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Guidelines for the management of assets of water supply and wastewater systems —

Part 1: **Drinking water distribution networks**

Lignes directrices pour la gestion d'actifs des systèmes d'eaux usées et d'eau potable —

Partie 1: 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).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is Technical Committee ISO/TC 224, *Service activities relating to drinking water supply systems and wastewater systems — Quality criteria of the service and performance indicators*.

A list of all parts in the ISO 24516 series can be found on the ISO website.

Introduction

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

Drinking water utilities 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 drinking water utilities and are the consequence of the accumulated capital investments and operational expenditures on maintenance and rehabilitation over many years. In many of these utilities, the replacement value of these past investments will amount to many millions (even billions) of US 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 programmes are in place to assure their protection or their sustainability. Like many other organizations having assets, drinking water utilities undertake programmes of activities to manage the assets to ensure they continue to meet the needs of the community for reliable delivery of drinking water. These management activities can be at the strategic, tactical or operational level. The activities can be part of a formal management system, the result of specific legislative requirements, or simply the result of due diligence by the service operators and managers.

This document can serve as a supporting document for utilities operating an asset management system regardless of whether the utilities make use of any management system standard (e.g. ISO 55001).

In many countries, there is a recognized sustainability problem, sometimes referred to as the infrastructure gap, which recognizes that for various reasons, the infrastructure has not been maintained over the years on a truly sustainable basis, i.e. funding and implementation of rehabilitation programmes have 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 from aspects of quality, quantity, pressure, safety, reliability, environmental impact, degree of treatment 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.

As the installation and development of water assets mature, the optimization of networks will become necessary in many places in order to respond to changing societal and economic conditions. Consequently, networks are subject not only to ageing as well as wear and tear but also to adaptation processes resulting from growth, new legislative requirements, or changing customer service level expectations. This requires drinking water utilities not only to focus on maintenance and rehabilitation but also to keep future requirements and developments in mind. Rehabilitation will thus become essential in management of assets, with ever more stringent requirements on the design and execution of rehabilitation (partial replacement of specific sections of the entire network is also considered as rehabilitation).

In recent years, much effort has been applied to the whole issue of management of assets on two levels:

— What are the principles and structure of an asset management system?

— 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, renovation or replacement) take place?

This document describes the information required and how to collect and process reliable inventory, condition, operational and context data about drinking water systems. Condition data for the underground water infrastructure notably include data on failure. These data serve mainly as a basis for systematic maintenance and can also contribute data needed for benchmarking.

Reliable failure statistics and the database description of the condition are of particular significance for establishing investigation, maintenance and rehabilitation priorities.

This document also provides guidance on how to define a strategy on management of assets with regard to the overall performance expected by the drinking water utility and other stakeholders. It includes several aspects of the operation and maintenance, including asset condition assessment and investment strategies (new assets and rehabilitation).

The approaches offered in this document are intended to be universally applicable, regardless of the structure of a given water system.

The usual and expected goal of the effective management of assets is to provide an appropriate service life while fulfilling given requirements in a cost-effective manner.

This document is intended to provide guidance on the assets typically owned or operated by drinking water utilities (networked drinking water systems) that are expected to meet customer needs and expectations over longer (multi-generational) periods.

Additional information on objectives of management of assets is provided in Annex A. Information on the assessment of typical service life and age-based failure rates of pipes is shown in Annex B and risk-based prioritization of pipe rehabilitation in Annex C.

Guidelines for the management of assets of water supply and wastewater systems —

Part 1:
Drinking water distribution networks

1 Scope

This document specifies guidelines for technical aspects, tools and good practices for the management of assets of drinking water networks to maintain value from existing assets.

This document does not apply to the management of assets of waterworks (including catchment and treatment, pumping and storage in the network), which are also physically part of the drinking water system and can influence the management of assets of the pipe network.

NOTE 1 The drinking water network is taken to include both pressurized and non-pressurized (i.e. containing free surface flow) conduits and accessories such as valves and control or metering equipment.

NOTE 2 The management of assets of drinking water pumping stations and storage in the network will be included in another part of the ISO 24516 series.

This document focuses on the assets typically owned or operated by drinking water utilities (networked drinking water systems) that are expected to meet customer needs and expectations over longer (multi-generational) periods.

This document includes examples for good practice approaches on the strategic, tactical and operational levels.

This document is applicable to all types and sizes of organization and/or utilities operating drinking water systems, and all different roles/functions for the management of assets within a utility (e.g. asset owner/responsible body, asset manager/operator, service provider/operator).

NOTE 3 Depending on the size and structure of an organization, the utility can decide to what extent it applies the guidance in this document, but in any case, the philosophy of this document remains applicable to small and medium utilities.

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 http://www.iso.org/obp

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

3.1
asset
capital-forming goods used for the provision of the service

Note 1 to entry: Assets can be tangible or intangible. Examples of tangible assets are: land, buildings, pipes, wells, tanks, treatment plants, equipment, hardware. Examples of intangible assets are: software, databases.

Note 2 to entry: Contrary to consumables, assets can be depreciated in accounting systems.

[SOURCE: ISO 24510:2007, 2.4]

3.2
asset management
processes that enable a water utility to direct, control and optimize the provision, maintenance and disposal of infrastructure assets, including the necessary costs for specified performances, over their life-cycle

[SOURCE: ISO 24510:2007, 2.5]

3.3
asset system
set of *assets* (3.1) that interact or are interrelated

[SOURCE: ISO 55000:2014, 3.2.5]

3.4
asset type
grouping of *assets* (3.1) having common characteristics that distinguish those assets as a group or class

Note 1 to entry: Examples of asset types include, but are not limited to, physical assets, information assets, intangible assets, critical assets, enabling assets, linear assets, information and communications technology (ICT) assets, infrastructure assets, moveable assets, etc.

Note 2 to entry: Examples of physical asset types in the water sector are pipes, valves, pumps or filters of the same class, coating, year of manufacture, producer or the ageing process.

[SOURCE: ISO 55000:2014, 3.2.6]

3.5
failure
local inadmissible impairment of the operability of an asset of a drinking water or wastewater system

3.6
failure data
data describing the characteristics of the *failure* (3.5) caused at a certain point in time on a certain asset of a drinking water or wastewater system

3.7
failure rate
number of *failures* (3.5) per unit

Note 1 to entry: In the case of pipelines, expressed per kilometre per year.

Note 2 to entry: For drinking water networks, in the case of connections and valves, expressed per thousand per year.

3.8
inspection
identifying the actual status of an asset or asset system

3.9
investigation
gathering of all information necessary for a decision making process

Note 1 to entry: This includes both qualitative and quantitative information.

[SOURCE: EN 15898:2011, modified]

3.10
level of service
service to users which reflects social and economic goals of the community safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost and availability

Note 1 to entry: A defined level of service can include any combination of the aforementioned parameters deemed important by the asset owner, users or relevant stakeholders.

3.11
life cycle cost
total cost of an *asset* (3.1) throughout its service life, including planning, design, construction, acquisition, operation, maintenance, rehabilitation and disposal costs

3.12
maintenance
combination of all technical, administrative and managerial actions during the life cycle of an asset intended to retain it in, or restore it to, a state in which it can perform the required function

[SOURCE: ISO 24510:2007, 2.19]

3.13
management of assets
operation, maintenance and rehabilitation of assets of water supply and wastewater systems as a functional activity

Note 1 to entry: This encompasses all necessary activities for sustainable operation and maintenance of the assets in drinking water and wastewater systems.

3.14
operation(s)
action(s) taken in the course of normal functioning of drinking water or wastewater systems

EXAMPLE Monitoring and regulation or diversion of drinking water or wastewater.

[SOURCE: EN 752:2015, modified]

3.15
operational plan
documented collection of procedures and information that is developed, compiled and maintained in readiness for the conduct of operations

3.16
performance indicator
metric or measure by which the achievement of an objective can be assessed

[SOURCE: ISO 19440:2007, 3.1.62]

3.17
rehabilitation
measures for restoring or upgrading the performance of existing asset systems, including renovation, repair and replacement

[SOURCE: EN 16323:2014, modified]

3.18
rehabilitation rate
percentage of entire inventory which is rehabilitated or to be rehabilitated on an annual basis

3.19
service
result of a process

Note 1 to entry: Adapted from the definition of "product" in ISO 9000:2005.

Note 2 to entry: Services are one of the four generic categories of products with software, hardware and process materials. Many products comprise elements belonging to different generic product categories. Whether the product is then called "service" depends on the dominant element.

Note 3 to entry: Service is the result of at least one activity necessarily performed at the interface between the provider of the service and, in the first place, its user and, in the second place, a stakeholder. Service is generally intangible. Provision of a service can involve for example the following:

— activity performed on a tangible product supplied by the user, e.g. wastewater,

— activity performed on an intangible product coming from the user, e.g. processing new connection requests,

— delivery of an intangible product, e.g. delivery of information,

— creation of ambience for the user, e.g. reception offices.

Note 4 to entry: The word "service" in common English can also refer to the entity providing the actions related to the subject in question, as is implicit in such phrases as "bus service", "police service", "fire service" and "water or wastewater service". In this context and usage, "service" implies the entity that is delivering the service, e.g. "the public transport of passengers", "the provision of public security", "fire protection and response", and "delivering drinking water or collecting wastewater". If "service" can be understood in this way, "water service" becomes synonymous with "water utility"; hence in this document, in order to avoid confusion, only the definition in 3.19 applies.

[SOURCE: ISO 24510:2007, 2.44]

3.20
service life
period of time after installation during which an asset or an asset system meets or exceeds the technical requirements and functional requirements

[SOURCE: EN 15978:2011, modified]

3.21
strategic plan
plan containing the long-term goals and strategies of an organization

Note 1 to entry: Strategic plans have a strong external focus, cover major portions of the organization and identify major targets, actions and resource allocations relating to the long-term survival, value and adoption to ongoing changes of an organization.

3.22
tactical plan
prioritization in the medium term on the basis of influencing factors/indicators on performance, costs, risk and failure probability and scale of failure, including general determination

EXAMPLE 1 Indicators of damage probability can be age, usage and damage.

EXAMPLE 2 Indicators for the magnitude of failures can be hydraulic importance and vulnerable infrastructures.

EXAMPLE 3 General determinations can be technology of rehabilitation and material.

4 Principles aspects of the management of assets

4.1 Objectives and requirements

4.1.1 Objectives

According to ISO 24510 and ISO 24512, the objectives of drinking water utilities are the following:

— protection of public health;

— meeting users' reasonable needs and expectations;

— providing services under usual and emergency situations;

— promoting the sustainability of the drinking water utility;

— promoting sustainable development of the community;

— protection of the environment.

Drinking water utilities, in undertaking management of asset, should aim to manage their facilities systematically and efficiently in order to sustain their function, through establishment of clear objectives, based on assessment and forecasting of the condition of their often extensive and complex facilities.

The objective of the management of assets is to ensure that the drinking water utility complies with agreed sustainable levels of service, while also meeting economic performance objectives such as attaining the least possible overall life cycle cost.

For further information on objectives of management of assets for drinking water networks, see Annex A.

