INTERNATIONAL STANDARD

ISO 24516-2

First edition
2019-05

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

Part 2: **Waterworks**

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

Partie 2: Installations de production, pompage et stockage d'eau potable

Reference number
ISO 24516-2:2019(E)

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Published in Switzerland

Contents

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

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

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

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

Introduction

This document is written within the overall concept of 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 users in their service areas. The assets (e.g. reservoirs, wells, treatment plants, pumping stations, underground pipes and storage tanks) collectively form the physical infrastructure of 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 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 infrastructure and programs are in place to ensure their protection or their sustainability. Like many other organizations with assets, drinking water utilities undertake programs 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 or not the utilities make use of any management system standard, for example 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 programs 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 drinking water service from the aspects of quality, quantity, pressure, safety, reliability, environmental impact, sustainability, degree of treatment and efficiency. Drinking water 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 matures, the optimization of drinking water infrastructure will become necessary in many places in order to compensate for ageing and wear and tear, and to respond to changing societal and economic conditions. Consequently, water infrastructure assets are subject not only to ageing and wear and tear but also to adaptation processes resulting from growth, new legislative requirements, technical innovations or users' changing 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 the management of assets, with ever more stringent requirements on the design and execution of rehabilitation.

In recent years, much effort has been applied to the whole issue of 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) should take place?

This document describes the information required and how to collect and process reliable inventory, condition, operational and context data about technical assets of drinking water systems, including failures. These data should be the basis for a systematic management of assets and can be used for benchmarking purposes. A reliable database that supports analysis of failures and of operational data (including a description of the condition of facilities or units) is of particular significance when establishing a risk-based investigation to determine maintenance and rehabilitation priorities.

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

The usual and expected goal in 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 (waterworks – including collection, treatment, pumping and storage) that are expected to meet users' needs and expectations over longer (multi-generational) periods.

Additional information on objectives for management of assets of waterworks is provided in Annex A. An outline of the content of a drinking water master plan is provided in Annex B. Examples of inventory, condition and operational data are provided in Annex C. Methods for the risk-based assessment for rehabilitation are shown in Annex D.

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

Part 2: Waterworks

1 Scope

This document specifies guidelines for technical aspects, tools and good practices for the management of assets of waterworks to maintain value from existing assets. This document includes the following asset types: treatment plants, sludge treatment facilities, pumping stations, reservoirs, tanks and dosing equipment, metering and ancillary infrastructure irrespective of where they are sited, in the waterworks or in the drinking water distribution network.

For further guidance on drinking water distribution networks see ISO 24516-1.

NOTE 1 The management of transmission mains is addressed in ISO 24516-1 irrespective of where these assets are sited in the drinking water system.

This document is focused on the assets typically owned or operated by drinking water utilities (drinking water systems) that in parts are expected to meet users' needs and expectations over longer (multi-generational) periods.

This document includes examples of 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.

NOTE 2 Depending on the size and structure of an organization, the utility can decide to what extent it applies the guidance in this document. In any case, the philosophy of this document remains applicable even to small and medium utilities.

NOTE 3 This includes all different roles/functions for the management of assets within a utility (e.g. asset owner/responsible body, asset manager/operator, service provider/operator).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 24513, *Service activities relating to drinking water supply, wastewater and stormwater systems — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 24513 apply.

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

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

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

4 Principle aspects of the management of assets

4.1 Objectives and requirements

4.1.1 Objectives

The key generic objectives for the management of assets of drinking water systems are identified from ISO 24510 and ISO 24512 as:

— protection of public health;

— meeting users' reasonable needs and expectations;

— providing services in standard and emergency situations;

— promoting the sustainability of the drinking water utility;

— promoting sustainable development of the community;

— protection of the environment.

Drinking water utilities should aim to manage their facilities systematically and efficiently in order to sustain their function. This takes place on the basis of clearly defined objectives, based on assessment and forecasting of the condition of their often extensive and complex facilities.

Setting objectives for the management of assets should help to ensure that the drinking water utility conforms to an agreed and sustainable level of service, while also exerting a major influence on its economic performance and taking into account risks to the achievement of those objectives. The level of service should be well defined, communicated, tied to risk, and current as customized to a particular drinking water utility.

For further information on objectives of the management of assets of waterworks see Annex A.

4.1.2 Functional requirements

Functional requirements should be established to aid the achievement of the objectives.

Functional requirements of a drinking water utility cover the acquiring of water (from catchments, wells and rivers), transmitting (pumping as necessary) and storing water prior to treatment, treating the water to a drinking water standard, storing the water prior to (and onward within) distribution via drinking water distribution networks (pumping again as necessary). A variety of equipment and facilities support the main functionalities and are also subject to management of their associated assets to ensure sustainable access to drinking water. The functional requirements should be considered in respect of the whole drinking water system to ensure that additions or modifications to the system do not result in failure to meet the target(s).

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 the civil authorities), ensure that the drinking water system does 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 to 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	Protection of occupational health and safety	Providing services in standard and emergency situations	Promoting the sustainability of the drinking water utility	Promoting sustainable development of the community	Protection of the environment
Control of water quality parameters	XXX	XX	XXX	XXX	XX	XXX	XX
Ensuring drinking water quality	XXX	XXX	XX	XX	XX	X	XX
Continuity of service	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 in emergency situations	XXX	XXX	X	XXX	XXX	—	XXX
Suitability of products and materials for drinking water	XXX	XXX	XX	XX	XXX	X	X
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 failures	XX	X	X	X	XXX		XXX
Prevention of noise	XX	X	X	X	X		X
NOTE The number of Xs gives guidance on the importance of the requirement in achieving the objectives.							

4.1.3 Performance requirements

In order to evaluate the performance of the waterworks and to allow development of design criteria, 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 should influence the performance requirements. Public expectations should be reflected in the level of service set by the utility to provide to its users.

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 drinking water system should be updated after major extension, maintenance or rehabilitation.

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

Performance indicators are essential tools for the understanding of the actual and desired performance of the infrastructure of a drinking water utility and in parallel, enable indicator-supported infrastructure planning and decision-making. Reasonably designed and applied, performance indicators provide information about the condition of the assets and the level of their contribution to the achievement of the objectives of a drinking water utility.

Performance indicators should be defined at strategic, tactical and operational levels, for example:

— strategic: conformity of drinking water quality with given requirements, meeting future water demand;

— tactical: meeting peak consumption;

— operational: use of chemicals and energy per m^3.

They should make clear how actions at the operational level contribute to achieving strategic-level objectives. Strategic-level performance indicators are often called “outcomes” while operational- and tactical-level performance indicators are called “inputs” “and outputs”, respectively.

4.2 General aspects

4.2.1 General

In management of assets a distinction can be made between two principal focal points:

— the wider drinking water utility or responsible body in question;

— that organization's drinking water system to be managed.

The former could include, for example: strategic financial, reputational and non-operational assets as part of ensuring the drinking water utility's overall objectives are met.

The latter should take into account:

— attention to stakeholder (e.g. users, operator, relevant authorities, responsible bodies) requirements, needs and expectations;

— sustainability of the asset system and the provided service;

— safe water quality;

— the management of risk;

— financial stability of the utility.

4.2.2 Principal aspects — Drinking water utilities

The management of the physical infrastructure of drinking water utilities is recognized as a critical activity in realizing users’ and other stakeholders’ expectations. Key activities include:

— the determination of the utility’s current and longer-term objectives;

— planning and implementing activities to achieve objectives;

— the prediction of future water demand as an additional basis for rehabilitation;

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

The management of the utility’s assets should be directed towards ensuring the utility’s objectives are met.

