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Service activities relating to drinking water supply, wastewater and stormwater systems — Guideline for a water loss investigation of drinking water distribution networks

Activités relatives aux systèmes d'eau potable, d'assainissement et de gestion des eaux pluviales — Lignes directrices pour l'investigation des pertes d'eau dans les réseaux de distribution d'eau potable

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 224, *Service activities relating to drinking water supply, wastewater and stormwater systems.*

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Water is essential to life and forms part of the environment. Global concern for the state of the environment has identified that water resources are subject to significant pressure from water demand. Large amounts of abstracted water do not reach the intended users. Many water utilities lose large volumes of water through leaks and pipe bursts. Due to increasing urbanization, growing demand, rising costs and ageing distribution networks, water loss is a growing challenge for drinking water utilities.

In addition to the failure rates, the amount of water lost from a network is also an indicator of the condition of that network, which can only be improved through appropriate operation, maintenance and long-term rehabilitation. Still, careful handling of water is a fundamental requirement for drinking water utilities.

Identifying and reducing water loss is an important task in the overall concept of managing of water distribution network assets (see ISO 24516-1:2016, 4.1; 5.8). Minimizing water loss is a major functional requirement in fulfilling the objectives given in ISO 24510 regarding promoting the sustainability of the drinking water utility, protecting the environment and protecting public health and safety.

A system water loss investigation can contribute to the sustainability of drinking water utilities and protection of the environment. It is a critical first step in the establishment of an effective water loss management programme, which is an important activity within the management of water distribution assets. With a successful completion of a system water loss investigation, water utilities can gain an understanding of the current status of the drinking water distribution network regarding non-revenue water (NRW) components (i.e. unbilled authorized use, apparent water loss and real water loss) and begin to formulate a water loss management plan.

Water loss consists of real and apparent water loss. Real water loss includes the treated water volume lost through all types of leaks in pipes and other components of the system, as well as storage tank overflows. It also depends on flow rates, water loss rates, pressure and the average duration of individual leaks and the frequency at which they occur. Apparent water loss covers all types of inaccuracies associated with users' metering and billing, plus unauthorized use (theft or illegal use). Unauthorized use occurs through deliberate actions of authorized or unauthorized users who draw water from the system without permission. Such water loss can take many forms, including illegal connections, illegal reconnections of disconnected users, meter bypasses, meter tampering and illegal connections to fire hydrants. This document deals with the various components of water loss as part of the water loss investigation.

The International Water Association Water Loss Specialists Group (IWA WLSG) has developed terminology, methodology, strategy and diverse tools for water loss management. This document includes and considers these.

The purpose of this document is to establish current know-how in water loss and to set a formalized scope of work for water loss investigation. It also includes an annex that describes relevant technologies and methods.

Service activities relating to drinking water supply, wastewater and stormwater systems — Guideline for a water loss investigation of drinking water distribution networks

1 Scope

This document provides a methodology for undertaking a water loss investigation and establishing general principles for water loss management in drinking water distribution networks in order to improve the sustainability of drinking water utilities and protect the environment by saving water, energy and use of chemicals.

This document establishes a procedure to estimate water loss components through water balance calculations and to define general principles of water loss management. This document deals with the preparation of a water loss management plan for water loss reduction and management projects but does not cover its execution.

This document does not cover bulk drinking water supply systems, but can relate to pumping, storage and transmission within the drinking water distribution network.

This document can be used analogously for non-public supply systems, raw water and industrial water systems.

This document is intended for drinking water utilities and other stakeholders.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
active leakage control
ALC
process of undertaking leakage detection surveys on a targeted or regular basis in order to manage leakage within a *drinking water distribution network* (3.10)

3.2
apparent water loss
unauthorized use of water, such as theft or illegal use of water, and any inaccuracies associated with errors in metering, errors in estimation of unmetered water use and errors arising from the data acquisition and analysis process

3.3
authorized use
volume of metered or unmetered water, or both, taken by registered *users* (3.22), the water supplier and others who are implicitly or explicitly authorized to do so by a water supplier

Note 1 to entry: Authorized use includes domestic, commercial and industrial purposes, including *exported water* (3.12). It also includes billed water and uses that are not billed (e.g. firefighting).

Note 2 to entry: The International Water Association prefers the term "consumption" rather than "use".

3.4
background and bursts estimates
BABE
concept using auditable assumptions to calculate the components that make up the annual volume of *real water loss* (3.18)

Note 1 to entry: The International Water Association uses the term "component loss model (CLM)" and states that the CLM is constructed to estimate each type of leakage. Component loss models include BABE estimates.

3.5
background water loss
leaks at joints and fittings, not visible or audible with currently available technology

3.6
billed authorized use
billed authorized consumption
components of *authorized use* (3.3) which are billed and produce revenue

Note 1 to entry: Billed authorized use is equal to billed metered consumption plus billed unmetered consumption, and also known as revenue water. It is a component in the IWA Standard *water balance* (3.23).

Note 2 to entry: The term “billed authorized use” is sometimes referred to as “billed authorized water consumption”.

3.7
connection
service connection
set of physical components ensuring the link between a point-of-delivery and the local water main or the point-of-collection and the sewer

Note 1 to entry: For drinking water systems, the term “service pipe” is currently used, but the connection can include components other than the service pipe, such as valves and meters.

Note 2 to entry: For the purposes of this document, the term “service connection” is not related to the point-of-collection and the sewer.

[SOURCE: ISO 24513:2019, 3.3.37, modified]

3.8
current annual real loss
CARL
current best estimate of the average *real water loss* (3.18) over a year, evaluated using the IWA Standard *water balance* (3.23), in the form of volume per year or volume per day

3.9
district metering area
DMA
section in a *drinking water distribution network* (3.10) for which water supply can be discretely measured

Note 1 to entry: There can be more than one district metering area meter measuring the flows at the boundary or the interior of the district metering area.

3.10
drinking water distribution network
asset system for distributing drinking water

Note 1 to entry: Drinking water distribution network can include pipes, valves, hydrants, pumping stations and reservoirs, and other metering and ancillary infrastructure and components.

Note 2 to entry: Pumping stations and reservoirs can be sited either in the waterworks or in the drinking water distribution network.

Note 3 to entry: For the purposes of this document, a drinking water distribution network does not include bulk drinking water supply systems, but can include pumping, storage and transportation to the drinking water distribution network.

Note 4 to entry: For the purposes of this document, "storage tank" is used in addition to "reservoir".

[SOURCE: ISO 24513:2019, 3.5.12.2.1, modified]

3.11
drinking water utility
whole set of organization, processes, activities, means and resources necessary for abstracting, treating, distributing or supplying drinking water and for providing the associated services

Note 1 to entry: Some key features for a drinking water utility are:

— its mission to provide drinking water services;

— its physical area of responsibility and the population within this area;

— its responsible body;

— the general organization, with the function of operator being carried out by the responsible body or by legally distinct operator(s);

— the type of physical systems used to provide the services, with various degrees of centralization.

Note 2 to entry: The term addresses a utility dealing only with drinking water.

Note 3 to entry: When it is not necessary, or it is difficult to make a distinction between responsible body and operator, the term "drinking water utility" covers both.

Note 4 to entry: In common English, "drinking water service" can be used as a synonym for "drinking water utility", but this document does not recommend using the term in this way.

[SOURCE: ISO 24513:2019, 3.3.1.1]

3.12
exported water
water which is supplied to the *drinking water distribution network* (3.10) but is then transferred to another drinking water system

Note 1 to entry: Exported water is adjusted for known errors.

3.13
fixed and variable area discharge
FAVAD
concept that interprets the pressure:leak flow relationship

Note 1 to entry: The leak flow can come from a variety of paths which do not necessarily vary with pressure.

3.14
intermittent supply
drinking water distribution system that delivers water to *users* (3.22) for less than 24 hours in one day

3.15
minimum flow
lowest flow observed in a *district metering area* (3.9) for a *water loss investigation* (3.25) process, taken over a consistent period of time for the investigation

Note 1 to entry: In many *drinking water utilities* (3.11) this is referred to as minimum night flow (MNF).

3.16
non-revenue water
NRW
difference between the volumes of *water supplied* (3.27) and *billed authorized use* (3.6)

Note 1 to entry: non-revenue water includes not only the *real water loss* (3.18) and *apparent water loss* (3.2), but also the unbilled authorized use.

3.17
performance indicator
PI
parameter, or a value derived from parameters, which provides information about performance

Note 1 to entry: Performance indicators are typically expressed as ratios between variables. These ratios can be commensurate (e.g. %) or non-commensurate (e.g. $/m^3).

Note 2 to entry: Performance indicators are means to measure the efficiency and effectiveness of a water utility in achieving its objectives.

[SOURCE: ISO 24513:2019, 3.9.6]

3.18
real water loss
physical water loss
amount of water escaping from the pressurized system through all types of leaks, bursts and overflows, up to the point of *user* (3.22) metering or transfer of responsibility to the *user* (3.22)

3.19
system input volume
SIV
total water volume supplied into a drinking water system from all sources, including imported water

3.20
unavoidable annual real loss
UARL
lowest technically achievable annual volume of *real water loss* (3.18) for a well-maintained and well-managed system

3.21
unmetered authorized use
authorized use (3.3) which is not metered and is estimated for billing or *water balance* (3.23) purposes

Note 1 to entry: The term “unmetered authorized use” is sometimes referred to as “unmetered authorized water consumption”.

EXAMPLE Unmetered use of water in public institutes such as schools or public gardens.

3.22
user
consumer
person, group or organization that benefits from drinking water delivery and related services, wastewater service activities, stormwater service activities, or reclaimed water delivery and related services

Note 1 to entry: Users are a category of stakeholder.

Note 2 to entry: Users can belong to various economic sectors, such as domestic, institutional, commercial, industrial or resource exploitation (e.g. agriculture, forestry, mining).

Note 3 to entry: The term “consumer” can also be used, but in most countries the term “user” is more common when referring to public services.

[SOURCE: ISO 24513:2019, 3.1.8.4]

3.23
water balance
quantified volume of total water into the system, authorized use (billed and unbilled, metered and unmetered) and *water loss* (3.24) (apparent water loss and real water loss)

3.24
water loss
difference between water supplied and *authorized use* (3.3), consisting of *real water loss* (3.18) and *apparent water loss* (3.2)

3.25
water loss investigation
activities for the collection of information and quantification of the water uses and *water loss* (3.24) from a water system, which include the calculation of a *water balance* (3.24) and *performance indicators* (3.17)

Note 1 to entry: Also known as *water loss* (3.24) audit or *water loss* (3.24) survey.

EXAMPLE Calculation of a water balance and *performance indicators* (3.17).

3.26
water loss management plan
overview of the required activities of a *water loss* (3.24) reduction project, expected benefits, time schedule and budget based on the results of the *water balance* (3.23) and *performance indicators* (3.17)

Note 1 to entry: A *water loss* (3.24) management plan can include pressure control, *active leakage control* (3.1), universal metering and establishment of *district metering areas* (3.9).

3.27
water supplied
provision of drinking water into the *drinking water distribution network* (3.10) for use, calculated as the *system input volume* (3.19) minus *exported water* (3.12)

4 Defining objectives for the water loss investigation

The objectives of the water loss investigation should be aligned with the strategic objectives of the drinking water utility. It should aim at quantifying the volumes of water entering the system, authorized use (billed and unbilled, metered and unmetered) and water loss (apparent water loss and real water loss), through the water balance, calculation of water loss performance indicators and collection of current operational, maintenance and rehabilitation practices. Another objective of the water loss investigation should be to create a water loss management plan (see Clause 13).

