Unit 3. Performance Indicators of Water Losses in Distribution System

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1. Component of water loss
2. Unaccounted for water
3. Unavoidable Annual Real Losses
4. The Infrastructure Leakage Index
5. The Apparent Loss Index
6. World Bank Institute Banding System
7. Field Test in water distribution system (District meters and data logger)
8. References
Understanding and managing losses in water distribution system

Step 1: Analysis of network characteristics and operating practices

Step 2: Use appropriate tools and mechanisms to suggest appropriate solutions

Component of water loss

- **Water loss**
  - **Physical loss**
    - House connection leaks
    - Pipe break and leaks
    - Storage overflow
  - **Commercial loss**
    - Billing anomalies
    - Metering error
    - Water theft
<table>
<thead>
<tr>
<th>System Input volume</th>
<th>Authorized consumption</th>
<th>Billed authorized consumption</th>
<th>Billed metered consumption (including water exported)</th>
<th>Revenue water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unbilled authorized consumption</td>
<td>Unbilled metered consumption</td>
<td>Unbilled unmetered consumption</td>
<td>Non-Revenue water</td>
</tr>
<tr>
<td>Water losses</td>
<td>Apparent losses</td>
<td>Unauthorized consumption</td>
<td>Metering inaccuracies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Real losses</td>
<td>Leakage on transmission and/or distribution mains</td>
<td>Leakage and overflows at utility storage tank</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leakage on service connections up to point of consumer metering</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What is Unaccounted-For-Water (UFW)?

**Definition:** Unaccounted-for water (UFW) represents the difference between "net production" (the volume of water delivered into a network) and "consumption" (the volume of water that can be accounted for by legitimate consumption, whether metered or not).

\[
\text{UFW} = \text{“net production”} - \text{“legitimate consumption”}
\]

Non-revenue water (NRW) represents the difference between the volume of water delivered into a network and billed authorized consumption.

\[
\text{NRW} = \text{“Net production”} - \text{“Revenue water”} = \text{UFW} + \text{water which is accounted for, but no revenue is collected (unbilled authorized consumption).}
\]
Calculating Water Loss

Water loss is expressed as

- percentage of net water production (delivered to the distribution system)
- as $m^3$/day/km of water distribution pipe system network (specific water loss)
- Others
  - $m^3$/day/connection
  - $m^3$/day/connection/m pressure

- Water loss as % of net water production is the most common.

- It could be misleading for systems with different net productions with same amount of real & apparent losses.
Magnitude of Water Losses

- Water loss levels (UFW or NRW) vary widely per country and within one country per city.

- UFW values ranging from 6% to 63% have been reported

- A certain level of water losses can not be avoided from a technical point of view and/or is considered acceptable from an economic point of view.

Mean UFW in Large Cities in Africa, Asia, Latin America and the Caribbean and North America
What is an Acceptable Water Loss?

1. It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost (of water) saved.

2. American Water Works Association (AWWA) Leak detection and Accountability Committee (1996) recommended 10% as a benchmark for UFW.

3. UFW levels and action needed

   < 10% Acceptable, monitoring and control

   10-25% Intermediate, could be reduced

   > 25% Matter of concern, reduction needed
**Components of Water Losses**

Good understanding of the relative weights of different components is important for development of a sound water loss reduction program.

<table>
<thead>
<tr>
<th>Component of UFW (%)</th>
<th>Indonesia</th>
<th>Thailand</th>
<th>Malaysia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical losses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk mains, distribution system</td>
<td>21</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Service connections</td>
<td>10</td>
<td>34</td>
<td>17</td>
</tr>
<tr>
<td>Non-Physical losses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illegal connections</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Under registration and billing</td>
<td>6</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Total UFW %</td>
<td>43</td>
<td>46</td>
<td>36</td>
</tr>
</tbody>
</table>
Leakage distribution (% of total volume)

<table>
<thead>
<tr>
<th>Country</th>
<th>Trunk mains</th>
<th>Distr. pipes</th>
<th>Service reserv.</th>
<th>Service conn.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>10.4</td>
<td>43.8</td>
<td>-</td>
<td>45.8</td>
</tr>
<tr>
<td>Britain</td>
<td>10.9</td>
<td>43.5</td>
<td>4.4</td>
<td>41.2</td>
</tr>
<tr>
<td>USA</td>
<td>9.0</td>
<td>77.7</td>
<td>5.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Israel</td>
<td>12.5</td>
<td>47.5</td>
<td>5.0</td>
<td>35.0</td>
</tr>
</tbody>
</table>
### Breakdown of Distributed Water Volume Nuremberg, Germany as example