Additionally, for ensuring long and economic life cycles, proper operation and stable water service, the management should include:

— knowledge of the layout of the entire drinking water system;

— knowledge of the entire drinking water system together with knowledge of costs (planning, constructing, operation, maintenance and decommissioning);

— knowledge of availability and need of resources;

— the selection of appropriate materials and components;

— the choice of installation technologies and installation contractors;

— quality control of technologies, facilities, materials used and both source and drinking water;

— maintenance of the drinking water system and its assets, including routine and incident-related inspection and investigation;

— monitoring of operating conditions.

Efficient management of assets ensures a continuous provision of the level of service as defined by the drinking water utility to meet users' and wider stakeholders' expectations and minimize life cycle costs.

Management of the assets includes:

— education and training of the personnel to achieve relevant competences;

— maintaining an up-to-date drinking water system inventory;

— monitoring and documenting of data;

— assessing the condition of the drinking water system;

— planning, maintaining or rehabilitating the drinking water system;

— operation of the drinking water system in a manner that increases service life while maintaining the agreed level of service;

— optimizing life cycle costs;

— identifying and managing risk;

— ensuring proper operation;

— ensuring stable water service by taking into account the timing and duration of various rehabilitation works;

— considering the environment in which the assets are functioning.

4.2.3 Principal aspects — Drinking water systems

The management of assets of drinking water systems should cover the complete drinking water infrastructure and the interrelationship between asset types and individual assets (e.g. assets for catchment, treatment, pumping, storage and distribution) and the impact on the resulting water quality. In addition, the management of assets should consider changes in needs and expectations/requirements of users and other stakeholders, change in behaviour of water users and usage of water as well as environmental effects such as climate conditions, consumption of resources, population migrations, and demography as far as data are or can be made available. This can be laid down in a drinking water master plan which can be a stand-alone document or captured within the strategic plan. See also an outline of the content of a drinking water master plan in Annex B.

Hence, this document should be used in conjunction with other standards regarding management of assets of drinking water systems, such as ISO 24516-1.

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

— delivery of safe drinking water of the required/agreed quality;

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

In general, a drinking water system comprises the following potential functions:

— water source;

— intake and transport;

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

— storage, transport and distribution;

— monitoring of water quality at all relevant stages in the waterworks and in the drinking water network.

4.2.4 Integrating the principal aspects

Management of assets is the application of the drinking water utility's management of asset principles, as described in this document, within the management of the drinking water system, comprising the waterworks and drinking water distribution networks, see 4.4.1.

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 modification of existing risk controls or introduction of new ones. 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, maintenance, extension and disposal 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;

— risk control.

NOTE Risk control can include risk treatment and risk mitigation.

Hazard analysis involves study of a risk event's occurrence and the likelihood that an 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 the 'scores' of individual risks (the product of a risk's impact × likelihood ratings against the organization's risk criteria) — using a risk matrix to present the results. Systematically monetizing the impact of individual risks can aid overall risk prioritization.

The evaluation of measures to address (prevent/reduce) the impact and/or likelihood of the occurrence of individual risks should be carried out by comparing the effectiveness of individual risk treatment measures and their related costs, practicability and acceptability to stakeholders. The outcome of this evaluation process can feed into a wider decision-making process utilizing cost-benefit-analysis techniques, see 7.3.

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

a) **non influenceable risks**, such as natural disasters (e.g. earthquakes, storms, floods) or economic situations;

b) **influenceable risks**, such as events arising from accidental damage, facility deterioration, asset malfunction or malicious interference with assets.

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

— sizing;

— operating pressure;

— function;

— access constraints;

— proximity to other significant assets, infrastructure or areas;

— rehabilitation cost.

The following are examples of data reports relevant for assessing likelihood (of failures):

— abnormalities of hygiene;

— exceedance of parametric values;

— maintenance;

— telemetry;

— employees' feedback;

— incidents;

— condition;

— stakeholders' complaints,

— security;

— social behaviour;

— environmental influences.

4.3.2 Life cycle

Life cycle cost should be minimized by keeping the drinking water system in a stable operating condition as stated in the objectives.

This should include:

— optimized maintenance planning;

— waterworks investigation/inspection at regular intervals;

— use of suitable construction methods and durable material;

— co-operation 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 (e.g. organizational, operational, technical) in the utility;

— participation in benchmarking projects;

— 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 the budget while aiming to minimize the life cycle cost of each asset. To avoid simultaneous rehabilitation and equalize rehabilitation cost, the service life of some assets should be prolonged or shortened by advancing or delaying rehabilitation measures.

4.4 Structuring the process for the management of assets

4.4.1 General

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

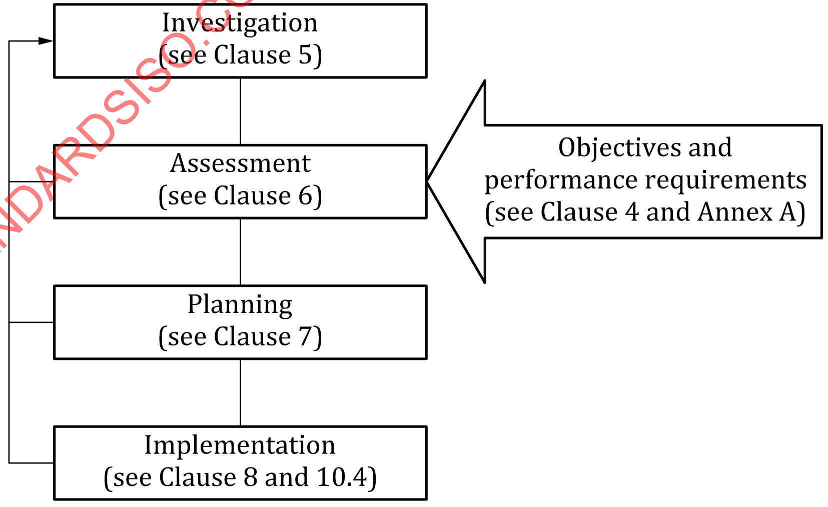


Figure 1 — Integrated waterworks management process

The integrated waterworks management process as shown in Figure 1 has four principal activities:

— an appropriate level of investigation of all aspects of the performance of the waterworks;

— 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 waterworks management forms the basis for the operation, maintenance and rehabilitation of the waterworks. The information should be regularly updated for the future management of the waterworks.

For large waterworks, for example serving a large city, an outline integrated waterworks management plan can first be developed following an outline investigation of the whole system. More detailed plans can then be developed for each facility within the context of the strategic outline plan.

The integrated waterworks management plan should be further developed during the implementation phase by subsequent investigation, assessment and planning to develop work programmes and individual projects to implement the plan.

The given 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 (4.1) included in the drinking water master plan. The risks of not achieving these objectives and requirements should be identified and managed appropriately. Based on whichever of the two strategies – the **condition-based** (or **inspection**) **strategy** or the **incident-based** (or **failure**) **strategy** – is chosen, the risks can be estimated and controlled.

To increase the likelihood of achieving the objectives and requirements as stated in 4.1 the drinking water infrastructure assets should be managed and maintained according to the **condition-based** or **inspection strategy**[14].