4.1.2 Functional requirements

In order to achieve the objectives, functional requirements should be established.

Functional requirements cover the drinking water network, together with pumping installations, pressure control devices, reservoirs, waterworks and other components. The functional requirements should be considered in respect of the whole system to ensure that additions or modifications to the system do not result in failure to meet the target.

Functional requirements should be established that, while taking into account sustainable development and whole life costs including indirect costs (e.g. traffic congestion, military aid provided by civil authorities), ensure that drinking water networks do not cause unacceptable environmental nuisance, risk to public health, or risk to personnel working therein.

Each functional requirement can relate to more than one objective. An indication of the relevance of each of the functional requirements in achieving the objectives is shown in Table 1.

Table 1 — Relationship between objectives and functional requirements

Functional requirements	Objectives						
	Protection of public health and safety	Meeting users' reasonable needs and expectations	Occupational health and safety	Providing services under usual and emergency situations	Promoting the sustainability of the drinking water utility	Promoting sustainable development of the community	Protection of the environment
Ensuring the drinking water quality	XXX	XXX	XX	XX	XX	XX	XX
Continuity of supply	XXX	XXX	—	XXX	XXX	XXX	X
Ensuring adequate pressure	XXX	XXX	X	XX	XX	—	X
Maintainability	XX	X	XXX	XX	XX	XX	XX
Providing service under emergency situations	XXX	XXX	X	XXX	XXX	—	XXX
Sustainability of products and materials	—	XX	—	XX	XXX	—	XX
Sustainable use of energy	—	X	—	XX	XXX	—	XX
Long design life of assets	X	XX	X	XX	XXX	—	XXX
Minimizing of leakages	XX	X	X	X	XXX	—	XXX
Prevention of noise	XX	X	X	X	X	—	X
Not endangering adjacent structures and environment	XX	X	XX	X	XX	—	X
NOTE The number of X indicates the relevance of the requirement in achieving the objectives.							

4.1.3 Performance requirements

In order to evaluate the performance of the network and to allow development of design standards, measurable performance requirements should be determined from each functional requirement.

For each functional requirement, there can be legal requirements, public expectations and financial constraints which will influence the performance requirements.

For each aspect of performance, different levels can be required, for example:

a) trigger levels which justify early upgrading action according to priority;

b) target levels to aim for in upgrading, which should be equal to the requirements for new construction, but which sometimes can only be achievable or necessary in the longer term.

Performance requirements should be reviewed periodically and updated, if necessary. The performance requirements for the network should be updated after major extension, maintenance or rehabilitation.

In principle, the performance requirements for a rehabilitated network should be the same as those for a new network.

Performance indicators are an essential tool in understanding a utility's infrastructure conditions and needs and, in parallel, enable indicator-supported infrastructure planning and decision making. Properly implemented, indicators provide information on the condition of the assets and the level of their contribution to the achievement of the utility's objectives.

Performance indicators should be defined at strategic, tactical and operational levels. They should make clear how actions at the operational level contribute to achieve strategic level objectives. Strategic level performance indicators are often called "outcomes". Operational and tactical level performance indicators are called "inputs" and "outputs" respectively.

4.2 General aspects

4.2.1 General

A distinction can be drawn between aspects of the management of assets for the drinking water utility or responsible authority and aspects for the drinking water system to be managed.

Management of assets should take into account

— attention to stakeholders' requirements, needs and expectations,

— sustainability of the asset system and the provided service, and

— the management of risk.

The management (of the organizing authority) of the utility's assets will be directed towards ensuring the utility's objectives are met (see ISO 24510).

4.2.2 Principal aspects — Drinking water utilities

The management of the physical infrastructure of drinking water utilities is recognized globally as a critical activity if user's and other stakeholders' expectations should be realized. Key activities include

— the determination of the utility's current and longer term objectives,

— planning and implementing activities to achieve objectives, and

— the means of measuring the performance of the utility in meeting these objectives.

Additionally, for ensuring long and economical life cycles, they include

— knowledge of the layout of the entire water supply system together with knowledge on costs (planning, constructing, operation, maintenance),

— knowledge on availability and need of resources,

— the selection of appropriate materials and components,

— the choice of installation technology and corresponding contractors,

— quality control of materials used and of installation,

— maintenance of assets and asset systems including routine and incident-related inspection and investigation, and

— monitoring of operating conditions.

Effective management of assets is a balance of minimizing life cycle costs while continuously providing the levels of service established by the utility to meet customer and stakeholder expectations.

Management of the assets includes

— maintaining an up-to-date system inventory,

— monitoring and documenting data,

— assessing system condition,

— planning, maintaining or rehabilitating the system,

— optimizing depreciation and reinvestment,

— identifying and managing risks,

— ensuring the system is utilized/operated as intended, and

— the environment in which the assets are functioning.

4.2.3 Principal aspects — Drinking water systems

The management of assets of water supply systems should cover the complete asset system and the interrelationship of all assets such as abstraction, waterworks, and treatment plants including the resulting water quality, reservoirs, pumping stations and mains. In addition, the management of assets should consider changes in needs and expectations of users and other stakeholders as well as environmental effects such as climate conditions, consumption of resources, population migrations, and demography.

Hence, this document should be used in conjunction with other standards regarding management of assets on water supply systems such as drinking water plants including treatment, pumping and storage (and any storage in the network).

Drinking water systems are used to provide a service to users and communities. This can be briefly (and typically) described as

— delivering of safe drinking water in the required/agreed quality, and

— supporting the fire brigades with water for firefighting if possible (depending on local regulations).

In general, drinking water supply system generally comprises four components:

— water source;

— intake and transport;

— treatment if necessary, and if appropriate, disposal of residues;

— storage, transport and distribution.

4.2.4 Integrating the principal aspects

Management of assets is the application of the drinking water utility's asset management principles, as described in this document, within the management of the drinking water system including the drinking water network.

Management of the drinking water network assets is implemented with the framework of integrated drinking water network management.

4.3 Risks and life cycle aspects

4.3.1 Risk

Risk considerations are necessary at all levels in the management of assets — the strategic, the tactical and the operational levels.

Appropriate treatment of risks arising within the context of an organization is an important objective in the management of that organization's assets. Risk treatment is typically done by the introduction, or modification, of existing risk controls. Selection of the most appropriate risk controls should result from a process of assessing organizational hazards (e.g. arising from an asset's positioning or failure). Appropriate countermeasures can then be introduced in a prioritized manner. Such measures can include operation and maintenance activities as well as rehabilitation.

There are many alternative techniques for identifying, analysing, evaluating and treating risk in different fields (see IEC 31010 and the water sector-specific EN 15975-2). The risk assessment methodology proposed in this document is based on generally recognized risk assessment principles (e.g. ISO 31000).

These principles involve

— risk identification (in this case, principally by hazard analysis),

— risk analysis,

— risk evaluation, and

— risk treatment (risk control).

Hazard analysis involves study of hazards as potential causes of risk events. Risk analysis considers the impact (and related consequences) of a risk event's occurrence and the likelihood that that event can occur. The drinking water utility should define its utility-specific risk analysis approach and criteria for risk evaluation, based on organizational objectives and external and internal contexts. Risk criteria should be determined in terms of the same dimensions as the parameters used in the risk analysis. The order of priority for inspection/survey plans should be determined by risk evaluation (which considers the significance of each risk relative to all the risks under consideration). Typically, this comparison is conducted by comparing individual risks' "scores" (the product of a risk's impact × likelihood ratings against the organization's risk criteria), using a risk matrix to present the results.

The prioritization of measures to treat (prevent/reduce) the impact and/or likelihood of individual risks' occurrence should be carried out by comparing the effectiveness of individual treatment measures and their related costs, practicability and acceptability to stakeholders.

Drinking water-related asset risks can be categorized into the following two groups:

a) non-influenceable risks, such as natural disasters (earthquakes, storms, floods, etc.) or economic situations;

b) influenceable risks, such as events arising from accidental damage, asset deterioration, mis-operation of assets, or malicious interference with assets.

The following are a few examples of asset data relevant for assessing impact:

A pipe's

— diameter,

— operating pressure or function,

— proximity to other significant assets,

— access constraints,

— social influence, and

— (repair or rehabilitation) cost.

The following are a few examples of asset data relevant for assessing likelihood:

— maintenance data;

— telemetry data;

— employee feedback;

— incident data;

— condition data;

— user complaints;

— security reports.

4.3.2 Life cycle

Life cycle cost should be minimized by keeping the system in an operating condition as stated in the objectives.

This should include

— optimized maintenance planning,

— pipeline network investigation/inspection at regular intervals and water loss assessments,

— use of suitable construction methods and durable materials,

— cooperation with other services or contractors,

— energy management,

— optimized stand-by service,

— proper control of operational processes,

— efficient deployment of staff and accomplishment of tasks (by qualified and/or certified contractors, if necessary, while retaining core competences in the utility),

— participation in benchmarking projects, and

— demand-based materials management and control (procurement and stock keeping).

For example, to rehabilitate facilities, the priority of the project should be determined in the framework of budget while aiming to minimize the life cycle cost of each asset.

4.4 Structuring the process for management of assets

4.4.1 General

Integrated management of assets in drinking water networks is the process of achieving an understanding of existing and proposed drinking water networks and of using this information to develop strategies to ensure that the hydraulic, structural and operational performance meets the specified performance requirements taking into account future conditions and economic efficiency.

The integrated drinking water networks management process is illustrated in Figure 1.

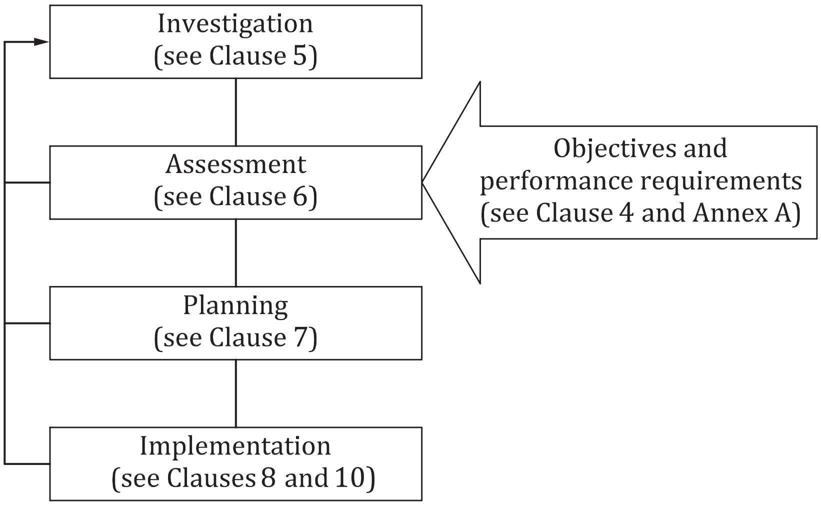


Figure 1 — Integrated drinking water networks management process

The integrated drinking water networks management process has four principal activities:

— an appropriate level of investigation of all aspects of the performance of the drinking water networks;

— assessment of the performance by comparison with the performance requirements including identification of the reasons for the performance failures;

— developing the plan of measures to be taken;

— implementation of the plan.

