Technical Report

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Examples of good practice for the management of assets of water supply and wastewater systems —

Part 1: Water supply

Exemples de bonnes pratiques de la gestion d'actifs de systèmes d'approvisionnement en eau potable et d'assainissement —

Partie 1: Approvisionnement en 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).

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This document was prepared by Technical Committee ISO/TC 224, *Drinking water, wastewater and stormwater systems and services*.

This first edition of ISO 24589-1, together with ISO 24589-2, cancels and replaces ISO 24589.

A list of all parts in the ISO 24589 series can be found on the ISO website.

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

This document is written within the overall concept of asset management, which is an activity all organizations undertake in some manner and to some degree. It focusses on the details of managing the physical assets at the operational level rather than the organizational (corporate management) level.

Water services are reliant on their assets to deliver their services to the resident populations in their jurisdictions. The assets (underground pipes, reservoirs, storage tanks, treatment plants, etc.) collectively form the physical infrastructure of the water services and are the consequence of the accumulated capital investments and operational expenditures on maintenance and rehabilitation over many years. In many of these services, the replacement value of these past investments amounts to many millions (even billions) of dollars depending on the size of the community served. The infrastructure represents therefore a major societal investment in essential services contributing to public health and the protection of the environment.

In many countries, these assets have been identified as critical infrastructures and programs are in place to assure their protection or their sustainability. Like many other organizations having assets, water services undertake programs of activities to manage the assets to ensure they continue to meet the needs of the community for reliable delivery of potable water. These management activities can be at the strategic, tactical or operational level. The activities can be part of a formal management system, or the result of specific legislative requirements, or ultimately just the result of due diligence by the service operators and managers.

This document is expected to serve as a supporting document for utilities operating management of assets in accordance with ISO 24516.

In many countries there is a sustainability problem, sometimes referred to as the infrastructure gap: this recognizes that, for various reasons, the infrastructure has not been maintained over the years on a truly sustainable basis, in other words funding of rehabilitation and replacement programs has been postponed, with a focus instead on short term repairs, or an allowed decrease in the level of service provided.

The condition of water infrastructures greatly influences the adequacy of the water service, specifically its quantity, pressure, quality, safety, reliability, environmental friendliness, degree of purification and economic efficiency. System condition-based rehabilitation approaches serve to meet these requirements with a focus on a holistic approach of condition-based, risk-oriented maintenance.

Once the installation and development of water assets is almost completed, the optimization of networks will become necessary in many places in order to respond to changing societal and economic conditions. Networks are subject not only to aging and to wear and tear, but also to adaptation processes resulting from growth, new legislative requirements, or changing customer service level expectations. This requires water utilities to focus increasingly on the growing need to rehabilitate existing water networks rather than removal and replacement of the networks. Rehabilitation will thus become essential in asset management, with ever more stringent requirements on the design and execution of rehabilitation.

In recent years, much effort has been applied to the whole issue of asset management on two levels: what are the principles and structure of an asset management system, and what are the good practices that can be implemented on a technical level to assess the condition of the assets and help decide when asset interventions (repair, rehabilitation or replacement) take place.

This document offers examples of how an asset management strategy is defined with regard to the overall performance expected by the owner. It includes several aspects of the operations and maintenance, including asset condition assessment and investment (new assets, rehabilitation and renewal) strategies.

The focus is on the following selected activities of the management of assets of water supply systems as addressed in ISO 24516-1 and ISO 24516-2.

— Clause 4 covers the principal aspects of the management of assets, including examples of:

  — objectives;

  — strategies;

  - structure of the process.
- Clause 5 covers the tools and methods for investigation, including operational data collection, tools for diagnosis, and other sources of information, such as:
  - non-destructive pipe condition assessment techniques;
  - high density polyethylene (HDPE);
  - hydraulic performance;
  - drinking water storage tanks.
- Clause 6 covers the assessment of the system against its performance expectations for the following aspects:
  - practical tools and methods for structural, functional, hydraulic performance;
  - examples of degradation factors and models of degradation;
  - practical tools and methods for criticality assessment (plants and networks);
  - examples of calculation to assess the likelihood of a failure.
- Clause 7 covers the implementation of sustainable field works, providing examples of what matters from an asset management point of view.
- Clause 8 covers the operation and maintenance by providing examples of leakage management, flushing, energy management, monitoring and control, pressure regulation and maintenance of civil structures.
- Clause 9 covers the prioritization of rehabilitation of assets with examples of how it is done practically.

The examples of good practice for asset management of water supply systems covered in this document are applicable to all types and sizes of organization and utilities operating water systems.

Examples of good practice for the management of assets of water supply and wastewater systems —

Part 1: Water supply

1 Scope

This document contains selected examples for good practice approaches for the management of assets of drinking water supply systems. This document is intended as a supporting document for ISO 24516-1 and ISO 24516-2, which contain guidelines for the management of assets of drinking water systems. As such, this document can contribute to realize value from existing assets when following the guidelines for the management of assets of drinking water systems approaches in the strategic, tactical, and operational plans given in ISO 24516-1 and ISO 24516-2.

NOTE A recapitulative table of the examples covered in this document is provided in Annex A.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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

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

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

4 Principal aspects

4.1 Objectives

4.1.1 Water utility with multiple waterworks and distribution networks

Table 1 contains an example of objectives for a water utility with multiple waterworks and distribution networks. This example is obtained from Japan. The good practices highlighted in Table 1 include:

— objectives of a mature water utility facing risks of natural disasters (earthquakes);

— clear break-up of main objectives into sub-objectives and indicators;

— clear baseline and medium/long term targets.

Table 1 — Objectives for multiple waterworks and networks

Macro-objectives	Indexes	Results: financial year 2019 (%)	Planned: financial year 2030 (%)	Calculation method
Stable supply of pure and high-quality water	Duplex improvement rate of water conveyance facilities	81	88	$\frac{\text{Number of duplicated water conveyance facilities}}{\text{Number of water conveyance facilities to be duplicated}}\times 100$
	Improvement rate of water transmission pipe networks	81	93	$\frac{\text{Length of networked transmission pipes}}{\text{Total length of transmission pipes for formation of water network}}\times 100$
	Securing rate of stable water supply	84	89	$\frac{\text{Capacity of service reservoirs in purification plants and water supply stations}}{\text{Planned maximum water supply volume for 12 h of a day}}\times 100$
	Achievement rate of residual chlorine target	87	94	$\frac{\text{Number of 0,1 mg/l to 0,4 mg/l water tap data}}{\text{Total number of water tap data}}\times 100$
Preparation for various disasters	Rate of earthquake-resistant purification facilities	14	69	$\frac{\text{Capacity of earthquake-resistant purification facilities}}{\text{Total capacity of purification facilities}}\times 100$
	Rate of earthquake-resistant distribution reservoirs	80	98	$\frac{\text{Capacity of earthquake-resistant service reservoirs}}{\text{Total capacity of service reservoirs}}\times 100$
	Rate of earthquake-resistant-joint pipes introduction	45	61	$\frac{\text{Length of earthquake-resistant-joint pipes}}{\text{Total length of pipelines}}\times 100$
	Rate of water suspension during earthquake occurrences	29	21	$\frac{\text{Population affected by water suspension}}{\text{Service population}}\times 100$
	Rate of earthquake-resistant-joint pipes used in supply routes serving important facilities	82	100 (2022)	$\frac{\text{Length of pipelines on supplying routes with earthquake-resistant-joint}}{\text{Total length of pipelines on target supplying routes}}\times 100$
	Resolution rate of pipes difficult to replace (Rate of conversion to ductile iron pipes 100 %)	5	100 (2026)	$\frac{\text{Length of replaced pipes difficult to replace}}{\text{Total length of pipes difficult to replace}}\times 100$

a Areas in which water suspension rate is over 50 %.

Table 1 *(continued)*

Macro-objectives	Indexes	Results: financial year 2019 (%)	Planned: financial year 2030 (%)	Calculation method
	Resolution rate of pipe replacement priority areas [a]	67	100 (2028)	$\frac{\text{Number of municipalities that fall below 50 \% of water suspension rate}}{\text{Number of target municipalities}}\times 100$
	Rate of earthquake-resistant-joint pipelines in replacement priority areas	65	100 (2028)	$\frac{\text{Length of earthquake-resistant-joint pipelines}}{\text{Total length of required pipelines with earthquake-resistant-joint in replacement priority areas}}\times 100$
	Rate of earthquake-resistant service pipes installed in private roads	47	67	$\frac{\text{Length of earthquake-resistant service pipes}}{\text{Total length of service pipes in target private roads}}\times 100$
	Securing rate of water supply available during massive power outage	63	92	$\frac{\text{Available water supply volume}}{\text{Estimated required water volume at massive power outage}}\times 100$
	Securing rate of fuel for independent power generation equipment (72 h)	45	83	$\frac{\text{Fuel stock volume}}{\text{Required fuel stock volume for 72 h continuous operation}}\times 100$
	Undergrounding rate of river crossing pipelines	0	18	$\frac{\text{Number of undergrounding places of river crossing pipelines}}{\text{Number of priority undergrounding places of river crossing pipelines}}\times 100$

[a] Areas in which water suspension rate is over 50 %.

4.1.2 Water distribution network

Table 2 contains an example of objectives for a water distribution network in Germany. The good practices highlighted in Table 2 include:

— three main objectives: continuity, quality, quantity;

— good break-up and indicators.