A proactive inspection should enable more efficiencies, though reactive and proactive maintenance, and will need to be appropriately balanced for a particular drinking water utility. A greater level of proactivity and subsequent ability to be more strategic and prioritized in rehabilitation should help a drinking water utility to be more capable of attaining its level of service, as measured by performance indicators.

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 rehabilitation funds, although it cannot 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.

Organizational constraints, continuance of existing practices or acceptance of the consequences of low-impact risks can lead to use of an **incident-based** (or **failure**) **strategy**, which incurs lower maintenance costs in the short term but can lead to disproportionately high costs in the long term. Probable consequences can include inadequate operating safety margins, increased failure rates, flooding, and premature loss of the existing structure and value of the infrastructure assets. The risk of failures and inadequacies can be extremely high. An **incident-based** (or **failure**) **strategy** can usually only be successful if the risk linked to the asset is low and will not be affected by an increased downtime or deficiencies in the water quality.

Different boundary conditions per subject matter lead from the point of view of proportionality inevitably to a differentiated application of the strategies.

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

Strategic planning of waterworks should intersect with the strategic planning for the development of the drinking water network. Although there are technically very different requirements, they are inherently closely coupled.

Drinking water systems are typically physical infrastructures with a very long useful life. Periods of many decades should, as far as possible, be considered in the strategic planning.

An appropriate level of care should be exercised during planning on the strategic level due to the very high levels of investment in the drinking water system and the technical and financial implications of subsequent adjustments.

4.4.3 Periods of planning

The sustainable process for the management of assets is, on the basis of the planning period under review, subdivided into the following three interdependent logical steps[12] (see Figure 2):

— long-term planning (i.e. strategic planning);

— medium-term planning (i.e. tactical planning);

— short-term planning (i.e. operational planning).

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

Common time horizons are:

— 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 projects and the rehabilitation budgets required to achieve and to maintain sufficient service quality and facility condition levels. It is based on an asset type approach, for example certain asset (facility) types (e.g. pumps, filters, basins, reservoirs, coatings), but not on individual assets.

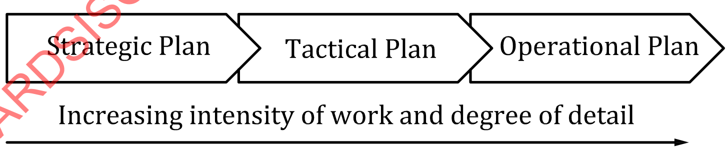


Figure 2 — Logical steps for the implementation and evaluation of targets for the management of assets[12]

Asset types should be taken into account in the "strategic planning" step. In the "tactical planning" step, the required projects are determined and prioritized for a medium-term period based on an asset evaluation. The technologies and material should be preselected. In the "operational planning" step, the actual execution of the rehabilitation measures in terms of process, 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 planning 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 evaluation and measurement of these 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 and occupational safety, public and occupational health protection, environmental protection and user satisfaction;

— expressing these levels in the form of performance indicators;

— linking these performance indicators to asset performance indicators;

— establishing adequate tariffs and billing coverage and recovery rates suitable in time to ensure sustainable revenues;

— quantifying sustainable and predictable infrastructure funding requirements;

— assessing capacity against future demands;

— establishing effective risk control measures and necessary levels of resilience redundancy within the entire drinking water system;

— controlling costs.

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;

— 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;

— controlling costs;

— preselection of process and rehabilitation technology and materials.

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[12].

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[13];

- implementing preventive and corrective maintenance activities;
- operating the system within its operational parameters;
- responding to incidents, asset failures and emergencies, and restoring service;
- selection of process and rehabilitation technology and material;
- 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 waterworks and its components.

Investigation is the first stage in the integrated management of assets of waterworks as described in 4.4.1.

Damaged, defective or incorrectly sized assets represent a potential hazard for drinking water provision (volume, pressure, quality, no continual supply).

Data about age, period of operation, maintenance intervals and history of disorder support investigation and condition assessment. The results of the investigation should be backed up conveniently in a database to facilitate subsequent evaluations. The structure of the database should build on an asset labelling system, which assigns a unique identification to each important asset.

In addition to the assessment of the condition of assets, an investigation of the relevant processes should be done. This could, for example, be done on the basis of individual performance tests of functional groups, or on the whole waterworks. These results should be documented accordingly.

The problems found in existing waterworks 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 facilities and waterworks so that all problems and their causes can be considered together. In large drinking water systems, it can be necessary to start by investigating appropriate parts of the drinking water system. The procedures described in this document can be applied in any waterworks, but detailed application should take account of the age, location and type of the drinking water system and the materials used in its construction, together with functional and climatic factors.

5.2 Purpose of investigation

Investigation should be carried out in order to make an assessment of the performance and the condition of the waterworks 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, desired level of accuracy) and the way in which the results are assessed.

The assets of the waterworks included in the investigation should be those that are necessary to fulfil the purpose of the investigation. Examples include wells, dams, treatment plants, pumping stations, inspection chambers, metering chambers, service reservoirs, monitoring facilities and control facilities. Data on assets of related drinking water distribution networks should also be taken into account in regard to their interaction with waterworks, including their different 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 all the facilities of a waterworks or even the entire drinking water system. The extent and detail of the subsequent investigation of the hydraulic, process technology, environmental, structural and operational aspects should be determined.

Based on the technical expertise gained from these initial investigations the scope and format of future investigations should be defined. The investigations should be formalized as far as possible and conducted according to uniform criteria, and evaluated to ensure the comparability of the results.

5.4 Types of investigation

5.4.1 Hydraulic investigation

An investigation of hydraulics or process technique should ideally be made on the basis of inventory data from the construction of the asset and updated on the actual status. The interaction between pumping stations, treatment plants, storage reservoirs and the network should be considered. In some cases, especially for larger assets, a simulation model may be required to understand the hydraulic system or the treatment plant.

The results of the hydraulic investigation can influence the operational and process management of the waterworks and the interaction with other parts of the drinking water system. These dependencies should be taken into consideration.

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 drinking water system.

5.4.2 Investigation of the process technique

The electrical and mechanical equipment in waterworks can be controlled by a process control system. Typically, this process control system consists of hardware and software. The entire process control system should be monitored regarding interfaces with other IT systems or external communication links, and non-conformities investigated. The aim is to establish the existence, or not, of a proper maintenance regime, a patch management process, a complete and current set of documentation and evidence of conformity with all IT security requirements. The results of these studies and activities should be documented as well as every subsequent change in the process control system.

5.4.3 Structural investigation

The structural investigation can include either a complete survey of the structures of the waterworks or a more selective approach in order to avoid duplication of previous works. In particular, investigations of, for example, wells, dams, storage reservoirs, filter basins and other buildings should be in focus. It can be useful to examine the costs of rehabilitation versus investment in new facilities. Consideration should be given to the age and location of existing infrastructure, geotechnical data and the vulnerability of existing facilities.

Where appropriate, other qualitative and quantitative investigation techniques can be used. These include laboratory analysis and field condition assessment to identify the integrity and remaining strength of a component.

5.4.4 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, process interruptions) should be reviewed.

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

The causes of significant recurrent operational incidents should be investigated.

Control system technologies (e.g. performance measurement, vibration measurement, efficiency determination) enable operators to evaluate more complex causes of failures through trend analysis, providing an opportunity to assess interactions among the asset types. It applies in particular with regard to the interactions between drinking water networks and waterworks and between asset types within, and across, these systems.