The need for further investigation can become apparent either during the performance assessment or the development of the plan.

Integrated drinking water networks management forms the basis for the operation and rehabilitation of the drinking water networks. The information is regularly updated for the future management of the drinking water networks.

For large drinking water networks, for example, where one serving a large city, an outline integrated drinking water management plan may first be developed following an outline investigation of the whole system. More detailed plans may then be developed for each sub-distribution section within the context of the strategic outline plan.

The integrated drinking water network management plan is further developed during the implementation phase by subsequent investigation, assessment and planning to develop work programmes and individual projects to implement the plan.

The boundary conditions should also be considered.

4.4.2 Strategies for the management of assets

The strategies for the management of assets should be based on objectives and requirements (see 4.1). The risks of not achieving these objectives and requirements should be identified and managed appropriately.

Drinking water infrastructure assets should be managed and maintained according to the condition-based or inspection strategy. This requires devising an inspection strategy (see also Reference [15]).

The condition-based or inspection strategy takes into account the development of the condition of the asset system and single assets and pursues a long-term approach. It warrants the efficient and economical use of restoration funds although it may not reduce overall rehabilitation and life cycle costs over a defined long-term planning period, but can spread these costs out over a longer term and can avoid social costs. Costs depend on actual maintenance requirements. Based on this strategy, the risks can be estimated and controlled in relation to the objectives determined in accordance with 4.1.

Only repairing failures leads to an incident-based or failure strategy, which incurs lower maintenance costs in the short term but disproportionally high costs in the long run. Probable consequences can include inadequate operating safety, high water losses, increased failure rates, water quality degradation, and premature loss of the existing structure and value of the infrastructure assets. The risk of failures and inadequacies in supply is extremely high.

Fundamental prerequisites for economically efficient maintenance should be defined as early as possible, including in the design and construction phases of water infrastructure.

4.4.3 Periods of planning

The sustainable rehabilitation process for the management of assets is, on the basis of the planning period under review, subdivided into the following three interdependent sub-processes[15] (see Figure 2):

— long-term rehabilitation — strategic planning;

— medium-term rehabilitation — tactical planning;

— short-term rehabilitation — operational planning.

NOTE The duration of the planning stages depends on local circumstances and the nature of the installed pipes or components.

Common time frames are the following:

— strategic planning, about 20 years to 40 years;

— tactical planning, about 2 years to 5 years;

— operational planning, next year.

The development of the rehabilitation strategy for a long-term period focuses on the scope of rehabilitation measures and the rehabilitation budgets required to achieve and to maintain sufficient supply quality and network condition levels. It is based on an asset type approach, e.g. certain pipe types (material, nominal diameter, etc.), but not on individual line sections.

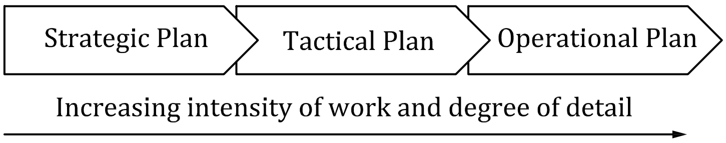


Figure 2 — Logical steps for the implementation and evaluation of rehabilitation targets[16]

Individual mains sections and their environment are taken into account only in the rehabilitation planning. During the sub-process “tactical plan”, the required rehabilitation measures are determined and prioritized for a medium-term period based on a network evaluation. The rehabilitation technology and material are preselected. In the implementation phase, the actual execution of the rehabilitation measures in terms of line routing, nominal diameter, material and construction method is then examined and fixed in consideration of possible alternative measures. For this purpose, the sub-processes cannot be considered as independent, and their results with regard to rehabilitation strategy, tactics and operational plan should be harmonized not only with one another, but also with the strategic network structure and capacity planning.

4.4.4 Strategic level activities

Decision making support requires in the first step the identification of measurable strategic objectives (see 4.1) and the necessary evolution and measurement of the objectives[15]. Common activities related to determining strategic objectives (see also 4.1) should include the following strategic activities:

— establishing acceptable/required levels of service, public safety, public health protection, environmental protection and user satisfaction;

— expressing those levels in the form of performance indicators;

— linking those performance indicators to asset performance indicators;

— establishing adequate billing rates and a water price suitable in time to ensure sustainable revenues;

— quantifying sustainable and predictable infrastructure funding requirements.

4.4.5 Tactical level activities

Activities on a tactical level should include:

— analysing infrastructure asset life cycles;

— establishing operational information to be collected at the operational level;

— establishing a system for managing information;

— analysing reported information;

— analysing the value and performance of the assets;

— analysing of (specific) cost of planning, installation, operation, maintenance and rehabilitation;

— prioritizing infrastructure spending from available funds;

— maintaining an accurate asset data collection system;

— assessing the risks of asset failure or inability to meet the intended function;

— ensuring that the required maintenance is performed.

A major activity at the tactical level is the process of reviewing indicators to determine only productive and useful coherent information, in order to avoid overloading the information management process. The information should be manageable and relevant [15].

4.4.6 Operational level activities

Activities on an operational level should include:

— collecting, monitoring and reporting asset operational information and condition (see Clause 5);

— controlling costs;

— planning preventive maintenance schedules[16];

— implementation of rehabilitation projects.

5 Investigation

5.1 General

The investigation should be carried out in order to make an assessment of the condition and the performance of the drinking water networks and their components.

Investigation is the first stage in the integrated management of assets of drinking water networks as described in 4.4.1.

Damaged, defective or hydraulically overloaded mains represent a potential hazard regarding inadequate drinking water supply (volume, pressure, quality, no continual supply). The problems found in existing drinking water networks are frequently interrelated, and upgrading works will often be designed to overcome a number of problems at the same time. The investigation and planning of rehabilitation work should be carried out on complete areas of supply so that all problems and their causes can be considered together. In large drinking water networks, it can be necessary to start by investigating appropriate parts of the system. The procedures described in this document can be applied in any drinking water network, but detailed application should take account of the age, location and type of the network, the materials used in its construction, together with functional and climatic factors.

5.2 Purpose of investigation

5.2.1 General

The investigation is carried out in order to make an assessment of the performance of the drinking water network and its components. This can include:

— investigation aimed at tactical planning;

— investigation aimed at operational planning.

The purpose of the investigation influences the way in which it is carried out (e.g. choice of method, degree of detail, level of desired accuracy) and the way in which the results are assessed.

The assets of the drinking water networks included in the investigation should be those that are necessary to fulfil the purpose of the investigation. Examples include raw water mains, transmission mains, trunk mains, principal and local mains, service pipes, manholes, inspection chambers, metering chambers, pumping stations, inverted siphons, service reservoirs, draining mains, monitoring facilities, control facilities and flushing facilities.

5.3 Determine the scope of the investigation

Following the review of the current performance information, it is possible to decide whether to carry out an investigation and whether the extent of the problems justifies an investigation of the entire supply area. The extent and detail of the subsequent investigation of the hydraulic, environmental, structural and operational aspects should be determined.

5.4 Data collection

5.4.1 General

Acquisition of data is an indispensable basis for the management of assets but it carries a cost. The drinking water utility should consider what data are important to acquire promptly and what further data should be acquired opportunistically. 5.4 contains details of types of data associated with a range of objects that can be important to inform the drinking water utility's decision making process[17]. The drinking water utility should consider the purpose for which the data are to be gathered and design data recording methods to suit those needs.

Where there is insufficient information, the inventory should first be updated where required and any other information should then be collected during the hydraulic, environmental, structural and operational investigation.

5.4.2 Data requirements

The quality of data should be assessed, taking into account whether it is

— complete,

— compatible,

— accurate,

— at a suitable scale,

— consistent,

— current, and

— credible.

5.4.3 Inventory data

Inventory data provide essential technical information on the drinking water network and its components. Table 2 gives examples of inventory data.

Table 2 — Examples of inventory data

Inventory data attribute, if applicable	Objects		
	Pipeline section	Valves/control and metering equipment	Service pipe
Location (e.g. mains ID, coordinates, address)	X	X	X
Type of mains (trunk mains, principal mains, local mains, service pipe)	X	—	X
Type of component (e.g. fitting, joint, gate valve, butterfly valve, hydrant, air valve, ferrule, metering equipment)	—	X	—
Material	X	X	X
Manufacturer	O	X	O
Length of mains section	X	—	X
Nominal diameter and/or external or internal diameter	X	X	X
Year of installation	X	X	X
Year of decommissioning (permanent decommissioning)	X	O	X
Year of rehabilitation	X	O	X
Type of rehabilitation	X	O	X
Year of calibration	—	X	—
Operating pressure (OP)	X	O	O

X should be mandatory;

O should be optional;

— not applicable;

ID identification number of an asset;

SDR standard dimension ratio (a method of rating a pipe’s durability against pressure).

Table 2 *(continued)*

Inventory data attribute, if applicable	Objects		
	Pipeline section	Valves/control and metering equipment	Service pipe
Maximum allowable operating pressure of component (PMA)	X	O	O
Type of connections	X	X	O
Other technical data (e.g. wall thickness, SDR, type of coating, water quality, type of jointing)	O	O	O

X should be mandatory;

O should be optional;

— not applicable;

ID identification number of an asset;

SDR standard dimension ratio (a method of rating a pipe's durability against pressure).

5.4.4 Failure data

Failure data provide information on failures found in drinking water networks and are linked to inventory data. At the minimum, the following data should be collected:

— date of documentation, after final remedy;

— date of failure occurrence, if known;

— location (e.g. mains ID, coordinates, address);

— point of failure;

— type of failure;

— cause of failure (e.g. ageing, damage due to other construction, etc.);

— type of remedy (repair, renovation, replacement);

— costs of eliminating failure;

— consequence of failure (e.g. road collapse, leakage volume, number of customers without service).

For the determination and diagnosis of failures, uniform assessment criteria should be used and executed by well-trained personnel.

5.4.5 Further condition data

In addition to failure data, more information on the condition of drinking water networks should be acquired as it provides valuable information on the prioritization of rehabilitation measures.

Condition data on drinking water networks are limited, with the data collection methods differing fundamentally from the collection of inventory and failure data.

The following data should be collected, if applicable and discernible:

— date of condition data collection;

— location of investigation (e.g. mains ID, coordinates, address);

— identification and plausibility information (e.g. material, nominal diameter, pipe coating, type of jointing);

— bedding;

— mains depth;
— overbuilding;
— adhesion of pipe coating;
— failure to pipe coating;
— data of cathodic protection systems;
— elasticity of pipe coating;
— extent of external corrosion;
— form of external corrosion;
— depth of external corrosion;
— mains condition/failure (e.g. scoring, deformation);
— internal deposits;
— context data;
— operating pressure fluctuations (minimum and maximum values);
— ambient temperature;
— accuracy of metering, controlling-related devices.

Context data provide technical information about the local in the vicinity of a drinking water network asset, by and large corresponding to the content of Table 3.