Table 2 — Objectives for network

Indicator	Objective
Failure rate	0,10 failures/(km·year)
Water loss	< 0,10 m^3/(hour·km)
Pressure	> 2,35 bar [a] – houses with first floor > 2,70 bar – houses with second floor and 0,35 bar for each next floor
Water quality	In accordance with national requirements
Minimal risk	Low failure rates, water losses and service interruptions, risk minimization requirement
Duration of service interruptions	< 10 min/year and costumer

a 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2

4.1.3 Waterworks

Table 3 contains an example of objectives for a waterworks in Spain. The good practices highlighted in Table 3 include:

— ISO 55001 certified plant, with renewal objective;

— break-up of actions and indicators.

Table 3 — Plant asset management strategy

Processes/ origin	Owners – responsible – resources	Type of indicator [a]	Indicator	Remarks	Objective value	Goals and actions	Periodicity and dates	Records and documents
Implement an asset management system that consolidates the experience of the plant's management team and ensures optimal asset management.	Plant manager/ external certifying company	Q	Renewal of ISO 55001 certification in May 2019.		Obtaining a certificate	Phase 1 external audit, documentary. Phase 2 external audit implementation.	04/04/2019 08/05/2019	— ISO 55001 certificate — Internal audit plan — Action plan
Endorse the professional ties with the client, through a win-win relationship, complying with and enforcing the contractual and legal framework, in addition to accompanying in the technical challenges.	Plant manager / client	Q	Joint assessment of the condition of assets by the asset condition assessment (ACA) method.		List of evaluated equipment (ACA)	1. Customer training 2. Joint assessment condition assets client – driving equipment 3. Decline of results in asset registry	1. Initial 2. Initial and final contractual period 3. Initial and final contractual period	List of evaluated equipment (ACA)
		AM	Monetized impact of unrealized corrective maintenance (critical and non-critical) that depends on the client. I_{GA7} = sum of the monetized criticality of unrealized corrective maintenance (critical and non-critical) that depends on the customer.				Monthly	— Minutes of meetings — Monthly data by registration
		EE Env AM Q	I_{GE1} = kWh consumed/ m^3 treated water. I_{05} = kg of chemical reagents consumed/m^3 treated water.		Comparison of previous years.		Semi-annual	Indicators and objectives report

[a] Types of indicators: Q = Quality, EE = Energy management, Env = Environment, S = Safety, AM = Asset management

Table 3 *(continued)*

Processes/ origin	Owners – responsible – resources	Type of indicator [a]	Indicator	Remarks	Objective value	Goals and actions	Periodicity and dates	Records and documents
Comply with and enforce in a holistic and optimal way the management systems (OSHAS 18001[7], ISO 14001, ISO 9001, ISO 50001, ISO 55001), ensuring the competence required for the perenniality and sustainability of the process.	Coordinator quality management	Q	Internal and external audits related to asset management. Internal: evaluate the possibility of doing cross-audits with other entities in 2020. External: monitoring by external auditor.		At least one internal audit per year once certification is achieved.	Carry out an annual audit plan.	Annual	— Program annual internal audits — Internal and external audit plan — Internal and external audit report
Ensure the integrity and well-being of staff.	Plant manager	S	Number of accidents with sick leave and without sick leave.	KPI analysed monthly with the plant management. Compliance with the organization's accident target. It is an indicator at the workplace level.	1 accident without sick leave 0 accidents with sick leave		Monthly	Accident plan of the centre
		Q	Perform evaluation of the competencies required for asset management to the personnel involved.	Verify that you have the competencies required for asset management (identify competencies, operating plan, training plan, procedure professional categories, ...).	At least 50 % of the staff involved in the 2019 asset management system and 100 % in 2020			— Action plan — Matrix of competences — Priority training plan — Employment authorization documents (EAD)

[a] Types of indicators: Q = Quality, EE = Energy management, Env = Environment, S = Safety, AM = Asset management

Table 3 *(continued)*

Processes/ origin	Owners – responsible – resources	Type of indicator [a]	Indicator	Remarks	Objective value	Goals and actions	Periodicity and dates	Records and documents
Study the optimization of the total cost of the life cycle (LCC) of the assets.	Plant manager	AM	I_{GA1} = renovation costs/ replacement value of equipment. I_{GA2} = total cost of preventive maintenance/ total cost of the plant. I_{GA3} = total corrective maintenance cost/total plant cost.	— Asset management KPIs. — Preventive maintenance value > corrective maintenance value			Quarterly	The data that feeds these indicators are analysed monthly in the asset management indicators dashboard.
			Investments over € 10 000 with LCC/investments over € 10 000.		1			Make LCC for investments over € 10 000 before the purchase order.
Mobilize the necessary human, material and financial resources in order to implement the strategic asset management plan.	Plant manager	Q	Have the risk assessment, training plan, EAD.		1			Action plan
Promote the continuous improvement of the asset management system.	Plant manager	Q/S/Env/ EE/AM	Report 1 REX file/average year of the contract period.		2		Contract duration	REX tab
		AM	Update of the criticality plan once a year and whenever there is a relevant change.		1			Criticality plan

[a] Types of indicators: Q = Quality, EE = Energy management, Env = Environment, S = Safety, AM = Asset management

Table 3 *(continued)*

Processes/ origin	Owners – responsible – resources	Type of indicator [a]	Indicator	Remarks	Objective value	Goals and actions	Periodicity and dates	Records and documents
		AM	Impact of planned and unrealized maintenance orders (critical and non-critical). I_{GA5} = number of critical equipment orders not performed/number of critical equipment orders planned. I_{GA6} = sum of monetized criticality of critical equipment with planned and unrealized order.		$I_{GA5} = 0$ $I_{GA6} = 0$		Weekly maintenance meetings	Dashboard AM
		AM	I_{GA4} = Planned maintenance orders/maintenance orders made.	Asset management KPIs.	> 90 %		Quarterly	The data that feeds these indicators are analysed quarterly in the asset management indicators dashboard.
Promote close cooperation between all processes involved in asset management.	Plant manager	Q/S/Env/ EE/AM	Perform audit of the 5S.		1		Initial and annual	Audit report
The application of the asset management policy together with the support of the functional teams and integrated management system.	Plant manager	Q	Implementation of the asset management system in the workplace and ensuring compliance with said management system.	— Maintenance ISO 55001 certification — Indicators — Audits — Action plan — Awareness talks — Training/competences	1			— Action plan — Audit plan — Monitoring indicators

[a] Types of indicators: Q = Quality, EE = Energy management, Env = Environment, S = Safety, AM = Asset management

Table 3 *(continued)*

Processes/ origin	Owners – responsible – resources	Type of indicator [a]	Indicator	Remarks	Objective value	Goals and actions	Periodicity and dates	Records and documents
Ensure communication and understanding of this policy at all levels of the organization.	Plant manager	Q/S/Env/ EE/AM	Make communications plan.		Make communications plan = 1			Communications plan

[a] Types of indicators: Q = Quality, EE = Energy management, Env = Environment, S = Safety, AM = Asset management

4.2 Strategies

4.2.1 Maintenance strategy

Figure 1 contains an example of preventive maintenance (PM) strategy based on criticality analysis for a waterworks in Jordan.

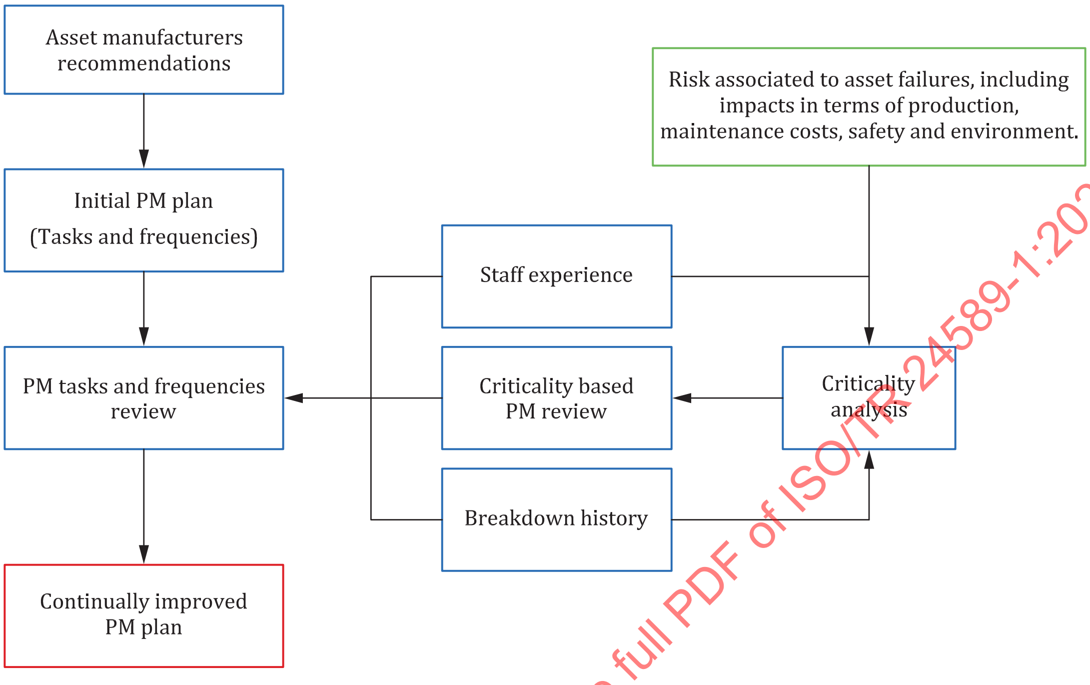


Figure 1 — Preventive maintenance

Table 4 illustrates corrective maintenance prioritization based on criticality analysis for a waterworks in Jordan.

