tasks include tracing illegal connections and reducing illegal use**

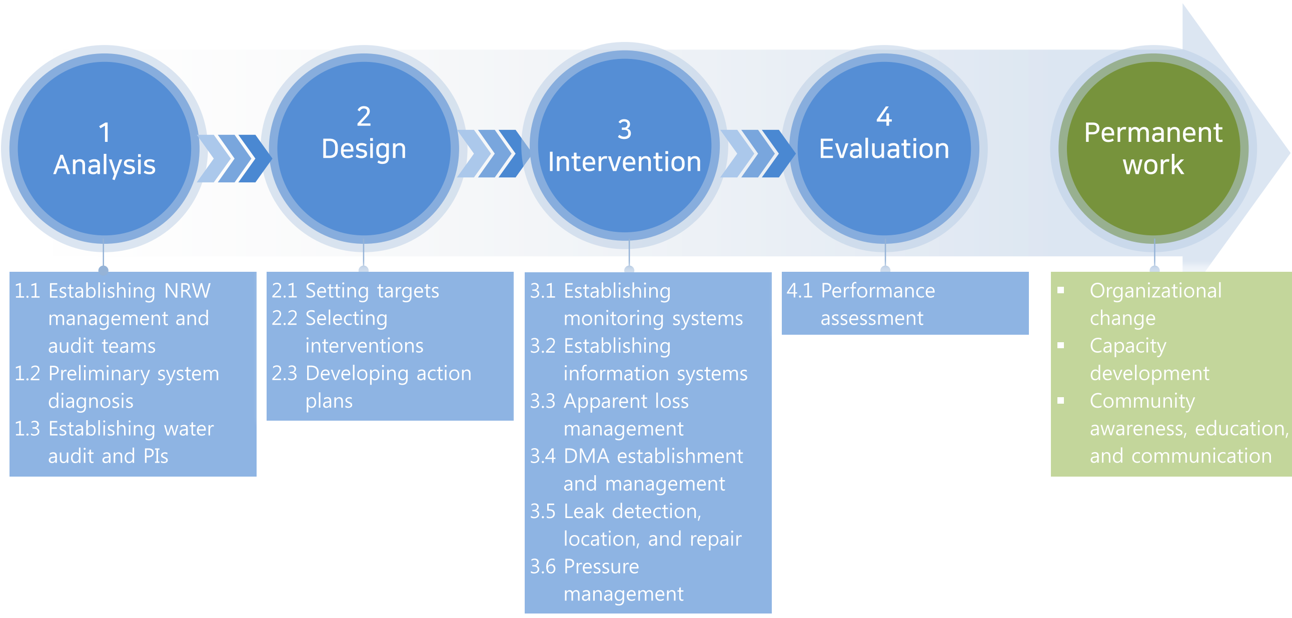


[Reduction of Unauthorized Consumption and Related Tasks During the Apparent Loss Management Process]

4. Water Loss Control Program

4. Water Loss Control Program

- **The process is composed of four phases, namely, analysis, design, intervention, and evaluation, with permanent work**



[Process of Water Loss Control Program]

5. Analysis

5.1 Analysis Phase
5.2 Establishing NRW Management and Audit Teams
5.3 Preliminary System Diagnosis
5.4 Water Audit and Performance Assessment

5.1 Analysis Phase

- **The main objectives of the analysis phase are assessing the distribution, metering, and billing operations and determining the volume of water loss and its location**

[Analysis Phase in the Water Loss Control Program]

5.2 Establishing NRW Management and Audit Teams

- **NRW management team: Water utilities should consider establishing a team to develop a strategy, ensure that all components of NRW are addressed, and verify that the proposed strategy is feasible and practical in terms of workload and budget**

- **Members: Selecting suitable team members promotes ownership among the various utility departments involved in the implementation of the strategy and facilitates consensus at the senior management level**

  - The team should comprise members from operational departments, such as production, distribution, customer service, finance, procurement, and human resources

5.2 Establishing NRW Management and Audit Teams

- **Audit team: The NRW audit team is not responsible for any physical activities to reduce NRW but should be dedicated to assessing all departments involved with NRW activities**
  - An independent team should be established to audit progress because the process is a utility-wide undertaking

01 ESTABLISHING ANNUAL TARGETS

- The NRW audit team will establish annual targets for each department using one or more of the indicators

02 MONITORING MONTHLY PROGRESS

- The team will monitor progress on a monthly basis

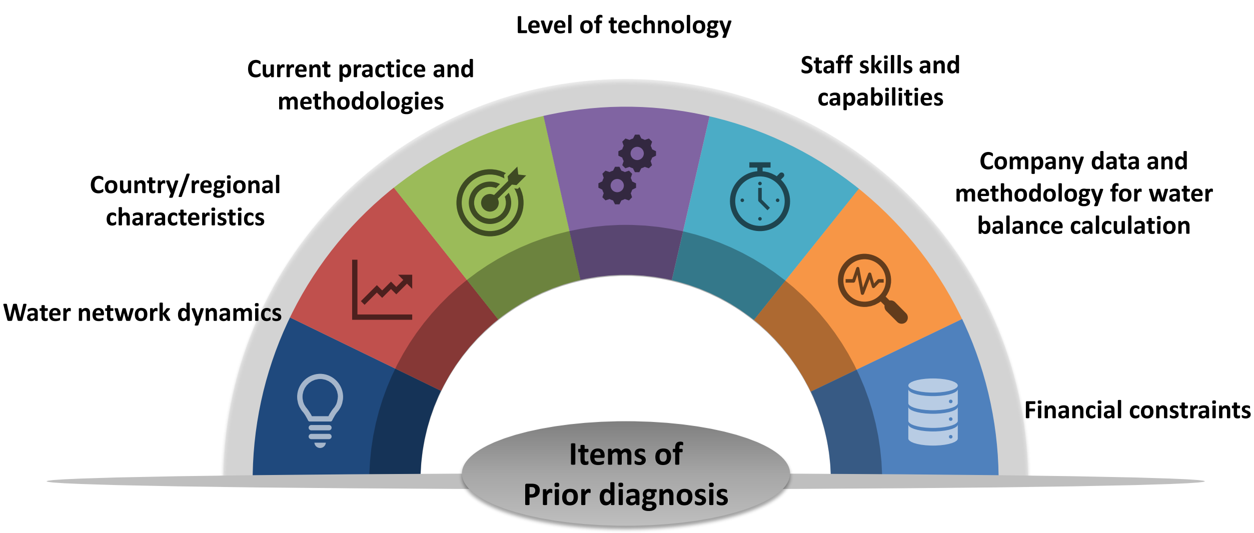
03 MANAGING GOVERNANCE

- The head of the NRW audit team will support the chair by providing technical details and progress reports

[Main Tasks of the Audit Team]

5.3 Preliminary System Diagnosis

- **Importance of preliminary system diagnosis: Prior diagnosis is necessary to determine a starting point**
  - Current water loss must be understood and assessed using a diagnostic approach before an appropriate water loss reduction program can be developed



[Main Items of Preliminary System Diagnosis]

5.3 Preliminary System Diagnosis

- **Sources of data: Items for prior diagnosis can be gathered through existing data, metering, discussion with staff, field visit, and pilot scale test**

01 EXISTING DATA COLLECTION

Collecting existing data from water utility or municipality

02 METERING

Analyzing the current operating status through metering for flow rate, pressure, and water quality data

03 DISCUSSION WITH STAFF

Discussing system features and practice with senior staff and operation staff

04 FIELD VISIT

Visiting fields to appraise current practices and skills

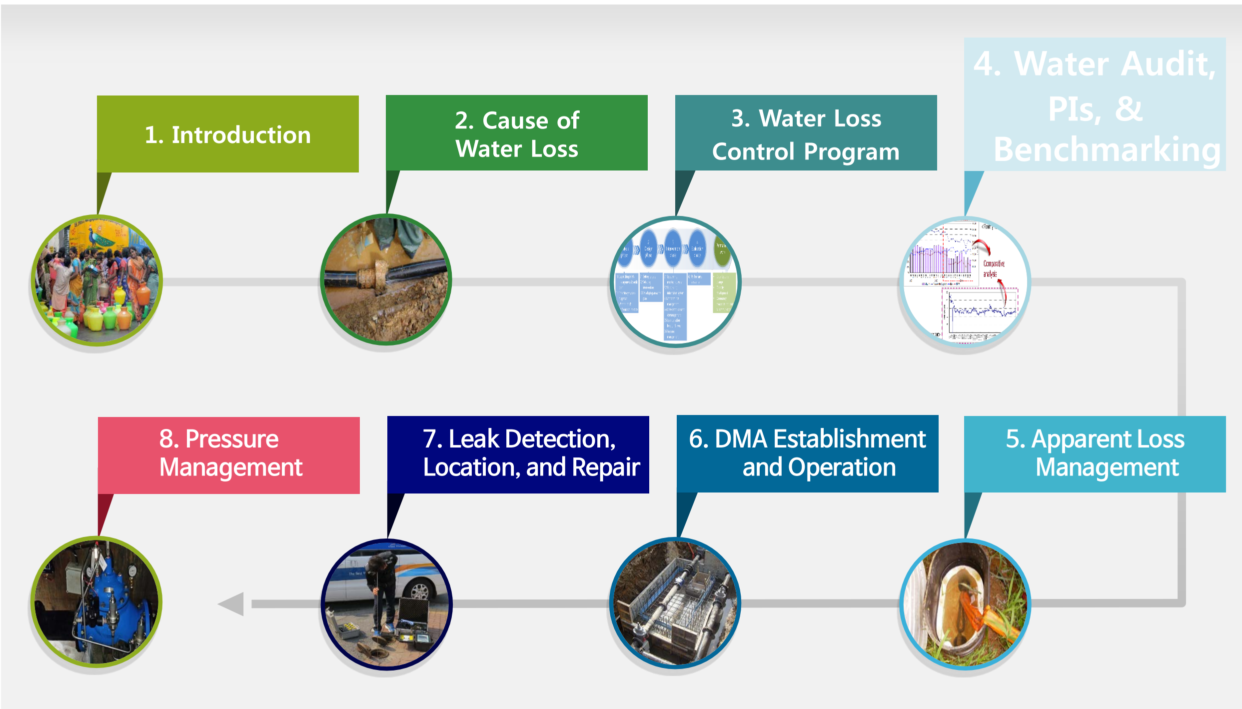
05 PILOT SCALE TEST

Conducting a small-scale pilot test on a suitable pilot area to demonstrate techniques and equipment, gather results, demonstrate benefits, and train staff

[Source of Data]

5.4 Water Audit and Performance Assessment

* This topic will be explained in Section 4. Water Audit, PI, & Benchmarking

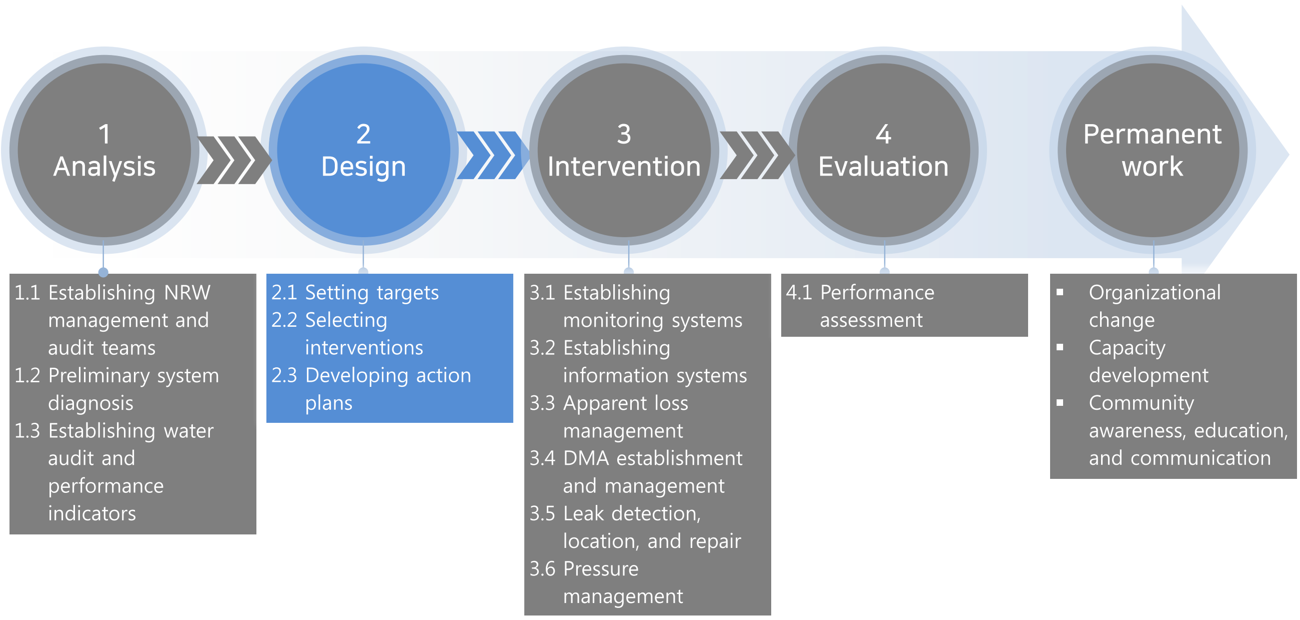


6. Design

6.1 Design Phase
6.2 Setting Targets
6.3 Selecting Interventions
6.4 Developing Action Plans

6.1 Design Phase

- **(Objects) The main objects of design phase should be to develop a holistic NRW master plan based on the results of analysis phase and setted targets**



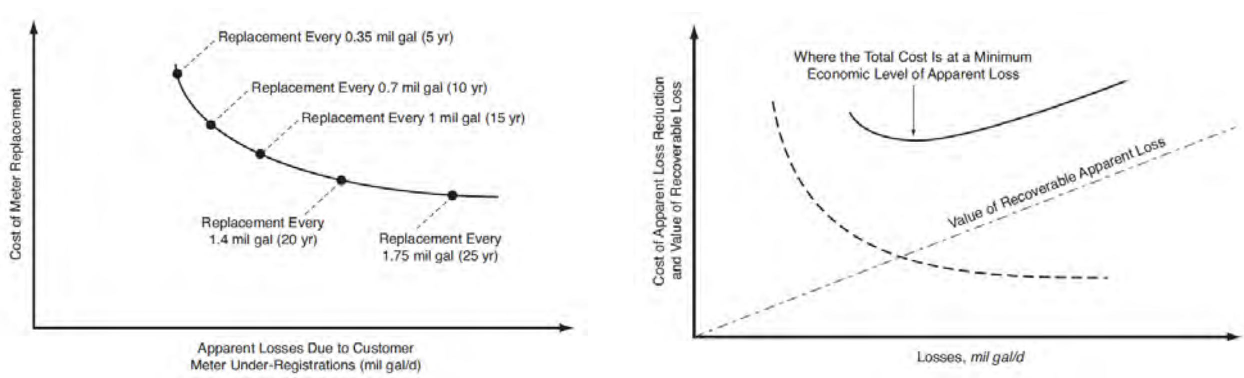
[Design Phase in Water Loss Control Program]

6.1 Setting Targets

- **Rough targets: At the early stages of the water loss control program, targets are mainly based on assumptions, which will later be supplemented by accurate information collected throughout the process**
  - The strategy development team should firstly set a company-wide target for NRW reduction by considering the other goals or policies of the utility's that may complement or conflict with NRW reduction
- **Methods: The economic level of leakage (ELL) or target-setting guidelines can be used in formulating a leakage reduction target**
- **Factors in consideration: The target level will be a compromise between a series of competing factors, such as available budget, human resources, technical feasibility, time constraints, and even political considerations**

6.1 Setting Targets

- **Target-setting method #1: By considering ELL, a limit on loss reduction investment is defined, after which exceeding the cost of water production is no longer economically feasible**
  - The ELL denotes the level of leakage at which the cost of undertaking additional leakage control activity is equal to the cost of producing water



[Economic Balance for a Solution to Apparent Loss Reduction]

Source: AWWA (2009)

6.1 Setting Targets

- **Target-setting method #2: Target-setting guidelines If a water utility has not calculated its ELL, then target-setting guidelines can be used**
  - The table, which was developed by the AWWA Water Loss Control Committee, suggests approximate target levels using the ILI and water resources, operational, and financial considerations that utilities typically encounter (Kumkel et al., 2003)

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. 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 via the bottom-up approach.		

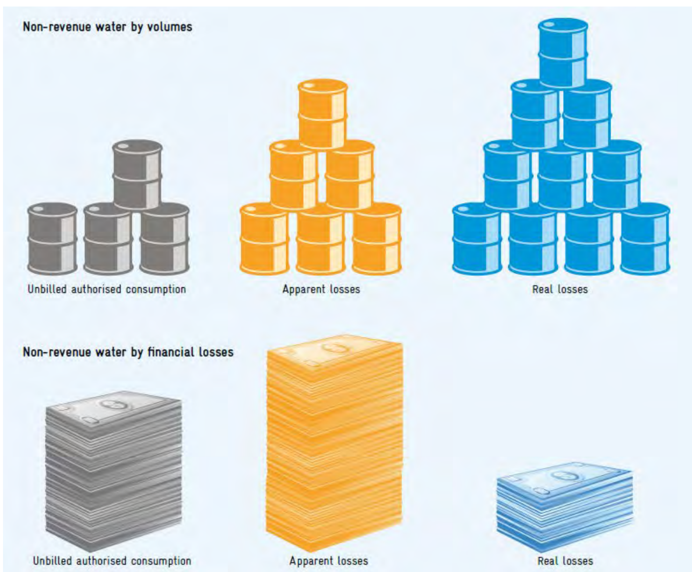
[Target-setting Guidelines for Leakage Management]

Source: Kunkel et al. (2003)

6.2 Selecting Interventions

- **Prioritizing NRW reduction components: After setting the utility-wide NRW target, utility managers should calculate the proposed volume of water saved by comparing the NRW baseline with the target level**

- **Comparing components from the financial viewpoint: Water utilities should first focus on the components of NRW, where investments will generate the highest rate of return**

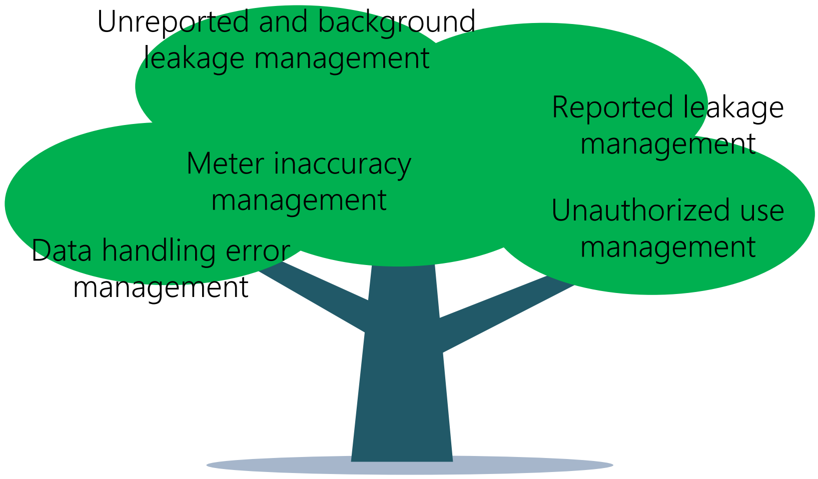


[Examples of Possible Volumetric and Financial Distributions of Loss]

Source: GIZ (2011)

6.2 Selecting Interventions

- **Low-hanging fruit (apparent loss): Reducing apparent loss requires a low level of investment with a short payback period but requires sustained management commitment, political will, and community support**



[Easy Components of Water Loss Reduction]

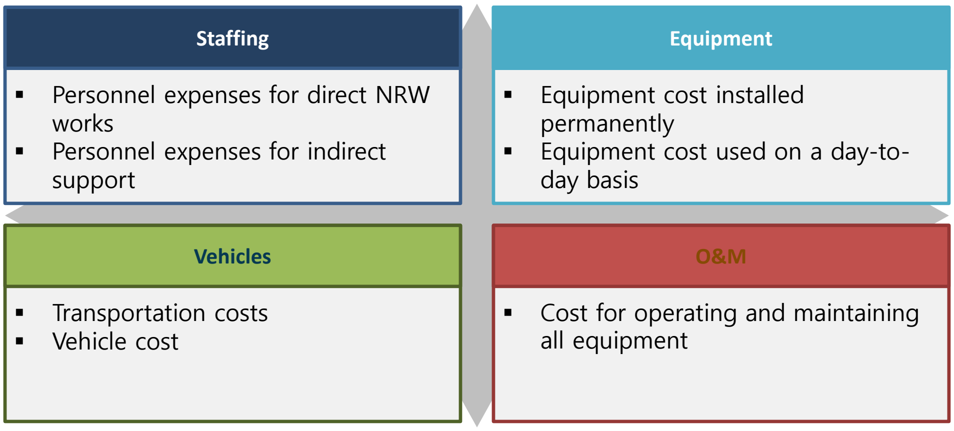
6.2 Selecting Interventions

- **Counteractive measures: A set of specific counteractive measures is available for each component of NRW**

[Specific Counteractive Measures]

6.2 Selecting Interventions

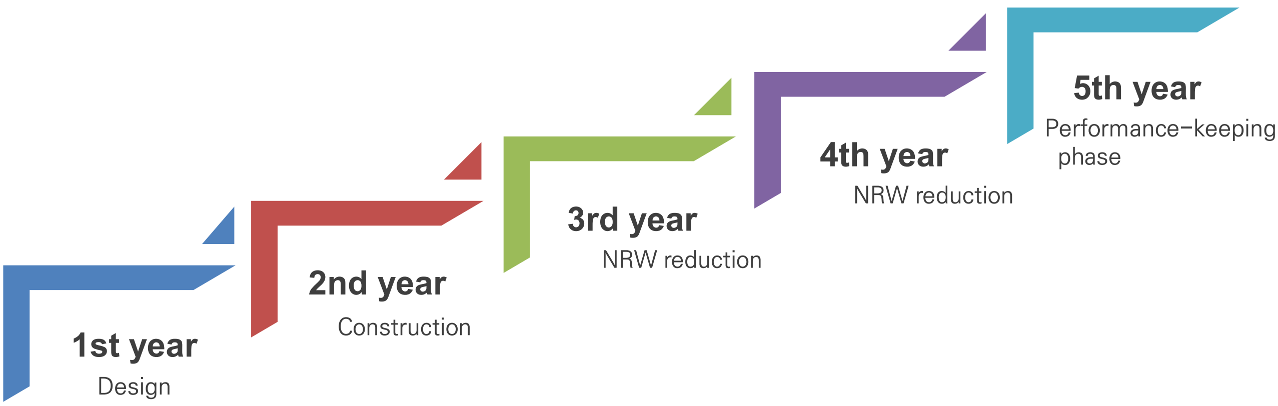
- **Budget consideration: Many NRW management strategies can last for years. Thus, the overall cost may be relatively substantial**
  - Many NRW strategies start off at full speed but frequently fail due to budget cuts over time
  - Undertaking pilot projects to estimate the cost of the program is useful



[Items for Cost Calculation]

6.3 Developing Action Plans

- **After understanding the components of water loss and their relative significance, action plans can be developed to address each of the causes of the loss**
  - Training and skill transfer are essential components of the program to ensure the sustainability of good leakage management

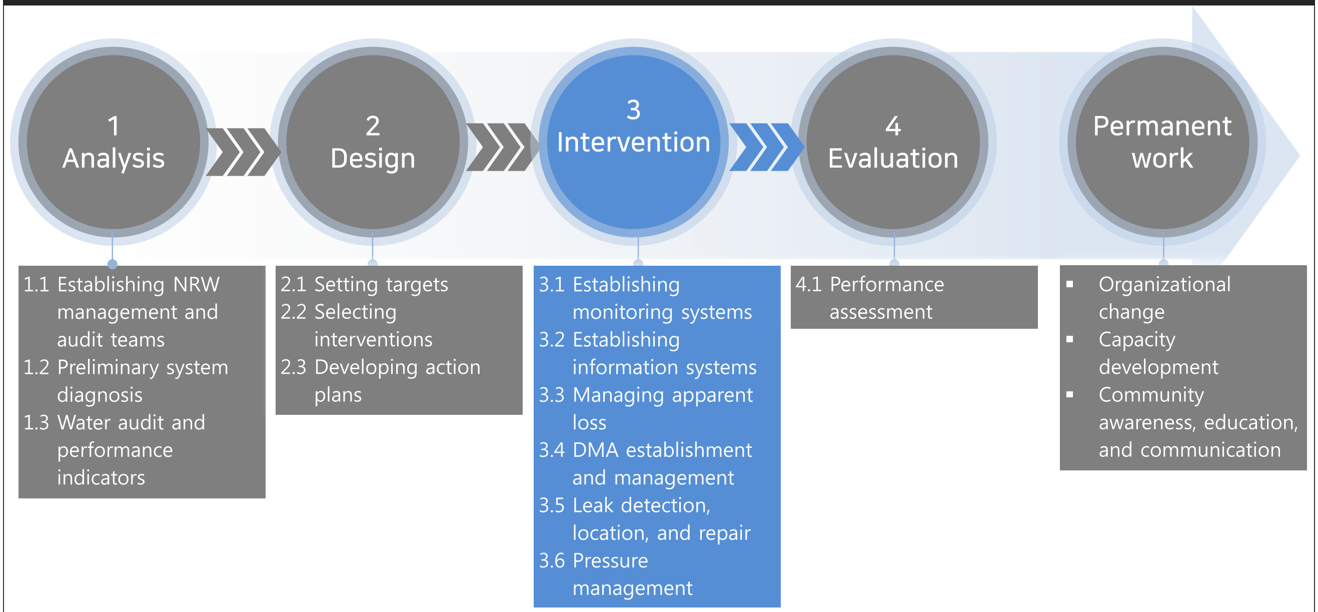


[Phases of Action Plan]

7. Intervention

7.1 Intervention Phase

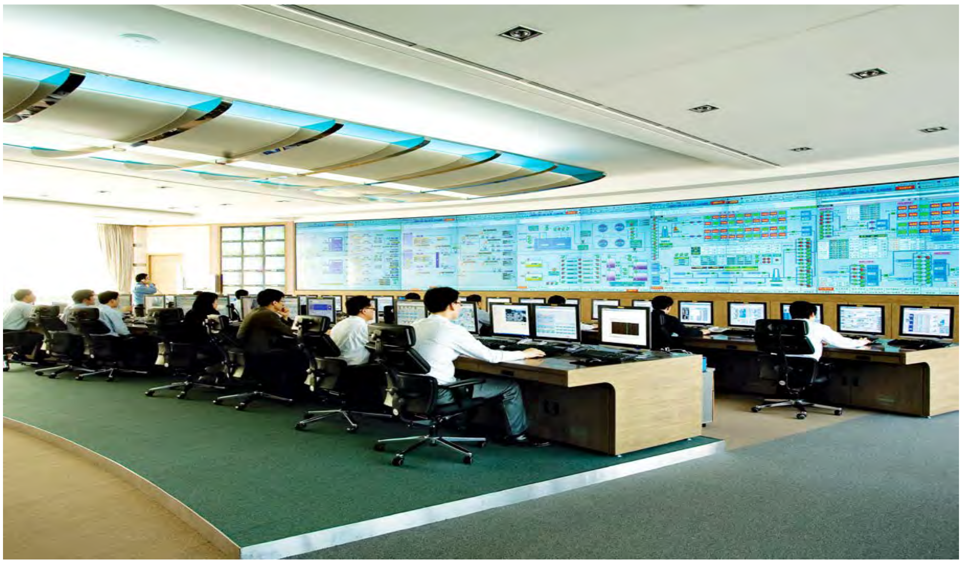
- **The main objectives of the intervention phase is selecting interventions and their order on the basis of budget constraints, public benefit, and priority of other scheduled capital improvements**



[Intervention Phase in the Water Loss Control Program]

7.2 Establishing Monitoring Systems

- Importance of monitoring: Using a reliable system for recording and reporting data is essential for an appropriate understanding and management of the water distribution network



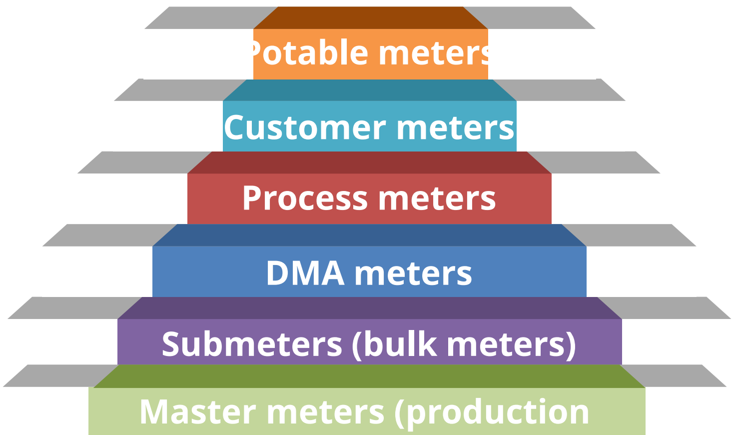
[Integrated Bulk Water Supply Monitoring System]

Courtesy of K-water

7.2 Establishing Monitoring Systems

- Requirements: Suitable selection and field application with appropriate installation are key conditions for the positive performance of meters

- Flow monitoring: The most common scheme for monitoring any water system that aims to locate potential leakage is based on flow meters or water meters located from the source to customers



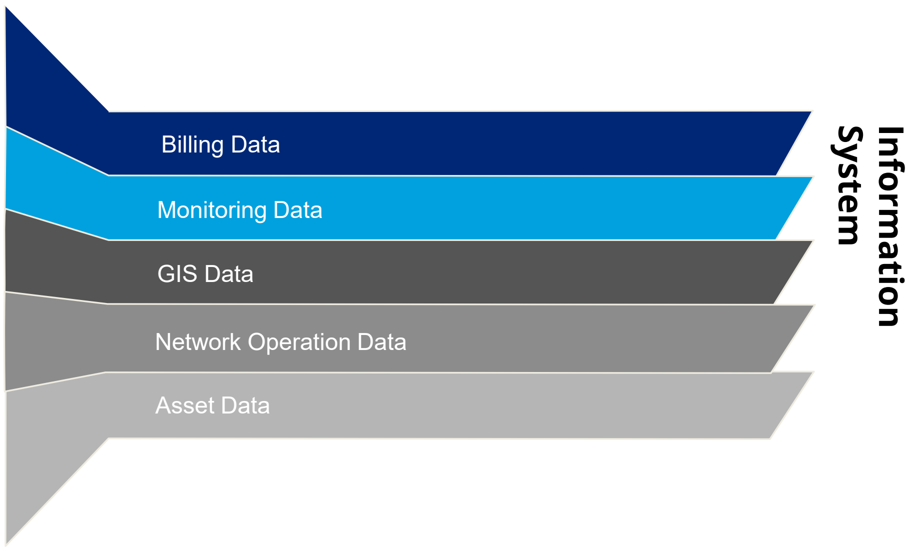
[Hierarchy of Flow Metering]

7.3 Establishing Information System

- **Importance: Precise information is required for water utilities to enable efficient work**
  - This information is derived from data which have to be collected, processed, and interpreted via information systems
- **Utilization: Data collection should never become the goal in itself. Instead, water utilities should appreciate the value of collected data**
  - Modern water utilities collect and process large amounts of data from different departments and with different departments with various purposes on a daily basis
  - Unfortunately, plenty of collected data remain in the original department without being utilized

7.3 Establishing Information Systems

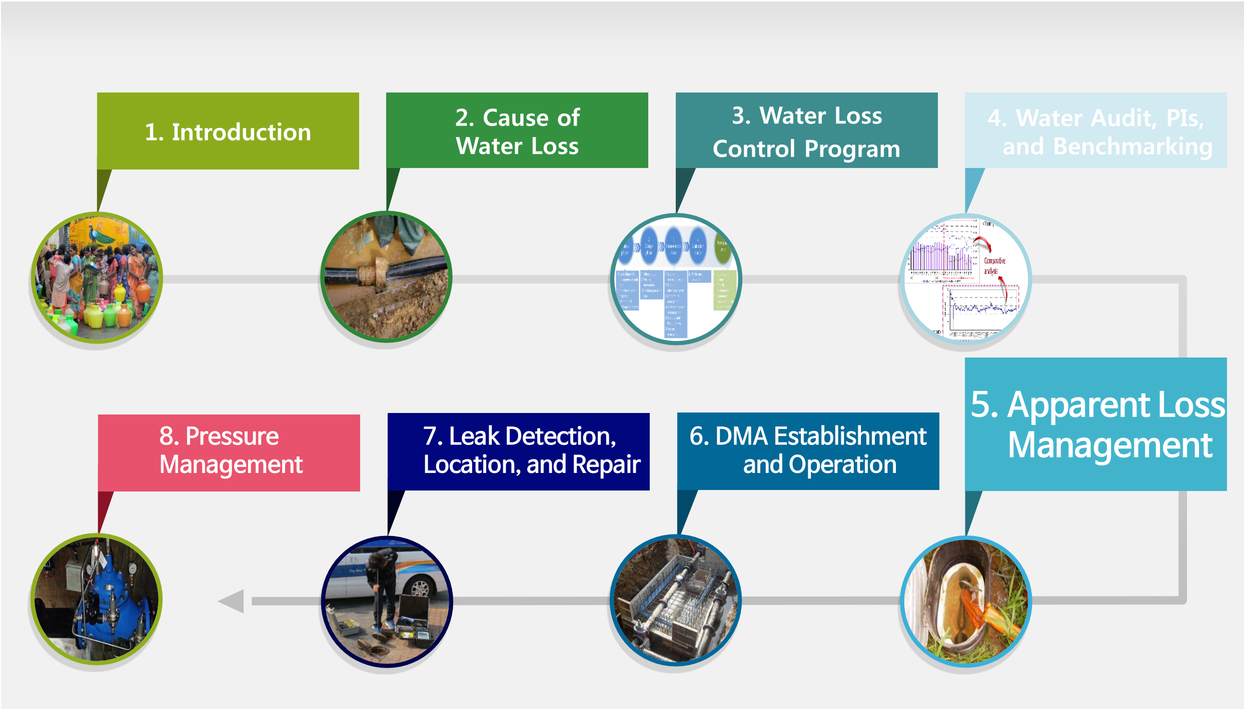
- **Components of information systems: Water utilities use several types of information systems with numerous interactions between various information systems**



[Components of Information Systems]

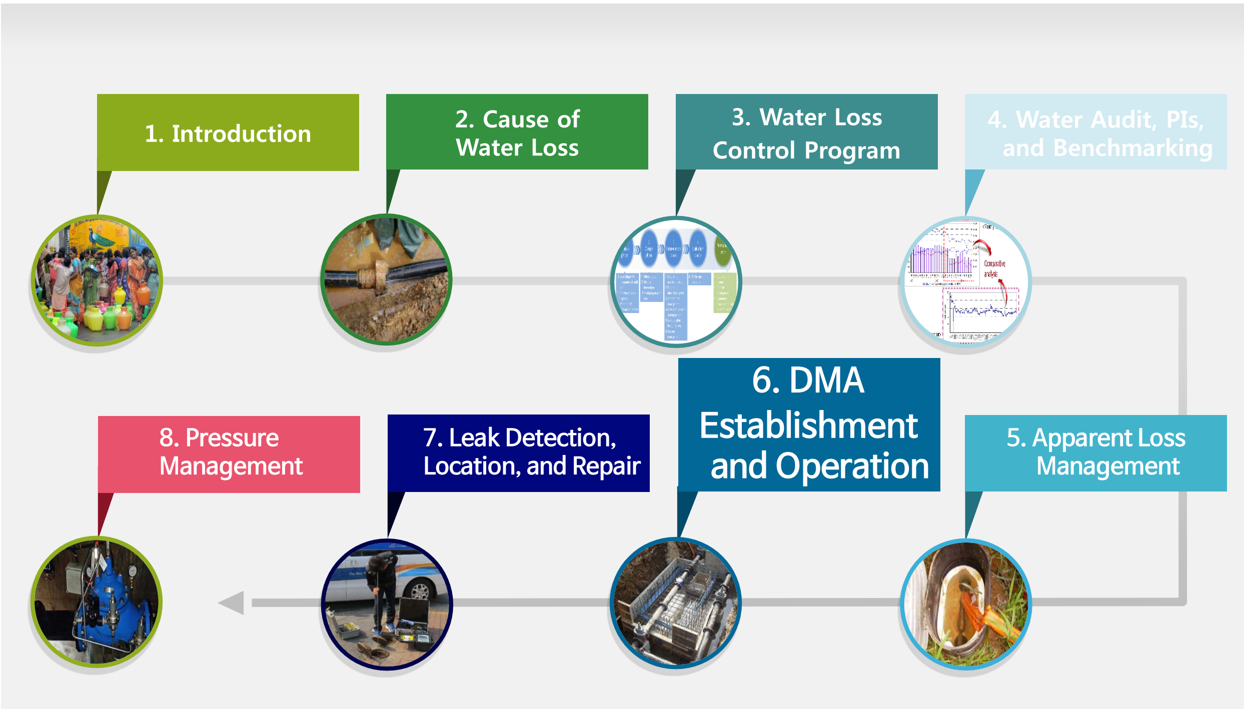
7.4 Apparent Loss Management

* This topic is explained in 5. Apparent Loss Management



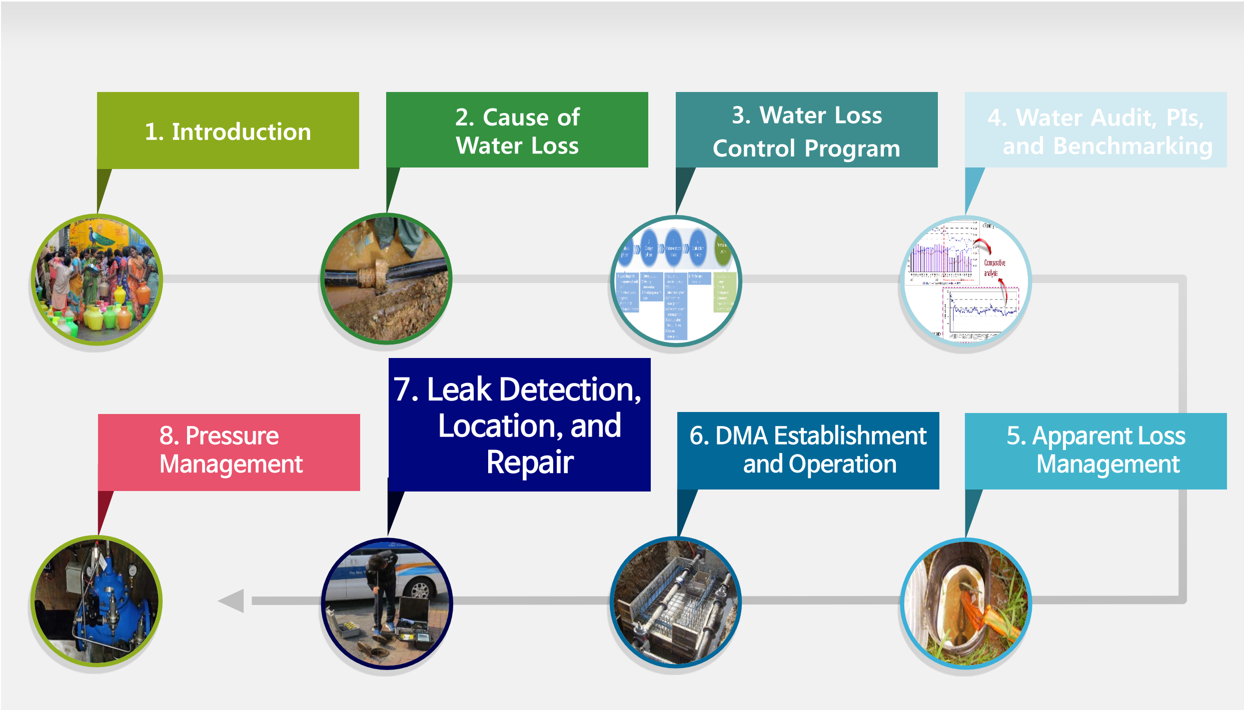
7.5 DMA Establishment and Management

* This topic is explained in 6. DMA Establishment and Operation



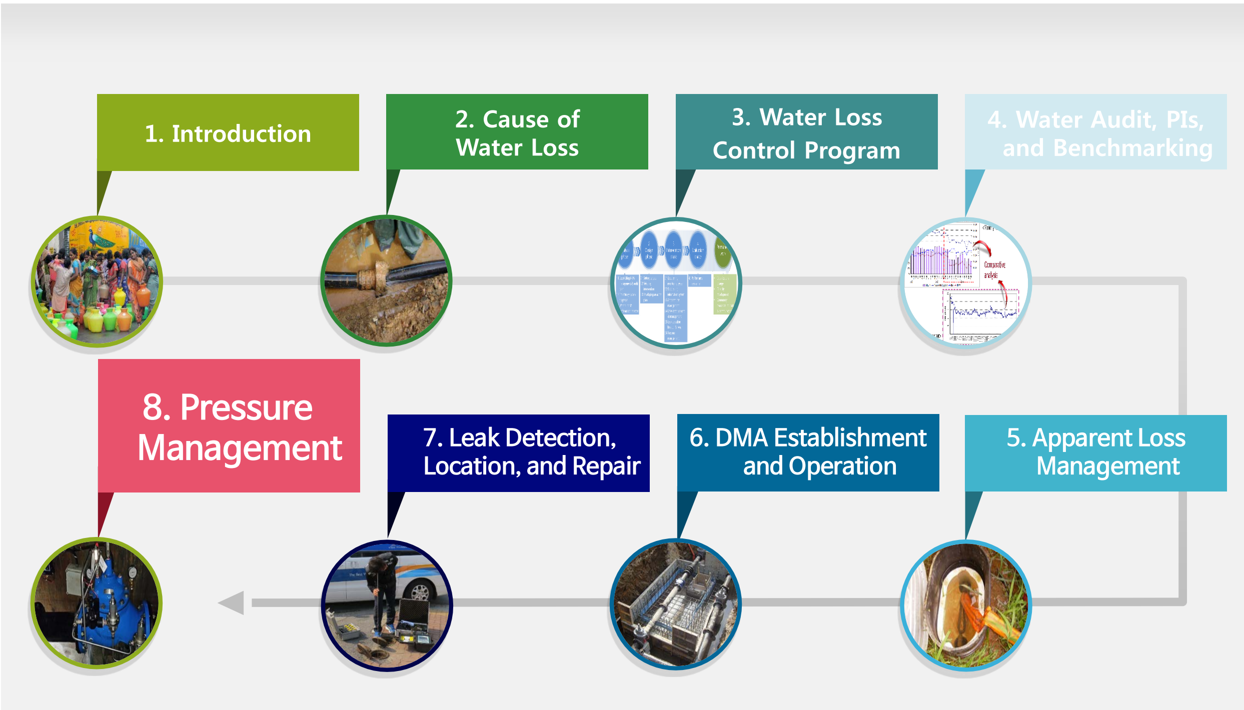
7.6 Leak Detection, Location, and Repair

* This topic is explained in 7. Leak Detection, Location, and Repair



7.7 Pressure Management

* This topic is explained in 8. Pressure Management



8. Evaluation

8.1 Evaluation Phase
8.2 Performance Assessment and Benchmarking

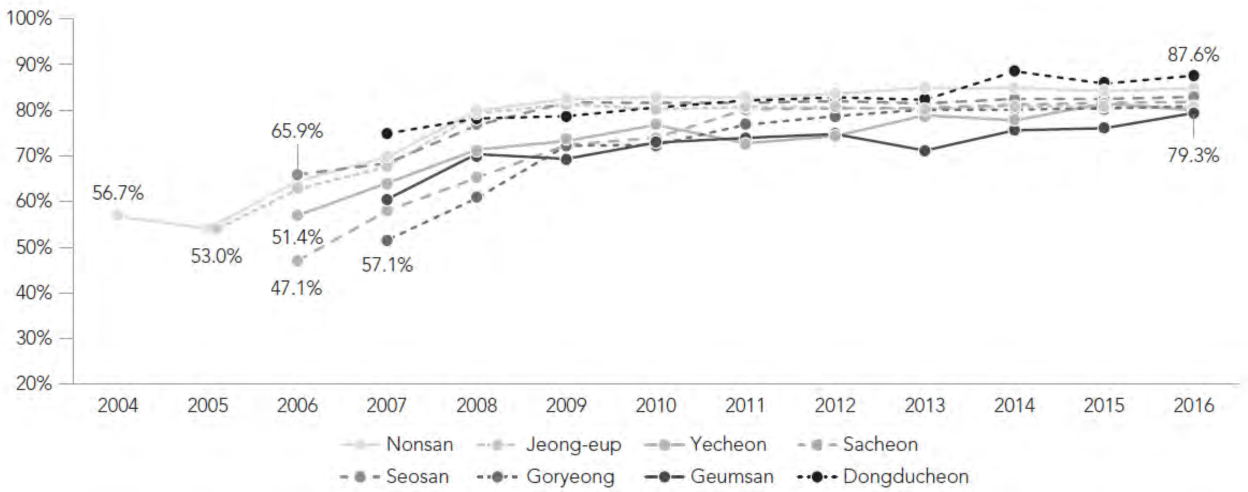
8.1 Evaluation Phase

- **(Objects) The main objects of evaluation phase are assessing the success of the intervention actions and this evaluation must be carried out on a monthly basis during water loss control porgram**

[The Evaluation Phase in Water Loss Control Program]

8.2 Performance Assessment & Benchmarking

- Using performance indicators: Benchmarking with PIs is a simple and effective evaluation method
- Several PIs should be considered in the evaluation phase



[Revenue Water Ratio of Eight Local Water Systems in Korea]

Reference : Kim (2018)

9. Permanent Works

9.1 Permanent Work

- **Objectives: For successful programs and sustainable performance, permanent works should include organizational change, capacity development, and increased community relationship**

[Permanent Works in the Water Loss Control Program]

9.2 Organizational Changes

- **Required organizational changes: Effectively addressing NRW requires a combined effort from the management and staff throughout the utility**

- **Divided structure: One of the most serious problems faced by many water utilities in developing countries with regard to water loss control is the divide between the technical and financial departments within the utility**

- **Best practice: Indeed, the fact that when utilities change from a relatively passive attitude toward the problem of water loss to a proactive approach in conjunction with the emergence of positive results from the new strategy tends to promote an increase in motivation that initially gives rise to a new dynamism across the utility structure**

9.3 Capacity Development

- **Importance: NRW reduction is not only a technical issue. Implementing a successful NRW program and achieving strong results require committed management and trained staff that continuously work to retain low levels of NRW**
  - To adapt and reap the full benefits from an NRW management system, the water utility must implement a comprehensive training and technology transfer program to secure continued positive results

- **Definition: Capacity development is the process of strengthening the abilities of individuals, organizations, companies, and societies to effectively and efficiently utilize resources and realize goals on a sustainable basis**

- **Agreement: Trainers and trainees should reach a consensus on a carefully designed strategy for capacity development, which includes a comprehensive training concept, because conditions vary across countries**

9.4 Community Awareness, Education, and Communication

- **Importance: Water loss is not only an engineering problem but also a reflection of the sociocultural situation that requires changes in community behavior and attitude toward water usage.**
  - For many years, community awareness and education have been considered the ugly, useless step-child of water demand management.

