
**Guidelines for performance evaluation
of treatment technologies for water
reuse systems —**

**Part 1:
General**

*Lignes directrices pour l'évaluation des performances des techniques
de traitement des systèmes de réutilisation de l'eau —*

Partie 1: Généralités

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 282, *Water reuse*, Subcommittee SC 3, *Risk and performance evaluation of water reuse systems*.

A list of all parts in the ISO 20468 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

The rapidly growing global market for water reuse technologies inevitably demands standards which are applicable on a world-wide basis be developed. Many regions in the world are facing water shortages, and there is great interest in fit-for-purpose water reuse technologies that can treat and reclaim wastewater to a water quality level that is suitable for a wide range of reuse applications that can satisfy non-potable water demands, thereby conserving precious potable water resources. The implementation of water reuse programs raises public and regulatory concern regarding potential human health, environmental and societal impacts. This has led to an increasing need to specify various aspects of water reuse projects, and regulators, reuse technology suppliers, and users of those technologies have a growing need for international standardization. A great number of opportunities for sustainable water use and development based on water reclamation can be lost without ISO water reuse standards.

Standardization needs to include objective specification and evaluation of levels of service and water reuse system performance dependability including safety, environmental protection, resilience and cost-effectiveness considerations. Hence, appropriate methods are needed to evaluate the performance of treatment technologies for water reuse systems.

The performance of treatment technologies for water reuse, *inter alia*, should be evaluated properly in order to select the most appropriate technologies in an unbiased way to achieve the objectives of water reuse projects. Despite considerable research and development on treatment technologies, such scientific knowledge is largely held within commercial interests. Performance evaluations are also useful for assessing the efficiency of existing wastewater reclamation systems and operations, including the identification of continuous improvement opportunities. To address these challenges, this document provides methods and tools, which can be accepted by most stakeholders, to evaluate the performance of treatment technologies for water reuse systems for a multitude of applications. This document provides treatment technology functional requirements and non-functional requirements, the former based on water quality parameter concentration or removal efficiency and the latter based on performance indicators. A step-by-step procedure for evaluating the functional requirements and examples of non-functional key performance indicators and evaluation methods are provided.

This document is intended for use by planners and managers of water reuse projects, technical advisors, designers, operators of the treatment systems, those involved in monitoring, assessing, regulating and other activities of third-party organizations or relevant authorities, as well as treatment technology manufacturers.

The application of the guidelines for performance evaluation at the stages of procurement, designing and operation of treatment systems can enable, for example:

- designers to identify and evaluate an optimal treatment system design which will meet regulatory performance requirements;
- manufacturers to determine technology performance expectations;
- operators to evaluate and improve the operating efficiency and performance of water reuse treatment systems.

This document is not intended to address the design and integration of specific unit treatment processes or overall treatment system design.

This document can be useful for the application of management system standards, such as ISO 9001, ISO 14001, ISO 22301, ISO 50001, and ISO 55001.

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Guidelines for performance evaluation of treatment technologies for water reuse systems —

Part 1: General

1 Scope

This document gives guidelines on performance evaluation of treatment technologies for water reuse systems. It provides typical parameters of water quality and treatment efficiency that are associated with the performances of treatment technologies. It also includes a comparison of measured and target values, and provides treatment technology functional requirements and non-functional requirements.

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 reference, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms, definitions and list of abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 Terms and definitions

3.1.1

availability

<performance> ability of a treatment technology to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

Note 1 to entry: This ability depends on the combined aspects of the reliability performance, the maintainability performance, and the maintenance support performance.

Note 2 to entry: Required external resources, other than maintenance resources, do not affect the availability performance of the treatment technologies.

[SOURCE: IEC 60050-191:1990, 191-02-05]

3.1.2

benchmarking

tool for performance improvement through systematic search and adaptation of leading practices

[SOURCE: Benchmarking Water Services - *Guiding water utilities to excellence* (2011)]

3.1.3

correction

action to eliminate a detected nonconformity

[SOURCE: ISO 9000:2015, 3.12.3, modified — Notes 1 and 2 to entry have been deleted.]

3.1.4

corrective action

action to eliminate the cause of a nonconformity and to prevent recurrence

[SOURCE: ISO 9000:2015, 3.12.2, modified — Notes 1 to 3 to entry have been deleted.]

3.1.5

dependability

collective term used to describe the availability performance and its influencing factors

EXAMPLE Reliability performance, maintainability performance and maintenance support performance.

[SOURCE: IEC 60050-191:1990, 191-02-03]

3.1.6

downtime

amount of time that a system or a component is not able to operate or meet required functions

3.1.7

failure

state in which a treatment technology does not meet a functional or a non-functional requirement

3.1.8

functional requirement

requirement related to the transformation of water quality by a treatment technology

3.1.9

maintainability

<performance> ability of a treatment technology under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources

[SOURCE: IEC 60050-191:1990, 191-02-07, modified — Notes 1 to entry has been deleted.]

3.1.10

maintenance support performance

ability of a maintenance organisation, under given conditions and maintenance policy, to provide, upon demand, the resources required to maintain the treatment technology

Note 1 to entry: The given conditions are related to the treatment technology and to the conditions under which the treatment technology is used and maintained.

Note 2 to entry: When evaluating the treatment technologies, required maintenance support performance can be used as a given condition to evaluate the maintainability.