The objectives of the water loss investigation should be to provide a rational, scientific framework to assess:

— water loss factors;

— selection of technologies for the assessment of water loss;

— costs of non-revenue water (NRW) components;

— performance indicators of water loss;

— drinking water utility operations;

— water loss management structure;

— appropriate targets for water loss reduction;

— likely activities and budget for water loss reduction projects.

5 Water loss investigation steps

The water loss investigation should include estimations of all water volumes entering and leaving a system, as well as in-depth record and field examination of the drinking water distribution system. Apparent water loss and real water loss estimations can provide valuable information to help assess the operational efficiency of the distribution system.

The water loss investigation is a first step in the establishment of an effective water loss management plan, which should address activities to reduce real water loss and apparent water loss.

The water loss investigation should consist of the following steps:

— determination of scope of the water loss investigation (see Clause 6);

— collection of data and validation methods (see Clause 7);

— calculation of water balance (see Clause 8);

— selection of water loss performance indicators (see Clause 9) and calculation (see Annex C);

— assessment of apparent water loss status (see Clause 10);

— assessment of real water loss status (see Clause 11);

— assignment of real water loss and apparent water loss cost (see Clause 12);

— preparation of water loss management plan (see Clause 13);

— selection of activities for apparent water loss management (see Clause 14);

— selection of activities for real water loss management (see Clause 15).

6 Water loss investigation scope determination

6.1 General

The following parameters should be defined prior to the water loss investigation in order to determine the framework and the extent of the investigation:

— the geographical area of the water loss investigation (6.2);

— the time period of the water loss investigation and tests (6.3);

— the units of each measurement (6.4).

6.2 Water loss investigation area

The boundaries of the water loss investigation area should be defined. Interconnecting points with the surrounding areas should also be defined.

A water loss investigation area may include pumping, storage and transportation within the drinking water distribution network.

A schematic plan displaying the water loss investigation's boundaries should be prepared.

6.3 Time period of the water loss investigation

The water loss investigation should be carried out regularly.

For the water balance calculation, it is usual to cover 12 months in order to minimize the effects of mismatches between meter readings. Nevertheless, the water loss investigation may be complemented with measurements in a shorter period for a detailed assessment of water loss components, although this could mean that errors due to variations in meter reading cycles, volume of leakage and climatic conditions are introduced.

The water loss investigation should be repeated, although the frequency at which this is done depends on the type of measurement and local conditions.

6.4 Units of measurement

Units of measurement should be uniform and consistent throughout the water loss investigation for such aspects as system input volume (SIV), water supplied, water use, pipe diameter, diameter of other appliances and storage tank or reservoir volume. Units of measurement are generally either metric (e.g. litres) or imperial (e.g. gallons or US gallons).

7 Data collection and validation methods

7.1 Data collection methods

Data collection should involve data for water balance calculations and inventory data about the drinking water distribution network. All data sources and collection processes should be transparently documented such that they are replicable and auditable.

Water loss cannot be measured directly but should be estimated. The simplest method of doing this is by calculating a water balance. This is likely to require many assumptions, all of which should be recorded and validated as further data and information become available. Therefore, written procedures for each component of the water balance, containing adopted assumptions, identification of input data characteristics, data sources and methods adopted, should be prepared and followed to ensure that periodic calculation of the water balance is systematic.

The inventory data (e.g. nominal diameter, material, length, year of installation, rehabilitation, type of connection) and condition data (e.g. date, point, type of failure, bedding, depth of cover, extent and depth of external corrosion) should be recorded and assigned as described in ISO 24516-1:2016, 5.4 and 5.5. The resulting maps should be used as a basis for further investigations on water loss.

A schematic plan of the drinking water distribution network should be used, although this may be on a different layer or set of plans, including:

— The drinking water distribution network, beginning with water source through to users.

— District metering areas (DMAs), shown on the plan.

— Identification of all drinking water inputs, whether drinking water utilities' own resources or other sources.

— Definition of the main facilities, including pressure zones, pumping stations, tanks and reservoirs, water treatment facilities and pressure regulating stations, as well as water export connections to neighbouring drinking water systems.

— Identification of bulk water meters, particularly water meters at the entrances to the drinking water distribution network and network zones. For each water meter, a type should be specified, as well as diameter, date of installation and relevant information related to date of servicing, calibration and calibration data.

— List of metered and unmetered water inputs and outputs.

— Location of major water users.

— Databases of all meters, connections, DMAs, pressure-reducing valves and other major control valves.

7.2 Data validation of water balance calculation

7.2.1 Validation methods

As part of the data collection process, the accuracy of existing data should be assessed for all inputs and missing data should be identified. Initial validation of the water balance components may be undertaken through examinations of available records for any evidence of errors, detection of missing data and confirmation of correct methods for calculating the water balance from those records.

Advanced validation of data should be employed as soon as is feasible, as this provides a greater understanding of uncertainty in the water loss investigation. Additional validation methods may include the following:

— verification or calibration tests of bulk flow meters, including flow meters used to measure exported or imported water;

— verification of SIV data transfer integrity from primary measurement via secondary signal conversion to final archived value (if applicable);

— data-mining and detailed analysis of the SIV database to identify data gaps and anomalies;

— utilization of DMAs for zonal water balance and minimum flow analyses;

— field or bench accuracy testing of user meters;

— data-mining of the water use database to analyse and quantify the impacts of lag-time between timestamp for supply measurement and timestamp for water use measurement;

— analysis of water use history for profiling of meters, user classes, zero and inactive accounts, use by type, measured versus billed use, meter right-sizing and verification of use summary report totals;

— detailed analysis of user account inventory for verification of revenue-dependent field values such as rate code and meter size;

— analysis of water use for unmetered user data;

— field investigation of inactive accounts and other potential sources of unauthorized use;

— analysis and cross-referencing of any geographic information system and user databases for unauthorized use indicators;

— temporary hydrant metering for verification of estimated flow rates used in determining authorized, unmetered use volumes;

— pressure logging for refinement of average system operating pressure calculations.

Various technologies are available for use during the data collection stage to provide more reliable data. The accuracy of measurement devices, particularly meters, should be taken into account in the calculation of the water loss variables.

See Annex J on the effects of uncertainties in data. ISO 24510:2007, Annex C, also discusses uncertainties in data.

7.2.2 Data quality

Data quality should be checked to ensure that it fulfils the requirements stated in ISO 24516-1:2016, 5.4.2 (e.g. compatible, accurate, consistent, current, credible). If that is not the case or if insufficient data exists, schemes should be prepared to include all relevant parts of the system. Missing or unrealistic data should be identified.

Sources should be identified and uncertainties should be quantified for the calculation of the water balance and related performance indicators. Sources of uncertainty can include primary instrumentation, data conversion, communication, data archival and retrieval, as well as the investigator's interaction with the data and the extent to which estimations are utilized. When quantifying uncertainty, at least the following should be considered and accounted for:

— instrumentation in situ conditions;

— instrumentation management practices;

— data management practices;

— methods and instruments used in tests.

Uncertainty should be estimated quantitatively for water balance components and water loss performance indicators. See, for example, the confidence-grading scheme in ISO 24510:2007, Annex C. Quantitative assessments of uncertainty should be based on the uncertainty propagation theory.

7.2.3 Practices rating

The extent to which best management practices are employed in a drinking water distribution network can improve reliability of the underlying data used to execute the water loss investigation. Qualitative scoring or rating systems may be utilized to assess and benchmark the robustness of practices in place, and may include practices for water loss programme management, management of supply measurement instruments, management of user meters, estimation of unmetered use, information systems, data management, monitoring and analysis.

8 Water balance calculation

8.1 General

The water balance summarizes the components of water supply, water use and NRW, thus providing accountability. This is possible as all water placed into a distribution system is supposed to equal, in theory, all water taken out of the distribution system.

NOTE With the balance proposed, only direct distribution to users is considered for estimation of revenue water.

A water balance should be performed as defined in the steps listed in 8.2, see also Table 1.

Table 1 — Best practice for water balance

<table>
<tr><td rowspan="7">Volume from own sources
(corrected for known error)</td><td rowspan="12">SIV</td><td colspan="5">Exported water
(corrected for known error)</td></tr>
<tr><td rowspan="11">Water supplied</td><td rowspan="4">Authorized use</td><td rowspan="2">Revenue water</td><td rowspan="2">Billed authorized use</td><td>Billed metered authorized use</td></tr>
<tr><td>Billed unmetered authorized use</td></tr>
<tr><td rowspan="9">NRW</td><td rowspan="2">Unbilled authorized use</td><td>Unbilled metered authorized use</td></tr>
<tr><td>Unbilled unmetered authorized use</td></tr>
<tr><td rowspan="7">Water loss</td><td rowspan="4">Apparent water loss</td><td>Unauthorized use</td></tr>
<tr><td>User metering errors</td></tr>
<tr><td rowspan="5">Imported water
(corrected for known error)</td><td>Data handling errors</td></tr>
<tr><td>Unmetered use estimation errors</td></tr>
<tr><td rowspan="3">Real water loss</td><td>Leakage on transmission and distribution mains</td></tr>
<tr><td>Leakage and overflows at utility's storage tanks</td></tr>
<tr><td>Leakage on service connections up to point of user metering</td></tr>
</table>

8.2 Parameters of the water balance

8.2.1 General

The following elements of the water balance, as stated in Table 1, should be measured or respectively calculated as stated in 8.2.2 to 8.2.11. Some of these terms are defined in Clause 3; see measurement and calculation procedure of the elements of water balance in Annex A.

8.2.2 System input volume

SIV should be calculated as the sum of:

— volume from own sources; and

— imported water.

8.2.3 Exported water

Exported water should be calculated as the sum of metered or unmetered water, or both, supplied to neighbouring zones.

8.2.4 Water supplied

Water supplied should be calculated as the difference between:

— SIV; and

— exported water.

8.2.5 Billed authorized use or revenue water

Billed authorized use to users in the drinking water distribution network, which is equal to revenue water, should be calculated as the sum of:

— billed metered authorized use; and

— billed unmetered authorized use.

8.2.6 Unbilled authorized use

Unbilled authorized use should be calculated as the sum of:

— unbilled metered authorized use; and

— unbilled unmetered authorized use.

8.2.7 Authorized use

Authorized use should be calculated as the sum of:

— billed authorized use; and

— unbilled authorized use.

8.2.8 Non-revenue water

NRW should be calculated as the difference between:

— water supplied; and

— billed authorized use.

8.2.9 Water loss

Water loss should be calculated as the difference between:

— water supplied; and

— authorized water use;

or as the difference between:

— NRW; and

— unbilled authorized use.

8.2.10 Apparent water loss

Apparent water loss should be calculated as the sum of:

— unauthorized water use;

— user metering errors;

— data handling errors; and

— errors in estimates of unmetered use.

8.2.11 Real water loss

Real water loss should be calculated as the difference between:

— water loss; and

— apparent water loss.

The filling of customer storage tanks should be taken into account.

NOTE 1 The real water loss on an annual basis of an actual year is the current annual real loss (CARL).

NOTE 2 Real water loss can also be estimated from night flow measurements in DMAs using estimates of night consumption from surveys.

Real water loss may be broken down into components: leakage at transmission and distribution mains, leakage and overflows at storage tanks and leakage on service connections up to the point of the user's meter. See detailed explanation of real water loss components in Clause 11.

9 Water loss performance indicators selection

9.1 General

A performance indicator system should be adopted in order to monitor the impact of any activities on the drinking water utility's performance, to ensure a sustainable increase in efficiency and effectiveness of its operations and improved quality of service. For further detail, see 9.2 and 9.3.