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

— location of assets;

— condition of assets;

— cause and location of failures;

— consumption of energy;

— quality of construction or repair of structural and technical equipment;

— leakages.

Operational investigation techniques available include:

— diverse electronic sensors;

— closed circuit TV (CCTV) inspection of wells and pipelines;

— flow and pressure metering;

— sampling and analysis;

— leak monitoring.

Irrespective of the strategy and the methods used, drinking water infrastructure assets should be monitored on a permanent basis 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.

Even after commissioning of the drinking water infrastructure assets a routine monitoring of the level of service, and particularly an inspection of the age-related conditions of the assets and their maintenance, should be started. The designer and/or the owner or operator should specify the nature and frequency of the maintenance and inspection of the asset system or single assets[13]. If condition data based on routine inspection are not available, all other available data based on condition assessment should be used[13].

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.

Measurable 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. Without such understanding, operational problems can subsequently arise in the various components of the waterworks.

5.5 Data collection

5.5.1 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. 5.5 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[13]. 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 at first the inventory should be updated where required and any other information should then be collected during the hydraulic, process technology, environmental, structural and operational investigations.

5.5.2 Data requirements

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

— complete;

— compatible;

— accurate;

— at a suitable scale;

— consistent;

— current;

— credible.

5.5.3 Inventory data

Inventory data provide essential technical information on the assets within a waterworks. Table C.1 gives examples of inventory data.

5.5.4 Condition data

5.5.4.1 Failure data

Failure data provide information on failures found in aggregates of components of waterworks and are linked to inventory data. The following data should be collected:

— date of documentation, after final remedy;

— date of failure occurrence, if known;

— location (e.g. asset identification number, location);

— point of failure;

— type of failure;

— cause of failure (e.g. ageing, damage due to others' construction works);

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

— costs of eliminating failure;

— cost of putting back into operation and cost of temporary remedy;

— consequence(s) of failure (e.g. exceeding parametric values, loss of pressure, interruption of the treatment process or service).

For the determination and diagnosis of failures, uniform assessment criteria should be used and executed by well-trained personnel. See also Table C.2.

5.5.4.2 Further condition data

In addition to failure data, more information on the condition of facilities and components of waterworks should be acquired as it provides valuable information on the prioritization of rehabilitation measures.

The availability of condition data on waterworks can be limited, because the data collection of condition data differs fundamentally from the collection of inventory and failure data.

The following data should be collected, if they are obtainable and appropriately describe the condition of the assets:

— date of condition data collection;

— definition of the assets' respective technical facilities (e.g. coordinates, part of the asset);

— identification and plausibility information (e.g. water quality, material, coating, flow velocity);

— condition/failure (e.g. temperature of bearings, efficiency of pumps or motors);

— operating pressure fluctuations (minimum and maximum values);

— ambient temperature;

— operational incidents;

— context data.

Context data, for example differing source water quality within the catchment area, electricity supply, condition of the surface water body, earth movements/mining activities or topography, provide technical information about the local surroundings of drinking water systems, which should be factored into the risk-assessment process. See also Table C.2.

5.5.5 Operational data

In addition to the data mentioned in 5.5.1 to 5.5.4, operational data (e.g. hours of operation of an asset, changes in flow rate or pressure) should be acquired, as it provides valuable information on the facilities and components and on the prioritization of rehabilitation measures. See Table C.3.

5.6 Data registering and data assignment

5.6.1 Data registering

The data to be registered as defined in 5.5 should be compiled, integrated, processed and safely stored and readily recoverable by the utility. The stored data should be checked and updated periodically or appropriately. They form the basis for developing maintenance plans and strategies.

The data collection process itself determines the value of the data for asset maintenance. The data should relate to the asset inventory (see 5.5.3, 5.5.4 and examples in Annex C). The data's value increases in line with their quantity and quality registered and with the possibility to assign individual pieces of data to the respective drinking water system under consideration.

Table C.1 applies to the inventory data which should be registered, Table C.2 applies to failure and other condition data and Table C.3 applies to operational data which should also be registered. Data collection should be comprehensive, uniform, continuous and free from interpretation, and based on previously and unambiguously defined default values ("multiple choice"). Free text should be avoided because it offers only limited evaluation possibilities.

Data collection can 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 for a given drinking water system.

5.6.2 Data assignment

All inventory, condition and context data registered should be correctly assigned to the associated asset types (e.g. electro-technical equipment, pumps, basins, filters) and/or individual assets. Likewise, failure data (e.g. ageing, fatigue, damage caused by other processes or equipment, poor maintenance) should be registered in such a way as to enable the retroactive elimination of events not relevant for maintenance.

Inventory, condition and context data can be used for devising rehabilitation strategies and tactics, depending on the asset to which they are assigned.

5.6.3 Locational referencing

Using the above-mentioned databases for medium- and short-term rehabilitation planning can require locational referencing and the unambiguous assignment of data records to their associated assets. Using selective locational referencing, condition and context data can provide important information when defining a rehabilitation strategy.

Capturing data [e.g. in geographic information system (GIS), process and instrumentation (P & I), computerized maintenance management system (CMMS), flow sheet, enterprise-resource-planning (ERP), asset information systems] is recommended for processing and using maintenance-related data. Reference to individual assets should be preserved even when decommissioned assets have ceased to form part of a current facility. Historical data also supply important information for devising a rehabilitation strategy.

5.7 Review existing information

The collection and review of all available relevant information about the waterworks' asset inventory should be carried out and is the basis from which all other activities are subsequently planned.

A review should also be undertaken of the information required to manage the waterworks.

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

5.8 Inventory update

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

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

At a minimum, each asset should be assigned a unique identification number. Formulating a hierarchical structure in the data is also helpful for information retrieval, analysis and reporting needs. Asset data attributes should be captured for each asset together with their source (e.g. design documents, information system). Mapping the data workflows among their sources and recipients can enable better functionality, efficiency and quality.

5.9 Review of performance information

An indication of the type of performance problems, if any, on existing drinking water systems is likely to be known through reports of incidents. These can include breakdown or malfunction of machines or valves; loss of pressure; deterioration of drinking water quality (exceeding limit or guidance values) within the treatment process or drinking water network. Data on such problems can be gathered from online monitoring, 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 other such information include:

— hydraulic performance analysis;

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

— results of monitoring performance and condition.

Where several waterworks or treatment steps are in need of investigation, the existing information collected can also be used to assign priorities to the investigation of the perceived problems in each service area (for example by comparing the cost of the investigation with the benefit that might be achieved). These priorities can then be used to draw up a comprehensive program with the intention to investigate facilities with the most serious projected problems or risks first.

5.10 Planning of investigation

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

— target facilities and period for investigation;

— determination of type and extent of survey (see 5.4);

— suitable survey method, items, standards;

— estimated cost.

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

5.11 Performance testing

The performance of assets in waterworks should be tested and assessed during construction, at the completion of the construction stage and also during the operational life of the drinking water system. The following are examples of applicable test methods:

— efficiencies of pumps, function and watertightness of valves;

— visual inspection;

— hydraulic performance;

— monitoring of equipment or process availability over the time in question;

— water quality measurement under different load conditions until going to the peak load, possibly beyond the design limit;

— monitoring of the water quality input to the treatment plant and at various treatment steps;

— monitoring the drinking water quality;

— flow measurement.

The scope of the tests and the methodologies to be undertaken to determine the performance of waterworks depend on whether it is a new asset, a long-established asset or a rehabilitated asset.