[SOURCE: IEC 60050-191:1990, 191-02-08, modified — Note 2 to entry has been added.]

3.1.11

nonconformity

non-fulfilment of a requirement

[SOURCE: ISO 30000:2009, 3.8]

3.1.12

non-functional requirement

requirement that specifies criteria or constraints on the design or implementation of a treatment technology

3.1.13**performance evaluation**

overall process to judge whether, or to measure the extent to which the outputs or state of a system, or a component, fulfill the requirements

Note 1 to entry: See ISO 9001:2015, Clause 9.

3.1.14**performance indicator**

parameter, or a value derived from parameters, which provides information about the performance of a subject matter with a significance extending beyond that directly associated with a parameter value

Note 1 to entry: See ISO 24511:2007, 2.16.

3.1.15**predictive analysis**

practice of extracting information from existing data sets in order to determine patterns and predict future outcomes and trends

3.1.16**removal efficiency**

efficiency of removal of a constituent

Note 1 to entry: Removal efficiency and log removal value for some specific constituent are defined by the following [Formula \(1\)](#) and [Formula \(2\)](#):

$$(RE) = 1 - \frac{(C_e)}{(C_i)} \quad (1)$$

$$(\log RV) = -\log_{10} [1 - (RE)] = -\log_{10} \left[\frac{(C_e)}{(C_i)} \right] \quad (2)$$

where

RE is the removal efficiency;

C_e is the effluent constituent concentration;

C_i is the influent constituent concentration;

RV is the removal value.

Note 2 to entry: Removal efficiency is often expressed as a percentage. A value of indicator for the constituent can be used in place of concentration of the constituent. Log removal value is often used for microbial constituents.

3.1.17**requirement**

need or expectation that is stated, generally implied or obligatory

[SOURCE: ISO 9000:2015, 3.6.4, modified — Notes 1 to 6 to entry have been deleted.]

3.1.18**robustness**

ability of a structure to withstand adverse and unforeseen events or consequences of human errors without being damaged to an extent disproportionate to the original cause

[SOURCE: ISO 2394:2015, 2.1.46, modified.]

3.1.19

safety

freedom from risk which is not tolerable

[SOURCE: ISO/IEC GUIDE 51:2014, 3.14]

3.2 List of abbreviated terms

BOD	biochemical oxygen demand
COD	chemical oxygen demand
<i>E. coli</i>	<i>Escherichia coli</i>
LCA	life cycle assessment
LCC	life cycle cost
LRV	log removal value
MBR	membrane bioreactor
PAA	peracetic acid
QA	quality assurance
QC	quality control
RO	reverse osmosis
TDS	total dissolved solids
TSS	total suspended solids
UV	ultraviolet

4 Concepts of treatment technology for water reuse systems

4.1 General

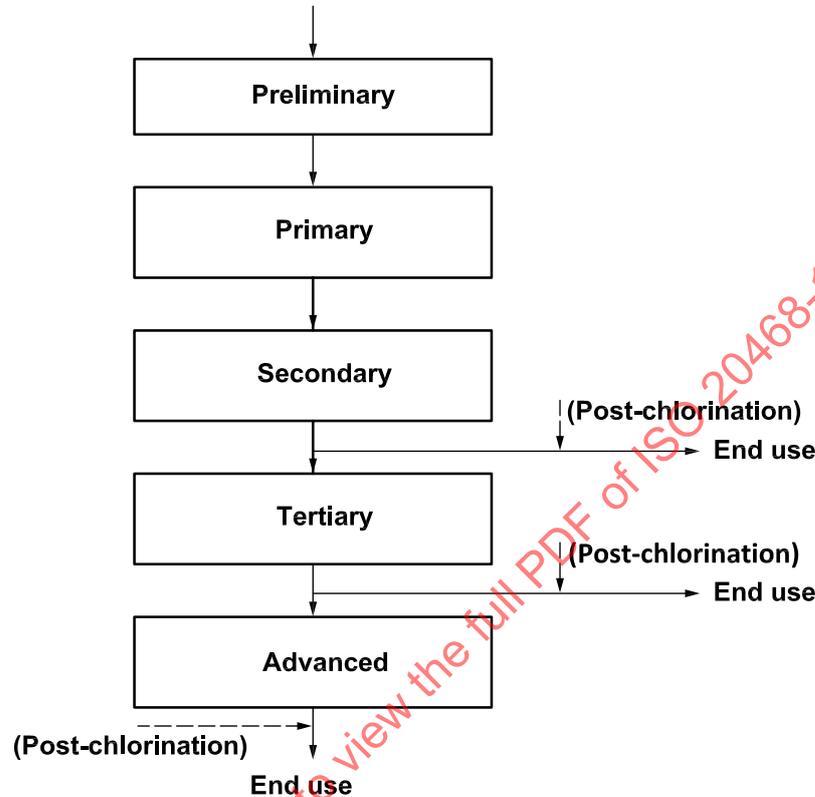
[Clause 4](#) outlines information on treatment technologies including treatment systems and processes.

The constituents found in untreated wastewater are derived from the substances that come into contact with water used for various domestic, commercial, and industrial uses; as well as those carried by stormwater which flows into sanitary system. The focus of this document is on the performance of the processes and systems with respect to constituents of concern for water reuse applications that include suspended solids, colloidal turbidity, dissolved constituents (i.e. dissolved organic and inorganic substances such as sugars and fats, heavy metals, nutrients, etc.), and pathogens (disease causing viruses, bacteria, protozoa and helminths) assessed by indicator microorganisms. Various treatment processes can be used individually or combined to remove a target constituent.