<table>
<thead>
<tr>
<th>Distribution water 100%</th>
<th>Accounted for water 91.3%</th>
<th>Charged water 84.8%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unaccounted for water 8.7%</td>
<td>Bulk supply water 6.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other meters water (park, fountains etc.) 0.3%</td>
</tr>
<tr>
<td></td>
<td>Apparent losses 3.5%</td>
<td>Unmetered usage 0.5%</td>
</tr>
<tr>
<td></td>
<td>Real losses 5.2%</td>
<td>Own water works consumption 1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meter errors 2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pipe breaks 3.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>House connection corrosion 1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other losses 0.7%</td>
</tr>
</tbody>
</table>
Unavoidable Annual Real Losses (UARL)

- It is impossible to eliminate all real losses from a distribution system
  - some losses are “unavoidable”

- some leakages are believed to be undetectable (too small to detect) or uneconomical to repair

- An estimate of Unavoidable Annual Real Losses (UARL) can help to evaluate the feasibility of real loss minimization (provides better understanding of real loss components).
Unavoidable Annual Real Losses (UARL)

• The UARL is computed based on Background and Burst Estimates (BABE) concept.
Unavoidable Annual Real Losses (UARL)

\[
\text{UARL (L/day)} = (18 \times L_m + 0.80 \times N_c + 25 \times L_p) \times P
\]

where

\( L_m = \) Length of mains in km

\( N_c = \) Number of service connections

\( L_p = \) Total length in km of underground connection pipes (between the edge of the street and customer meters)

\( P = \) Average operating pressure in m
**Unavoidable Annual Real Losses UARL** in liters/service connection/day for customer meters located at edge of street

<table>
<thead>
<tr>
<th>Density of connections $N_c$ /$L_m$ (per km mains)</th>
<th>Average operating pressure (P) in meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20 40 60 80 100</td>
</tr>
<tr>
<td>20</td>
<td>34 68 112 146 170</td>
</tr>
<tr>
<td>40</td>
<td>25 50 75 100 125</td>
</tr>
<tr>
<td>60</td>
<td>22 44 66 88 110</td>
</tr>
<tr>
<td>80</td>
<td>21 41 62 82 103</td>
</tr>
<tr>
<td>100</td>
<td>20 39 59 78 98</td>
</tr>
</tbody>
</table>
Unavoidable Annual Real Losses (UARL)

Generalized Equation

\[ \text{UARL (L/day)} = (A \times L_m + B \times N_c + C \times L_p) \times P \]

where

- \( A \) = specific real losses for mains (L/day/km/m pressure)
- \( B \) = specific real losses for service connections (L/connection/m pressure)
- \( C \) = specific real losses for underground service pipes (L/day/km/m pressure)
## Typical UK distribution system background leakage levels at 50 m pressure

<table>
<thead>
<tr>
<th>Infrastructure element</th>
<th>Estimated leakage level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Distribution main (l/km/h)</td>
<td>20.0</td>
</tr>
<tr>
<td>Average for all metered service pipes:</td>
<td></td>
</tr>
<tr>
<td>• meter at property boundary (l/connection/h)</td>
<td>1.50</td>
</tr>
<tr>
<td>• meter in - house (l/connection/h)</td>
<td>1.75</td>
</tr>
<tr>
<td>In house plumbing losses</td>
<td></td>
</tr>
<tr>
<td>• Average over all houses (l/property/h)</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Source: Twort et al. 2000
The Infrastructure Leakage Index (ILI)

- A better indicator
- Describes the quality of infrastructure management
- Is the ratio of Current Annual Real Losses to Unavoidable Annual Real Losses

\[
\text{ILI} = \frac{\text{CARL}}{\text{UARL}}
\]
World Bank Institute Banding System

- to Interpret ILIs
- ILI is classified into Bands A to D
- Different limits for developed & developing countries
- Each Band has a general description of performance
- Each Band suggests a range of recommended activities

<table>
<thead>
<tr>
<th>Developing countries</th>
<th>Developed countries</th>
<th>BAND</th>
<th>General description of real loss performance management categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILI Range 4 to &lt;16</td>
<td>ILI Range 2 to &lt;4</td>
<td>A</td>
<td>Further loss reduction may be uneconomic unless there are shortages; careful analysis is needed to identify cost effective improvement</td>
</tr>
<tr>
<td>ILI Range 8 to &lt;16</td>
<td>ILI Range 4 to &lt;8</td>
<td>B</td>
<td>Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance</td>
</tr>
<tr>
<td>ILI Range 16 or more</td>
<td>ILI Range 8 or more</td>
<td>C</td>
<td>Poor leakage record; tolerable only if water is plenty and cheap; even then analyze level and nature of leakage and intensify leakage reduction efforts</td>
</tr>
<tr>
<td>ILI Range 16 or more</td>
<td>ILI Range 8 or more</td>
<td>D</td>
<td>Very inefficient use of resources; leakage reduction programs imperative &amp; high priority</td>
</tr>
</tbody>
</table>
## WBI Recommended Activities