The prioritization of corrective maintenance is given by operation team, based on operational context and following criteria of Table 4.

Table 4 — Corrective maintenance

Priority rank	Criteria	Detail
1	Safety impact	
2	Water treatment and/or environmental impact	Priority per volume/hour at stake
3	Cost impact	Priority per cost/hour at stake
4	Operational inconvenience	
5	Availability of required material and human resources	

The priority is expressed as:

— very urgent (today);

— important (2 days);

— normal (week);

— minor (month).

4.2.2 Renewals decision

Figure 2 illustrates renewal prioritization for assets to be renewed at a waterworks in Jordan. The good practices highlighted in Figure 2 include:

— methods applied at an ISO 55001:2014[1)] certified site;

— prioritization based on criticality analysis, condition assessment and funding.

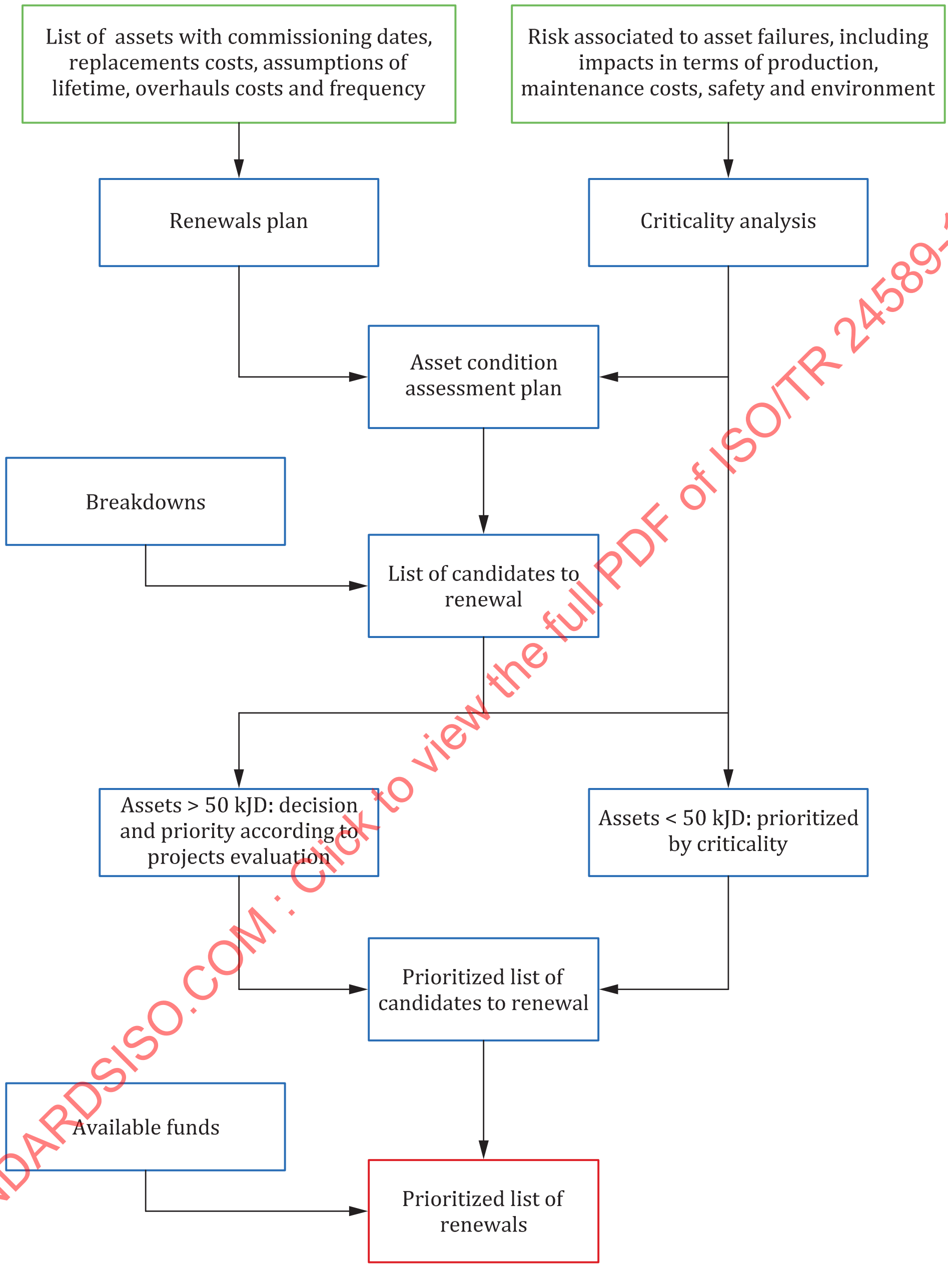


Figure 2 — Prioritization of renewals

4.2.3 Inspection strategy of water supply network

Figure 3 illustrates the inspection strategy of water supply network. This example is obtained from France. The good practices highlighted in Figure 3 include:

— clustering in representative groups of pipes, selection of samples;

1) Withdrawn.

— selection of best representative samples to be inspected for calibration of the degradation model;

— extrapolation to whole network.

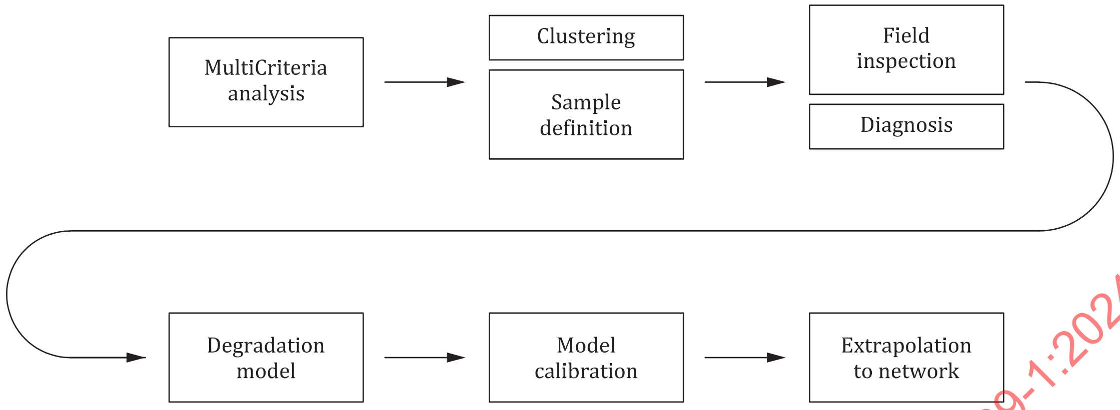


Figure 3 — Inspection strategy of water supply network

— Clustering is based on the material, the diameter, the degradation defined from the historical number of failures or failure rate and the likelihood of failure. A supervised clustering of the last level of clustering (degradation) is performed to associate each pipe of the network to the asset and to operational and environmental data in order to characterize the degradation cluster and associate pipes to a cluster in case of missing burst information on these pipes. The degradation clusters are defined for a generalized Gaussian mixture model in order to detect different patterns/levels of burst and the supervised clustering is based on machine/deep learning process in order to maximize the association between pipes characteristics and these patterns/levels.

— Selection of the best representative samples to be inspected is tuned according to either an expected accuracy from the sample (objective = minimize sample size and budget) or a predefined budget or network length to inspect (objective = maximize accuracy). The selection can include strategic pipes. This selection is based on optimization technique (genetic algorithm) to look for the sample that maximizes accuracy or minimizes budget.

— Extrapolation is performed within each cluster (maximizing the accuracy compared to a global estimation) using machine/deep learning processes (e.g. regression random forest) in order to generate for each pipe a proper and adequate state grade from the asset, operational and environmental characteristics.

4.3 Structuring the process

4.3.1 Initial steps for the management of assets of water distribution systems

The following five steps illustrate the initial steps to structure the management of assets of a water distribution system. This example is obtained from Germany.

a) Defining objectives and identifying the information that is useful and relevant for high-level decision-making.

b) Creating an inventory of the utility's assets; this includes the extent and nature of drinking water, sewer and storm drainage systems, including the physical location, age and material composition.

c) Establishing an asset information management system in which the inventory of assets data can be recorded, periodically updated, and analysed.

d) Populating the asset information management system with asset performance and condition indicators which include:

1) estimated current and replacement value of the asset;

2) assessments of current asset condition which is regularly and periodically updated;

3) historical repair and work history data;

4) repair and replacement cost data;

5) current and future budget allocations.

e) Operating the information management system, and, to do so successfully, the utility does:

1) ensure the importance and relevance of infrastructure data and indicator collection are understood and valued throughout the utility;

2) integrate data collection and indicator development support into operational activity wherever possible;

3) train staff to manage data collection, input and analyses.