- **Critical factor to success: Frequently, well-designed and implemented technical interventions fail miserably because the community being served is excluded from the overall process. As a result, the community does not *buy-into* the project.**

- **Difficulty in monitoring: Unfortunately, activities geared toward community awareness and education are difficult to monitor with regard to cost compared to savings achieved. Both aspects are impossible to quantify.**


Thank you very much

Water audit & Performance Indicators

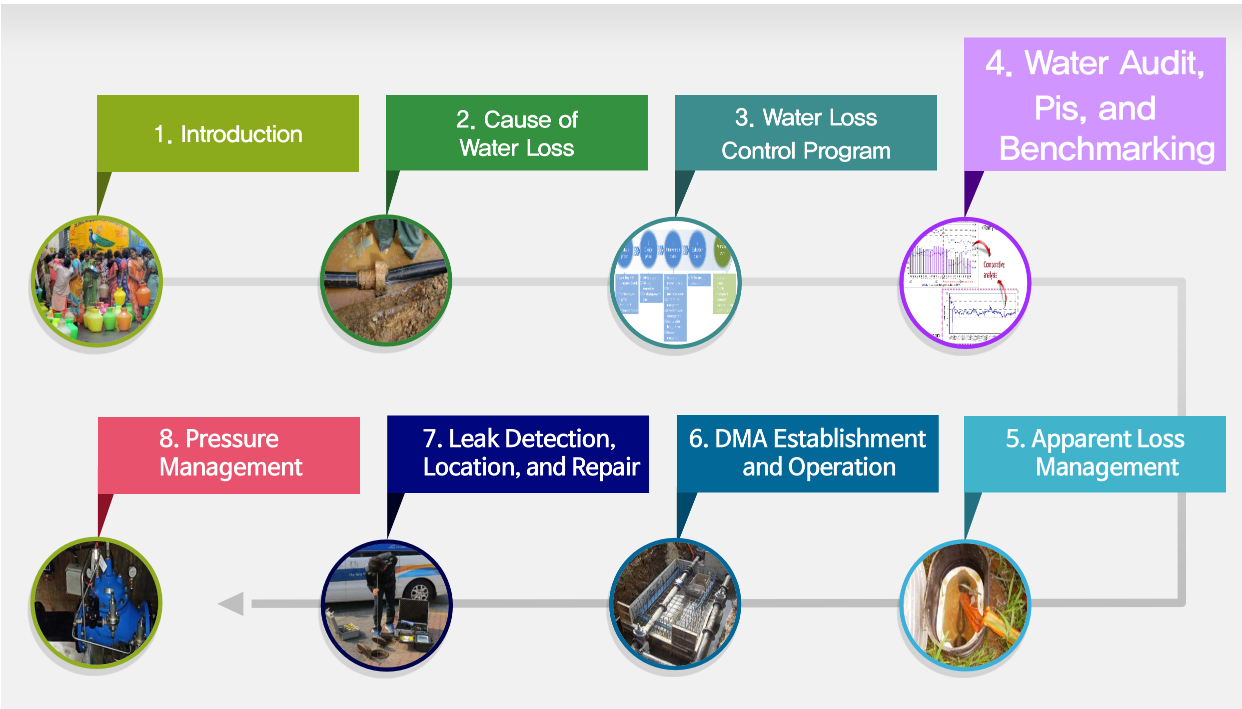
Water Loss Management

4. Water Audits, Performance Indicators, and Benchmarking

United Nations Educational, Scientific and Cultural Organization

International Centre for Water Security and Sustainable Management

Training Course



Aims and Objectives

- The course aims to:

  (1) Provide a background on the water audit process, PIs, and benchmarking methods;
  (2) Enable trainees to perform a water audit of and evaluate the system

- The objectives are that trainees will understand:

  (1) Top-down and bottom-up approaches in water balance calculation;
  (2) Performance indicators

Contents

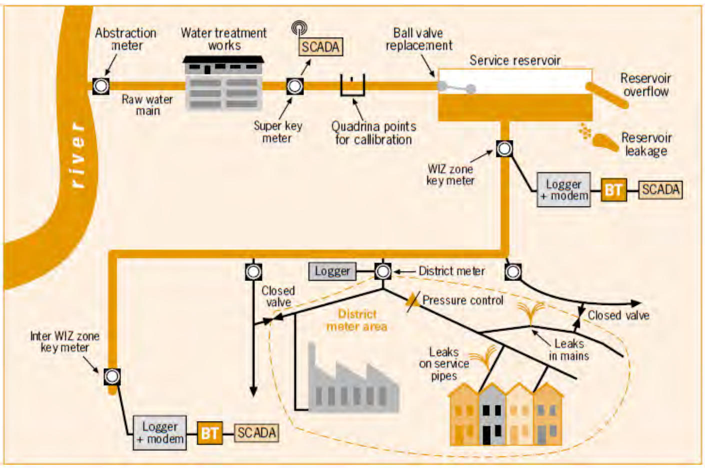
1. Overview
2. Introduction
3. Top-down Approach
4. Bottom-up Approach: Minimum Night Flow Analysis
5. Performance Indicators and Benchmarking
6. Tools and S/W
7. Conclusions

1. Overview

1.1 Background
1.2 Water Audit Approach
1.3 Standardized Definitions of Terminologies and Methods
1.4 Issues in Application

1.1 Background

- **Definition: Water audit determines the amount of water loss from a distribution system**
  - Water audit quantifies the total water loss and leakage in a network
  - In effect, it is a water balance calculation, where the amount of water in distribution is compared with the sum of the components of water consumed or used
  - Water balance is called water audit in the USA

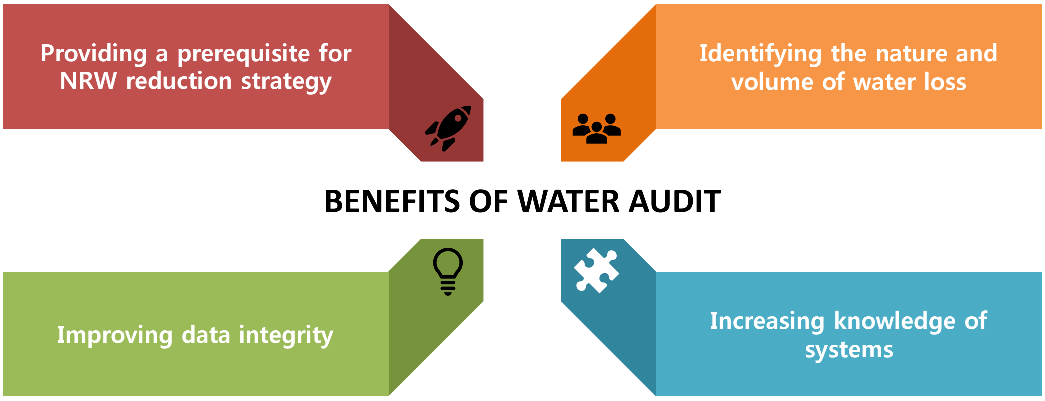


[Potential Leakage Points]

Source : Farley (2001)

1.1 Background

- **Importance: Water audit is the foundation and critical first step in establishing an effective water loss management program**



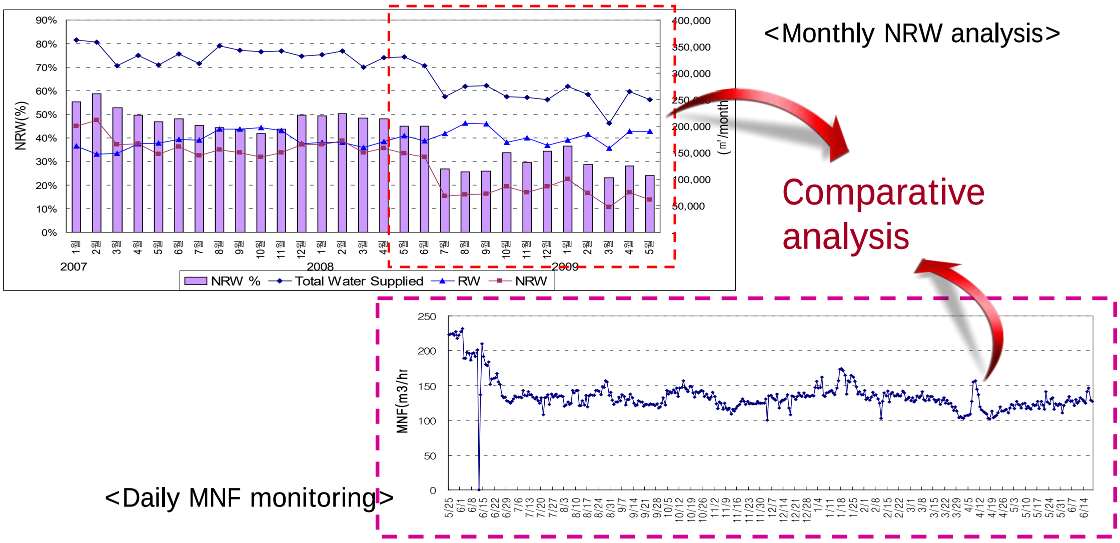
[Benefits of Water Audit]

1.1 Background

- **From guess to science: Thirty years ago, NRW management was based on guesswork than on precise science**
  - However, this tendency has changed dramatically for many industrialized countries, which was kick-started by the regulatory pressure on UK water companies to cut leakage
- **Amount, not location: NRW assessment basically involves quantifying loss in a particular system without considering the location of the loss**
- **Tools: Designing a worksheet or spreadsheet to perform water balance calculations is recommended**
  - Commercial software is available to support collection of necessary data and performing calculations
  - A number of techniques for calculating water balance exist and should be combined to achieve reliable results

1.1 Background

- **Comparative analysis: Utility managers must, therefore, verify the result using component analysis (top-down approach) or physical loss assessment (bottom-up approach)**



[Comparative Analysis in the Water Audit Process]

Courtesy of K-water

1.1 Background

- **GIGO: Noting that the accuracy of water loss volume is dependent on the accuracy and quality of data used in the calculation is extremely important**

  - Reliable metering of all water volumes entering and exiting the supply system is a fundamental requirement
  - Data validation also play a key role in assessing water loss volume

- **Wrong Information: Reported low levels of NRW whether due to deliberate misinformation or, more likely, lack of accurate information, will be unable to help the water utility to reduce costs or increase revenue**
  - Instead, it will mask the real problems affecting the operating efficiency of the water utility

1.2 Water Audit Approach

- **Water balance calculation can be classified into top-down and bottom-up approaches**
  - First, a top-down water balance should be prepared using the IWA methodology and continually refined as data become available to enable a bottom-approach

- **Objectives of each approach**
  - Top-down: estimation of crude water balance
  - Bottom-up: complementary analysis for top-down analysis from the water balance point of view and analysis in DMA-scale and prioritization between DMAs for active leakage detection and leak awareness

[Top-down and Bottom-up Approaches]

Source: EPAL (2017)

1.3 Standardized Definitions of Terminologies and Methods

- **Precondition for BM: The precondition for calculating internationally comparable PIs is a standardized terminology and water accounting methodology**
  - Until the early 1990s, no reliable and standardized methods were available for accounting for water loss
  - Leakage management performance was measured in terms of unaccounted-for water

- **Standardization: In 2000, the International Water Association (IWA) developed standard terminologies and methods to assist water systems in tracking water loss and performing water audit**
  - As a part of an initiative started in the late 1990s, the IWA established the Water Loss Task Force (WLTF) to examine international best practices and develop PIs related to water loss
  - The IWA developed standard terminologies and methods to assist water systems in tracking water loss and in performing water audit (Lambert & Hirner, 2000)
  - The IWA water audit methodology is based on the water balance table, which specifies different types of water consumption and loss

1.4 Issues in Application

(1) Not calculating a water balance

- **(Not) performing water audit: Many water utilities are not used to producing a water balance**
  - Therefore, the split between physical and commercial losses is rarely known
  - The scenario renders the calculation of meaningful NRW PIs nearly impossible

- **Valuable, even if wrong: Establish a water balance is always worth the effort, even if main elements are based on estimates**
  - By so doing, producing a catalogue of required actions to improve the accuracy of water balance becomes possible

1.4 Issues in Application

(2) Lack of data

- **Lack of data: Frequently, even the most basic information, such as system input volume, average pressure, supply time, length of mains, and number of service connections, is initially unavailable**
  - The process of calculating each component and PI of water balance will reveal such deficiencies
  - Utility management should then take corrective action to close these data gaps and improve data quality

- **Absence of monitoring system: Most water utilities lack adequate monitoring systems for assessing water loss, and many countries lack national reporting systems that collect and consolidate information on water utility performance**
  - The result is that data on water audit are not readily available
  - Even available, data may not be always reliable because several poorly performing utilities are known to practice window dressing to conceal the extent of their inefficiency

1.4 Issues in Application

- **GIGO: Using incomplete or inaccurate data for water balance calculation will not produce useful results – garbage in, garbage out**

- **Required data: An extremely important aspect to note is that the accuracy of water loss volume is dependent on the accuracy and quality of data used for calculation**
  - The top-down method requires that bulk and customer water meters are installed and read for the period of at least 1 year
  - The accuracy of installed bulk meter should be determined via field tests, e.g. through a volumetric test, portable insertion, or clamp-on flow meters

1.4 Issues in Application

(3) Manipulating NRW

- **Fabrication: The amount of publicly available data water audit is limited. Even worse, data are frequently wrong and misleading**
  - In countries where the legal situation requires water utilities to maintain the level of NRW below a certain level, a strong tendency occurs to report lower-than-actual numbers to meet legal or regulatory requirements
  - For example, this scheme was common in the former Soviet Union, where utilities were required to maintain NRW below 18%. All utilities reported low levels, despite actual levels often exceeding 50%

1.4 Issues in Application

(4) How can the water utility estimate unmetered components?

- **Accurate estimates: In the absence of actual metering, effort should be made to reach a precise assessment of each component of water volume and use to determine realistic quantities for water balance**
  - Methods used to estimate any unmetered components of the water balance should be recorded and defined

- **AL in developing or developed countries: Although AL is a major concern in low- and mid-income countries, it lacks recognition in input data for the majority of water audit analyses**
  - Providing extensive detailed input for AL results in accurate results

2. Top–down Approach

2.1 Top–down Approach
2.2 IWA 'Best Practices' for Water Balanc
2.3 Procedure
2.4 Defining Key Parameters Before Water Audit
2.5 Estimates
2.6 Quantified Values
2.7 Uncertainty Analysis

2.1 Top-down Approach

- **Starting point of audit: The top-down approach is the recommended starting point for water utilities compiling an initial water audit**
- **Paper exercise: The top-down approach initiates the process with all available information, usually being undertaken on paper or as a desktop exercise, in which no field work is but a number of estimates are made**
  - This approach begins with a macro-analysis of losses that assesses the need for intervention over the whole network
- **Interval: Each water utility should perform a top-down water balance on an annual basis**

2.1 Top-down Approach

Preliminary assessment of water loss

With relatively modest effort, the top-down method can provide a good preliminary assessment of water loss status and insight into the quality of available data on water supply

Identifying components for validation

The top-down audit identifies components that require further validation

Easy PI calculation

After calculating the IWA standard water balance, best practice NRW PIs can be calculated for target monitoring and leakage benchmarking

Errors and uncertainty

The procedure is subject to errors and uncertainty

Retrospective approach

The utility should consider that the annual water balance is a retrospective approach. In other words, it cannot provide an early warning system for identifying new leaks and bursts

[Pros and Cons of Top-down Approach]

2.2 IWA "Best Practice" for Water Balance

- **Best Practice: The IWA developed the top-down annual water balance as a best practice method**
  - The top-down method requires that bulk and customer water meters are installed and read for a period of at least one year

A	B	C	D	E
System Input Volume M^3/year	Authorised Consumption M^3/year	Billed Authorised Consumption M^3/year	Billed Metered Consumption (including water exported)	Revenue Water M^3/year
			Billed Unmetered * Consumption	
		Unbilled Authorised Consumption M^3/year	Unbilled Metered Consumption	Non-Revenue Water** M^3/year
			Unbilled Unmetered Consumption	
	Water Losses M^3/year	Apparent Losses M^3/year	Unauthorised Consumption	
			Metering Inaccuracies	
		Real Losses M^3/year	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer metering	

[Components of Water Balance for a Transmission or Distribution System]

Source: Lambert and Hirner (2000)

2.2 IWA "Best Practice" for Water Balance

- **RL and AL: Water losses consist of real and apparent losses**
  - Real loss: burst pipes, leaking joints, fittings, service pipes, and connections
  - Apparent loss: illegal connections, under-registration of customer meters, inaccurate meters, stopped meters, vandalized meters, by-passed meters, billing errors, inadequate meter reading policies, and bribery and corruption of meter readers
- **Administrative NRW: Unbilled authorized consumption and apparent loss are referred as administrative NRW**
- **Terminology: Unbilled, unmetered authorized consumption is any kind of authorized consumption this is neither billed nor metered**
  - This component typically includes items, such as fire fighting, flushing of mains and sewers, street cleaning, and frost protection
  - In many countries, water is provided for free to certain consumer groups (i.e., religious institutions)
- **Room for manipulation: Unbilled, unmetered authorized consumption, which traditionally includes water used by the utility for operational purposes, is frequently seriously overestimated**
  - Oftentimes, the underlying cause is simplification (e.g., using a percentage of the total system input) or deliberate overestimation to reduce the amount of NRW

2.3 Procedure

(1) IWA (2000)

- **Steps for calculating NRW and water loss**

A	B	C	D	E
System Input Volume M³/year	Authorised Consumption M³/year	Billed Authorised Consumption M³/year	Billed Metered Consumption (including water exported)	Revenue Water M³/year
			Billed Unmetered * Consumption	
		Unbilled Authorised Consumption M³/year	Unbilled Metered Consumption	Non-Revenue Water** M³/year
			Unbilled Unmetered Consumption	
	Water Losses M³/year	Apparent Losses M³/year	Unauthorised Consumption	
			Metering Inaccuracies	
		Real Losses M³/year	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer metering	

Steps for Calculating Non-Revenue Water and Water Losses

Step 1: Define *System Input Volume* and enter in Col. A

Step 2: Define *Billed Metered Consumption* and *Billed Unmetered Consumption* in Col. D; enter total in *Billed Authorised Consumption* (Col. C) and *Revenue Water* (Col. E)

Step 3: Calculate the volume of *Non-Revenue Water* (Col. E) as *System Input Volume* (Col. A) minus *Revenue Water* (Col. E)

Step 4: Define *Unbilled Metered Consumption* and *Unbilled Unmetered Consumption* in Col. D; transfer total to *Unbilled Authorised Consumption* in Col. C

Step 5: Add volumes of *Billed Authorised Consumption* and *Unbilled Authorised Consumption* in Col. C; enter sum as *Authorised Consumption* (top of Col.B)

Step 6: Calculate *Water Losses* (Col. B) as the difference between *System Input Volume* (Col.A) and *Authorised Consumption* (Col. B)

Step 7: Assess components of *Unauthorised Consumption* and *Metering Inaccuracies* (Col. D) by best means available, add these and enter sum in *Apparent Losses* (Col. C)

Step 8: Calculate *Real Losses* (Col. C) as *Water Losses* (Col. B) minus *Apparent Losses* (Col. C)

Step 9: Assess components of real losses (Col. D) by best means available (night flow analysis, burst frequency/flow rate/duration calculations, modelling etc), add these and cross-check with volume of *Real Losses* in Col. C which was derived from Step 8

[Components of Water Balance for a Transmission or Distribution System]

Source: Lambert and Hirner (2000)

2.3 Procedure

(2) AWWA (2006)

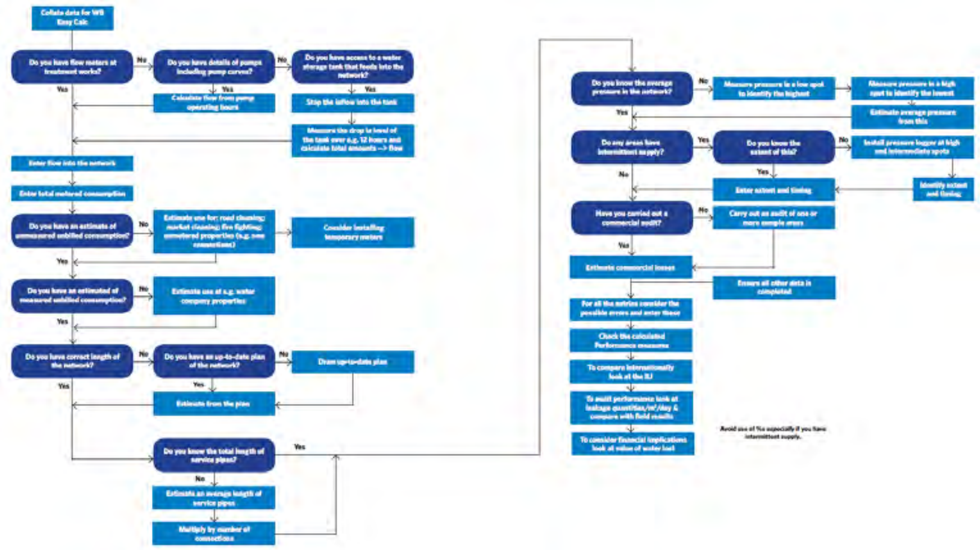
- **The procedure is provided in detail in the AWWA M36 manual**
  - AWWA suggests similar procedure with 10 tasks

Step	Task
1	- Collect distribution system description information
2	- Measure Water supplied to the distribution
3	- Quantify billed authorized consumption
4	- Calculate Nonrevenue water
5	- Quantify unbilled authorized consumption
6	- Quantify water loss
7	- Quantify apparent losses
8	- Quantify real losses
9	- Assign cost of apparent and real losses
10	- Calculate the performance indicators

2.3 Procedure

(3) Water and Sanitation for the Urban Poor (WSUP; 2017)

- **WSUP suggested a detailed procedure using tools**

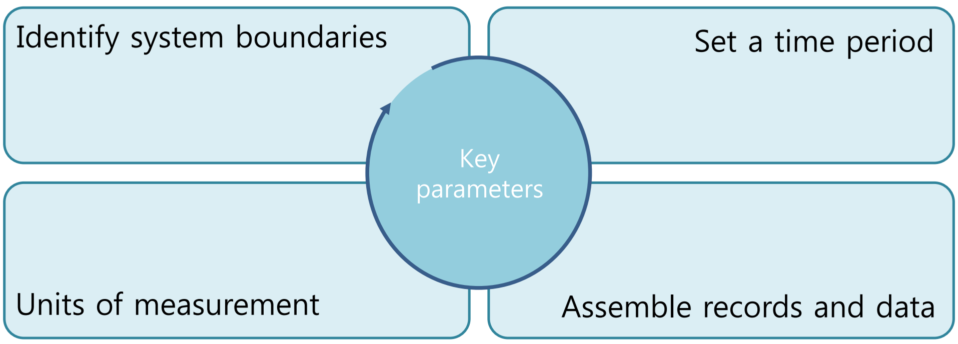


[Procedure for Determining Current Performance]

Source: WSUP (2014)

2.4 Define Key Parameters Before Water Audit

- **Key parameters at the initial stage: At the onset, defining several key parameters for water audit is important**



2.5 Estimates

- **Based on measurement: Water balance should be based preferably on the actual measurement of flow rates and volumes**

- **Last resort (estimation): However, in the absence of a reliable duly verified measurement, every effort should be made to evaluate as accurately as possible the volume and consumption of each component and realistically estimate each component of water balance**

2.5 Estimates

- **Estimated components: In the top-down water audit, unbilled authorized consumption and apparent loss components can be estimated**
  - To determine inaccuracies in customer meters, a representative sample is tested in the laboratory at different flow rates representative of the field condition
  - Data handling and billing errors are estimated by investigating historical billing records and trends
  - Estimating the amount of unauthorized use is challenging. Therefore, it is commonly assumed arbitrarily

Parameter			Suggested Default	
Unbilled Unmetered Authorised Consumption			0.5%	of Billed Authorised Metered Consumption
Unauthorised Consumption			0.2%	(excluding Water Exported)
Customer Meter Inaccuracies	Direct pressure systems	Residential	2.0%	of metered residential consumption
		Non-residential	2.0%	of metered non-residential consumption
	Storage tanks supplied by gravity	Residential and Non-Residential	Usually > 5% of metered consumption, influenced by many factors. Assess on country by country basis.	

Note: default volumes to be calculated as simple % of metered consumption

[Suggested Estimates for Water Audit]

Source: Lambert et al. (2014)

2.5 Estimates

- **Selection between estimated and quantified values: To quickly quantify this category, the default value can be used instead of quantifying numerous minor wastes, uses, or losses**
  - Quantifying work can be time-consuming. The auditor should use good judgment to determine whether the extra effort to analyze many undocumented occurrences of consumption is likely to lead to a consumption level that exceeds the default value
  - A recommendation is that the default value should be applied unless the auditor has documented evidence

Preference	Details
Estimate	- In general, the auditor's time will be better saved if dedicated to quantifying and controlling real and apparent losses - In most cases, the extra effort to document these consumptions is not worthwhile
Quantified value	- Under certain conditions, such as severe drought, the publicly visible use of water for flushing or other operations could generate negative public perceptions for water utilities. In such cases, auditing should review all instances of unbilled authorized consumption and ensure efficient management - If the auditor feels that the consumption is notably larger than the default value, then detailed estimates of these components can be obtained

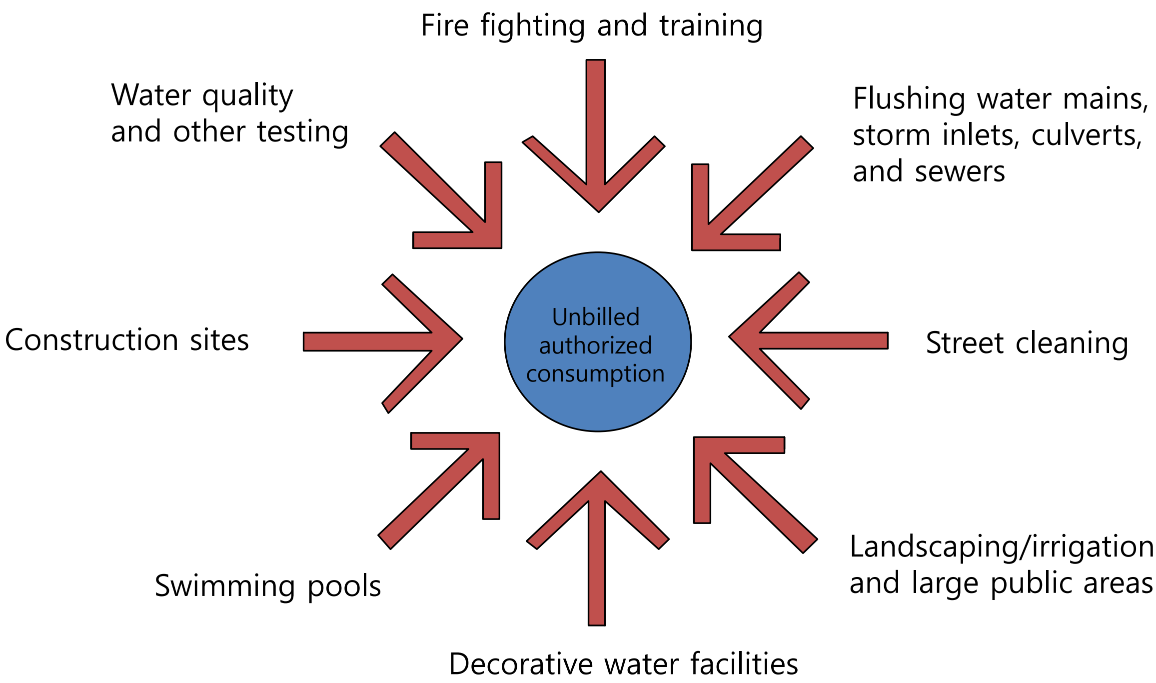
2.6 Quantified Values

(1) Quantifying unbilled authorized consumption

- **No measurement and flat fee: Unbilled authorized consumption is rarely metered. It can be directly billed, although revenue is frequently recovered via flat fees paid by the fire department or other users**

- **No policies and procedures: Unfortunately, many water utilities lack clearly written policies that include procedures for safely supplying such an unbilled water consumption**
  - Similarly, good accounting is lacking for the types and volumes of such consumption occurring throughout the year
  - A recommendation is that the auditing process should review utility policies and practices and improve as needed to ensure that such water consumption is safe or appropriately utilized and can be accounted for in terms of the extent of its practicality

2.6 Quantified Values



2.6 Quantified Values

(2) Quantifying apparent losses

- **Difficulty: Quantifying apparent loss in a distribution network is a difficult task, which has to be based mostly on assumption and estimates**
- **No meter, no meter inaccuracy: For water utilities with unmetered customer consumption, no amount of apparent loss is caused by customer meter inaccuracy. This component does not apply**
- **No general method: Accurate methods for calculate apparent loss values are lacking. However, recommendations are provided for estimating the indicators of this type of loss**

2.6 Quantified Values

- **Quantification of three components: These assumptions should be drawn separately for each of the three main sources of apparent loss as follows.**
  - Although assumed volumes of apparent loss are subject to errors and thus approximate to a certain degree, this step is required to determine water balance

Main source	Details
Assessing meter inaccuracies	- Apparent loss due to meter inaccuracies can be estimated by selecting a representative group of domestic meters while taking into account the different meter types, brands, sizes, and age groups and verifying them using a test bench - Large bulk meters can be tested on-site and in operation through calibrated portable flow meters - Average meter inaccuracies (percentage of over- or under-registration) for each group of meters can then be applied to the entire meter park
Assessing data handling errors	- Errors during data handling can be detected and quantified through standard database software - Meter reading errors can be reduced through a continued training of meter readers and by introducing standardized working routines
Assessing unauthorized consumption	- The water utility should estimate the number of illegal connections to quantify unauthorized used of water, e.g., by conducting a house-to-house survey in a pilot zone - The estimated number of illegal connections should be multiplied by the typical household size and per capita water consumption - Illegal connections accidentally discovered by water utility workers should thus be registered - The number of broken, by-passed, or manipulated meters should be taken into account based on information from meter readers or other utility personnel

2.6 Quantified Values

- **Meter inaccuracies: From the random sampling test, the weighting factors for flow rates and mean registration can be derived. These values can be used to quantify apparent loss as a result of meter inaccuracies**
  - The test should be classified into two categories, namely, small-sized meter for residential use and large-sized meter for industrial, commercial, or agricultural use
  - Weighting factors for flow rates:
  - Mean registration: accuracy

Percent of Time	Range, gpm	Average, gpm	% Volume†
15	Low 0.50–1.0	0.75	2.0
70	Medium 1–10	5.00	63.8
15	High 10–15	12.50	34.2

* Based on information from Tao, Penchin, "Statistical Sampling Technique for Controlling the Accuracy of Small Meters," *Journal AWWA*, 6:296 (1982).

† Percent volume refers to the proportion of water consumed at the specified flow rate, as compared to the total volume consumed at all rates. In this example, only 2.0 percent of the total water consumed occurs at the low-flow range of approximately 0.5–1.0 gpm.

Instead of using the percentage of volumes shown here, the utility may compute its own percentage volume data. Using special dual-meter yokes and recording meters, the utility can determine the actual flow rates for their water meters.

Test Flow Rates, gpm	Mean Registration, %
Low (0.25)	88.8
Medium (2.0)	95.0
High (15.0)	94.0

Percent Volume* (%V)	Total Sales Volume† (Vt), mil gal	Volume at Flow Rate (Vf) (%V × Vt), mil gal	Meter Registration (R)‡, %	Meter Error (ME) ME = Vf/(0.01R) – Vf, mil gal	Meter Error (ME), mil gal
2.0	2,318..8	46.38	88.8	[(46.38/0.888) – 46.38]	5.85
63.8	2,318.8	1,479.39	95.0	[(1,479.39/0.95) – 1,479.39]	77.86
34.2	2,318.8	793.03	94.0	[(793.03/0.94) – 793.03]	50.62
		Total residential meter error (Line 18 of Figure 2-4)			134.33

[Example of Quantifying Apparent Loss Caused by Small-sized Meter Inaccuracy]

Source: AWWA (2009)

2.6 Quantified Values

Flow Rates	% Volume Delivered
Low	10
Medium	65
High	25

* For this example, assume flow recordings were made for 24 hr in July and February to indicate the percent of volume delivered by large meters at low-, medium-, and high-flow rates.

Meter ID Number	Size, in.	Meter Type	Date of Installation	Manufacturer	Test Date	Mean Registration at Various Flow Rates: (designated as percent of registration)		
						Low	Medium	High
XYZ001	3	Turbine	June 1991	Sensus	Oct 2006	89	93	100
X00ZAA	3	Turbine	June 1993	Sensus	Oct 2006	70	95.2	98
NB123	4	Displace	July 1980	Sparling	Oct 2006	95	99	102
NB456	6	Compound	Sept 1977	Sparling	Oct 2006	98	96.5	102
AA002	6	Propeller	May 1966	Hersey	Oct 2006	98	99	103
				Sum of mean registrations		450	482.7	505
				Mean registration for five meters tested		90	96.54	101

Percent Volume* (%V)	Total Sales Volume† (Vt), mil gal	Volume at Flow Rate (Vf) (%V × Vt), mil gal	Meter Registration (R)‡, percent	Meter Error (ME) ME = Vf/(0.01R) – Vf, mil gal	Meter Error (ME), mil gal
10	939.2	93.92	90.0	[(93.92/0.90) – 93.92]	10.43
65	939.2	610.48	96.54	[(610.48/0.9654) – 610.48]	21.86
25	939.2	234.80	101.0	[(234.80/1.01) – 234.80]	–2.32
Total meter error for large meters (Line 19 of Figure 2-4)					29.97

[Example of Quantifying Apparent Loss Caused by Large-sized Meter Inaccuracy]

Source: AWWA (2009)

2.7 Uncertainty Analysis

- **Inherent error: Water balance is based not only on measurements but also on estimates of water production, consumption, and losses**
  - Hence, the resulting volumes of NRW and real and apparent losses will be subject to a greater or lesser degree of error

- **Effect of error: Errors in determining real and apparent loss volumes will influence the economic analysis of options and may lead to an inappropriate strategy for water loss reduction**
  - Therefore, an important aspect of this scheme is that all measured data and necessary estimates should be as close to the real conditions as possible, such that valid and useful results can be achieved

- **Importance of uncertainty analysis: Introducing the uncertainties of the water balance components is a significant achievement in raising awareness of the limitations of water balance and practical means to improve them**
  - Uncertainty analysis points out that input data should be verified to minimize the uncertainty of an interesting output

2.7 Uncertainty Analysis

- Benefit #1: Using uncertainty analysis to improve output is not questionable and strongly recommended (Alegre et al., 2016; AWWA, 2016; Lambert et al., 2014)
- Benefit #2 Uncertainty analysis can improve the output of water loss assessment methods, although it does not demonstrate the accuracy or validity of methods (Al-Washali et al., 2020)
- Accuracy or validation score: Relevant to uncertainty analysis is the use of validation scores for the input and output of the tool to determine the validity and reliability of the tool's output

2.7 Uncertainty Analysis

(1) Accuracy band

- For example, if NRW is 21% with an accuracy of +/− 66%, then the actual NRW ranges between 7% and 35%
- Guess on accuracy: In practice, no detailed information is available about data accuracy and reliability. However, water utilities can provide competent guesses about the accuracy band of certain input data (Alegre et al., 2007)

Data origin	Description	Accuracy bands
Measured volumes	System input, metered consumption, metered export	± 0.1 to 2.0%
Estimated volumes	Unmetered consumption, apparent losses	± 5 to 50%
Derived volumes	Non-revenue water, real losses	Depends on accuracy of measured and estimated input data

[Example of the Relationship Between Data Origin and Data Accuracy]

Source: GIZ (2011)

2.7 Uncertainty Analysis

- **Production meter #1: The accuracy of production flow meters is critical to the calculation of system NRW**
  - Different meter types render varying levels of accuracies, as shown in the following table

- **Production meter #2: Over time, these meters can be influenced by several factors, such as water quality, pipe vibration, dirt entering the meter, and electronic malfunction**
  - Utility managers should regularly check the accuracy of the electronic functionality of the meter (if electronic) and volumetric accuracy

Equipment/Method	Approximate Accuracy Range
Equipment/Method Approximate Accuracy	
Electromagnetic Flow Meters	<0.15 -0.5%
Ultrasonic Flow Meters	0.5 - 1%
Insertion Meters	<2%
Mechanical Meters	1.0 - 2%
Venturi Meter	0.5 - 3%
Weirs in open channels	10 - 50%
Volume calculated with pump curves	10 - 50%

Note: Actual meter accuracy will depend on many factors (like flow profile, calibration, meter installation, maintenance), and has to be verified case by case.

[Indicative Examples of Meter Accuracy]

Source: WBI (2007)

2.7 Uncertainty Analysis

(2) Uncertainty analysis

- **Uncertainty analysis. Water balance is frequently accompanied by uncertainty analysis because it is associated with uncertainties**

- **Method: Uncertainty of water balance can be calculated in a straightforward manner using error propagation theory**

	Data origin*	Volume [m³]	Accuracy Band [%]		Standard deviation σ	Variance V = σ²
System input Q_I	(M)	1,996,139	± 1.0	→	10,184	103,721,650
Revenue water Q_{RW}	(M)	1,801,146	± 0.2	→	1,838	3,377,891
Non-revenue water Q_{NRW}	(D)	194,993	± 10.4	←	10,349	107,099,541
Unbilled authorised consumption Q_{UA}	(E)	30,000	± 20.0	→	3,061	9,371,095
Water losses Q_{WL}	(D)	164,993	± 12.8	←	10,792	116,470,637
Apparent losses Q_{AL}	(E)	32,999	± 50.0	→	8,418	70,862,896
Real losses Q_{RL}	(D)	131,994	± 20.3	←	13,687	187,333,533

* With: (M) = metered, (D) = derived, (E) = estimated volumes.

[Example for the Determination of Accuracy Bands]

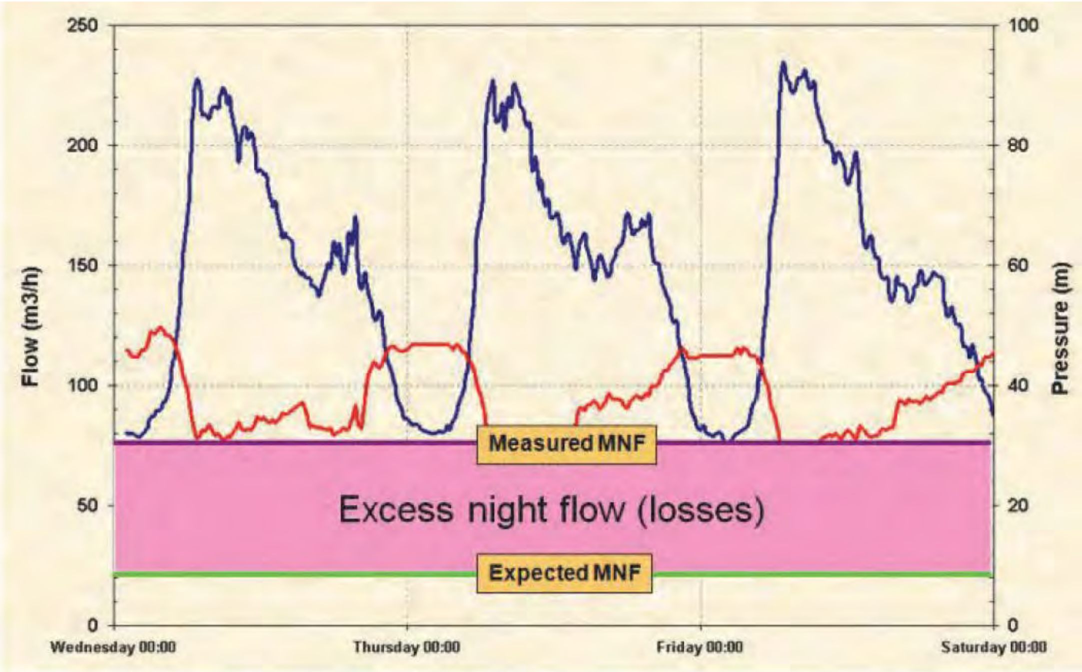
Source: Liemberger (2008)

3. Bottom–up Approach: Minimum Night Flow (MNF) Analysis

3.1 Bottom-up Approach

- **Small-scale assessment #1: DMA and night flow analysis (bottom-up method) are two major tools used for the bottom-up assessment of distribution system leakage**
  - To adopt the bottom-up approach, the network should be progressive and properly structured and equipped in accordance with normal operation, which can analyzed through permanently sectored district metered areas (DMAs)
- **Small-scale assessment #2: The bottom-up approach, when applied in cases of sectorized systems and equipped with continuous monitoring, denotes the possibility of calculating the volume of real loss from the night flow valve**
- **Accompaniment: The bottom-up analysis based on night flow measurements is recommended as an complement to the annual water balance to develop an appropriate strategy for water loss reduction**
- **Crosschecking: The bottom-up assessment is a useful tool for crosschecking the real loss volume obtained from the top-down water balance and component analysis**

3.1 Bottom-up Approach



[Example of Basic Flow and Pressure Logging]

Source: Mckenzie (2014)

3.2 Monitoring Minimum Night Flow

Items	Details
Time	- In most situations, the minimum night flow occurs between 02.00 and 04.00 h (Farley, 2001) - MNF typically found occurs between 12 am and 4 am when the consumption in the network is at the lowest level (Mckenzie, 2014)
Logging frequency	- Logging frequency, i.e., the average period for each measurement, is typically 15 min (UK Water Industry Research Ltd. & WRc, 1994). Correction factors can be used to change non-1-hour minimum night flows to 1-hour flow equivalents

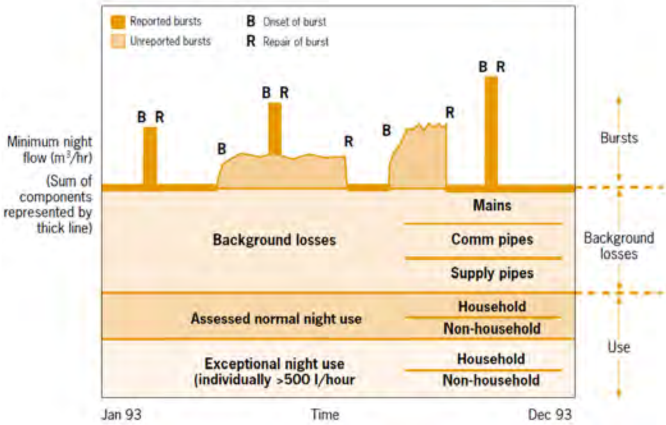
Measurement period	Multiplier for net night flow
15 minutes	1.02
30 minutes	1.01
1 hour	1.0
2 hours	0.98

[Correction Factors for Changing Non-1-hour Minimum Night Flows to 1-hour Flow Equivalents]

Source: Farley (2001)

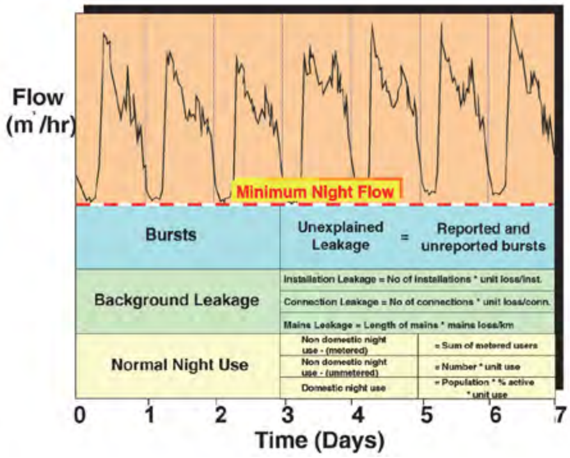
3.3 Interpretation: BABE Methodology

- **Components of MNF: This approach considers the MNF to consist of three main components, namely, normal legitimate night use, background loss, and burst pipes**



[Components of Minimum Night Flow]

Source: Farley (2001)



[Interpretation of the Minimum Night Flow]

Source: Mckenzie (2014)

3.3 Interpretation: BABE Methodology

(1) Normal legitimate night use (legitimate night flow)

- **Using allowances #1: Allowances for night use are made, which are derived from a sample in each category of customer because monitoring all consumers is impossible**

Components	Equations
Normal domestic night use (unmetered)	- 1.7 l/property/h or 0.6 l/head/h (UKWAR & WRc, 1994) - 6% of the population * 10 l/h (Mckenzie, 2014)
Non-domestic night use (unmetered); small non-domestic night use	- 8 l/p/h (UKWAR & WRc, 1994); simple method - 0.7–60.6 l/p/h according to SIC codes (UKWAR & WRc, 1994)
Non-domestic night use (metered); large users	

3.3 Interpretation: BABE Methodology

- **Using allowances #1: Managing Leakage-Report E (1994) gives a table of average values of night flow delivered to non-household customers**
  - It is based on one company's survey of 3,000 customers
  - The customers are classified in standard industrial classification (SIC) codes and in five groups of customers with similar average uses

Category	Customer type	Night use allowance (l/hr)
A	Unmanned fire/police stations, telephone exchanges, banks, churches, chapels, gardens/allotments, market gardens, water and sewage treatment works	0.7
B	Shops, offices, craft centres, launderettes, depots, large domestic properties, guest houses, garages/filling stations, touring caravan sites, farms, smallholdings, cattle troughs	6.3
C	Hotels, schools/colleges, restaurants, cafes, public houses, social halls, residential caravan sites, livery stables	10.4
D	Hospitals, factories, public toilets, works sites	20.7
E	Old peoples homes, mines, quarries	60.6

[Non-household Night Use Categories]

Source: UKWAR and WRc (1994)

3.3 Interpretation: BABE Methodology

(2) Background leakage

- **Background leakage can be related with UARL**

Components	Equations
Background leakage from each kilometer of mains	- 0.04 l/km/h (UKWAR & WRc, 1994) - Normal diameter water mains (Mckenzie, 2014): * 40 l/km/h * New pipelines: 20 l/km/h * Old pipelines: 100 l/km/h or higher
Background leakage from each connection	- None (UKWAR & WRc, 1994) - 3 l/property/h (Mckenzie, 2014)
Background leakage from each property	- ICF * PCF * 4 l/property/h (UKWAR & WRc, 1994) - 1 l/property/h (Mckenzie, 2014)

3.3 Interpretation: BABE Methodology

(3) Calculation of Unexplained Bursts

- **Calculation: Difference denotes unexplained loss that is attributable to unreported bursts or errors in the assumptions made during the calculation**

Description	Value
Length of mains	9 300 m
Number of connections	600
Number of properties	672
Estimated population	3 000
Average zone night pressure (AZNP)	50 m
Measured minimum night flow (MNF)	14.4 m^3/h
Background losses from mains	40 l/km/h
Background losses from connections	3 l/connection/h
Background losses from properties	1 l/connection /h
% of population active during night flow exercise	6%
Quantity of water used in toilet cistern	10 l
Number of small non-domestic users	30
Average use for small non-domestic users	50 l/h
Use by large non-domestic users	1.2 m^3/h

[Basic Information Required for MNF Analysis]

Description	Calculation	Value
Domestic night use	3 000 @ 6%/h @ 10 l	1.8 m^3/h
Small non-domestic use	30 @ 50 l/h	1.5 m^3/h
Large non-domestic use	1 @1.2 m^3/h	1.2 m^3/h
Total normal night use		**4.5 m3/h**

[Estimate of Normal Use]

Description	Calculation	Value
Mains losses	9.3 km @ 40 l/km/h	0.37 m^3/h
Connection losses	600 @ 3 l/connection/h	1.80 m^3/h
Property losses	672 @ 1 l/property/h	0.67 m^3/h
Total background leakage at 50 m pressure		**2.84 m^3/h**
Pressure correction factor	$(50/50)^{1.5}$	1.00
Total background leakage at 50 m pressure		**2.84 m^3/h**

[Estimate of Background Leakage]

Description	Value
Expected background leakage	2.84 m^3/h
Expected normal night use	4.50 m^3/h
Total expected night use	**7.34 m^3/h**
Measured minimum night flow	14.40 m^3/h
Unaccounted-for leakage (14.40 – 7.34)	**7.06 m^3/h**

[Estimate of Burst Leakage]

3.3 Interpretation: BABE Methodology

(4) Daily Leakage

- **Snapshot of leakage: The leakage calculated for the MNF period will not be a true representation of leakage across a 24-hour period**
  - Leakage is proportional to the pressure in the system
  - Water flow in DMA is different; therefore, head loss is not constant during day

3.3 Interpretation: BABE Methodology

- **Night to day factor (NDF): To determine the daily water loss from the assessed zone, the ratio of night to day zonal pressure should be considered by calculating the NDF**
  - Pressure profiles at the average zone point (AZP) should be measured, and the leakage exponent α of the system should be determined to calculate the NDF
  - Utility managers must determine a pressure factor (T Facto), which creates a true average 24-hour leakage value when applied to the net night flow (NNF)
- **Typical values of NDF: The typical values for the NDF range from 20 or less in gravity-fed systems to over 30 h per day in pressure management areas with flow-modulated systems**

$$Q_{in} = Q_{dom} + Q_{bulk} + Q_{trans} + Q_{loss}$$

Where:

Q_{in}	[m³/h]	System input
Q_{dom}	[m³/h]	Domestic night consumption
Q_{bulk}	[m³/h]	Non-domestic night consumption
Q_{trans}	[m³/h]	Transfer of water to neighbouring zones
Q_{loss}	[m³/h]	Water losses

$$Q_{loss,d} = NDF \times Q_{loss}$$

$$NDF = \sum_{i=0}^{24} \left(\frac{P_i}{P_{MNF}}\right)^{\alpha}$$

Where:

$Q_{loss,d}$	[m³/d]	Daily real loss volume
NDF	[h/d]	Night to day factor
Q_{loss}	[m³/h]	Average minimum night flow rate
P_i	[m]	Average pressure at AZP during 24 hours
P_{MNF}	[m]	Average pressure at AZP during MNF conditions
α	[-]	Leakage exponent

4. Performance Indicators and Benchmarking

4.1 Performance Indicators and Benchmarking

- **Requirement of PIs: Performance indicators numerically evaluate different aspects of the distribution system and should be consistent, repeatable, and presented in meaningful standardized units**

- **Importance: The aspect of NRW measurement and benchmarking has been one of those important interventions, which many water utilities has been pursuing and developing over the years**

- **NRW and infrastructure leakage index (ILI): In developed countries, NRW is used as a financial indicator instead of an operational indicator, whereas the ILI is used as a technical performance indicator for real loss (Kelay et al., 2006)**
  - Although a percentage of NRW can provide a high-level financial perspective of the water utility, it is not a good operational PI and is unsuitable for effective management of water loss (AWWA, 2003; Fanner et al., 2007; Liemberger et al., 2007)

4.1 Performance Indicators and Benchmarking

(1) Functions & advantages

- **Function #1: A PI system can be considered a key assessment tool for the achievement of targets by applying a coherent set of indicators**
  - PIs and benchmarking are identified as appropriate tools for the evaluation of the performance of the water supply systems
  - PIs extract necessary information from large amounts of data and are useful tools for decision-making processes
  - Different PIs should be calculated and analyzed to determine whether these losses are comparatively high or low
  - However, PIs are not solely tools for national or international benchmarking between water supply utilities and should never be a goal in themselves

- **Function #2: Calculating performance indicators enables a comparison between the management of utilities in different countries and of varying dimensions. They are relevant as a decision-making tool and aim for continuous improvement and knowledge cultivation regarding the supply system conditions and performance**

4.1 Performance Indicators and Benchmarking

(2) Limitations

- **Percentage: A general consensus worldwide is that percentages should not be used because they can be extremely unreliable and frequently provide wrong illustrations**
  - Despite the general international agreement on the non-use of percentages, they remain the indicator of choice in most parts of the world
  - If the use of percentages is acceptable worldwide, then they should be accompanied by a form of warning and, if possible, at least one of more reliable indicators should be included

(3) Requirement

- **Requirement of PIs: Performance indicators should be clear and easy to understand and calculate and has a rational basis**

4.2 Classification

(1) Level

- **PIs can be classified into three categories (i.e., basic, intermediate, and detailed)**

Level	Function		Performance indicator: Service connection density >20/km of mains	Performance indicator: Service connection density <20/km of mains	Comments
1—Basic	Financial	NRW	Volume of NRW as % of SIV	Volume of NRW as % of SIV	Simple, not recommended
1—Basic	Operational	AL	m^3/serv. conn./year	m^3/km of mains/year	For target setting, not comparing systems
1—basic	Operational	RL	L/serv. conn./day	L/km of mains/day	For target setting not comparing systems
1—Basic	Operational	RL	L/serv. conn./day w.s.p.	L/km of mains/day w.s.p.	Allows for intermittent supply situations
2—Interm.	Operational	RL	L/serv. conn./day/m pressure	L/km of mains/day/m pressure	Useful for comparing systems
3—Detailed	Financial	NRW	Value of NRW as % of annual cost	Value of NRW as % of annual cost	Allows different unit costs
3—Detailed	Operational	RL	ILI	ILI	Powerful for comparing systems

[NRW Key Performance Indicators]

Source: Alegre et al. (2016)

4.2 Classification

(2) PIs for financial, operation, and water resources

- **One of the most commonly used approaches in defining performance indicators is understanding their subdivision into district groups, such as financial, operational, and water resources**
- **The following tables were prepared by the IWA Water Task Force and outlined details related to the most commonly used PIs (EPAL, 2017)**

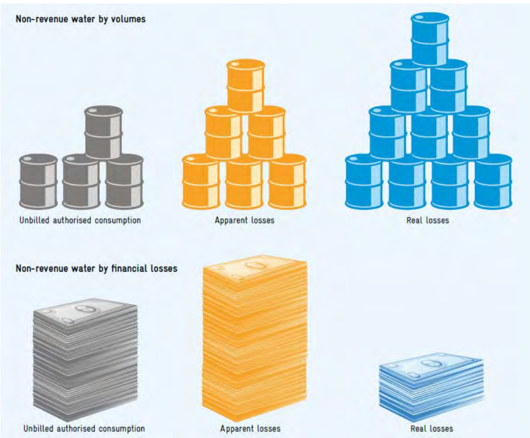
Component	Type	Performance Indicator base	Performance Indicator detail
Non-Revenue Water	Financial	NRW volume as % of water volume in system	NRW system value as % of system cost
Water Losses	Operational	m^3/service connection/year	-
Apparent Losses	Operational		m^3/service connection/year
Real Losses	Water Resources	Real losses volume as % of water volume in system	-
Real Losses (in each case, this indicator is calculated "per day" when the system is pressurized to allow for the effect of intermittent supply	Operational systems	Litres/service connection/day for systems with 20 or more service connection per km of main or use m^3/km/day for systems with less than 20 service connection per km.	Infrastructure Leakage Index (ILI): defined as the ratio between current annual real losses and unavoidable annual real losses = CARL / UARL.