The water quality requirements of a given reuse application governs the type of treatment needed and the degree of treatment reliability. Because health and environmental concerns are primary issues in implementing water reuse, attention should be focused on developing treatment systems to ensure whether water quality requirements are consistently met. With respect to performance of disinfection technologies, a multi-barrier approach is recommended (i.e. two or more different processes including at least one form of disinfection and additional barriers with accepted levels of pathogen reduction).

4.2 Treatment objective

Because of the importance of water quality in water reuse applications, different technologies are often combined to achieve desired levels of constituent removal. [Figure 1](#) shows progressive stages of wastewater treatment processes.



NOTE Post-chlorination is applied depending on the end use.

Figure 1 — Wastewater treatment stages as per reuse applications^[20]

One of the primary objectives of treatment technologies for water reuse is to reduce the pathogen content to reduce public health risk associated with exposure to reuse water. While disinfection requirements can vary depending on the specific water reuse application, disinfection is most commonly accomplished by the use of chemical oxidants (e.g. chlorine based oxidants, and ozone), UV, membrane filtration and (more recently) PAA. Disinfection can include treatment strategies that incorporate multiple disinfection technologies or ultrafiltration/reverse osmosis treatments in series as necessary – referred to as a multi-barrier approach to disinfection. The purpose of the multi-barrier approach is, in part, to provide a back-up disinfection mechanism in the event one of the technologies relied upon for disinfection should underperform because of design or equipment failure; however, it is also carried out in recognition that not all pathogens are equally affected by a particular disinfection technology, and that combinations of disinfection/treatment technologies can achieve a more effective and broader range of pathogen reduction. A multi-barrier approach can also include the maintenance of a residual level of disinfectant (e.g. post-chlorination) in water to prevent recontamination.

The general categories of treatment technologies in this document are shown below^[20].

— Preliminary treatment

Preliminary treatment is to remove from the wastewater any constituents which can clog or damage pumps or other equipment, or interfere with the operation or maintenance of the subsequent treatment processes. It consists of removal of large size, suspended or floating materials and also heavy settleable solids such as rags, sticks, grit, and grease.

— Primary treatment

Primary treatment targets the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming. Enhanced removal of suspended solids and organic matter from the wastewater can be accomplished by chemical addition or filtration (e.g. fine mesh filtration).

— Secondary treatment

In secondary treatment, biological, chemical and physical processes are used to reduce most of the soluble organic matter and organic and inorganic particulates, measured as BOD or COD and TSS. There is a very wide range of biological processes used for secondary treatment including those that incorporate suspended bacteria, fixed film and hybrid (i.e. suspended and fixed film bacteria) followed by a solid-liquid separation step, typically by sedimentation (e.g. clarifier). Typical biological processes used for secondary treatment include activated sludge, trickling filters, rotating biological contactors and non-conventional treatment processes such as lagoons, wetlands that are capable of achieving secondary treatment water quality criteria. Secondary biological treatment can also remove nutrients. MBR is an alternative biological treatment process for secondary treatment.

— Tertiary treatment

Tertiary treatment follows the secondary treatment of wastewater, and aims at producing higher quality treated wastewater. Effluent from secondary treatment plants typically contains residual dissolved organic constituents, suspended solids and colloidal particulate matter that, in certain jurisdictions, and/or depending on the particular reuse application, can require further reduction. Their removal can be achieved by filtration. Color and odor can also be constituents targeted for removal by tertiary treatment. Tertiary treatment can include additional removal of nitrogen and phosphorus.

— Advanced treatment

Advanced treatment targets the removal of TDS and/or trace constituents as required for specific water reuse applications. This can include, for example, complex and/or toxic organic compounds, heavy metals, color, odor, compounds remaining after tertiary treatment and emerging contaminants (e.g. pharmaceuticals, nanotechnology byproducts, etc.). Technologies to achieve advanced treatment can include chemical or physical processes such as ozonation, advanced oxidation, adsorption, or ion exchange, either singly or in combination with membrane technologies.

— Disinfection

Disinfection is enhanced by the upstream removal of particulate matter that often shields pathogenic organisms from the disinfecting agent, and this is especially critical for UV disinfection. Technologies used to remove particulates (e.g. filtration) not only improve the efficacy of disinfection technologies, but can also reduce the number of pathogens present prior to disinfection and form part of a multi-barrier approach to disinfection to ensure public health protection and maximize process reliability. Disinfection can be used after secondary, tertiary, or advanced treatment as necessary (see [Figure 1](#)).

— Post-chlorination

Post-chlorination is a method of adding and maintaining a minimum level of chlorine within the reuse water distribution system. It provides the control of chlorine residual for the prevention of regrowth of microorganisms or recontamination in distribution systems. Post-chlorination is typically performed before reuse water is delivered to end users.