End uses of the information system can also include:

— creating infrastructure budgets based on projected needs;

— prioritizing infrastructure projects based on available funds;

— assessing the reasonableness of individual infrastructure project costs;

— showing the relationship between overall asset condition and funding level;

— developing multiple "what if" scenarios based on different priorities, backlog levels and funding levels;

— evaluating infrastructure life cycle trends;

— conducting a year-to-year budget review;

— reviewing current municipal practices, priorities and work methods;

— exchanging information and making comparisons with other utilities;

— tying into a geographic information system (GIS) and other utility information systems.

To understand assets, information is processed from the following activities:

— Identifying existing assets (nature, number, length, volume, location, etc.):

  — What is the current condition of the asset?

  — When was the asset constructed-acquired/rehabilitated/replaced?

  — What is the asset's life expectancy (theoretically)?

  — What is the actual or projected life of the asset based on inspection?

  — What is the present and projected deterioration?

  — Can the asset be rehabilitated?

  — What is the cost and impact on its life?

  — What measurements are in place to monitor the condition of the asset?

  — What are the impediments to measuring the condition of the asset?

— Assessing the asset's performance:

  — Is the asset performing and meeting user requirements?

— What limitations exist with regards to safety, capacity, and the regulatory and environmental requirements?

— What levels of service have been set for the asset?

— Are assets ranked, based on a systematic evaluation (i.e. from inadequate to excellent)?

— Are benchmarking indices available?

4.3.2 Linkage of tool or activity to specific utility objective

Table 5 illustrates a toolbox for the asset management of drinking water supply network. This example is obtained from France. The good practices highlighted in Table 5 include:

— strategy based on statistical analysis of leak/bursts;

— prediction tool for future evolution of leakage;

— scenarios to adjust financial effort to desired target performance.

Table 5 — Toolbox for the asset management of a drinking water network

Network component	Performance objective	Short-term decision aiding tool or activity	Long-term decision aiding tool or activity
Service pipes	Continuity of supply and leakage	Module for statistical analysis of water networks and water quality network model	Simple investment planning (OPEX is close to CAPEX in the mid-term)
	Water quality	Geographic information system (GIS)-based tool for system data integration	
Distribution network	Continuity of supply and leakage	Module for statistical analysis of water networks and water quality network model	Prediction module (complex decision aiding tool as OPEX is less than CAPEX but cost optimizations are possible in the long term)
	Water quality	Water quality network	
Trunk mains	Continuity of supply and leakage	Risk prioritization based on network inspection	Simple investment planning by ranking (OPEX is much less than CAPEX even in the long term)
	Water quality	Water quality network	

At first a module for statistical analysis of water networks facilitates the analysis of burst and leak history on the network to calculate:

— a probability of future failure for each pipe thanks to proven statistical methods (Poisson or Survival models);

— a global risk for each pipe in order to prioritize renewals;

— the future evolution of total number of bursts and leaks.

This module is therefore used to implement annual renewal programs and provide to the prediction module the future burst evolution.

A second tool for optimisation of leaks detection can facilitate the night flow analysis for each district metering area (DMA) in order to:

— calculate the efficiency of burst repairs and leak detection/repair on leakage;

— calculate the costs associated for each DMA;

— define where leakage detection efforts can be made;

— calculate the future evolution of leakage.

This tool is therefore used to prioritize leakage detection actions and provide to the third tool the future evolution of leakage.

A third tool is used to allow the long term (5 to 10 years):

— optimization of OPEX and CAPEX Performance for continuity of supply and leakage targets;

— optimization of either OPEX or CAPEX under constraints on performance and OPEX or CAPEX.

It is therefore used to optimize and visualize the result of different scenarios of OPEX or CAPEX performance and at least the optimal renewal rate on a given network.

A GIS-based tool for system data integration makes the link between network characteristics, network hydraulics, customer complaints and network events in order to understand water quality problems and take the appropriate actions. If a water quality issue is due to an exceptional event on the network, the action taken will be to make sure this exceptional event does not happen again or at least that it is managed. If a water quality issue is due to the structure and age of the network (e.g. red water problems) the action taken will be to plan the rehabilitation or renewal of the network accordingly.

Each one of the tools presented above is used at a different level in the asset management global policy as shown in Table 5. The relation to strategic, tactical and operational revised performance indicators is shown in Figure 4.

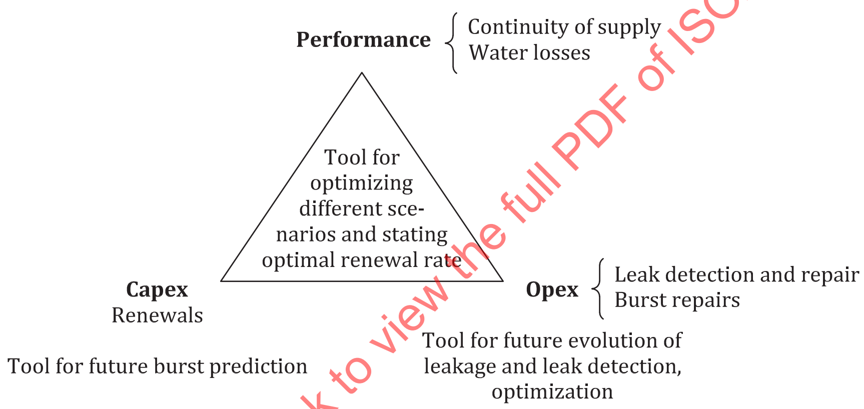


Figure 4 — Relation to strategic, tactical and operational revised performance indicators

The tool for optimizing different scenarios and stating optimal renewal rate is used to define the asset management strategy, i.e. to state the desired future function(s), performance and condition of existing and new asset systems and critical assets, on timescales aligned to those of the organizational strategic plan.

All these tools are used to define the asset management plans,i.e. to prioritize and guide the renewal and operational activities to reach performance and manage risk.

4.3.3 Flowchart to sustain the asset management plan

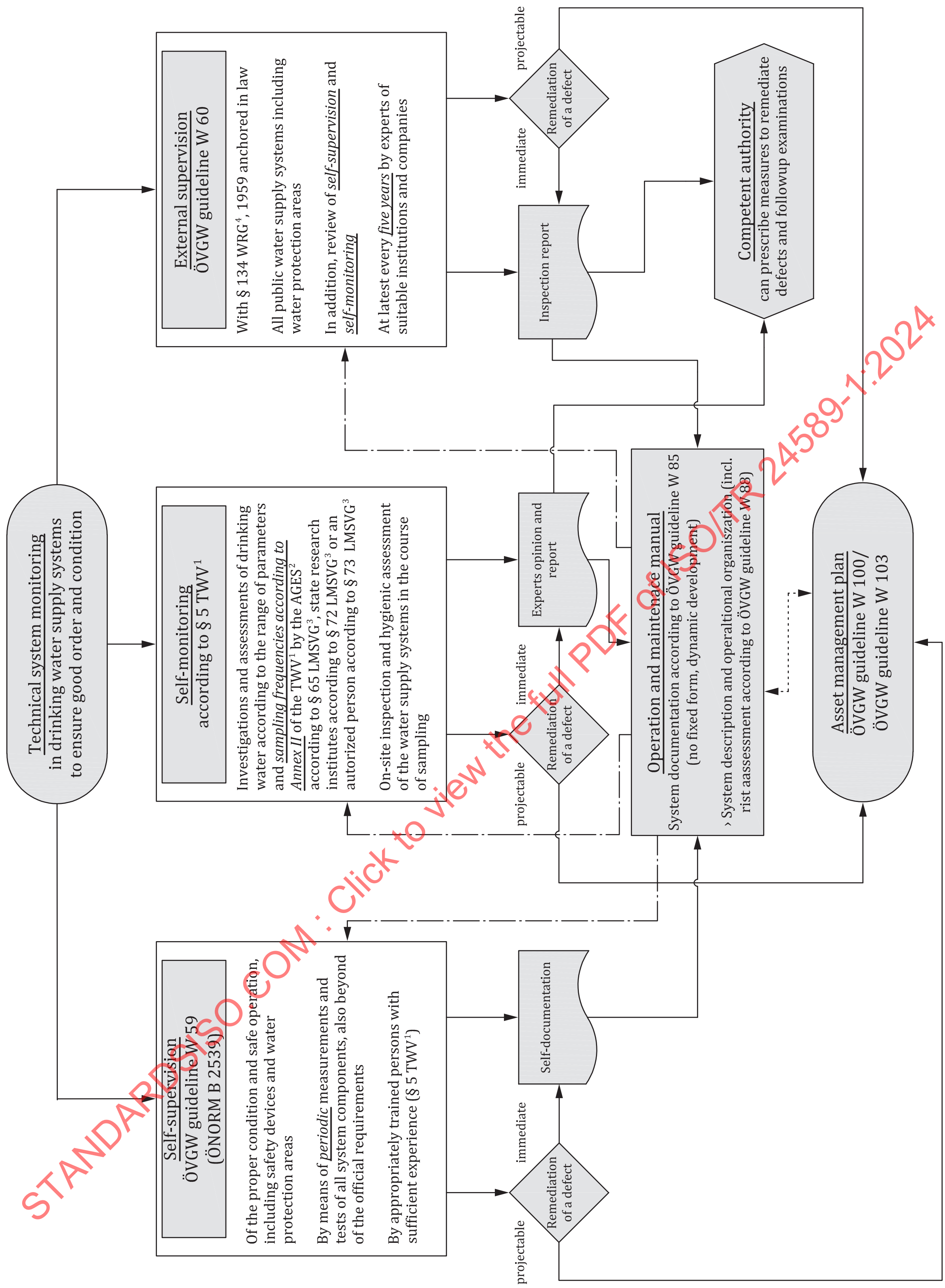
Figure 5 illustrates a flowchart to sustain the asset management plan. This example is obtained from Austria. The good practices highlighted in Figure 5 include:

— structured flowchart within a water utility;

— mapping and interdependencies;

— mandated by a comprehensive regulatory framework (national laws and guidelines, see References [8] and [9]);

— regulatory framework co-designed with the professional association of water utilities.