9.2 Defining performance indicator purposes

In defining the purposes of performance indicators, the following principles should be considered:

— tracking progress and setting targets within a single drinking water utility or system;

— comparing technical performance between water utilities with similar key characteristics;

— communicating system performance.

The type of audience to whom the information is being communicated can also affect the appropriate performance indicator, particularly differentiating between a non-technical and a technical audience.

See additional information on performance indicators in Annex C.

9.3 Selecting performance indicators

In selecting the performance indicators, the following principles should be applied:

— fit for the intended purpose;

— clearly defined and auditable;

— quantifiable, avoiding personal or subjective appraisal;

— easy to measure;

— simple and easy to interpret meaningfully.

Selecting preferred performance indicators may be based on the list introduced in Annex C. This applies to systems with continuous 24/7 supply. If the supply is intermittent, then real water loss should be considered on a theoretical 24-h basis. For further detail, see Annex E.

10 Apparent water loss status assessment

10.1 General

Apparent water loss represents water reaching an end user who is not fully accounted for. When apparent water loss is mitigated, its associated revenue can be correctly captured by the drinking water utility.

As apparent water loss consists of unauthorized use of water (e.g. theft) and all types of inaccuracies associated with users' metering errors, errors in estimation of unmetered water use and errors throughout the data acquisition process, a disaggregated approach should be utilized for its assessment.

10.2 Analysis of user database

The audit of the available water use database enables the detection of anomalies and discrepancies. It is a prerequisite in order to define any further field survey.

The database analysis should include the following activities:

— analysis of the data acquisition process, including meter reading and data entry;

— study of the process of treating malfunctions and erroneous readings;

— demand estimations, including those for unmetered use and in the case of meter malfunctions.

10.3 Field surveys

Field or laboratory surveys should be deployed to quantify each component of the apparent water loss. The specific studies that are needed to achieve the investigation should be carried out in pilot zones or, preferably, on samples of, for example, pipes, users and meters, which can be statistically extended to cover the whole area.

10.4 Assessing unauthorized use

The level of unauthorized use is not only the consequence of poverty, dishonesty or cultural aspects; it also often results from the laxity of the drinking water utility and its poor strategy regarding social involvement and communication. Relevant solutions may include the following:

— general census in pilot areas or sampled areas, including detection of anomalies;

— partial targeted field surveys in selected areas or fields;

— targeted investigations based on preliminary analysis of the database;

— comparison with other utilities' user databases (e.g. electricity, telephone).

10.5 Assessing user metering errors

When assessing metering errors, at least the following affecting factors should be considered:

— user demand profiles;

— installation procedures;

— orientation of the meters;

— age and type of the meters;

— operating pressure;

— water quality: presence of suspended solids and particles, tuberculation in pipes, presence of air bubbles or pockets;

— intermittent supply.

Reliable prediction of metering errors necessitates testing meters in the laboratory or the field. The laboratory tests should be designed to verify the real metrology of the meters and other functioning characteristics that are not considered in the standards, such as the strength of the magnetic coupling and meters' starting flow. For further detail, see Annex E.

10.6 Assessing errors on the data acquisition process

Errors associated with the acquisition of data are sometimes much more significant than any other type of error. Errors in data can be introduced at all stages of the data acquisition process.

Assessment of the data acquisition process should refer to:

- meter reading
  - the method (manual or digital portable device or transmitted);
  - the frequency of the reading;
- data entry: method of transferring the data into the billing system (manual/digital);
- billing and accounting errors
  - erroneous calculation;
  - erroneous or misleading algorithms;
  - programming errors in the billing software;
  - quantity of estimated bills;
  - factors or criteria used for the bill estimation;
  - billing corrections;
  - discounts that are manually processed and that are not taken into account in the final statistics and results.

10.7 Assessing errors in estimates of unmetered use

In estimating the volume of unmetered use, the following two cases should be considered:

- A limited number of service connections are not measured due to some meters malfunctioning. This can occur when all the users are metered but some meters are malfunctioning. In that case, drinking water utilities should have specific procedures. For instance, they may bill the same amount as during the same period the previous year. When some devices are metered, the use should be assessed.
- Some service connections are not metered. In this case there are a number of methods which may be used to calculate household water use as described in A.4.2.

11 Real water loss status assessment

11.1 General

Real water loss represents physical water loss from the pressurized system, up to the point of user metering. When it is mitigated, its associated cost of production, purchase or both are reduced. As it comprises multiple components, a disaggregated approach should be utilized to assess it. For further details, see Annex B.

11.2 Real water loss components

11.2.1 General

After the CARL has been estimated with the water balance, the components of real water loss, namely background leakage, reported bursts and unreported bursts, should be estimated in order to establish its profile. This is necessary to determine activities in the water loss management plan.

For example, the background and bursts estimates (BABE) and fixed and variable area discharge (FAVAD) are common methods which use auditable assumptions to determine the three components that make up the annual volume of real water loss. It is common for the data required for this analysis to be incomplete and estimations to be utilized. See further description of these concepts and their associated methods and technologies in Annex D, Annex F and Annex H. The methods in the following subclauses are described in general terms.

Leakage can occur at transmission and distribution mains, service connections up to the point of responsibility of the water utility, for example the water meter, and storage tanks. To estimate the first two components, reported leaks (leaks that surface), background water loss (small, undetectable leaks) and unreported leaks (leaks that do not surface but are detectable) should be analysed and calculated for each component as described in 11.2.2 to 11.2.4. The estimation of leakage and overflows from storage tanks is described in 11.2.5.

11.2.2 Estimating reported real water loss

Records should be kept on the repair of all surface leaks. The annual volume of reported real water loss from the network should be estimated based on the number of annual reported leak events, estimated average flow rates and total leak run times, identifying average pressure and then calculating the resultant annual volume.

11.2.3 Estimating background real water loss

Background water loss should be estimated using system-specific parameters. This can be done using the unavoidable annual real loss (UARL) formula related to the lengths of mains and service pipes and the numbers of connections or any other method developed from studying the specific network.

A system-specific infrastructure condition factor, which allows for the difference between, for example, newly laid mains and ones which can be decades old, may be added.

The ICF represents the ratio of the condition of the network under investigation versus the background water loss estimate, with infrastructure in good condition, whereby:

$$V = (6{,}57 \times L_m + 0{,}256 \times N_c + 9{,}13 \times L_t) \times P_c$$

or

$$V = (18 \times L_m + 0{,}8 \times N_c + 25 \times L_p) \times P$$

where

V is the UARL in m^3/year or l/d, respectively;

L_m is the underground mains length, in km;

N_c is the number of underground service connections;

L_t is the total length, in km, of underground service connections (main to meter);

P_c is the current average operating pressure, in mH2O;

L_p is the total length, in km, of the underground pipe between the edge of the street and the customer meter.

Where there are DMAs or zones, the background real water loss may be estimated based on minimum achieved levels after intensive ALC and pressure modulation, where applicable.

11.2.4 Estimating unreported real water loss

Unreported water loss should be calculated as real water loss (8.2.11) minus the sum of reported real water loss (11.2.2) and background real water loss (11.2.3). If a drinking water utility has an ALC programme, records of unreported leaks found during any proactive leak detection (during the water loss investigation period) may be used to estimate that portion of unreported water loss which has already been addressed.

This can be done using the UARL formula related to the lengths of mains and service pipes and the number of connections or any other method developed from studying the specific network. This indicator has limitations according to the network configuration in terms of number of connections or density of connections, see Table C.3 for details.

11.2.5 Estimating leakage and storage tanks overflow

Tests should be periodically carried out in storage tanks and reservoirs to estimate leakage. The water level should be monitored and overflows should be detected and estimated.

The water loss from trunk mains may be estimated using a number of different methods, for example trunk main flow monitoring areas and internal surveys.

11.3 Bursts and active leakage control assessments

The water loss investigation should estimate the effectiveness of ALC in water loss reduction and management processes.

12 Real water loss and apparent water loss cost assignment

12.1 General

An assessment of the cost impact of all water loss investigation components should be made for the effective operation of the drinking water utility, as specified in 12.2 and 12.3.

12.2 Determining the cost impact of apparent water loss components

In the case of apparent water loss, any reduction in its volume leads to an increase of billed water. Therefore, the valuation should be assessed based on the variable component of the average water charge for direct water use.

Any unmetered portion of users should be taken into account. These should be costed as in 12.3.

12.3 Determining the cost impact of real water loss components

The total cost of real water loss can include tangible costs such as abstraction charges, power, chemicals and sludge disposal, and intangible costs such as social and environmental impact estimates. The total cost should be calculated by multiplying the volume of real water loss by its unit cost. This may be conducted for the total real water loss and for each real water loss component discussed in Clause 11.

The unit cost structure should be defined according to the water network specifics and water resource availability, and should consider the following:

— Marginal costs for extraction, treatment and delivery of an additional unit of water to the network should be calculated.

— Different hydraulic zones may need to be considered separately, as production and pumping costs can vary by zone.

— The long-term costs of water savings may be estimated and can include environmental, economic and social costs.

— Imported bulk water purchase charges should be calculated and applied where water loss has an impact on the quantity of imported water.

— In the case of water scarcity, where water loss savings are used as an alternative to new water source development, the unit cost of the new alternative sources should be considered.

— In cases where user water restrictions are in effect or there is demand for more water connections which cannot be catered for with existing water resources, the saving of real water loss can increase the sale of equivalent volumes of water to users. The unit cost of the real water loss savings yielding increased demands may be valued at the retail rate.

13 Water loss management plan preparation

13.1 General

13.1.1 Introduction

The ultimate goal of any water loss investigation should be to create the basis for an effective water loss management plan. This clause puts water loss investigation in the context of the whole planning and activity implementation process and an asset management plan as described ISO 24516-1.

The water loss management plan should refer to the following main stages:

— definition of the objectives and the corresponding performance measurement system, which should include criteria, metrics and targets;

— diagnosis to identify the components of water loss and any issues to reduce them;

— priority setting and activity definition, scheduling and budgeting, as well as human and technological resource allocation;

— plan implementation of operational projects;

— monitoring by the comparison between initial and ongoing performance indicators and corresponding targets and evaluation of the degree of implementation of each activity.

13.1.2 General principles of a water loss management plan

The following principles of a water loss management plan should be considered:

— A water loss investigation should include the calculation of the water balance and water loss performance indicators, together with information about the water supply system, its current status and current operational, management and rehabilitation practices.

— The preparation of a water loss management plan should be based on a water loss investigation.

— A water loss management plan should include activity scheduling and budgeting as well as human and technological resource allocation.

— The water loss management plan should address activities to reduce real water loss and apparent water loss, and additional activities (e.g. training, information management) as required for the transition from the current level of water loss to the short- and long-term targets. The water loss management plan may also address the management of unbilled authorized use that, although not water loss, contributes to the NRW.

— A water loss management plan should be aligned with the drinking water utility's strategies, taking into consideration external factors such as electricity tariff, resource availability (particularly water-related), environmental impact and public water policies.

— A water loss management plan should outline the corporate objectives and assessment criteria. Besides economic goals, water loss management also contributes to improving other dimensions, including the level of service, the physical asset sustainability and the environmental sustainability.

— The water loss management plan should contain, for each assessment criterion, the corresponding performance indicator(s) and target(s), as part of the performance assessment system (see 9.3). Performance indicators should be understandable, transparent, consistent and straightforward. Targets should be sustainable in the long term and flexible in the short term. Target setting should take into account local regulatory requirements and influencing factors, namely topography, network topology, current infrastructure condition, water, human, economic and technological resources and demand projections.

— A water loss management plan should include a statement of the current situation, priority setting and activity definition based on the results of the water loss investigation and on the use of the performance assessment system.