[Key Performance Indicators Related to Water Loss]

Source: Alegre et al. (2007)

4.2 Classification

- **Comparing components from the financial perspective: Water utilities should first focus on the components of NRW where investments will generate the highest rate of return**
  - Comparing the components of NRW not only by volume but also by financial impact is important
  - A small volume of commercial loss may have a higher financial value. Therefore, if the objective is to increase financial resources, then commercial losses should be prioritized



[Example of Possible Volumetric and Financial Distributions of Loss]

Source: GIZ (2011)

4.2 Classification

(3) PIs for total, real, or apparent loss

- PIs can consider the aspects of total, real, and apparent losses

Object	Details
Total loss	- NRW, NRW%
Real loss	- Liter per service connection per day (l/c/d) - Liter per service connection per day per meter of pressure (l/c/d/m pressure) - Liter per kilometer of pipeline per day (l/km/d) - Infrastructure leakage index (ILI)
Apparent loss	- Apparent loss index (ALI) - Percentage of authorized consumption

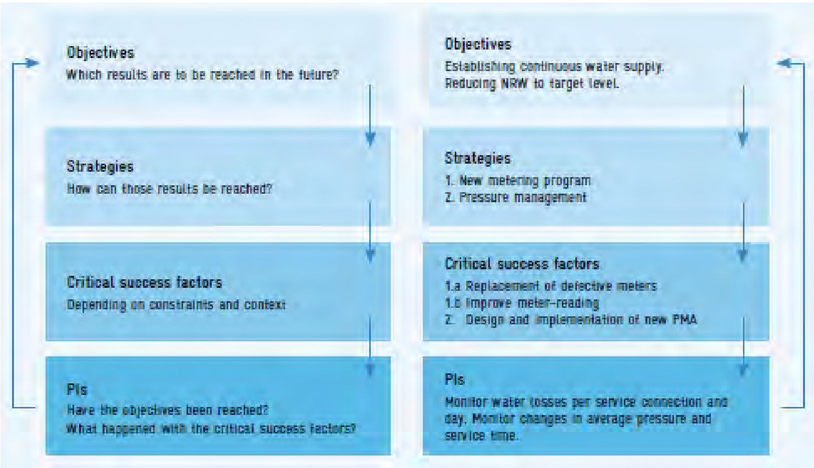
4.3 PI Selection Process

- No general rule: Selecting appropriate performance indicators to quantify and monitor leakage from a water network is frequently contentious

- Contextualization: Given the diversity of situations that occur in water supply networks and the intrinsic characteristics of their functions, contextualizing several key concepts inherent to the calculation of the abovementioned indicators is important to ensure a uniform perception

4.3 PI Selection Process

- **PI selection**
  - 1st Step: Define precise and clear objectives and determine the most suitable strategies
  - 2nd Step: Select appropriate PIs and necessary input data collected

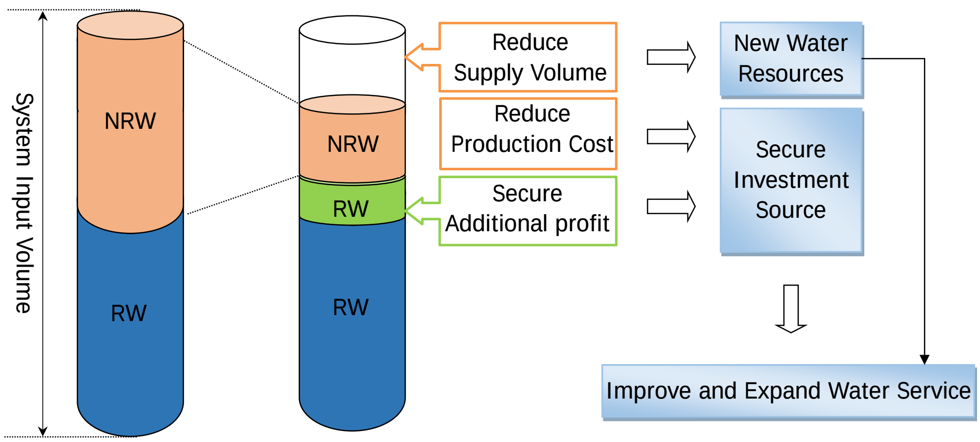


[Use of PIs in Decision-making Processes: General Approach and Example]

Source: Alegre et al. (2007)

4.4 NRW

- **Definition: Non-revenue water is defined as the water produced and lost before reaching consumers**
- **Effect: High levels of NRW are detrimental to the financial viability of water utilities and the quality of water itself**



4.4 NRW

- **Operational and financial Pis: NRW is a good indicator of water utility performance. NRW is a measure of a utility's efficiency in terms of operational and financial performance**
  - High levels of NRW typically indicate a poorly managed water utility

- **Widely accepted PIs: Managers, policymakers, regulatory agencies, and financing institutions use NRW PIs to rank the utility's performance against industry standards and those of other water utilities**

4.4 NRW

- **Deviance from the exact procedure #1: Published NRW data are typically problematic, suspicious, or inaccurate or provide partial information**
  - Many utilities invent "creative" definitions of NRW, use wrong or misleading performance indicators, and fail to quote important information, such as average pressure and supply time

- **Component division of NRW: In many utilities, the exact breakdown of NRW components and sub-components is simply unknown; thus, decision making on the best course of action for NRW reduction is difficult**

- **Deviance from the exact procedure #2: Creative definitions for NRW are used to reduce the reported numbers (e.g., minimum leakage or unbilled consumption is deducted to wrongly reduce the volume of NRW)**
  - Wrong numbers are frequently also reported to meet regulatory requirements

4.5 Benchmarking

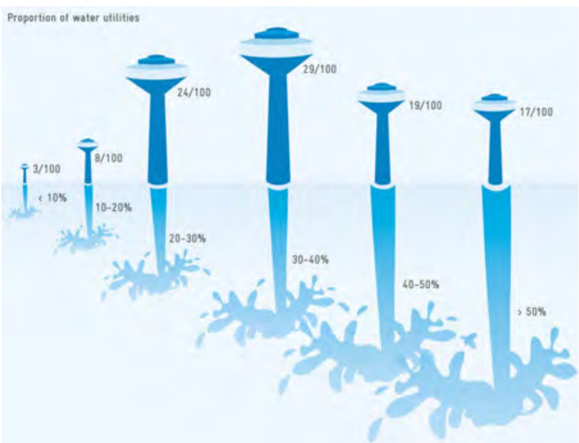
- **Benchmark (BM): A performance indicator (or collection of several indicators) can be used to establish a benchmark**
  - A BM enables a PWS to evaluate its performance over a period of time by repeating performance-indicating tests and comparing them with previous results
  - PIs and BMs enable comparisons between public water providers

- **Interval: Benchmarking can be conducted at any increment of time: daily, monthly, yearly, or every few years**
  - Evaluating its performance
  - Identifying areas for improvement
  - Comparing itself to other water systems
  - Evaluating financial options
  - Gauging itself in a competitive manner
  - Providing data for reports to the public, regulators, and, ultimately, water users

- **Difficulty in ELL: Deciding the acceptable level of water loss is a difficult task because it is dependent on the specific conditions of each utility (operational, i.e., network length, connection density, and service pressure, and commercial)**

4.5 Benchmarking

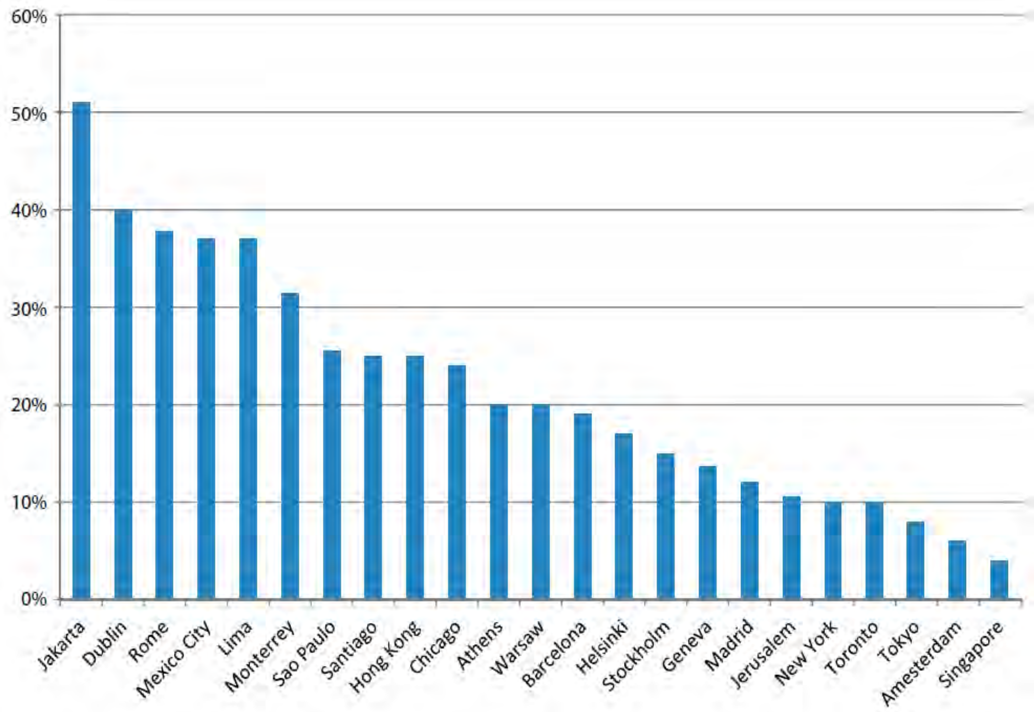
- **Example of BM: The World Bank estimates that the actual figure for over NRW level in developing countries ranges from 40% to 50% of water produced**
  - Based on a study on 40 water utilities in South-East Asia and IBNET database on water utility performance for over 900 utilities in developing countries



[Levels of NRW in Water Utilities in the Developing World Based on the IBNET Database]

Source: Kingdom et al. (2006)

4.5 Benchmarking



[Comparison of Water Loss Levels in Major Cities]

Source: Swan-Smart Water Network Forum (2011)

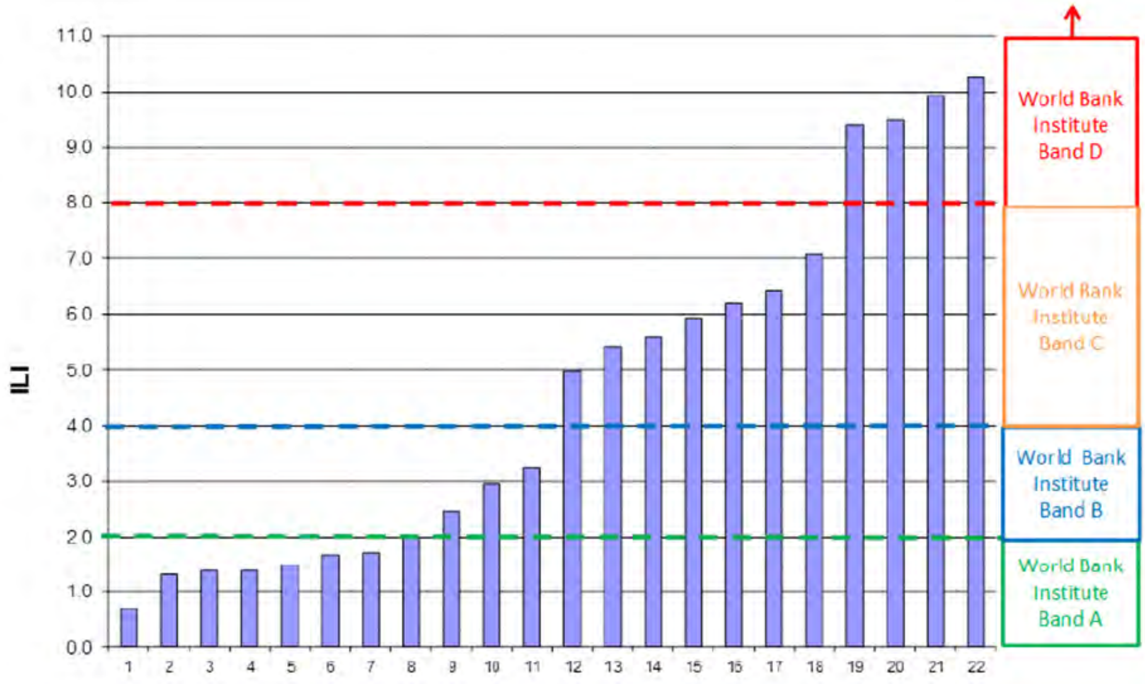
4.5 Benchmarking

Technical Performance Category		ILI	Real Losses in Litres/Connection/Day (when the system is pressurised); at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50 - 100	75 - 150	100 - 200	125 - 250
	C	4 - 8		100 - 200	150 - 300	200 - 400	250 - 500
	D	> 8		> 200	> 300	> 400	> 500
Developing Countries	A	1 - 4	< 50	< 100	< 150	< 200	< 250
	B	4 - 8	50 – 100	100 - 200	150 - 300	200 - 400	250 - 500
	C	8 - 16	100 - 200	200 - 400	300 - 600	400 - 800	500 - 1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

[Physical Loss Target Matrix (from WBI NRW Training Module 6: Performance Indicators)]

Source: Liemberger (2007)

4.5 Benchmarking



[European Dataset of 22 ILIs from 12 Countries for 2005]

Source: Lambert (2014)

5. Tools and Software

5. Tools and Software

- **Out of the 21 tools reported in the literature, 12 are freely available (Al-Washali et. al., 2020)**
  - Many (commercial) tools are designed to assist water utilities assess losses and plan reduction interventions

#	Tool (version)	Reference	Developer	Environment	Description	Approach	Scale
1	AquaLite (v4.5)	(Mckenzie, 2007)	WRC	Windows-based	A tool to establish WB and PIs	Top-down	Global
2	AWWA Water Audit (v5)	(Water Loss Control Committee, 2014)	AWWA	Excel-based	A tool to establish WB and PIs. Uses validity score (qualitative), not uncertainties	Top-down	Global
3	BenchLeak	(Mckenzie, Lambert, Kock, & Mtshweni, 2002)	WRC	Excel-based	A tool to establish WB and PIs	Top-down	Global
4	BenchLoss (v2a)	(GWR-Ltd, 2008)	GWR	Excel-based	A tool to establish WB and PIs	Top-down	Global
5	CalacuLEAKator (v4.3)	(Koldžo & Vuc'ijak, 2013)	Djevad Koldzo	Excel-based	A tool to establish WB and PIs, based on MNF analyses	MNF	DMA, global
6	CheckCalcs (v6b)	(Lambert, 2015a)	ILMSS Ltd.	Excel-based	A tool to establish WB and PIs. Provides insights on leakage relationships, N_1, N_2, N_3	Top-down	Global
7	Component Analysis	(Sturm et al., 2014)	WRF	Excel-based	WB and PIs are inputs. Analyses potential of leakage reduction interventions	Top-do., BABE, PM, ALC	Global
8	EconoLeak (v1a)	(Mckenzie & Lambert, 2002)	WRC	Excel-based	A tool to establish the ELL with cost–benefit analysis of ALC	ELL	Global
9	PresMac (v4.4)	(Mckenzie & Langenhoven, 2001)	WRC	Windows-based	Operational tool for pressure management in a DMA, using PRVs	BABE, FAVAD, PRVs	DMA
10	SanFlow (v4.6)	(Mckenzie, 1999)	WRC	Windows-based	A tool to model MNF in a DMA and breakdown leakage into components	MNF, BABE	DMA
11	WB-EasyCalc (v5.16)	(Liemberger and Partners, 2018)	Roland Leimberger	Excel-based	A tool to establish WB and PIs. Analyses impacts of changes in pressure, SIV, and supply time	Top-down	Global
12	WB-PI Calc-UTH (v2.2)	(Tsitsifli & Kanakoudis, 2010)	Tsitsifli and Kanakoudis	Excel-based	A tool to establish WB and PIs. Considers the overbilling practices in the balance	Top-down	Global

Abbreviations: ALC, active leakage control; AWWA, American Water Works Association; BABE, burst and background estimates; DMA, district metered area; ELL, economic level of leakage; FAVAD, fixed and variable area discharge; GWR, global water resources; MNF, minimum night flow; PRV, pressure reducing valve; SIV, system input volume; WRC, Water Research Commission; WRF, Water Research Foundation.

[Free Software Tools for NRW Assessment]

Source : Al-Washali et al. (2020)

Thank you very much

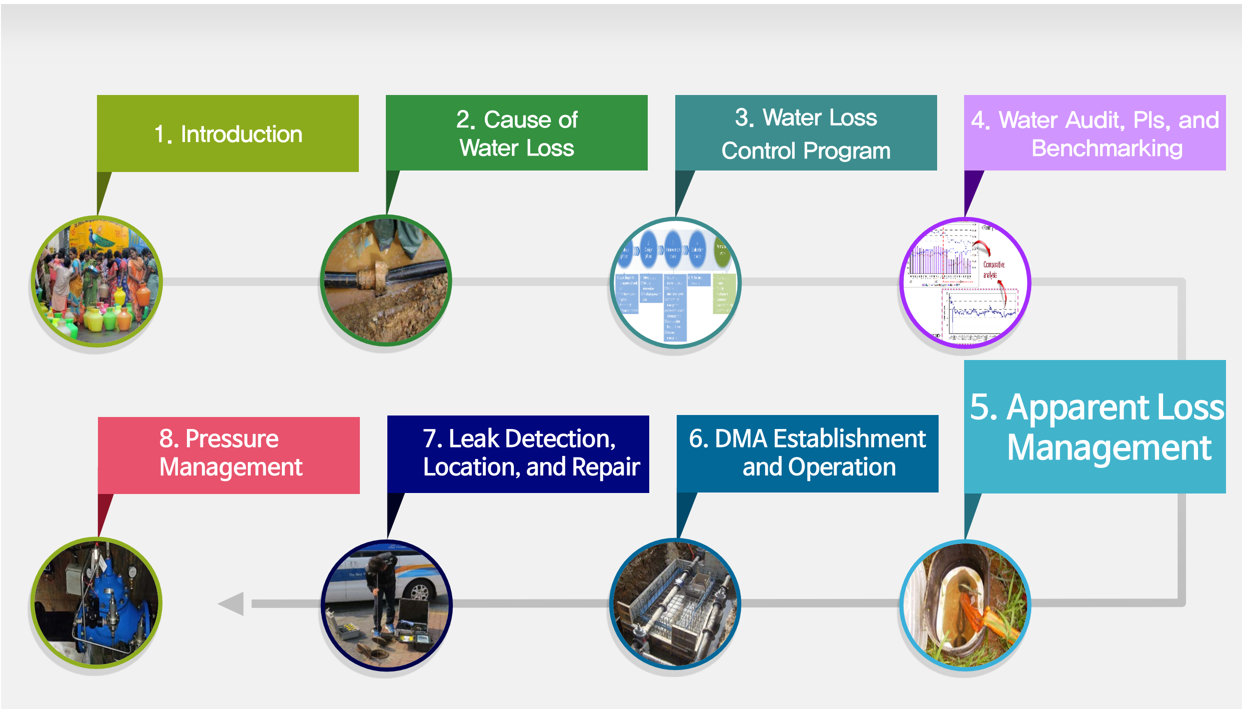
Apparent loss management

Water Loss Management

5. Apparent Loss Management

UNESCO
United Nations Educational, Scientific and Cultural Organization
i-WSSM
International Centre for Water Security and Sustainable Management

Training Course



Aims and Objectives

- The course aims to:

(1) Provide trainees with activities for controlling apparent loss;
(2) Enable trainees to establish an apparent loss management plan based on results of water audit

- The objectives are that trainees will understand:

(1) Activities to reduce data handling errors;
(2) Activities to reduce unauthorized consumption;
(3) Activities to manage meter inaccuracy

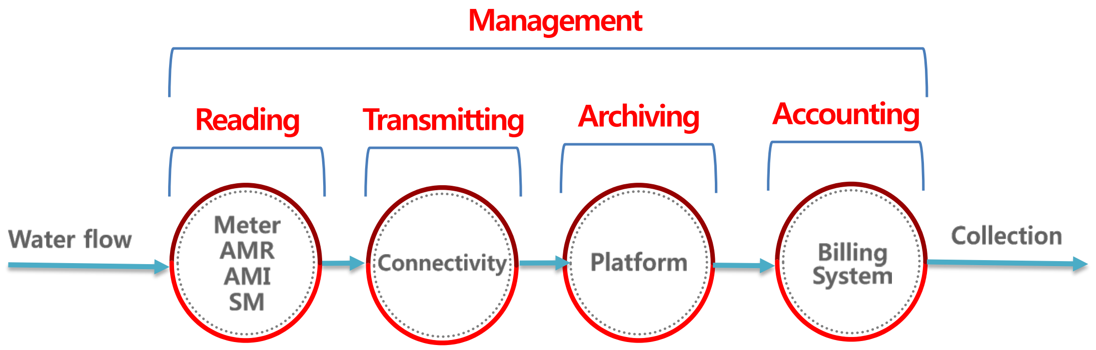
Contents

1. Overview

1.1 Background
1.2 Classification of Apparent Loss
1.3 Causes of Apparent Loss

1.1 Backgrounds

- Apparent Loss: Apparent loss occurs as a result of inefficiencies in the management, reading, transmitting, archiving, and accounting operations to track water volume in the water utility
- Influencing factors: Apparent loss can be influenced by social, cultural, political, and financial factors and may require organizational and institutional changes to reduce apparent loss



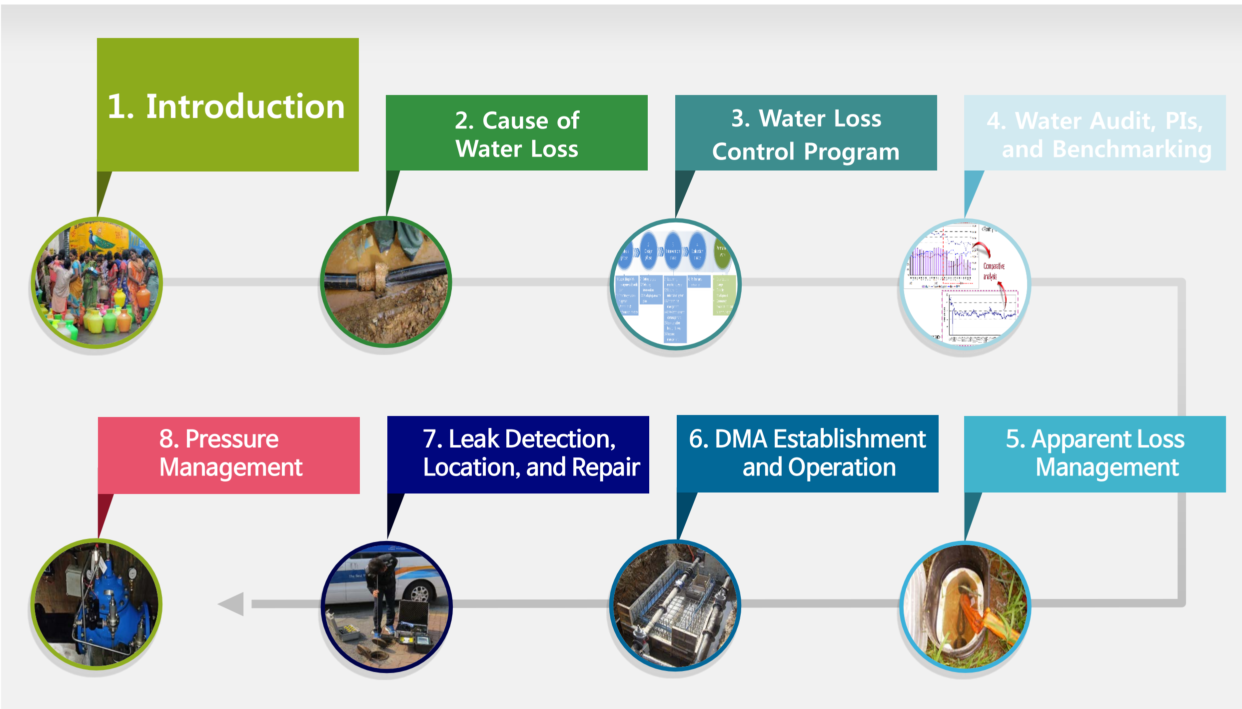
[Path of Water Volume Data]

1.1 Backgrounds

- Rigorous procedures: Procedures for installing, registering, maintaining, reading, and billing for all new meters should be rigorous
- Low-hanging fruits: Reducing apparent loss can be achieved in many cases at relatively low costs and is therefore typically a good starting point with a quick pay-off to the water utility
- Amount of apparent and real losses: Apparent loss is nearly always less in volume than real loss. However, it does not mean that apparent loss reduction is less important

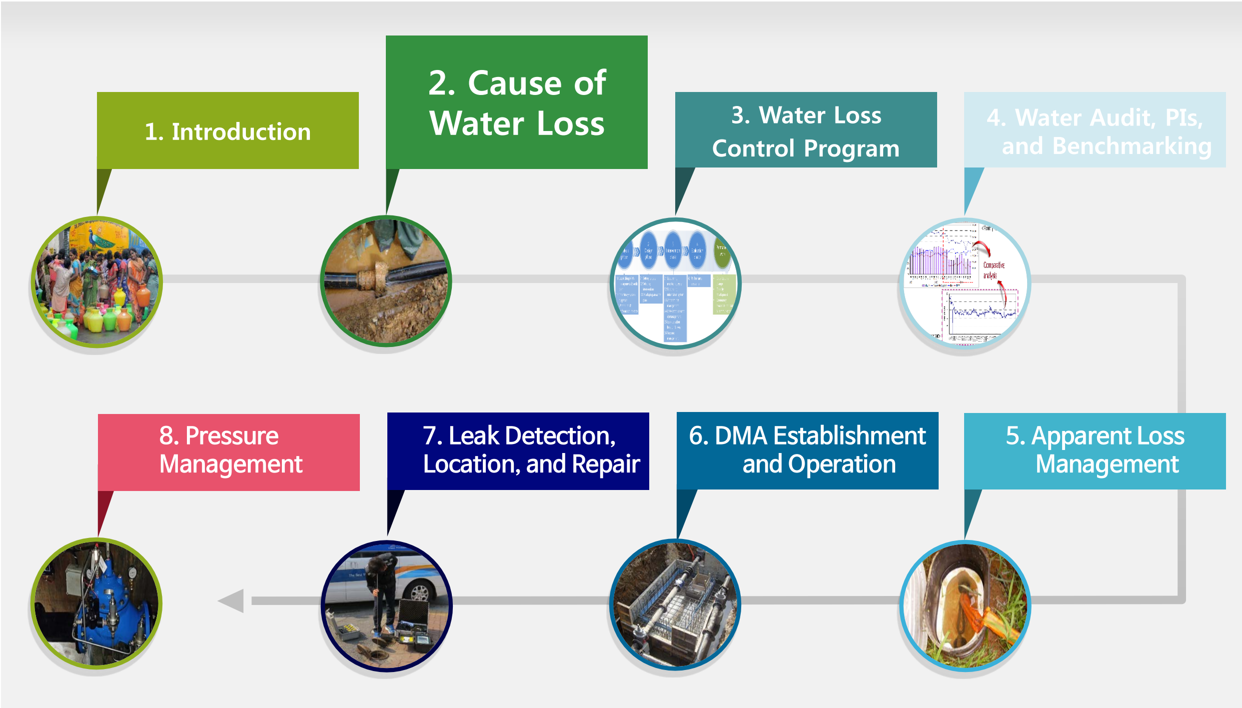
1.2 Classification of Apparent Loss

* This topic was explained in 1. Introduction



1.3 Cause of Apparent Loss

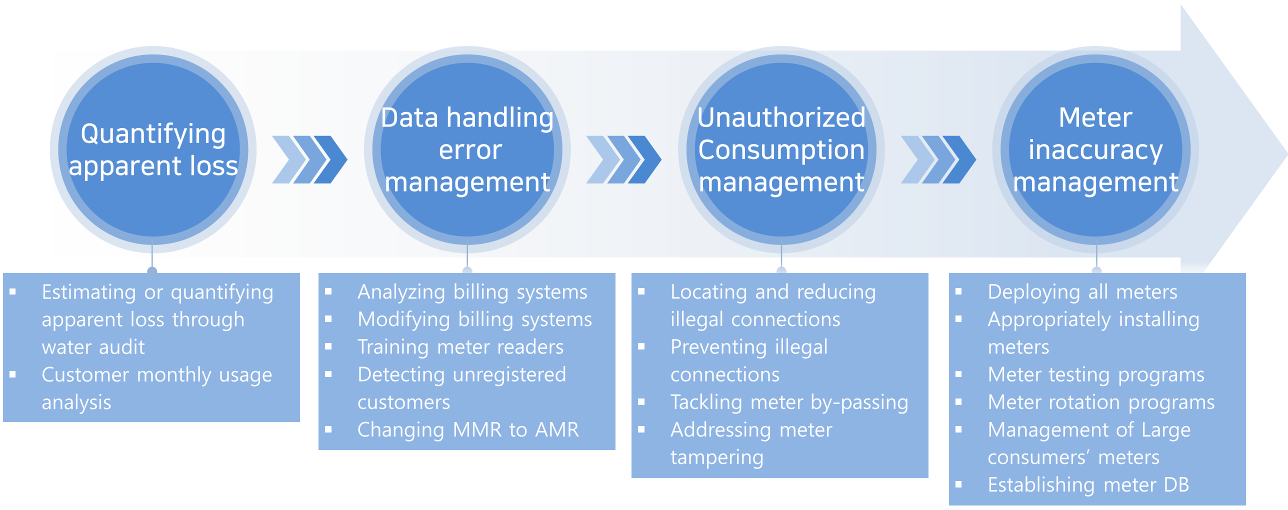
* This topic was discussed in 2. Cause of Water Loss



2. Apparent Loss Management Program

2. Apparent Loss Management Program

- **Apparent loss management program: The following figure identifies a sequence of steps for developing and implementing the apparent loss control program after the compilation of the initial top-down water audit**
  - After quantifying apparent loss, the management of data handling error, unauthorized consumption, and meter inaccuracies is implemented one by one



2. Apparent Loss Management Program

- **Intervention order (first option): Reducing data handling error is the first step in apparent loss management**
  - A recommendation is that the billing system analysis should be performed as the initial step because integrity in this process can influence data used in the other steps

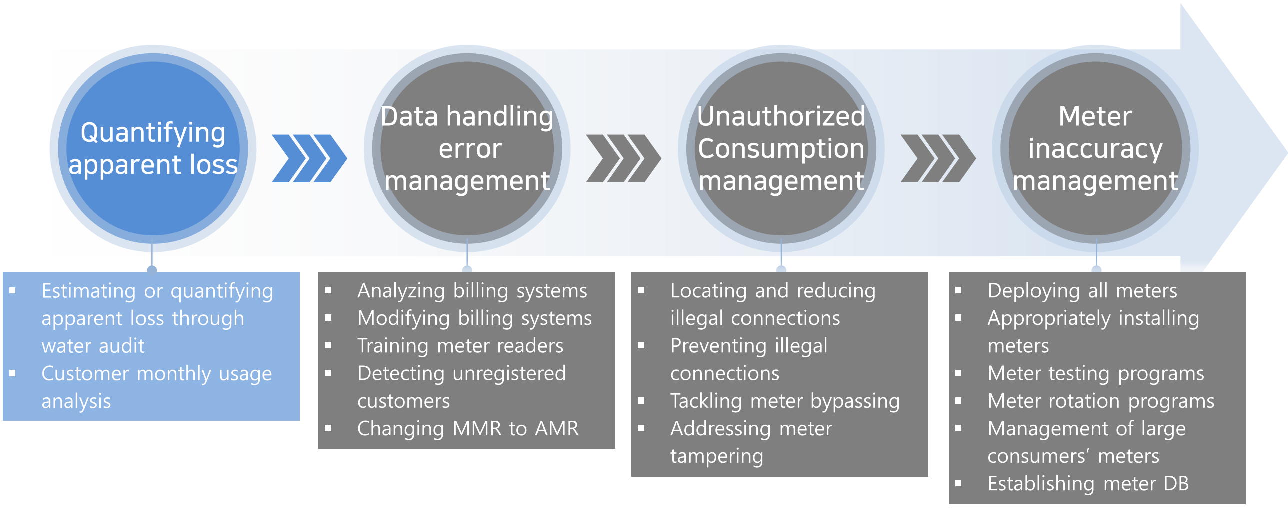
- **Intervention order (last option): Replacing meters is the last resort in apparent loss management**
  - Many water utilities tend to assume that the apparent loss in their system is solely caused by customer meter inaccuracy and that replacement of the entire customer meter population is the best intervention for reducing apparent loss
  - Implementing a comprehensive customer meter changeout is a very expensive and inefficient proposition if the bulk of the apparent loss cases was in fact caused by billing system data errors or unauthorized consumption
  - However, many water utilities continue this scheme and become perplexed when, after spending millions of dollars on new meters, the apparent loss standing remains the same

3. Quantifying Apparent Loss

3.1 Quantifying Apparent Loss
3.2 Quantifying Apparent Loss through Water Audit
3.3 Customer Monthly Usage Analysis

3.1 Quantifying Apparent Loss

- **(Interventions) The interventions for quantifying apparent loss include estimating & quantifying apparent loss with water audit and customer monthly usage analysis**



3.2 Quantifying Apparent Loss with Water Audit

(1) Water audit

- Understanding the characteristics of apparent loss: The auditor should first assemble the water audit and identify the nature, quantity, and cost impact of the three components of apparent loss in each water supply system
- Establishing a strategy: Establishing a strategy for apparent loss control based on the results of the water audit is the best way to proceed
- Understanding the dynamic characteristics: Water utilities should understand that apparent losses are not only multidimensional but also dynamic in nature

3.2 Quantifying Apparent Loss Through Water Audit

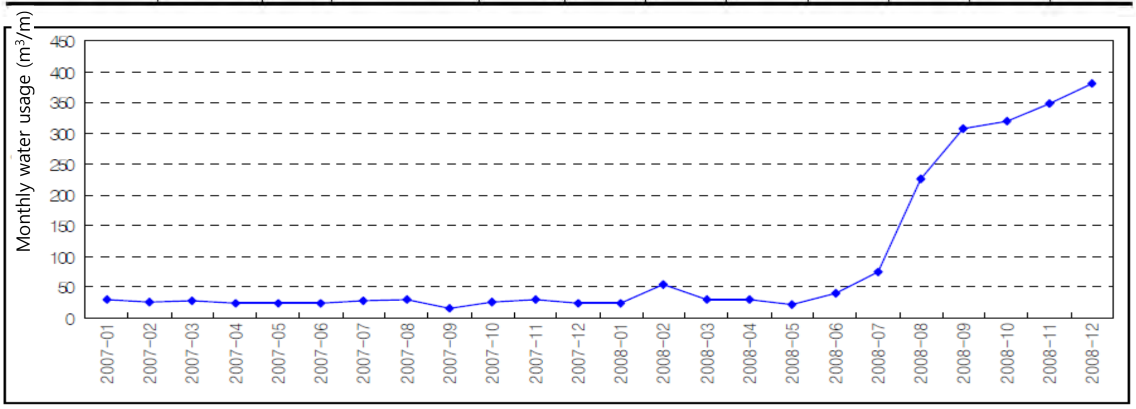
(2) Data validation and bottom-up water audit

- Data validation: Before setting a definitive strategy, auditors should perform a detailed investigation of the source data or functions to validate the preliminary data and obtain an accurate picture of apparent loss
- Bottom-up process: The bottom-up process involves a detailed investigation and auditing work, which is similar to the detailed financial audits performed by accountants
- Quantifying exact values: If the three components of apparent loss are calculated with estimated values in the top-down audit, then the quantification of these components is performed in the bottom-up audit

3.3 Customer Monthly Usage Analysis

- **Identifying issues for each customer: Prior to the on-site survey, the standardized customer monthly usage analysis should be used to identify the problems of each customer**

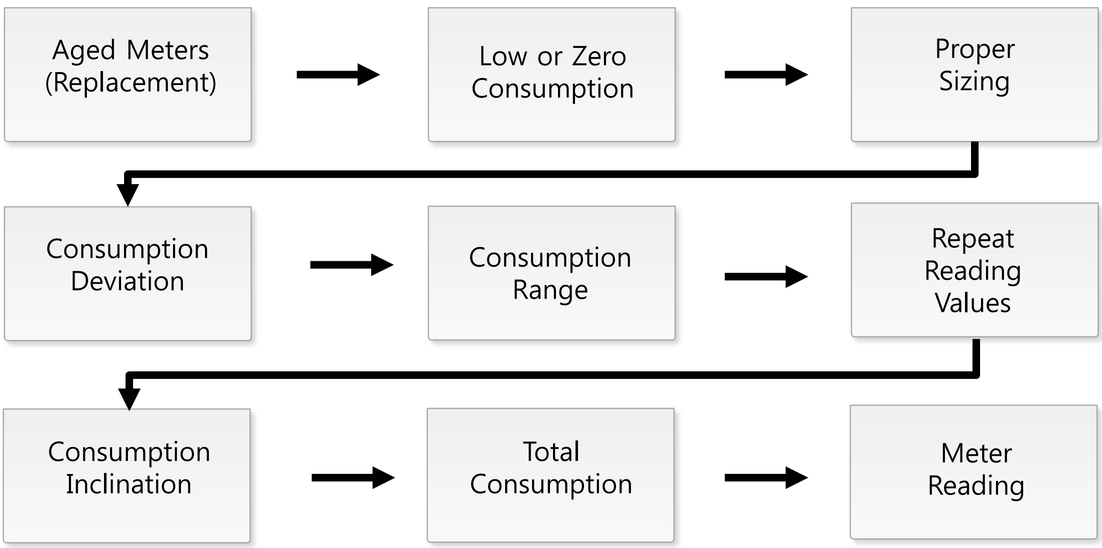
Water Meter					Monthly water usage (m^3/m)						
No.	Name	Size	Installation	Use	2002	2003	2004	2005	2006	2007	2008
47900-02-01955	○○○	13	'08.4.30	commercial	11.4	22.7	26.8	49.9	39.2	26.1	155.1



[Example of Basic Customer Water Usage Data]

Courtesy of K-water

3.3 Customer Monthly Usage Analysis



[Flowchart for Customer Monthly Usage Analysis]

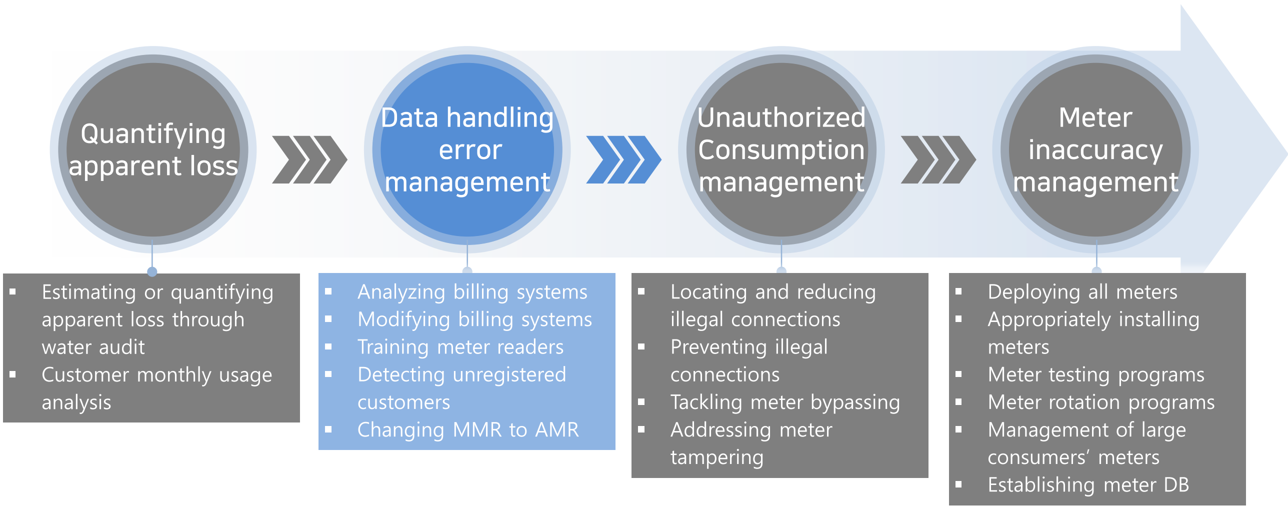
Courtesy of K-water

4. Management of Data Handling Errors

4.1 Data Handling Error Management
4.2 Analyzing Billing Systems
4.3 Modifying Billing Systems
4.4 Training Meter Readers: Reducing Meter Reading Error
4.5 Detecting Unregistered Customers
4.6 Changing Manual Meter Reading to Automatic Meter Reading

4.1 Management of Data Handling Errors

- **Interventions: The interventions for data handling error management include analyzing and modifying billing systems, training meter readers, detecting unregistered customers, and changing manual meter reading to automatic meter reading**



4.1 Management of Data Handling Errors

- **Processes where errors occur: Data handling errors occur during reading, transmitting, archiving, and reporting customer consumption total values**
  - Considerable data handling errors can occur during the customer meter reading process
- **Fast payback: Although data handling errors can be subtle and require considerable investigative time to detect, corrections are typically quick and inexpensive and requires only minor procedural or programming changes**
- **Increasing data integrity: Addressing data handling flaws early in the water loss control program creates a foundation for data integrity that is essential as the loss control program matures**

4.2 Analyzing Billing Systems

- **Analyzing billing systems: Billing systems can be analyzed by outlining the flow paths of billing data and documenting information-handling policies, procedures, practices, and programming**
- **(Outline data handling process) Constructing a series of flowcharts that outline the information data handling process is a systematic approach that can reveal gaps in policy, procedures, practices, or programming**

01

CHECKING POLICIES

- Policies regarding customer metering, billing, water rates, and customer service connection piping responsibilities

02

CHECKING PROCEDURES

- Existence of written procedures
- Procedures to ensure consistent metering, meter reading, and billing functions

03

CHECKING PRACTICES

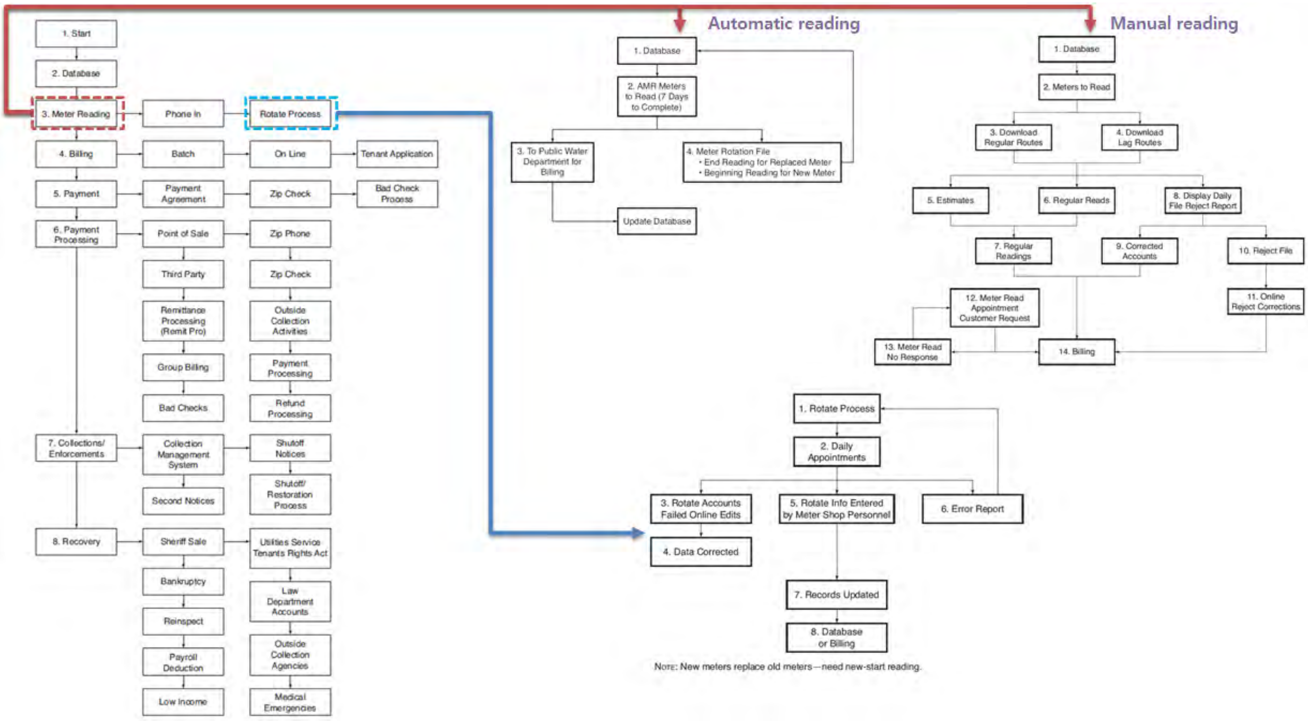
- Actual practices that reflect the mandates of the procedures
- Whether meter readers, billing clerks, or similar employees are properly monitored and supervised to detect and minimize human error

04

UNDERTAKING A FLOWCHARTING EXERCISE

- Undertaking a flowcharting exercise of the billing process to identify any impacts to the integrity of customer consumption as well as any apparent loss components from the data handling process

4.2 Analyzing Billing Systems



[Overview Flowchart of the Customer Billing System in Philadelphia, USA]

Source: AWWA (2009)

4.3 Modifying Billing Systems

- Modifying the system: Water utilities should modify the sources of apparent loss as a result of data handling errors to establish a highly detailed picture of the billing process

01

CORRECTING DB

- All properties are on the billing system, are billed, and payments are up to date
- Utilities ensure that all customers/properties are on the correct tariff

02

SEPARATING FINANCIAL AND ENGINEERING SYSTEM

- Although a negative consumption value can be acceptable for billing (financial) purposes, it is relatively harmful to the integrity of the data for operational (engineering) purposes

4.4 Training Meter Readers: Reducing Meter Reading Errors

- **Contribution: The content of training meter readers can contribute to immediate reporting, implementation of new procedures, and verification of the customer database**
- **Benefits: Training meter readers promotes diligent, good customer meter maintenance, and decreased meter reading errors**

01 IMMEDIATE REPORT OF PROBLEMS

- Meter readers should immediately report any observed problems
- The maintenance team should take immediate action to remedy the problem
- If remedial action is slow, then meter readers may become demoralized and less inclined to report problems

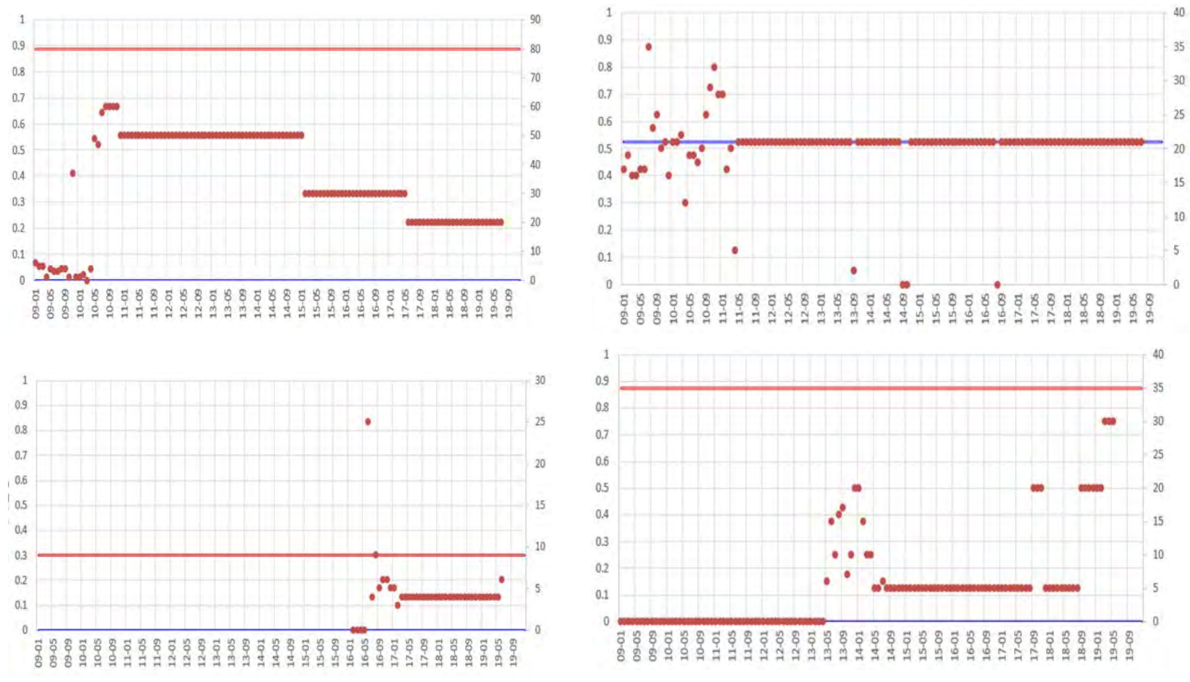
02 IMPLEMENTING NEW PROCEDURES

- Meter reading errors are addressed by implementing new systems for meter reading and billing

03 VERIFYING CUSTOMER DATABASE

- During routine meter reading, meter readers can be instructed to confirm the supply status of consumers

4.4 Training Meter Readers: Reducing Meter Reading Errors



[Monthly Water Usage Data of Suspected Estimated Meter Reading]

Courtesy of K-water

4.5 Detecting Unregistered Customers

- **Registering service connections: Detecting unregistered connections and registering in DB are required tasks because intentionally and accidentally omitted service connections can cause apparent loss**

01

DETECTION DURING A REGULAR METER READING CYCLE

- Unregistered customers can be detected during a regular meter reading cycle when diligent meter readers find meters that are not listed in their reading book
- However, this process may not identify all errors in the billing system

02

CONDUCTING A COMPLETE CUSTOMER SURVEY

- Conducting a complete customer survey within each DMA, where utility representatives visit every property in the DMA, is the best method for comprehensively identifying errors in the billing system
- The survey should include the following information: property address, name of owner, and meter make and number
- The representative should also conduct a meter test to ensure that accurate flow is recorded