Key

Line and arrow "Data collection/Reporting process"

Dots and lines and arrow "Reflecting/Review process"

Dotted line and arrows "Regulation process"

1 TWV: Austrian drinking water regulation.

2 AGES: Austrian Agency for Health and Food Safety GmbH.

3 LMSVG: Austrian food safety and consumer protection law.

4 WRG: Austrian water rights law.

SOURCE: Reference [5], reproduced with the permission of the authors.

Figure 5 — Structured flowchart for asset management plan within a water utility

5 Investigation

5.1 Non-destructive pipe condition investigation techniques

Tools and software that permit the level of network degradation to be assessed without interrupting water supply are preferred, in particular for large diameter cast iron pipes. For instance, magnetic flux-based methods aiming at localizing the zones with the highest corrosion potential without digging or shutting down the service.

Table 6 lists non-destructive pipe condition investigation techniques with their application context. This example is obtained from France.

Table 6 — List of usual methods and tools to assess structural pipe condition

Method	Technology and application context
Magnetic flux leakage	Spot assessment of pipe's residual wall thickness with magnetic flux analysis. Materials: cast iron, ductile iron, steel.
Acoustic	Spot assessment of average residual wall thickness through acoustic sensors. Materials: cast iron, ductile iron, steel and mortar lined, asbestos cement, pre-stressed concrete cylinder.
Tracer gas leak detection	Assessment of structural pipe condition through leak detection, using helium. Materials: all.

Selected feedback from practical application in Australia is also available (References [10] and [11]).

5.2 High density polyethylene (HDPE)

Considering the growing use of polyethylene, particular attention is drawn to this material. Understanding the polyethylene ageing mechanisms and mastering its installation techniques are key in order to benefit from the advantages provided by this material. Knowledge was gained through research projects, e.g. the ten-step polyethylene's sustainable life cycle.[12] The ten-step cycle describes the different measures implemented in order to ensure an optimal length of service life of a network in polyethylene.

This example obtained from France illustrates the reverse bend back test (RBBT) that can be done on the field allowing an immediate assessment of the level of deterioration of service connections. Figure 6 illustrates the tool designed for examining pipes less than 5 mm thick, Figure 7 shows the sample, Figure 8 shows the sample after reverse bending, and Figure 9 shows the interpretation grid.

Figure 6 — RBBT tool

Figure 7 — Sample for reverse bend back test

Figure 8 — Sample after reverse bending

a) No degradation – no craze

b) Average degradation – thin crazes (round shape)

c) Strong degradation – big crazes/cracks visible to naked eye

Figure 9 — Interpretation grid for reverse bend back test results

5.3 Hydraulic performance

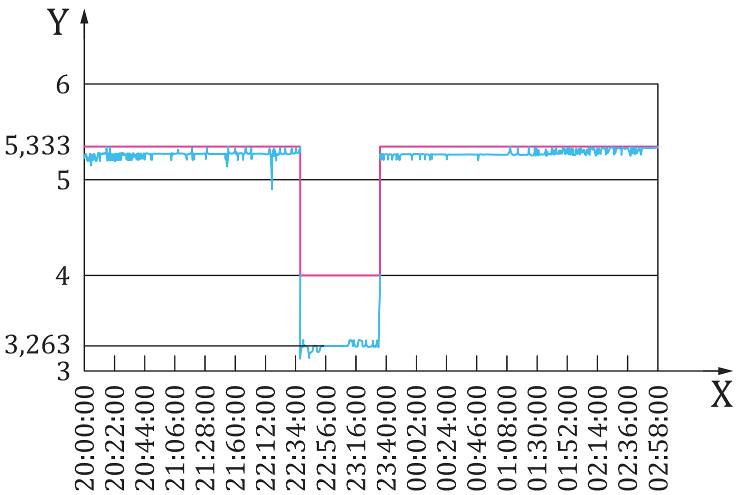
This example obtained from Germany illustrates the application of hydraulic modelling to prioritize improvement work within a water network. The actual hydraulic performance of a supply system can be analysed by a hydraulic evaluation for several loading cases. A calculation of a defined hydraulic load case (night flow, firefighting, etc.) calibrated by on-site measurements will lead to significant statements for closed or semi-closed valves, enough supply pressure or hygienic problems according to raised hydraulic residence time. According to Reference [13], a minimum supply pressure of 2,0 bar[2)] is required at the customers connection. In case of firefighting a minimum supply pressure of 1,5 bar is temporarily tolerable.

To set up a hydraulic model with software, basic information about the network is used. Besides a plan of a map including diameter of pipes and installations such as valves, booster stations and reservoirs, information about elevation head, customer consumption and special bulk consumer is also available. Additional information on the existing water resources or information about planned housing is also taken into consideration.

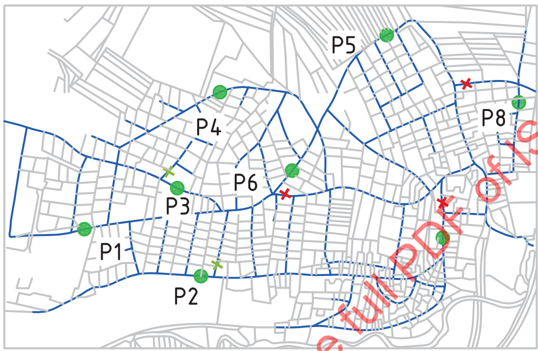
For network calibration, pressure loggers are distributed across the system and a pressure reduction caused by a defined measured withdrawal is recorded. According to Reference [14], this pressure reduction should be at least 1,5 bar or 20 % of the static pressure. For a detailed calibration, one pressure logger per km is necessary.

Figure 10 shows typical outcomes of a network calibration.

2) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2



a) Difference between metered and calculated pressure reduction



b) Set-up for calibration

Key

X time (hh:mm)

Y pressure (bar)

closed valve

semi-closed valve

outflow

Difference between metered and calculated values Δp = 0,737 bar

dp = 5,333 – 4,000 = 1,333 bar

Δp = 5,333 – 3,263 = 2,070 bar

Figure 10 — Sample of a result of a network calibration

Any inaccuracies in the network model can lead to a deviation between the calculated and recorded pressure in a single pressure logger. This deviation can be the consequence of a wrong pipe diameter, a closed or semi-closed valve or a wrong pipe connection.

In an urban supply network, a single pipe break can have little influence on the customers supply, as in some cases the pressure can drop marginally. In other cases, when the trunk main supplying the network bursts, the whole area cannot be supplied. When a calibrated hydraulic model is available, the customer consumption leads to a specific flow of water inside the pipe network. By a theoretical stepwise closing of pipes, the influence on customers can be calculated, e.g. whether the customer is supplied with a pressure below a defined minimum value or whether they are not supplied at all. The impact on the system will depend on the influence of the single pipe with respect to the total supply volume.

The result of an analysis can be pictured in different colours (red, blue, green) with respect to the relevance of a pipe, as shown on Figure 11. The red pipes have a high relevance, followed by the blue and green pipes. For the rest of the network a break of a single pipe only has a minor influence on the pressure at the customers side. For these pipes a repair strategy is also possible, as the customers are not influenced.

The aspects and the methodology of the hydraulic performance of a single pipe with respect to the whole network can also be used for optimization of a diameter with the focus on the boundary condition of minimum and maximum supply pressure, the influence on a volume for firefighting or the minimum flow velocity in a network.