The effectiveness of maintenance should be assessed using the tests or methodologies applied (see 9.3). In the case of a condition-based strategy the equipment availability can be used as an assessment. Using the reactive maintenance strategy, target response times can be used as an assessment. This also forms the basis for future planning.

6 Assessment

6.1 Process

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

The performance of the drinking water system should be assessed against the performance requirements (see 4.1.3). The performance assessment should include the evaluation of risks of failure to achieve the performance requirements[5].

Figure 3 shows the process of assessment.

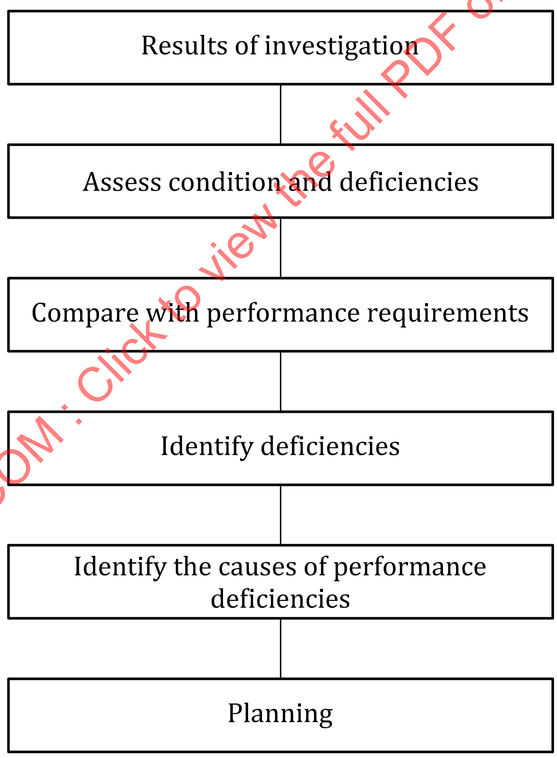


Figure 3 — Process of assessment

6.2 Assessment of hydraulic and drinking water quality performance

Based on the results of the investigation of the processes, the performance of the drinking water system should be assessed with regard to the requirements for the maximum required power demand. This should consider peak hour, day and year requirements depending upon the design of the total supply (if necessary) and also for the minimum necessary supply. The resilience for normal operation should be safeguarded by the necessary security and redundancy arrangements in accordance with risk management principles.

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

6.3 Assessment of process performance

The treatment and pumping process performance of a waterworks should be monitored by both manual and online methods for determining the quality of source and finished drinking water. Where it is appropriate, water quality after specific treatment steps should be monitored to facilitate the determination of the source of deviations from the target values.

Deviations from the required performance should be evaluated and, after taking future requirements into consideration, can serve as a basis for improvement measures.

6.4 Assessment of structural condition

Further criteria are relevant for the assessment of the structural condition of waterworks such as operational availability, stability, protection of the equipment against environmental influences, flood protection and flood control, lightning protection, fire protection and escape routes, and protection against unauthorized access.

6.5 Assessment of operational performance

The operational performance of the waterworks can be assessed by a number of measures. For example, the number of operational incidents or failures occurring within a given time period. Performance should be recorded in a database.

6.6 Comparison with performance requirements

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

Performance indicators are a method of comparing the overall performance of a waterworks with performance requirements and for comparing different treatment plants. They can also be used as a basis for benchmarking purposes (see ISO 24523). Any performance indicators used should be:

— clearly defined, concise and unambiguous;

— verifiable;

— simple and easy to use;

— tied to level of service.

6.7 Identification of unacceptable impacts

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

6.8 Identification of causes of performance deficiencies

Based upon the results of the hydraulic, procedural, structural and operational investigations, the causes of performance deficiencies should be determined. The relative impact and likelihood of a risk event resulting from each cause should be assessed against the drinking water utility's risk criteria in order to develop appropriate solutions and to set the priority for action.

7 Planning

7.1 General

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

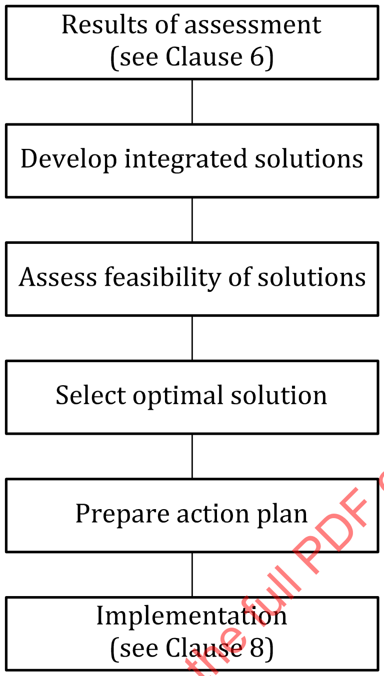


Figure 4 — Process of planning

7.2 Develop integrated solutions

Integrated solutions should be developed that fulfil the performance requirements, taking into account risk considerations and expected future conditions. Various solutions that can be used for planning of rehabilitation are listed in Table 2 by type and options.

Table 2 — Solution types and options for rehabilitation

Type	Options
Hydraulic	Optimize use of existing flow capacity
	Adjust diameters and pipe-wall friction characteristics to water demand and pressure
	Increase the waterworks' flow capacity (e.g. by replacement impellers of aged pumps)
	Attenuate peak flows
	Exercise flow control (reduce output by using storage volume of reservoirs in the network)
NOTE This list is not exhaustive.	

Table 2 *(continued)*

Type	Options
Procedural	Adjust capacities and ensure effective assurance of water quality
	Optimize energy use, improve efficiency, reduce CO_2 emission
	Reallocate structures of waterworks or the drinking water distribution network
	Anticipate improvements necessary to meet future requirements where these are cost-effective to implement now
	Optimize service pressures, energy management, overall efficiency
	Optimize the overall drinking water system including the influences of the catchment, upon the drinking water distribution network and the influences of the drinking water distribution network on the waterworks
	Optimize planning for demographic and climate changes
Structural	Achieve long-term preservation of the function (e.g. renovation of water-storage facilities)
	Safeguard occupational safety, protect the environment, structurally rehabilitate plant or buildings
Operational	Undertake planned inspection and cleaning of a facility
	Optimize frequency of maintenance of pumps 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.	

The combination of individual options should be integrated into an optimal solution which can influence the drinking water masterplan, see 4.2.3 and Annex B, which should then be updated.

7.3 Assess solutions

The proposed solutions can be subject to both internal and external constraints. Internal constraints involve financial and performance perspectives of the utilities. External constraints (e.g. regulatory or governmental requirements) can take different perspectives (e.g. societal costs and benefits). Both perspectives are governed by financial limitations (current or future) on the availability of funds. For a drinking water utility in which available funds could be limited, this also introduces the economic notion of opportunity cost, i.e. if this measure is undertaken, then what other desirable measure(s) may have to be postponed, or not taken within the time horizon. Therefore, the prioritization of solutions, including cost-benefit analysis, should be performed.