Table 3 — Examples of context data

Context data attribute	Objects		
	Mains section	Valve/control and metering equipment	Service pipe
Date of context data collection	X	X	X
Location (e.g. pipeline ID, coordinates, address)	X	X	X
Type of soil	X	X	X
Soil assessment	O	O	O
Structure in the vicinity which can harm the mains or be harmed by it	X	X	X
Distance to building site	X	X	—
Distance to long-haul traffic routes (e.g. A-roads and motorways, railway lines)	X	X	—
Traffic load	X	O	O
Protection strip	X	—	—
Working width	X	—	—
Surface utilization	X	O	O

X should be mandatory;
O should be optional;
— not applicable;
ID identification number of an asset.

Table 3 *(continued)*

Context data attribute	Objects		
	Mains section	Valve/control and metering equipment	Service pipe
Earth movements/mining activities	X	O	X
Hillsides	X	O	O
Structure of user	X	X	O
X should be mandatory; O should be optional; — not applicable; ID identification number of an asset.			

5.5 Data registering and data assignment

5.5.1 Data registering

The stored data should be checked and updated periodically or appropriately.

The data to be registered as defined in 5.4 should be compiled, integrated, processed and correctly stored by the utility. They form the basis for developing maintenance plans and strategies.

The data collection process itself determines the value of the data for assets maintenance. The data should relate to the assets' inventory (see examples in Tables 2 and 3). The data's value increases in line with its quantity and quality registered and with the possibility to assign individual pieces of data to the respective drinking water networks/objects (assets) under consideration.

Table 2 applies to the inventory data which should be registered, whereas 5.4.3 and 5.4.4 apply to failure and other condition data to be registered. Context data in accordance with Table 3 should be registered for individual objects in accordance with Table 2 (line or spot objects). In certain supply areas, however, it is also recommended to register two-dimensionally, in which case they should be clearly referenced to the individual objects described in Table 2.

Data collection should be comprehensive, continuous and free from interpretation. Data registered for one supply area and/or utility should be uniform and based on previously and unambiguously defined default values ("multiple choice"). Free text should be avoided because it offers only limited evaluation possibilities.

Unlike inventory, failure or context data, other condition data (and, accordingly, pipeline analyses) can be registered only during the visual inspection of buried pipeline sections unless cathodic protection measurements are involved. To this end, utilities should avail themselves of the opportunities offered by excavations accompanying work on pipeline networks or civil engineering works conducted by third parties. Other condition data should be registered notably during remedial activities. Destructive testing may also be performed (e.g. brittleness of plastic materials).

Data collection may be performed using either mobile data collection devices or forms to be filled in manually (preferably box-ticking forms). It should be ensured that all data can be digitally aggregated in one place or system.

5.5.2 Data assignment

All inventory, condition and context data registered should be correctly assigned to the associated asset types (e.g. PE 100 pipes or valves) and/or individual assets. Failure on valve bodies, for example, should not be assigned to pipeline data. Likewise, failure data should be registered in such a way as to enable the retroactive elimination of events not relevant for maintenance, e.g. pipe damage caused by third-party interference.

Inventory and condition data can be used for devising a rehabilitation planning and strategy, depending on the object to which they are assigned (see Table 4).

Table 4 — Usability of inventory, condition and context data depending on the object (asset) to which they are assigned

Database	Strategy		Planning and implementation
	Asset type	Asset	Asset
Inventory data	X	O	X
Failure data	X	O	X
Other condition data	—	O	O
Context data	—	O	O
X should be mandatory; O may be optional; — may be not applicable/only if exceptional.			

5.5.3 Geo-referencing

Using the above-mentioned databases for medium- and short-term rehabilitation planning requires geo-referencing and the unambiguous assignment of data records to their associated objects. Using select geo-referencing condition and context data can provide important information when defining a rehabilitation strategy.

Capturing data in geo-referencing systems (GIS, network information systems, computer network models, etc.) is the best approach for processing and using maintenance-related data. If the data are assigned only to pipeline or material groups instead of individual pipeline sections, location-related information (for example, about environment conditions) is rendered useless for rehabilitation planning purposes even if such information is available. Reference to individual assets as well as geo-referencing information should be preserved even when individual assets have ceased to form part of a currently existing network. Historical data also supply important information for devising a rehabilitation strategy.

5.6 Review of existing information

The collection and review of all available relevant information about the drinking water network should be carried out and are the basis from which all other activities are subsequently planned.

A review should also be undertaken of the information required to manage the drinking water network.

This information should be assessed to determine what further information is required in order to carry out the investigation.

5.7 Inventory update

Where the inventory is incomplete, it should be updated so that a sufficient record of the network is available to carry out the investigation.

NOTE The update of the other information is included in the hydraulic, environmental, structural and operational investigations.

5.8 Types of investigation

5.8.1 Hydraulic investigation

In general, it is not possible to understand the hydraulics of the system without using a hydraulic model. This flow simulation model should be based on an as-built report updated after on-site investigation of the mains works. However, a model is not usually necessary in small networks.

Testing and inspection procedures can be required in order to ensure an adequate hydraulic performance of flows (peak and usual demand, flow under firefighting conditions). Surveys should include flow measurements (including no/low flow conditions leading to deposition of suspended material that may later contribute to coloured water problems) and identification of leakages and closed valves.

Calibration and/or verification of the models should be carried out under peak flow situations, at night low flow conditions and by generating bigger abstractions by flushing hydrants.

Having identified possible causes of error, it is often necessary to confirm these by site inspection and then adjust the model accordingly. Data should not be modified without justification based on an inspection of the system.

5.8.2 Structural investigation

It is important to ensure that investigation of the system is selective in order to avoid duplication of previous work. The structural investigation can include either a complete survey of the drinking water network or a more selective approach. Consideration should be given to the age and location of existing infrastructure, geotechnical data including the pipe bedding and surround, and the vulnerability of existing buildings and other utility services.

Where appropriate, other qualitative and quantitative investigation techniques may be used. These include laboratory analysis and field condition assessment to identify pipe wall integrity and remaining strength. Investigation of the chemical composition of the groundwater and the soil should be carried out where this can affect the structural integrity.

The results of the structural investigations can also be relevant to the assessments of the hydraulic performance and environmental impact.

5.8.3 Operational investigation

Existing operational procedures, inspection schedules and maintenance plans should be identified and documented.

The frequency and location of recorded operational incidents (e.g. loss of pressure, pumping station failures, etc.) should be reviewed.

The impact of operational problems on the hydraulic performance of the system should be determined from incident records.

The causes of significant recurrent operational incidents should be investigated.

To deal with operational problems in the most cost-effective way, it is necessary to investigate and understand their causes and effects. Investigations can be required to determine the following:

— location and route of a pipeline;

— cause and location of pipe bursts and failures;

— cause and location of emergent water;

— quality of construction or repair;

— condition of a pipe;

— leakage.

Operational investigation techniques available include the following:

— electronic localization;

— closed circuit television for transmission mains;

— flow measurement;

— sampling and analysis;

— leakage control.

Indicators are an essential tool in understanding a utility's infrastructure conditions and needs and in parallel, the use of indicator-supported infrastructure planning and decision making. Properly implemented, indicators provide information on the state of the assets and the level of their contribution to the utility's objectives.

Irrespective of the strategy and the methods used, water infrastructure assets should be monitored permanently, and their components and operating equipment should be maintained and inspected regularly for their operating condition and functionality and in accordance with functional asset requirements.

A routine inspection of the condition of the service quality and particularly the asset ageing-related conditions and the maintenance should start when commissioning water infrastructure assets. The designer and/or the owner or operator should specify the nature and frequency for the maintenance and inspection of the asset system or single assets[16]. If condition data based on routine inspection are not available, all other available data based on condition assessment should be used [17].

A sufficient and reliable database on water infrastructure asset inventory and asset condition is indispensable for maintenance including strategy, planning and implementation. It is based on the qualified and quality-assured collection, processing, evaluation and storage of asset-related data. All maintenance data, especially inspections, should therefore be recorded and documented.

Measureable condition data give decision makers the ability to see more clearly the consequences of their decisions and to avoid the many pitfalls that result from making funding decisions with an incomplete understanding of their infrastructure assets and needs. Operational problems concern the various components of drinking water network. The techniques available to resolve them are described in Annex B.

5.9 Review of performance information

An indication of the type of performance problems, if any, on existing systems is likely to be known through reports of incidents such as pipe bursts, leakages, loss of pressure and deterioration of drinking water (coloured water) from previous investigations or users' complaints. Records of past incidents and any other relevant information should be brought together and a detailed review should be carried out to establish the scope of the investigations.

Examples of such other information include:

— hydraulic performance analysis;

— performance of mechanical/electrical equipment (e.g. metering or control devices);

— results of monitoring, performance and condition.

Where large numbers of complete or partial supply areas are in need of investigation, the existing information collected may also be used to assign priorities to the investigation of the perceived problems in each supply area (for example, by comparing the cost of the investigation with the benefit that might be achieved). These can then be used to draw up a comprehensive programme so that the supply area with the most serious projected problems is investigated first.

5.10 Planning of investigation

The following should be evaluated for design of the survey work:

— target facilities and period for inspection/survey;

— determination of survey type (see 5.4.5);

— survey method, items, standards;

— estimated cost.

Target facilities and the execution period for medium-term survey plans should be decided according to the priority order based on risk assessment. The medium-term plans should be based on the total work amount mentioned in the long-term survey plan.

5.11 Performance testing

The performance of the drinking water network should tested and assessed during construction, at the completion of the construction stage and also during the operational life of the system.

The following are examples of tests and assessments:

— leakage measurement;

— visual inspection;

— flow measurement;

— water quality measurement.

The tests to be undertaken to determine the performance being achieved by a drinking water network depend on whether it is a new asset, a long-time existing asset or a rehabilitated asset.

The effectiveness of maintenance should be assessed by comparing the performance of the network with its stated requirements. In addition, for reactive maintenance, target response times can be used as an assessment.

6 Assessment

6.1 Principles

The performance of the system should be assessed against the performance requirements (see 4.2). The performance assessment should include the evaluation of risks of failure to achieve the performance requirements.

Figure 3 shows the process of assessment.

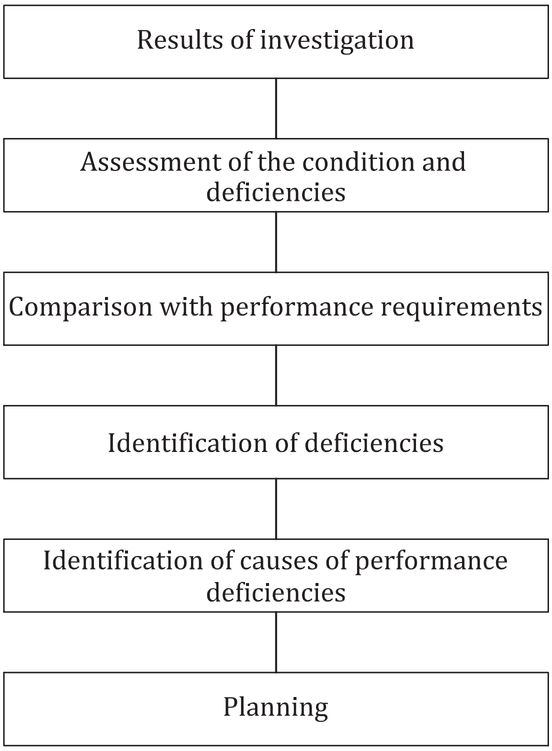


Figure 3 — Process of assessment

6.2 Assessment of the hydraulic performance

The results of the hydraulic surveys and/or the verified flow simulation model should be used to assess the hydraulic performance of the system related to the performance requirements for peak flow and, if appropriate, for firefighting conditions.