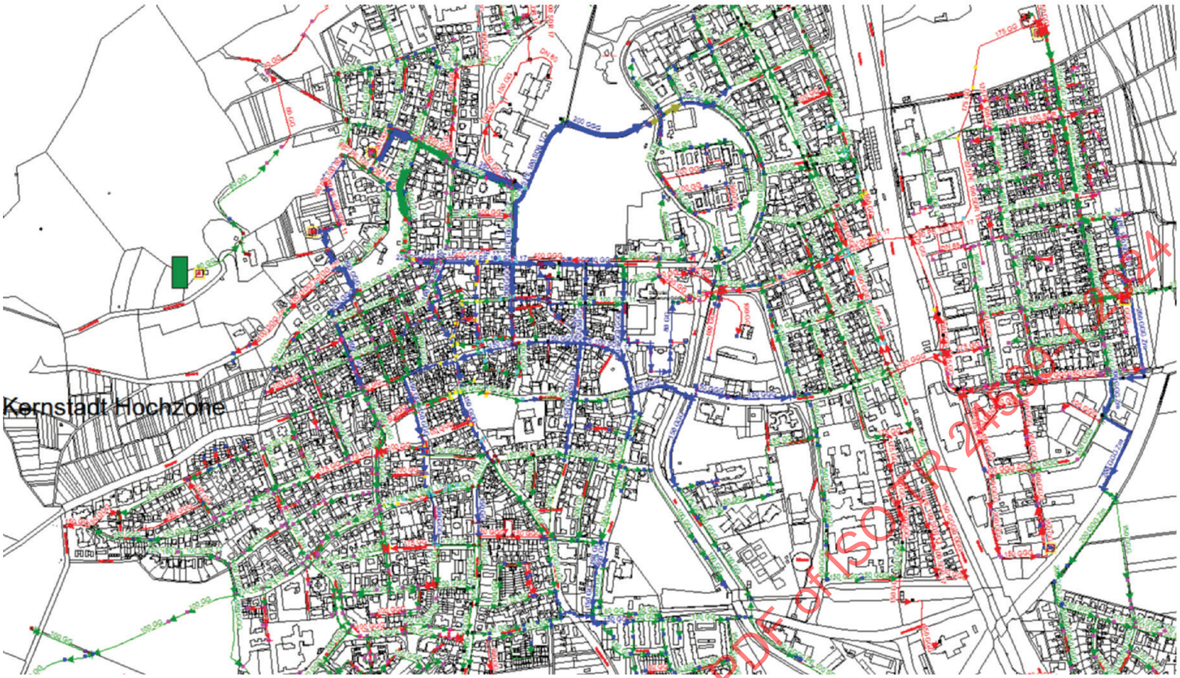


Figure 11 — Coloured pipes with low flow velocity in a supply area

5.4 Condition assessment framework for drinking water storage tanks – prioritisation based on visual inspection

Tables 7 to 10 illustrate the condition assessment framework for drinking water storage tanks. This example is obtained from Germany. The good practices highlighted in Tables 7 to 10 include:

— list of relevant components inspected and condition indicators based on DVGW (German technical and scientific association for gas and water) regulations;

— clear break-up as a basis for a condition assessment of storage tanks.

Table 7 — Components inspected in the outside area of storage tanks

Component	Inspection	Indicators	Impact on	Point of attention
Access routes, stairs, pavements	Condition, carrying capacity, slope, width, drainage, accident risks	Unevenness, fouling, vegetation, cracks, holes, erosion	Safety	—
Slope area	Inclination, vegetation, accident risks			—
Soil covering	Depth, erosion, vegetation			No vegetation above the compartment (static load, root ingrowth).
Greening	Vegetation, size, amount	—	Safety	Removal of deep-rooting plants, removal of large trees above the compartment (static load).
Fence system	Security concept, height, stability	Condition, damages, instability, corrosion	Safety, security	—
Exterior lighting	Energy efficiency, object protection, work safety	—	Safety, security	—

Table 8 — Control building components inspected

Component	Inspection	Indicators	Impact on	Points of attention
Doors	Size, work safety, object security, amount, requirement, leakproofness, function, barrier for insects and animals	Corrosion, condition/presence of sealings, damages, break-in resistance	Security, quality	Minimization of openings that lead to the exterior. Minimization of light incidence.
Windows/other openings	Amount, requirement, object security, leakproofness, function, barrier for insects and animals			
Front	Condition, damages	Discoloration, contamination, detachment, cracks, spalling, water penetration, moisture	Quality, structure	
Roofs/ceilings				
Floors/galleries				—
Wall ducts (pipes and cables), construction joints				—
Drainage opening	Function, barrier for insects and animals	Damages	Quality	Barrier for insects and animals.

Table 9 — Compartment components inspected

Component	Inspection	Indicators	Impact on	Points of attention
Doors	Amount, requirement, object security, leakproofness, function, barrier for insects and animals	Corrosion, condition/presence of sealings, damages	Security, quality	No incidence of light into the compartment. No openings that lead to the exterior. No openings above the free water surface.
Ventilation inlet holes, windows, other openings	Amount, requirement, object security, leakproofness, function, barrier for insects and animals			
Visual inspection water surface	Complete visibility, arrangement, sizing of the opening, lighting system		Quality	—
Ceiling	Condition, leakproofness	Discoloration, contamination, cracks, detachments, spalling, porosity, hydrolysis, corrosion	Quality, structure	—
Construction joints	Amount, requirement, condition			—
Sloping floor	Condition, joints, wall connections, evenness			—
Walls and columns	Condition, joints, ceiling and bottom connections			—

Table 10 — Technical equipment inspected

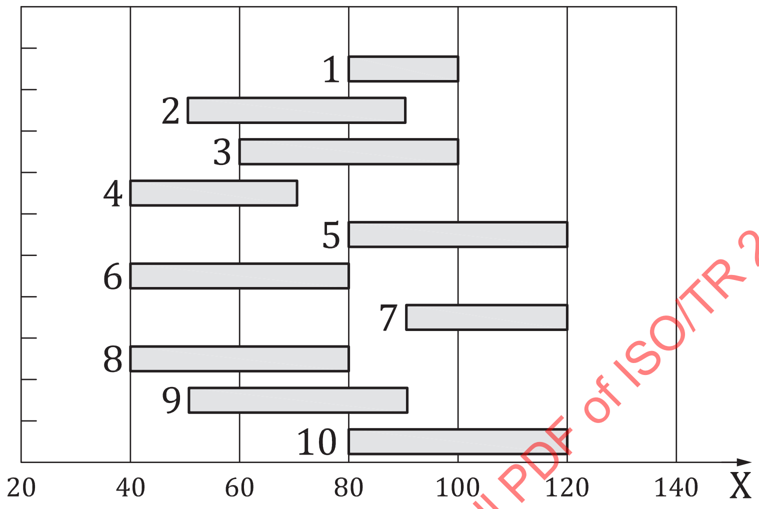
Component	Inspection	Indicators	Impact on	Points of attention
Inlet	Dimension, arrangement, function	Corrosion, position	Quality	Inlet under water surface. Inlet and outlet with sufficient distance.
Outlet	Dimension, arrangement, function, valves	Corrosion, position	Quality	Inlet and outlet with sufficient distance
Overflow	Dimension, arrangement, function control, barrier for insects/animals	Corrosion, position	Quality	No valves on the overflow system, no direct connection to other installations. No ventilation through the overflow system.
Drain	Dimension, arrangement, function, valves, control of the system to the point of discharge, sewer or receiving water, leakproofness	Corrosion, leakage	Quality	No direct connection to other installations.
Vents, ventilation system	Filters, air inlets (outside), ventilation holes (inside), barrier for insects/animals	Condition, damages	Quality	Installation of barriers for insects and animals.
Pipes and pipe supports	Leakproofness, corrosion	Corrosion, leakage	Quality, structure	No stagnation areas.
Valves	Corrosion, tightness, operability, leakproofness	Corrosion, leakage, age	Quality, structure	—
Steel gratings, guardrails	Stability, corrosion, fixing,	Instability, corrosion, damages	Safety	—
Electrotechnical equipment including lightning protection	Authorised electrician can conduct the inspection, lightning protection, technology status	Outdated, damages	Safety, continuity	—
Electronic instrumentation and control (E/I&C)	Technology status, availability of spare parts	Outdated, rare spare parts, recurring failures	Safety, continuity	—

6 Assessment

6.1 Degradation models based on service life

This example is obtained from Germany. Figure 12 shows the clusters of expected lifetimes of materials. Similar cluster can be developed based on experience in different contexts.

The rehabilitation strategies can be elaborated by means of a software which is based on a cohort-survival model and which permits the calculation of the annual pipe network renewal demands on the basis of service life distributions.



Key

X year

1 AC

2 PVC

3 PE 80 3. Gen./PE 100

4 PE 63/PE80

5 steel after 1980

6 steel until 1980

7 DI with PE, ZN or cem coating

8 DI without coating

9 CI after 1930

10 CI until 1930

Figure 12 — Experience-based assessment of service life of different pipe types

6.2 Assessment of maturity of operations to define action plans

This example is obtained from France. The good practices highlighted include:

— maturity self-assessment of utility's business processes by reviewing a set of standardized criteria;

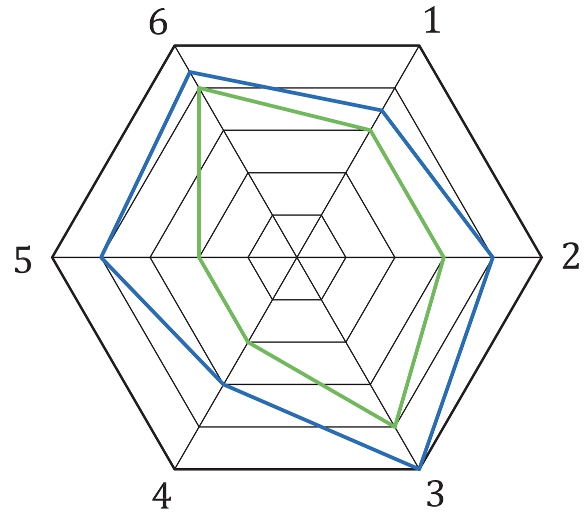
— based on initial assessment, objectives and priority action plans can be decided;

— annual self-assessment follow-up to measure the progress of actions.

The method consists in assessing the basic business processes that make up drinking water distribution activities, customer management and cross-activity services.

The first step is to set out a complete and precise assessment of performances and skills of the operation unit to place it on the international scale. This work is done through assessment grids, prepared by process experts and specific for each process. The challenges mentioned previously are addressed in the grids. Each grid can be made of approximately 40 objective and standardized criteria that can define 6 level scale of mastery: from poor mastery (level 1), through maturity threshold (level 3) to international leadership (level 6).