4.6 Changing Manual Meter Reading to Automatic Meter Reading

- **Smart meter: Smart metering eliminates the need for meter readers and will eliminate many inaccuracies in metering and billing through the use of electronic meters and/or meter reading devices**

[Concept of Smart Metering]

Courtesy of K-water

5. Management of Unauthorized Consumption

5.1 Managing Unauthorized Consumption

- **The interventions for unauthorized consumption management include locating illegal connections and reducing illegal uses (e.g., preventing illegal connections, tackling meter bypassing, and addressing meter tampering)**

Quantifying apparent loss
- Estimating or quantifying apparent loss through water audit
- Customer monthly usage analysis

Data handling error management
- Analyzing billing systems
- Modifying billing systems
- Training meter readers
- Detecting unregistered customers
- Changing MMR to AMR

Unauthorized Consumption management
- Locating and reducing illegal connections
- Preventing illegal connections
- Tackling meter bypassing
- Addressing meter tampering

Meter inaccuracy management
- Deploying all meters
- Appropriately installing meters
- Meter testing programs
- Meter rotation programs
- Management of large consumers' meters
- Establishing meter DB

5.1 Management of Unauthorized Consumption

- **This is more of a technical problem: Although other problems in NRW management are technical, water theft is a political and social issue**
- **Support from the local government: Reducing illegal use is beyond the scope of the utility because it requires a high level of political support**
  - Reducing this part of apparent loss is neither technically difficult nor costly but requires making difficult and unpleasant managerial decisions that may be politically unpopular
- **Frequently related to the poor: Regularization of illegal connections, which often occur in poor areas, will impact the poor in many cases**
- **Reflecting utility level: The value that the community and water utility place on water supply and the management of the effectiveness of the water utility are often reflected by the amount of unauthorized consumption that occurs within a locale**

5.2 Locating Illegal Connections

- **Detection: Water utilities should employ mechanisms for detecting trends of unauthorized consumption**

01 **BILLING DATA REVIEW**

- Billing data should be reviewed for suspicious trends that may reflect unauthorized consumption

02 **CHECKING FIRE HYDRANTS**

- Utilities should review opportunities for the unauthorized use of fire hydrants and ensure the existence of a rational policy regarding fire hydrants

03 **HOUSEHOLD INSPECTIONS**

- Household inspections can be conducted on select zero consumption accounts

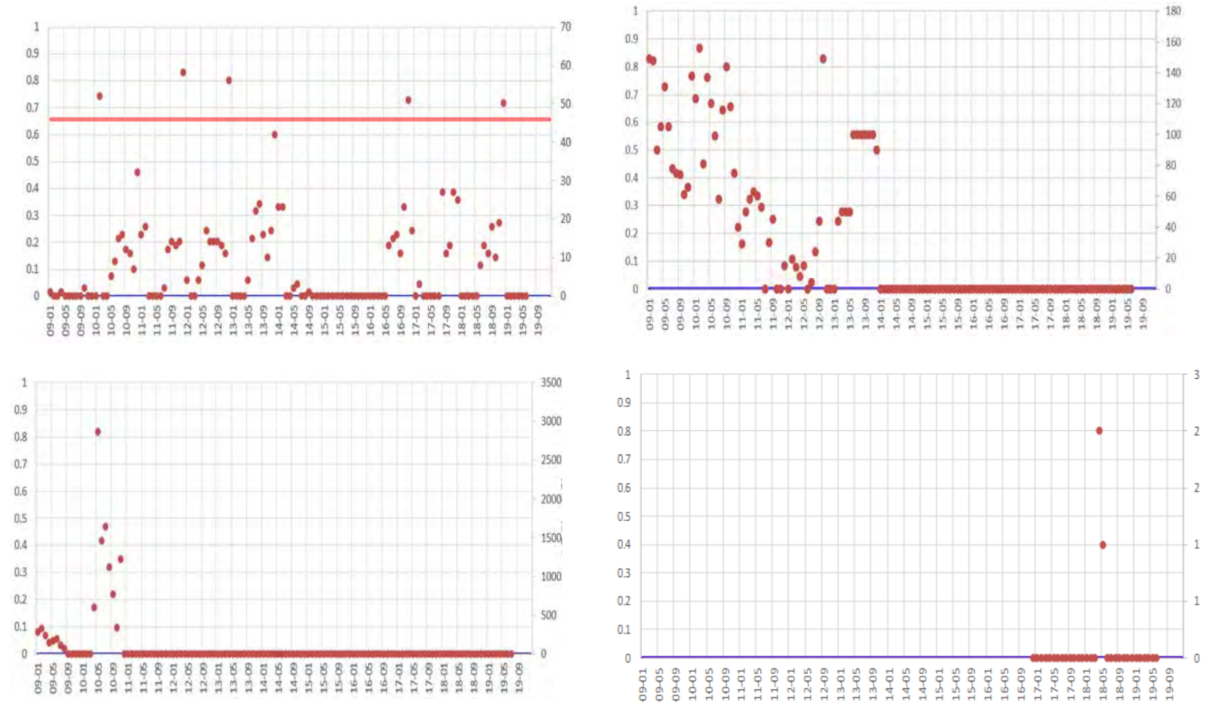
04 **INSPECTION OF SHUTOFF CUSTOMERS**

- If utility policies enable customer service to be terminated because of payment delinquency, then follow-up random inspections should be conducted to ensure that customers have not reactivated their service illegally

05 **BOUNDARY VALVE INSPECTION**

- Boundary valves for neighboring water systems should be inspected periodically to ensure that they are in the proper positions

5.2 Locating Illegal Connections



[Monthly Water Usage Data of Suspected Illegal Users]

Courtesy of K-water

5.3 Reducing Illegal Connections

- **Effective enforcement: To control unauthorized consumption on a long-term basis, the water utility should employ effective policies and enforcement capabilities**

01 CHANGING REGULATIONS

- A strong legal framework will ultimately allow the water utility to operate with enforcement powers to maintain unauthorized consumption to an economic minimum

02 REVIEW POLICIES AND PROCEDURES

- Review service connection policies and procedures to ensure that they do not encourage illegal connections
- Simplify connection application procedures

03 LOCKABLE VALVE

- Lockable valves limit illegal connections

04 LEAKAGE STEP TEST

- The utility should undertake customer surveys and leakage step tests to determine where the missing flow occurs

05 USING BETTER QUALITY METER

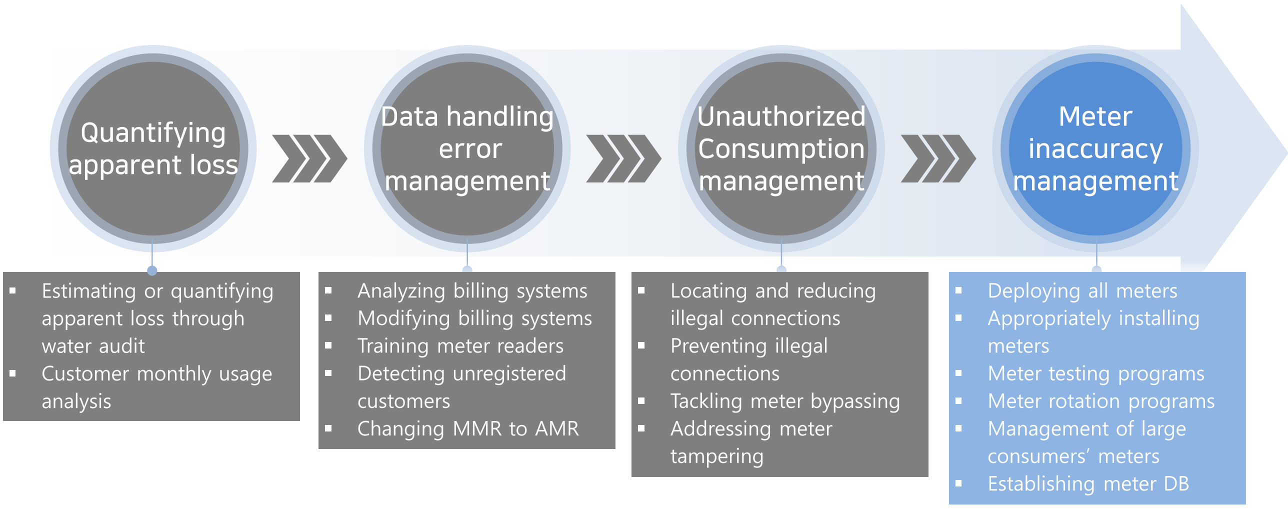
- Most reputable meter manufacturers produce meters that are tamper-resistant with non-metallic parts, strong clear plastic windows, and impenetrable casing

6. Management of Meter Inaccuracy

6.1 Meter Inaccuracy Management
6.2 Installing Meters at All Monitoring Points
6.3 Appropriately Installing Meters
6.4 Meter Testing Programs
6.5 Meter Rotation Programs
6.6 Management of Large Consumers' Meters
6.7 Establishing Meter Database

6.1 Management of Meter Inaccuracy

- **The interventions for meter inaccuracy management include deploying all meters, appropriately installing meters, meter testing programs, meter rotation programs, management of large consumers' meters, and establishing a meter database**



6.1 Management of Meter Inaccuracy

- **Critical part in revenue: A well-managed customer meter scheme is critical to the revenue stream of the water utility**
- **Understanding of meters: Managing a large population of customer meters requires knowledge of meter and meter reading equipment as well as customer relations**
- **Understanding of policy: This understanding is required to verify the current policy of universal metering and metering programs as follows:**
  - Guidance on which meter to install and when to replace it
  - A hierarchy of metering application exists in the majority of water supply systems

6.1 Management of Meter Inaccuracy

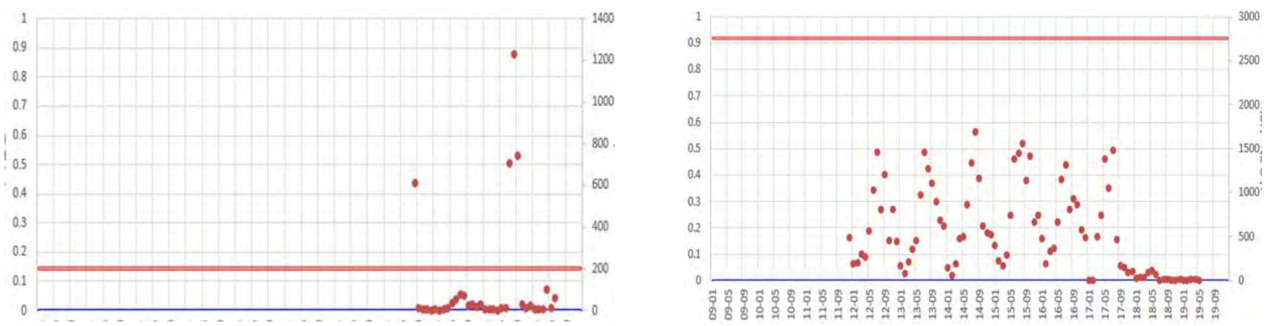
- **Maintenance cost: The upkeep of the meter population requires expenditures for installation, maintenance, calibration, testing, and replacement**
- **Lack of experience: An incoming water utility manager with a lack of experience in ongoing meter testing, rotation, or right-sizing is expected**
- **Poor documentation: The size, type, make, and performance of the meter population is poorly documented and understood**

6.2 Deploying All Meters

- **Fixed tariff scheme without meter: Many small utilities charge a flat monthly rate for water and may meter only several large-use customers, if at all**
  - Flat rates may be based on the type of use, such as residential, commercial, industrial, or agricultural or based on occupancy
- **Deploy all meters: General meter management exists in the context of water utilities with a fully metered customer population**
- **Representative sample monitoring: Systems that do not meter their customers can obtain an approximation of customer consumption. Metering and data-logging representative samples of customer accounts can be used, and the results are statistically evaluated to infer the general trends of consumption**

6.3 Appropriately Installing Meters

- **Appropriate metering: Selecting the appropriate type and size of the meter is important as well as its proper installation**
- **Appropriate type of meter: Selecting the appropriate meter can help ensure the accuracy of customer consumption data**
- **Size: Meter sizing is very important because the accuracy of the meter is dependent on the design type and design flow**

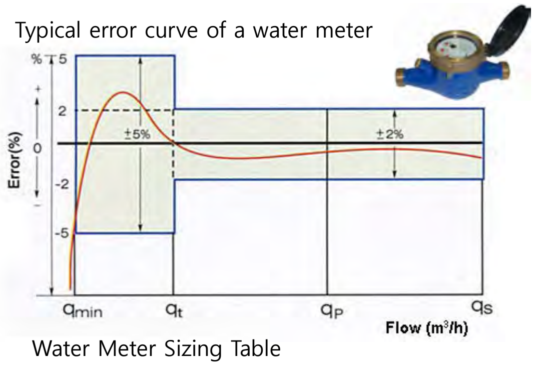


[Monthly Water Usage Data From an Improper Meter Size]

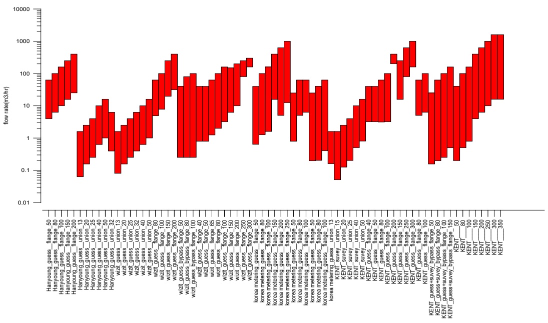
Courtesy of K-water

6.3 Appropriately Installing Meters

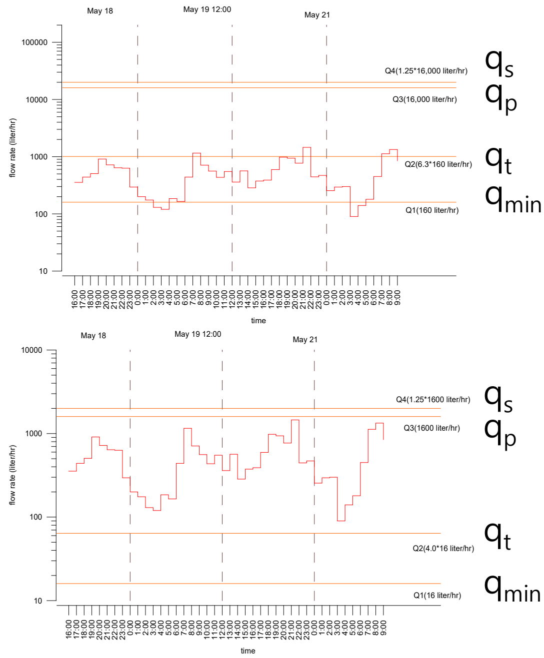
Typical error curve of a water meter



Water Meter Sizing Table



Sizing Consideration for Time-dependent Flow



[Example of Water Meter Selection]

Courtesy of K-water

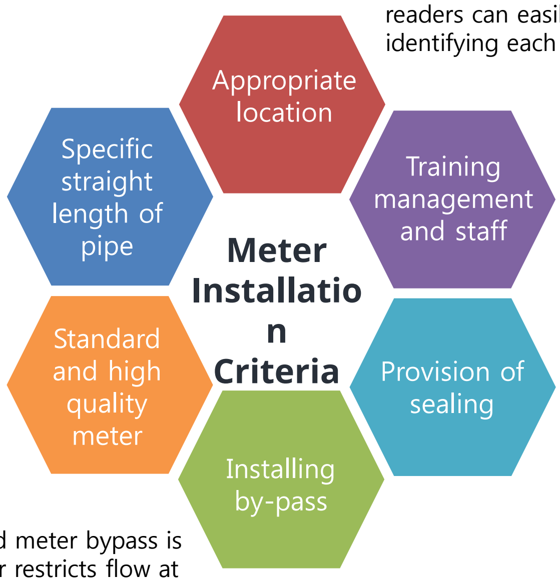
6.3 Appropriately Installing Meters

- **Installation: Following the manufacture's installation instructions for a meter is crucial for proper meter operation**

Meters should be installed where meter readers can easily find them and where identifying each property's meter is easy

Several meters require a specific straight length of pipe upstream and downstream of the meter

The management and staff responsible for meter installation should be trained on proper handling of meters



Utilities should purchase the meters on the customers' behalf, so that only standard, high quality meters are used

Utilities should provide a seal for meters to indicate future tampering

In many cases, an authorized meter bypass is necessary because the meter restricts flow at a high rate

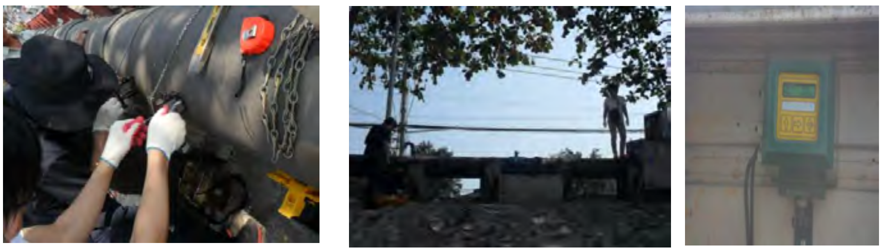
6.4 Calibrating and Testing Meters

- Meter deterioration: Mechanical meters will slow down with age and become less accurate. As such, they must be replaced or re-calibrated at regular intervals, which is every few years
- Effects: Under-registration results in lower billing and loss of potential revenue and erroneously indicates an increased level of water loss from the system at the same time, which can alter the results of water audit results
- Meter calibration process: Meters should be calibrated according to the manufacturers' instructions
- (DB) Testing results can be used as a basis for quantifying apparent loss in water audit or meter repair and replacement

6.4 Calibrating and Testing Meters

- Methods can be classified into a calibrated meter test bench or a field meter testing: comparing volume flow over time against accurate a master meter

[Meter Test Bench]



[Field Meter Testing]

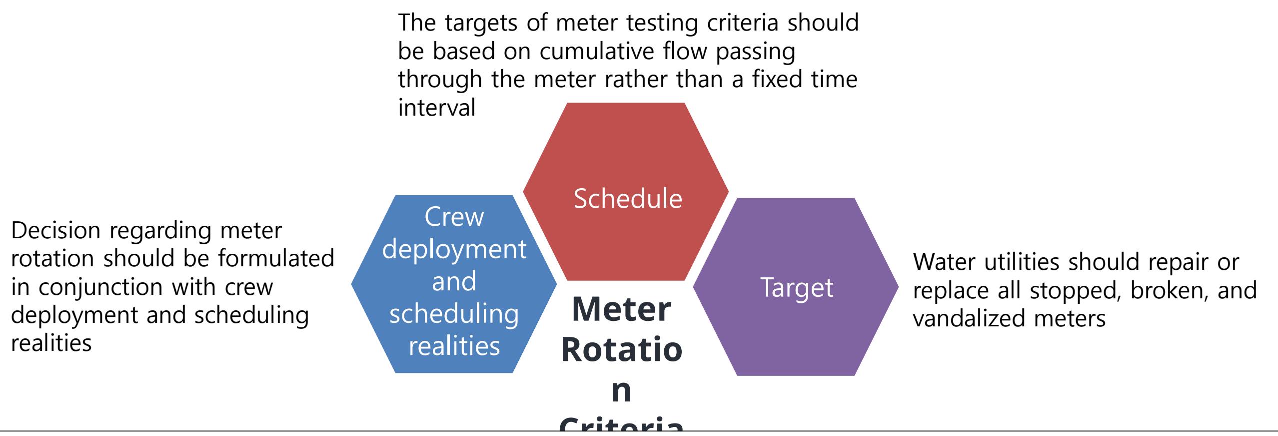
Courtesy of K-water

6.4 Calibrating and Testing Meters

- **Procedure: A meter test bench for measuring the accuracy of customer meters should be conducted monthly**
- **Outsourcing: Independent companies provide testing services if the water utility does not own a meter test rig**
- **Sampling: The number of meters tested may need to be large and depends on the number of meters in the water supply systems and statistical confidence levels with which the utility is comfortable**
  - If several customer meter brands are in operation, then the sample selection should include meters from each brand

6.5 Meter Rotation Programs

- **Meter rotation: A scheduled maintenance and replacement program should be in place to manage meter problems**
- **Criteria: A single, agreed-upon standard regarding when meters should be replaced does not exist. However, meter replacement (or rotation) programs should include the following criteria:**
  - In general, the utilities replace the meters systematically, beginning with the oldest meters and those with the worst condition



6.6 Large Consumers' Meter Management

- **Poor maintenance: In many municipalities, metering and billing of large consumers are poor in performance with numerous meters buried or broken or old and many un-metered connections**

- **Importance: Utilities should focus initially on large consumers, such as industrial or commercial users, because they consume large volumes of water and pay high tariff rates**
  - Revenue generated from a small number of large industrial consumers can exceed the remaining revenue generated from residential customers

- **Only cost effective for large meters: Many water utilities found that calibration or repair of small residential meters is not cost-effective because the majority of meter models retain accuracy over a long time. In addition, the cost of a new meter is less than the cost of calibration or repair**
  - Calibration and repair remain common for most models of large commercial and industrial meters

6.7 Establishing a Meter Database

- **Meter DB: The basic demographics and accuracy levels of the meter population should be established**

- **Meter demographics: If the meter population characteristics are unknown, then the auditor can conduct research using purchase and installation records, billing records, customer complaint histories, and meter accuracy test results to compile information on the sizes, types, manufacturers, ages, and cumulative consumption levels of customer meters**

- **Testing for data: To determine the physical accuracy of the meter population, many water utilities operate their test facility and equipment and perform ongoing accuracy testing of meters that were rotated out of service**


Thank you very much

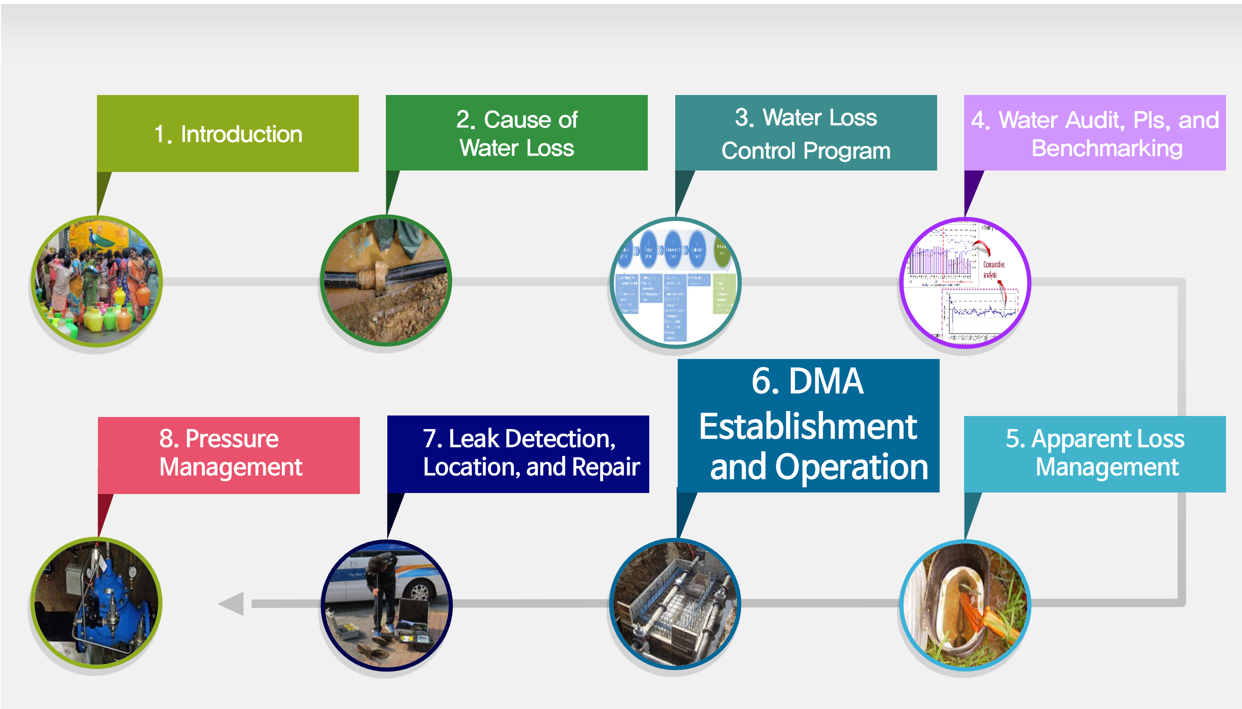
MEMO

DMA

Water Loss Management

6. DMA Establishment and Operation

Training Course



Aims and Objectives

- The course aims to:

(1) Provide trainees with information on establishing, operating, and sustaining DMAs;
(2) Enable trainees to sectorize the water network based on DMA design guidelines and improve current DMA operation and maintenance

- The objectives are that trainees will understand:

(1) DMA design criteria and guidelines;
(2) Monitored data analysis and intervention in DMA;
(3) DMA boundary management

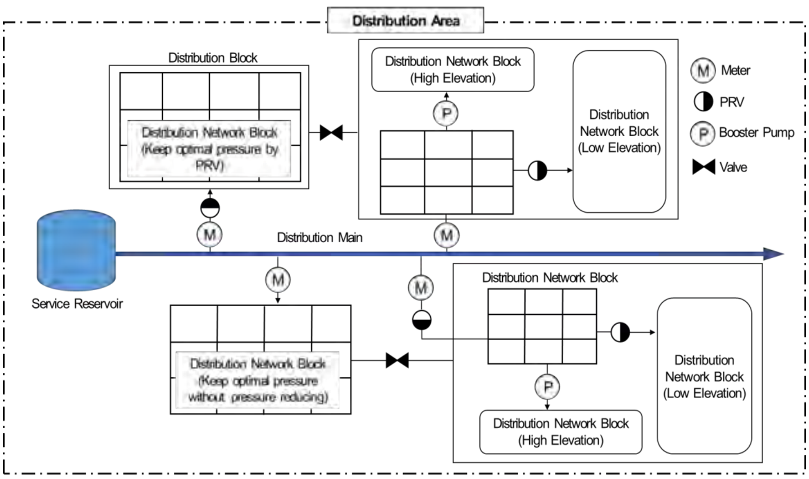
Contents

1. Overview

1.1 Background
1.2 Pilot Studies

1.1 Backgrounds

- A DMA is defined as a discrete sector of the distribution network, which is formed naturally or imposed and can effectively evaluate the continuous in-flow of supply through flow meters installed at the input and output metering points



[DMA Schematics]

Source : Ministry of Environment of Korea (2010)

1.1 Backgrounds

- **Benefits: Partitioning the network into DMAs yields enormous benefits, such as pressure control, network management, leakage monitoring, leakage detection, maintenance of water quality, and asset management**

Planning
- With sectorization, water utilities can easily plan operation and maintenance

Water loss quantification
- Enables the measurement of background leakage to be distinguished from unreported leaks

Leak detection
- Well-managed DMAs serve as early warning systems of newly emerging leakage and can alter the operator

Prioritizing vulnerable area
- DMAs enable water utilities to quantify the current level of leakage in a discrete area and to consequently prioritize leak detection activities

Pressure management
- The network is operated at the optimum level of pressure by managing the pressure in each district or group of districts

Emergency response
- Water utilities can respond emergency by isolating the problematic DMA only

Safeguard water supply
- Establishing DMAs enable water utilities to prevent the deterioration of water quality in the distribution network

Continuous water supply
- Although bursts occur in one DMA, water utilities can supply water to other DMAs continuously

[Benefits of DMA]

1.1 Backgrounds

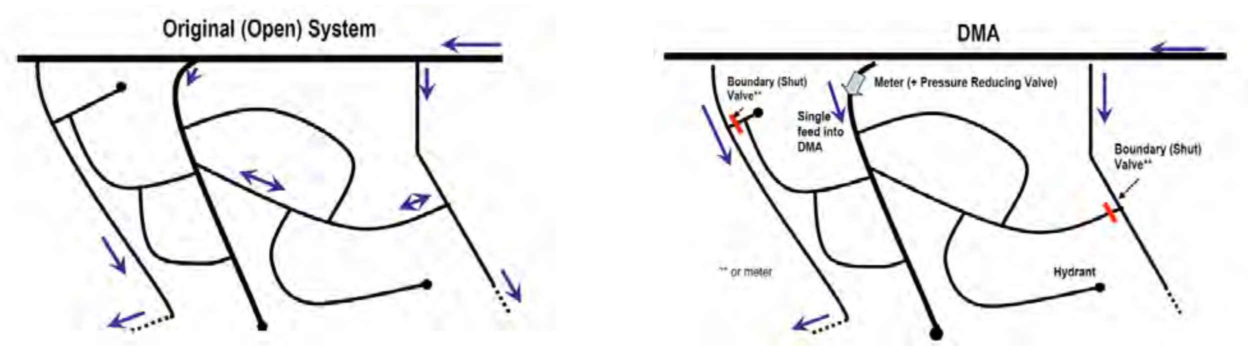
- **Starting point of real water loss management: Unfortunately, although sectorizing is recognized as very important, recognizing that sectorizing is only a means to an end and not the end itself is equally important**
  - Only establishing DMAs do not reduce water loss. However, water utilities can easily manage water loss with established DMAs

- **Increasing the knowledge of the network: The implementation of a plan for network sectoring, which aims to monitor leakage, will result in major improvements in the management and knowledge of the network**

- **Measures for intermittent supply: Creating DMAs may also be the first step in counteracting intermittent supply**
  - DMAs facilitate the location and repair of major leaks and thus may enable the reduction of periods of supply interruption

1.2 Pilot Studies

- **Pilot studies on natural DMAs: For ease and experience gain, initiating the network sectorization process by implementing natural DMAs, namely, the areas of the network that were already naturally closed, is advisable**
  - A suggestion is that one or two pilot DMAs be set up to implement the principles and procedures of the water loss control program

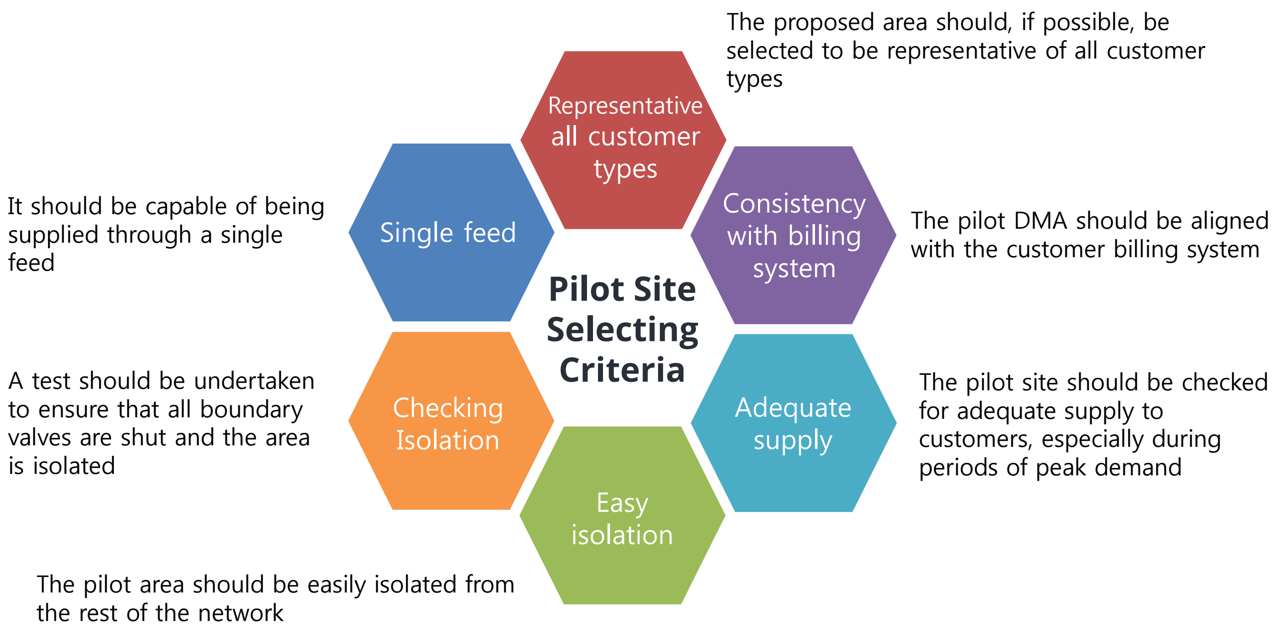


[Establishing a Pilot Study DMA]

Source: Trent (2005)

1.2 Pilot Studies

- **Selecting the pilot site: Selecting the first pilot area is important and will be based on a combination of several factors**



[DMA Pilot Site Selecting Criteria]

1.2 Pilot Studies

- Accumulating experience: Pilot studies are the best means for building knowledge and understanding of these areas
- Accountability: A staffing structure should be allocated to each DMA to ensure staff accountability. DMA leaders are also appointed to guarantee accountability for the management and performance of the DMA
- Performance evaluation: The pilot area will be used to measure, qualify, identify, and rectify apparent and real losses
- Scale-up pilot: The successful planning and implementation of a pilot area that produces measurable results will provide motivation to eventually extend the trials to the entire area

2. Design Guidelines

2.1 Status, Guidelines, and Design
2.2 Current Status and Information
2.3 Design Criteria

2.1 Status, Guidelines, and Design

- **DMA Design: Current status analysis should be conducted before designing the DMA. The design must comply with the criteria**

Current Status analysis
- Network Characteristics
- Area Characteristics
- Economic Consideration
- Operational Condition

Design Criteria
- General
- Boundary
- Size
- Inlet

DMA Design
- DMA Planning
- DMA Testing
- Site Survey
- DMA Construction
- DMA Assessment

[DAM Design Process Based on Current Status and Design Criteria]

2.2 Current Status and Information

- **In-depth knowledge: Designing DMAs requires in-depth knowledge of the water supply system**
- **Required information: A number of factors should be considered for the correct design of a DMA, such as network, area, and geographical characteristics and network operation conditions**

01 NETWORK CHARACTERISTICS
- Existence of sensitive or critical areas for correct supply
- Existence of large customers and constraints
- Complete and up-to-date network information

02 AREA CHARACTERISTICS
- Size and physical characteristics of the area
- Topographical information

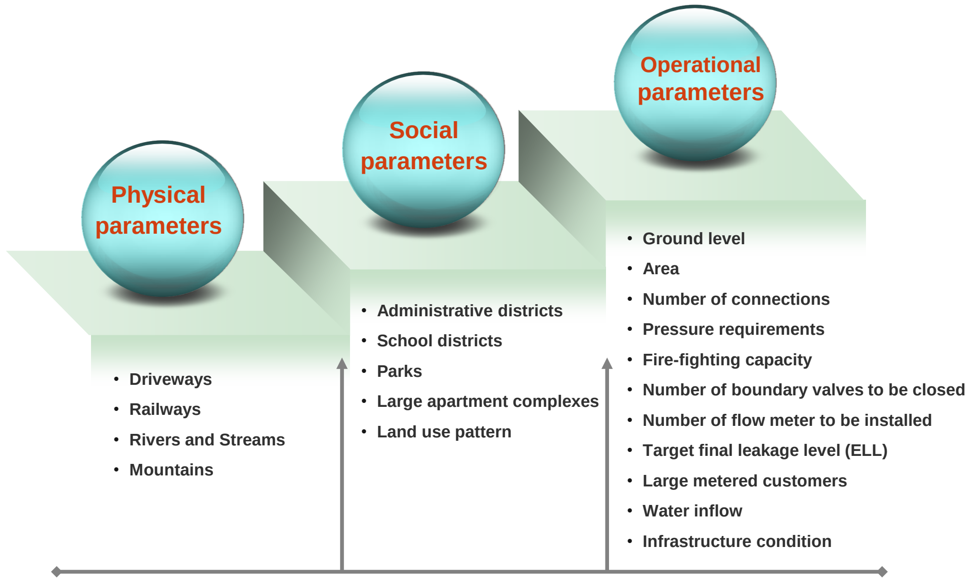
03 GEOGRAPHICAL CHARACTERISTICS
- Geographical density of customers (population density in the supply network)
- Geographic or demographic factors, such as urban, industrial, or rural areas

04 OPERATION CONDITIONS
- Water consumption pattern
- Operational data about flows and pressure
- Calibrated hydraulic model
- Techniques available or applicable for leakage control
- Types of pipe materials and age
- Service levels and water quality

[Items to be Surveyed for Current Status Analysis]

2.2 Current Status and Information

- **Considering parameters: Collected information should be linked with physical, social, and operation design parameters**

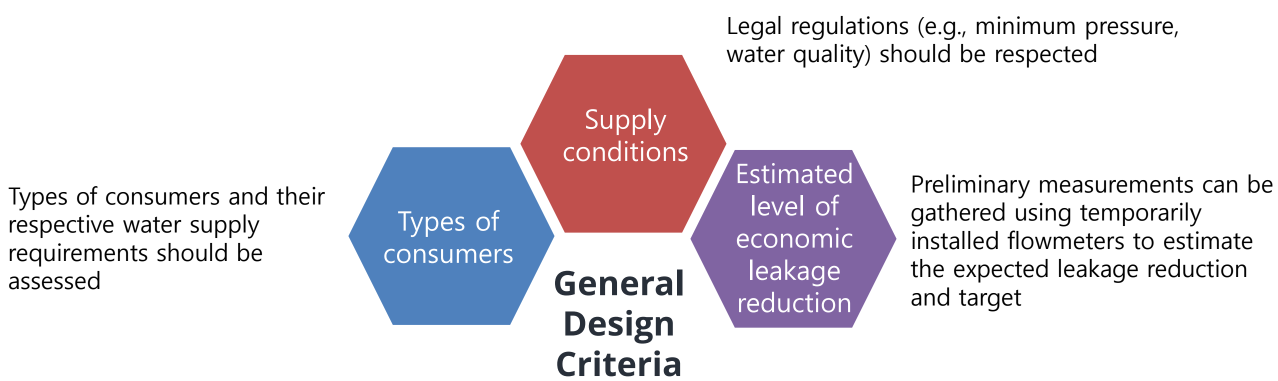


[DMA Design Parameters]

Courtesy of K-water

2.3 Design Criteria: General

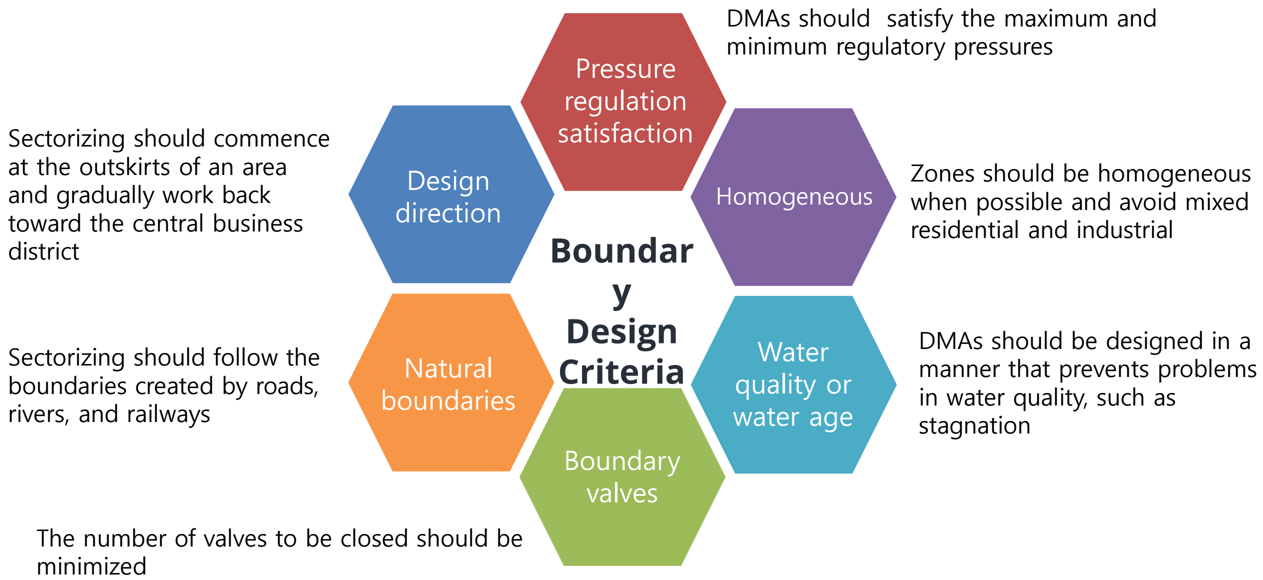
- **No general rule: The design of a series of DMAs is extremely subjective. Moreover, a case of two utility engineers working on the same network and formulating the same design is unlikely**
  - When establishing zones in an area, a few general rules of thumb should be followed and considered
  - Each company will have its own criteria for setting the economic levels of leakage and leakage targets for each DMA



[General DMA Design Criteria]

2.3 Design Criteria: Boundary

- **DMA boundary: The DMA boundary line should follow the path of the least flow resistance and the following criteria**



[DMA Boundary Design Criteria]

2.3 Design Criteria: DMA Size

- **No ideal size exists for a DMA**
  - The size, whether 500 or 5,000 service connections, is always a tradeoff
  - The decision has to be made on a case-by-case basis

- **Influencing factors: The size of an individual MDA will vary depending on local factors and system characteristics, such as**
  - required economic level of leakage;
  - geographic/demographic factors;
  - previous leakage control techniques;
  - individual water company preference;
  - hydraulic conditions

- **Significant influencing factors: An important influencing factor is the condition of the infrastructure**
  - If the mains and service connections are fragile, then bursts will become more frequent and the optimal DMA will be relatively small
  - Conversely, in areas with brand new infrastructure, DMAs can be large and remain manageable

2.3 Design Criteria: Inlet Design

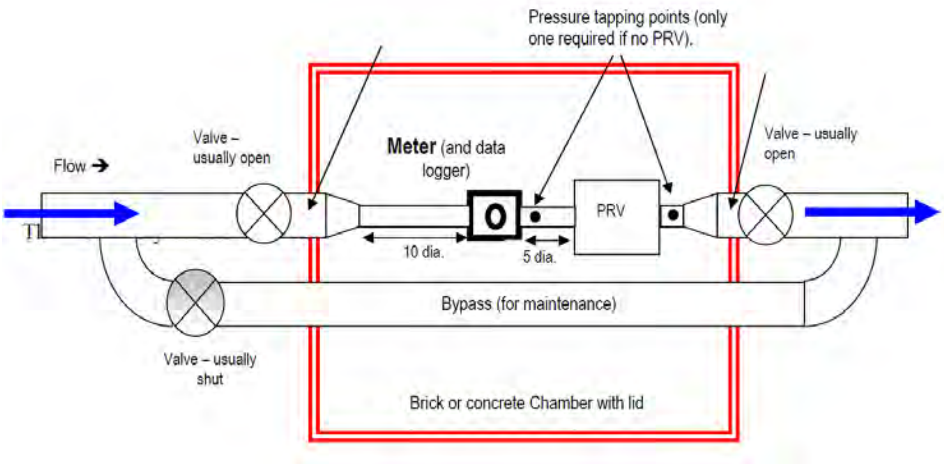
- **Inlet design: The process is composed of survey information, meter site selection, meter (flow meter and PRV) selection and installation, and pipe-work arrangement**

- **Meter site selection: Once the DMA has been selected, the location of the single supply should be examined**
  - Ideally, the location should not be in a carriageway
  - The water mains should be at a standard depth and be easily accessible for future meter readings and maintenance
  - The area should not be flooded in general
  - If vandalism is rife, consideration should be given to the use of secure chamber lids

- **Meter selection: Installing the correct size and type of meter is important**
  - When determining the dimensions of the flow meter, the following should be considered: existing pipe diameter, expected flow range, admissible head loss at peak flow, and reverse flow requirements

2.6 Design Criteria: Inlet Design

- **Pipe-work arrangement: The meter (and PRV if required) should be fitted in a water-tight chamber with safe access to meter reading and maintenance and with substantial lids**
  - Positioning the PRV within the meter chamber is not always possible



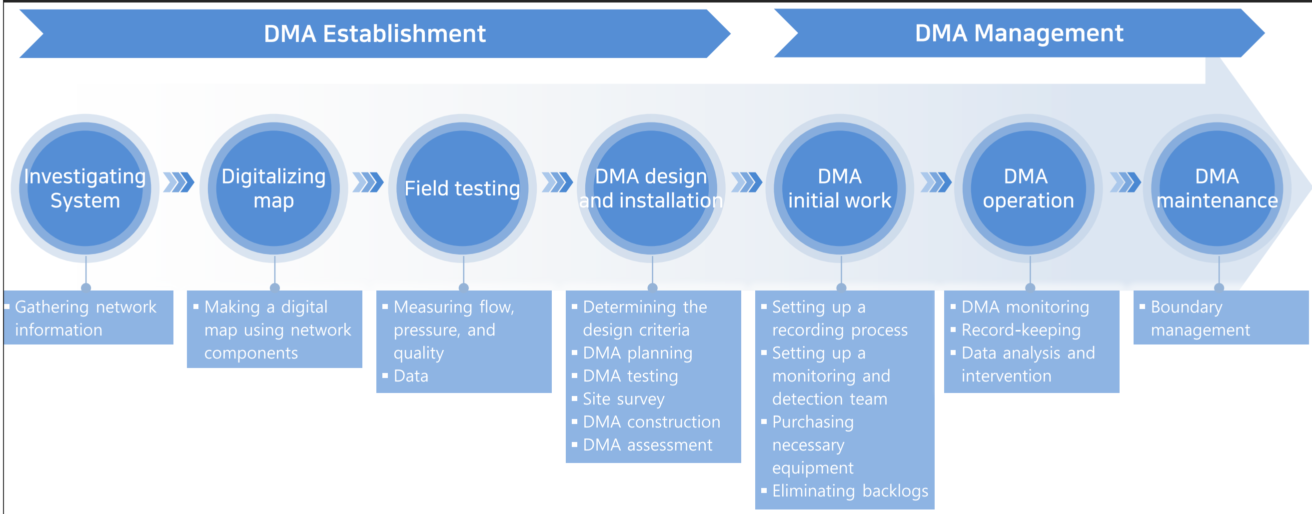
[Typical DMA Pipe-work Arrangement]

Source: Trent (2005)

3. DMA Establishment and Management Processes

3. DMA Establishment and Management Processes

- **The process can be classified into two categories, namely, DMA establishment and management**
  - DMA establishment: DMA is designed using the plans of the distribution network and applying local knowledge of the supply system
  - DMA management: After setting up the DMA, proper initial, operation, and maintenance work should be performed to prevent DMA demolition in a few years



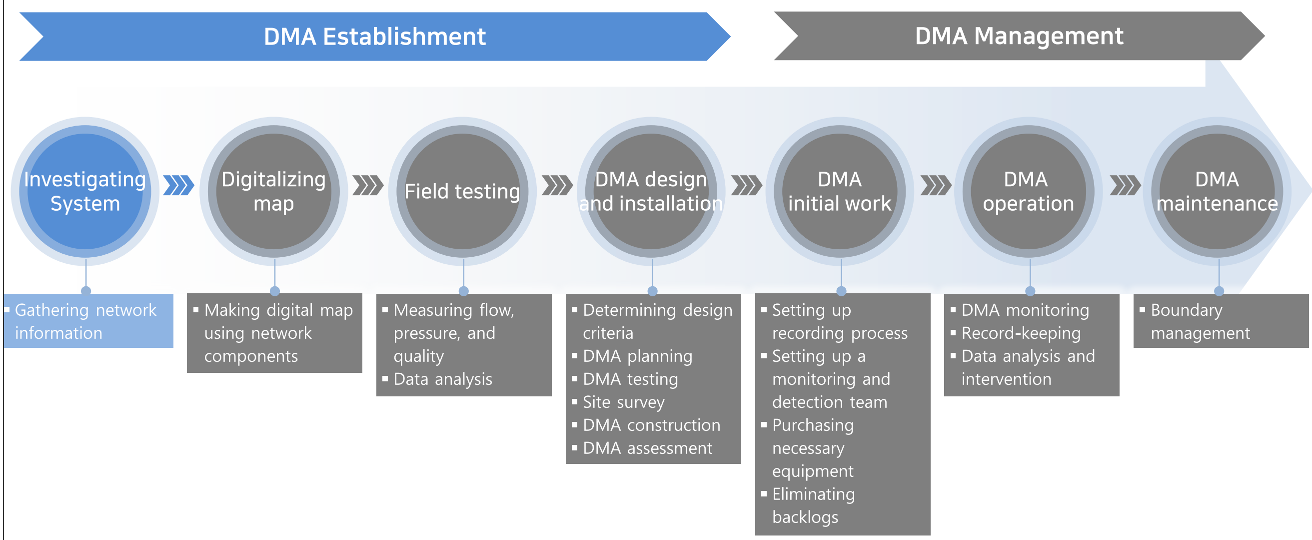
[Process of DMA Establishment and Management]

4. DMA Establishment

4.1 System Investigation
4.2 Map Digitalization and Updating
4.3 Field Testing
4.4 DMA Design and Installation

4.1 System Investigation

- **Data collection: System investigation is the first step in DMA establishment. In this step, all forms of documents related to the water distribution network and its operation and maintenance should be collected**

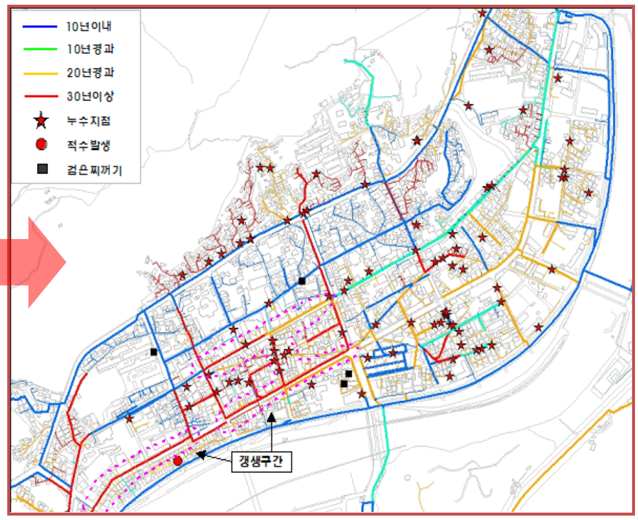


[System Investigation in DMA Establishment]

4.1 System Investigation

- **Items: Information related to devices (e.g., valves), distribution mains, service connections, and customers are surveyed**

Valves	• Valve and Valve Chamber location • Valve type, operation status, etc	
Distribution Main	• Distribution network information (size, length, material, etc) • Soil characteristics, etc	
Connection, Meter	• Flow meter location, size, condition, etc • Meter cover condition, private storage tank, etc	
Customer	• property, population, and monthly demand • Service pressure, etc	