4.3 Treatment technologies used in fit-for-purpose water reuse

The required water quality for reuse water depends on the intended non-potable reuse application and the degree of health and environmental risks associated with that application. As a rule, domestic,

commercial and irrigation water demands can be met using reclaimed water with a water quality lower than drinking water, with the primary consideration being the degree of disinfection required to protect public health. As a result, many jurisdictions have multiple reuse water quality standards, or treatment objectives, that reflect the public health and environmental risks associated with specific categories of water application. Treatment to remove the risks of clogging, biofilms, etc. is also necessary for some industrial, urban or irrigation (for example, drip, sprinkler etc.) reuse applications. This framework can be called “fit-for-purpose water reuse”, which achieves beneficial, safe and sustainable water reuse with minimum energy and cost while protecting human health and the environment. The primary goal to the success of this framework is to reclaim water to the water quality level that is acceptable for its intended use, while ensuring the economic viability of water reuse projects, especially in the case of decentralized small wastewater treatment systems, without significant impact on the environment.

Examples of types of treatment levels and technologies appropriate for various reuse applications are provided in [Table 1](#). Municipal wastewater treated to the level of primary treatment is generally not considered suitable for water reuse applications. The level of secondary treatment with a degree of disinfection suited to the associated potential risk of human contact is generally required for most reuse applications. The degree of health risk is generally determined by the likelihood or ability for the public to come into direct contact with the reuse water, as well as the concentration of health hazardous constituents. Consequently, a lower level of disinfection can be acceptable for water reuse applications where the public is restricted from, or has limited, access, such as for remote silviculture or agricultural irrigation, and industrial water uses. Generally secondary or tertiary treatment incorporating disinfection technologies to reduce pathogens is suitable for most non-potable water applications.

Table 1 — Examples of types of treatment levels and technologies appropriate for various reuse applications [20][24]

Treatment level	Increasing levels of treatment ----->			
	Preliminary/Primary	Secondary	Tertiary	Advanced
Process	Screening, grit and grease removal Sedimentation	Biological oxidation followed by a solid-liquid separation	Chemical coagulation, biological or chemical nutrient removal, and filtration	Activated carbon adsorption/biofiltration, ion exchange, membrane technologies, advanced oxidation processes, ozonation, soil aquifer treatment.
End use	No uses recommended	<ul style="list-style-type: none"> — surface irrigation of orchards and vineyards — non-food crop irrigation — restricted landscape impoundments — wetlands, wildlife habitat, stream augmentation — industrial processes 	<ul style="list-style-type: none"> — landscape and golf course irrigation — toilet flushing — vehicle washing — food crop irrigation — unrestricted recreational impoundment — industrial systems, e.g. cooling — ground water recharge of non-potable aquifer 	<ul style="list-style-type: none"> — surface water reservoir augmentation — direct aquifer recharge (e.g. seawater intrusion barrier) — industrial system, e.g. boiler
NOTE Disinfection can be used after secondary, tertiary, or advanced treatment as necessary.				

Performance evaluation is required in selecting a “fit-for-purpose” water reuse treatment system.

5 Principles and general guidelines for performance evaluation

5.1 General

The purpose of performance evaluation is to determine whether individual treatment processes or treatment systems can reliably and consistently meet specified water quality requirements. Depending on the scale of the technology and application, performance evaluation testing may require a highly specified testing protocol that includes:

- influent and effluent water quality and quantity criteria;
- testing conditions and duration;
- statistical criteria for use in data analysis.

There are two kinds of performance requirements: functional and non-functional. Functional requirements are usually written in the form of “system shall do <requirement>”, and are related to the ability of the technology to transform the influent water quality constituents. Non-functional requirements are written in the form of “system shall be <requirement>”, and are related to the quality of the equipment being tested (e.g. water tightness of tanks, noise generation, labelling, etc.)

Performance evaluation is generally achieved by following specified testing protocols and data gathering procedures that include real-time online monitoring, sampling and testing, ancillary data collection, documentation and scientifically valid data analysis procedures.

Performance evaluation also assists in developing an understanding of the treatment system performance over a sufficient period of time to determine the dependability of the technology and risk of failure. Combined with failure mode analysis, the analysis of long-term process performance provides a relevant basis to develop adequate preventive and corrective measures to consistently achieve the required water quality criteria, and to reduce the financial, health and environment risks associated with such failure. See [Annex A](#) and [B](#) for additional information.

Performance requirements for water reuse systems or processes depend on stakeholders as well as water reuse applications. Stakeholders can include regulators, manufacturers, designers, installers, operators and end users. The performance evaluation requirements to fulfil the needs of these stakeholder groups are expected to include both functional and non-functional criteria as well as quantitative and qualitative parameters.

5.2 Performance requirements

5.2.1 Treatment technology functional requirements

Functional requirements for treatment technologies address the transformation of influent water quality constituents to produce reuse water, and include both water quality and water quantity parameters. Functional requirements are associated with safety objectives. Performance of treatment technologies can be expressed as the concentration of constituents in the reclaimed water or by the degree of constituent removal expressed as a percentage or logarithmic removal value. The functional requirement for water quantity is generally expressed as the minimum, average, and maximum volume of water that can be reclaimed, expressed as a daily flow and a maximum instantaneous flow rate, while consistently meeting water quality requirements.

Functional requirements are generally expressed as statistical parameters including maximums, minimums, arithmetic or logarithmic averages (means), medians or percentiles.

When performance evaluation is conducted based on a test, functional requirements generally involve specifying the analytical methods of monitoring water quality parameters as well as specifying the reference values which are used to judge whether the treatment technology fulfils the requirements.