6.3 Assessment of the structural condition

Once the system has been inspected, the next stage is to examine the results to identify those areas requiring action.

6.4 Assessment of operational performance

The operational performance of the system as measured by the number of operational incidents or failures should be assessed. This should be recorded in a database.

6.5 Compare with performance requirements

The results of the assessment of the hydraulic, structural and operational performance should be brought together so that the overall performance of the system and its components can be compared to the performance requirements (see 4.1.3).

Performance indicators are one method of comparing the overall performance of a network with performance requirements. Any performance indicators used should be

— clearly defined, concise and unambiguous,

— verifiable, and

— simple and easy to use.

6.6 Identification of unacceptable impacts

Details of those parts of the system where the hydraulic, structural or operational performance of the networks or its components does not meet the performance requirements should be recorded.

6.7 Identify causes of performance deficiencies

Based upon the results of the hydraulic, structural and operational investigations, the causes of performance deficiencies should be determined. The relative impact of each cause should be assessed in order to develop appropriate solutions and to set the priority for action.

7 Planning

7.1 General

The integrated drinking water networks management plan can take one of two forms.

a) The plan describes the approach to be taken (e.g. a major mains serving a new housing or commercial area to alleviate loss of service pressure or serving an area by water from another waterworks). An outline plan is likely to take this form; further information may be included in detailed plans for parts of the distribution.

b) The plan outlines the proposed activities and measures (e.g. a major mains serving a new housing or commercial area to alleviate loss of service pressure or serving an area by water from another waterworks) and specifies the resources and timescales.

Strategic plans are likely to be more long term (e.g. 20 years to 40 years) than medium-term (tactical) plans (e.g. 2 years to 5 years) or detailed work programmes (next year).

The process of planning to fulfil the performance requirements is outlined in Figure 4.

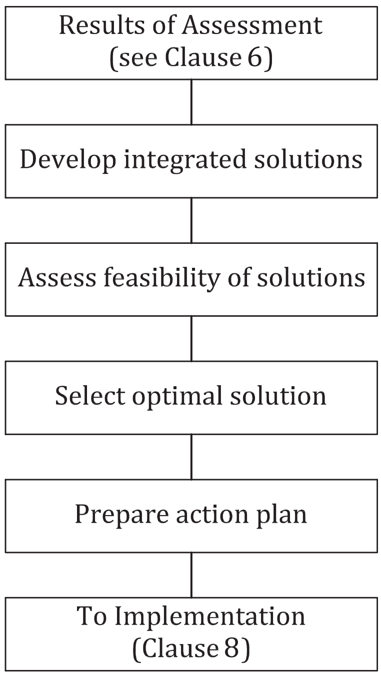


Figure 4 — Process of planning

7.2 Develop integrated solutions

Integrated solutions should be developed that fulfil the performance requirements, taking into account future conditions. Different types and groups of solutions are listed in Table 5.

Table 5 — Solution types and groups for rehabilitation

Type	Group
Hydraulic	Maximize use of existing flow capacity
	Adjust diameters to water demand and pressure
	Increase the reliability (n-1 criteria) of the networks in case of failures or incidents
	Target grid planning
Structural	Protect fabric of mains by provision of appropriate linings or internal coatings
	Rehabilitate pipeline
Operational	Undertake planned inspection and cleaning of mains
	Optimize frequency of maintenance of valves and other equipment
	Provide additional resilience in the event of future failure (e.g. provision of stand-by equipment or emergency storage)
NOTE This list is not exhaustive.	

7.3 Assess solutions

Solutions should be assessed and the optimal solution selected, with regard to the basic performance requirements and factors such as the following.

a) **Safety in construction and operation** — The minimization of risks to health and safety during construction and subsequent operation of the system.

b) **Social disruption** — The disruption to local residents and other members of the public due to traffic delays, dust, noise and other social factors should be considered.

c) **Sustainable use of resources** — The use of energy and other finite resources in the construction and operation of the system should be taken into account. The ability to recycle materials used in the rehabilitation works and any waste produced should be considered.

d) **Phasing of the works** — The possibility of integrating the solution into a staged programme of works should be considered. This should take into account the priorities of the works and the benefits in terms of improved performance associated with each identified phase of the works and the cost savings associated with deferral of the later stages.

e) **Relationship to other infrastructure works** — The benefits of phasing the works with other infrastructure works should be considered.

f) **Capacity and resource constraints** — Account should be taken of the resource constraints (e.g. personnel, supply chain and financial) in the selection and phasing of the options.

g) **Future maintenance liabilities** — The cost of future maintenance works and other operational costs of the system should be taken into account.

h) **Economic appraisal** — The costs and benefits should be considered to determine whether the additional benefits of one solution over another, for example, increased asset life, are justified.

i) **Whole life cost** — The whole life cost of a solution is the present value of all the costs over the life of the solution including temporary works and diversion of other utility services. All design, construction, investigation, maintenance and operational costs should be taken into account as well as the indirect costs (e.g. cost of social disruption). When comparing different options, the whole life cost should be calculated over the same period for each option.

7.4 Prepare action plan

The selected integrated solution should be documented to give a single plan for the drinking water network. The documentation should include:

— detailed objectives;

— legal requirements and permits, including any timescales for rehabilitation;

— performance criteria;

— priorities;

— proposed works including costs and phasing;

— relationship to other construction or planned development;

— consequences for operations and maintenance.

Four types of plan can be prepared:

— new development plan;

— operations and maintenance plan;

— rehabilitation plan;

— contingency and emergency plan.

8 Implementation

8.1 General

The implementation plan should take into consideration the financial risk(s) situation to the drinking water utility and be based on the principle of the "plan-do-check-act" (PDCA) approach; see Figure 5.

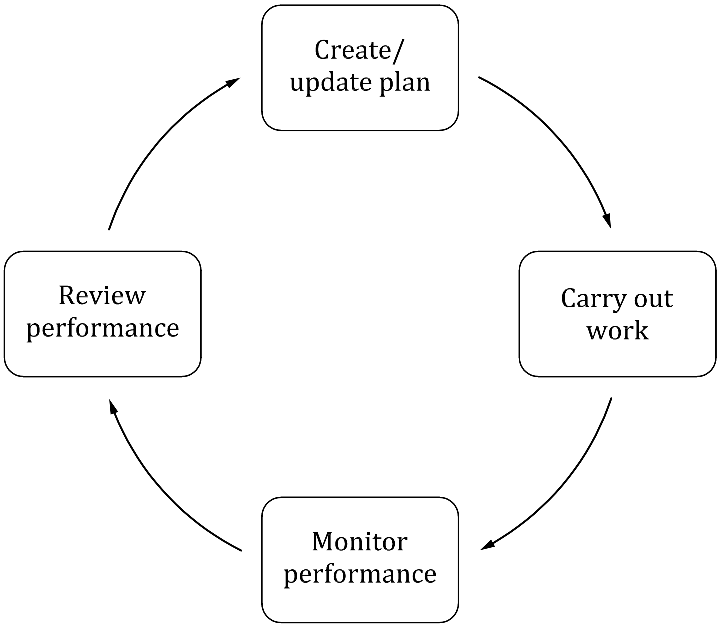


Figure 5 — Process for implementation following the PDCA approach

8.2 Create/update plan

Firstly, the objectives and functional requirements, as well as the technical processes to investigate, assess and create maintenance, rehabilitation and operation plans, should be established to keep or improve the performance of the asset system.

Necessary works to extend, reduce or rehabilitate the drinking water network as specified in the rehabilitation plan or the operational plan should be undertaken.

The implementation plan should be updated as necessary. If the performance requirements change, then the whole planning process should be repeated so that the entire plan remains up to date.

8.3 Carry out work

Where it is necessary to extend, reduce or rehabilitate the drinking water network, these works should be designed.

The management of asset should include:

— quality control of materials;

— quality of installation;

— appropriate technology, materials choice and procurement (quality control of materials used and of the works).

8.4 Monitor performance

It is important to monitor the effectiveness of work undertaken and to update the plan, including the records (inventory) and the hydraulic model.

8.5 Review performance

The performance requirements should be reviewed periodically.

9 Operation and maintenance

9.1 General

Operation and maintenance should ensure that

— the entire system is operationally ready at all times and functions within the performance requirements,

— the operation of the system is safe, environmentally acceptable, and economically efficient, and

— as far as possible, the failure of one section of the drinking water network does not adversely affect the performance of the other parts.

Examples for the relation between major terms of management of assets are shown in Table 6.

Table 6 — Relation between major terms of management of assets

Existing systems				Examples
Term	**Retain original performance (routine activities)**	**Restore original performance**	**Upgrade performance**	
Operation	Yes	No	No	Monitoring, regulation of flow, diversion of wastewater flow, operation of pumps and valves
Maintenance	Yes	Yes (routine)	No	Cleaning or flushing sewers, adjusting metering equipment, cleaning and/or lubrication of a pump or valve
Rehabilitation	No	Yes	Yes	Relining of pipe; repair of a broken pipe, pump or valve; replacement or enlarging of an asset

Effective operation and maintenance of the drinking water networks are important elements of the management of assets for keeping condition of the drinking water network in the required status and providing the assets a long service life. Operation and maintenance depend on, for example:

— planning;

— rights of access;

— a sufficient number of competent personnel;

— clear assignment of responsibilities;

— suitable equipment;

— knowledge of the system, its operational components and the users connected;

— adequate records and analysis.

There can also be requirements relating to the resolution of performance deficiencies, for example, to remedy failures and problems within acceptable timescales.

9.2 Operation

The purpose of operation is to ensure that the drinking water network performs in accordance with its functional requirements and in accordance with any operational plan(s).

Operation includes the following:

— handling, switching/operation on pumps;

— controlling valves and other equipment;

— acting in accordance with contingency and emergency plans;

— measuring water quality;

— inspecting periodically;

— making connections to existing mains and to users;

— check of disused larger mains;

— check of building activities over or adjacent to mains;

— monitoring and controlling flow, pressure etc.;

— active leakage management.

Urgent interventions that are generally intended to be temporary are included in operations.

9.3 Maintenance

The purpose of maintenance is to ensure that the drinking water network performs in accordance with its functional requirements and in accordance with any maintenance plan.

Maintenance includes:

— local repair or replacement of damaged pipes, valves or other assets in order to maintain their functioning;

— flushing, cleaning, removal of sediments, disinfecting, etc. to restore hydraulic capacity and to ensure hygiene;

— regular attention to accessories like valves, control and metering equipment.

10 Rehabilitation

10.1 General

Once an asset system is installed and operated, the highest expenditure in costs over the life cycle is determined by decisions on rehabilitation of those assets. The preferred way and timing of the rehabilitation essentially influence the assets' life cycle costs. Therefore, a sustainable process for managing water assets should be subdivided into the following three logical steps that build upon each other so as to be able to identify and assess (including by way of comparison) the short-, medium- and long-term impact of rehabilitation[15] (see also Figure 2):

a) determining a long-term rehabilitation strategy;

b) drafting a medium-term rehabilitation tactic;

c) implementing operational rehabilitation measures required in the short term.