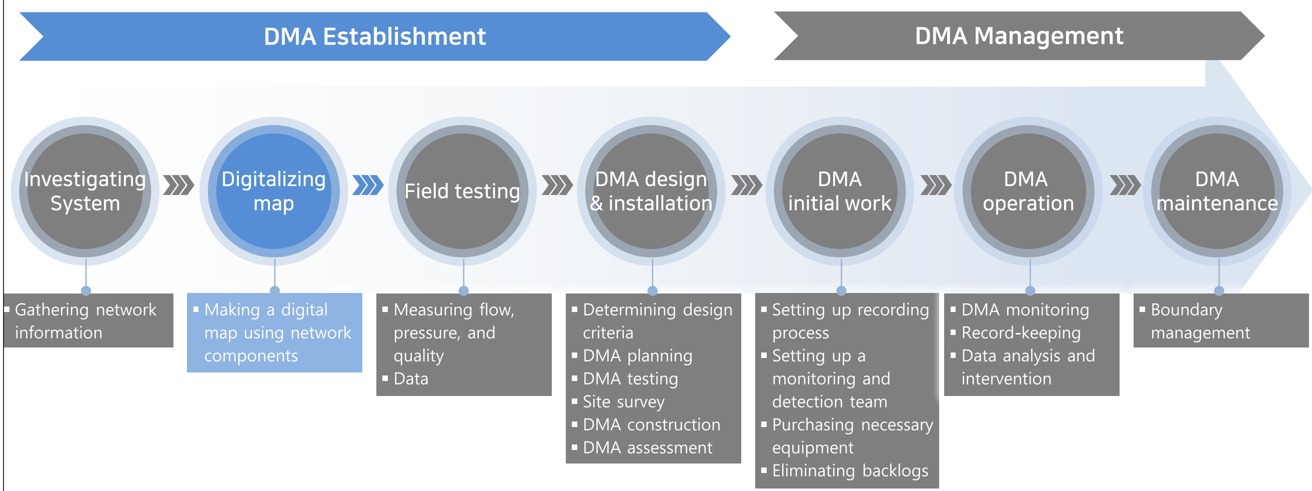


[Items for Water Network System Investigation]

Courtesy of K-water

4.2 Map Digitalization and Updating

- **Map digitalization: Based on the collected data, a digitalized map should be made in the form of CAD or GIS**
- **Updating: Data on network components and operation and maintenance should be regularly updated**

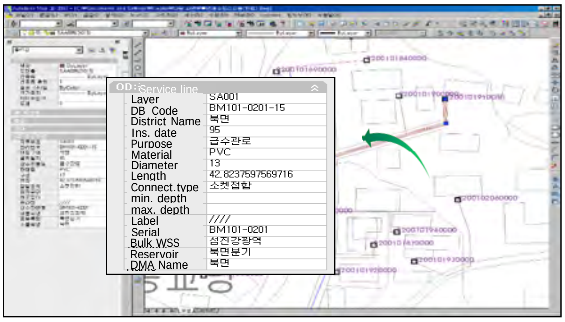


[Map Digitalization in DMA Establishment]

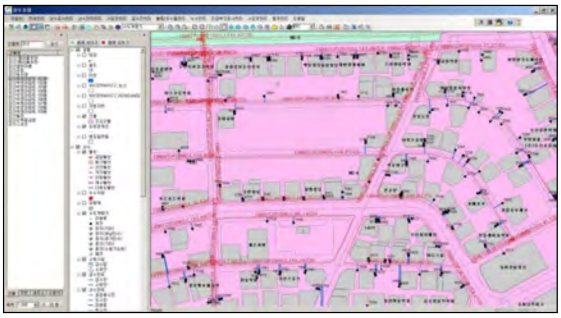
4.2 Map Digitalization and Updating

(a) Paper Map

(b) Digitized Map (CAD, General Version)



(c) Digitized Map (CAD, Map Version)



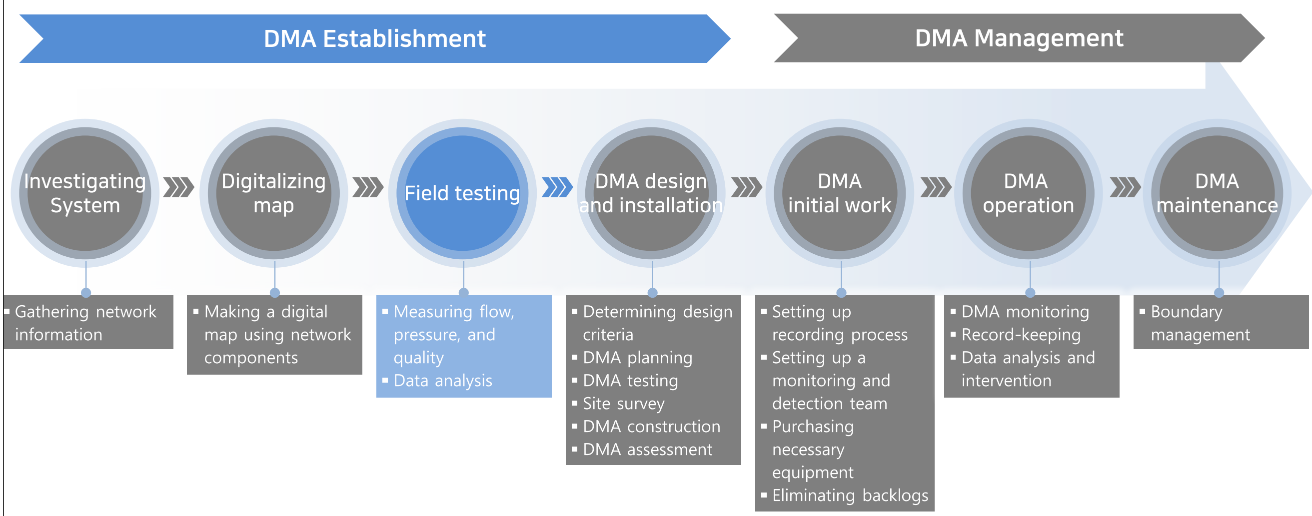
(d) Digitized Map (GIS)

[Example of Map Digitalization]

Courtesy of K-water

4.3 Field Testing

- **Flow rate, pressure, and residual chlorine concentration are measured to analyze and diagnose hydraulic and water quality performance within a network**
  - Field testing provides an understanding of system behavior



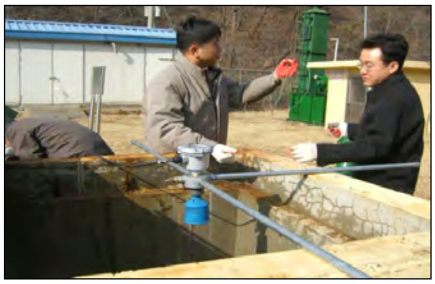
[Field Test in DMA Establishment]

4.3 Field Testing

(a) Pressure Measurement

(b) Flow Measurement

(c) Water Quality Measurement (Residual Chlorine)



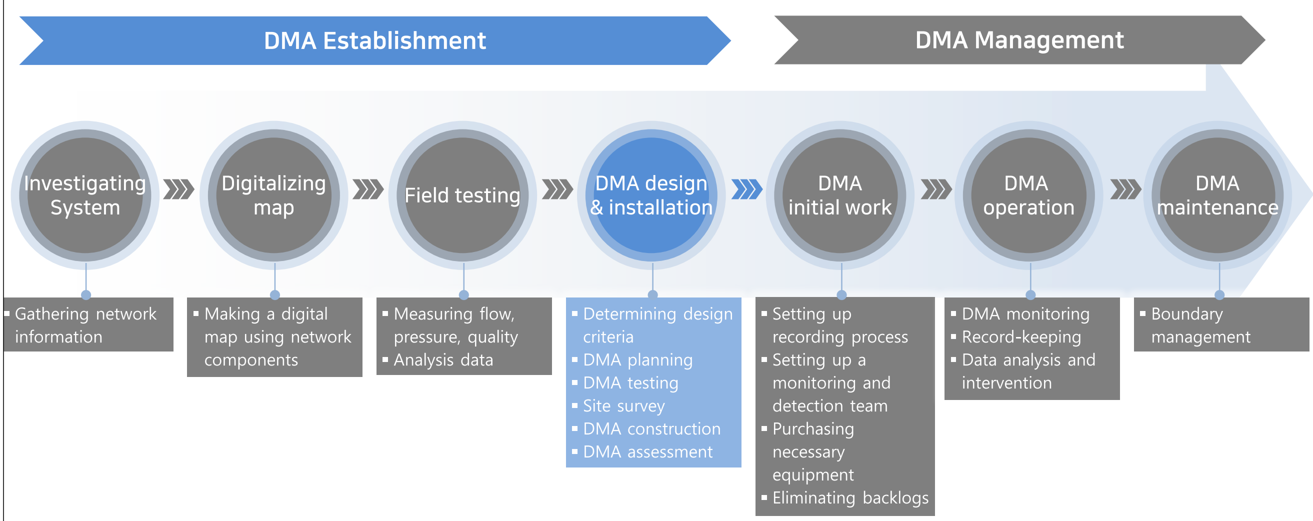
(d) Reservoir Level Measurement

[Example of Field Testing]

Courtesy of K-water

4.4 DMA Design and Installation

- The process includes determining the design criteria, DMA planning (outline planning), DMA testing, site survey, DMA construction, and DMA assessment



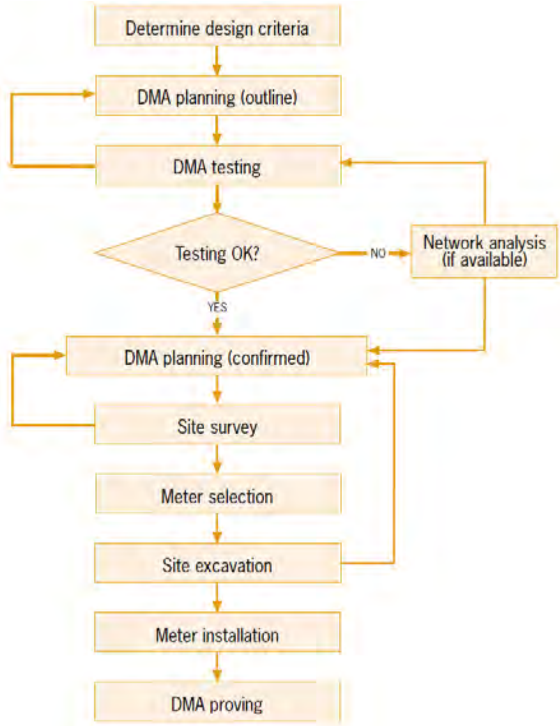
[DMA Design and Installation in DMA Establishment]

4.4 DMA Design and Installation

- Process: The figure is a flow diagram that demonstrates the stages of design and installation

- Interrelated tasks: The planning and design of a DMA can be described as performing a series of interrelated tasks

- Iterative process: The overall shape is iterative, which corresponds to the development resulting from the integration of information obtained from the surveys and field investigations throughout the process



[Stages of DMA Design and Installation]

Source : Farley (2001)

4.4 DMA Design and Installation

(1) Determining the Design Criteria

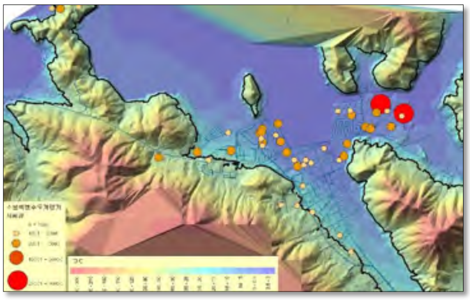
- The details were explained in Chapter 2.2

(2) DMA Planning (Outline Planning)

- Outline planning: The planning stage is the process of dividing the distribution system into suitable-sized DMAs. Outline planning is the first step, which uses small-scale distribution maps of the mains to draw provisional boundaries

- Provisional drawing: The provisional drawing of the DMA border should be prepared using GIS with the aim of characterizing the DMA and establishing procedures for continuous implementation. At the same time, the supply quality and pressure should be secured during periods of high consumption

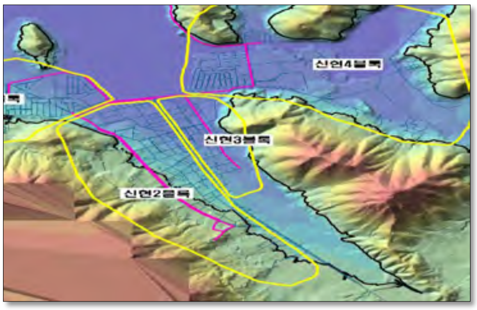
4.4 DMA Design and Installation



(a) Analysis of Elevation and Demand

(b) Analysis of Natural Boundaries

(c) Analysis of Distribution Main Pipes



(d) DMA Outline Planning on the Map

[Example of DMA Planning (Outline)]

Courtesy of K-water

4.4 DMA Design and Installation

(3) DMA Testing

- Objectives: The objectives of DMA testing are to verify whether the DMA can supply water without low pressure problems and whether the DMA can be isolated
- Checklist: Before conducting DMA testing, the valve condition should be checked

Check list	Details
Valve tightness	- Before any further work, a trial closure of the DMA boundary valves should be conducted - The boundary valves for the proposed DMA should be checked for tight-closure by listening on the valve key when the valve is fully shut - Once the limits of a new DMA have been determined, a site survey should be executed; the existing boundary valves should be closed and tested for tightness - Testing the valves is essential because one leaky valve will distort the leak assessment not only in the actual DMA but also in the neighboring DMAs
Installing new valves	- In the absence of valves or in cases where valves do not shut tight, new valves should be fitted - Defective valves should be replaced, and a new valve should be installed at boundaries without valves
Labeling	- Undertake the sealing and labelling of DMA boundary valves, such they can be easily identified on the ground by the operational and maintenance staff

4.4 DMA Design and Installation

- Low pressure (verifying service pressure): This process ensures that DMA pressures are maintained up to the standard of service
- Low pressure (application time): The implementation process should be applied during a period of high consumption, thus verifying that the pressure values at the critical point satisfy the regulation and guaranteeing appropriate supply to customers
- Low pressure (handling negative impact during the process): If a significantly negative impact is observed on network pressure, then a rapid opening of the DMA boundary valves should be undertaken
- Low pressure (redesign): If pressures are not maintained, then the outline planning stage should be repeated, and extra meters should be installed to replace the closed valves

4.4 DMA Design and Installation

- Isolation (drop test): After closing all boundary and inlet valves, the pressures in the DMA should be measured using recorders/loggers to ensure that the DMA is isolated
- Isolation (water quality problem): The isolation process can cause problems in water quality because it can change flow direction and velocity
- Isolation (not isolated): If the pressure does not drop or if it rises again after closing the hydrant, then a partially closed boundary valve or unknown connections to an adjacent zone are highly probable
  - The area of the potential inlet can be localized by assessing the pressure head (hydraulic grade line) throughout the DMA

4.4 DMA Design and Installation

Plan | Notice and Isolation | Pressure Zero Test

[Example of DMA Isolation Test (Drop Test)]

Courtesy of K-water

4.4 DMA Design and Installation

(4) Detailed Site Survey

- A site survey is necessary to verify the potential meter location that was decided in the planning exercise

01 LINE OF THE MAINS

After an accurate location of the line of the main, "walking" the main and noting and verifying the positions of valves, bends, and connections are advised

02 OTHER UTILITIES

Determining the position of other utilities is necessary, such that they can be avoided when excavating the meter site

03 AUDITING OF EXISTING FACILITIES

This step is required to ensure that flowmeters, PRV, and boundary valves are operating normally

04 TELEMETRY

While conducting the site survey, noting the proximity of the facilities required for the telemetered DMA outstation is beneficial

05 BYPASS INSTALLATION

Most companies install a bypass at the DMA meter site, which can be a bypass around the meter or a meter on a bypass

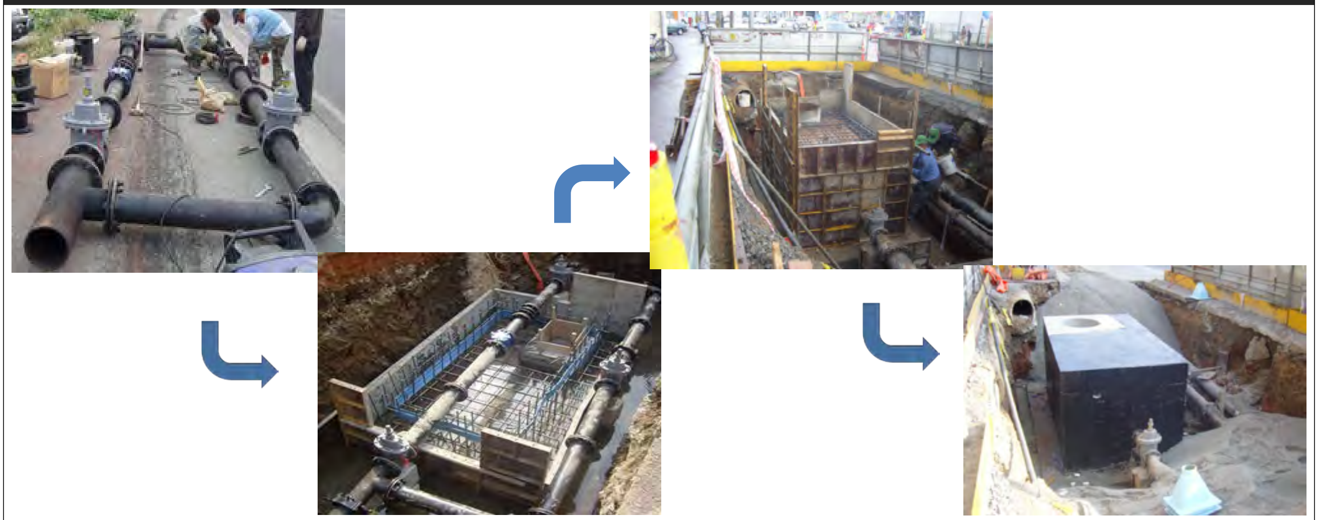
06 SPACE FOR METER LOGGER

Accessibility problems can be overcome by connecting the meter to a logger, which can be located in a small chamber

4.4 DMA Design and Installation

(5) DMA Construction

- **The DMA inlet, SCADA system, and water network integrated operation system should be installed**



[Construction of Flow Meter Chamber at DMA Inlet]

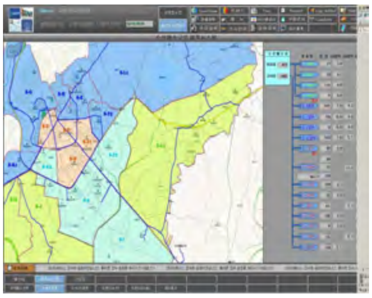
Courtesy of K-water

4.4 DMA Design and Installation

[Equipment for Monitoring and Control at DMA Inlet]

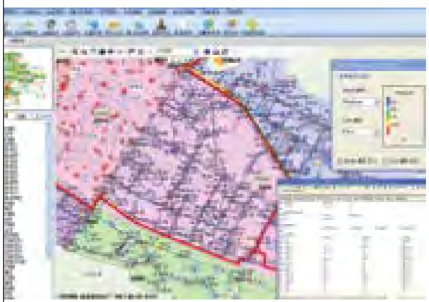
Courtesy of K-water

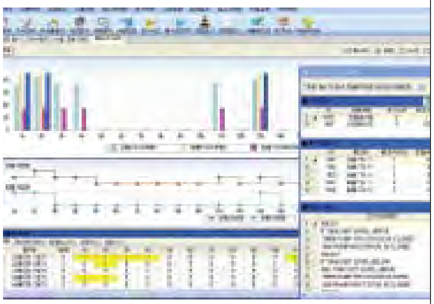
4.4 DMA Design and Installation



[SCADA System]

Courtesy of K-water





[Integrated O&M System]

Courtesy of K-water

4.4 DMA Design and Installation

(6) DMA Assessment (DAM Proving)

- DMA assessment: In this process, low pressure and isolation are verified again, and installed equipment and flow capacity are tested
- Low pressure: If an unacceptable pressure reduction occurs in operating the DMA, then revising the DMA design may be necessary to provide sufficient pressure within the DMA
- Equipment test: After installing and testing, an assessment should be performed to establish whether all flow meters are working appropriately

4.4 DMA Design and Installation

- **Inlet flow monitoring: After the successful completion of the initial tests, the total inflow to the DMA should be monitored over several days under normal conditions**

- **Flow capacity test: After determining that the DMA boundary is hydraulically intact, the operator should confirm that the DMA supply can meet peak demands**
  - High flow conditions can be created by opening a boundary valve to a neighboring lower pressure zone or DMA to create an additional flow demand through the subject DMA
  - Alternatively, one or more fire hydrants can be opened to simulate fire-fighting conditions

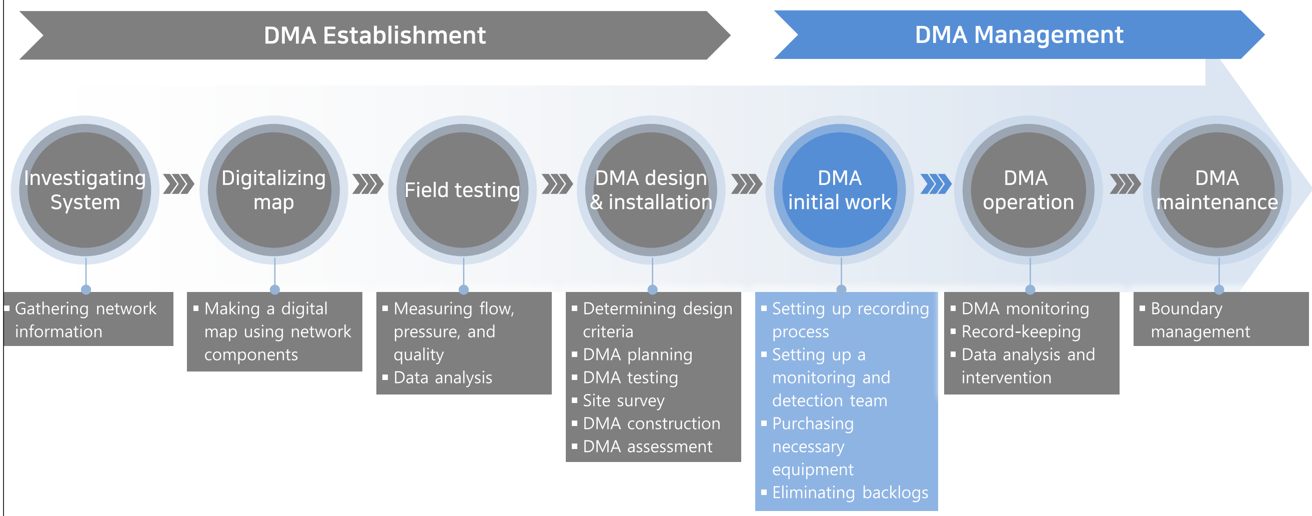
- **Revising the design: If problems were incurred during the tests, then the DMA design should be revised**

5. DMA Management

5.1 DMA Initial Work
5.2 DMA Operation: DMA Monitoring
5.3 DMA Operation: Record-keeping
5.4 DMA Operation: Data Analysis and Intervention
5.5 DMA Maintenance: Boundary Management

5.1 DMA Initial Work

- **DMA Initial work: Once the DMA has been set up, initial work should be conducted, such as determining leakage and eliminating the backlogs of detected and undetected leaks**



[Initial Works in DMA Management]

5.1 DMA Initial Work

- **Setting up the recording procedures: Data recording forms and procedures for established DMA should be systematized**

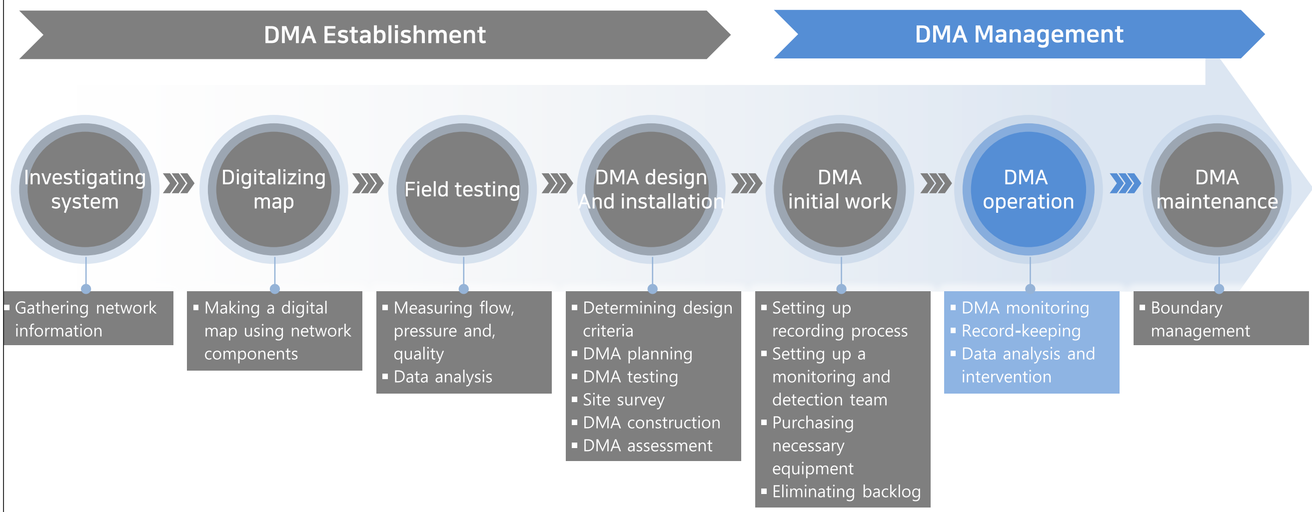
- **Setting up a monitoring and detection team: A team that will take ownership of the monitoring and detection for leakage control should be established**

- **Purchasing the necessary equipment: Purchasing officers should complete equipment orders as quickly as possible because delays in purchasing will hinder the subsequent process**

- **Eliminating backlogs: After installing a new DMA, an intensive leak detection and repair campaign should be undertaken to determine and eliminate the backlogs of visible and hidden leaks in the district**

5.2 DMA Operation: DMA Monitoring

- **Monitoring for MNF: Data for the bottom-up approach (i.e., MNF analysis) is possible in cases of sectorized systems and equipped with continuous monitoring**
  - DMA and night flow analysis are two major tools used in the bottom-up assessment of distribution system leakage



[DMA Operation in DMA Management]

5.3 DMA Operation: Record-keeping

- **Record-keeping: Records and files should be collated in a DMA filing system and be accessible to all leakage staff**
  - Record-keeping is an essential part of DMA management

- **Record types: DMA records should related to physical records (asset records) and record for leakage analysis (operation records)**

- **Record items: DMA records are static records related to the following:**
  - DMA identifiers
  - Meters
  - Boundary valves
  - PRV
  - Pressure monitoring points
  - Mains network and hydrants

5.3 DMA Operation: Record-keeping

- **Record forms: In addition to PC based-records, each DMA should have a dedicated paper-based file containing all DMA plans and records**
  - The forms are subject to a company's information system (in-house or bought-in; PC based or paper-based)
  - Many companies use GIS to generate plans mounted on portable PCs for field use
  - PCs can also contain software for entering DMA data and algorithms for calculating net night flows and leakage

01 REGIONAL SCHEMATICS

This is a small-scale (e.g., 1:10,000 or 1:25,000) map of the distribution network
It should show the DMA information and supply zone drawings

02 DMA PLANS

Boundary valves and meters, large-metered customers, and features of network and customers with special needs should be included in DMA plans

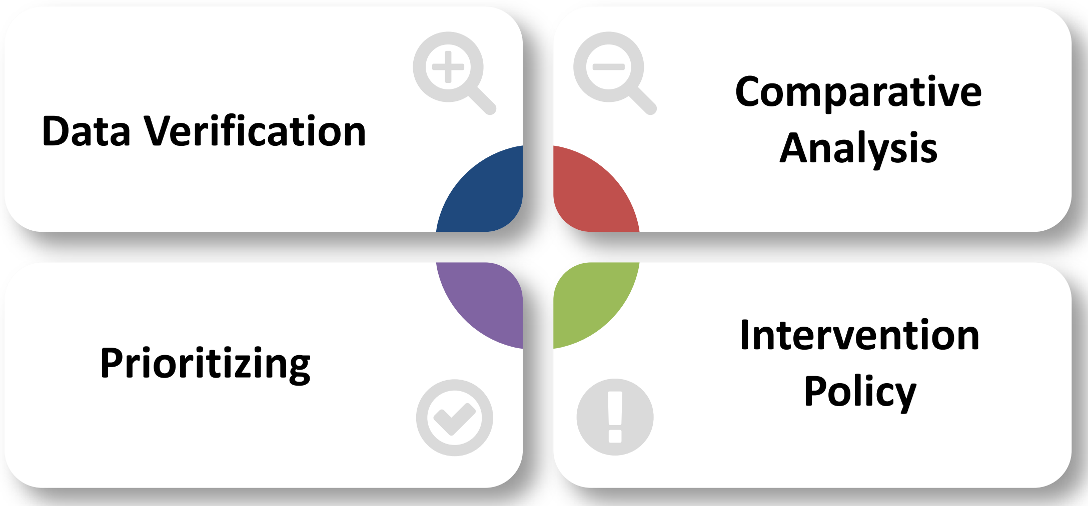
03 METER RECORDS

These records contain information required for data interpretation and meter maintenance

[Recording Items in DMA Operation]

5.4 DMA Operation: Data Analysis and Intervention

- **DMA operation with analysis: The monitoring team analyzes the verified monitoring data to prioritize vulnerable DMAs and implement interventions from the point of view of water loss control**



[Main Tasks in DMA Data Analysis and Intervention]

5.4 DMA Operation: Data Analysis and Intervention

(1) Data verification

- Several checks should be conducted by the monitoring the staff before initiating further activities

01 NIGHT USE ALLOWANCE
Night use allowances should be checked for obvious anomalies

02 COMPARISON WITH NORMAL VARIATIONS IN NIGHT FLOW
Comparison with normal variations in night flow in the DMA and length of time over which the increased flow has been measured

03 EXCEPTIONAL NIGHT USE
Tracking down exceptional night use is possible, especially if the night use patterns of the large customers are known

04 BOUNDARY INTEGRITY
Sudden changes in minimum night flow are frequently caused by the closure and opening of DMA boundary valves

05 REPORTED BURST REPAIRS OUTSTANDING
Any burst repairs in a DMA should be identified by a leakage engineer

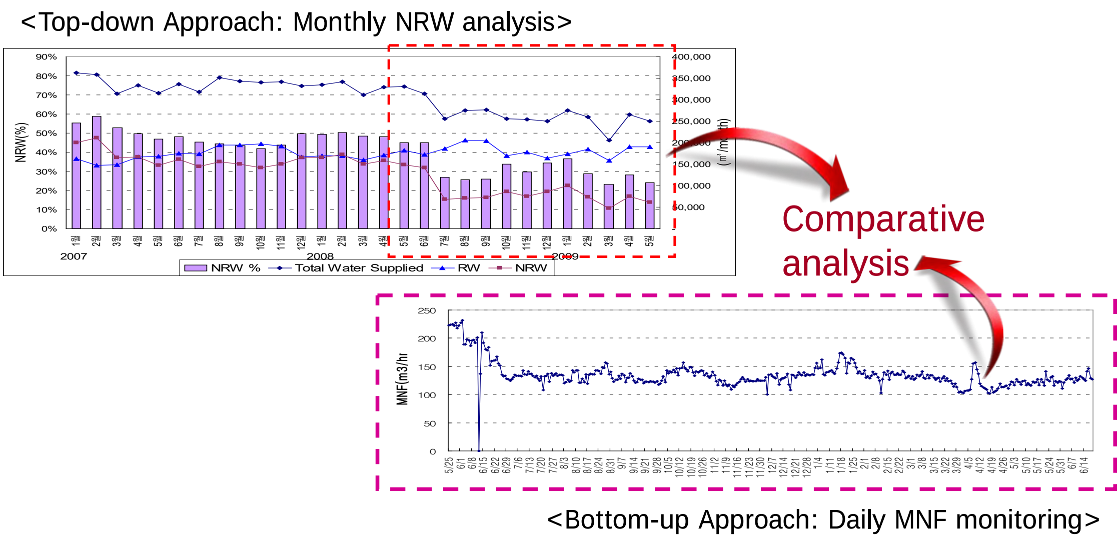
06 CHANGES IN TOTAL DAILY FLOWS
This point should be verified to ensure that the increase in night flow may be related with a corresponding increase in daily flows

[Monitored Data Verification Items]

5.4 DMA Operation: Data Analysis and Intervention

(2) Comparative analysis

- Before determining the intervention, comparative analysis using top-down and bottom-up approaches should be conducted



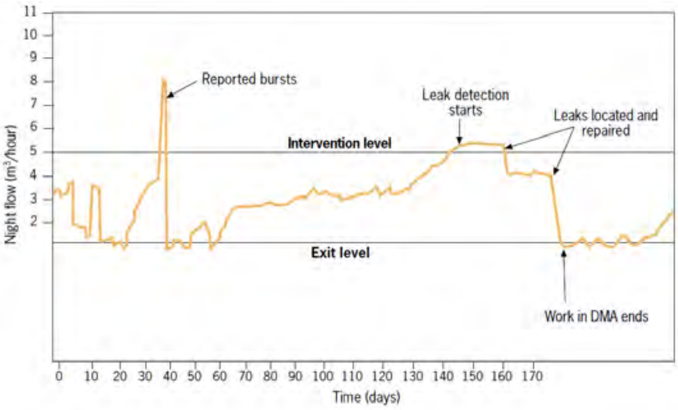
[Example of Comparative Analysis]

Courtesy of K-water

5.4 DMA Operation: Data Analysis and Intervention

(3) Intervention policy

- **Setting intervention policies: Intervention denotes the decision-making process for entering a DMA to inspect and locate any leaks and for withdrawing from a DMA**
- **Establishing the intervention level: Converting leakage targets from the company level to the local intervention and exit levels should be possible in a DMA**



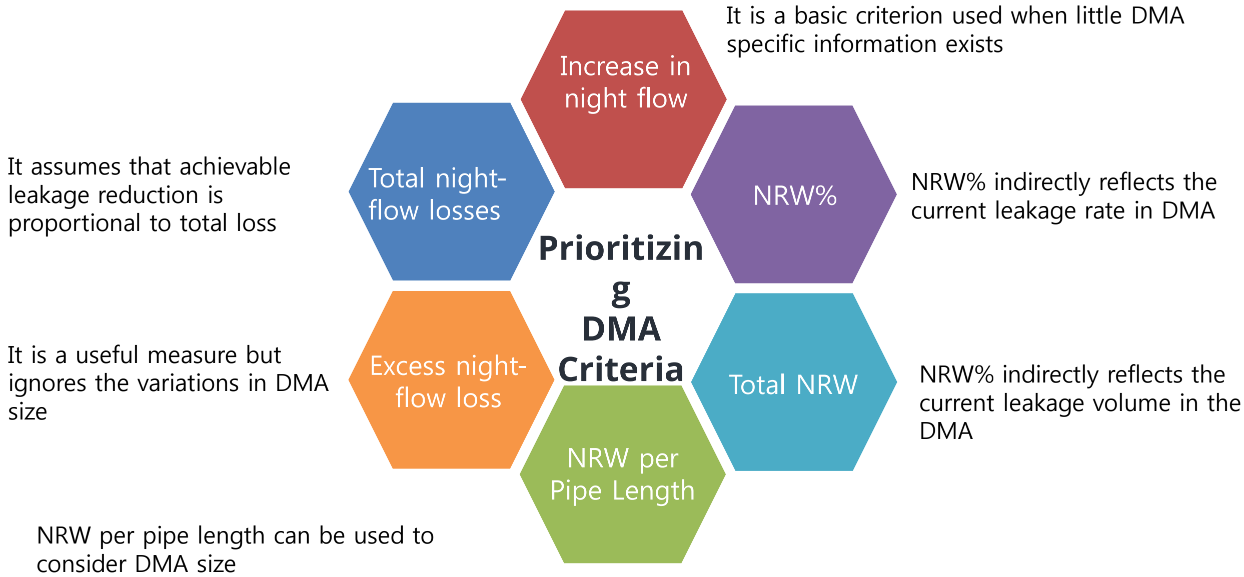
[Illustration of Intervention and Exit Levels]

Source : Farley (2001)

5.4 DMA Operation: Data Analysis & Intervention

(4) Priority

- **Prioritizing DMA: Several criteria are in place for prioritizing leakage detection from the results of DMA losses**



[Criteria for Prioritizing Vulnerable DMAs]

5.4 DMA Operation: Data Analysis and Intervention

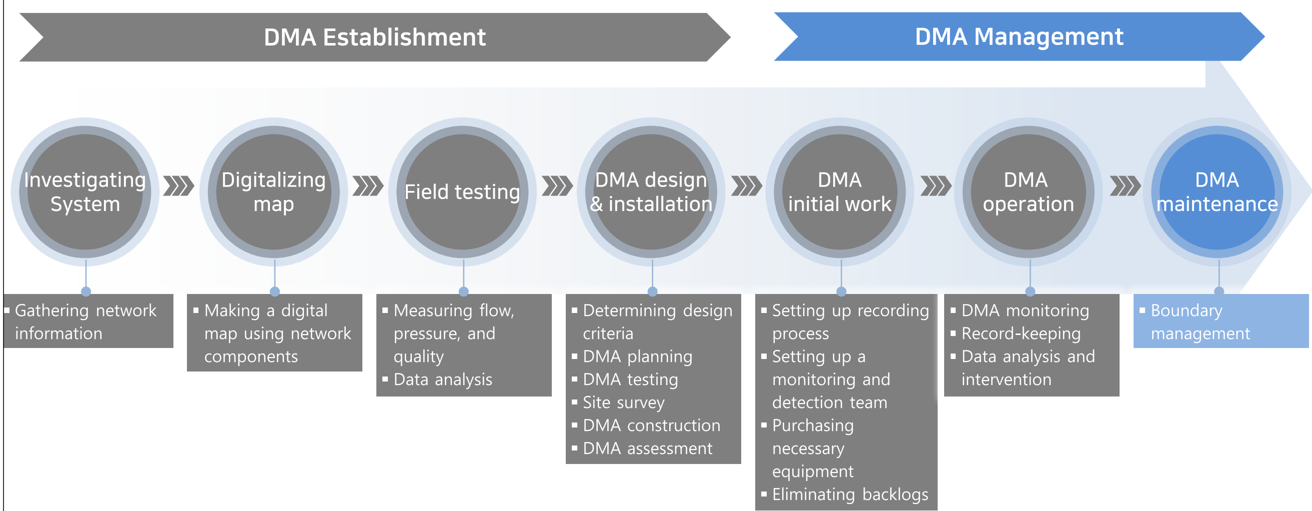
DMA	Demand (㎥/day)	Supply (㎥/day)	NRW %	NRW (㎥/year)	Pipe length (km)	NRW (m^3/km)	Priority No. For Activities
Total	**24,559**	**30,617**	**19.8%**	**2,211,397**	**557.411**		
NS	7,139	9,885	27.8%	1,002,187	120.166	8,340	3
BH	1,077	1,550	30.5%	172,652	34.362	5,025	5
ND	2,761	3,264	15.4%	183,689	20.592	8,920	2
KG	2,852	3,390	15.9%	196,439	101.995	1,926	7
YM	3,643	4,533	19.6%	324,988	109.453	2,969	6
MS	6,446	6,917	6.8%	172,089	13.604	12,650	1
SD	428	515	17.0%	31,850	88.563	360	8
YS	272	585	53.5%	114,118	22.259	5,127	4

[Example of Prioritizing DMA for Leakage Reduction Activities]

Courtesy of K-water

5.5 DMA Maintenance: Boundary Management

- **DMA maintenance: The maintenance of the DMA is a continuous process and should be part of any overall DMA management strategy**



[DMA Maintenance in DMA Management]

5.5 DMA Maintenance: Boundary Management

- **DMA deterioration: Thus far, the biggest problem facing water utilities worldwide is the continual breaching of DMAs within the system**
  - Breaching is frequently committed by officials from the water supplier

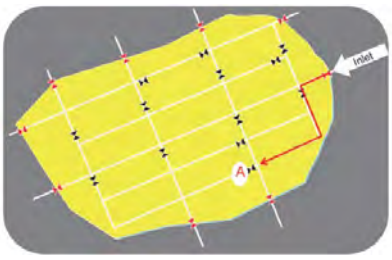
- **No measures for monitoring deterioration: Very few water utilities implement any system in place to monitor and manage their DMAs**
  - Without such monitoring, the supplier is unaware that the DMA has been compromised and is no longer functioning properly

- **Results of DMA deterioration: If any of the boundary valves are opened or closed by mistake (or on purpose), then the DMA can be compromised and will no longer act as a DMA**
  - This DMA deterioration leads to a less intact DMA and changes flow path and pressure

5.5 DMA Maintenance: Boundary Management

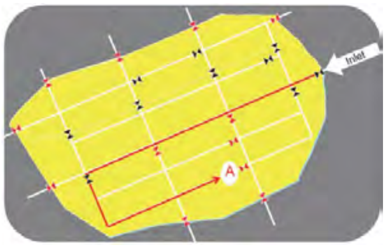
[Pressure Profile after Re-establishment of Zones]

[Opening the Boundary Valve between Two Pressure Zones]



[Sectorized Zone Showing Flow Path of Supply to Point A]

[Leak near Point A showing Valves Closed for Repair]



[Flow Path to Point A after Leak Repair]

Source : Mckenzie (2014)

5.5 DMA Maintenance: Boundary Management

- **Implementing and maintaining routine operation: Utilities always provide budget for ongoing maintenance of DMAs because they must continually be monitored and verified for discreteness at regular intervals**

01 UPDATING KEY INFORMATION

Information (e.g., DMA boundaries, flow meter locations, and household and other consumers' records) should be up-to-date

02 REGULAR DISCRETIZATION INSPECTION

Verifying that the DMAs are discrete is part of operation and maintenance

03 RECORDING OPERATION RECORDS

Records of pipe flushing or boundary valves being opened for operational reasons should be kept

04 FLOW METERS

Flow meters should be properly maintained to ensure a high level of data accuracy

05 CUSTOMER COMPLAINTS

Customer complaints about low pressure, service interruption, and water quality problems should be monitored to identify potential shortcomings on the part of the DMA

5.5 DMA Maintenance: Boundary Management

- **Protection methods: A number of strategies can be used to address the potential problems caused by unauthorized opening of boundary valves**

01 CUTTING AND CAPPING

The most drastic method is cutting and capping cross-boundary connections

02 COVERING

Covering is to close the valve and fill the box with sand and place a thin layer of cement over the sand

03 CUT AND INSTALLING FIRE HYDRANTS

This approach denotes cutting pipes and placing fire hydrants on both sides of the zone

04 MARKING

Connections between adjacent zones should be clearly marked to ensure that cross-boundary connections are closed

[DMA Boundary Protection Methods]

5.5 DMA Maintenance: Boundary Management

(a) Shut-off Valve (b) Boundary Valve

[Manhole Lid for Different Purposes]

Courtesy of K-water

[Approaches Used to Identify Cross-boundary Connections]

Source : Mckenzie (2014)

Thank you very much

MEMO

Leak Detection, Location, and Repair

Water Loss Management

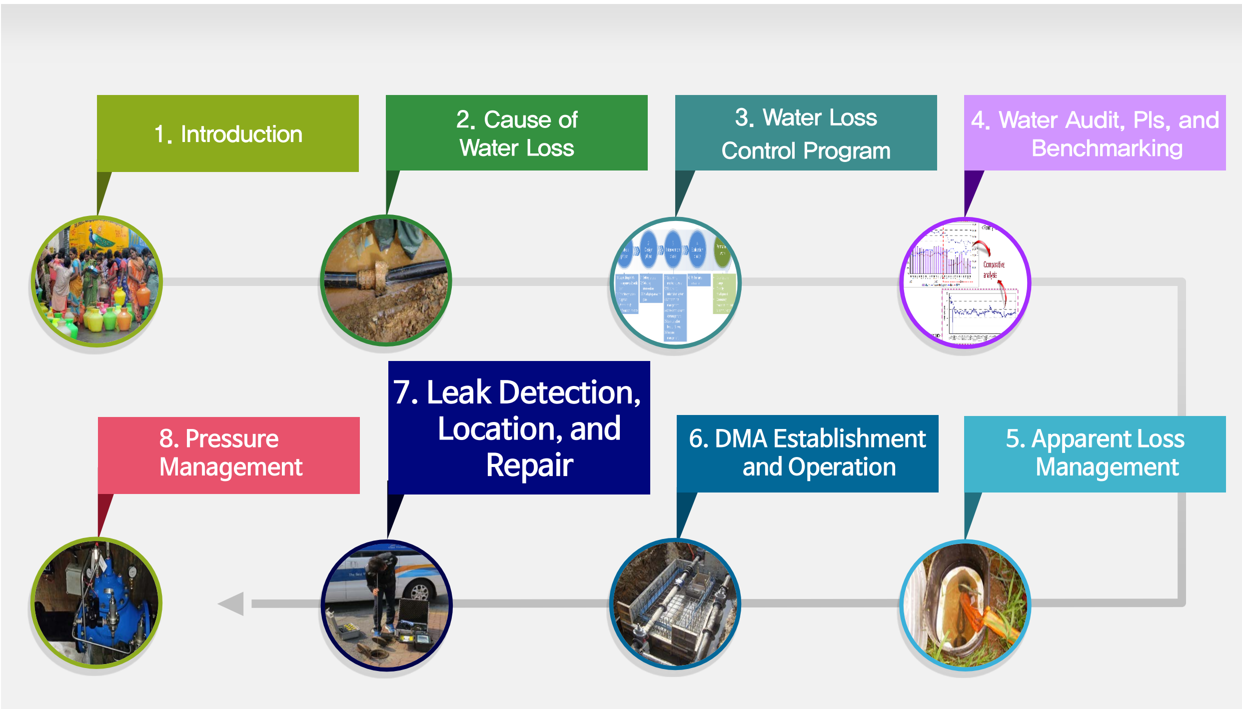
7. Leak Detection, Location, and Repair

United Nations Educational, Scientific and Cultural Organization

i-WSSM

International Centre for Water Security and Sustainable Management

Training Course



Aims and Objectives

- The course aims to:

(1) Provide knowledge on leakage management procedures including leakage detection and repair methods;
(2) Enable trainees to select and implement appropriate leak detection techniques in the water network systems and to repair leakage within a short period

- The objectives are that trainees will understand:

(1) The characteristics of acoustic sound;
(2) Leakage detection and location equipment
(3) Leakage repair methods

Contents

1. Overview

1.1 Background
1.2 Classification of Real Loss
1.3 Causes of Real Loss

1.1 Backgrounds

- **Terminologies: Leak awareness, detection, and location are defined as follows:**

Leak awareness

- Leak awareness denotes a continuous monitoring and analysis of flows to gain awareness of new leaks at an early stage
- DMAs provide a good opportunity for monitoring discrete areas of the water distribution network and facilitate early awareness of even small leaks

Leak detection

- Leak detection pertains to the narrowing down of a leak or leaks to a section of the pipe network
- Leak detection activities may be carried out routinely or in precise areas of the network and guided by analysis of DMA data

Leak location

- Leak location is the identification of the position of a leak prior to excavation and repair, although finding the exact location cannot be guaranteed
- Location survey can be carried out with or without prior leak detection activities

1.1 Backgrounds

- **Fundamental activity: Leakage control and management is the most fundamental activity in reducing real loss**
  - Efficiently undertaking and managing leak repairs is a pre-requisite for effective leakage management and control

- **General activity: Identifying and repairing leaks are considered in addressing water loss**

- **Initial activity: An intensive program for leak detection and repairs can be an important as an early step when funding for a comprehensive NRW program is initially lacking**

1.1 Backgrounds

- **Long-term activity: Leak detection should not be regarded as a one-time exercise**
  - Once initial leak repairs have been undertaken, the area should be re-tested to ensure that large leaks have been identified

- **Increasing difficulties: The diversity of new materials used in networks, especially with plastic mains, combined with low operating pressure and lack of access points, have limited the application of acoustic techniques**
  - Leak detection is becoming increasingly difficult due to the greater use of plastic pipes, which do not transmit noise from the leak in the same extent as metal pipes

- **Difficulty in water supply: In systems with poor pressure and intermittent supply, leakage and burst rates are reduced but identifying leak location is more difficult**

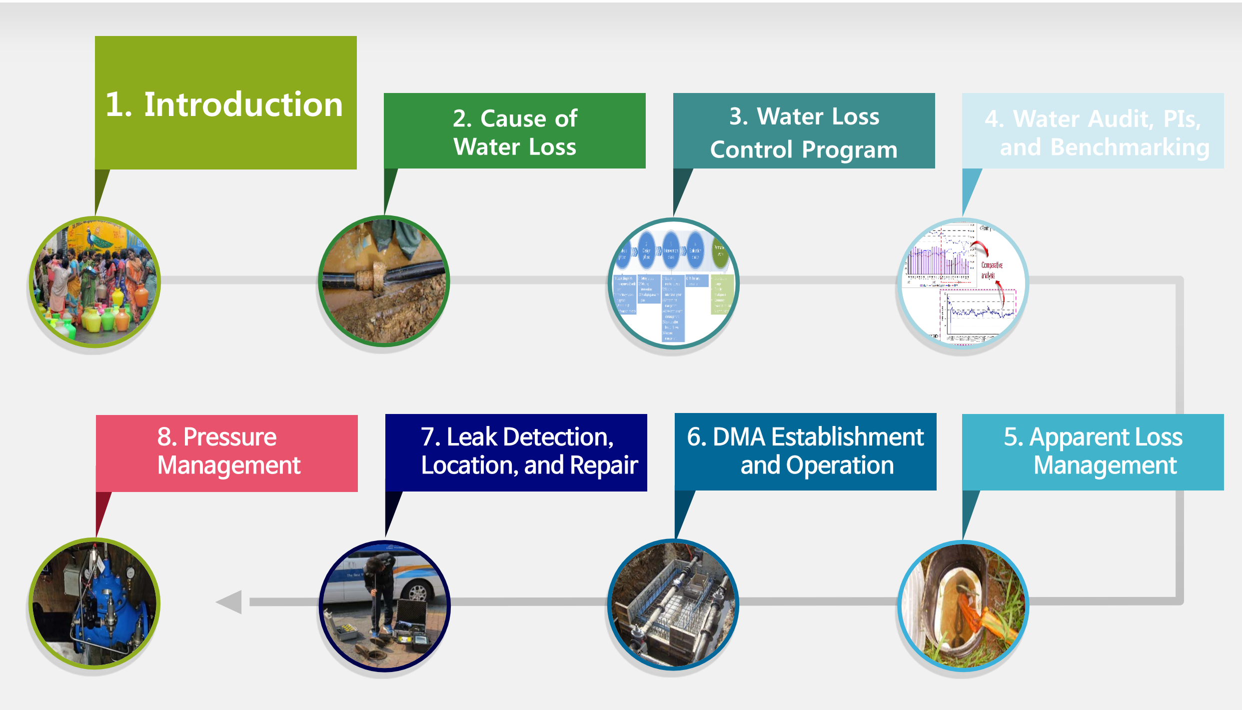
1.1 Backgrounds

- **Balloon effect: Notably, fixing leaks will result in an increase in the system pressure which, in turn, will push up the leakage through any existing leaks and cause the formation of new leaks**
  - Therefore, any large-scale leak location and repair projects should be undertaken with a form of pressure management, where the system pressures can be reduced if necessary as the leaks are repaired
  - If the pressure is not managed properly, then system leakage will quickly revert to pre-leak repair levels and will be no longer beneficial