The functional requirements focus on the following treatment technology effects:

- treated effluent characteristics (i.e. concentration of residual constituents);
- removal of constituents [e.g. removal efficiency or log removal value (LRV)];
- changes in other water quality indicators (e.g. temperature, toxicity, colour).

5.2.2 Treatment technology non-functional requirements

There can be a variety of non-functional requirements related to wastewater treatment technologies including:

- dependability (e.g. duration of operation without operator intervention; long-term, trouble-free operation);
- efficiency (e.g. water recovery ratio, energy consumption, chemicals use and plant operation);
- sustainability (i.e. economic, social and environmental factors and values);
- resilience (e.g. stress testing for over and under-loaded operating conditions, power failure, etc.);
- residual and byproduct generation (e.g. biosolids generation, odours, noise, disinfection byproducts);

— materials (e.g. structural integrity).

5.2.3 Characteristics of functional and non-functional requirements in performance evaluation

Characteristics of functional and non-functional requirements in performance evaluation are described in [Table 2](#). Each country or local government may apply some items of this table appropriately depending on the type of water reuse application and local regulation.

The explanations of functional and non-functional requirements are provided in [Clauses 6](#) and [7](#), respectively.

Table 2 — Characteristics of functional and non-functional requirements in performance evaluation of water reuse systems

Characteristics	Technology performance evaluation	
	Functional requirement	Non-functional requirement
	Absoluteness (compliance/non-compliance)	Relativeness (comparison, improvement)
Representative parameters or indicators for evaluation	Water quality parameters and removal efficiency associated with the following: Public health target — health risk target — water quality target Environmental target — water quality target	Performance indicators associated with followings: Environmental performance — energy consumption — chemical consumption — waste generated and requiring disposal — greenhouse gas emission Economic performance — capital cost — operating cost — life cycle cost Dependability — availability — reliability (failure frequency) Alarms — audible, visual, remote
Possible methods for evaluation and management	Representative application — qualitative risk control approach and/or quantitative risk control approach (see ISO 20426) Evaluation methods — comparison with target value Management methods — preventive and corrective actions	Evaluation methods — benchmarking, comparison with best practices — comparison with past trend Management methods — continuous improvement

5.3 Performance evaluation and meeting requirements

5.3.1 General

There are two approaches to evaluate whether performance requirements are being achieved or not. One is to monitor and record the water quality parameters measured onsite during operation of the facilities and compare the recorded data with the target performance criteria. The other is to measure

water quality parameters and calculate the removal efficiency based on the monitoring data and compare the results with predicted values.

Appropriate water quality parameters should be selected or identified to quantifiably describe the treatment technology performance requirements.

5.3.2 Monitoring plan

A monitoring plan should be established to collect the necessary data to obtain the variables and other parameters related to the treatment system operation and performance. The monitoring plan should specify the treatment system operating conditions during data collection, with the expectation that these conditions are representative of those the process will experience over its operational life-span, and over a sufficient duration to be deemed representative of those conditions. These conditions include both expected normal routine operation as well as conditions reflecting abnormal operation such as extended periods without use or loading (e.g. family vacations), extended periods of power failure, and overloading.

The frequency of sampling and the amount of data collected should be determined taking into consideration the expected variation in constituent concentrations and other monitored parameters to ensure the data collected is representative and, as needed, to establish statistical characteristics of the values of water quality parameters and removal efficiency. For package plant or pilot test facility performance evaluation, the entire test plan should be specified and clearly formulated before conducting the test.

Where the constituents of interest are present at extremely low concentrations that are close to the analytical detection limits, or where standardized analytical methods are not available and it is impossible or too expensive to measure the constituents of interest, surrogate parameter(s) that are directly associated or correlate well with the target parameter(s), can be used. Use of online monitoring (for target constituents and surrogates) is very important to assess the treatment reliability.

5.4 Application of the guidelines to treatment systems

5.4.1 Treatment system design

The raw wastewater quality and quantity characteristics should be determined based on reasonable population projections combined with the collection and analysis of flow and water quality monitoring data to predict the range in constituent concentrations and flows that can be experienced over the expected operating life-span of the system. Similarly, the functional performance requirements of potential reuse applications to satisfy non-potable applications, and offset potable water demands, should take into consideration the water quality and quantity requirements of those reuse applications. For a single treatment system application, the design should be based on fulfilling the functional and non-functional requirements of the highest-risk reuse application under consideration, taking into account the source wastewater characteristics. However, opportunities should also be considered for the application of point-of-entry and/or point-of-use advanced water treatment, rather than necessarily treating all of the reuse water to the same standard.

In addition to meeting both functional and non-functional performance requirements for the selected highest risk reuse application, the treatment system design should consider what combination of treatment processes is most suited to meet more stringent requirements: such as multi-barrier options and point-of-use additional treatment, which are mentioned in ISO 20760-1 and ISO 20760-2.

5.4.2 Treatment system configuration

Treatment system configuration refers to the arrangement of the treatment system components and includes the treatment system, water storage for flow equalization and operational stability, and pumps, pipes and fittings that connect treatment system elements. The configuration also includes electrical, instrumentation and control system elements for the purpose of ensuring the stable and

reliable performance of the treatment facility as a whole. Redundancy of some critical elements (e.g. power supply, stand-by pumps and blowers, etc.) should be also taken into consideration.

Although the boundary condition for carrying out performance evaluations is usually the treatment system being evaluated, it can extend from the wastewater source through to the site of reuse applications.