— The planned activities may be combined and implemented through discrete projects. Project implementation should be monitored in order to provide the necessary feedback for the continuous improvement of the whole water loss management process.

— The water loss management plan should also address monitoring and revision procedures, responsibilities and frequency. Monitoring should be supported by the use of the performance assessment system. The revision consists of the assessment of differences relative to defined targets and implementation of corrective activities that ensure the fulfilment of the objectives established in the water loss management plan.

13.1.3 Water loss management plan stages

The water loss management plan should refer to the following main stages:

— Provisional long-term target programme. Addressed to achieve the water loss reduction targets and maintain water loss at an optimized level, which can vary depending on external factors such as electricity tariffs and resource availability.

— The provisional glide path. Annex G shows the principal activities required for transition from the current level of water loss to the provisional short- and long-term targets. The water loss management plan should include annual water loss targets and the investment required for the various leakage management options.

13.1.4 Water loss management plan investments

When preparing the investment plan to meet the water loss reduction targets, operational expenditure (opex) and capital expenditure (capex) actions should be broken out. The investigation should include the assessment of capex financing options, whether internal or external. It should also explore whether the water utility has sufficient cash flow to meet the opex components. If financial sources are not sufficient, plan and target reviews should be made.

13.2 General principles for apparent water loss management

13.2.1 General

Water utilities should select appropriate activities for apparent water loss management, taking into account the water tariff structure, the social context, security issues, water use profile and the factors that affect the accuracy of users' meters.

13.2.2 Unauthorized water use

Unauthorized water use can occur through illicit hydrant access, meter tampering, meter bypass, illicit tappings installed on a water main and other means. Detection of unauthorized water use may include activities to find and control illegal connections, tracking meter bypassing, installing magnets and reversing meters to prevent the illegal use of hydrants and actively checking the user billing system.

A policy should be in place to establish the appropriate penalties or actions for unauthorized water use. This policy should be consistently enforced when unauthorized water use is discovered.

13.2.3 User metering errors

User meters can experience measurement inaccuracy which results in apparent water loss. Measurement inaccuracy can occur due to, for example, meter wear, poor installation, poor siting and hydraulic conditions, and incorrect meter selection for a given application.

Activities for the management of user meters may include adequate selection and sizing of water meters, the quality of control of procured meters, the control of water meter installation and adoption of adequate tests, maintenance and replacement schedule for the meters.

13.2.4 Data handling errors

Activities to reduce meter-reading errors may involve training and motivation of the meter readers to register and report data efficiently. Errors due to incorrect written data, incorrect data processing by the billing system or invoicing mistakes may involve improving existing billing and user databases.

An automated data collection process may be used to help avoid errors. Misplaced decimal separators may be discovered by review of the user account database and a plausibility check of the user invoice.

Cut-off errors appear due to reading meters after or before a cut-off date, user meter readings at various points during the year and extrapolation of reading sums for a reading period that differs from the accounting period. Cut-off errors may be estimated by, for example, comparing data from a number of previous years when the reading period is consistent and there were similar weather conditions.

13.2.5 Unmetered use estimation errors

Short-term improvement in unmetered use estimation errors may be accomplished by increasing the statistical rigor of sampling and estimation methods. Long-term improvement in unmetered use estimation errors may be accomplished by expanding the portion of users who are metered, thereby reducing the portion of users who are unmetered.

13.3 General principles for real water loss management

13.3.1 General

Drinking water utilities should select appropriate methods to investigate leakages and overflows, taking their operational and regional restrictions into account.

Further information on the drinking water distribution network, its current status regarding its technical condition and zoning should be collected as a preliminary stage for generating a water loss management plan.

Achievement and sustainment of low leakage levels requires a thorough understanding of the complex interplay between many different parameters, and the influence of past and present management decisions.

Drinking water utilities should implement adequate measurements such as improved system rehabilitation, construction of DMAs and pressure management and ALC to improve the water loss situation.

13.3.2 Management plan of district metered areas

13.3.2.1 Managing real water loss using district metered areas

A district metered area (DMA) is defined as a discrete area of a drinking water distribution network. It is usually created by closing boundary valves so that it remains flexible to changing demands. However, a DMA may also be created by permanently disconnecting pipes to neighbouring areas. Drinking water flowing into and out of the DMA is metered and flows are periodically analysed in order to monitor the level of leakage. DMAs can principally be categorized into three different types: single inlet DMAs, multiple inlet DMAs and cascading DMAs.

The DMA assessment should be performed by a desktop study or by using a hydraulic model, if available, for a preliminary study in order to identify potential zones, installation points and benefits and costs.

Virtual DMAs may be established. This is a concept of monitoring and identifying leaks throughout the entire drinking water distribution networks without creating actual DMAs or a sub-DMA. Instead, flow meters are installed at key positions in order to create "virtual DMA zones" (see Annex I).

13.3.2.2 DMA design

For any DMA design, the following should be considered:

— the current leakage level using minimum night flow (MNF) (see Annex K) and water balance;

— the target level of leakage in the system;

— the improvement of operation of the network;

— the variation in topography;

— the type factors: urban, rural, industrial or other;

— the available technologies for ALC and event management: advanced technologies such as event management systems, burst detection, automated meter reading that enables larger DMAs;

— the individual drinking water utility preference: discrimination of service pipe breaks, ease of leak investigation deployment;

— the hydraulic conditions: limitations in closing valves, minimum and maximum pressure requirements, local standards of service;

— the topology of the current water network: for example, structure of drinking water distribution network, water source, location of mains and inlet pipes;

— the minimum flow and pressure, as well as fire flow requirements;

— the ability to maintain adequate drinking water quality when employing additional closed valves.

13.3.2.3 DMA management plan

Once set up, DMA structures should be reviewed regularly to ensure that they are still appropriate.

13.4 Planning an active leakage control management plan

Active leakage control should consist of managing the duration of unreported leaks by looking for them, finding and repairing them. Although a small proportion of unreported leaks can be visible (usually in inaccessible locations), most unreported leaks do not surface and should be detected and repaired in order to maintain the target level of leakage.

The management plan for ALC should include the following:

— Selection of ALC method: may be performed by one or more of the available tools, such as acoustic leak detection investigations, fixed acoustic leak detection, ground-penetrating radar (GPR), satellite pictures analysis, event management software tools based on flow and pressure metering, and gas tracing. These are described in Annex H. The ALC method should be chosen according to its performance given the specifications of the water network such as budget, material, condition of pipes and type of soil.

— Detailed activity plan for leak detection investigations: size, frequency, benefits and costs.

— The speed and quality of repairs are also critical for the cost-effective reduction of physical water loss and the plan should consider whether this area needs to be improved.

The financial analysis of ALC should be generated by comparing cost versus water loss estimated reduction.

13.5 Pressure management

Pressure management may be considered a first approach to reducing leakage and water loss. However, it does not eliminate the need to find and repair leaks in the short term or the need to rehabilitate or replace pipes in the longer term. Reducing the pressure can also worsen the service to users, especially those living in upper floors of multistory buildings without booster pumps. This should be considered in assessing the feasibility of pressure management.

Fulfilling minimum pressure and flow conditions at critical point locations should be taken into account when determining candidate pressure management areas.

The influence of pressure on leakage flow rates should be examined via the following steps:

a) A preliminary assessment which includes:

   — Identification of areas with potentially high or excessive pressure and a preliminary design of pressure control areas with an estimate of pressure reduction.

   — Analysis of water use to identify if reduced pressures might affect this and assessment of the impact on revenue.

   — Preliminary cost-benefit analysis: an initial estimated cost-benefit assessment should be calculated to identify the economic feasibility for real water loss recovery in the pressure management scheme. Approximations relying upon operator knowledge and preliminary estimations may be used at this stage.

   — Identification of options for management of pressure, which may be achieved by pressure regulating devices or changes in supply network configuration.

b) Selection of test areas: existing DMAs or temporary closed areas should be selected, representing the water loss investigation area by type of pipes and topography.

c) If applicable, pressure step tests should be performed to assess the impact of pressure reduction on leakage by reducing inlet pressure to the area in increments or “steps”, resulting in reduction of inflow rate and average zone pressure.

d) A pressure management plan, defining the required supply pressure and means for static or dynamic pressure modulation (see Annex L), should be developed.

13.6 Improved system maintenance and rehabilitation

Adequate maintenance and rehabilitation of drinking water distribution network assets are crucial for short-, medium- and long-term real water loss management. The principles of this activity are covered in more detail in ISO 24516-1. Management of the drinking water distribution network assets requires priority setting and decision-making on whether to restore or upgrade the performance of existing assets, while simultaneously planning other activities, such as pressure management or ALC for short-term and medium-term real water loss management. Effective decision-making requires a balance between the desired performance and the acceptable risk level, while attaining the least possible overall life-cycle cost of assets, in full alignment with the water utility’s objectives.

14 General principles for water loss target setting

Water loss is an important indicator of the state of the drinking water distribution network. While most short-term improvements can reduce water loss in the near term, adequate rehabilitation or replacement of the distribution network is essential in the longer term. Prudent usage of water is a fundamental requirement for effective operation of a water utility, and water loss targets should be developed to guide water loss intervention measures.

The aim of the water utilities should be to reach and maintain appropriate water loss levels. The following principles for water loss target-setting should be considered:

— sustainability in the long term and flexibility in the short term;

— practical to apply, in relation to data and analytical requirements;

— consideration of system-wide and zonal water loss levels;

— economic considerations for efficient operations.

Targets should take into account specific local conditions, including:

— water resources (actual and future demand);

— water quality and public-health-oriented operation;

— water costs (extraction, treatment, import, distribution);

— economical aspects (costs of water loss, efficiency of operation, demand on rehabilitation, costs of water loss intervention measures);

— topography (necessity of pressure zones or DMAs, pressure management);

— network topology and spatial characteristics;

— technical aspects (e.g. bedding condition, soil and groundwater condition);

— infrastructure condition and its effects on the economics of ALC and the need for investment in network asset management;

— quality of service;

— regulatory requirements;

— sustainability of measures, scarcity of drinking water supply and other environmental aspects.

Both near-term and long-term water loss targets should be developed. The result of all measures regarding water loss reduction should be analysed on the whole system and, if applicable, on a zonal and DMA structural basis at least once a year. As intervention measures are implemented and evaluated, or as specific local conditions change, both targets and measures should be updated accordingly.

15 Example of an organizational structure for the management of non-revenue water

The water utility should be responsible for the water loss investigation and management, and determine the number and qualifications of employees responsible for the problem of NRW in the drinking water distribution network.

Areas of activity which should be included in NRW management are:

- NRW planning, monitoring and training
- data collection and validation
- DMA management
- water balance calculation and PI
- apparent losses
- unauthorized use
    - metering error and meter management
    - acquisition and estimation errors
- real water loss
    - construction control
    - bursts and ALC
    - pressure management
- cost management

The water utility should be structured to manage these activities. Some activities may be outsourced to a suitably qualified contractor, in which case the facilities to manage and monitor the performance of that contractor should be included.

Annex A
(informative)

Additional guidance on how to measure or calculate elements of water balance

A.1 General instructions

A.1.1 General

— Records and data should be assembled from a wide variety of operations in the drinking water utility, and from multiple data sources. Procedures and contacts should be established for the collection of this data.

— All data associated with water balance and performance indicator calculations is likely to include errors and uncertainties.

— During the water loss investigation process, the reliability and accuracy of information sources should be taken into account: who provides the data, in what format and in what degree of confidence.

— After assessing a 'best estimated' value for each input parameter, confidence limits should be assigned for the parameter.

— Data collection and data processing should be documented: data sources, data collection methods, assumptions and calculations performed.