After this initial assessment the desired level of maturity to be reached after a period of time is defined with the stakeholders (asset owner, operator, regulator, etc.). Action plans are then built accordingly. Figure 13 shows an example of initial diagnosis and target value for relevant indicators.



Key

1 environmental footprint

2 water network yield (%)

3 patrimonial indicator (%)

4 rate of pipe renewal (% over 5 years)

5 linear water losses index (m^3/d/km)

6 unforeseen service interruptions (number/1 000 customers)

Figure 13 — Example of initial diagnosis and target value for relevant indicators

6.3 Criticality

6.3.1 Networks: simplified criticality map base on the impact of a failure

This example of criticality mapping is obtained from India, and the good practices highlighted include:

— Criticality score of pipes can be allocated by using simple criteria such as impact of failure based on flowrate in the pipe (the highest, the more customer impacted) and visual representation of sensitive customers as shown on Figure 14.

— Additional criteria can be based on the typology of road (residential, commercial, etc.).

— Prerequisites: an GIS, hydraulic model, link between road and pipes.

Key

■ (green)	reservoir	■ (blue)	apartment
—	0,00 – 0,47 (low)	■ (yellow)	church
—	0,47 – 1,96 (medium)	■ (pink)	commercial
—	1,96 – 4,54 (high)	■ (dark red)	hospital
— (red)	4,54 – 20,03 (very high)	■ (red)	school
□ (red)	proposed boundary building parcels	■ (lavender)	temple

Figure 14 — Criticality mapping

6.3.2 Treatment plant: implementation of simplified and monetized FMECA (failure mode, effects and criticality analysis)

This example of simplified and monetized FMECA ($iFMECA) is obtained from Jordan and is derived from a wastewater treatment plant. The good practices highlighted include:

— applied at an ISO 55001:2014 certified site;

— practical implementation of a systematic method initially developed for complex systems in the aviation industry.

The simplified and monetized FMECA ($iFMECA) offers an interesting trade-off between the ease of implementation (cost) and quality of outcomes. This method allows reaching relevant results in a relatively short time. Moreover, the monetization allows expressing risk and resources in the same unit and facilitates decision making.

$iFMECA consists of considering the loss of each asset function and describing its effects over the system. Unlike FMECA, only one failure mode is considered for most of the assets: function lost. The criticality level is then estimated based on the severity of the failure mode expressed in JOD (Jordanian Dinar) and its frequency. In order to develop the criticality analysis of the plant, the first step consists of defining the assumptions for setting the context and monetizing the weight of each failure mode impact severity. The assumptions depend strongly on the local context. The same assumptions are applied to all the assets to ensure consistency. The following part focuses on assumptions.

The impact on production is estimated based on following assumptions:

— Context of operation: a same failure can have different impacts if the plant is operated at full capacity or at 30 % of it. We assume that the facility is operated in a context of yearly average production.

— Water quality out-of-spec is considered as untreated water.

— Untreated water volume due to a failure mode is estimated based on assets flows (yearly average) and estimated mean recovery time.

— In order to attribute a severity weight to the loss of drinking water treatment, the following principle is used. The organization gets an income from the community for treating drinking water. If a volume of drinking water is not treated properly, it is considered that the organization does not deserve the income associated with the volume lost. Consequently, a cost of per hour of untreated drinking water, corresponding to the yearly average revenue divided by 8 760 hour/year is considered.

— In case of impact on energy consumption or energy production, an energy cost per kWh is considered. The yearly energy consumption bill of a facility can be used for estimating energy impacts.

— The yearly consumption cost of a reagent in a facility can be used for estimating a failure mode impact over a chemical consumption.

— A minor operational inconvenience cost per hour is to reflect variable severity in case of minor inconvenience, minor energy or reagent on consumption.

— The severity weight of the loss of a coagulation, flocculation and sediment removal is estimated case by case, considering impacts in terms of energy consumption (e.g. more coagulation chemicals and aeration is required if sludge dissolved and suspended particle extraction is stopped and concentration increases), reagents, trucks, sediment removal and disposal cost, etc.

The assumptions for the impact on maintenance cost are as follows:

— A labour cost per man-hour is considered.

— Spare parts availability assumption is based on the most realistic current scenario for the considered asset failure mode.

— The average spare parts cost is estimated case by case based on available data and operators' inputs.

— Required means and skilled labour are considered always available for addressing failures.

The assumption for the environmental impacts is as follows:

— The environmental impacts are included in the production.

The assumptions for the impact on safety are as follows:

— The main safety risk exposure is experienced by the technicians during the corrective interventions for recovering the asset function after a failure. Consequently, it is considered that safety risk is associated with the number of man-hours required for addressing the failures. An assumption of cost per corrective man-hour is made.

— When required, an additional specific safety impact can be decided on a case by case basis (e.g. chlorine leak).

The assumption for the impact on reputation is as follows:

— In order to reduce the number of severity criteria (simplification), the reputational impact can also be included in production.

The assumption for severity is as follows:

— The failure mode's severity is expressed in JOD and corresponds to the sum of maintenance cost, production loss, safety and environment impact costs.

The assumption for probability is as follows:

— Without any other information (e.g. technology change, renewal), we assume that the asset behaviour in the future is determined by its behaviour in the past. Consequently, the probability (likelihood) of a failure mode occurrence is equal to its frequency (from asset history).

NOTE Potential climate change impacts are considered for both short-term and long-term risks.

The criticality is then expressed in JOD per year and corresponds to the multiplication of severity (in JOD) by frequency (average number of failures per year). The Table 11 is an example of severity rating.

Table 11 — Example of rating

Rating	Severity = Sum (safety, cost, quantity, environment)					Frequency	Detection
	Safety	Cost	Water quantity	Water quality	Environment		
1	No effects	< 5 000 $	No impact	No impact on quality	No impact	Never happened	Warning signs or alarm. Failure can easily be avoided with a preventive action.
3	Accident without work stoppage	< 20 000 $	Less than 1 hour production loss	—	Minor incident manager internally	Already happened	Detection within 2 h
5	Accident with work stoppage less than 1 week	< 50 000 $	Less than 6 hours production lost	Impact on quality within specification	Minor incident involving external parties	Once a year	Detection within 8 h
7	Accident with work stoppage more than 1 week, no consequences	< 10 000 $	Less than 12 hours production lost	—	Serious incident	Many times a year	Detection > 8 h
10	Accident with consequences	> 100 000 $	More than 12 hours production lost	Impact on quality out of specification	Major incident		

6.4 Likelihood of failure: multicriteria evaluation for networks

This example obtained from India illustrates the application of a multicriteria-based evaluation of the likelihood of failure of trunk mains. The highlighted good practice includes a practical calculation of likelihood of failure score that can be easily automated and displayed in a GIS.

Table 12 and Table 13 illustrate the scoring system that is applied to the different characteristics of the pipes: material, age of pipes, the type of road and traffic above the pipes, the leak history, the service pressure and soil characteristics. The likelihood of failure is the weighted sum of individual scores and is plotted as shown in Figure 15.

Table 12 — Scoring chart based on age and material

Age/Material (weight 2)										
Score	Age range (AR)									
	AR0	AR1	AR2	AR3	AR4	AR5	AR6	AR7	AR8	AR9
Asbestos cement (AC)	0,5	1	1	2	2	3	3	4	4	5
Cast iron (CI)	0,5	0,5	0,5	1	1	1	1	2	2	2
Ductile iron (DI)	0,5	0,5	0,5	0,5	1	1	1	1	2	2
Mild steel (MS)	0,5	1	1	1	2	2	3	3	3	4
Prestressed concrete (PSC)	0,5	1	1	1	2	2	3	3	4	4
Polyvinyl chloride (PVC)	0,5	1	2	2	3	3	4	4	5	5

Table 13 — Scoring chart based on other criteria

Category	Criteria	Score
Road type (weight 0,5)	Slum area	3
	Mud road	2
	Mud road cent	2
	Asphalt road	1
	Asphalt road centre	1
	Asphalt road edge	0
	Tank location	0
	Concrete road centre	0
	Metal road	0
	Pipeline not coming road side	0
Traffic (weight 0,5)	Heavy	2
	Medium	1
	Low	0
Leak number (weight 1)	0	0
	1	1
	2	1
	3	2
	4	2
	5	3
Resistivity (weight 1)	< 700	4
	700 to 1 200	2
	1 200 to 2 000	1
	> 2 000	0
Pressure (weight 0,5)	0	0
	1	1
	2	2
	3	2

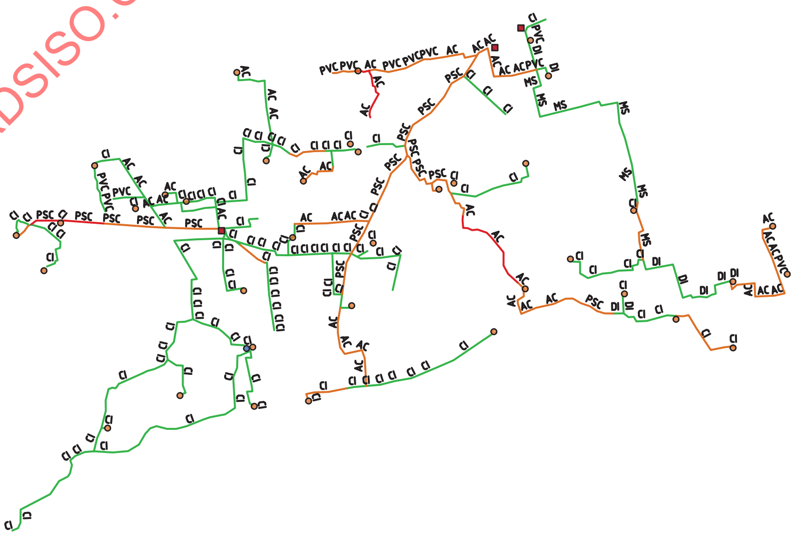


Figure 15 — Visualization of likelihood of failure

7 Implementation

7.1 Prioritization of works

Table 14 illustrates the prioritization criteria of rehabilitation for 24 × 7 conversion. This example is obtained from India.