6 Functional requirements

6.1 General

Functional performance evaluation addresses whether the unit treatment process(es) and/or treatment system(s) meet predetermined treatment specifications and water quality requirements. Depending on the scale of application, this evaluation may be carried out under highly-controlled and prescriptive testing conditions, or it may follow an established data collection and analysis protocol intended to ensure reasonable replicability and costs. In addition to establishing equipment and system treatment performance capacities it may also be used for

- identifying process limitations and required modifications to improve reuse water quality at existing water reclamation facilities,
- establishing equipment design parameters during design phase through pilot testing,
- process acceptance evaluation testing during the commissioning phase, and
- performance/compliance monitoring to verify ongoing water quality compliance and assess process deficiencies during the operating phase.

Testing is typically done by third parties, including accredited testing agencies and facilities, qualified consultants and regulatory authorities, depending on the stage of the water reuse project and local regulations. However, it may also be part of an ongoing internal (to the facility) operations quality control and quality assurance program.

6.2 Performance evaluation procedures

The general methodology for performance evaluation includes the following steps.

Step 1: Setting reuse water unit process and treatment system performance criteria and objectives

Public health concerns are of primary importance. Reuse water quality standards vary depending on local regulations and site or application specific requirements outlined in the water reuse management plan. There is an extensive number of contaminants in wastewater that could have potential health and environmental impact. To avoid the complexity and difficulty of monitoring all constituents, the established practice is to place emphasis on assessing those parameters that reflect the overall water quality and process treatment performance, and microbial indicators including:

- confirmation of achieving consistent biological treatment by monitoring the BOD, the COD and/or ammonia, if applicable;
- confirmation of satisfactory solid-liquid separation to minimize interference with disinfection processes by monitoring the effluent TSS and/or turbidity levels;
- confirmation of satisfactory disinfection by monitoring the number of indicator microorganisms present (e.g. total coliform, faecal coliform, *E. coli*, coliphage, and parasite indicators);
- confirmation of chlorine residual to control bacterial regrowth in distribution systems, if required.

A typical example of the use of these parameters in describing the multiple levels of water quality is provided in [Table 3](#). In addition, the relationship between ISO 20469, ISO 16075-2, and this document

is provided in [Table 4](#). Monitoring techniques with suitable sensitivity (standard method, if available) need to be carefully selected to ensure that the reuse water quality goals have been achieved.

Table 3 — Example of monitoring parameters in non-potable water reuse projects as a function of water quality level

Water quality level	Typical monitoring parameters
A (High)	BOD, Turbidity or TSS, <i>E. coli</i> ^a , Chlorine Residual
B (Medium)	BOD, Turbidity or TSS, <i>E. coli</i> ^a , Chlorine Residual
C (Low)	TSS, <i>E. coli</i> ^a , Chlorine Residual
D (Very low)	Typically no monitoring required
^a Other microbial indicators may be used according to the local jurisdiction.	
NOTE Water quality levels in ISO 20426 are identical with those in this document.	

Table 4 — Approximate correspondence of treatment levels in this guideline with those of ISO 20469 and ISO 16075-2

Standards	ISO 20468-1	ISO 20469:2018	ISO 16075-2: 2015
Table #	Table 3	Table 1	Table 1
Treatment levels	A (High)	High	A (Very high)
	B (Medium)	Medium	B (High)
	C (Low)		C (Good)
	D (Very low)	Fair	D (Medium)
	—		E (Extensively)

Performance evaluation is an inherently labour intensive and expensive process involving: the operation and maintenance of composite and grab sampling equipment; sample collection and transport; water quality analyses; instrument calibration and maintenance; and data analysis and reporting. Consequently, to avoid unnecessary cost, it is essential the information collected is representative. This is achieved by following established testing and data gathering protocols and procedures as well as clearly defined performance criteria, goals and objectives.

In addition, to ensure the functionality and reliability of water reclamation processes for pathogen control in the case of high risk of exposure, the health risk management strategy can also include targets for LRVs. Technology performance evaluation can be used to establish LRVs for individual secondary, tertiary and/or advanced unit treatment process, validated through extensive monitoring and data analysis proportional to the risks involved, for use by regulatory agencies in setting LRV criteria to minimize health risk. Other water quality parameters can be relevant for specific non-potable water applications, such as those described in ISO 16075-1 to 4 for irrigation. Further information on the risk assessment and management approach can be found in ISO 20426, ISO 20761 and Reference [23].

Step 2: Performance evaluation program

The sampling type and frequency of sampling carried out during the performance evaluation depends on the specific objectives and goals set for the evaluation, taking into consideration the anticipated daily and seasonal variability in influent wastewater characteristics and operating conditions.

Water reclamation systems performance criteria can be based on the following statistics:

- a) fixed value(s) at any time (e.g. maximum and minimum values);
- b) average or median values over specified periods (e.g. daily, weekly and monthly averages);
- c) range of data expressed as a percentile (e.g. 70 to 95 percentile, as defined by regulations) of continuously monitored water quality data that is in compliance, or exceeds the target values for a given period of time.

It is recommended to compare the results with the target defined for each criterion and parameter.