Determining a strategy starts by identifying the scope of rehabilitation works required and the pertinent budget on the basis of a long-term perspective so as to obtain and/or maintain adequate system condition and resulting levels of service. The tactic includes identifying and defining the sequence of rehabilitation measures required in the medium term and pre-selecting the rehabilitation technology and materials. The operational level includes reviewing the actual execution of the rehabilitation work and taking into account possible alternative options.

Shorter periods of review require more intense work and higher degrees of detailing of the respective sub-processes, entailing a higher total expenditure in terms of both time and cost. More precise details render the necessary rehabilitation measures more certainty. The results of the individual logical steps should be synchronized with one another.

The key objectives of the rehabilitation of water systems consist in

— minimizing failures and supply interruptions in any situation,

— reducing water losses or maintaining them at low levels,

— avoiding hazards to humans, third-party assets and the environment,

— improving or maintaining the level of service, and

— continuity of supply arising at the lowest possible total expenditure.

The extent to which achievement of each of these objectives can be influenced is indicated in Table 7.

Table 7 — Rehabilitation objectives

Rehabilitation objective		Strategic plan (How much?)	Tactical plan (Where and when?)	Operational plan (How?)
Minimizing pipe failures and supply interruptions	Complete system	X	X	—
	Asset type	X	X	—
	Asset	—	X	X
Reducing water leakages or keeping them at low levels		O	X	X
Avoiding hazards to humans, third-party assets and the environment		—	X	X
Improving or maintaining level of service	Pressure and quantity	—	X	X
	Water quality	O	X	X
	Availability	X	X	X
Minimizing the required total cost of maintenance while keeping up the necessary supply standard		X	X	X

X implementable;

O implementable if allocation to asset type is possible;

— not implementable.

The risks arising from or affecting water infrastructure assets should be well known in order to attain the rehabilitation objectives. A more detailed breakdown of occurrence likelihood and impact of failure is given in 10.2. While asset type-related failure likelihood is the only risk factor a strategy may consider, planning and option analysis permit evaluating all potential risk factors based on precise knowledge of the actual location of the individual asset.

10.2 Strategic plan for rehabilitation of physical infrastructure (long-term planning)

10.2.1 General

A rehabilitation strategy should be worked out for all defined areas of supply. As a matter of principle, the extent of the rehabilitation work required should be determined on the basis of homogenous asset types exhibiting identical or similar condition developments/ageing behaviours, whose condition developments and/or service lives are expected to be statistically comparable. This can involve subdividing the drinking water network into at least the following major asset types:

— long-distance and trunk mains;

— primary and local mains;

— service pipes;

— other installations (e.g. valves, meters and hydrants).

Depending on the available data and following an analysis of the existing system, its pipelines and valves within major asset types should be broken down further, for example, by:

— pipe and/or valve groupings (e.g. age, material, design and connection type, corrosion protection);

— renovated pipelines (depending on the renovation method, e.g. with subsequent in-situ cement mortar lining);

— asset types and/or areas of the same nominal diameter range;

— asset types of comparable bedding, location and installation conditions;

— asset types of comparable modes of operation and/or conditions of use;

— asset types equipped with cathodic protection.

Certain areas or asset types exhibiting unusual or above-average water leakage and quality problems — such as turbidity — that have a major impact on the rehabilitation strategy should be broken down accordingly into asset sub-groups.

The rehabilitation need of the supply area under review is determined on the basis of the rehabilitation lengths and numbers identified for the individual asset types.

Typically, the rehabilitation strategy varies between different major asset types. Rehabilitation of fittings and service pipes is usually event-oriented, whereas for mains with larger diameter and length, rehabilitation is condition-oriented.

The rehabilitation strategy should be defined at a point in time that permits identifying and responding appropriately to the probable long-term need for rehabilitation. A period of review of 40 years is generally sufficient to completely cover the relevant condition developments of the asset system or types to be rehabilitated. A longer period can make sense only for younger pipeline network sections featuring pipelines expected to have a longer service life. Function, condition of installation and operation of each asset type should be considered in setting the review period.

10.2.2 Service life and failure rate development

The service life of a pipeline network is an important factor when determining its need for rehabilitation. In the first step, the service lives of asset types can be estimated on the basis of

— empirical data and historical rehabilitation statistics of the utility,

— cathodic protection measurements,

— cross-utility statistics,

— special investigations, and

— other sources, e.g. technical literature.

Cathodic protection systems, if installed, play a major role in condition-based maintenance of steel pipes and, consequently, the calculation of their service lives. By continually measuring the protective current requirement (including on- and off-potentials), service life can be prolonged by pro-active maintenance. Damaged coatings and the resulting corrosion can be affected by protective current and be located from the earth's surface, thus making it possible to assess the condition of mains without digging.

Information in the technical literature should be critically compared with empirical data from the utility's direct experience.

The age-related development of the failure rate significantly affects the service life of different asset types. Therefore, the estimation of the remaining service life for each asset type should be verified and compared with the age-related development of failures (assuming statistical data on long-term failures are available). Care should be taken in this step to ensure that the available data sample meets statistical analysis requirements.

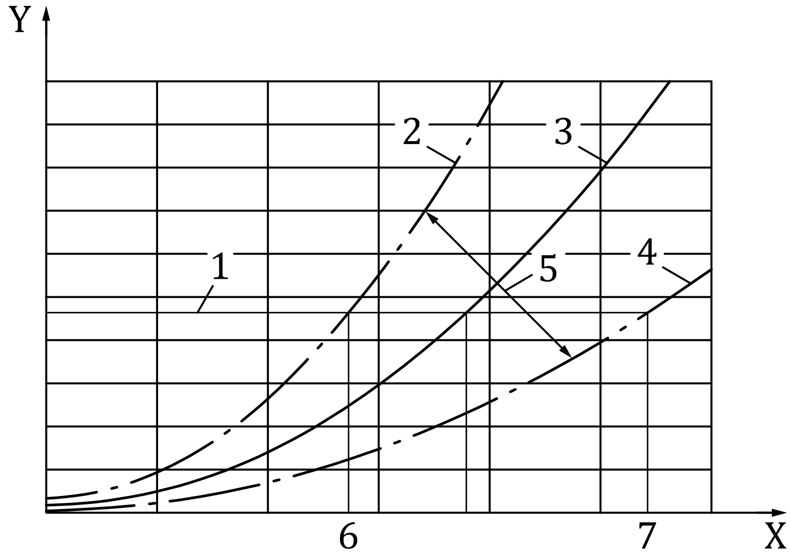
In general, the following asset type data are required for a methodologically correct analysis in a rehabilitation strategy context:

— failure data and age of the relevant asset;

— age-based existing asset lengths and numbers dating from the beginning of failure data recording.

Failures of assets already out of operation should also be included.

Established trend or regression functions may be employed to describe the calculated age-related progression of failures, to determine the service life and to forecast failure rate development. If necessary, experts should be consulted for this failure statistics analysis (for an example, see Figure 6).



Key

1 permissible failure rate

2 increase of annual failure rate of, for example, 3 %

3 average failure grade

4 increase of annual failure rate of, for example, 1 %

5 spread of failure grade

6 worst-case scenario

7 best-case scenario

X technical service life, in years

Y mean failure rate, in failures/km/year

Figure 6 — Example illustrating service life derivation on the basis of alternative failure rate progressions (1 % and 3 %)

In the presence of insufficient data on current asset type failure rates and precluding statistical evaluations, an annual age-related percentage increase of the current failure rate may be assumed. This is an approximate reference value assumed to occur if the asset type is not rehabilitated.

In such cases, orientation values of 1 % to 3 % annual increase in the current failure rates may be used to calculate the service life scenario. The future development of a failure grade can be calculated with a progression of 1 %/a as the best-case scenario and a progression of 3 %/a as worst-case scenario. The real scenario is in between the spread of both failure grades.

Service life ends and the asset should be rehabilitated when the actual failure rate permanently exceeds the permissible failure rate. The permissible failure rate for a drinking water network should be defined by the drinking water utility and/or agreed with relevant stakeholders as an accepted level of service.

Frequently, the risk assessment of individual mains forms the only basis for determining a rehabilitation strategy for long-distance and transmission systems. Other factors such as condition of surrounding soil, traffic load, operating pressure, and installation quality should also be considered. Furthermore, the failure rates should be lower than those applying to distribution networks. In principle, however, each pipeline system should be addressed separately with regard to the vulnerability against failure as any failure can entail large-scale water supply interruptions resulting in substantial impact (e.g. hazards to humans and property). By contrast, redundant long-distance and trunk mains do not pose any increased risks and may be treated like mains within the network.

If the available data do not permit a failure forecast, the pipe deterioration of the drinking water network may, alternatively, be assessed on the basis of the estimated residual service life; see also Annex B.

10.2.3 Determining the need for rehabilitation of physical infrastructure

10.2.3.1 General

The annual rehabilitation need depends largely on the service life expected for the individual asset types. The following methods may be used to determine the required rehabilitation rates on the basis of the data available (volume, quality, currentness). Results become more reliable the greater the body of data available and the greater the level of detail. If a correspondingly detailed data collection and analysis are available, the preferred method should be Method 3, in particular with a view to enhancing economic efficiency and planning safety (see Reference [17]).

10.2.3.2 Method 1: Direct asset type-specific derivation from service life

The reciprocal of the expected service lives (and/or the residual service lives if little or no rehabilitation measures have been taken so far) of the asset types concerned may be used as a first approximation for determining the required annual rehabilitation rate. This is true particularly for drinking water networks that have grown homogenously over a long period of time, and for which no reliable data are available on age-related length distributions within the asset types. An expected asset type service life of 50 years or 100 years, for example, entails strategic rehabilitation rates of 2 % or 1 % per annum, respectively.

Taking into account all asset types within a drinking water network, this is an easy way to derive as a first approximation, the required long-term rehabilitation rate for the entire drinking water network.

For asset type-based technical service life experience, see example in Figure B.1.

10.2.3.3 Method 2: Derivation from technical service lives and age-related existing asset lengths

If data on existing assets are available with reference to age and asset types within a drinking water network, their rehabilitation needs over time can be determined as a first approximation. As a first step, the service life (see 10.2.2) of the asset type concerned is assumed to apply to all individual assets.

Based on the individual year of construction, the respective rehabilitation time frames can be estimated from the estimated end of their technical life. Taking into account all asset types within the drinking water network, the rehabilitation needs applicable to the entire drinking water network over the long term are thus determined analogously to Method 1.

While the rehabilitation rate can level out because the service lives assumed for the individual asset types can possibly overlap, the resulting overall rehabilitation rate generally shows volatility on a year-to-year basis. It is therefore recommended to average the resulting rehabilitation rates over 5 years or 10 years in order to obtain stable values, always observing the asset type to which they pertain.