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

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

b) **Sustainable use of resources** — The use of energy and other finite resources in the construction and operation of the waterworks. The ability to recycle materials used in the rehabilitation works and any waste produced.

c) **Phasing of the works** — The possibility of integrating the solution into a staged programme of works. 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.

d) **Capacity and resource constraints** — the resource constraints (e.g. personnel, supply chain and financial) in the selection and phasing of the options.

e) **Future maintenance liabilities** — The cost of future maintenance works and other operational costs of the waterworks.

f) **Economic appraisal** — The costs and benefits of one solution over another to determine whether their respective net benefits (e.g. from increased asset life) are economically justified.

g) **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; during construction; and during its subsequent decommissioning. 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 waterworks. 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 Introduction

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

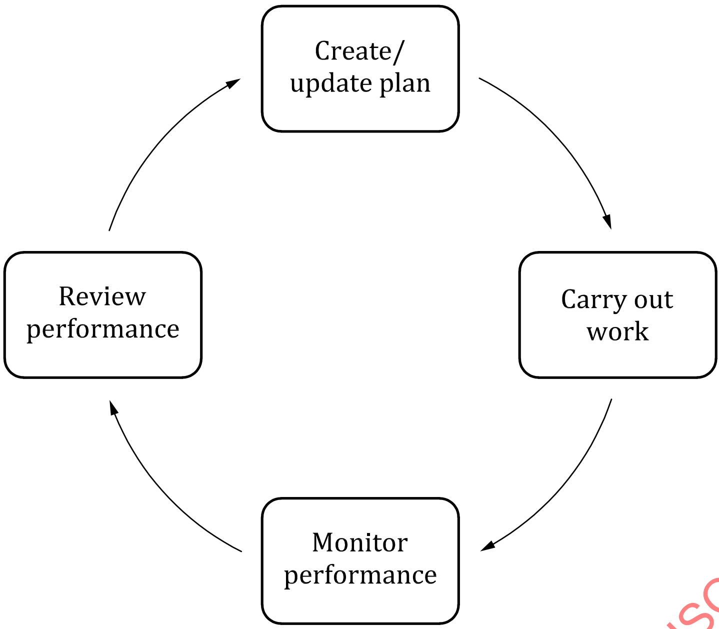


Figure 5 — Process for implementation following the PDCA approach

8.2 Create/update plan

For maintaining or improving the performance of the asset system, the objectives and functional requirements should first be established, followed by the technical processes to investigate, assess and create maintenance, rehabilitation and operational plans to maintain or improve the performance of the asset system.

Necessary works to rehabilitate, maintain and operate the waterworks should be defined in the rehabilitation, maintenance and operational plans.

The implementation plan should be updated as necessary. This includes updating to identify a path forward enabling the drinking water utility to further improve its practices for management of assets to better attain its desired level of service while minimizing costs and effectively managing risk. Improvement should be a continual process. 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

In the context of management of assets for extending, reducing or rehabilitating a waterworks, the following should be considered:

— selection of appropriate technologies and materials;

— selection of a constructor(s) appropriately experienced in use of the technologies and materials;

— quality control of materials (specification and procurement);

— quality of installation and conformity with installation requirements;

— evaluation of the process performance of each asset.

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 process and hydraulic models or treatment process simulation model by the use of performance indicators.

Monitoring data should be identified and captured. That is specifically relevant to identifying the extent to which performance indicators are attained in meeting the committed level of service. Only this specific data should be captured to minimize the effort of management of assets.

8.5 Review performance

The performance requirements should be reviewed periodically.

The monitoring data captured should be reviewed to identify the extent to which key performance indicators are attained to meet the committed level of service.

9 Operation and maintenance

9.1 General

The purpose of operation and maintenance is to ensure that the waterworks performs in accordance with the functional requirements defined in Clause 4 and in accordance with any operation and maintenance plan.

Operation and maintenance should ensure that:

— the entire drinking water system is operationally ready at all times and functions within the performance requirements;

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

Examples for the difference between the terms operation and maintenance are shown in Table 3.

Table 3 — Difference between the terms operation and maintenance

	Existing drinking water systems			
Term	**Retain original performance (routine activities)**	**Restore original performance**	**Upgrade performance**	**Examples**
Operation	Yes	No	No	Monitoring, regulation of flow and water quality, operation of pumps, treatment equipment and valves. Flushing filters
Maintenance	Yes	Yes	No	Cleaning filters and tanks, adjusting metering equipment, local repair and replacement and/or lubrication of a pump or valve. Replacement of electro-mechanical equipment or SCADA, repair of a pipe, pump or valve.

Effective operation and maintenance of waterworks are important elements in the management of assets for maintaining the condition of waterworks' assets in their required state and achieving a long service life for each asset. Operation and maintenance depend on, for example:

— planning;

— sufficient numbers of competent personnel;

— clear assignment of responsibilities;

— suitable equipment;

— knowledge of the drinking water system and its operational components;

— 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 waterworks performs in accordance with its functional requirements and in accordance with any operational plan(s).

Operation should ensure that the aim of the drinking water utility — to successfully deliver the service of drinking water provision in the required quantity, pressure and quality — can be achieved at all times. This is achieved if the functional requirements of the operation and maintenance plans are met (see 4.1.2) and the necessary resources for this purpose are available (e.g. funds, expertise, personnel).

Operation includes:

- controlling pumps, machines and technical equipment;
- monitoring and intervention to ensure that the processes of catchment, treatment, pumping, storing and transport are adequately delivered;
- acting in accordance with contingency and emergency plans;
- measuring water quality;
- regularly inspecting and documenting;

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 waterworks performs in accordance with its functional requirements and in accordance with any maintenance plan. Well-executed maintenance will also contribute to optimization of the assets' operational lives and risk mitigation.

Maintenance includes:

- pursuing a complementary balance of proactive maintenance with reactive maintenance to enable a more strategic approach that aims to achieve an optimal combination of cost and risk mitigation;
- local repair or replacement of damaged pumps, motors, pipes, valves or other assets in order to maintain their functioning and safeguards;
- cleaning, removal of sediments and disinfecting to restore hydraulic capacity and to ensure hygiene, water quality and performance restoration;
- regular attention to accessories like valves, dosing, control and metering equipment.

A generally applicable maintenance strategy for all equipment cannot be stated. A risk analysis of the assets leads to selection of an appropriate maintenance strategy from the alternatives available, which takes into account costs and the probability of successfully achieving the intended benefits. This is consistent with the reliability centred maintenance (RCM) approach. This concept focuses on the reliability of an asset and aims to reduce the maintenance costs while optimizing the reliability.

The goal is achieved through an analysis of each subject matter, which is based on the following questions:

- Does the subject matter conform with function (performance)?
- Which disorder or failure can impair the function?

— What caused the error?

— What is the effect due to the disorder or failure?

— How can the disorder or failure be predicted or even avoided?

— What can be done if the disorder or failure cannot be predicted or avoided?

From the assessment of the answers to these questions the proper strategy can be derived approximately, leaving a degree of discretion on each subject matter.

When assessing the impact of disorder or failure upon an asset, consideration should be given to the wider impact upon the waterworks because of the composite nature of the asset within the waterworks.

A brief overview of the alternative maintenance strategies available is given in Table 4.