— Various software tools are available for the calculation of the water balance and the performance indicators.

A.1.2 System input volume

a) Data from each entry point should be collected, including imported sources and input volumes from the drinking water utility's own sources, such as utility treatment works, wells or desalination plants.

The method for data collection at the entry points can be manual or transmitted from a monitoring system.

b) At points where there is no measurement device, or a faulty water meter, a measurement system may be installed temporarily for the purpose of the water loss investigation.

c) The SIV is calculated as the difference between the meter reading at the end of the investigation period and the meter reading at the beginning of the investigation period and should be corrected from systematic metering errors before entering the water balance.

d) Water supply data should be calculated from all sources specified to the defined water loss investigation period. If no data exists for the entire period (missing data history) or if there are unmeasured points, an estimation of the annual amount should be made based on existing data.

e) A data error estimation should be performed, including measurement error: in water supply and demand variations, reading errors, collecting and data errors.

f) The amount of water entering the network should be calculated as a sum of total inputs to the network.

g) Drinking water of imported sources and drinking water input from the drinking water utility's treatment works should be quantified. The total can be accumulated as drinking water of imported sources and input from the drinking water utility's treatment works.

A.2 Exported water (metered or unmetered, billed or unbilled)

a) It should be determined if exported water is applicable for the water system.

b) If applicable, the methods described in 7.2 should be used for the data collection and calculation of the exported water volumes.

A.3 Calculating water supplied

Water supplied is simply the difference between SIV and exported water.

A.4 Determining billed authorized use

A.4.1 Billed metered authorized water use

a) The existing system for water meters should be documented in a file to include water meter details including address, serial number of the water meter, type and diameter of water meter, type of user (e.g. industrial, trade, urban gardening), date of installation, final call, status.

b) The water meters should be divided and authorized by category of use (e.g. private, industrial), diameter of water meter and method of data reading (manual, terminal and remote).

c) The amount of water measured should be summed in each water loss investigation period.

d) Date-reading times should be normalized according to the water loss investigation time periods, usually years.

A.4.2 Billed unmetered authorized water use

A.4.2.1 General

It is not always possible or acceptable to meter all properties, particularly domestic properties. Therefore, a method of estimating the water use of unmeasured properties should be used. Different methods have varying levels of accuracy and cost and can be more or less appropriate depending on the percentage of properties not measured. All approaches introduce some level of uncertainty into the water balance and the acceptable level should be taken into account. Errors will be reduced if some sort of segmentation of households on the basis of, for example, likely occupancy, income or size can be carried out.

NOTE It is frequently the case that a small percentage of the users represents a large proportion of the water use.

A.4.2.2 Methods

A.4.2.2.1 General

Two main methods have been developed as listed in A.4.2.2.2 and A.4.2.2.3.

A.4.2.2.2 Individual property monitors

This approach uses properties which do not pay charges based on a measured quantity of water. A meter is installed to measure the flow into the property for the use of the drinking water utility only. This may be done with the cooperation of the householder, in which case additional information can be collected such as the number of people in the household and the number of water-using appliances, or the monitoring can be done 'blind', i.e. without involving the householder.

A.4.2.2.3 Small area monitors

In this, the total flow into a small area is measured and any measured flow is subtracted. The remaining flow is divided between the properties in the monitor plus any allowance for leakage within the drinking water utility's network. This approach can also be used for blocks of apartments where each one cannot be individually measured.

a) All service connections should be divided and summarized by categories of use (e.g. private, industrial).

b) For residential users, the evaluation should be reached by multiplying the number of occupants with the amount of specific water use per person or per property. The measured average drinking water use should be used as a basis and multiplied, if necessary, by a factor for excessive drinking water use without measurement.

c) For a non-residential user, the amount of water used should be evaluated based on similar metered users.

d) If possible, measuring accessories should be added, such as a temporary water meter or a regional water meter, to assess every type of user in the region. Installation should be done according to accepted methods, including specifications of the equipment and installation requirements.

A.5 Non-revenue water

A.5.1 General

The total volume of NRW should be calculated as water of imported sources and input from drinking utility treatment works minus billed authorized use and exported billed water.

A.5.2 Unbilled metered authorized water use

Types of unbilled metered authorized use should be inventoried, including firefighting, pipeline washing, water facilities, public gardening and public institutions use.

The procedure for summation should be repeated, as specified in A.4.1.

A.5.3 Unbilled unmetered authorized water use

Types of unbilled unmetered authorized use should be inventoried, including firefighting, pipeline washing, water facilities, public gardening and public institutions use.

Estimation methods should be documented and the summation procedure should be repeated, as specified in A.4.2.

A.6 Water loss

Water loss, i.e. the difference between water supplied to the network and authorized water use, should be calculated. It can also be calculated as the difference between NRW and unbilled authorized water use.

A.7 Apparent water loss components

A.7.1 General

In the case of apparent water loss, field investigations and laboratory experimentation or measurements should be made to quantify each component of the apparent loss. At a very preliminary stage, current annual apparent water loss (CAAL) can be assessed through a benchmarking approach. However, because there are so many parameters, confirmation from field investigations should be obtained before any meaningful strategies are developed.

Table A.1 provides selected examples of the numerous causes for apparent water loss, classified by categories and subcategories, together with recommended methods for evaluating their magnitude.

Table A.1 — Causes of apparent water loss and methods for evaluation

Categories of AL	Subcategories of AL	Cases	CAAL method for evaluation	UAAL applicability
Errors through data acquisition cycle	System input and water supplied	Error in bulk metering	Calibration procedures (protocol of calibration)	No
		Error in data capture and transmittance	Technical audit	No
	Errors in user metering	Manual or semi-manual meter reading	Sampling and field investigation	No
		Automatic meter reading	Technical audit	No
	Data processing errors	Billing system errors	Billing system and procedures audit	No
		Errors in other data manipulation	User management and procedures audit	No
Metering errors	Meter errors (small meters)	Meter aging	Sampling/user profile/meter errors graph	Yes (but difficult)
		Inappropriate meter installation	Sampling and field meter tests	No
		Impact of user's in-house installation	Sampling/census/laboratory tests	Yes (but difficult)
	Meter errors (large meters)	Meter aging	Sampling/user/profile/meter errors graph.	No
		Meter oversizing	Sampling/user profile/meter errors graph	Yes (but difficult)
		Inappropriate meter installation	Sampling and field meter tests	Yes (but difficult)
		Impact of user's in-house installation (domestic tanks for instance)	Sampling/census/laboratory and field tests	Yes (but difficult)
	Meter management	Meter out of operation	Sampling and meter tests	No
		Errors in meter reading	Computer analysis/field check	No
		Estimated meter reading	Computer analysis/field checking	No
NOTE In the case of sampling investigations, the extrapolation can only be considered as valid when the sampling procedure is valid. The confidence limits of the CAAL values relate to the choice of the sampling procedures.				

Table A.1 *(continued)*

Categories of AL	Subcategories of AL	Cases	CAAL method for evaluation	UAAL applicability
Unauthorized water use	Registered users	Meter bypass and other fraud	Sampling and field investigations	Yes (but difficult)
		Additional unregistered connections	Sampling and field investigations	Yes (but difficult)
		Disconnected users illegally reconnected	Sampling and targeted field investigations	Yes (but difficult)
		Non-active users illegally reconnected	Sampling and targeted field investigations	Yes (but difficult)
	Unregistered users	Unregistered (illegal) connection	Sampling and field investigations	Yes (but difficult)
		Unregistered water use in low income areas	Sampling and field investigations	Yes (but difficult)
	Network equipment	Water theft from hydrants or other equipment	Sampling and field investigations	Yes (but difficult)
Misestimate of unmetered water use	Small users		Sampling and field investigations	Yes (but difficult)
	Large users		Meters must be installed	No
NOTE In the case of sampling investigations, the extrapolation can only be considered as valid when the sampling procedure is valid. The confidence limits of the CAAL values relate to the choice of the sampling procedures.				

A.7.2 Field and laboratory investigations

Pilot areas and samples should be selected such that the results obtained can be realistically extrapolated. If the samples have been properly defined and based on a scientific statistical approach, the sampling approach should be used.

Several pilot areas representing the various parts of the city, and based on urbanism and social criteria, should be selected.

A.7.3 Unauthorized water use investigation

A mini pilot census should be made to receive a first indication on the importance of possible fraud and other anomalies, which could exist between the field reality and the technical and user databases.

The investigations should cover 3 % to 5 % of the users, who should be selected according to geographical location, category and social condition. Users' zero or abnormal low use, and cut-off users, should also be investigated.

The following ratios should be calculated:

— total number of illegal users/total number of inactive users visited;

— total number of non-registered users/total number of users visited;

— total number of fraud on the water meters/total number of meters;

— percentage of anomalies found in the field with respect to the data on the existing files.

A.7.4 Data handling and billing estimation errors investigation

This type of water loss can be the result of incorrect tariff application, meter reading errors or absence of reading, billing corrections or discounts not being taken into account.

The different levels of associated activities should be investigated, for example installation of a meter, meter reading, back office and front office or bill delivery. The errors and the anomalies should be the subject of detailed investigations that can call into question, and improve, the procedures.

In meter reading, the following should be the subject of a specific analysis or audit:

— quantity of unread meters (why and since when?);

— critical analysis of the meter reading;

— control of unread meters (e.g. inspection);

— quantity of estimated bills;

— factors used for the estimation.

A.7.5 Under-measurement

Under-measurement errors are most often found in the oversizing and ageing of the meters, which leads to a progressive deterioration of accuracy.

Several types of analysis should be conducted:

— structure of meter fleet and detection of the large users – it is frequently the case that 3 % to 4 % of the users account for more than 50 % of the total water use;

— verification via the user database of the probability of the oversizing of the large user meters;

— verification of samples of meters using data loggers;

— definition of the water use profiles for each type of user;

— laboratory testing to establish error graphs of meter samples of different ages and volume use.

A.8 Real water loss

Real water loss is calculated as the difference between water loss and apparent water loss. It can also be calculated as NRW minus unbilled authorized use and apparent water loss.

Annex B
(informative)

Factors affecting real water loss

Real water loss is affected by the following factors:

- Factors affecting the network
  - length of mains;
  - number and density of connections, number and length of service connections;
  - number, density and functionality of valves;
  - service pressure;
  - dynamic pressure fluctuation (water hammers);
  - failure rate (depending on materials, jointing techniques, age structure, corrosion protection, quality of installation);
  - quality of installation and repair;
  - character of soil;
  - climatic conditions;
  - quality of storage to avoid degradation due to damage or exposure to UV light.
- Drinking water quality (influencing corrosion)
- Operation and maintenance
  - intensity of monitoring and inspection on detection of leakages (frequency of inspection, permanent flow metering);
  - rapid repair of leakages, effectiveness of rehabilitation regarding limiting duration of leakages and sustainability of elimination of deficiencies;
  - approach to operating valves promoting or interfacing with a calm network.
- Locality
  - depth of cover in relation to penetration of frost, heat and traffic loads;
  - periods of extreme cold;
  - traffic load and soil movements regarding stress input;
  - bedding, soil characteristics and ground water level regarding external corrosion.
- Crucial soil characteristics
  - corrosiveness of soil, in general increases from granular soil (rock, gravel, sand) to cohesive soil (loam, clay);
  - soil movements (particularly when the soil moisture is changing);
  - detectability of leaks at the surface.

Annex C
(informative)

Performance indicators

C.1 List of performance indicators

Performance indicators are listed in Table C.1.