- **Economics: Assembling a cost-effective basis is important for the definition of the size, schedule, and functions of the leak detection program**
  - The costs of creating an in-house leak detection staff or contracting leak detection services can be considerable

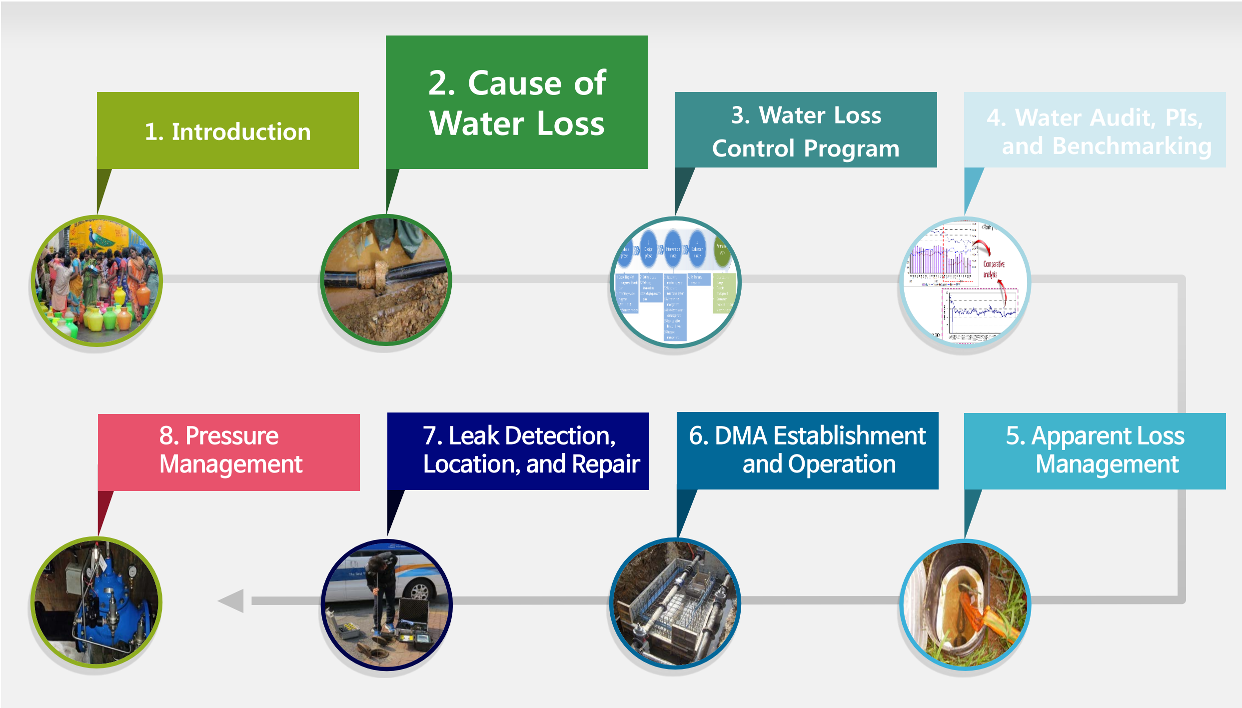
1.2 Classification of Real Loss

* This topic was explained in 1. Introduction



1.3 Cause of Real Loss

* This topic is explained in 2. Cause of Water Loss



2. Acoustic Sound Characteristics

2.1 Sound
2.2 Volume
2.3 Speed
2.4 Travel Distance
2.5 Frequency

2.1 Sound

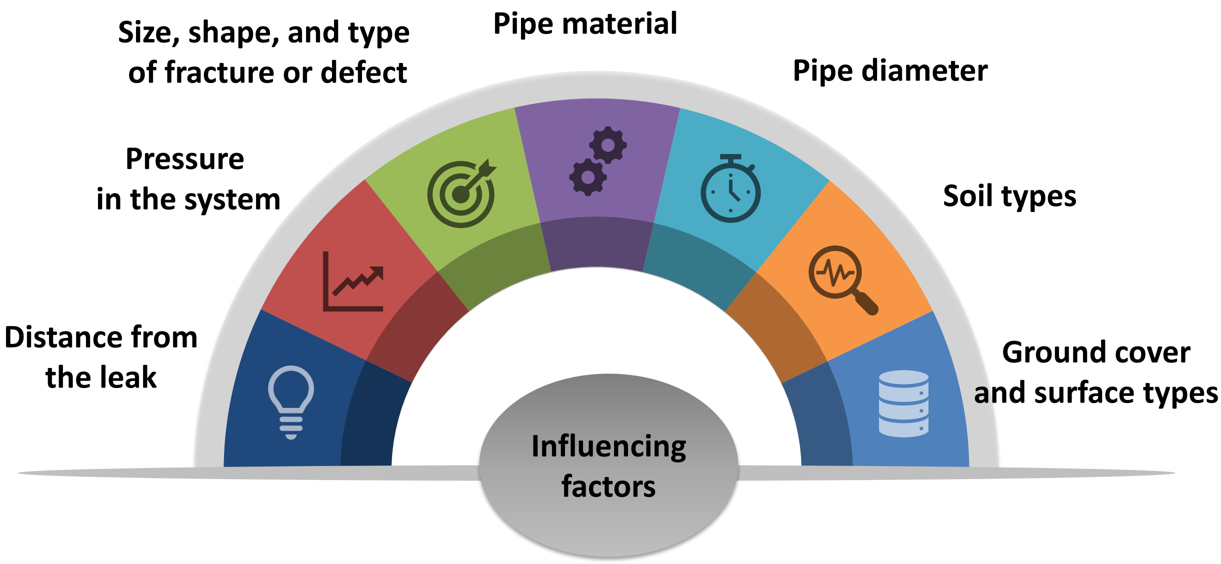
- **Definition: Sound is defined as oscillation in pressure, stress, particle displacement, particle velocity, and other aspects propagated in a medium with internal forces (e.g., elastic or viscous) or the superposition of such propagated oscillation**

- **Sound generation: When water escapes from a pressurized pipeline, a characteristic and recognizable leak sound is generated in the pipe at the point of leakage**
  - Pressurized water force through a leak loses energy to the pipe wall (structure-born noise) and to the surrounding soil area (soil-born noise)
  - The energy creates audible sound waves that can be sensed and amplified by an electronic transducer or, in some cases, simple mechanical devices

- **Sound transmission: Vibration is transmitted along the pipe as structure-borne and in the surrounding underground as ground-borne noise**

2.2 Volume

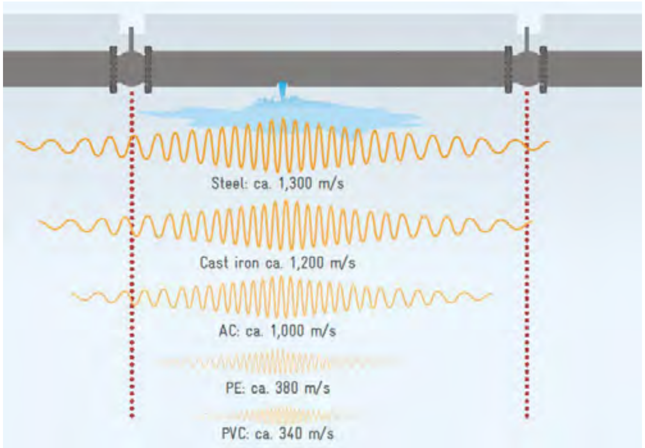
- **Volume of sound: In general, the volume of the noise will be dependent on the following factors:**



[Influencing Factors on Sound Volume]

2.3 Speed

- **Wave speed: The noise is distributed along the pipe at a speed dependent on the particular characteristics of the material**
  - Air: 340 m/s
  - Water: 1,493 m/s
  - Aluminum: 5,100 m/s
  - Water pipe: approximately 1,000 m/s



[Relationship Between Material and Propagation of Acoustic Waves]

Source: GIZ (2011)

2.4 Travel Distance

- **Travel distance: On metal pipes, noise can sometimes be heard from over 100 m. However, on plastic pipes, noise may disappear within a few meters and cannot be picked up unless the observer is on top of the leak**

Type of Pipe	Pipe Dia.	Typical Sound Travel Distance
Iron Pipe	6”	1,000 – 1,200 ft
	12”	800 – 1,000 ft
	24”	600 – 800 ft
AC Pipe	6”	800 – 1000 ft
	12”	700 – 900 ft
	24”	400 – 600 ft
PVC Pipe	6”	400 – 600 ft
	12”	200 – 300 ft
	24”	100 – 150 ft
Leak Noise Travel Distances in Service Lines (for a 2 gpm leak @ 50 psi)		
Copper Tubing		600 – 1,000 ft
Galvanized Steel Pipe		800 – 1,200 ft
“Poly” Plastic Tubing		50 – 100 ft

[Leak Noise Travel for Distances in Distribution Mains and Service Lines]

Source: EPA (2011)

2.5 Frequency

- **Frequency: Vibration can be perceived at different frequencies and heard through a device similar in operation to an amplified stethoscope**
  - Vibrations are frequently detected on the ground surface in the 200 Hz to 600 Hz frequency range and directly on the distribution network mains between 600 Hz and 2,000 Hz

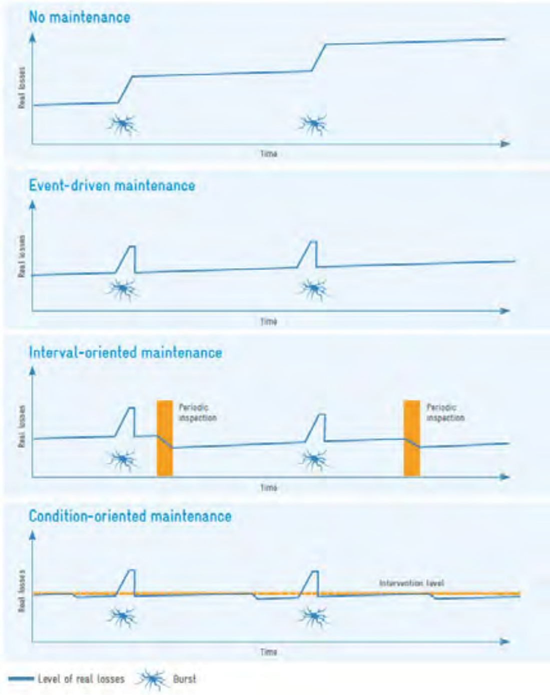
Types of leak sounds	Details
Orifice-pipe vibration	- Leak noises within a range of 500 Hz to 800 Hz usually originate as orifice-pipe vibration phenomenon and are transmitted along the pipe wall and in the water and in many instances, a considerable distance from the actual leak - Identifying this sound by systematically testing valves, hydrants, and curb-stop valves frequently locates potential leaks
Impact of water on soil	- This leak sound emanates from a range of 20 Hz to 250 Hz - It is caused by the impact of water on soil in the area of the leak - In contrast to vibration on the pipe wall, the travel distance of the lower frequency sounds is limited to the immediate area of the leak - Due to the limited range, these low-frequency sounds are essential for pinpointing the leak
Water circulation	- This leak sound emanates from a range of 20 Hz to 250 Hz - The sound is caused by water circulation, usually in a cavity in the soil near the leak - The sound resembles those of water emanating from a fountain - In contrast to the vibration on the pipe wall, the travel distance of the low-frequency sounds is limited to the immediate area of the leak - Due to limited range, these low-frequency sounds are essential for pinpointing the leak

3. Active and Passive Leakage Control

3.1 Leakage Control Policy
3.2 Passive Leakage Control (PLC)
3.3 Active Leakage Control (ALC)

3.1 Leakage Control Policy

- **Leakage control policy: As part of the strategy implementation, the policy aspect of leakage management can be classified into two operational policies as follows.**
  - Passive leakage control (PLC)
  - Active (proactive) leakage control (ALC)
- **Selecting a policy: The choice of policy to be taken by the utility is dependent intrinsically on the systems and financial capacity as well as the determinants of service-level aspects, such as network pressure, burst frequency, level of background leakage, leak identification, and location times as as well as the stipulated time for repair**



[Comparison Between Different Intervention Strategies to Combat Real Loss]

Source: GIZ (2011)

3.2 Passive Leakage Control

- **PLC: pertains to reacting to reported bursts or drops in pressure, which are typically reported by customers or noted by the utility staff while implementing duties apart from leak detection**
- **Usually practiced in less developed systems: This type of leakage control is practiced in less developed supply systems, where the occurrence of underground leakage is less understood**
- **High leakage: Overall losses are typically high because no efforts are made to locate and repair unreported leakage and reduce background leakage**
- **Increasing leakage: Without exceptional circumstances, leakage will continue to increase under PLC**

3.2 Passive Leakage Control

- **Failure to reach the desirable level: Notably, the PLC cannot, in general, attain desirable levels of efficiency, particularly in terms of water loss**

- **Cost effectiveness: Although PLC is clearly not ideal from the viewpoint of leakage reduction, the key issue is determining which is cost effective in PLC and ALC**
  - PLC can be effective for a limited period of time in new systems built from scratch using appropriate and quality projects and materials

- **Appropriate situations: PLC can be justified in areas with adequate raw water resources and water treatment capacity and low marginal costs**

3.3 Active Leakage Control

- **ALC: An intervention method for counteracting real loss. A water utility deploys funds, personnel, and technical equipment to actively detect and repair unreported leaks**

- **Repair visible leak first: Notably, all visible leaks should be repaired before any activities are undertaken to locate new and unreported leaks**
  - If the initial visual inspection highlights a large number of clearly visible leaks, which are running without being repaired, then efforts should be exerted to locate leaks that have not come to the surface only after the obvious leaks have been eliminated

- **ALC with quick repair: Undertaking ALC does not solve the problem. In all cases, the utility must continue to ensure that all reported or detected leaks are repaired quickly and effectively**
  - A utility with a proper and efficient PLC process in place can drive leakage down to acceptable levels, whereas a utility undertaking ALC on a regular basis but does not repair the leaks quickly or properly may face a serious leakage problem

3.3 Active Leakage Control

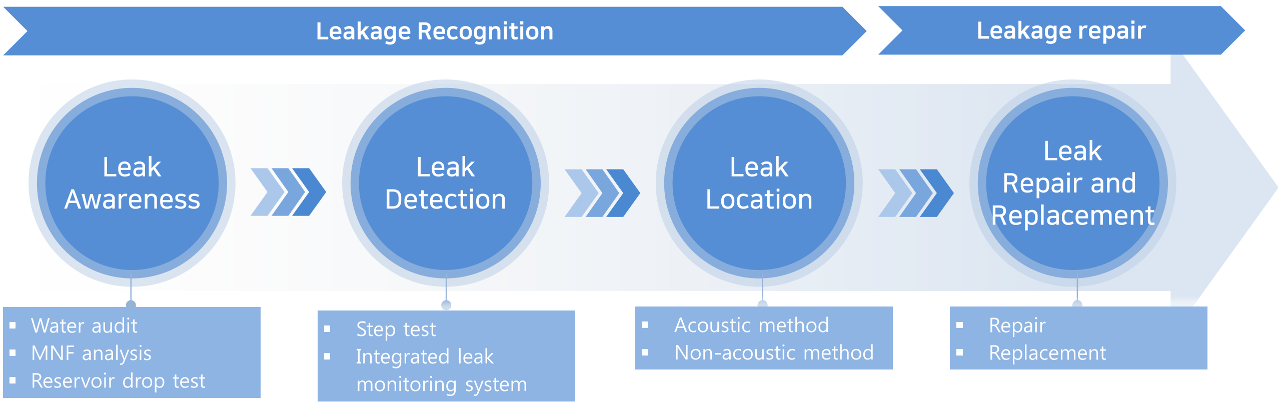
- **Combined with awareness: ALC is cost effective in certain cases but should not be undertaken in a blanket fashion but rather in a targeted fashion, where specific problem areas are firstly identified (e.g., MNF analysis)**

- **Cost effectiveness: ALC may or may not be cost effective depending upon the level of leakage in a specific area**
  - If an area is known to have high leakage (e.g., the area will have high MNF), and the network is known to be in a poor condition, then sending in a team of leak locators to identify unreported leaks may be worthwhile and cost effective

4. Leakage Management Process

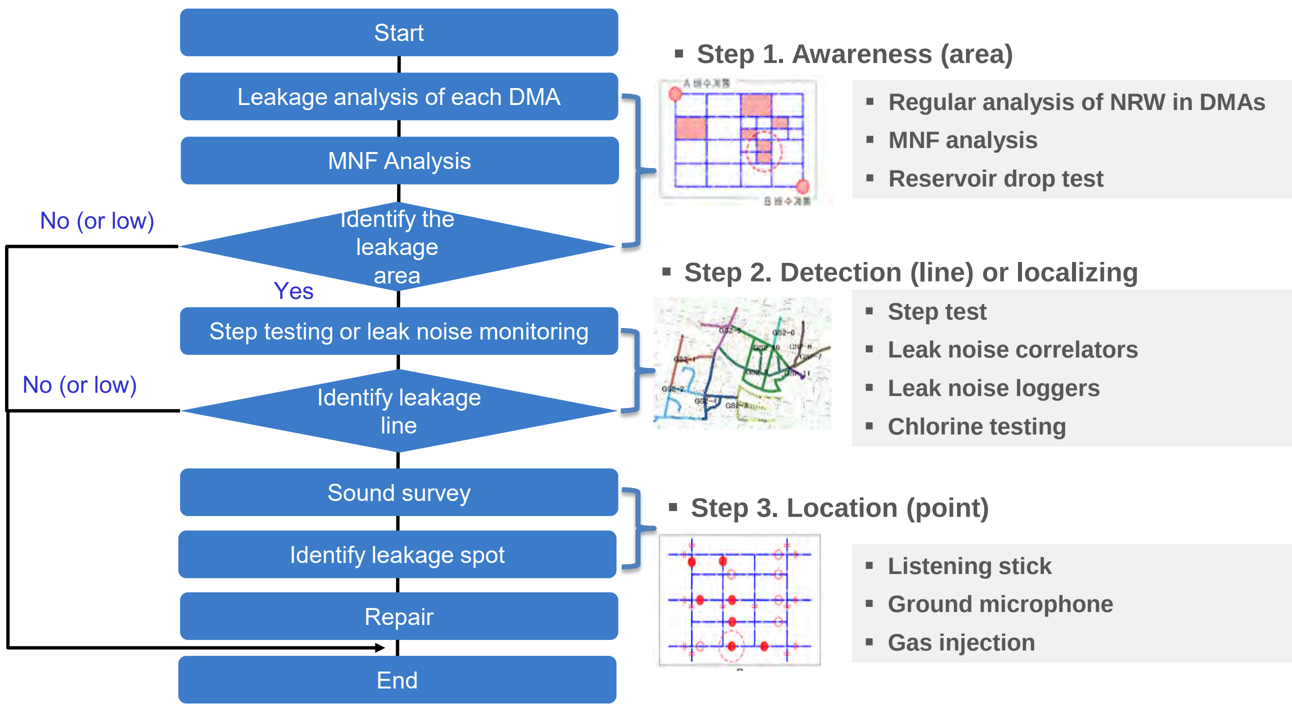
4. Leakage Management Process

- **Procedure: Leakage amounts in the water network can be reduced through leakage recognition and repair**
  - The procedure of leakage recognition is composed of three main steps, namely, leak awareness, detection, and location



[Process of Leakage Recognition and Repair]

4. Leakage Management Process



[Leakage Management Procedure]

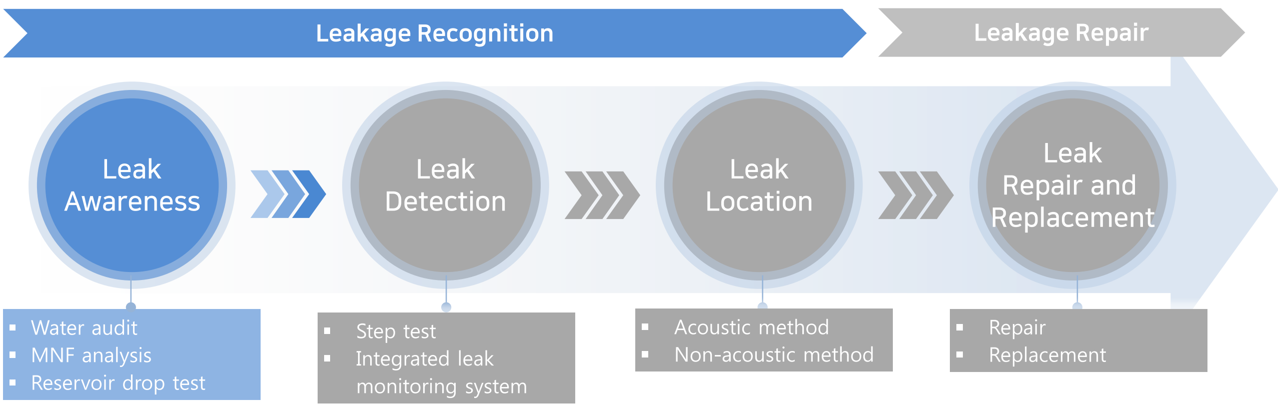
Courtesy of K-water

5. Leakage Awareness

5.1 Leakage Awareness
5.2 MNF Analysis

5.1 Leakage Awareness

- **Leak awareness: Modern flow metering and data capture technologies play a major part in the rapid identification of bursts and estimating the gradual accumulation of small leaks**



[Leakage Awareness in Leakage Recognition Process]

5.1 Leak Awareness

- **Methods: In the DMA inlet, flow and pressure can be monitored and analyzed**
- **DMAs and monitoring system: To effectively monitor flow and pressure, adequate DMAs and DMA inlet monitoring system should be established**

01 FLOW MONITORING

- Pipe breaks and bursts cause a more or less abrupt rise in the flow rate, which can be detected by constantly monitoring the inflow into an open network or DMA
- To this end, inflow should be monitored continuously or for at least 1 h during MNF conditions and compared to previously measured reference values

02 PRESSURE MONITORING

- Monitoring pressure in a network can only detect major leaks because small leakage flow rates will not significantly reduce pressure

[Methods for Leakage Awareness]

5.1 Leak Awareness

(a) Flow and Pressure Meter

(b) PLC or RTU

(c) SCADA System

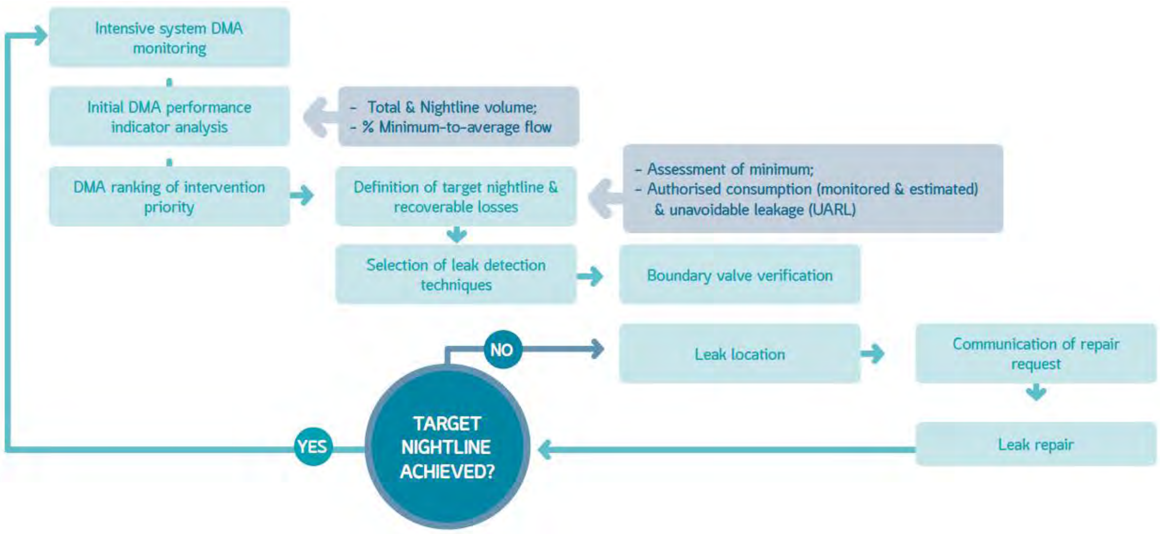
(d) Monitoring and Analysis

[DMA Inlet Monitoring System]

Courtesy of K-water

5.2 Minimum Night Flow Analysis

- **MNF analysis: A gradual increase in minimum hour flows over periods of days or weeks is a good indication that new leaks have developed**



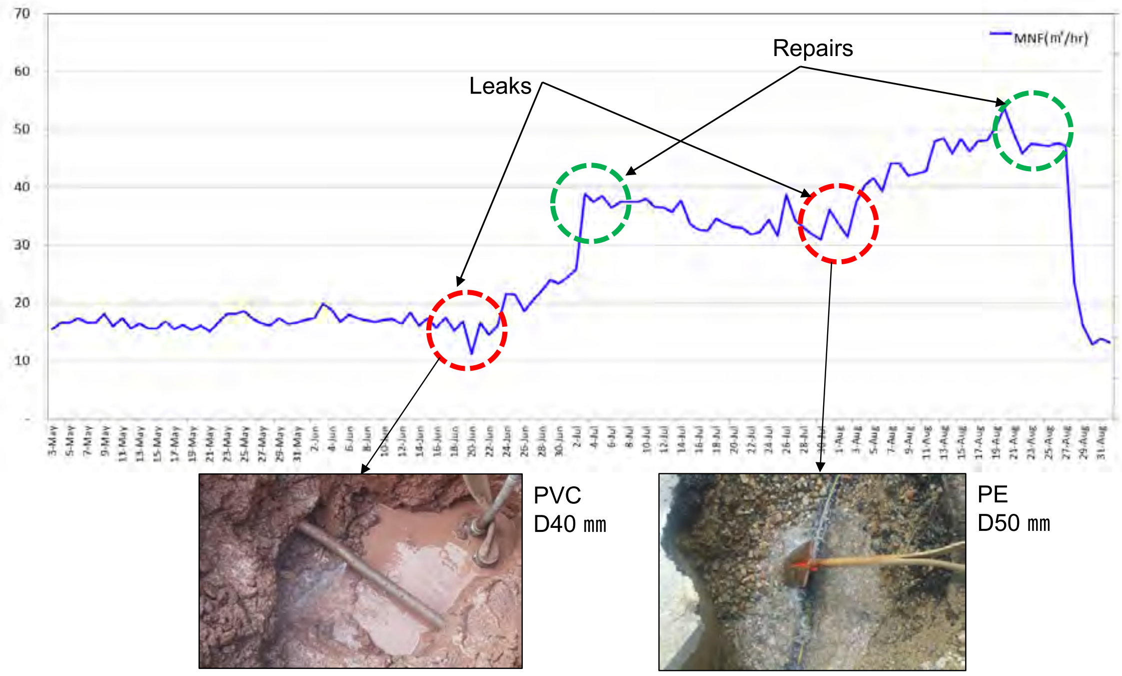
[Integration of Network Monitoring with Leak Detection]

Source: EPAL (2017)

5.2 Minimum Night Flow Analysis

- **Without DMA: If the DMA system is not constructed, then leakage analysis can be performed per unit of service reservoirs**
- **Monitoring large consumers: Large-volume night users (e.g., factories) should have their meters read manually during the testing period if logging is unavailable**
- **Average zone night pressure: The average zone night pressure should be recorded within the same period**
  - These data will not be used for MNF analysis but will provide valuable data for pressure reduction purposes and future sophisticated leakage calculations
- **Waiting a few days: If the increased flow rate remains stable for more than three days, then the change is probably caused by a leakage and not exceptional customer usage**

5.3 Minimum Night Flow Analysis



[Example of Minimum Night Flow Data]

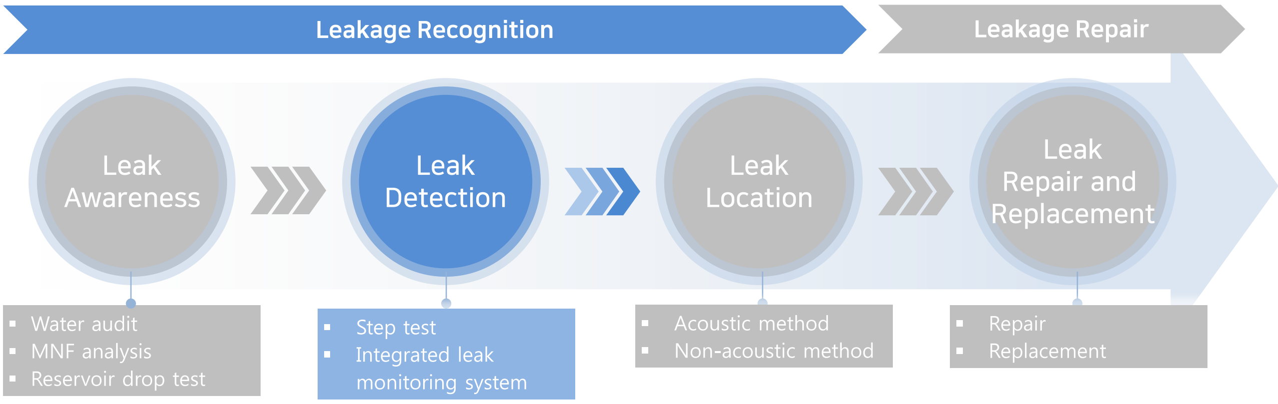
Courtesy of K-water

6. Leakage Detection

6.1 Leakage Detection
6.2 Sub-division of DMAs
6.3 Step Test
6.4 Integrated Leak Monitoring System

6.1 Leakage Detection

- **Procedure: For suspicious DMAs, leak detection is performed based on the main pipeline**



[Leakage Detection in Leakage Recognition Process]

6.1 Leakage Detection

- **Methods: To narrow down the leak area, sub-division of DMA, step-test, main pressure mapping, and integrated leak monitoring system can be implemented**

01 SUB-DIVISION OF DMA

- Water utilities can divide DMAs into sub-divisions by temporarily closing valves or installing meters

02 STEP-TEST

- Step test enables operators to identify lengths of water mains that require further investigation

03 MAINS PRESSURE MAPPING

- Pressure mapping along supply mains can be used to leak detection

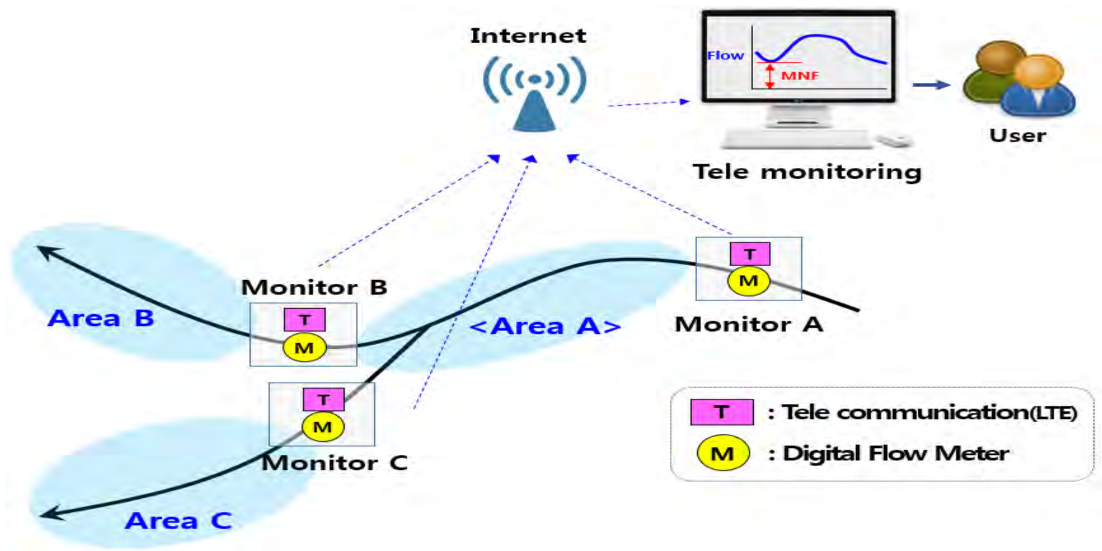
04 INTEGRATED LEAK MONITORING SYSTEM

- A relatively dense grid of noise loggers has to be temporarily or permanently situated to find a vulnerable pipeline

[Methods for Leakage Detection]

6.2 Sub-division of DMAs

- **Sub-division: Large-sized DMAs or zones can be sub-divided through internal valving or metering to detect leakage**



[Concept of DMA Sub-division by Metering]

Courtesy of K-water

6.2 Sub-division of DMAs

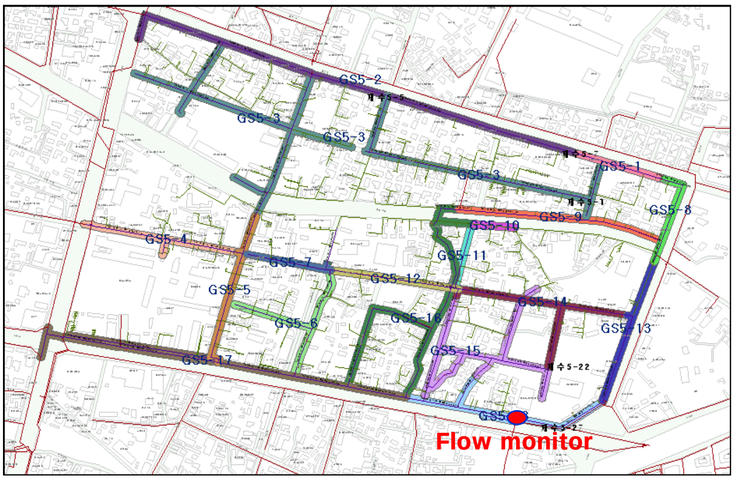
- **Targets: The sub-zoning technique is applied when the identification of excessive consumption in a DMA is considered**

- **Implementation with smart meters: With the increased use of smart meters, this method has become widely adopted in places where DMAs are not established**

- **Checking conditions: A procedure for checking conditions prior to the implementation of this type of test should be created to guarantee minimum pressure and water quality**
  - Notably, the opening of DMA boundary valves can cause changes in water quality if a length of pipe exists without considerable regular consumption upstream of these valves
  - In these cases, discharge using a specific valve or fire hydrant should be performed beforehand to mitigate potential problems with water quality

6.3 Step Test

- **Principle: The principle of the technique is to systematically reduce the size of the area by closing valves on each section of a pipe and noting changes in flow rate at the meter at the same time.**
  - Step testing should be conducted at night when demand is at the minimum level, and consumers should be notified beforehand that the supply will be disrupted

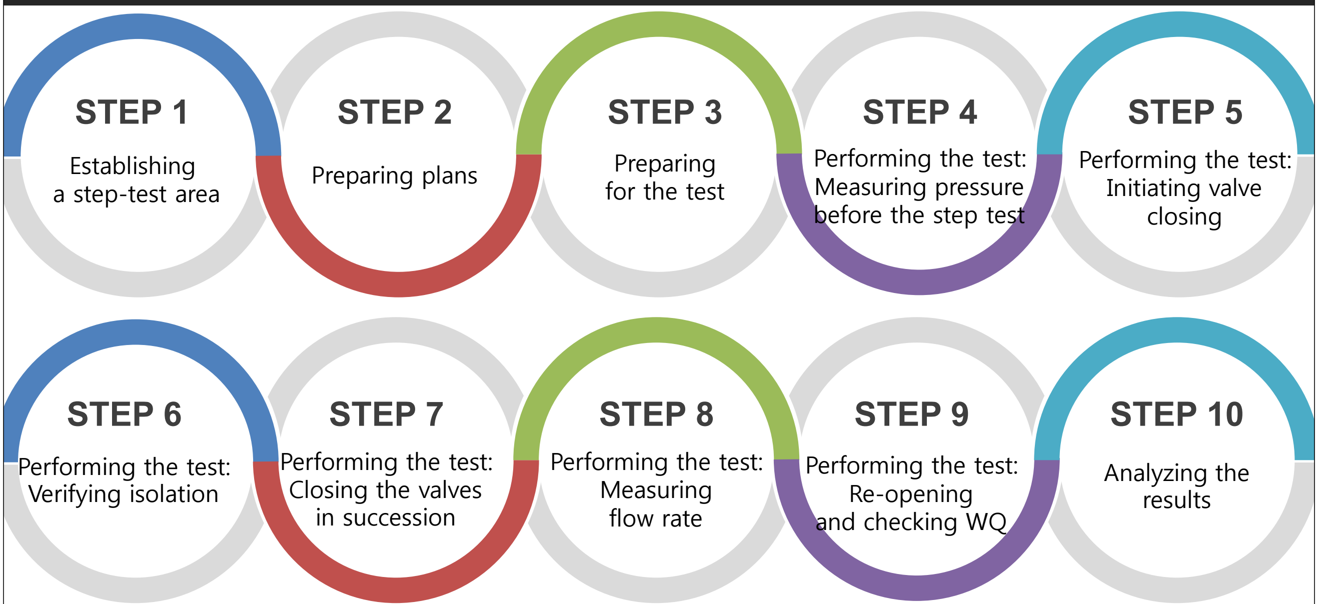


[Step Testing Schematic]

Courtesy of K-water

6.3 Step Test

- **Procedure: Step testing should be conducted at night when demand is at the minimum level, and customers should be notified beforehand that the supply will be disrupted**

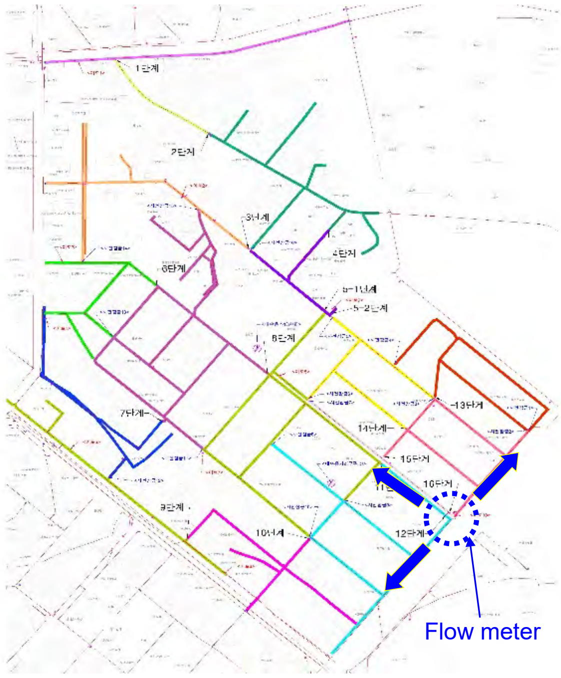


[Step Test Procedure]

6.3 Step Test

Test Overview

- Method: Complete Isolation
- Steps: 16 steps (valve: 33)
- Flow meter: Electromagnetic (㎥/min, ㎥/h)
- Pressure: 5.0 kgf/㎠ (fixed)
- Water supply shut-off : 800 households
- Date/time: 23 March/01 a.m.–05 a.m.



[Establishing a Step-test Area and Preparing Plans]

Courtesy of K-water

6.3 Step Test

[Preparation for the Test: Boundary Valve Check and Closure]

Courtesy of K-water

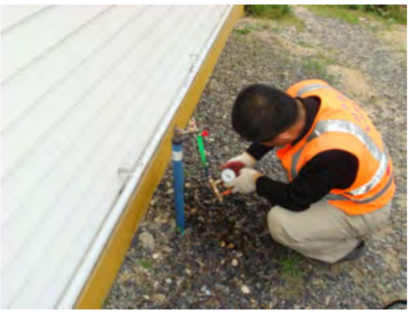
[Preparation for the Test: Step Test Valve Test]

Courtesy of K-water

6.3 Step Test

[Preparation for the Test: Investigating Pressure Check Points]

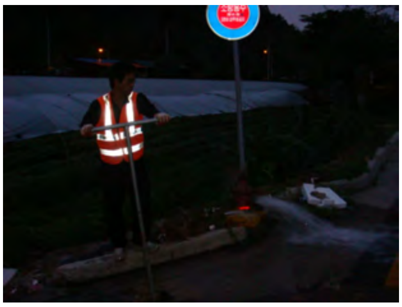
Courtesy of K-water

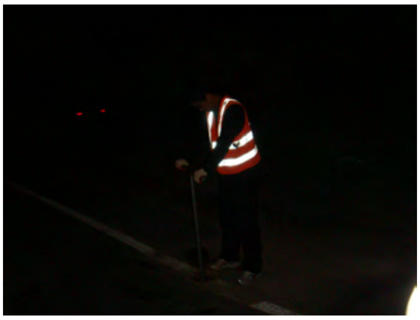


[Performing the Test: Measuring Pressure Before Step Test]

Courtesy of K-water

6.3 Step Test





[Performing the Test: Initiating the Step Test (Valve Closure)]

Courtesy of K-water

[Performing the Test: Valve Re-opening]

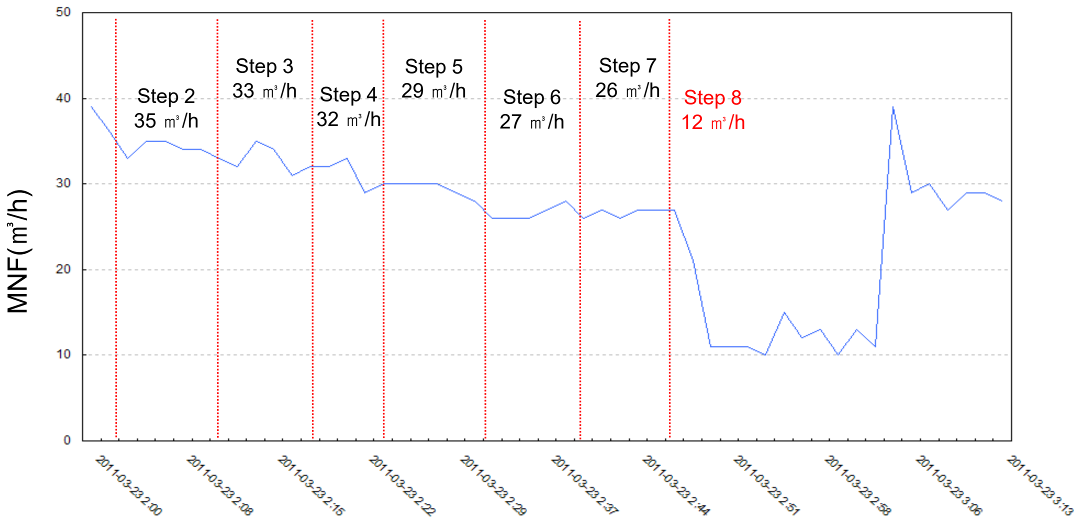
Courtesy of K-water

6.3 Step Test

[Performing the Test: Checking Water Quality at Hydrant or Water Tap]

Courtesy of K-water

6.3 Step Test



Test results: In Step 8, MNF decreased rapidly

- Step 7: 26 ㎥/h → Step 8: 12 and14 ㎥/h ↓
- Intensive leak detection is required in Step 8.