10.2.3.4 Method 3: Derivation from mathematical distribution functions

In real life, it is not only the service life of a homogenous asset type that cannot be determined with absolute certainty. Actual operating service lives of individual assets within an asset type also vary within certain boundaries, depending on the factors affecting the system's condition. This fact may be taken into account as well when devising rehabilitation strategies. By employing mathematical distribution functions (e.g. Gaussian, Weibull, Herz distribution), the probable point of transition into the projected poor condition (i.e. the end of the service life) can be calculated. This method ultimately provides a more meaningful picture of required, long-term annual rehabilitation rates.

Commercially available software products and the corresponding necessary data are available and may be employed to calculate service life margins and derive from this basis one or more of the above-mentioned probability distributions. This can help utilities to determine rehabilitation rates (see, as an example for a pipe type-dependent grade of failure rate, Figure B.2).

10.2.4 Budgeting

The rehabilitation budget required to implement a rehabilitation strategy is generally determined by the product of the annual rehabilitation rates and the respective asset lengths and numbers and the specific cost estimates.

Cost estimates should be based on utility-specific, long-term empirical data, as well as on any planned changes in pipe materials and systems. The results of possible strategic network optimization activities should likewise be included in the rehabilitation budget calculation. As far as mains and in particular trunk and long-distance mains are concerned, reliable budgeting generally always pre-supposes individual pipe examinations.

Since a rehabilitation budget calculated in accordance with the method described above only covers the condition-based rehabilitation of a drinking water network, expenditures on third-party induced replacement (in the absence of an urgent need for rehabilitation) should be added to the rehabilitation strategy budget. Such additions should be in the form of an average basic amount based on long-term empirical data, unless covered by a separate budget. Any activities carried out in the course of urgent network optimization procedures, such as remedying current functional weaknesses in the drinking water network, should be reflected by short-term rehabilitation budget increases.

10.3 Tactical plan for rehabilitation of physical infrastructure (mid-term planning)

10.3.1 Risk-based evaluation approach

Reaching the rehabilitation objectives presupposes knowledge of the risks involved. With the exception of quality problems (e.g. turbidity), which can have many different causes, the risk emanating from the drinking water network is generally derived from the probability of pipe failure (and indirectly also from water losses) and the respective extent of the failure resulting in hazards to humans, third-party assets and the environment. In addition, failures in the supply quality, direct added costs and possibly the resultant negative public perception of the failure and the image of the utility should be taken into account. The probability and the extent to which drinking water quality is affected can be derived from customer complaints, operating experience, measured values and pipe network simulations.

As far as the rehabilitation strategy is concerned, the aspect of risk can only be considered to a limited extent. The only feature that can be generally analysed and predicted in the technical evaluation of the rehabilitation strategy is the development of the asset type-related failure probability. If water losses or turbidity can be clearly attributed to individual pipe types (asset types) and not to individual line sections, these aspects, too, can be taken into account in the rehabilitation strategy. In rehabilitation planning and rehabilitation measures, all influencing risk factors can be evaluated by reference to the location of the individual assets.

All requirements should be completely fulfilled and cannot be offset one against another. Low failure rates do not necessarily imply a high supply quality even when water losses are high. This situation means that there are pipe failures which have not yet been discovered probably due to unfavourable soil conditions. Although increased inspection activities to reduce the water losses can help as a first step to detect and to reduce the water losses locally, the only way in the long run of keeping network failure rates, water losses and thus also the risks permanently low is a well-targeted rehabilitation strategy for the pipe network.

For further information on a risk-based evaluation approach, see Annex C.

The tactical rehabilitation plan pursues the objective of implementing in the medium term, i.e. within two years to five years, the rehabilitation rates determined by the rehabilitation strategy for the individual asset types. The rehabilitation measures required for the task should be identified and prioritized.

The prioritization criterion should be the risk emanating from hazards affecting a pipe section. This risk results from the probability of occurrence and the extent of loss or failure.

The utility should define utility-specific evaluation criteria and an evaluation approach adequately reflecting the selected criteria and producing evaluation results for each pipe section.

Risk assessment evaluation criteria can be subdivided into the following groups:

a) The probability of failure occurrence can be deduced from

  1) the failure rate development in an individual section,

  2) the failure rate development in the asset type (failure and/or empirical data),

  3) other pipe condition data (e.g. corrosion, connection type, pipe coating),

  4) ambient data (e.g. bedding, soil corrosiveness, stray currents, traffic load, overbuilding), and

  5) knowledge about fluctuating pressure changes.

b) The probability of occurrence of quality impairments can be deduced from

  1) customer complaints,

  2) operational experience,

  3) measured values, and

  4) calculations.

c) The extent of loss or failure can be assessed with a view to

  1) cost,

  2) quality of supply (pressure, quantity, quality, availability),

  3) hazards to persons and other assets (type of pipeline, location, distance from others' assets and traffic routes, dimension), and

  4) utility's image/public perception.

Network evaluation results serve to assess the risk for each pipe section on the basis of pre-defined criteria. The evaluation results for the entire network or for individual network sections determine the rehabilitation priority ranking of the pipe sections concerned. Risk can be expressed by a variety of units.

Figure 7 illustrates the general process for network evaluation.

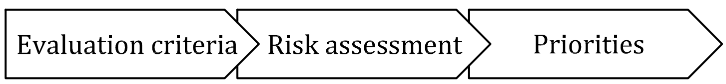


Figure 7 — Network evaluation process

10.3.2 Individual evaluation and prioritizing

An evaluation standard should be defined for the relevant criteria, e.g. in the form of points scored, with negative evaluations scoring more points. Each criterion should be applied to each pipe section, its final evaluation being attained by adding and/or multiplying the individual evaluation results. As this step constitutes the most crucial procedure at this stage of the process, it should be prepared and coordinated with due care. The mathematical combination of the individual evaluations should correctly reflect the weighting of the criteria against each other. Sorting the evaluation results then yields the priority ranking of the rehabilitation measures planned for the medium term.

When selecting evaluation criteria, care should be taken to ensure that information about each criterion is available for each pipe section or else the evaluation results can be inappropriately biased.

The list of priorities should provide the following information about the individual pipe sections as a minimum requirement:

— unambiguous pipeline identification (technical data, geography);

— length of section;

— quantitative evaluation (e.g. how many points have been scored).

The list of priorities should be compared to the pre-determined strategic rehabilitation objectives (e.g. attaining a certain level of rehabilitation). The list of priorities should be processed in accordance with the rehabilitation strategy. Any deviations from the list of priorities in the rehabilitation strategy should be evaluated and examined for their relevance to impacts on the rehabilitation strategy.

The prioritization should be made by using a risk matrix with the axis, e.g. failure extent versus failure probability system (see Figure C.1), or a risk scoring classification system (class A, B, C).

10.3.3 Coordination with other construction activities

Coordination with activities carried out by other industries or contractors (e.g. gas, wastewater, telecommunication, rehabilitation or reconstruction of roads) can entail a change in priority ranking, which, in turn, can make the utility’s construction work more economically efficient.

10.4 Operational plan — Implementation of rehabilitation measures (short-term planning)

The rehabilitation methods should be designed and implemented on the basis of the rehabilitation strategy and rehabilitation plan, always taking into account prevailing local conditions.

Alternative construction measures comparable from a supply technology point of view should be considered when planning the construction measures.

It can make sense to simultaneously rehabilitate adjacent pipe sections of roughly the same priority ranking so as to achieve economies in the rehabilitation programme (e.g. having larger units of project and appropriate construction equipment on-site for longer periods without incurring repeated relocation costs). Asset management and annual construction/rehabilitation measures are also constrained by the road programme implementation or the impact of the development projects. These projects can sometimes significantly impact the lists of sections to be rehabilitated, by anticipating mains not already ageing or by deferring the rehabilitation in time.

Dimensions, rehabilitation technology (open or trenchless installation technologies, renovation, predictable repair work, cleaning) and the rehabilitation materials should be defined for the individual pipeline construction measures. This should also include quality assurance of materials and installation, as well as requirements for the executing contractors.

11 Documentation and efficiency review

All major results and decisions should be documented so as to be able to understand the individual process steps, from the original strategic approach to the final execution of the work. Care should be taken in this context to include previous experience with such measures and apply it to planning future work. The documentation should be safely filed, publicized and made accessible.

Efficiency reviews should be carried out at regular intervals including all persons involved in the respective processes in order to be able to adapt the rehabilitation strategy and plan. To this end, the following questions should be addressed:

— Have the rehabilitation objectives been reached?

— Have the budget constraints been observed?

— Were the rehabilitation techniques and materials adequate or were there better solutions?

— Is there a need to modify any evaluation criteria and/or standards?

— Was the cost per service or capital spent target achieved?

— Were the infrastructure asset condition indicators accurate and useful?

— Do the indicators need to be adjusted?

— Were the rehabilitation works carried out without negative impact on the network users or the environment?

In all cases, if the assessment is negative, then the question "Why not?", if applicable, should be answered.

The efficiency review should be documented clearly and made accessible to the decision makers.

The rehabilitation strategy in place should be reviewed every five years (or less) and modified, if necessary.

The current rehabilitation plan should be reviewed on the basis of the performance monitoring reports, and no less frequently than once per year, and modified if necessary.

Annex A
(informative)

Further objectives of the management of assets of drinking water networks

Reasons for the management of assets of drinking water networks are the following:

— drinking water networks are exposed to risk-carrying internal and external interferences impacting hygiene and security of supply;

— water supply systems are designed to have long service lives;

— the absence of maintenance can endanger the continued existence of the drinking water utility by causing grave deviations from water quality and security of supply standards, resulting in serious damage to third parties;

— the user has a right to demand supply of safe drinking water;

— interruptions of supply should be kept to a minimum.

The management of assets of drinking water networks should take into account the following operational and maintenance objectives:

— minimizing environmental impairment;

— causing no detrimental impact to public health;

— avoidance of water quality impairments;

— reducing water losses or keeping them low;

— stabilizing the pressure level;

— keeping supply interruptions, especially those caused by pipe failure (number and duration per user), to a minimum;

— correcting failures and defects within a reasonable period of time;

— optimizing the service life of existing systems, while simultaneously maintaining supply quality;

— maintaining and improving user satisfaction;

— optimizing maintenance costs, while maintaining the required level of service;

— conserving the existing structure and safeguarding of the quality of the drinking water network;

— ensuring the environmental compatibility of all measures and activities.

The overall objective of the management of assets should be to ensure that the drinking water utility complies with its supply mandate while also maintaining a stable economic position.