NOTE It might appear logical to assume that length of system allows for more of the key factors than number of connections or length of mains. However, it was the experience of all the IWA WLSG members that (except at low density of connections) in well-run systems the majority of leaks and bursts (and of the annual volume of real water loss) occur on service connections rather than mains, with most frequent problems in the section of the service connection between the main and the edge of the street. The WLSG therefore recommended that the basic traditional PIs with the greatest range of applicability for real water loss are:

l/connection/d (if service connection density is < 20) and

l/km/d (if service connection density is > 20)

Table C.1 — List of performance indicators

Purpose	Performance indicators	Units	Other relevant criteria
Financial	**NRW by volume** NRW/(SIV – exported water) × 100 NRW (m^3); SIV (m^3)	%	This indicator may be used for drinking water distribution networks. Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.
Operational	**Water loss per mains length** (Water losses during the assessment period × 365/ assessment period)/mains length with: water losses (m^3); mains length (km); assessment period (days)	m^3/km/year	This indicator may be used for bulk supply and low service connection density distribution systems (i.e. with less than 20 service connections per km). Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.
Operational	**Water loss per connection** (Water losses during the assessment period × 365/ assessment period)/number of service connections with: water losses (m^3); service connections (no.); assessment period (day)	m^3/connection/year	This indicator may be used for drinking water distribution networks (i.e. with more than 20 service connection per km). Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.

Table C.1 *(continued)*

Purpose	Performance indicators	Units	Other relevant criteria
Operational	**Real water loss per mains length** Real losses during the assessment period × 24/ number of hours system is pressurized during the assessment period × 1000/ mains length with: water losses (m^3); mains length (km); time system is pressurized (hour)	l/km/d when system is pressurized	This indicator may be used for transmission systems and low service connection density distribution networks (i.e. with less than 20 service connections per km). Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.
Operational	**Real water loss per connection** Real losses during the assessment period × 24/ number of hours system is pressurized during the assessment period × 1000/ number of service connections with: real losses (m^3); service connections (no.); time system is pressurized (hour)	l/connection/d when system is pressurized	This indicator may be used for drinking water distribution networks (i.e. with more than 20 service connections per km). Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.
Operational	**Infrastructure leakage index** Real losses/technical achievable low level of real losses (when system is pressurized)	—	This indicator may be used to compare different systems on a common basis. Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.
Operational	**Apparent water loss** Apparent losses/(SIV – exported water) × 100 with: apparent losses (m^3); SIV (m^3)	%	This indicator may be used for drinking water distribution networks. Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.
Water resources	**Inefficiency of use of water resources** Real losses during the assessment period/SIV – exported water) with: real losses (m^3); SIV (m^3)	%	This indicator may not be used as a measure of efficiency and condition of system assets (trunk mains, transmission mains) but it may be used for drinking water distribution networks. Limitations for each performance indicator should be considered to accommodate key local factors at each water network, see C.2.

C.2 Limitations of performance indicators

C.2.1 Performance indicators versus key factors

The basic traditional performance indicators for real water loss, which are most widely used in different parts of the world to make comparisons of the annual volume of real water loss, are:

— percentage of input volume;

— volume lost per length of mains per unit time;

— volume lost per user per unit time;

— volume lost per service connection per unit time;

— volume lost per length of system per unit time (where length of system = length of mains + length of service connections up to point of user metering).

Traditional performance indicators for real water loss appear to be selected on the basis of the simplicity of calculation, country tradition, availability of data for the calculation or even the impression of performance. However, the differences can be substantial. The proper basis of selection should be the performance indicator that gives the most rational technical basis for comparisons. Table C.2 shows the limited extent to which each of the traditional performance indicators take into account the key local factors (other than ground conditions) which influence real water loss.

Table C.2 — Performance indicators versus key local factors

Basic traditional performance indicator for real water loss	Continuity of supply	Length of mains	Number of service connections	Location of user meters on services	Average operating pressure
% of volume input	No	No	No	No	No
Per user per day	No	No	Only if one user/ connection	No	No
Volume per service connection per day	No	No	Yes	No	No
Volume per length of mains per day	No	Yes	No	No	No
Volume per length of pipes in system	No	Yes	Possibly	Yes	No

C.2.2 Use of percentage

Table C.2 shows that real water loss expressed as a percentage of system input does not take account of any of the key local factors. Instead, under continuous supply conditions, the average rate of water use (which is not a primary explanatory parameter) dominates the calculated value. If real water loss average is 100 l/connection/d, then real water loss as a percentage of system input would be:

— 29 % for water use of 250 l/connection/d;

— 17 % for water use of 500 l/connection/d;

— 9 % for water use of 1 000 l/connection/d;

— 2 % for water use of 5 000 l/connection/d;

— 1 % for water use of 8 000 l/connection/d.

C.2.3 Use of ILI

Components for background leakage, reported and unreported leaks and bursts are based on clear and auditable assumptions for frequencies, flow rates and durations of leaks, at 50 metres pressure. These are shown in Table C.3. Lower limits for density of connections, average pressure and system size have always been recommended for application of the UARL formula. Table C.3 shows changes in these limits between 1999 and 2009 which reflect the increasing international use of ILI and snapshot ILI (derived from night flows) for small systems and DMAs.

Table C.3 — Changes in limits of application of UARL formula, 1999 to 2019

Parameter	Limits	Lambert et al., AQUA	Lambert and McKenzie	Liemberger and McKenzie	Lambert	Lambert
		1999	2001	2005	2009	2019
Density of connections/km	Minimum	20	20	Removed	No lower limit	No lower limit
	Maximum	100	Removed		No upper limit	No upper limit
System size	Minimum	Not stated	$Nc > 5\ 000$	$Nc > 3\ 000$	$Nc > 3\ 000 - 20 \times Lm$	If $Nc < 5\ 000$, or $P < 40$ or > 60 SCF calculation recommended
Average pressure P (m)	Minimum	20	25	25	See graph	
	Maximum			See graph		

SOURCE: Lambert (2019) in https://www.leakssuitelibrary.com/uarl-and-ili/. Used with permission.

ILI is the multiple obtained when the system's CARL in m^3/year is divided by the system's UARL in m^3/y. As the current pressure regime could not be optimal, ILI should be interpreted with some measure of pressure and only used for tracking progress if all justifiable pressure management has already been completed.

Annex D
(informative)

Bursts and background estimate (BABE)

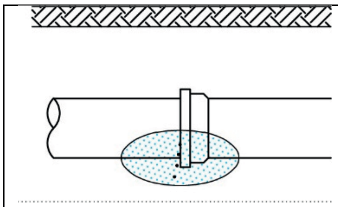
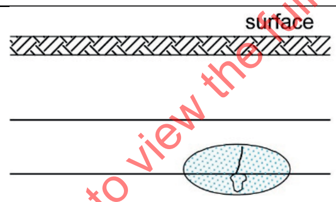
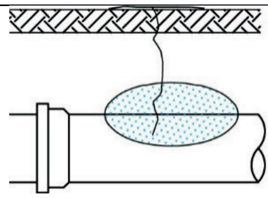
One of the keys to understanding the control of real water loss is component analysis of real water loss. The BABE concept uses auditable assumptions to calculate, from first principles, the components that make up the annual volume of real water loss[25].The leaks occurring in any drinking water distribution network are considered conceptually in three categories, as shown in Figure D1.

— Background leakage: small leaks at joints and fittings, not detectable using current methods.

— Reported bursts: events with larger flows, which are visible or which cause problems and are reported to the water utility.

— Unreported bursts: significant events that do not cause problems and can only be found by ALC.

Component analysis can be used to estimate the number of leaks. If the number of reported leaks is known and the ratio of mains leaks to service pipe leaks is assumed or derived from previous repair information, an estimate of the number and type of leaks may be made.

		
Background leakage	**Unreported leakage**	**Reported leakage**
Unreported and undetectable	Often does not surface but is detectable	Often surfaces and is reported by public or utility workers
Tools	Tools	Tools
Pressure stabilization	Pressure stabilization	Pressure stabilization
Pressure reduction	Pressure reduction	Pressure reduction
Mains and service pipe replacement	Mains and service pipe replacement	Mains and service pipe replacement
Reduction in number of joints and fittings	Reduction in number of joints and fittings	Reduction in number of joints and fittings
	Proactive leak detection	Optimized repair time

SOURCE BABE (Background and Bursts Estimates) concept for types of leakage (Lambert, 2009). Used with permission.

Figure D.1 — Typical characteristics of background leakage, reported and unreported leaks

The larger detectable events are usually referred to as bursts, while those too small to be located (if not visible) are referred to as background leaks. The threshold between bursts and background leaks can vary from country to country, depending upon factors such as minimum depth of pipes, type of ground and surface.

Using the BABE concept, Table D.1 shows other types of leaks that would lose the same volume of water (200 m^3) as the mains burst running for 8 h.

Table D.1 — Water loss volume of leak examples

Example of leak or burst	Average flow rate		Average run time	Volume lost
	l/h	m^3/d		m^3
Reported mains burst	25 000	600	8 hours	200
Unreported service connection leak	500	12	17 days	200
Reported but unrepaired service leak	100	2,4	12 weeks	200
Leaking valve or hydrant	33	0,8	8 months	200
Leaking toilet	15	0,4	16 months	200

SOURCE: Lambert, A. *Improving international management of leakage – The hidden water resource.* Acknowledgement: Jairo Tardeli Filho, Sabesp, Brazil. Used with permission.

Annex E
(informative)

Water loss investigation for intermittent supply networks

E.1 Step 1: intermittent water supply problem analysis

The first step in a water loss investigation for an intermittent water supply should be to analyse why there is intermittent water supply and to what extent.

If time, funding or expertise for a full water investigation is not available, at least an initial audit, or rapid NRW assessment, should be made. It is a simple, fast and usually inexpensive methodology to get a first understanding of the NRW situation in a drinking water utility. It is a precondition for understanding the magnitude of the IWS problems and the possibilities of transitioning to 24 × 7 supply. The following steps should be followed:

1) Collect all necessary information required to determine the following:
   a) daily volume of NRW;
   b) average supply time;
   c) average pressure;
   d) number of service connections.
2) Determine the annual average daily volume of NRW. Review available records, identify possible irregularities and determine the most likely average daily volume. Review billed water use data, both billed metered and billed unmetered, and determine the annual daily average volume of billed water use.
3) Calculate the average daily supply time. Identify areas with different supply times, determine the approximate number of service connections of each area and calculate a weighted average supply time using the number of connections as weighting factor.
4) The average pressure in a certain point is the 24-h average. Pressures are recorded with electronic pressure loggers for at least a 24-h period at each point. If no pressure loggers are available, pressures during low-pressure periods and high-pressure periods (usually night-time pressures) should be measured with pressure gauges. Identify areas with different pressure characteristics, measure pressures and calculate average pressure for each area. Determine the approximate number of service connections of each area and calculate a weighted average pressure using the number of connections as weighting factor. Only pressure during supply hours may be used in the calculation.
5) Determine the number of service connections (SC), which is in many cases not equal to the number of users. Only in cases where each user is supplied by an individual service connection does the number of connections equal the number of users. If, for example, every single condominium in a building is considered one user, then the number of service connections will be significantly less than the number of users (one condominium building can consist of, for example, 100 users but is supplied by only one service connection).

If the volume of NRW is not known:

— System input volume: if the SIV is not metered, short time measurements with portable flow meters should be made. At least crude data on the average daily SIV should be gathered.

— Use: if use is not metered, the actual water use should be understood. For this, water meters should be installed, ideally high-accuracy meters with data loggers, at about 100 truly randomly selected domestic users. Users should be metered for at least one week. Then apply the average water use per user/d and capita/d. The use of non-residential users (commercial, institutional, industrial) should be assessed separately. Once this is done, the total water use (whether billed or unbilled) of the area can be calculated.