[Analyzing the Results]

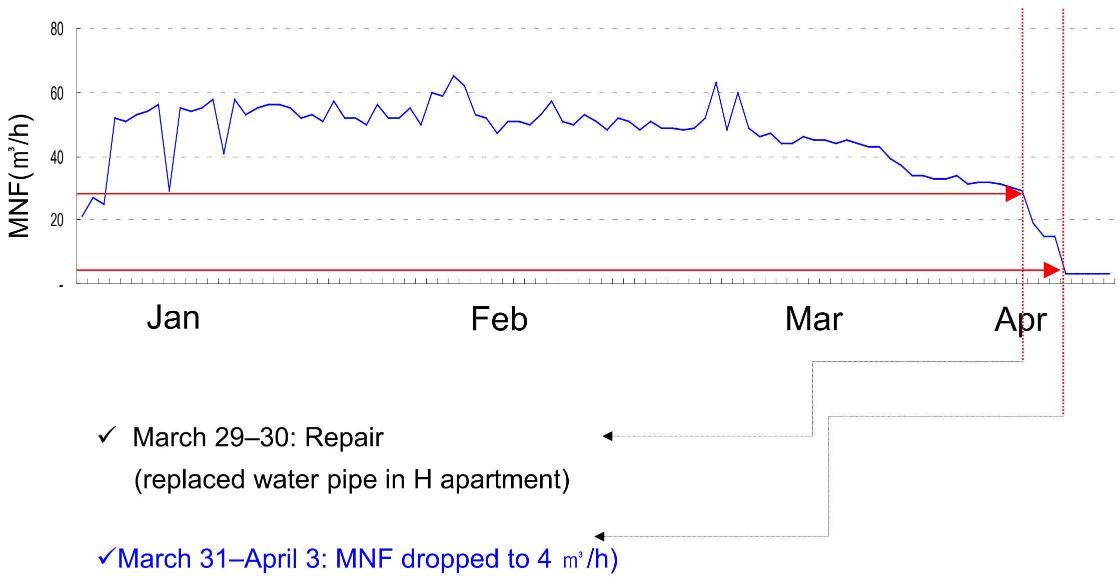
Courtesy of K-water

6.3 Step Test

[Analyzing the Result: Leak Location (H Apartment inlet pipe (SP D100 ㎜) elbow)]

Courtesy of K-water

6.3 Step Test



[Changes in MNF by Step Test and Leakage Repair]

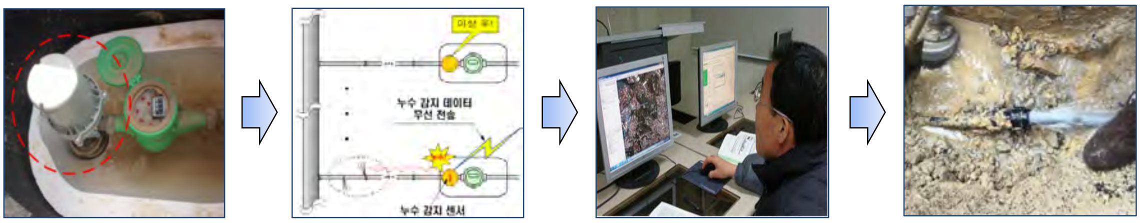
Courtesy of K-water

6.4 Integrated Leak Monitoring System

- **Objectives: Leak noise monitoring system aims for automatic monitoring and data collection with cost-effective, wireless, and movable noise loggers**

[Installing a Noise Logger on a Valve or Meter]

Courtesy of USOL

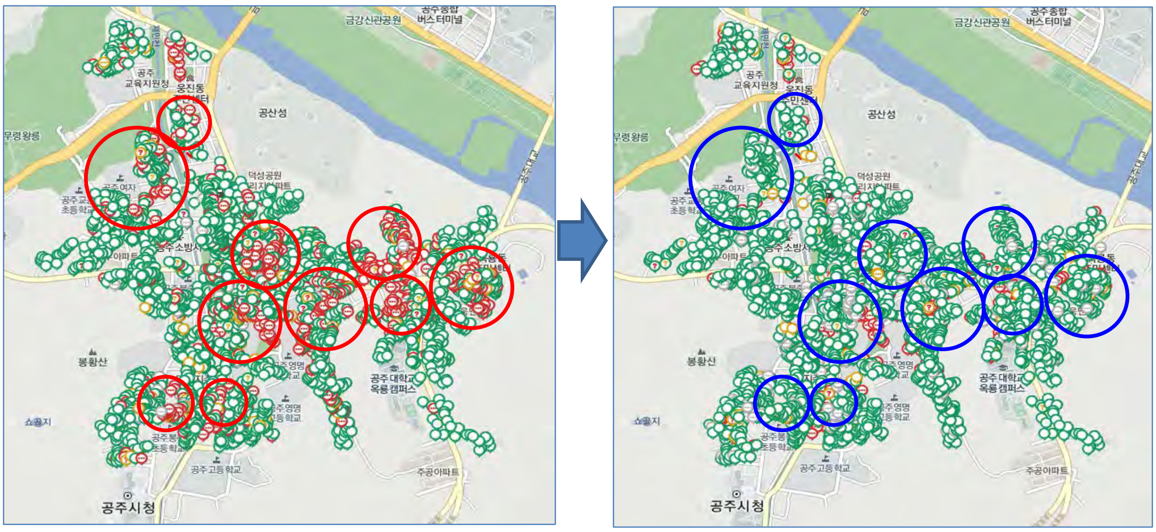


(a) Installation (b) Detection (c) Monitoring (d) Pinpointing and Repair

[Operating Process]

Courtesy of USOL

6.4 Integrated Leak Monitoring System



< Aug 15, 2015 > < May 8, 2016 >

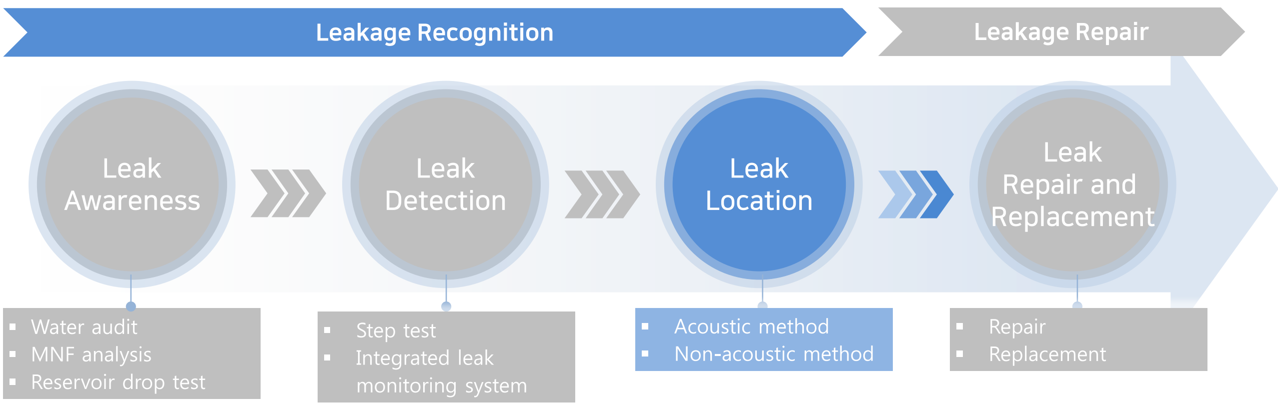
[System Monitoring and Repair Result]

Courtesy of USOL

7. Leakage Location and Equipment

7.1 Leakage Location

- **Leak location: Once the approximate area of a leak has been determined, leak location methods should be used to determine the exact location (±1 m) to reduce excavation efforts**



[Leakage Location in Leakage Recognition Process]

7.1 Leakage Location

- **Acoustic methods: Spotting the leakage points are performed by an acoustic detection check on valves, hydrants, and ground surface**
  - Several acoustic methods can be performed, such as listening sticks, ground microphones, and leak noise correlation
  - If acoustic methods are unsuccessful, then several non-acoustic methods are available

- **Must be performed after leak detection: Interventions must be preceded by an analysis process to identify vulnerable pipelines in the distribution network to reduce the time-intensive and labor-consumption leak location process**

7.2 Leak Survey Program

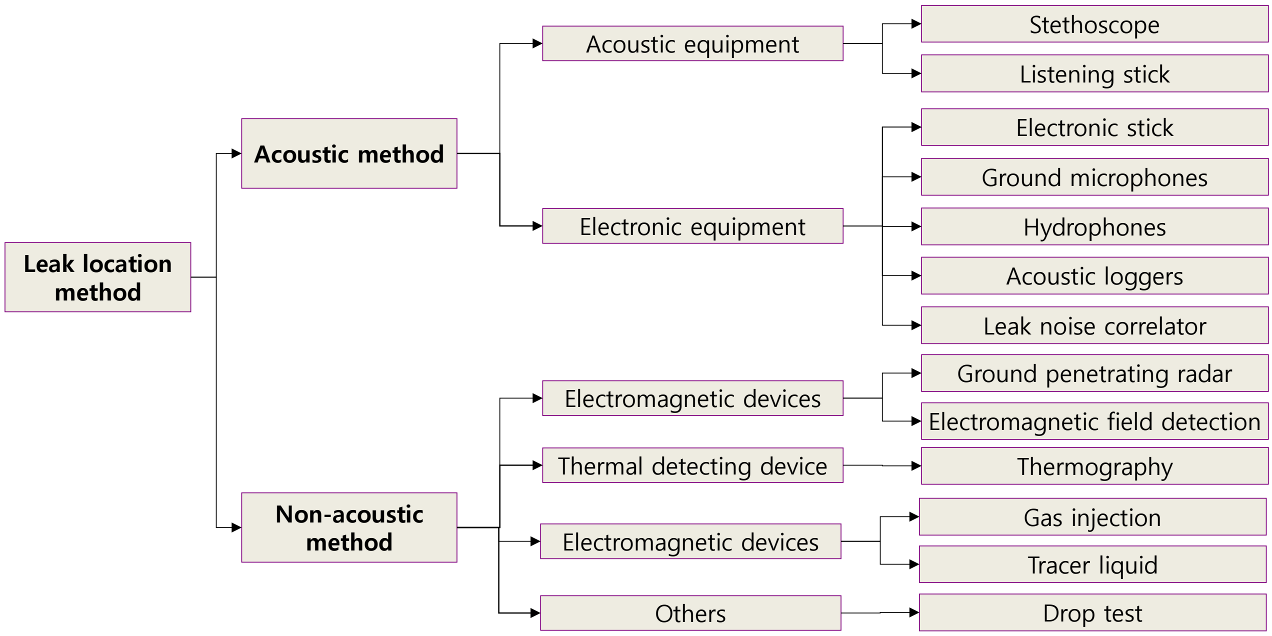
- **Leak survey program: The procedure in creating an in-house leak localizing program is as follows:**

Developing objectives	Determining methods	Assembling a detection team	Providing equipment	Providing training	Scheduling
Developing objectives for leak detection activities by reviewing the results of the water audit	Determining whether a leak detection survey work should be conducted manually using leak noise loggers or a combination of manual and automatic techniques	Assembling the leak detection team by selecting motivated employees	Providing crew members with good-quality leak detection equipment, safety equipment, tools for measuring leak flow rate, and standard water utility working tools	Providing crew members with appropriate training before conducting leak detection work	Scheduling the leak detection survey

[Procedure of Leak Survey Program]

7.3 Equipment Types and Selection

- **Equipment: Several types of leak location equipment with different operating principles can be used**



[Leak Detection Equipment]

7.3 Equipment Types and Selection

- **Selecting the equipment: Given the inherent supply conditions, the utilities should examine the network characteristics and the experience and ability of operators when selecting appropriate equipment**

Pipe material	Small-diameter pipes (75–400 mm)	Large-diameter pipes (from 300 mm)
Metals	- Gas injection - Manual listening stick - Accelerometer - Hydrophone - Leak noise loggers	- Accelerometer - Hydrophones - In-line detection techniques
AC	- Gas injection - Accelerometer - Hydrophone	- In-line detection techniques
PVC	- Gas injection - Hydrophone	- In-line detection techniques
Polyethylene	- Gas injection - Hydrophone	- In-line detection techniques

[Leak Detection Equipment Selection Guideline]

7.3 Equipment Types and Selection

- **Big market: ALC is a multi-billion dollar industry worldwide with many large companies specializing in developing and manufacturing various types of equipment for detecting leaks**

- **Exaggeration of equipment: Various manufacturers claim their equipment is a silver bullet for leak location and will find all leaks within a particular supply system**

- **Expensive equipment not required: The equipment used to identify unreported leaks should not be the most expensive or most sophisticated**
  - In many cases, a well-trained experience leak detector with a basic listening stick will frequently find more leaks than a poorly-trained leek locator with the most expensive equipment

7.4 Acoustic Equipment

- **Acoustic methods are based on the fact that a leak in a pipeline under pressure emits a permanent specific noise and is defined by a particular range of frequencies**
  - This method is the basic one used for leak location, which uses the human ear (with a listening stick or stethoscope) or electronic listening devices, such as ground microphones and leak noise correlators

- **Electronic devices have amplifiers, feature-insulated headphones, filters to screen out selected frequencies, and readout devices to provide a visual measure of noise**
  - Electronic listening sticks come in various levels of sophistication. However, they are basically listening devices with an electronic amplification of the sound generated by leaks

- **Conducting without interruption: One of the main advantages of applying this technique is the possibility of undertaking the pinpointing work without the need for supply suspension**

7.4 Acoustic Equipment

(1) Listening stick or stethoscope

- A stethoscope or listening stick with an earpiece is pressed against fittings to listen for nearby leaks in the pipe
- Affordable equipment: The basic listening stick or pocket stethoscope is an inexpensive tool that is effective and requires no power or maintenance
- Training: The uytility must provide proper training to the staff to maximize equipment use

[Listening Stick]

Courtesy of K-water

7.4 Acoustic Equipment

(2) Microphone: Electronic sticks

- Electronic listening sticks come in various levels of sophistication. However, they are basic listening devices that electronically amplifies the sound generated by the leak

[Use of Electronic Listening Stick]

Source : EPAL (2017)

7.4 Acoustic Equipment

(3) Microphone: Ground microphone or geophone

- **When the acoustic method is applied to listen to the ground surface above the mains, then a geophone or ground microphone is utilized**

[Ground Microphone]

Courtesy of K-water

7.4 Acoustic Equipment

(4) Leak noise logger (acoustic loggers)

- **Principle: Analysis of the readings is conducted by comparing the sound level and sound spread recorded at each logger**
  - The reading indicates the existence of leakage in the vicinity around the installation site, which is considered suspicious and, thus, subject to a detailed inspection using another type of leak detection equipment

[Acoustic Logger #1]

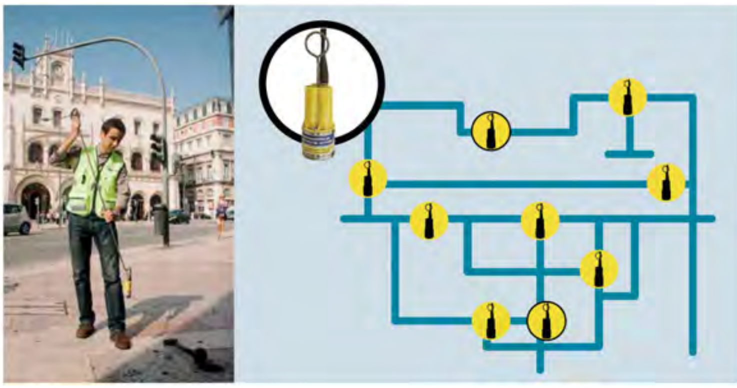
Source : Trent (2005)

[Acoustic Logger #2]

Source: http://www.seoyong.co.kr

7.4 Acoustic Equipment

- **Installation: In planning the installation process, two important aspects should be considered, namely, the material of the distribution network mains and existing pressure service because these two factors largely influence noise propagation**

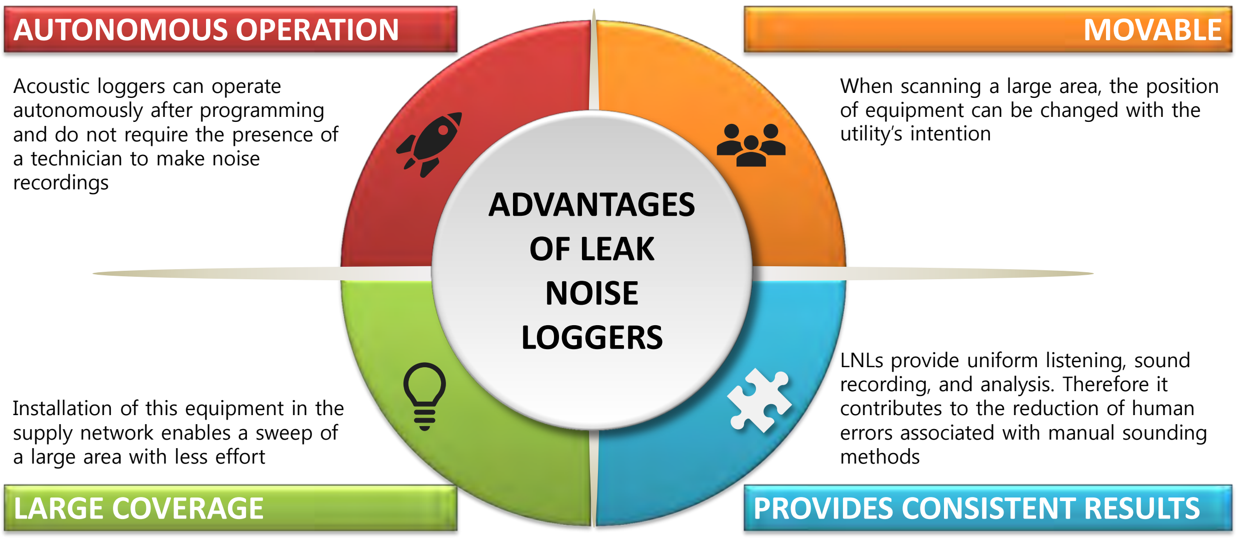


[Installation of Acoustic Noise Loggers]

Source : EPAL (2017)

7.4 Acoustic Equipment

- **Advantages: Leak noise loggers have several advantages as follows**



[Advantages of Leak Noise Logger]

7.4 Acoustic Equipment

(5) Leak noise correlators (LNCs)

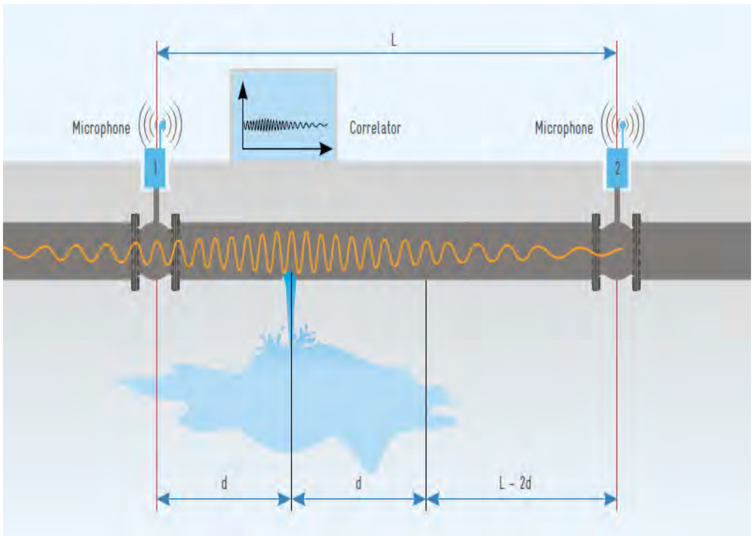
- Principle: LNCs compare noise detected at two points on the pipeline

[Leak Noise Correlator]

Courtesy of K-water

7.4 Acoustic Equipment

- Calculation: Correlation is a mathematical method for calculating the time delay between two signs emitted by the same source



$$d = \frac{L - v \times \Delta t}{2}$$

Where:

d	[m]	Distance from the leak to microphone 1
L	[m]	Length of pipe section
Δt	[s]	Time delay
v	[m/s]	Acoustic wave propagation velocity

[Schematics of the Functionality of Leak Noise Correlators]

Source : GIZ (2011)

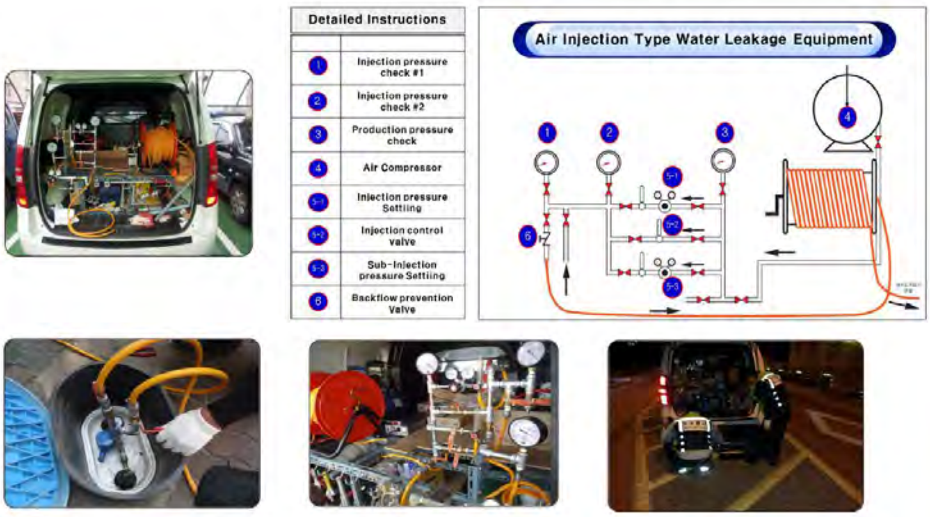
7.5 Non-acoustic Equipment

- A good alternative to acoustic methods: Non-acoustic methods may be a viable alternative to acoustic methods in networks with very low pressure or intermittent supply or for locating hard-to-find background leakage
- Requires training: Non-acoustic leak location methods usually require specially skilled personnel and involve great efforts
- Last resort: Non-acoustic method is very effective. However, it is expensive. Thus, this method should be applied only as a last resort

7.5 Non-acoustic Equipment

(1) Gas injection

- Principle: A tracer gas is injected and subsequently detected on the surface above the alignment of the mains



[Air Injection Method]

Source: http://www.seoyong.co.kr

7.5 Non-acoustic Equipment

- Process: The process starts with a supply suspension of the test section as well as all service connections prior to injecting the tracer gas through a hydrant or a similar accessory with sufficient pressure. In this manner, the gas is released through the leak hole in the mains

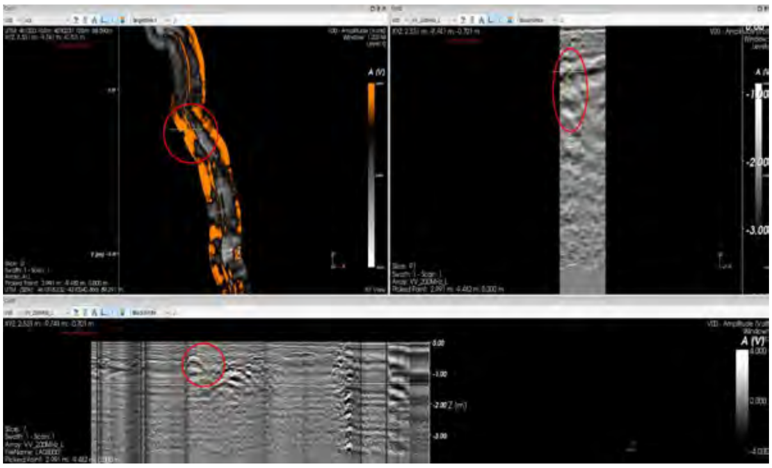
- Pros and cons: This method is very effective but costly because it involves consumables, such as the tracer gas

- Gas: Hydrogen is the most common gas employed, but helium can also be used

7.5 Non-acoustic Equipment

(2) Ground Penetrating Radar

- Principle: The ground penetrating radar operates on the principle of emitting a radar pulse through an antenna into the ground



[GPR Results]

Courtesy of K-water

7.5 Non-acoustic Equipment

[Pipe Detector]

[Manhole Detector]

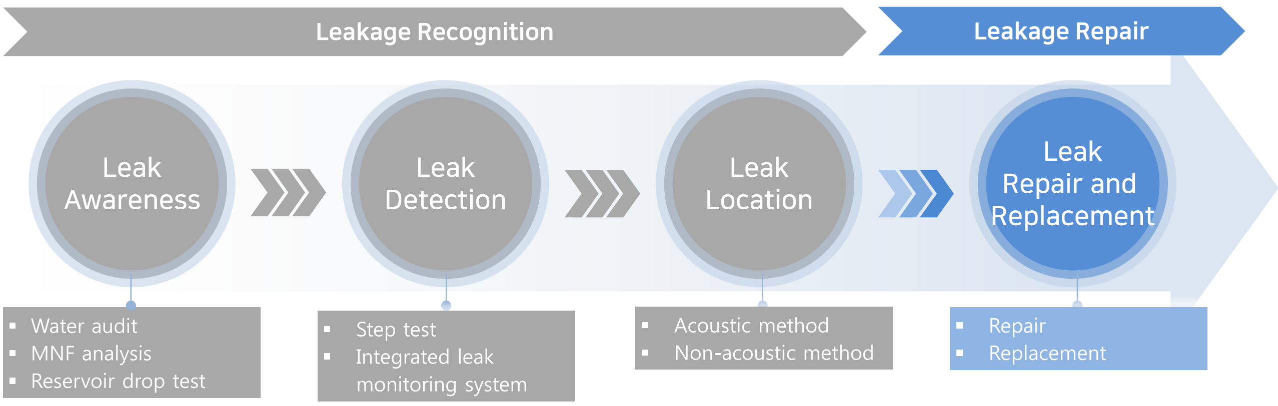
Courtesy of K-water

8. Leakage Repair and Replacement

8.1 Leakage Repair and Replacement
8.2 Repair Procedure
8.3 Repair and Replacement Methods

8.1 Leakage Repair and Replacement

- **Repair and Replacement: The major center of focus of an effective water loss management program is repair, rehabilitation, or complete replacement of water pipeline assets**



[Leakage Repair and Replacement]

8.1 Leakage Repair and Replacement

- **Repair quality: The quality of leak repairs plays a significant role in the overall leakage management process**
  - Poor materials, need for improvisation, and bad workmanship can lead to the probability that that new leaks will occur in the same place
  - Therefore, leak repairs should be executed by well-trained and skilled laborers
  - Despite the cost of repairing a leak, fixing it for the second time can be more than double the investment in labor and materials and leads to customer dissatisfaction

- **Most expensive step in repair: Many studies demonstrated that the most significant portion of leak repair cost and time is attributed to uncovering the leak sites and dewatering**

8.1 Leakage Repair and Replacement

- Good personnel (well-motivated and equipped): A leak repair personnel should be well motivated and equipped with the necessary equipment, vehicles, communication devices, and safety gear
- Good personnel (well-trained): Repair crews should be trained on a variety of fix approaches, such as a repair clamp, in-situ welding, or replacement of one or more sections of a pipe
- Good personnel (sufficient crews): The number of repair crews should be appropriate for the number of leaks and bursts to be repaired in specified target times

[Training: Competition for Leakage Detection]

Courtesy of K-water

[Training: Competition for Leakage Repair]

Source: Water Korea (2007)

8.1 Leakage Repair and Replacement

- Stock management: The warehousing department should ensure that frequently used parts are in stock because long delivery times for required spare parts are not tolerable

[Warehouse #1]

[Warehouse #2]

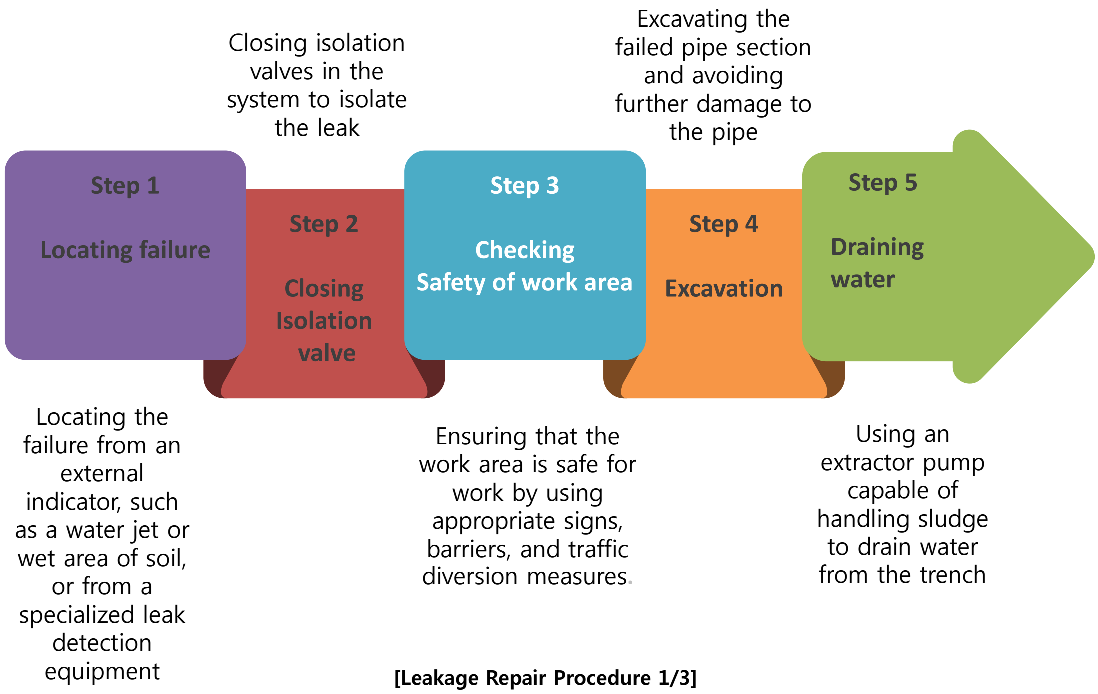
Courtesy of K-water

8.1 Leakage Repair and Replacement

- **Analysis of failure DB: Analyzing the failure database and failure rates may identify damage-prone types of pipes and valves**
  - Analysis of the leak repair history of the utility can greatly facilitate the selection of appropriate materials and quantities to stock
- **Networking: Many small-sized water utilities found that reaching out to neighboring water utilities that may have similar repair parts and equipment is advantageous for emergency cases**
- **Policy (effectiveness): The water utility's policy exert a strong influence on the speed and quality of repairs**
- **Policy (increasing performance): Repair times can be reduced by setting performance targets for how fast a main break, a service connection leak, or a detective valve can be repaired (e.g., all leaks found should be repaired within 24 h)**

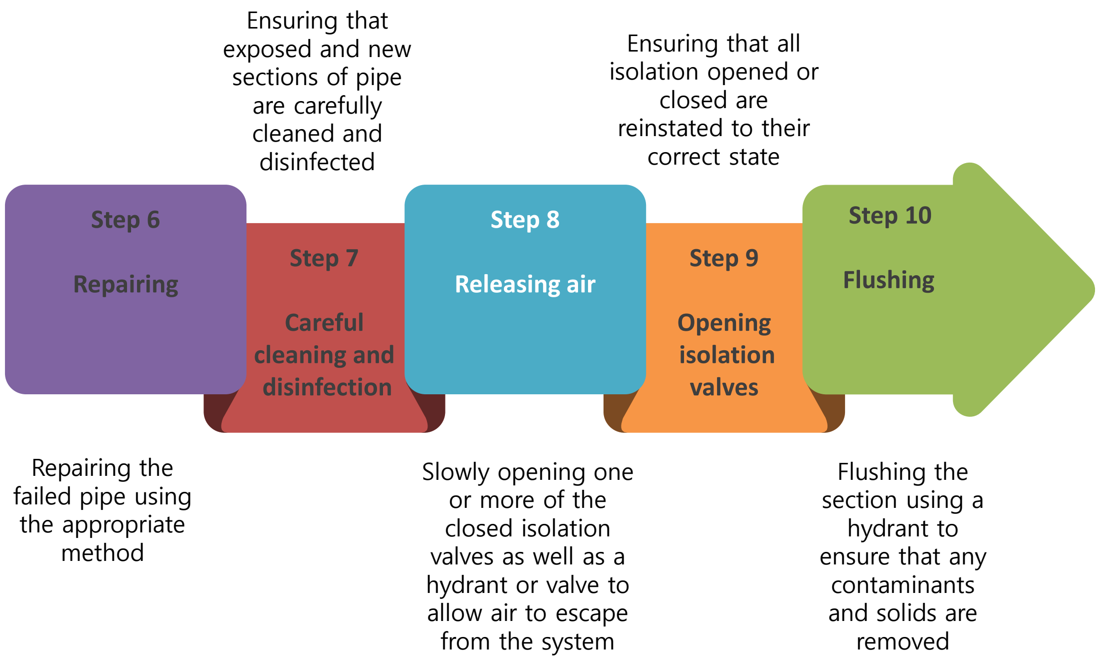
8.2 Repair Procedure

- **Repair procedure: The following steps are used to repair a leaking pipe**



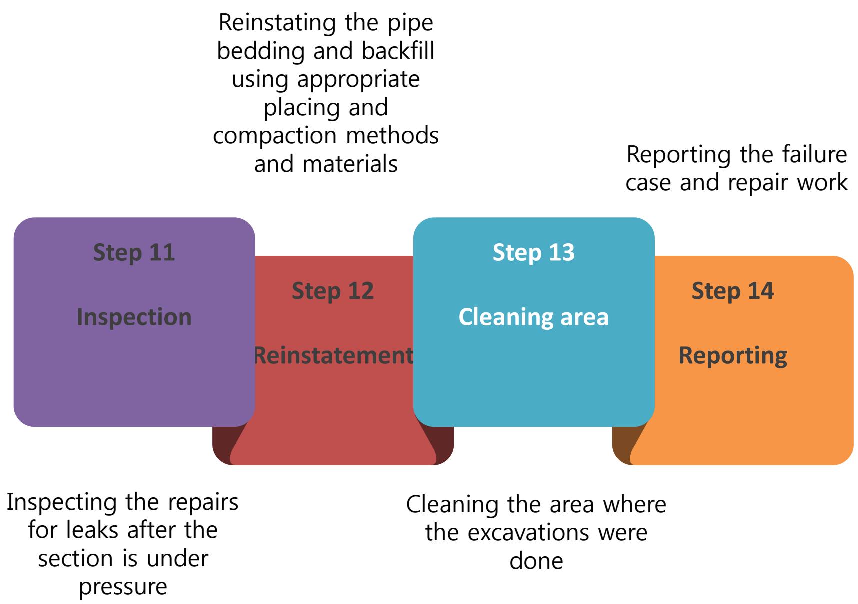
[Leakage Repair Procedure 1/3]

8.2 Repair Procedure



[Leakage Repair Procedure 2/3]

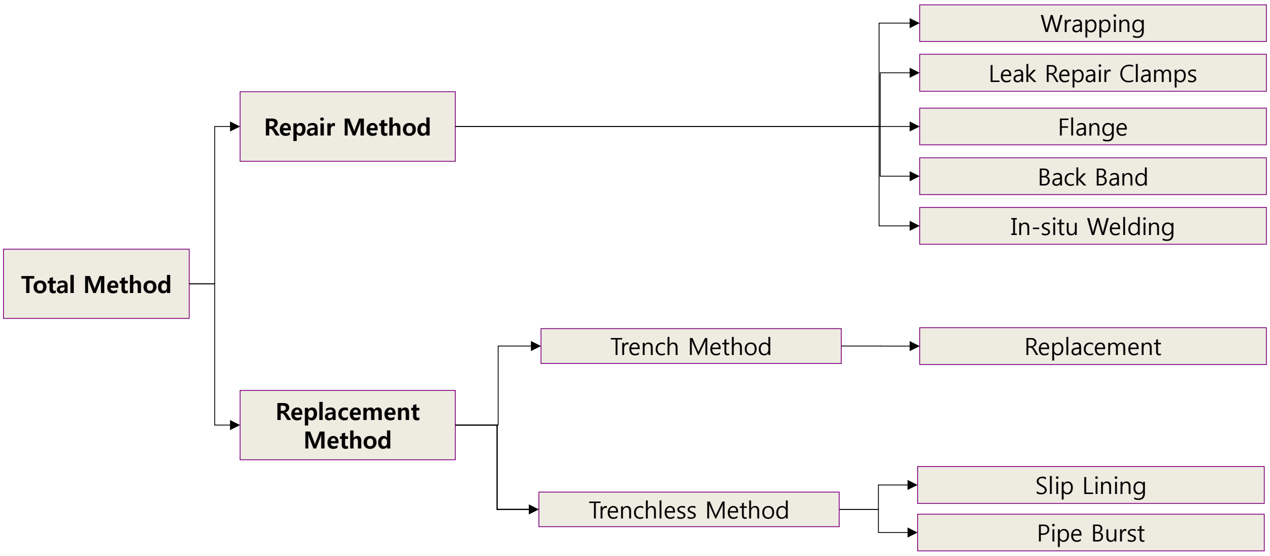
8.2 Repair Procedure



[Leakage Repair Procedure 3/3]

8.3 Repair and Replacement Methods

- Repair and replacement methods: In general, optimal repair and replacement methods vary depending on the type of leakage



[Leak Repair and Replacement Methods]

8.3 Repair & Replacement Methods

(1) Repair: Wrapping

- Wrapping: Small pipe leak repairs may be made using a surface wrap depending on the pipe material

[Wrapping]

Source : EPA (2010)

8.3 Repair & Replacement Methods

(2) Repair: Leak repair clamps (flexible clamps), flange, backing band, among others

- **Leak repair clamp: If the leak site is the result of small corrosion pitting or puncture holes, then a repair clamp will usually work quickly and well**

[Pipe Repair Using Repair Clamp #1]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Pipe Repair Using Repair Clamp #2]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Pipe Repair Using a Mechanical Joint (확인필요)]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Pipe Failure and Repair by External Force During Road Construction #1]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Leakage Repair Using Backing Band]

Courtesy of K-water

8.3 Repair and Replacement Methods

(3) Repair: In-situ welding

- For large steel pipes, repair may be in the form of in-situ welding

[Pipe Failure and Repair by External Force]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Pipe Failure and Repair by External Force During Road Construction #2]

Courtesy of K-water

8.3 Repair and Replacement Methods

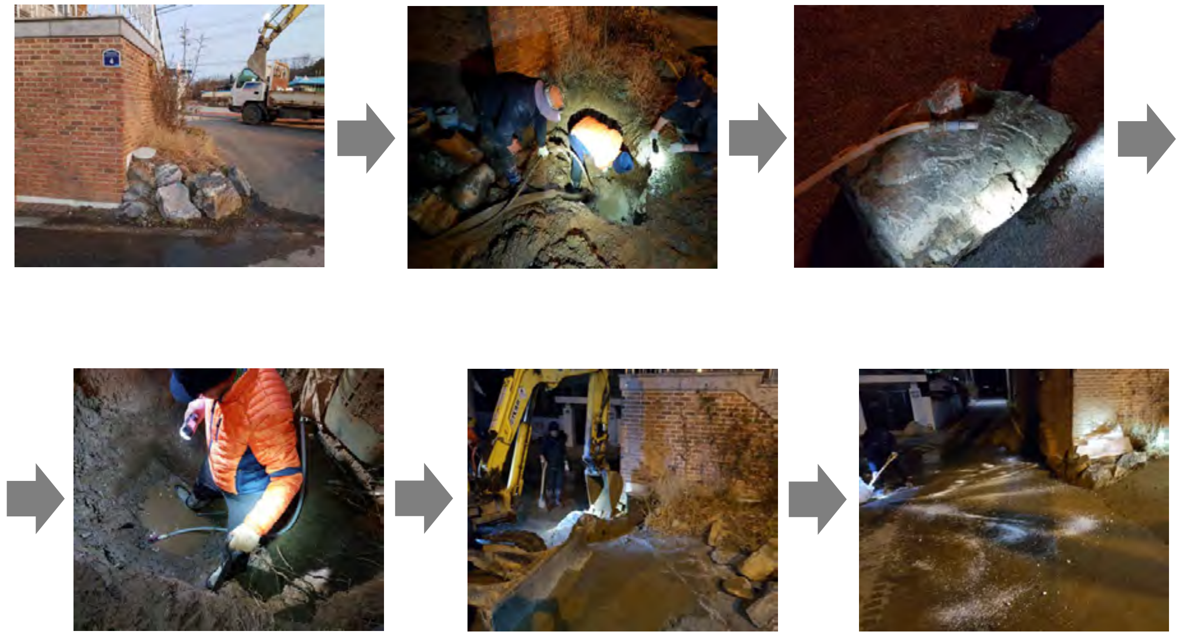
(4) Replacement: Open trench replacement

- Repair crews typically use this method to discover if a section of a leaking pipe is extremely deteriorated for repair with the application of a simple repair clamp

[Open Trench Method]

Courtesy of K-water

8.3 Repair and Replacement Methods



[Open Trench Replacement - Fittings, XLPE D16 ㎜]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Open Trench Replacement - Fittings, PE D100 ㎜]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Open Trench Replacement - Fittings, PE D16 ㎜]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Open Trench Replacement - Fittings, PE D100 ㎜]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Open Trench Replacement - Fittings, SP D300 ㎜]

Courtesy of K-water

8.3 Repair and Replacement Methods

[Open Trench Replacement - Saddle, DCIP D150 ㎜ × XLPE D16 ㎜]

Courtesy of K-water

8.3 Repair and Replacement Methods






[Open Trench Replacement - DCIP D500 ㎜]

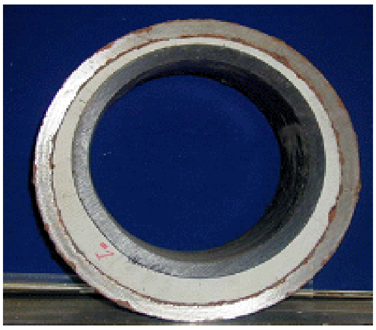
Courtesy of K-water

8.3 Repair and Replacement Methods

(5) Replacement: Slip lining as a trenchless replacement

- Slip lining is an effective approach for rehabilitating a deteriorating water main without uncovering it





[Slip Lining]

Courtesy of K-water

8.3 Repair and Replacement Methods

(6) Replacement: Pipe bursting as a trenchless replacement

- Pipe bursting is an alternative approach to destroying the existing pipe as a new one is being dragged through it

[Pipe Bursting]

Source : EPA (2010)

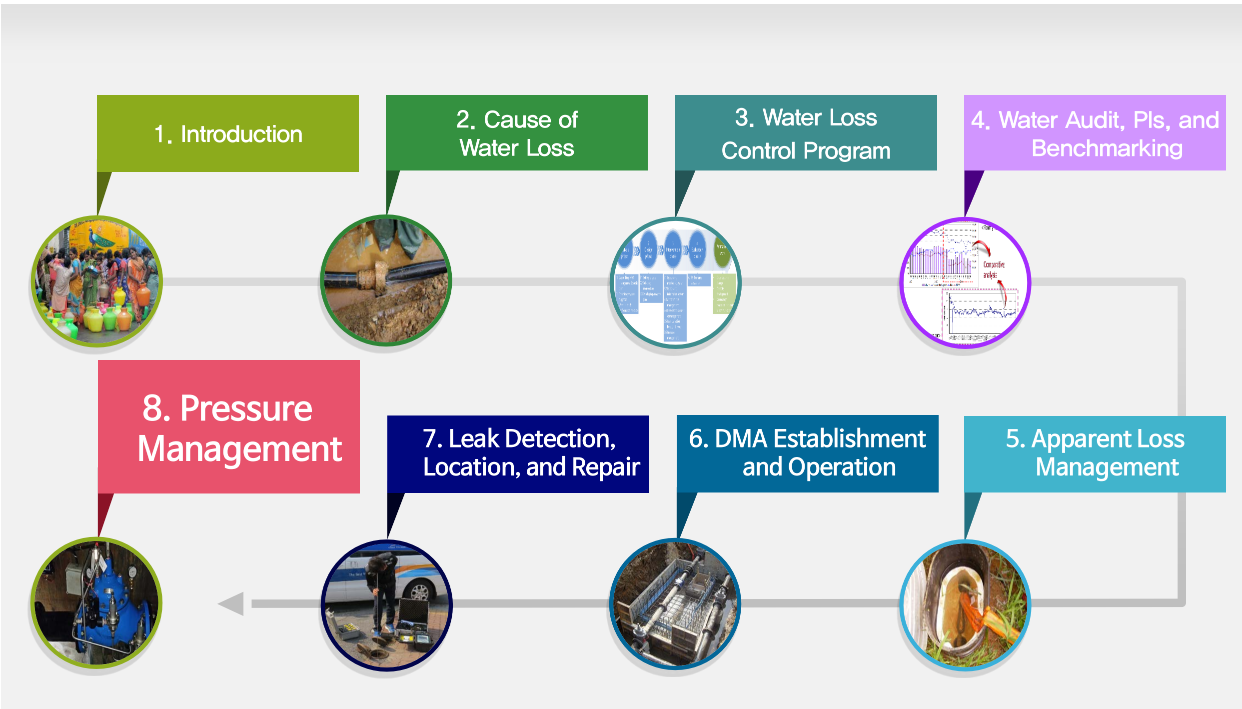
Thank you very much

Pressure Management

Water Loss Management

8. Pressure management

Training Course



Aims & Objectives

- The course aims to:

  (1) Provide trainees with detailed procedures for pressure management;
  (2) Enable trainees to design and implement press management in the water network system

- The objectives are that trainees will understand:

  (1) The relationship between pressure and leakage;
  (2) The pros and cons of pressure management;
  (3) The methods of pressure management

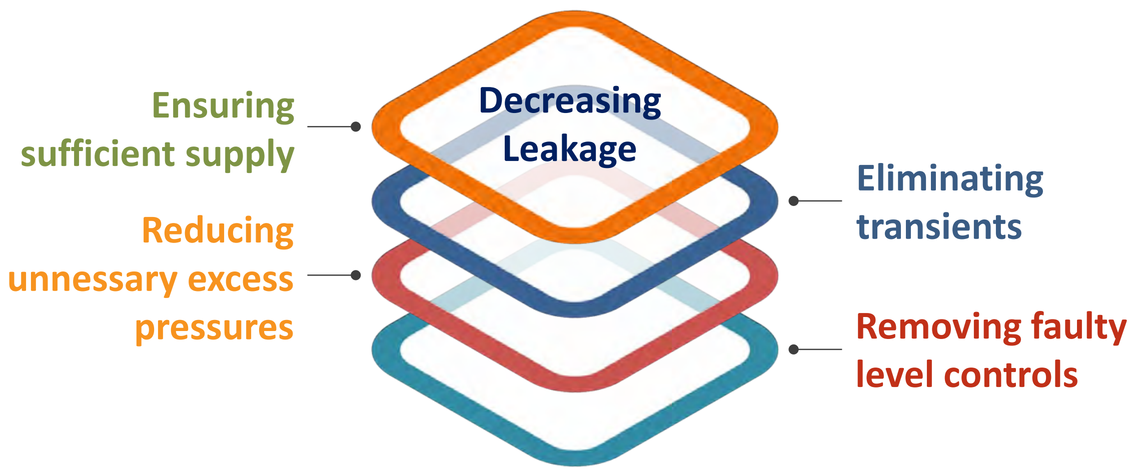
Contents

1. Overview

1.1 Background
1.2 Benefits
1.3 Limitation

1.1 Backgrounds

- Definition: Pressure management aims to maintain the optimum levels of service to ensure a sufficient and efficient supply to consumers and, at the same time, reduce unnecessary excess pressures and eliminate transients and faulty level controls, all of which lead to unnecessary leaks in the distribution system

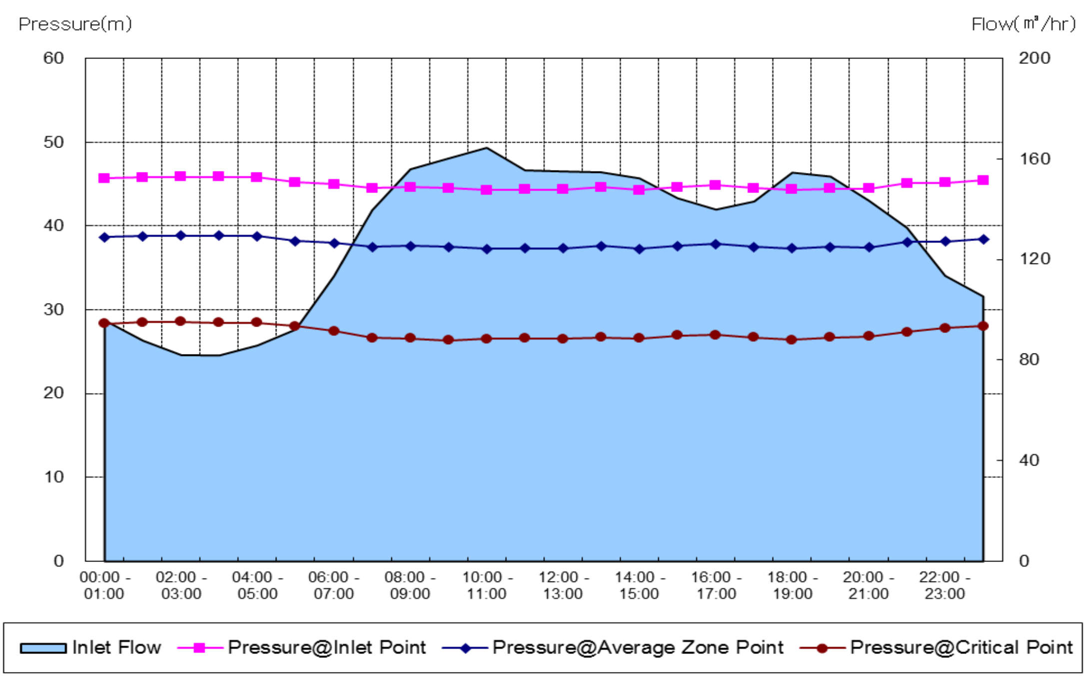


[Concept of Pressure Management]

1.1 Backgrounds

- **Minimum pressure: The outlet pressure should be sufficient to provide adequate pressure to customers at the most vulnerable prat of the pressure management zone (PMZ)**
  - The water utility, water authorities, or local legislation typically define the minimum supply pressure
- **Critical point: Notably, the location of the critical point (CP) within a PMZ can be altered depending on variations in consumption behaviors or due to changes in the system structure**
  - This point is referred to as the high ground or it could be at the end of a long, small diameter pipeline
- **Average zone point (AZP): The AZP is the point in a PMZ that is representative of the average pressure experienced by properties**

1.1 Backgrounds



[Inlet Flow and Pressure at Inlet Point, AZP, and CP]

Courtesy of K-water

1.1 Background

- **Causes of high pressure: In the same PMZ, a high-pressure area occurs due to the following reasons:**

Topography and/or distance from supply point

Areas with relatively high pressure will occur due to topography and/or distance from the supply point to ensure sufficient pressure at one critical point

This situation leads to the operation of many parts of a PMZ at pressures significantly higher than required

Different demand patterns

The systems are designed to accommodate pressure and flow requirements during periods with peak demand, which occurs at specific times of the day and during particular months in a year

This tendency results in the operation of a PMZ at pressures significantly higher than required of other periods

[Main Causes of High Pressure]

1.1 Background

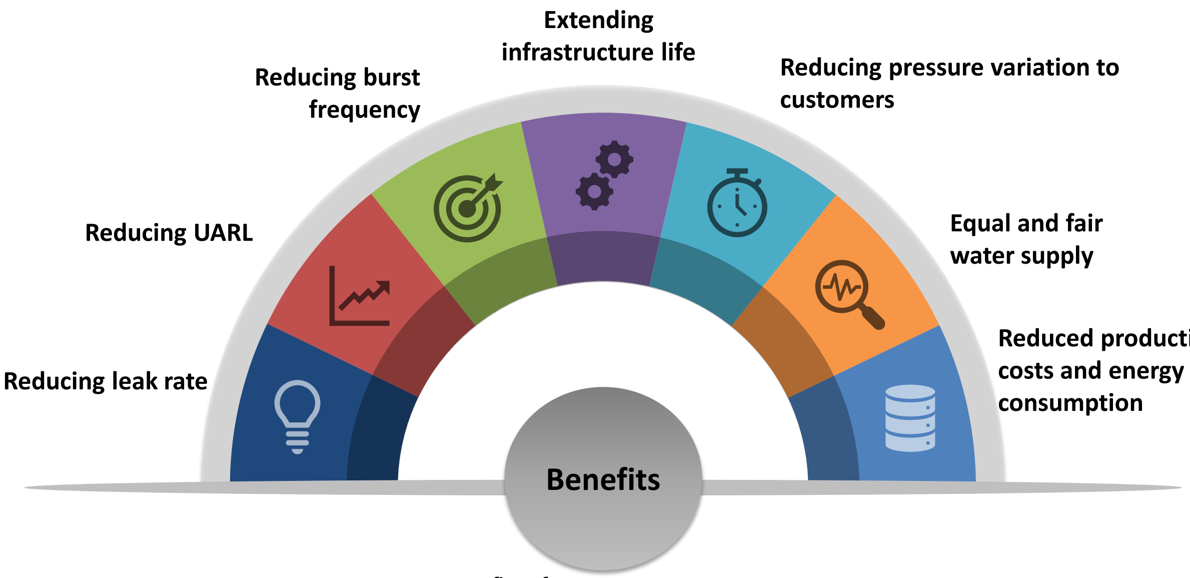
- **Starting point for managing real loss: Pressure management may be a good starting point for water utilities with high levels of leakage due to the relatively high savings and short payback periods**

- **Difficulty of implementing in developing countries: Implement pressure management in developing countries is difficult because the network and operation conditions are inadequate, and local water utilities lack a sufficient understanding of pressure management**
  - Before implementing effective pressure management, establishing DMA is required
  - Specialized external advice will be required when a water utility engages in pressure management

- **Operating with guess: In developing countries, press management is based on *guesstimates* provided by experienced plumbers**
  - No pressure records are collected. Furthermore, no pressure data loggers are available

1.2 Benefits

- **(Benefits) Numerous studies have indicated that reducing pressure in distribution mains leads to the following benefits:**
  - Pressure management is the only intervention method for reducing unavoidable annual real loss (URAL)



[Benefits of Pressure Management]

1.3 Limitation

- **It cannot be implemented in all sites: Notably, pressure management is not the answer to every case, although it is often one of the most cost-effective measures for leakage reduction**

- **It only alleviates: Water utilities should note that pressure management only alleviates the impacts but not cure the causes of real loss**

- **Caution is required: Even if pressure is only reduced to a level that still meets the requirements of domestic and commercial users, many appliances might be affected, such as instantaneous hot water systems, fire sprinkler stems, or home dialysis systems**

2. Pressure–Leakage Relationship

2.1 Pressure versus Leakage
2.2 Orifice Equation
2.3 Fixed and Variable Area Discharge (FAVAD)

2.1 Pressure versus Leakage

- Relationship: Pressure–leakage relationships are a complex issue. However, a utility can assume a roughly linear relationship between the two
- Multiple relationships: Intensive research and trials have provided firm evidence that multiple relationships occur between leakage and pressure

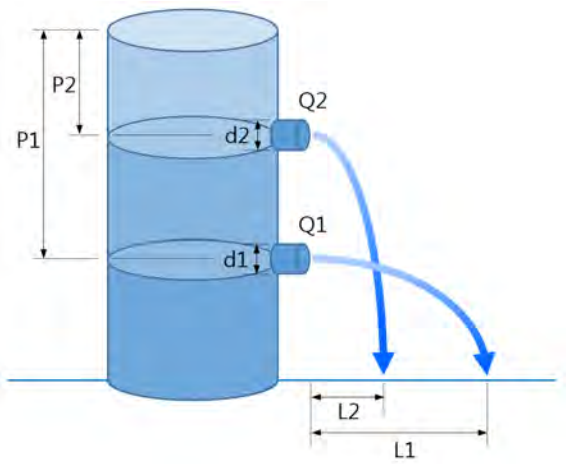
Low Pressure High Pressure

[Relationship Between Average Zone Pressure and Leakage Index]

Source: IWA (2014)

2.2 Orifice Equation

- **The orifice equation describes the rate of flow of liquid through an orifice**
  - It pertains to the basic relationship between pressure (head) and flow rate



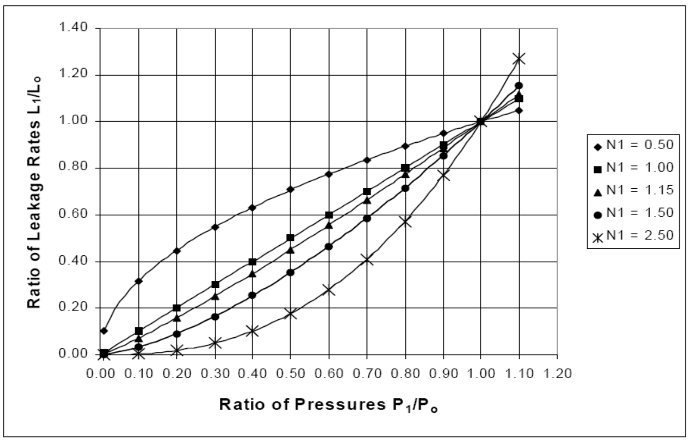
$$Q = C_d A \sqrt{2gh}$$

Q : Flow [m^3/s]
C_d : Coefficient of discharge
A : Area of orifice [m^2]
g : Acceleration from gravity [$9.81 m/s^2$]
h : Head acting on the centerline [m]

[Orifice Equation]

2.3 Fixed and Variable Area Discharge (FAVAD)

- **FAVAD: Many theories have been postulated to explain pressure–leakage relationships within municipal water supply systems with the FAVAD as the most widely accepted approach**
  - It postulates that leakage on the network will occur through a mixture of homes, many of which will have paths that do not vary with pressure, whereas other homes will have paths that vary with pressure



$$\frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N1}$$

L_0 : Initial leak flow rate at pressure P_0
L_1 : Leak flow rate at adjusted pressure P_1
P_0 : Initial average zone pressure
P_1 : Adjusted average zone pressure
N1 : Leakage exponent

[Interaction Between Pressure and Leakage for Different Values of N1]

Source : Lambert et al. (2001) "What Do We Know About Pressure Leakage Relationships in Water Distribution Systems?"