<table>
<thead>
<tr>
<th>WBI Recommendations for BANDS</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigate pressure management options</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Investigate speed and quality of repairs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Check economic intervention frequency</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduce/improve active leakage control</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify options for improved maintenance</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Assess Economic Leakage Level</strong></td>
<td><strong>Yes</strong></td>
<td><strong>Yes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review burst frequencies</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review asset management policy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Deal with deficiencies in manpower, training and communications</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5-year plan to achieve next lowest band</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fundamental peer review of all activities</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>
The Apparent Loss Index (ALI)

Similar to the concept of ILI, a index for apparent loss has been recommended by IWA task force.

\[
\text{Apparent Loss Index (ALI)} = \frac{\text{Apparent Loss}}{5\% \text{ of Water Sales}}
\]
Controlling Water Loss

- Water audit or Water balance
- Meter testing and repair/replacement, improving billing procedure
- Leak detection and control program
  - network evaluation
  - leak detection in the field and repair
- Rehabilitation and replacement program
- Corrosion control
- Pressure reduction
- Public education program; Legal provisions
- Water pricing policies encouraging conservation
- Human resources development
- Information system development
Four components of an active real loss management program

Source: Thornton (2002)
Four components of an active apparent loss management program

- Reduction of meter error by
  - Testing
  - Sizing
  - Replacement

- Reduction of theft by
  - Education
  - Legal action
  - Prepay measures
  - Pressure limitation
  - Flow control

- Reduction of human error
  - Training
  - Standardizing
  - Reporting
  - Auditing

- Reduction of computer error by
  - Auditing
  - Checking
  - Routine analysis
  - Upgrade

Source: Thornton (2002)
Guideline for Water Loss Level

For systems with per capita consumption of less than 150l/day the general rule for water loss level is:

Good condition of system < 250 Litre/connection /day
Average condition 250 - 450 Litre/connection/day
Bad condition of system > 450 Litre/connection/day

Another guideline for the water loss level is the “Benchmark” Liter/km mains/day:

Good condition of system < 10,000 Litre/km main/day
Average condition 10,000 – 18,000 Litre/km main/day
Bad condition of system > 18,000 Litre/km main/day

Source: Kfw funded programs
Leak Detection Methods

Acoustic (sound) method

Tracer techniques (N₂O)

leak noise correlator
Field Tests in Water Distribution Systems

- Provides insight into the system performance
- Data collection is the first step in the model calibration process.

Field test campaigns comprise:

- Pressure measurement on the network
- Fluctuations in reservoirs levels
- Network flow rates
Pressure measurements are located on the basis of the following criteria:

1. Good spatial coverage
2. Optimized use of available equipment

- All of the measurements must be performed simultaneously
- Accurate topographical readings to all pressure measurement points
Field Test Equipment

**Pressure**
- Pressure gauges
- Pressure sensors/transducers

**Flow**
- Flow meters with pulse heads
- Insertion electromagnetic flow meters

**Reservoirs Levels**
- Level meters
- Some tanks are equipped with electronic level measurements
Data loggers / recorders are very useful tool in field tests.
INTRODUCTION

Data logger introduction and physical sample

TYPICAL APPLICATIONS

A telemetry link can be provided either by telephone line using an internal PSTN modem or by using the cellular communications network with an internal GSM modem.

Alternatively, portable Multi Log units can be upgraded in the field to cellular communications with the addition of Radcom GSM.

ADVANCED DESIGN

Multi Log can be supplied with up to four inputs of any type. Each input is logged in two channels: a primary channel and a secondary channel. Both channels can be programmed independently.

ADVANCED DESIGN

Radcom's data loggers and controllers are compatible with Radlog for Windows™, the industry-standard for data logging, reporting, analysis, and archiving.