Step 3: Diagnosis of causes for unsatisfactory performance

If the outcome attained through the unit treatment process or treatment system performance evaluation is not satisfactory (i.e. if the targeted reuse water quality objectives are not reliably attained), the cause of the unsatisfactory performance needs to be investigated and corrected. Water reclamation processes can be equipped with multiple online real-time digital instruments for the purpose of continuously collecting and recording water quality data. This data can be of use to help identify the cause of the deviations from the targeted reuse water quality objectives and to verify the treatment reliability after implementing the correction measures. In some cases, the introduction of additional temporary monitoring instruments can be required to investigate and resolve unsatisfactory treatment performance. This diagnosis typically involves the short-term and strategic installation of additional sensors and monitoring equipment taking into consideration plant and technology characteristics, and is beyond the scope of this document.

7 Non-functional requirements

7.1 Examples of performance indicators

Key performance indicators can be considered and applied to both designing and operating stages. However, the method of calculation differs between the two stages. During the design stage the key performance indicator assessment is mainly based on predicted values, whereas during operation the assessment is based on the monitored/measured values.

7.2 Evaluation method of environmental performance

7.2.1 Energy consumption

Energy consumption is recognized as a key indicator for the performance evaluation of treatment systems and unit treatment processes at the design, procurement and operation stages, and for benchmarking treatment technologies, and is a significant factor affecting water reuse technology development.

NOTE Energy audits are a useful tool for the evaluation of energy consumption and can be performed using the national and ISO guidelines (e.g. ISO 50002:2014).

Energy consumption can be expressed as the total energy consumed by the treatment system within the project boundary per unit volume of wastewater treated (e.g. kWh/m³) and should include the calculation, acquisition or estimation of the following indicators per unit volume of water produced:

- energy consumed for wastewater treatment, and pumping;
- energy consumed for residuals management (e.g. biosolids digestion and dewatering, brine disposal, phosphorus recovery);
- energy recovery (e.g. energy recovery from anaerobic digestion and/or thermal heat recovery).

Embodied energy, such as the energy consumed in producing chemicals for treatment, can also be considered – depending on the degree of significance for the overall process. Energy production including solar or wind power energy could be accounted in both energy consumption and energy production, since these renewable energies are being used in some regions for general net distribution, as long as they are related with wastewater treatment.

It is recommended that evaluating the energy performance of a new facility be initially carried out based on annual energy consumption and annual volume treated, but may be carried out for shorter evaluation periods where there are seasonal factors that can influence performance. This may also be required when the differences between design and operational values are significant and need to be assessed. For established treatment facilities, energy consumption may be evaluated by the method best suited to

the organization, for example monthly evaluation to help improve the facility's treatment performance efficiency. The size of facilities and organizations should be taken into consideration in determining adequate methods of performance evaluation including the duration of the evaluation period.

When comparing the performance of two or more treatment systems, it is important that the plant performance evaluations be carried out under similar conditions and benchmarking techniques be applied. Energy consumption is usually evaluated by the unit of efficiency such as kWh/m³, kWh/kg removed solids or kWh/month. It can be further evaluated by comprehensive approach such as LCA according to the local jurisdiction.

Energy measurement should always be carried out in conjunction with a QA/QC program using calibrated measuring instruments.

7.2.2 Chemical consumption

The amount of chemicals consumed can be of major concern to treatment facility managers and operators from health and safety and environmental perspectives as well as cost. Chemical consumption can be a key performance indicator for design, procurement and operation, as well as for comparing water reuse technology performance.

Chemical consumption can be measured as the total mass of chemicals consumed during treatment facility operations and is typically expressed as the total mass of chemicals consumed per unit volume of water treated (e.g. kg/m³). Commonly used chemical such as described below can be managed individually:

- coagulants (ferric chloride, poly aluminium chloride, etc.);
- flocculants (polyelectrolytes);
- antimicrobial disinfectants (chlorine gas, sodium hypochlorite, peracetic acid, etc.);
- neutralizing agents and pH conditioners (acids and bases, lime, etc.);
- nutrition agents (methanol, phosphate ions, etc.);
- cleaning agents and others (membrane anti-fouling, scale inhibitors, antifoams, algicide, etc.);
- adsorbents (granular or powdered activated carbon).

Chemicals can be used in treatment and reuse systems for cleaning or functional purposes. Chemicals applied off-premise (e.g. chlorine boosting stations) or outsourced to external service providers can also be considered in calculating the chemical use performance indicator.

7.2.3 Amount of solid and liquid waste generated and requiring disposal

The amount of waste generated requiring disposal can be of major concern from the perspective of environmental management as well as cost. Key performance indicators of liquid and solid waste can be used to establish requirements for design, procurement and operation as well as to evaluate the overall performance of water reuse technologies.

Wastes generated during treatment have no value and are disposed of without being reused as resources that can be used to produce energy or agricultural fertilizers (treated secondary sludge), used within the treatment system, or that can be traded with external buyers.

The amount of waste generated can be expressed in terms of weight (e.g. kg or tonne) or volume (e.g. m³), and can be accounted in total or by individual amount. The treatability of waste should be taken into consideration. Example indicators include:

- grit and debris collected during preliminary treatment;

- primary and/or secondary biosolids generated by the treatment system which are transported off-site for disposal;
- reject brine from RO operations (including its impact on the wastewater treatment systems when it is returned);
- chemical precipitates (chemical sludge);
- waste chemicals and short-life consumables.

Liquid and solid waste can be assessed in terms of the mass or volume of waste generated or disposed per unit volume of water treated.