2.3 Fixed and Variable Area Discharge (FAVAD)

- **Leakage exponent N1: It is used to calculate the relationship between pressure and leakage**
  - Pressure management in developing countries is more important because they use more plastic pipes, which is more sensitive to pressure

Fixed area discharge

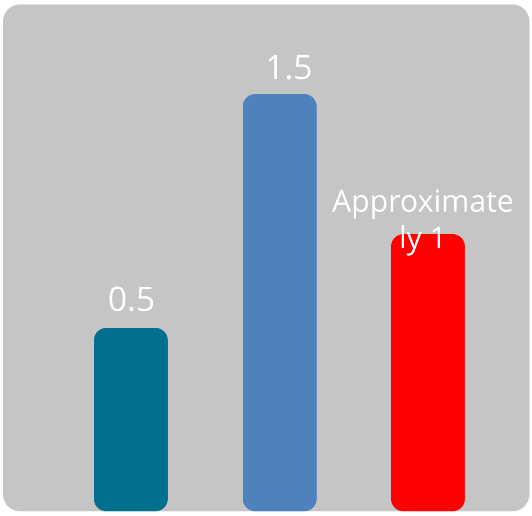
In the case of leaks from steel/iron pipes, the size of the leakage path (i.e., hole) remains constant during the change in pressure

Variable area discharge

In the case of leaks from plastic pipes or cracks in asbestos cement pipes, the surface area of the leakage path changes when pressure changes

Mixed discharge

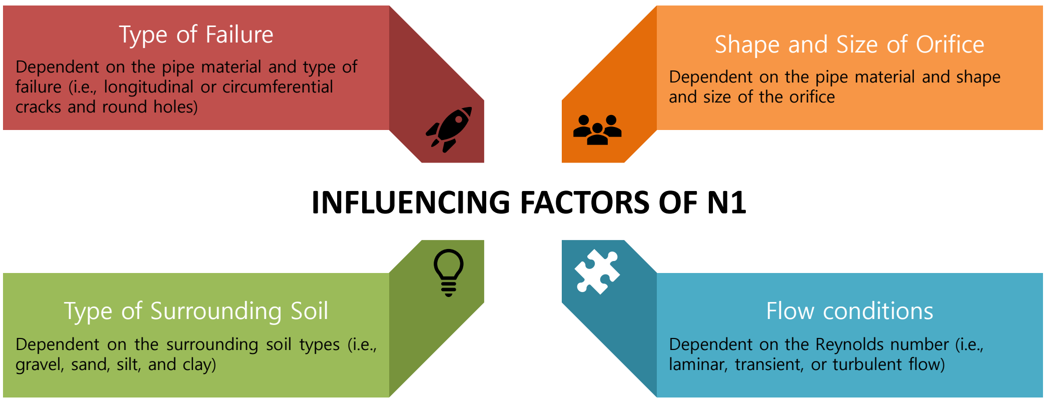
The split will depend on the proportion of steel/iron pipes to plastic/asbestos pipes.
The relationship is complex. However, utility managers should initially assume a linear relationship (i.e., N1 = 1)



[Value of Leakage Exponent N1]

2.3 Fixed and Variable Area Discharge (FAVAD)

- **Influencing factors of N1: Several factors have a significant impact on the range of leakage exponent**
  - The pipe material exerts a major influence on the pressure–leakage relationship



[Influencing Factors of N1]

3. Pressure Management Methods

3.1 Methods
3.2 Establishing the Pressure Management Zone
3.3 Pressure-reducing Valve (PRV)

3.1 Methods

- Methods: To manage pressure in PMZ, several methods can be implemented

01 CREATING A PRESSURE MANAGEMENT ZONE

Creating a pressure management zone is more important than any pressure controller

02 REDUCING PUMP HEAD

This method is applicable if the reduced level of pumping can maintain the required minimum pressure

03 VARIABLE SPEED PUMP CONTROL

In networks with direct pump infeed, variable speed pumps with intelligent control systems can be used to reduce excessive pressures during off-peak periods of the day

04 BREAK PRESSURE TANKS

Traditionally, water utilities will construct break pressure tanks and effective small service reservoirs to reduce pressure

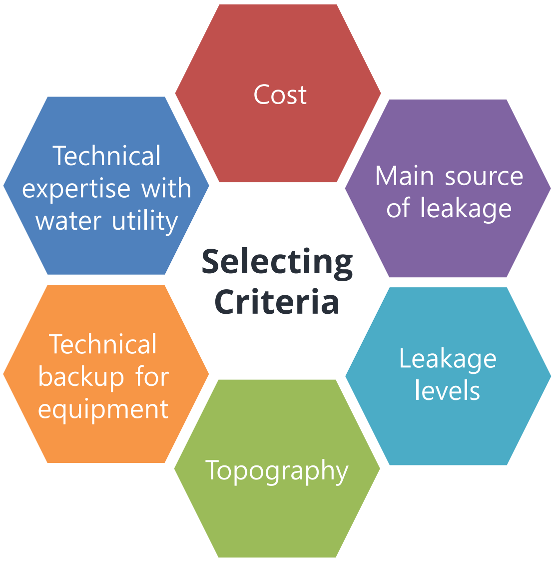
05 PRESSURE-REDUCING VALVE

The modern equivalent of break pressure tank is the pressure-reducing valve (PRV)

[Pressure Management Methods]

3.1 Methods

- **Selecting methods: Selecting the most appropriate form of pressure control will be based on many factors, such as cost, technical expertise with the water utility, technical backup for the equipment, topography, leakage levels, and the main source of leakage**



[Criteria for Selecting Pressure Management Methods]

3.2 Establishing the Pressure Management Zone

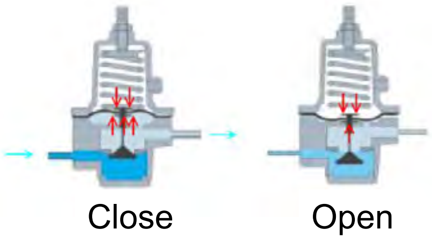
- **This is the most difficult task in the pressure management process: Installing and operating controllers are easy parts of this intervention, whereas establishing an appropriate pressure management zone is the most difficult and time-consuming part of the work**

- **Selecting the PMZ: Selecting districts for pressure reduction should be combined with the audit of existing districts and setting up of new ones**

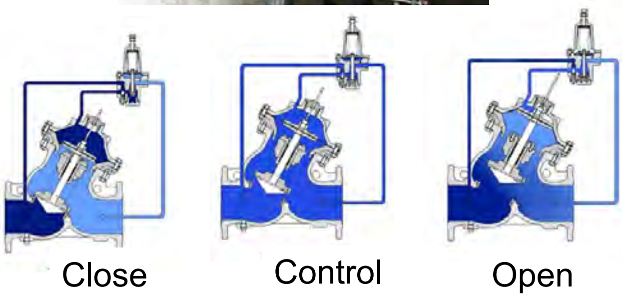
- **PMZ and DMA: Typically, DMAs and PMZs are identical**
  - However, if the difference of elevation or change in demand patterns in a DMA is large, then the DMA can be divided into several small PMZs

3.3 Pressure-reducing Valve (PRV)

- **A variety of PRVs are available, and suppliers should provide training in setting up and maintaining each PRV**



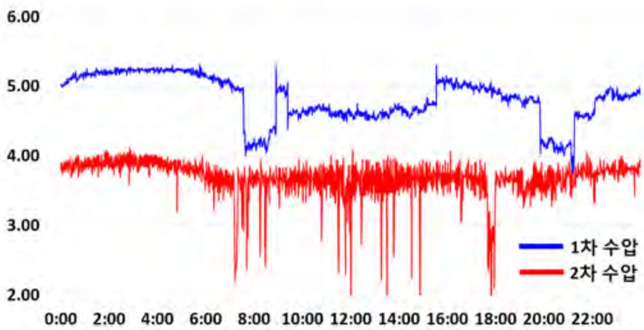
[Direct Acting Type]

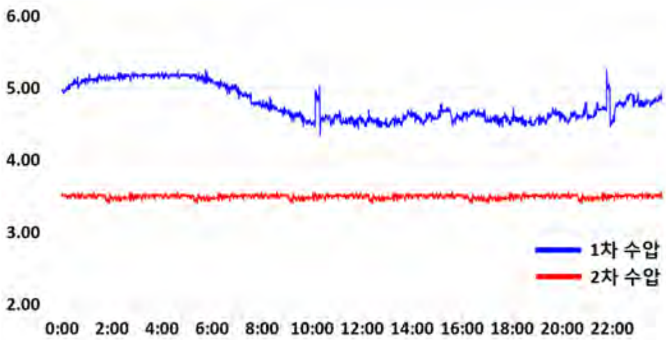


[Pilot Type]

Source : http://www.samjinvalve.com/

3.3 Pressure-reducing Valve (PRV)



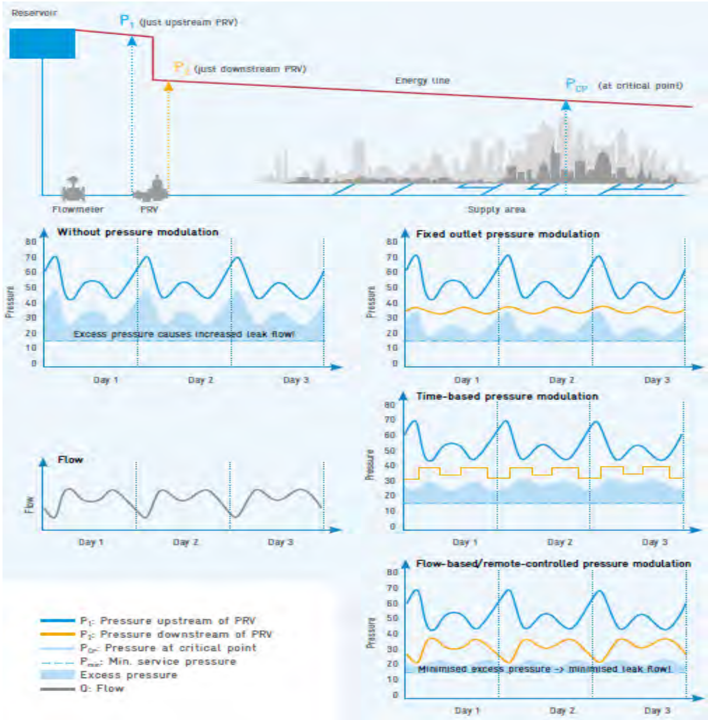


[Before and After PRV Implementation in PMZ]

Courtesy of K-water

3.3 Pressure-reducing Valve (PRV)

- **PRV Control Types: Three basic methods of operating the PRV and modulating system pressure are available:**
  - Fixed-outlet pressure control
  - Time-modulated pressure control
  - Flow-modulated pressure control



[Effects of different modulation concepts on excess pressure at the critical point]

Source: GIZ (2011)

3.3 Pressure-reducing Valve (PRV)

- **Fixed-outlet pressure control: The PRV's outlet pressure is maintained at the selected level at all times. It is the most basic pressure control system**

Advantage

- It is relatively simple to install because it requires only a PRV
- The cost is relatively low because it involves no electronic equipment
- Maintenance and operation is relatively simple

Disadvantage

- The system does not have the flexibility to adjust water pressure at different times of the day. As a result, the maximum possible savings cannot be achieved

[Pros and Cons of Fixed-outlet Pressure Control]

3.3 Pressure-reducing Valve (PRV)

- **Time-modulated pressure control: This method is conducted using a PRV similar to that of the fixed-outlet control. However, it varies the pressure setting over a 24-hour period**

Advantage

- The controller provides increased flexibility by allowing pressure to be reduced at specific times of the day, which results in greater savings
- The controller is relatively easy to set up and operate
- The installation does not require a flow meter because the controller connects directly to the pilot on the PRV

Disadvantage

- It does not react to the demand for water, which can be a problem if a fire breaks out and requires full pressure for fire-fighting
- The time-modulated option is more expensive than the fixed-outlet option

[Pros and Cons of Time-modulated Pressure Control]

3.3 Pressure-reducing Valve (PRV)

- **Flow-modulated pressure control: Different outlet pressures can be set for different flow rates to maintain the minimum required pressure in the zone during peak flow. The PRV can be opened when the threshold flow is exceeded (e.g., fire flow)**

Advantage

- It provides greater control and flexibility than the time-modulated option
- It will provide greater savings than the two other options
- One key advantage is that the flow-modulated option will not hamper the water supply in the case of fire

Disadvantage

- The electronic controller is more expensive
- It requires a properly-sized meter in addition to the PRV

[Pros and Cons of Flow-modulated Pressure Control]

3.3 Pressure-reducing Valve (PRV)

- **Control type selection: To select the optimal pressure control method, a comprehensive review of the following factors should be considered before decision making.**

Factors	Conditions		
	Fixed outlet	Time-based	Flow-based
① Is there a large change in the flow?	Small	Big	Big
② Does the change in pressure at the CP occur due to change in flow rate?	No	Yes	Yes
③ Between the pressure and flow at the inlet point, which has more effect on the pressure pattern at the CP ?	Inlet pressure	Flow pattern	Flow pattern
④ Does the flow rate change regularly?	Regular/Irregular	Regular	Irregular
⑤ Is the CP located upstream or downstream of the DMA?	Mid or Upstream	Downstream	Downstream
⑥ Are there large customers near the CP?	No	Yes	Yes
⑦ Are there many head loss from the inlet point to the CP?	Small	Big	Big

[Factors for Selecting the Pressure-reducing Valve Control Method]

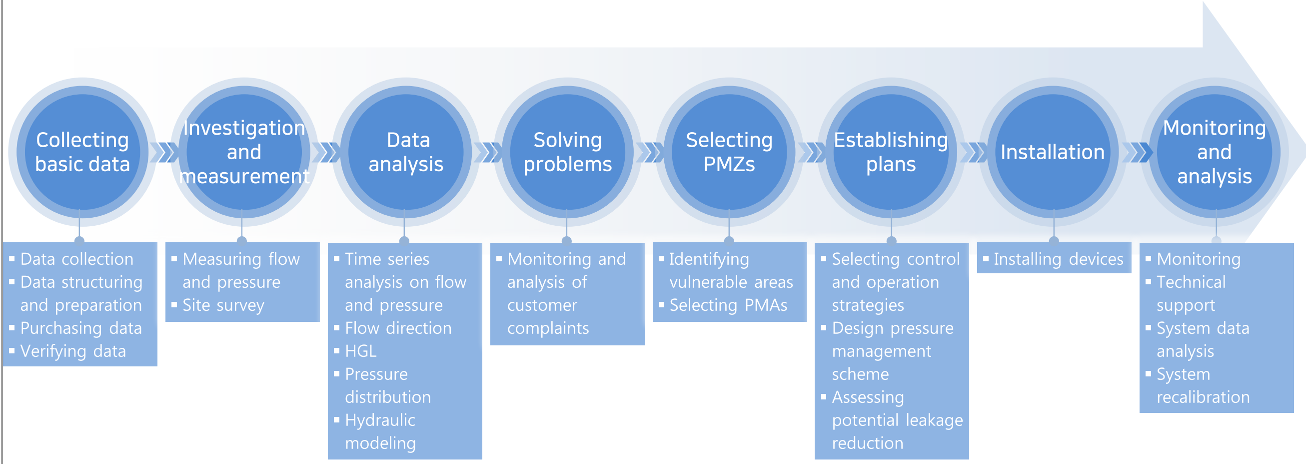
Courtesy of K-water

4. Pressure Management Process

4.1 Process
4.2 Collecting Basic Data
4.3 Network Investigation and Measurement
4.4 Flow and Pressure Analyses
4.5 Solving Pressure Problems and Complaint
4.6 Selecting Pressure Management Areas
4.7 Establishing Pressure Management Plans
4.8 Installing Pressure Management Systems
4.9 Monitoring and Result Analyses

4.1 Process

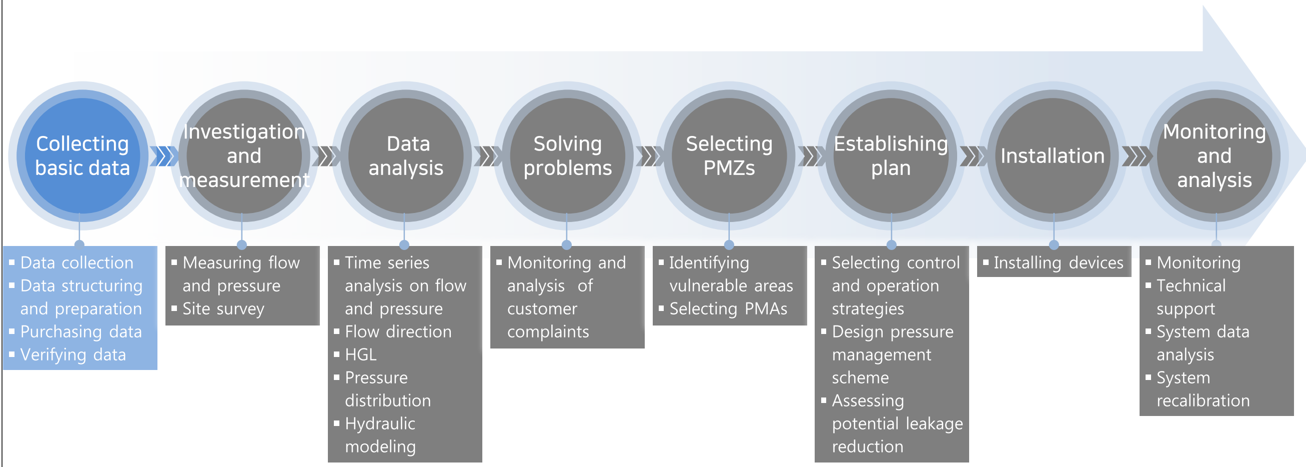
- **Process: A typical pressure management project is typically composed of the following steps**
  - Although several different types of operating pressure management systems exist, the basic steps and installations are always similar



[Pressure Management Process]

4.2 Collecting Basic Data

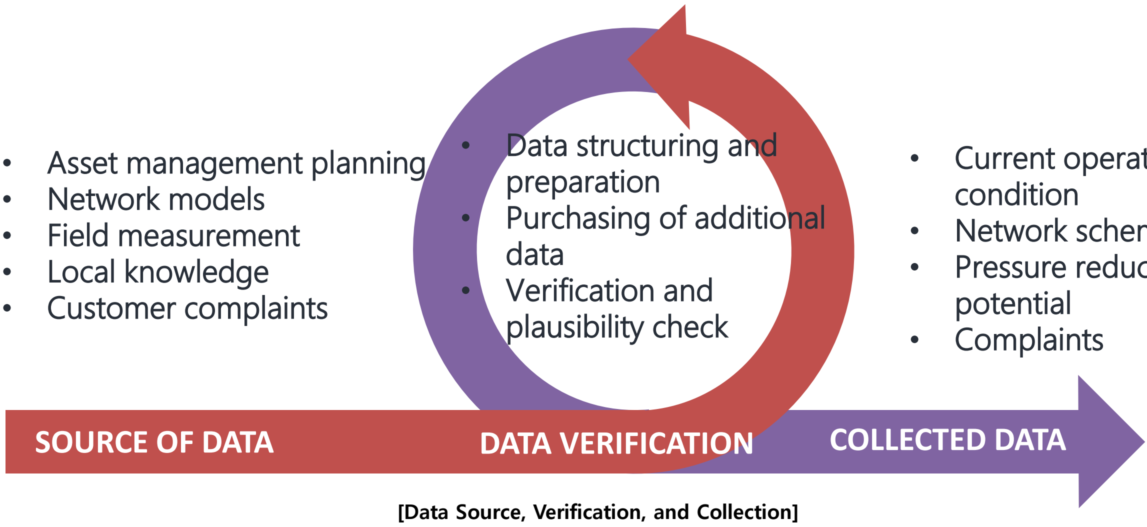
- **Data collection is necessary to determine the most suitable option and further optimize the system**
  - Data management will be beneficial even if the water utility does not adopt a pressure management program because it provides the water utility with better knowledge and understanding of the network



[Collecting Basic Data in Pressure Management Process]

4.2 Collecting Basic Data

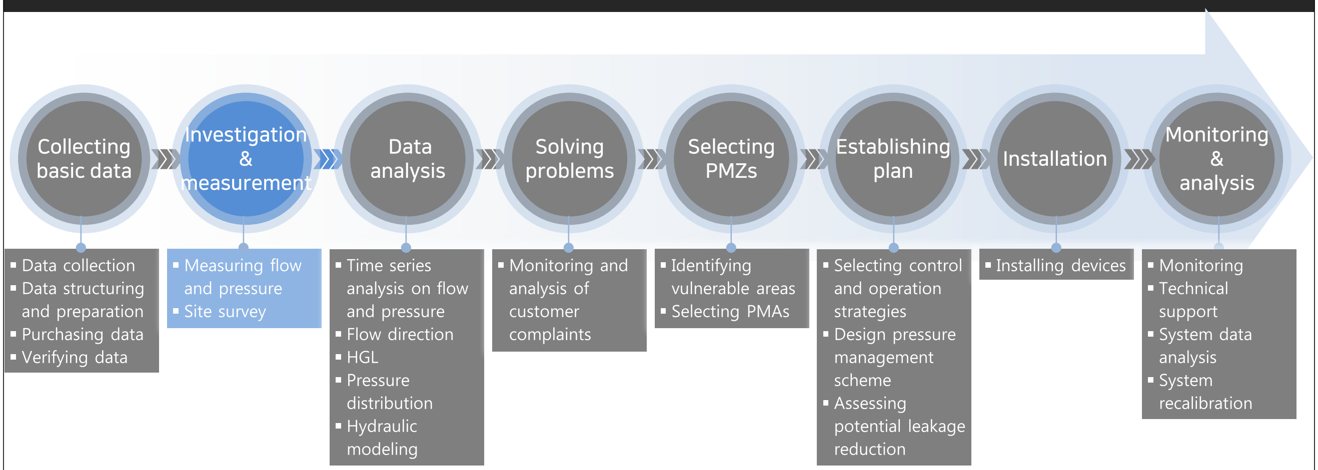
- **Time-consuming: Data collection and preparation can be time-consuming and labor-intensive depending on local conditions**
- **Tasks: Data can be collected from several sources, and collected data should undergo a verification process**



[Data Source, Verification, and Collection]

4.3 Network Investigation & Measurement

- **(Investigation) Network investigation and measurement includes following tasks**
  - Confirmation of DMA isolation
  - Location and operation of reservoir, pumping station, PRV, flow meter, etc.
  - Water demand pattern of large customers
  - Hydraulic status of customers who have civil complain for the water pressure
  - Inlet pressure & flow, and pressure at critical point and average zone point



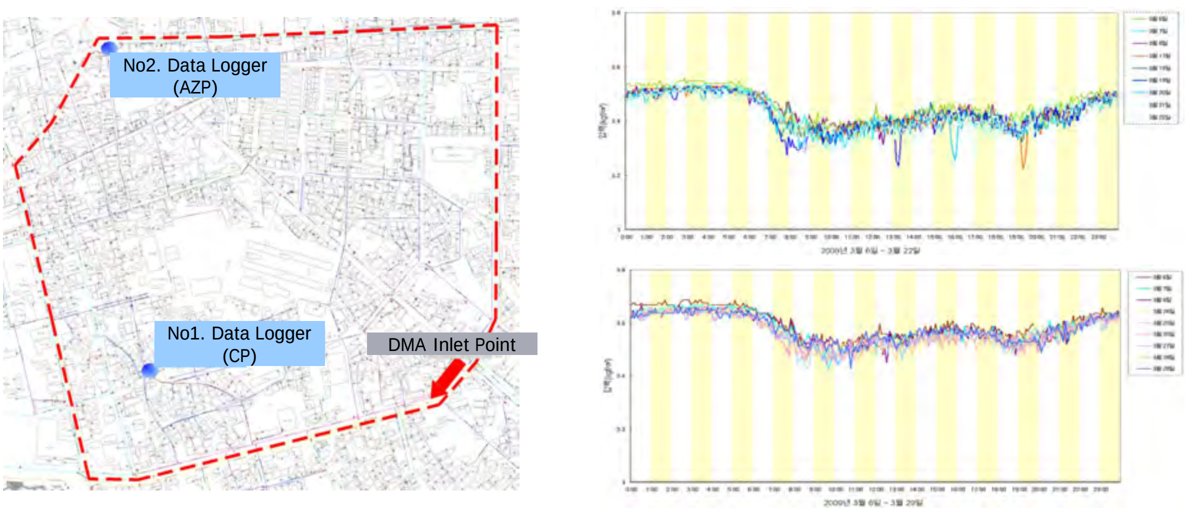
[Investigation and Measurement in Pressure Management Process]

4.3 Network Investigation and Measurement

[Field Investigation and Measurement]

Courtesy of K-water

4.4 Flow and Pressure Analyses



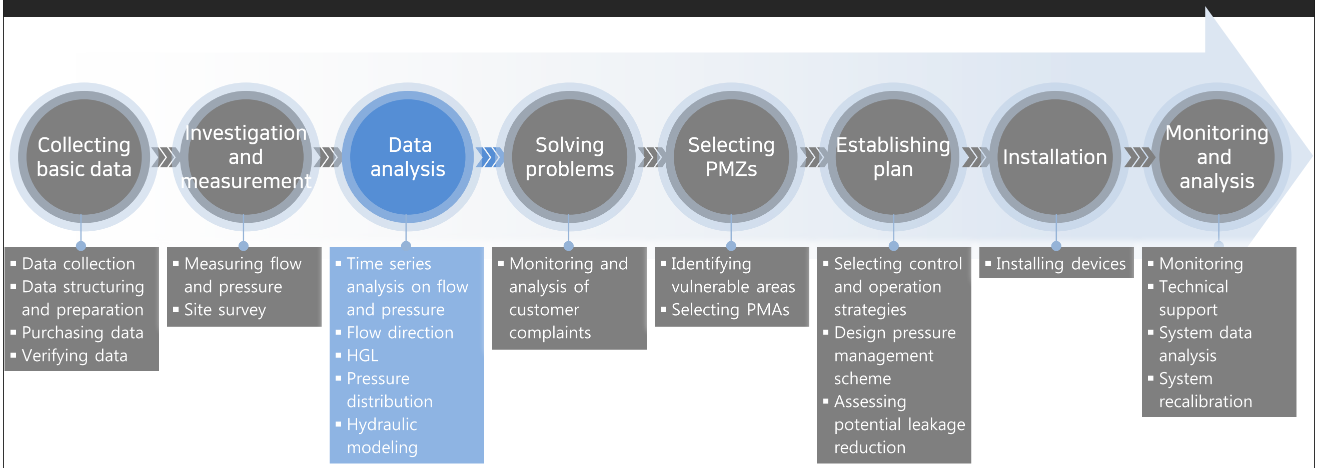
Pressure Point	Pressure (kgf/㎠)				EL (m)	Dynamic Head (m)	Period
	Min	Max	Deviation	Average			
No. 1 (CP)	3.2	3.6	0.4	3.4	36	72	Mar 6–Mar 22
No. 2 (AZP)	3.4	3.7	0.3	3.6	33	70	Mar.6–Mar 22

[Pressure Measurement at Inlet, CP, and AZP]

Courtesy of K-water

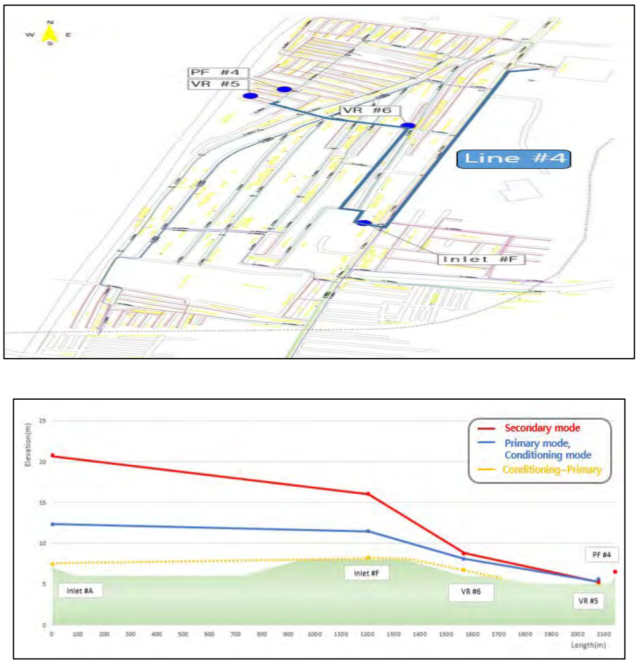
4.4 Flow and Pressure Analyses

- **Analysis: Based on measured data, flow and pressure changes over time, flow direction, hydraulic grade line, and pressure distribution are analyzed**
- **Hydraulic modeling is necessary to understand the network's existing and future behaviors**
  - Simulations not only analyze the current status but also provide different options to be tested and best-use case for the water utility to be determined

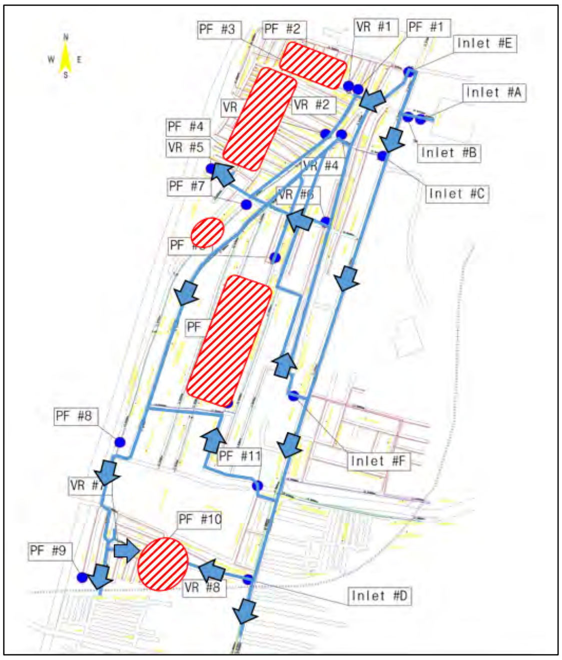


[Data Analysis in Pressure Management Process]

4.4 Flow and Pressure Analyses



(a) Hydraulic Grade Line

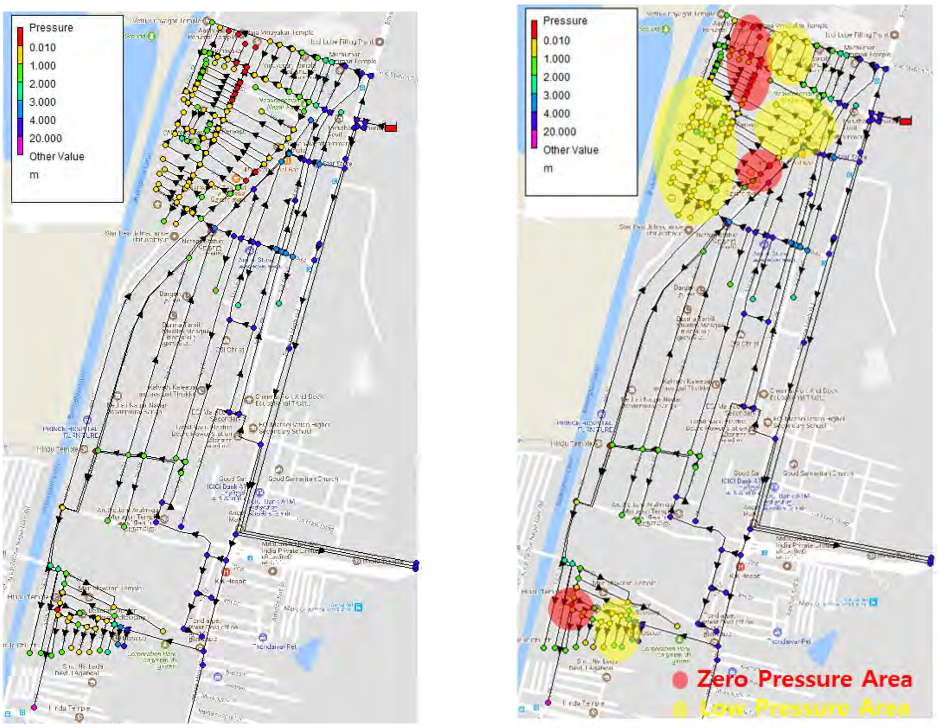


(b) Flow Direction

[Measured Flow and Pressure Analyses]

Courtesy of K-water

4.4 Flow and Pressure Analyses

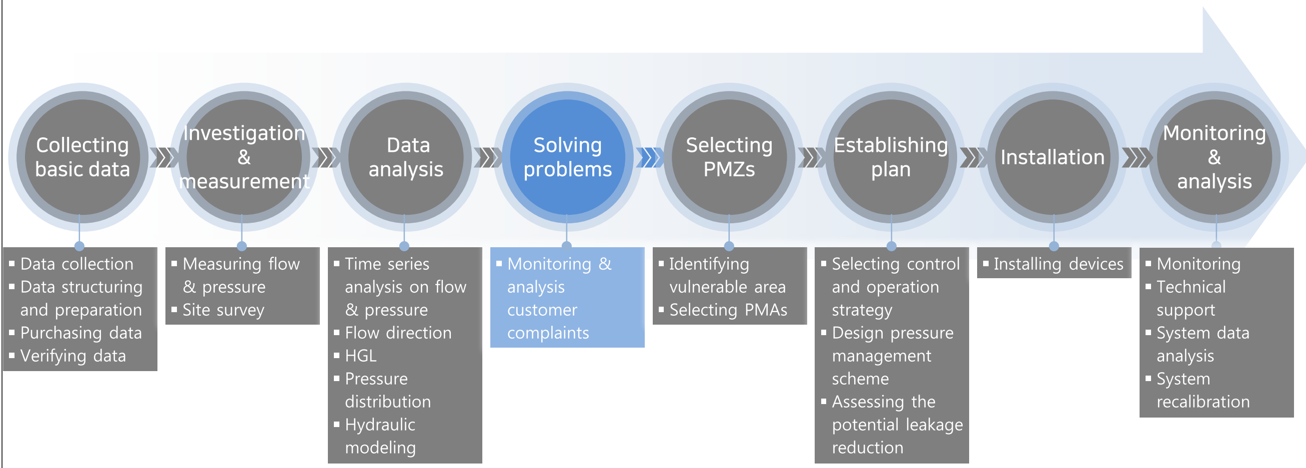


[Hydraulic Modeling Based on Measured Data]

Courtesy of K-water

4.5 Solving Pressure Problems & Complaints

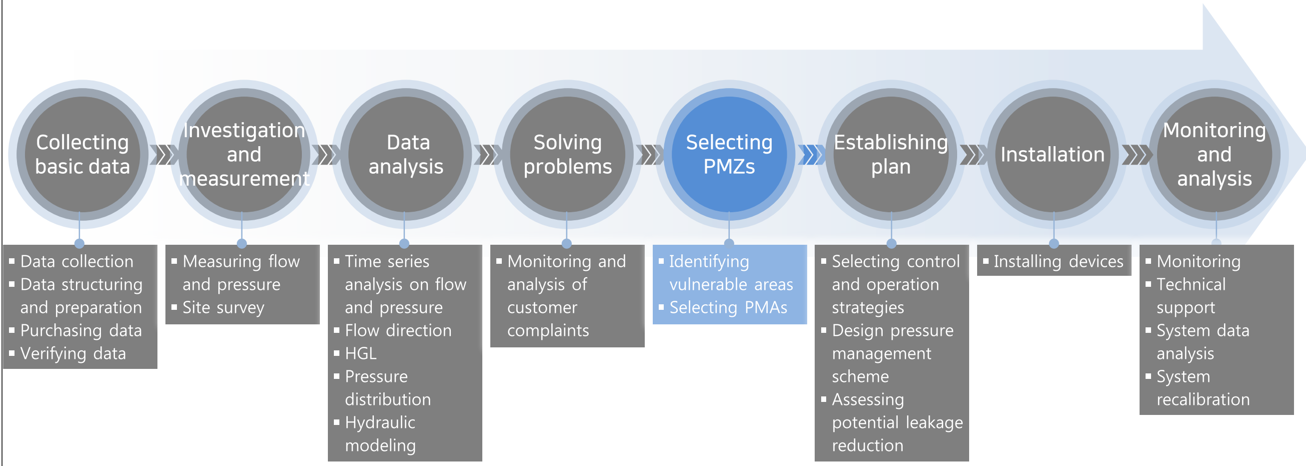
- **(Solving problems) When assessing the financial viability of pressure reduction, it is also important to monitor customer complaints as they can often influence how low the pressure can be taken**
  - The issue of pressure management will often come down to some form of subjective decision and trade-off between savings and complaints



[Solving Pressure Problems and Complaints in Pressure Management Process]

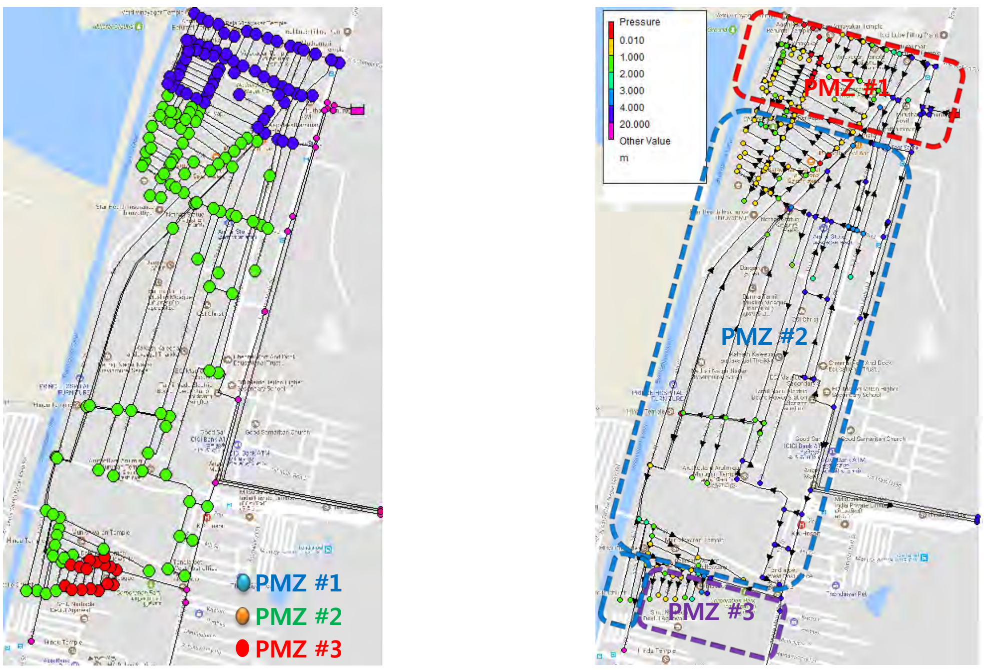
4.6 Selecting Pressure Management Zones

- **Selection criteria: The potential for the pressure reduction of entire PMAs can be examined by assessing pressure at critical, average zone pressure, and average zone night pressure points in PMZs**
- **Identification: Before determining the PMZs, areas with excess pressure, wide pressure fluctuation, and low pressure, and newly extended areas should be identified**



[Selecting Pressure Management Zones in the Pressure Management Process]

4.6 Selecting Pressure Management Zones

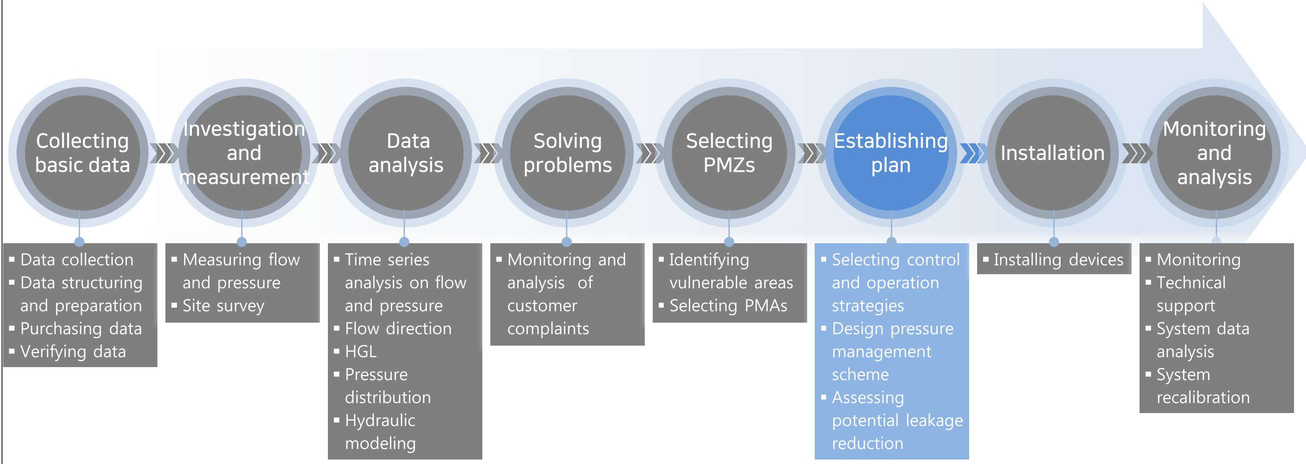


[Example of PMZ Selection]

Courtesy of K-water

4.7 Establishing Pressure Management Plans

▪ **Establishing a plan: A pressure management plan includes a selection of control and operation strategies, design and implementation of the pressure measurement scheme, and assessment of potential leakage reduction**



[Establishing Pressure Management Plan in the Pressure Management Process]

4.7 Establishing Pressure Management Plans

▪ **Selecting control and operational strategy: Selecting schemes for pressure reduction may be conducted by assessing potential schemes throughout a supply zone**

- Selecting the best operation strategy for valves and pumps
- Simulating a change in the operating mode (from intermittent to continuous water supply)

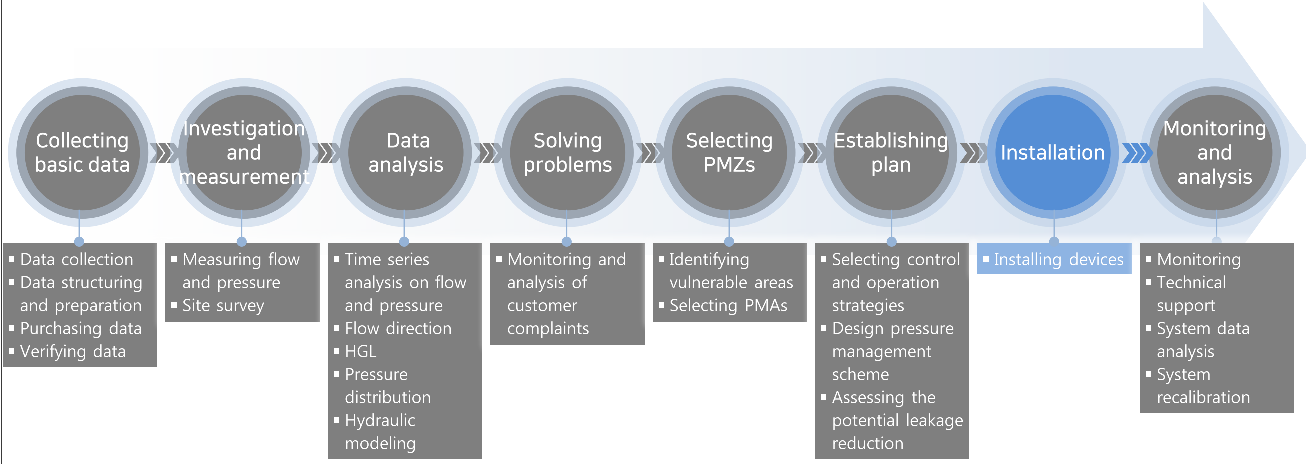
▪ **Design and implementation of the pressure management scheme: This step involves dimensioning, manufacturing, and installing the pressure management scheme and takes account of technical and engineering issues**

- Dimensioning the system (valves and components)
- Manufacturing and constructing the pressure management scheme
- Installing valves and programming control units
- Setting up the modulation scheme
- Performing intensive functional tests of the system
- Putting in place a monitoring system (SCADA technology)

▪ **Assessing potential leakage reduction: Individual schemes can be initially assessed for effectiveness using various methods**

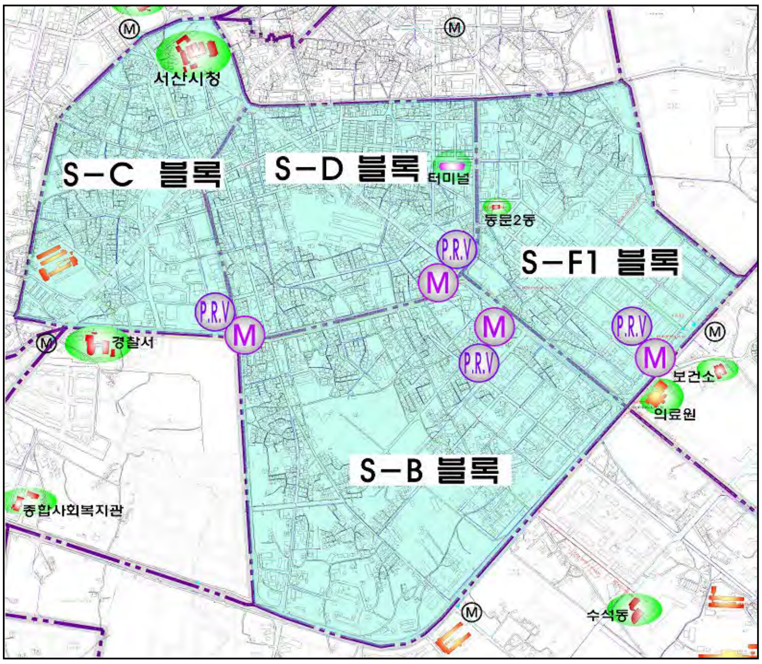
4.8 Installing Pressure Management Systems

- **Installing devices: A pressure-reduction valve (PRV), a pressure sensor, and a flow meter are installed at the inlet point into the PMA**
  - In advanced pressure management systems, a programmable logic controller (PLC) records, processes, and archives the measured sensor data required to control the PRV



[Installing Pressure Management System in the Pressure Management Process]

4.8 Installing the Pressure Management Systems

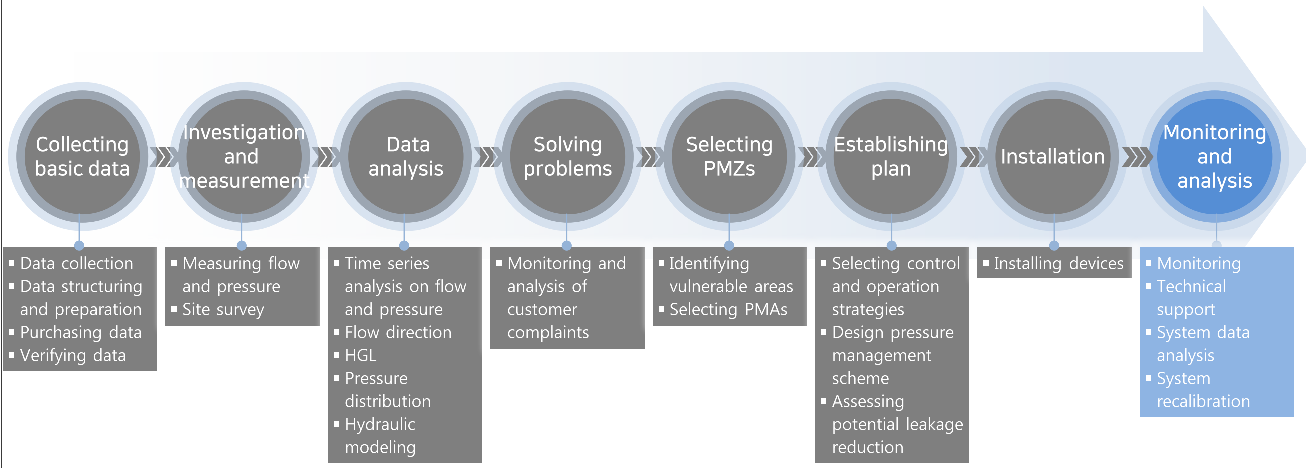


[Installing the Pressure Management System]

Courtesy of K-water

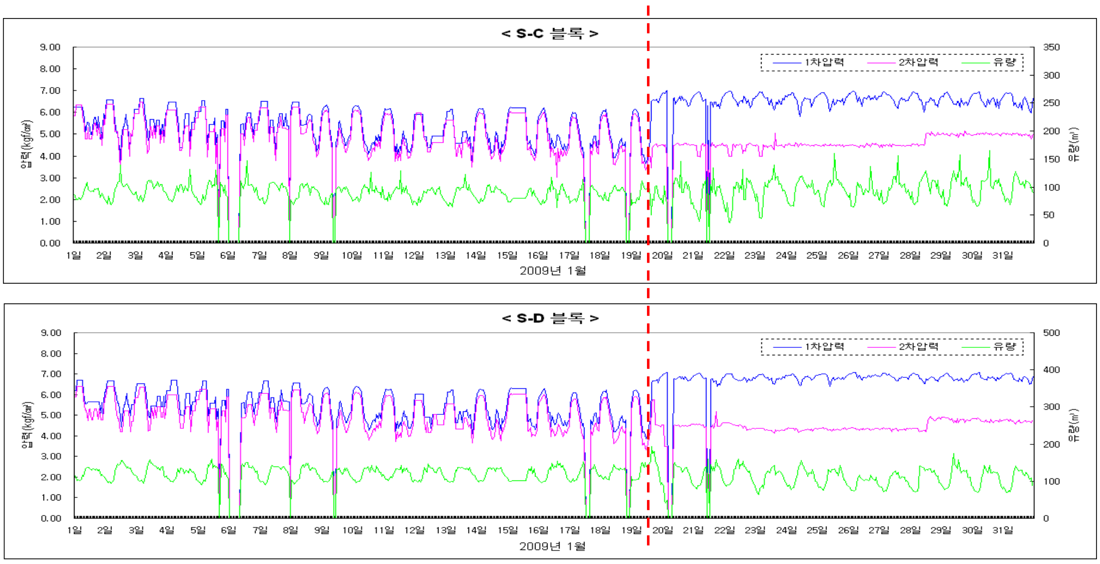
4.9 Monitoring and Result Analyses

- **Monitoring and analysis: Online (remote) or on-site system monitoring entails technical support and troubleshooting, system data analysis, and system recalibration in the case of changes in boundary conditions**



[Monitoring and Result Analyses in the Pressure Management Process]

4.9 Monitoring and Result Analyses



- **Reducing the NRW by 3% is equivalent to a 500-m³/day reduction of water supply**

[Result of Pressure Management Implementation]

Courtesy of K-water


Thank you very much