Table 4 — Overview of maintenance strategies

Maintenance strategy	Brief description	Advantages	Disadvantages
Incident-based maintenance	— No action, to determine the actual status of the asset/system — Only failure-based repair or replacement	— The service life of the asset is completely exploited — Low costs for inspection and documentation	— Unpredictable occurrence of failure — Consequential failures are possible, which leads to uneconomical repair — An incident- or failure-based strategy can usually only be successful if the risk linked to the asset is low and will not be affected by an increased downtime and redundancy is sufficient
Preventive maintenance	— Few measures are taken for condition assessment — The preservation of the nominal condition of the assets is performed by preventative replacement of wear and tear parts	— Low unplanned failure probability — Predictable decommissioning	— High cost by low utilization of service life — High downtime caused by repair
Condi-tion-based maintenance	— If the condition of the asset is regularly identified by inspection then the wear and tear is defined as the limit deviation in regard to the nominal performance — Risk-based maintenance is included	— Low unplanned failure probability — Predictable decommissioning — Optimal utilization of the service life	— Higher costs for the determination of condition — Higher qualification of the staff
Predictive maintenance	— Besides the determination of the condition it is also intended to improve the asset and to reduce the wear and tear	— The availability of the complete asset system increases — Long term, the expenses for maintenance decrease	— High costs for troubleshooting — Very high qualification for the staff

10 Rehabilitation

10.1 General

Rehabilitation should take into consideration all aspects of selection, installation, maintenance, repair, renovation, replacement and decommissioning to fulfil the objectives.

Once a waterworks is installed and operated, the highest expenditure of costs over its life cycle is determined by the consumption of resources. These include energy, dosing agents, disposal of residuals and for the personnel expenses for operation and maintenance plus decision-making concerning the rehabilitation of the waterworks. If the cost of maintenance and operation of the facilities increases beyond what is reasonable, or the quality of the source water or the legal requirements for drinking water change, the rehabilitation of assets or parts of the asset system can become necessary.

The time for rehabilitation is thus determined by the life cycle costs of the asset portfolio. Strategic and tactical plans form the basis of the further procedure.

Therefore, a sustainable process for managing water assets should be subdivided into the 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[12] (see also 4.4.3, 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 drinking water system conditions and the resulting level of service. The tactic includes identifying and defining the sequence of rehabilitation measures required in the medium term and pre-selecting the rehabilitation technologies 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 certain. The results of the individual logical steps should be synchronised with one another.

The key objectives of the rehabilitation of drinking water systems consist of:

— minimizing interruptions of service in any situation;

— retaining the necessary water quality (relevant water quality parameters);

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

— improving or maintaining the level of service;

— achieving the lowest possible total expenditure.

The extent to which achievement of each of these objectives can be influenced is indicated in Table 5.

Table 5 — Rehabilitation objectives

Rehabilitation objective		Strategic plan (how much?)	Tactical plan (where and when?)	Operational plan (how?)
Minimising asset failures and service interruptions	Complete asset system	X	X	—
	Asset type	X	X	—
	Asset	—	X	X
Keeping required drinking water quality		X	X	X
Resource reliability		X	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
Minimising the required total cost of maintenance while keeping up the necessary service standard		X	X	X

Key

X Implementable

O Implementable if allocation to asset type possible

— Not implementable

In order to achieve the objectives linked to the rehabilitation measures, good knowledge of the risks affecting the water infrastructure assets should exist. More details of likelihood and impact of failures or incidents are given in 10.3. While a strategy could consider only risk factors associated with asset-type-related failure likelihood, 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 the entire waterworks, including catchment areas. 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.

Important indications for a rehabilitation plan are the findings of maintenance and operation of the assets.

Usually, single units in function groups (i.e. exercising their function in the aggregate) should be combined and then undergo a joint rehabilitation of the whole functional unit largely to take advantage of a corresponding improvement potential.

As an example, this can involve subdividing the waterworks into the following major asset types:

— water catchment infrastructure, including wells;

— pumps;

— disinfection equipment;

— tanks and filters for various treatment steps;

— reservoirs and other structures;

— dosing and monitoring equipment;

— other installations (e.g. electrical and mechanical equipment).

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

— water catchment infrastructures, including wells and related technical equipment;

— intake assets;

— water source (e.g. aquifers, impounding reservoirs);

— source water (e.g. borehole, river, surface water);

— transmission mains (see ISO 24516-1);

— treatment in the relevant procedural requirement;

— storage reservoirs and tanks;

— pumping stations;

— equipment for general electrical supply (e.g. transformers, high, medium and low voltage switchgear);

— control equipment and automation technology;

— data transmission and supervision systems;

— metering technology;

— emergency power systems;

— buildings, properties, fences, supervision systems, security systems;

— asset types of comparable location and installation conditions;

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

Certain areas or asset types exhibiting unusual or exceptional underperformance, quality problems, exceptionally high operating costs and frequent disorder that have a major impact on the rehabilitation strategy should be broken down accordingly into asset sub-types with advanced differentiation.

The rehabilitation need of the waterworks or its facilities under review is determined on the basis of the data and findings identified for the individual asset types.

Typically, the rehabilitation strategy varies between different major asset types depending on maintenance strategy and risk assessment.

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 20 to 40 years is generally sufficient to completely cover the relevant condition developments of the asset system or types to be rehabilitated. Function, condition of installation and operation of each asset type should be considered in setting the review period.

10.2.2 Strategic approaches

A number of different approaches are possible for the formulation of the strategic plan on rehabilitation. These approaches can be combined to achieve the optimal strategy for a waterworks. Different approaches can be suitable for different parts of the drinking water system, depending on local conditions and the risk attached to consequences of failure. In the absence of better information, estimation by age can be used as a first step in estimating remaining service life. The statistical estimation can be used to understand future rehabilitation needs if the ageing deterioration was recognized in the inspection. When investigation results have been accumulated and assessed, it is advisable to improve the level of estimation.

Possible approaches include:

a) **Asset value approach** — A financial-based approach that is used to ensure that rehabilitation is carried out at a rate that ensures that the value of the drinking water system at the end of a specified period does not fall below a specified threshold.

b) **Asset-type-related approach** — One part of the assets of a waterworks is selected with common characteristics, requirements and properties, for example a treatment step, a well field or a monitoring system.

c) **Condition-based approach** — All components of a waterworks are inspected and those that do not meet some specified threshold condition are rehabilitated. If all components of a waterworks cannot be inspected in a short period, a sampling survey and a screening method can be used.

d) **Functional-related approach** — This is built around the need for changes to improve the performance of the drinking water system (e.g. the need to reduce or eliminate constituents of the source water) and takes the opportunity to do other rehabilitation work where this can be done more efficiently at the same time.

e) **Reactive approach** — This involves responding to failures and problems as they are identified. Examples can include restoring structural integrity.

The above-listed strategic approaches, including their advantages and disadvantages, are show in Table 6.

Table 6 — Advantages and disadvantages of different strategic approaches

Approach	Advantages	Disadvantages
Asset-value approach	— the changes in asset value of the drinking water system can be made transparent — suitable for determining a fixed-rate budget	— it is solely financially driven — needs to be used in combination with other approaches
Asset-type-related approach	— it is easy to get a clearer view of the work and the benefits — it is possible to carry out the work in a defined period — concentration of work in one area can be financially efficient — relevant asset types of the drinking water system are comprehensively rehabilitated	— a detailed cost estimate can only be made after detailed investigation of the area — problems remain in other areas of the drinking water system for a longer period
Condition-based approach	— status of structures and equipment is known by inspection — reduction in need for reactive rehabilitation — very efficient way of rehabilitation by selecting only assets with high priority — the complete drinking water system is maintained to a defined standard	— problems with a lower priority remain in the drinking water system for a longer period — loss of efficiency by the possible need to carry out further works in the same parts of the drinking water system at a later time

Table 6 *(continued)*

Approach	Advantages	Disadvantages
Functional-related approach	— future-oriented planning creates capacity, alleviating problems before they occur	— cannot be applied as sole approach
Reactive approach	— can be cost-effective where consequence of failure is low	— cannot prevent failures occurring — can only be safely based on a risk-based approach
Risk-based approach	— optimal risk – cost ratio, bundling of works to optimize time and manpower costs	— can lead to deficiencies of water quality, breakdowns or service interruptions if risks are not managed safely

The reactive rehabilitation approach should only be used where the risk of failure is considered, taking into account both the probability of failure and the consequences.