E.2 Step 2: water loss performance indicators

E.2.1 General

After completion of the drinking water investigation or the rapid NRW assessment, the physical water loss performance indicators should be calculated.

Real water loss is expressed in litres per service connection per day per meter (head) average pressure and adjusted for the average daily supply time: l/connection/d/m (wsp).

NOTE 'wsp' stands for 'when the system is pressurized' and means that the value of a performance indicator is adjusted (extrapolated) to the level it would have under continuous (24 × 7) supply conditions.

E.2.2 Step-by-step instruction

The following steps should be followed:

1) Determine daily volume of real water loss. These are the different scenarios:

   — Water loss investigation: simply take average daily volume of real water loss from the water balance.

   — Metered use data available but no water balance: assume volume of real water loss = 90 % of the volume of NRW.

   — Use data not available and use measurements have been carried out: [real water loss] = [SIV] – [calculated volume of water use].

2) Divide average daily real water loss by the number of service connections and express result in l/connection/d (real water loss in l/connection/d).

3) Adjust to supply time: [real water loss l/connection/d]/[average drinking water supply time (h/d)] × [24 h] = [real water loss l/connection/d (wsp)].

4) Divide by average pressure: [real water loss l/connection/d (wsp)]/[average pressure (meter head)] = [real water loss l/connection/d/m (wsp)].

E.3 Step 3: volumetric assessment

First it should be calculated how much additional water (SIV) would be required to supply the area under consideration 24 × 7 with the network still in its present, leaky condition. Second, a target leakage level for the rehabilitated network should be determined. Third, the volume of physical water loss and then the total water demand for 24 × 7 and a rehabilitated network can be calculated. In detail:

1) Additional volume of water required:

   a) Volume of physical water loss for present network condition and 24 × 7 supply:

      [number of SC] × [PL l/connection/d/m (wsp)] × [expected average pressure (meter head)]

   NOTE Pressure increases when supplied 24 × 7; a reasonable assumption can be based on the local situation.

b) [volume of PL for 24 × 7] – [volume of PL for IWS] = [volume of additional water required]

2) The target leakage level depends on the present leakage level. The following formula may be used to get an idea about a realistically achievable physical water loss target level:

[target PL l/ connection/d/m (wsp)] = [present PL l/connection/d/m (wsp)] × 0,05 + 8

Once this (still high) level of physical water loss has been achieved, further physical water loss reduction programmes can be designed and implemented to reduce physical water loss further until the most economic level is reached.

3) Calculation of the future SIV at 24 × 7 supply, target level of physical water loss and target pressure:

a) Volume of real water loss for future network condition and 24 × 7 supply:

[number of SC] × [target real water loss l/connection/d/m (wsp)] × [target average pressure (meter head)]

NOTE The target pressure depends on the hydraulic situation and the level of service policy of the drinking water utility.

b) [future volume of real water loss] + [water use] = [future SIV]

E.4 Step 4: planning the transitioning from IWS to 24 × 7

The last step should be to decide whether there is enough water available to supply. Based on the volumetric assessment, it can now be determined whether there is enough water available to immediately supply the entire system or the target zone 24 × 7. In general, this is not the case, otherwise there would be no reason for IWS. Therefore, small zones or even DMAs should be established close to a point where 24 × 7 supply is possible while the rest of the drinking water distribution network can still be operated intermittently. This will normally be close to a reservoir, treatment plant or along a transmission main, which is always pressurized.

Once a physical water loss had been reduced, the water saved can be used to supply the next isolated zone, and so on.

Transitioning from IWS to 24 × 7 supply is not an easy task. It requires commitment and dedication from all concerned: governments, water utilities and users. The following areas should be addressed simultaneously and in parallel in order to have a successful and sustainable impact:

— Technical: gradual increase in the hours of supply aiming for continuous service, introduction of user metering policies, improved network operation using DMA/sectorization practices and targeted rehabilitation or replacement of mains.

— Financial: implementation of tariff structures linked to performance incentives for saving water, cost recovery, adoption of commercial thinking and reform of drinking water utilities to make them accountable.

— Institutional: drinking water utilities that have fallen into intermittent water supply have major governance and incentive flaws and need in-depth reform; moving to continuous supply requires often very difficult political and institutional choices that many governments prove reluctant to make. A paradigm shift is imperative.

— Social: the drinking water utilities should gain the trust of the users, have the willingness to change and involve the public in this effort in order to provide the required level of service at all times in a reliable and sustainable manner.

— Communication with the users: it is of the utmost importance to communicate all this information in an effective and convincing manner to all involved in order to have the maximum possible impact.

Transitioning from IWS to 24 × 7 supply is possible if the appropriate approach, techniques, methodologies and practices are applied. However, it requires commitment and dedication from governments, regulators, drinking water utilities and users.

Annex F
(informative)

Fixed and variable area discharge pressure and leakage

The concept of using FAVAD to interpret pressure:leak flow relationships was proposed in 1994, and over the following 10 years FAVAD gradually replaced several empirical equations previously used to fit equations to pressure:leak flow relationships in hydraulics laboratories and in distribution systems.

As the limiting upper and lower power law values are 1,5 (if all leaks have only variable areas) and 0,5 (if all leaks have only fixed areas), the FAVAD leak flow versus pressure relationship should follow a power law between 0,5 and 2,5, which can be stated as: leak flow rate, L, varies with pressure, P, to the power N1 (PN1).

For water loss management practice in drinking water distribution networks, Formula (F.1) is generally known as the 'power:leakage' or 'power law' equation or the N1 approximation. It is popular with practitioners for predicting the changes in leak flow rates resulting from moderate changes in the system pressure. It is usually expressed as shown in Formula (F.1):

$$L_1/L_0 = (\mathrm{AZP}_1/\mathrm{AZP}_0)N_1 \quad \text{(F.1)}$$

where L_1 and L_0 are the leak flow rates at average zone pressures AZP_0 and AZP_1.

It is likely that practitioners have hundreds of pressure-managed zones within their distribution systems, so the calculation processes should be fast-tracked and simplified.

Although the power law equation is dimensionally awkward for hydraulic analysis, it is very flexible for use with a wide range of combination of units for flow and pressure, as the parameters L_1/L_0 and $\mathrm{AZP}_1/\mathrm{AZP}_0$ are expressed as ratios and are non-dimensional.

Annex G
(informative)

Economic leakage level (ELL): assessing economic level of real water loss

G.1 General

In a water loss investigation it is important to understand the difference between the current level of water loss and a potential target level that the water supplier should aim for and maintain in the longer term. Ideally, the aim would be to eliminate water loss completely. Water loss adds to the cost of producing and distributing water, and it can add to the asset capacity requirements for abstraction, treatment and supply. However, water loss is something that cannot be eliminated completely. For any drinking water distribution network there is a level of water loss below which is it not cost-effective to make further reductions. This occurs when the value of the water saved is less than the cost of making the further reduction.

Savings from water loss reduction can include:

— lower chemical usage for water treatment, and for secondary disinfection and conditioning plants within the distribution network;

— lower energy costs for treatment and pumping;

— lower costs for disposal of waterwork sludge;

— in some cases, volumetric charges apply to water abstraction and to taxes or local rates paid by the water supplier;

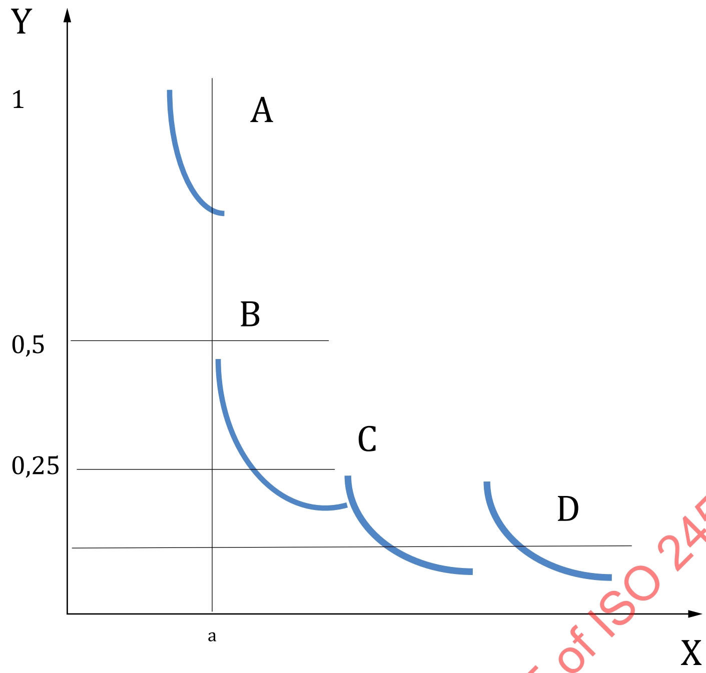
— reduction in maintenance costs if works can be taken out of service due to demand reduction.

These savings can be assessed to estimate a unit cost of water. Where the water supplier purchases water from a bulk supply authority then the unit cost is that which applies to the utility's charges. Each of the above savings should use data specific to the water supplier, but data gaps can be filled with assumptions to give an initial estimate until such time as systems can be implemented to improve data quality.

In addition, mains replacement and pressure management to reduce real water loss will have the benefit of a lower future burst frequency, resulting in lower cost of repairs and of dealing with the impact of these events on the network. Capital cost reductions can result from deferring the need to construct supply side schemes or from downsizing them.

On the other hand, works to reduce water loss cost money. If applied in a logical manner, all of these works will follow a law of diminishing returns (see Figure G.1), i.e. the more that is done, the higher unit cost of making a further unit reduction in water loss. The economic appraisal should consider the optimum level of each control activity and its impact on each component element of water loss.

When balancing the savings from water loss reduction and the costs of control projects, the aim should be to achieve an economic level of leakage (ELL) for real water loss. A similar procedure can be used to asses an economic optimum level of apparent water loss by balancing increased revenue from more extensive and accurate metering with the cost of investigations, meter installation, maintenance and replacement.



Key

A selective main replacement
B district metering and pressure management
C backlog reduction
D speed of repairs
X current level of leakage (million litres/day)
Y cost of leakage reduction ($ per million litres/day)
[a] Diminishing returns.

SOURCE Farley, M., Trow, S. *A Practitioner's Guide to Assessment, Monitoring and Control*. IWA, 2003. Used with permission.

Figure G.1 — Diminishing return from water loss reduction measures

G.2 Short-run ELL

G.2.1 General

In the short term, there are a number of key parameters which affect the level of real water loss:

— the average pressure in the system;

— the condition of the mains and service pipes;

— the facilities available for collecting data (i.e. district metering and telemetry);

— the extent and condition of customer metering.

These factors are effectively fixed unless and until capital investment is made. The only short-term option available is to change the number of people detecting and repairing leaks. Leak location and repair is referred to as ALC. There is a steady-state situation in which the marginal cost of the ALC effort is equal to the marginal cost of the water saved by adopting that ALC policy. When operating costs alone are included in the calculation, then the optimum level of leakage is known as the short run economic level of leakage (SR-ELL).