The provisions set forth in this guideline are intended to help attain these operation and maintenance objectives and prevent any negative consequences caused by potential hazards to the security of supply (quantity, pressure and quality). Hazards can be caused by, for example:

— incorrect dimensioning of pipes;

— inappropriate choice of materials and components;

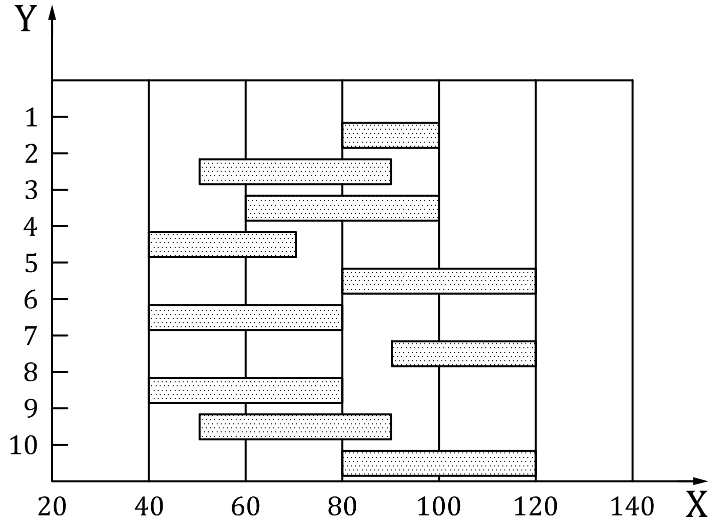
- unsuitable or faulty design or construction method;
- incorrect repair or maintenance measures having contact with drinking water;
- poor commissioning/decommissioning activities;
- operating with critical flow conditions (e.g. flushing);
- poor system disinfection or secondary disinfection in the pipeline network;
- inadequate rehabilitation practices;
- unsafe distribution concepts;
- functional faults and failure of systems and components;
- unacceptable water pressures;
- poor system operational management and/or security controls;
- impairment caused by environmental factors;
- poor third-party construction work;
- insufficient numbers or qualification of staff;
- inadequate plant management;
- stagnant water;
- poor storage of components;
- infiltration or feeding of non-potable water;
- high water losses;
- frequent pipe failures.

The hazards listed above can form the basis for further risk assessment.

Annex B
(informative)

Examples for the assessment of service life and failure rates of pipes

An example for the assessment of minimum and maximum service lives of pipes by pipes type based on experience is shown in Figure B.1.

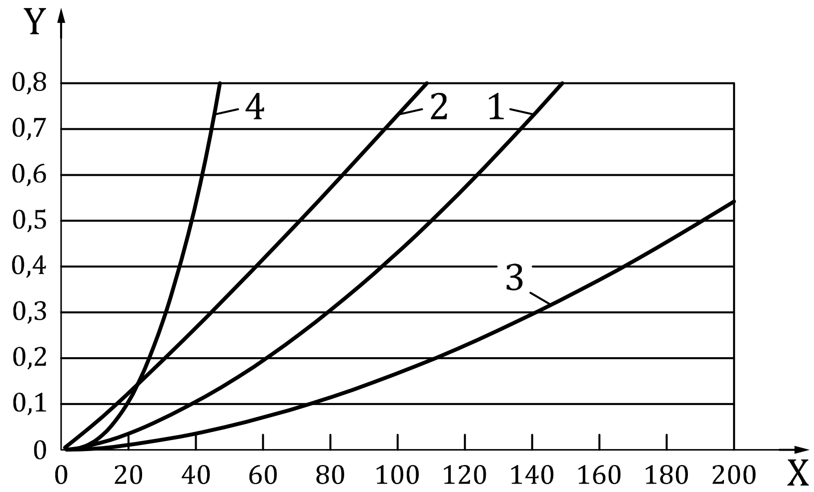


Key

1 AC
2 PVC
3 PE80 3. Gen/PE100
4 PE63/PE80
5 Steel after 1980
6 Steel until 1980
7 DI with PE, ZN or cement coating
8 DI without coating
9 Cl after 1930
10 Cl until 1930
X year
Y pipe material

Figure B.1 — Example for the assessment of service life of different pipe types

Figure B.2 shows as an example of the predicted failure rate development for different pipe types (type of material, coating, jointing, corrosion protection) based on the Kaplan-Meier[18] procedure and approximated by a Weibull function as basis for failure rate prognosis.



Key

1 CI [cast iron (in sand forms)] (until 1930)

2 ST1 (until 1980)

3 AC

4 PE63 (until 1980)

X service life, in years

Y failure rate, in failures/km/year

Figure B.2 — Example for predicted failure rate development of different pipe types

Annex C
(informative)

Examples for risk consideration in management of assets

C.1 Risk-based assessment for rehabilitation of pipes[19]

The probability of pipeline-accident occurrence may be set by following methods according to the collected data:

1) Period of years in use

To analyse the pipe types with high possibility of failure by the usage years.

In the first step, ages of assets can be used as the indicator of likelihood of pipe failure. For example,

— 5: Elapsed years of 80 or more;

— 4: Elapsed years of 60 or more to less than 80;

— 3: Elapsed years of 30 or more to less than 60;

— 2: Elapsed years of 10 or more to less than 30;

— 1: Elapsed years of less than 10.

2) Operation and maintenance information

To analyse the facilities and/or areas with high possibility of failure by interviewing personnel with operation and maintenance experience and consulting the operation and maintenance data (data concerning facility conditions obtained by inspection and repair, etc., consult data concerning users' complaints about coloured water, etc.) classified by area and facility that can be used to estimate likelihood.

For example, likelihood of failure should be estimated based on characteristics as follows:

— pipe under peculiar local conditions and environment, etc.;

— pipe operated with peculiar pressure;

— areas in which there were complaints and/or unusual cases (e.g. surroundings of a site of a road collapse, low cover, adverse laying conditions, complaints);

— pipe at a location where there is a special feature in the environment of its surrounding area (e.g. an area in which land subsidence is likely to occur, an area with an environment experiencing high groundwater salinity such as a coastal area);

— pipe conditions, e.g. material, diameter, joints, corrosion protection, lining.

3) Functioning rate estimation curve

To narrow down the facilities with the highest possibility of failure by the functioning rate estimation curve, the accumulated data "functioning rate" is used, which is the ratio of properly functioning mains to the mains as a whole (see 10.2.2 and Annex B).

"Functioning rate" is the ratio of properly functioning mains to the mains as a whole (see 10.2.2 and Annex B).

C.2 Example for risk-based prioritization for rehabilitation of pipes

Example for risk-oriented rehabilitation and a condition-based prioritization of pipes:

The extent of damage can result from a pipe failure under the aspects of

— hazards to humans and structures,

— supply quality (pressure, quantity, quality and availability),

— repair/follow-up costs

and may also be taken into consideration besides the failure probability. Turbidity effects may be taken into consideration based on frequency and intensity and independent of the pipe failure risk. A basic evaluation of risk-oriented rehabilitation can be carried out using Formula (C.1):

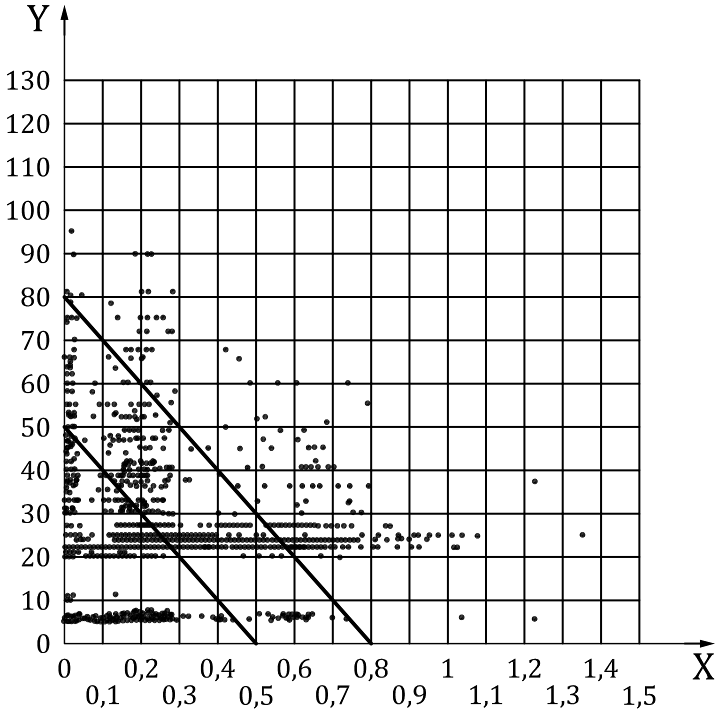
$$r = q_F \times \left(1 + s_1 + s_2 + s_3 + s_4\right) \times \left(f_H + f_Q + f_C\right) + \left(q_T \times f_T\right) \tag{C.1}$$

where

r	risk;
q_F	(type of pipe-related) failure rate;
q_T	rate of turbidity;
$s_1 ... s_4$	line-specific evaluation factors for failure probability;
f_H	failure extent regarding personal and environmental hazards;
f_Q	failure extent regarding supply quality;
f_C	failure extent regarding costs;
f_T	failure extent regarding turbidity.

C.3 Example for a condition-based prioritization for the rehabilitation of pipes

The following example for a risk matrix shows all single rehabilitation measures related to extent of failure versus failure probability. Measures on the upper line in Figure C.1 have the same risk. Measures right above the upper line should be in focus of rehabilitation.



Key

X failure probability, in failures/km/year

Y failure extent (risk points)

Figure C.1 — Risk matrix

The priority of measures is of course not the only selection criterion. It merely serves as a support in selecting the measures. The person in charge should consider this before any locally available information (e.g. coordination of the measures with other contractors, combination of measures) in his final decision concerning the implementation of the measures.

Bibliography

[1] ISO 9000:2005[1)], *Quality management systems —Fundamentals and vocabulary*

[2] ISO 19440:2007, *Enterprise integration — Constructs for enterprise modelling*

[3] ISO 24510:2007, *Activities relating to drinking water and wastewater services — Guidelines for the assessment and for the improvement of the service to users*

[4] ISO 24512, *Activities relating to drinking water and wastewater services — Guidelines for the management of drinking water utilities and for the assessment of drinking water services*

[5] ISO 31000, *Risk management — Principles and guidelines*

[6] IEC 31010, *Risk management — Risk assessment techniques*

[7] ISO 55000:2014, *Asset management — Overview, principles and terminology*

[8] ISO 55001, *Asset management — Management systems — Requirements*

[9] ISO 55002, *Asset management — Management systems — Guidelines for the application of ISO 55001*

[10] EN 15898:2011, *Conservation of cultural property — Main general terms and definitions*

[11] EN 15975-2, *Security of drinking water supply — Guidelines for risk and crisis management — Part 2: Risk management*

[12] EN 15978:2011, *Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method*

[13] EN 16323:2014, *Glossary of wastewater engineering terms*

[14] EN 752:2015, *Drain and sewer systems outside buildings*

[15] DVGW-W403 (M), April 2010, *Decision support for the rehabilitation for water distribution systems*

[16] DVGW-W400, Part 3 (A), September 2006, *Technische Regeln Wasserverteilungsanlagen (TRWV) — Teil 3: Betrieb und Instandhaltung*

[17] DVGW-W402 (A), September 2010, *Network and damage statistics — Registering and evaluating data for the maintenance of water pipe networks*

[18] Kaplan E. L., & Meier P. (1958), *Nonparametric estimation from incomplete observations*

[19] Heyen B. Rehabilitation of Water Distribution Facilities — *The Holistic Approach of the German DVGW Standards; International Water Association 4th Leading Edge Conference on Strategic Asset Management September 27-30, 2011, Mülheim an der Ruhr, Germany*

1) Cancelled and replaced by ISO 9000:2015.

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