10.2.3 Determining the need for rehabilitation of physical infrastructure

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

— empirical data and historical rehabilitation statistics of the utility;

— measurements in connection with investigations or assessment of condition;

— evaluation of statistics of failures or disorders;

— increasing amounts of maintenance;

— special investigations;

— other sources, such as technical literature, exchanges of technical information.

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

The age-related and usage-based development of wear (consumption of wear stock) significantly affects the service life of different asset types. Therefore, the estimation of the remaining service life for each asset type should be verified by failure analysis and compared with the age-related development of failures if available.

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;

— common operational usage.

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

Established trend or regression functions can 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.

The annual rehabilitation need depends largely on the service life expected for the individual asset types. The following methods can 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.

Maintenance and rehabilitation of machinery or asset types ensure their correct functioning to reach their technical service life. The maintenance strategy influences the scope of activity and this should be adapted specifically according to the requirements of safety efficiency.

10.2.4 Budgeting

The rehabilitation budget required to implement a rehabilitation strategy is generally determined by the rehabilitation plan. Cost estimates should be based on utility-specific, long-term empirical data as well as on any planned changes in components and treatment system. The results of possible strategic optimization activities should likewise be included in the rehabilitation budget calculation.

Since a rehabilitation budget calculated in accordance with the method described above only covers the condition-based rehabilitation of waterworks, expenditures on third-party-induced replacement (in the absence of an urgent need for rehabilitation) should be added to the rehabilitation strategy budget.

The future plans for rehabilitation work for the whole treatment plant should be estimated. Introduction of maintenance to extend the service life of treatment plants reduces life cycle cost and spreads the levels of the rehabilitation cost across the years to an extent balanced with strategic proactive capital improvements.

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

10.3.1 Risk-based approach to evaluation of priorities

Reaching the rehabilitation objectives presupposes knowledge of the risks involved. In addition, deficiencies in the level of service (e.g. quantity, pressure, drinking water quality), direct added costs and possibly the resultant negative public perception of a failure and the image of the drinking water 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 and measured values.

As far as the rehabilitation strategy is concerned, the aspect of risk can only be considered to a limited extent. The typical 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 failures can be clearly attributed to individual asset types and not to individual components, these aspects, too, can be taken into account in the rehabilitation strategy. In rehabilitation planning and execution of rehabilitation all influencing risk factors should be evaluated.

The tactical plan for rehabilitation pursues the objective of implementing within the medium term, for example within two years to five years, the amount of rehabilitation determined by the rehabilitation strategy for the individual asset types. The operational rehabilitation plan required for the task should be identified and prioritised.

The prioritization of measures for various parts of the waterworks, or even the whole drinking water system including asset types, is difficult and cannot be easily compared. The prioritization criteria should be made as objective as possible.

The criteria for prioritization should be based on the risk emanating from an asset or affecting its function. This risk results from the probability of occurrence and the consequence of failure. Health risks are of particular importance for all stakeholders. A key concern for the drinking water utility/operator/responsible body can be, in addition to the cost of loss, the avoidance of reputational damage.

The drinking water utility should define utility-specific risk-assessment criteria that support a risk evaluation approach capable of producing risk evaluation results for each facility.

The risk assessment process firstly requires establishment of risk analysis criteria for a risk event's likelihood (probability) of failure or occurrence and its potential impact (extent of failure or disorder).

Risk assessment criteria can be subdivided into the following groups:

a) The probability of failure occurrence can be deduced from:

   1) the failure development in a component (individually or in aggregate);

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

   3) characteristics of individual assets;

   4) other condition data of machinery or technical facilities (e.g. corrosion, cavitation, efficiency);

   5) knowledge about fluctuation of level of service.

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

   1) operational experience;

   2) measured values;

   3) calculations;

   4) user complaints.

c) The extent of failure or disorder can be assessed in relation to, for example:

   1) hazards to

      i) persons;

      ii) assets (tangible and intangible);

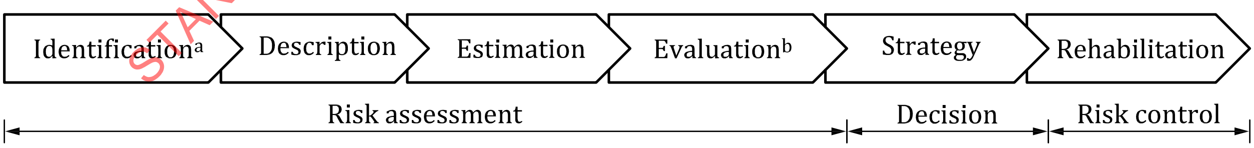
      iii) environment;

   2) cost;

   3) drinking water utility's image/public perception.

Having identified, described and analysed each risk using a consistent set of risk analysis criteria, a drinking water utility should then evaluate the relative significance of each risk compared with the others based on a consistent set of evaluation criteria. Evaluation results serve to assess the risk for each asset on the basis of pre-defined criteria. The evaluation results for the entire waterworks or for individual components should determine the rehabilitation priority ranking of the assets concerned. Risk can be expressed by a variety of units.

Figure 6 illustrates the risk-assessment process leading to the evaluation of assets' priority for rehabilitation.



a Of each risk individually.

b Of all risks relative to one another.

Figure 6 — Process of risk assessment, decision making and risk control

10.3.2 Evaluation of individual risks and prioritising for risk control

A risk-assessment process (4.3) should be defined and documented that contains the relevant criteria for the relative evaluation of the risks. Application of the process will produce data, for example in the form of points scored, with serious risks scoring more points. The process should determine how the risk assessment should be applied to assets and asset types with both similar and dissimilar characteristics.

Each criterion should be applied to asset types of equal technical characteristic. The final overall evaluation can be attained by comparing the individual evaluation results. As this step constitutes the most crucial procedure in the process, it should be prepared and coordinated with due care. The combination of the individual evaluations should correctly reflect the weighting of the criteria against each other within the same asset type and across similar asset types. Sorting the evaluation results then yields the competing 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 component or else the evaluation results can be distorted. The source and reliability of the information should be documented and should be considered in the evaluation process. The absence of information should not be a reason for excluding a risk from the evaluation process.

The list of competing priorities emerging from the evaluation of risks should provide the following information about the individual assets or asset types as a minimum requirement:

— unambiguous identification of a component (technical data);

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

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

A decision on the competing priorities can be aided using a risk matrix (e.g. incidence likelihood versus degree of impact) or a risk scoring classification system (see Annex D).

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

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

Alternative construction technologies should be considered.

Consideration should be given to simultaneous rehabilitation on competing assets/facilities of roughly the same priority ranking so as to achieve efficiencies in the rehabilitation program (e.g. energy efficiency, reduction of chemical use or reduction of other operating costs).

The following should also be specified:

— choice of technologies and materials;

— quality inspection of the materials and the installation;

— requirements for the executing contractors.

11 Documentation and performance 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