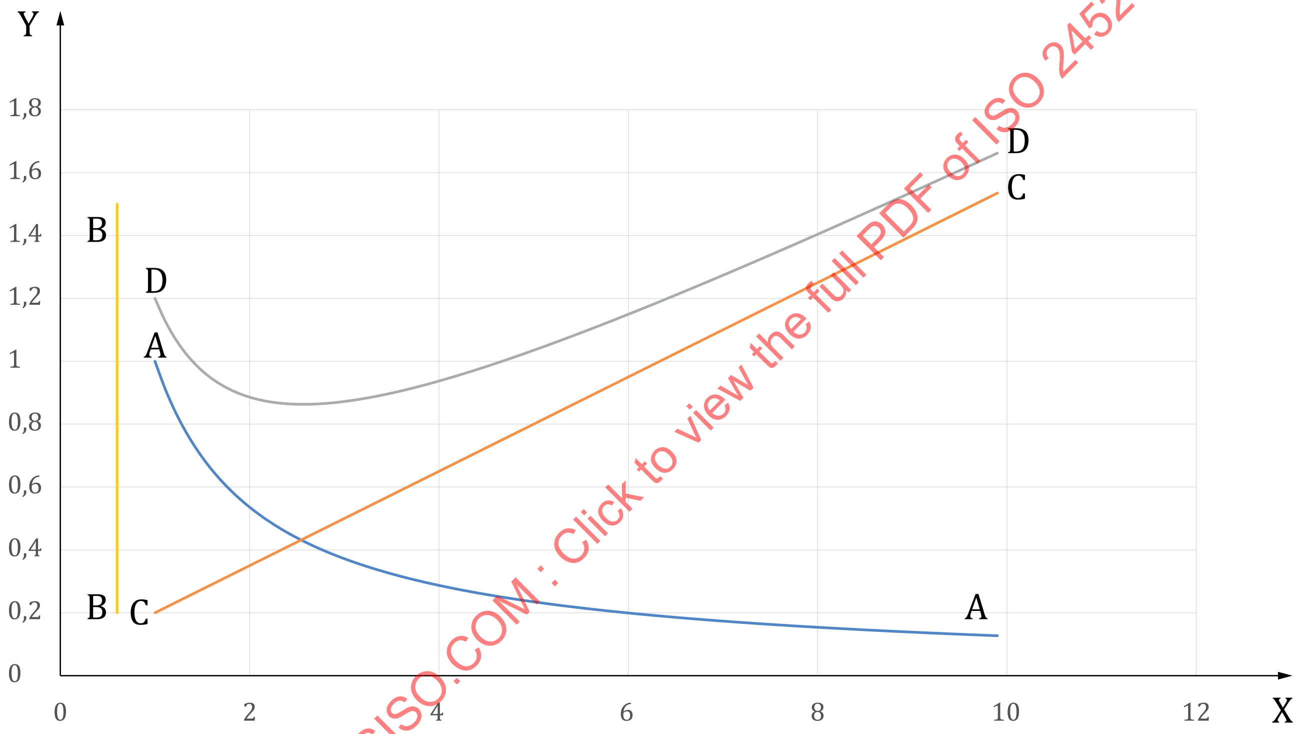
Figure G.2 represents the total annual costs and SR-ELL for operating a particular supply zone. The following factors determine the SR-ELL.

G.2.2 Background leakage

In any system there is a minimum achievable level of leakage or real water loss. This can be estimated using formulae (e.g. the UARL in the ILI formula) or by analysing the minimum achieved levels of leakage in areas such as DMAs after ALC works have been completed. The background level of leakage, plus leakage from reported bursts, is shown as line B-B in Figure G.2. This line forms the asymptote for the total cost curve and is often referred to as the policy minimum level of leakage, i.e. the minimum level of leakage which can be achieved with current policies and unlimited resources on ALC.

G.2.3 Unit or marginal cost of water

A higher unit cost of water leads to a lower ELL and vice versa. This is shown as line C-C in Figure G.2.



Key

(blue line)	cost of survey
(orange line)	cost of water lost
(grey line)	total cost
(yellow line)	policy minimum
X	leakage (million litres/day)
Y	cost ($/year)

SOURCE European Commission, Reference document, *Good Practices on Leakage Reduction*, 2014. Used with permission.

Figure G.2 — Short-run ELL

G.2.4 Unit cost of active leakage control

The ALC cost curve (line A-A in Figure G.2) depends on the efficiency and methods of the ALC operations and on the operating environment. Some ELL modelling methods assume a simple inverse relationship between ALC cost and the level of leakage above the policy minimum, i.e. doubling the resource will halve that level of leakage. Other methods derive the curve from historic costs.

G.2.5 The natural rate of rise of unreported leakage

The natural rate of rise of unreported leakage (NRR) is a function of the condition of the infrastructure and its burst rate. It is the amount by which leakage would rise in a year if all ALC operations were suspended. NRR can be estimated from trends in leakage in DMAs or it can be modelled using the current unreported burst rate with an estimate of burst flow rates and run times. Some ELL estimation methods use NRR.

G.2.6 Average operating pressure

Pressure influences the level of background leakage, the flow rate from existing leaks and bursts and also the NRR. The economic level of ALC should be established at the current operating pressure and then relatively quick and economic opportunities for further pressure management should be explored as part of the SR-ELL.

G.2.7 Current level of leakage

Bridging the gap between current level of leakage and the economic level incurs transition costs. Including transition costs tends to give a higher ELL than if they are not included. Transition costs include dealing with a backlog of repairs when moving from one steady state to another and costs associated with organizational change.

Line D-D in Figure G.2 is the total cost curve and the minimum point on the curve is the SR-ELL. Although the SR-ELL is often established as a single point on the total cost curve, there tends to be an economic range around the SR-ELL to the level of leakage.

There is an argument that repair costs should be excluded from the evaluation of ELL. This is because the number of bursts that occur in any year is assumed not to change in the short term. The change in ALC effort affects only the time (on average) for which bursts and leaks run before they are found.

Although this may be true for steady-state situations, i.e. where a certain level of water loss is maintained, care should be taken when water loss is being reduced from one level to another, as a backlog of leaks may have to be repaired to make the transition, and some smaller leaks previously included in the background level will be found with more intensive activity.

The short run accepts that the current infrastructure is fixed and is the optimum level of ALC with an optimum investment in pressure management that can be achieved in a short period of time (less than 5 years).

G.3 Long-term ELL

In the medium to long term, capital investment in facilities such as district metering, telemetry, more intensive pressure management, mains renewal and measures to control user side water loss will have an impact on the short-run ELL. The reduction in the short-run ELL and the associated savings can be balanced against the costs of making the investment. Investment costs are sometimes called transition costs, to make the change from one steady state of water loss to another, and these investments should also be compared with other options for improving the supply–demand balance, such as supply augmentation and water conservation.

The LR-ELL considers a longer-term planning horizon (typically 25 years). It should categorize zones into “constrained” (or “deficit”) or “unconstrained”, depending on whether there is a forecast supply–demand headroom deficit. In constrained zones, further leakage reduction options should be balanced against other supply–demand balance options.

The ELL will change over time to take account of:

— seasonal changes to burst frequency, often resulting from weather conditions;

— mains condition improvements;

— changes to the short-term unit cost of water, for example it will have higher value in times of drought;

— efficiencies due to new leak detection techniques;

— changes in the longer-term value due to supply side works and other demand management measures.

Calculating ELL can be based on simple arithmetic, the use of complex econometric models or methods in between. There are two general approaches:

1) Considering all available small leakage reduction options based on ALC, pressure management and district metering aimed at making a step change in leakage. The most cost-effective option is chosen first, followed by a review after each project has been completed. After all available cost-effective measures have been completed, the economic level of leakage can be maintained. The disadvantage of this approach is that there is no target to aim for and no vision of what may be possible in terms of leakage levels, operating costs and investment needs.

2) A component-based modelling tool is used to estimate the SR-ELL and LR-ELL to develop a plan of action for a period of up to 25 years. The disadvantage of this approach is that it relies on data and assumptions in the short term that may not be accurate.

In practice, a combination of these two approaches should be adopted. An initial leakage model and plan can be used to establish some high-level goals based on the best available data. Pilot exercises will generate data on costs and benefits, which can be used to refine the model as work progresses.

G.4 Sustainable ELL

This is the LR-ELL with an additional analysis to take account of the external social and environmental costs of leakage.

G.5 ELL comparison

Table G.1 summarizes the difference between SR-ELL, LR-ELL and sustainable ELL. The interventions referred to may involve opex projects only, such as ALC, or they may include capex schemes, such as district metering.

Table G.1 — Constrained and unconstrained ELL

		Short-run ELL	**Long-run ELL**	**Sustainable ELL**
Unconstrained	Interventions	Opex	Opex and capex	Opex and capex
	Driver	Economics	Economics	Economics
	Marginal value of water	Marginal cost of water production and distribution	Marginal cost of water production and distribution	Marginal cost of water production and distribution+ externalities
Constrained	Interventions	Opex	Opex and capex	Opex and capex
	Driver	Headroom	Headroom	Headroom
	Marginal value of water	> MCW ≤ marginal cost of next source	> MCW ≤ marginal cost of next source	> MCW ≤ marginal cost of next source + externalities

SOURCE: European Commission, Reference document, *Good Practices on Leakage Reduction*, 2014.

There are a number of modelling packages available to undertake ELL studies or the water supplier may opt to develop its own model making best use of the data which it has available.

The economic level of leakage should be established for each water supply or water resource zone in the utility as part of a strategic planning process for managing water resources. The ELLs for each supply zone can be aggregated to give an ELL for the organization as a whole and they can be disaggregated to give guidelines or targets for each DMA or subzone.

Targets for water loss should be based on the ELL for each supply zone, but there are other considerations that apply to the water supplier as a whole. Policies that affect customers should be consistent across the whole supply area. External influences should be taken into account, such as:

— comparisons with levels of water loss in other similar organizations;

— international comparisons;

— political influences, particularly if the ELL is relatively high in comparison with others;

— levels of risk associated with the security of water supplies to customers.

Annex H
(informative)

Examples of leak detection technologies

H.1 General

A vast number of techniques to detect where a leakage is occurring in the drinking water distribution network exist. Location accuracy depends on many factors. Some techniques are able to approximate or localize the position of a leak while others can find exact locations. This annex discusses the most common methods and devices currently available.

H.2 Method A: gas injection

This method uses a gas detector to find the presence of a tracer gas that has been injected into a pipeline. While helium can be used, the most common tracer gas is hydrogen due to its lower cost and high performance.

The gas injection method can be used to detect leaks in all pipe materials from 75 mm to 1000 mm in diameter. It can be used on pipes of greater diameter but a considerable amount of gas would be required. The pipeline can be empty of water or full; however, with the pipeline full of water less gas is required to be used to find the leak.

To accurately locate the leaking gas, which comes to the surface after leaving the leak in the pipe, the direction of the water flow needs to be known and the gas needs to be kept within the pipeline of where the leak is suspected. This requires the closure of any branches or offtakes which can cause the gas to be diluted or transferred away from the pipeline in question. The mixing of the gas with water does not affect the water quality. This methodology can be used in all types of sealed tubes, including cables and pipelines. The material has no effect on the gas injected.

H.3 Method B: manual listening stick

The stethoscope or listening stick has an earpiece and is used to listen to leaks on fittings and to pinpoint the location of a leak.

The material of the listening stick can be metal, wood or plastic. This technique is dependent on the ability of the engineer to hear the leak and uses no electronic equipment to enhance the sound.

This technique is best suited for use on metallic pipelines between 75 mm and 250 mm and with pressures above 10 m (15 psi). The material or pipe size does not prevent the listening stick from being able to pinpoint the leak from the surface, but what does affect this is the type of leak, ground backfill material, pressure of the water leaving the pipe, background noise and the ability of the engineer.

H.4 Methods C and D: leak noise correlation

H.4.1 General

Leak noise correlation works by comparing the noise detected at two different points in the pipeline. Assuming consistent pipe material and diameter, the noise travels from the leak in both directions at a constant velocity, so that if the leak is equidistant between two sensors then these sensors will detect the noise at the same time. Conversely, if the leak is not equidistant, the sensors will detect the same noise at different times – this difference in arrival times is measured by the correlation processes.