All of Radcom's data loggers and controllers are compatible with Radlog for Windows™, the industry-standard for data logging, reporting, analysis, and archiving.
Field Test at Water Well Outlet
The field test campaign

- Pre-field Test activities
- Main field Test activities
Pre-field Test activities

1. Selection of the measurement points
2. Determination of ground levels of pressure measurement points - contour map / conventional levelling techniques (if needed).
3. Definition and execution of site works needed to conduct the field tests.
4. Fabricating tapping points for pressure measurements.
5. Inspection & maintenance of water meters.
6. Installation of water meters for flow measurements as needed.
7. Identification of strategic valves within the distribution system.
Main field Test activities

1. Definition of test period and sampling rate.
2. Programming data loggers for flow and pressure measurement.
3. Installation of data loggers
4. Collecting manual reading as needed.
5. Tracking the status of valves during the field test.
Field Test Results

Flow: Litres/Sec  Municipal Supply Point: _200_01  Channel 4  Trial Dow
Field Test Results, continue

1 Pressure - Metres Head Municipal Supply Point: _200_01 Channel 1 Trial E
• **DISTRICT METERING:**

A water distribution network will, by definition, supply water to consumers, both domestic and commercial/industrial.

Depending on the country, varying amounts of water are "lost" or "unaccounted for" between the reservoir or storage facility or the operating well and the consumer.

Unaccounted For Water (UFW) is expressed as the difference between the volume of water entering the distribution system and the volume of water billed to customers. Depending on the country, UFW figures can range from single figure percentages to more than 40% in Gaza Strip.
- Apparent losses arise from the continued use of old consumer water meters. Almost any type of water meter will under read with time: the magnitude of this under-reading depends on the manufacturer, type and age of the meter. Under-reading obviously has a negative impact on the revenue accruing to the water utility and contributes to the overall UFW figure.

- It should also be noted that certain types of meter may over-read with time, depending on the condition of the water. The continued use of these meters could mask a potential UFW problem, as the apparent sum of the billed consumption may equal or exceed the amount of water entering the network, whereas in fact an unknown amount of water may be lost due to leakage or theft.
• In order to localize the problem areas, it is recommended that the network be divided into several District Meter Areas, (DMA), and that accurate bulk water meters be installed at the entry point into these districts. Ideally, the sum of the flow totals recorded by the district meters should equal the quantity of water measured at the outlet of the water well sources, allowing for recognized meter uncertainties as defined in international standards. If there are significant differences between the source reading and the sum of the district meter readings, the upstream network needs immediate investigation. However, as the pipe sizes, flow rates and pressures are likely to be greater in this part of the network, leaks are more likely to be obvious.
• In some networks, district meters are already installed. In these cases, a meter evaluation and, if necessary, replacement program is an essential part of the UFW reduction exercise. This should be implemented at an early stage and should include meters installed at large commercial and industrial customers which may represent a significant source of revenue for the utility. A detailed study needs to be conducted into the age, size and type of meter installed. A meter change-out program has the combined benefit of:

- (1) Producing more reliable information for the UFW evaluation team and
- (2) Increasing the revenue for the utility, as older under-reading meters are replaced with newer, more accurate meters.
Typical metering hierarchy and DMA design options
(reproduced from Managing Leakage—Report J)
sketch illustrating the DMA and other valves’ location with the boundary of the proposed district zone
DMA sub-division by valving

DMA sub-division by metering
Following is a chart summarizing the stages in designing and installing DMAs:

1. DMA planning (confirmed)
2. Site survey
3. Meter selection
4. Site excavation
5. Meter installation
6. DMA proving
Several key considerations in such a design or re-design a DMA is that it should include the followings:

1. Separate trunk mains from subsidiary networks
2. Limit the number of recording meters (ideally single-feed)
3. and Whenever possible each district should be fed by one and only one meter. Multiple meters will be allowable where no other network arrangements are practicable.
4. Best use of the existing network structure in order to limit additional network.
5. Existing billing zoning (readers rounds), if any, so that the reading of a particular district meter is comparable to the reading of the pertinent district meter.
Following is an example of installation of standard district meter and its accessories;

Fig. 7.4 Meter and bypass installation

These two valves to be shut after installation
### Meter and bypass installation: schedule of materials

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Materials</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150 flange adapter</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>150 SV</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>150 x 150 x 80 mm tee with W/O</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>150 x 150 x 150 mm tee</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>150 ductile iron pipe—length to suit</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>150 mm 90° elbow</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>150 mm ductile iron pipe—length 0.75 m</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>150 mm meter</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Pressure tapping</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>150 mm ductile iron pipe—length to 1.5 m</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>50 mm ducting</td>
<td>As required</td>
</tr>
<tr>
<td>12</td>
<td>Boxes</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Antenna</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Grade A chamber cover</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>GSM communications (temporary)</td>
<td></td>
</tr>
</tbody>
</table>
References


• Global Water Supply and Sanitation Assessment 2000 (WHO-UNICEF)

• International water association (IWA) http://www.iawahq.org

• American Water works Association (AWWA) http://www.awwa.org