Treatment technologies that do not generate wastes or minimize wastes should also be taken into consideration.

7.2.4 Performance indicators — Integrated considerations

Monitoring the key performance indicators can be of use to identify opportunities for improvement in the management of the treatment system. But there are sometimes trade-off relations between those indicators. For example, in some cases increases in chemical consumption can result in reduced energy consumption. In this context, it is desirable to integrate performance indicators into the sum of the relevant converted value such as the carbon dioxide emission or the expenditure.

7.3 Evaluation method of economic performance

Some conceptual cost estimating procedures can be applied for evaluating economic performance of water reuse systems. As a generic procedure, operating cost is calculated by including labour and maintenance (including contingency), plus chemical costs, generated waste disposal costs, and the specific electricity/energy requirements. Finally, the amortized system capital costs can be combined with the annual operational costs to obtain the total annual cost.

LCC, consisting of capital cost and operating cost, is analysed by measuring the costs to purchase, install, operate (including energy costs), maintain, and dispose of all system components. Used as a comparison tool between possible design and overhaul alternatives, LCC analyses offer ways to select the most cost-effective system and make reasonable comparisons using all the available data.

Most water reuse systems have LCCs dominated by energy and maintenance costs. It is therefore important to accurately determine the current cost of energy, the expected annual energy price escalation of its estimated life, and the anticipated maintenance labour and material costs. Other elements, such as downtime, decommissioning, and environmental protection, can often be estimated based on historical data for the facility.

Other elements related to dependability of operation and failure risk of the facility should be considered for more comprehensive evaluation of economic performance. The facility failure mode can be classified based on the frequency, severity and detectability to calculate the economic impact.

Annex A (informative)

Dependability of treatment technology

A.1 Subsidiary properties of dependability

Dependability is one of the most important properties which should be evaluated for water reuse systems, inter-alia a system of treatment technologies. Dependability is a critical non-functional requirement for water reuse treatment technologies. To evaluate the dependability of a system, it is necessary to identify and evaluate the subsidiary properties that determine dependability illustrated in [Figure A.1](#).

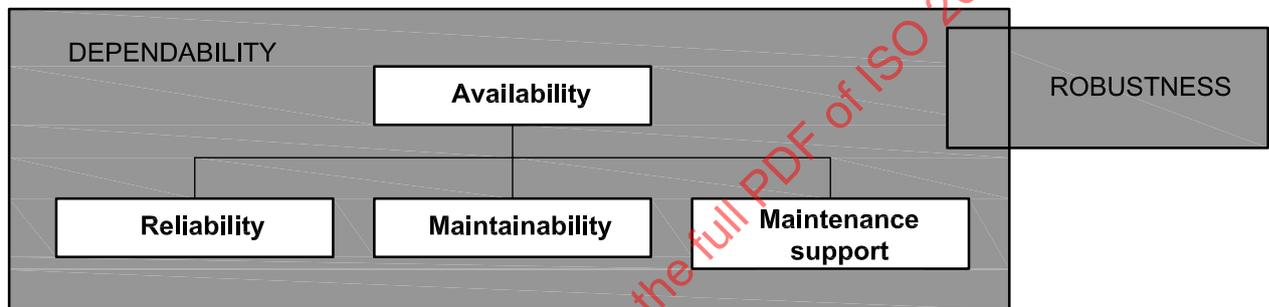


Figure A.1 — Dependability and its attributes and robustness

A.2 Availability

System availability depends on the availabilities of each of the unit treatment processes that make up the treatment system, and the way in which these parts interact in the overall treatment process. The way in which parts interact can include functional redundancy, functional fall-back and degradation. Availability depends on the procedures used and the resources available for maintaining the system. For example, a stock of spare parts or emergency storage provisions can increase the availability of the system.

The primary purpose of a treatment system is to produce water that fulfils the quality and quantity requirements, and failure can be in the context of water quality or quantity. Failure to meet water quality requirements inherently results in failure to meet water quantity requirements. Failure to detect non-conformance with either water quality or quantity requirements makes it difficult to evaluate the availability of the system in general, and is an issue of credibility.

Availability of treatment technologies or treatment systems for a given task can be quantified in two ways:

- a) Predictive analysis

The availability can be calculated as:

$$AV = \frac{MT_f}{(MT_f + MT_r)}$$

where

AV is the availability;

MT_f is the meantime to failure;

MT_r is the meantime to restoration.

b) Monitoring a system in operation

The availability can be calculated as:

$$AV = \frac{TT_p}{TT_e}$$

where

TT_p is the total time the system has been performing the task;

TT_e is the total time the system has been expected to perform the task.

Here, “perform the task” implies “fulfill the given requirement”. See IEC 61069-5.

Predictive analysis and monitoring are often employed in the design stage to assess availability. During the design stage it is not possible to monitor equipment performance, but data can be collected from similar systems that are in operation or from unit processes and treatment systems in a test facility to predict availability. Other methods of assessing availability include the collection of long-term performance data and performance data from multiple installations.

A.3 Reliability

Reliability is a concept similar to availability.

Reliability of a system depends on the reliability of the individual parts of the system and the way in which these parts contribute to the overall system performance. Reliability can also be inferred based on the materials used and the conditions under which the treatment technology is operated.

A.4 Analysis and assessment of system dependability

As for the assessment and analysis of system dependability, IEC 60300-3-1 and IEC 61069-5 can be of use.