Table 14 — Pipe renewal prioritization

Scale	Criteria	Detail	Analysis status	Output	Responsible
Zone-wise	Works feasibility	Permits constraints	Done	Zone-wise priority map	Works department
	Operations and maintenance (O&M) favourable condition	Retained feeder main	Done		
Pocket-wise	Service level improvement	Equity	Ongoing	Pocket-wise service level score	O&M department
		Shortage	To be done		
		Pressure	To be done		
		Losses	To be done		
Pipe-wise	Risk score	Condition x criticality	Done	Phase-wise pipe renewal map	Technical department
	Works feasibility	Physical constraints	To be done		
	Hydraulics	Critical headloss route	Ongoing		
	Fast track	Bursts concentration	To be done	Fast track	
		High criticality pipe	To be done	Phase I	
		Critical event	n/a	Phase II	
	Capex	Cost/km	To be done	Phase III	

7.2 Sustainable field works

This example is obtained from France. It highlights methods for low environmental impact works and optimized field works scheduling, using mobility tools.

Depending on the local context and specific requirements, the most adequate materials for constructing or renewing drinking water networks are qualified in conjunction with procurement experts and applied. The teams are provided with the best available skills (permanent training, best practice manuals).

Also, an adequate organization of the works is implemented. Teams are equipped with up-to-date mobility tools [personal digital assistants (PDAs), GPS, GIS laptops etc.], which makes them very reactive and flexible to fix any emergency. Systematic use of GPS allows to optimise routes, and thus to minimise car petrol consumption.

Carbon footprint, environmental and social impact of the works (e.g. implementation of no-joint polyethylene networks, trenchless works, clean pipes with ice, recycling of excavated material) are considered.

8 Operation and maintenance

8.1 Planned water leakage prevention action

8.1.1 General

This example is obtained from Japan. It highlights a leakage prevention action plan.

A water utility of "T city" has made efforts to prevent leakage that occurs underground and on the ground through a "planned work" and "mobile work". The water utility finds leakage in their water service area and undertakes early repair through these works.

8.1.2 Planned work

8.1.2.1 General

The purpose of planned work is to find underground leakage. This work is performed for a block which is delineated by 2 km to 3 km lengths of distribution pipelines buried in a grid shape that provide water to users in a network.

The planned work includes 3 phases which are the patrol works, the leakage volume measurement work and the leakage investigation and measurement work.

8.1.2.2 Phase 1: patrol work

The patrol work is individual investigation work that is conducted during the night when there is less traffic by using a leakage sound detection bar (Figure 16) and time integral type leakage detector (TIT leak detector) (Figure 17). The leakage detection is obtained by putting a water meter on each house along with acoustic investigation work to identify points of leakage with electronic leakage detector (Figure 18) from the road surface. The leak detection method is illustrated in Figure 19.

Figure 16 — Leakage sound detection bar

Dimensions in millimetres

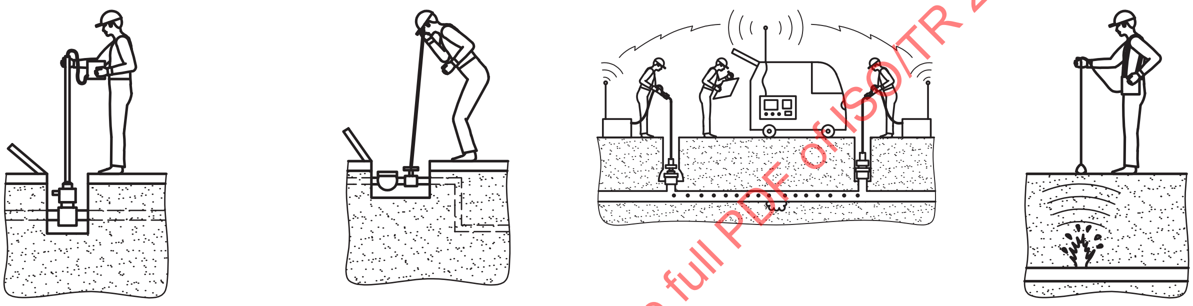
Weight: 330 g

Figure 17 — Time integral type leakage detector

Key

1 detector (pickup)

Figure 18 — Electronic leak detector



a) Time integral type leakage detector

b) Leakage sound detection bar

c) Leakage correlator

d) Electronic leak detector

Figure 19 — Leakage detection method

A flow chart of patrol work is given in Figure 20.

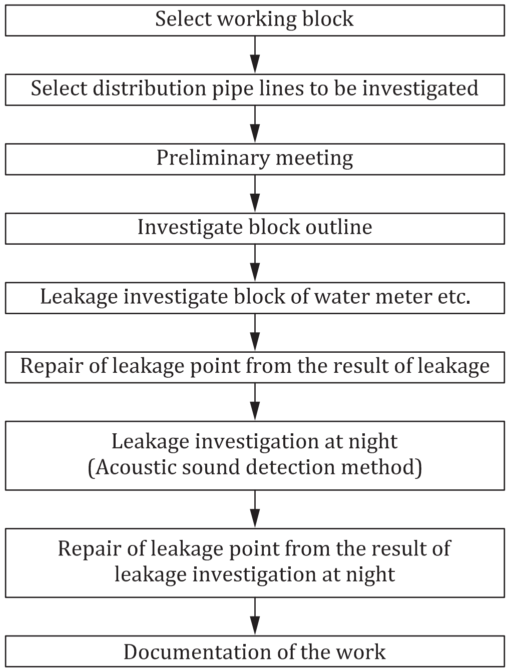


Figure 20 — Flow of patrol work

The selection of working block and distribution pipelines is made in consideration of past action, the situation of leakage in the previous year, and the number of remaining lead pipe.

The leakage investigation is implemented at all the water meters of houses in the block. If any leakage was found, the leakage point is identified by an acoustic sound detection method.

The leakage investigation and the identification of leakage point is implemented by an acoustic sound detection method. This investigation includes: "door to door survey" (to check if any leakage occurs by attaching an acoustic rod to the water meter of each house) and "acoustic sound detection method" (to identify the point of leakage by an electronic leakage detector on the surface of the road at night when traffic load is low). Also, in some blocks, the door-to-door survey is implemented by an integral leakage detector instead of an acoustic rod.

8.1.2.3 Phase 2: leakage volume measurement work

The purpose of this work is not only to estimate total leakage volume in the supply area but also to understand the trend of leakage. A flow chart of this work is given in Figure 21.

In order to assess the more accurate amount of leakage an urban area, the leakage volume is measured during the night hours when no one uses water. Figure 22 illustrates the method for minimum night flow measurement. By estimating leakage volume within a certain block, it is possible to make an assumption about total leakage volume.

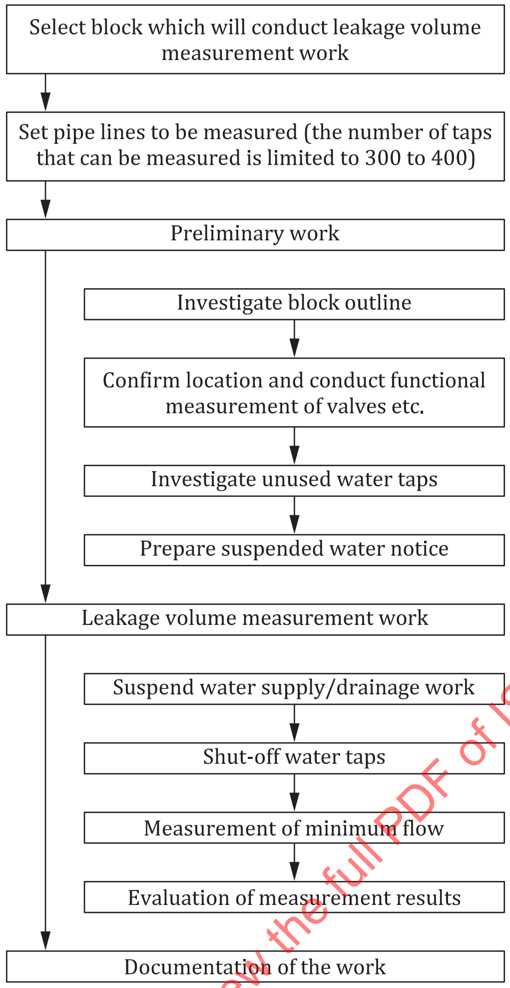


Figure 21 — Flow of the leakage volume measurement work