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# Guidelines for health risk assessment and management for non-potable water reuse

*Lignes directrices pour l'appréciation et la gestion du risque pour la santé relative à la réutilisation de l'eau pour des usages non potables*



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# Foreword

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

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This document was prepared by Technical Committee ISO/TC 282, *Water Reuse*, Subcommittee SC 3, *Risk and performance evaluation of water reuse systems*.



 

# Introduction

The reaffirmation of the importance of water along with food security and energy was a significant outcome in the actions and the follow-up framework passed at the United Nations Conference on Sustainable Development (Rio+20). Water is an indispensable resource for sustainable development including the eradication of poverty and hunger, public hygiene, food security, water power, agriculture, and development of farming and remote communities. In the management of water resources, essential actions include: the prevention of water contamination by households, industries, and agriculture; more efficient water usage and the treatment and reuse of wastewater as a water resource, particularly in growing urban areas.

Today, with many regions of the world facing potable water shortages, wastewater reuse can provide an alternative water source that is suitable for satisfying the majority of water demands, with the notable exception of drinking and cooking which require higher water quality. On the other hand, increased water reuse practices are raising concerns regarding potential health implications across the world. This has led to an increasing need to specify water quality parameters that are appropriate to specific water applications and uses, as well as the development of methods to assess and manage health risks from both regulator and user sides. Unless these needs are addressed, opportunities for sustainable development in the form of appropriate use of reclaimed water will be lost.

Direct or indirect contact with reclaimed water may have health implications for individuals, regardless of whether they are the intended users of the reclaimed water or not. Contact with reclaimed water can occur during the collection and treatment of wastewater, treated water storage and distribution, the use of reclaimed water, or after use. Health risks may also be present during the operations and/or maintenance work of the facilities and processes. These health implications can be moderate in some cases and serious in others, and continue for a short, moderate, or long period of time.

This document can be useful for the application of management system standards, such as ISO 9001 and risk management standards, such as ISO 31000.



 

# Guidelines for health risk assessment and management for non-potable water reuse

## 1 Scope

This document aims to serve as technical guidelines for the assessment and management of the health risks associated with pathogens contained in reclaimed water, which are expected to be caused by the use of reclaimed water, and/or by the production, storage, and transportation of reclaimed water.

This document is applicable to the use of reclaimed water made from any source water (i.e. raw sanitary sewage; treated municipal wastewater; industrial wastewater; stormwater potentially influenced by sewage) and for non-potable water reuse.

NOTE The approach described in this document can be applied to chemical contaminant, if applicable.

## 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 20670:—[1)], *Water reuse — Terminology*

## 3 Terms, definitions and 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:

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

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

### 3.1 Terms and definitions

**3.1.1**
**disability-adjusted life years**
population metric of life years lost to disease due to both morbidity and mortality

[SOURCE: WHO (2016) Quantitative Microbial Risk Assessment: Application for Water Safety Management]

**3.1.2**
**dose-response assessment**
determination of the relationship between the magnitude of exposure (dose) to a chemical, biological or physical agent and the severity and/or frequency of associated adverse health effects (response)

[SOURCE: WHO (2016) Quantitative Microbial Risk Assessment: Application for Water Safety Management]

1) Under preparation. (Stage at the time of publication ISO/DIS 20670:2017.)

**3.1.3**
**hazardous event**
event in which people are exposed to a hazard within the system

Note 1 to entry: It may be an incident or a situation that introduces or releases the hazard to the environment in which humans are living or working; amplifies the concentration of a hazard; or fails to remove a hazard from the human environment.

[SOURCE: WHO (2016) Quantitative Microbial Risk Assessment: Application for Water Safety Management]

**3.1.4**
**non-potable water reuse**
water reuse except reuse requiring drinking water quality according to local jurisdiction

**3.1.5**
**pathogen**
microorganism (e.g. bacteria and viruses) and parasite (e.g. protozoa and helminths) that can affect human health and cause disease

**3.1.6**
**performance control point**
activity, procedure or process where control of performance can be applied, and that is essential for preventing hazards that represent high risks or reducing them to acceptable levels

Note 1 to entry: See Australian Guidelines for Water Recycling [NRMMC, EPHC, AHMC (2006)].



### 3.2 Abbreviated terms

BOD biochemical oxygen demand

DALY disability-adjusted life years

MLSS mixed liquor suspended solids

PCP performance control point

QA quality assurance

QC quality control

TSS total suspended solids

UV ultraviolet irradiation

YLD years lived with disability

YLL years of life lost

## 4 Concepts of health risk assessment and management for non-potable water reuse

### 4.1 Risk assessment and management framework

There is a possibility that reclaimed water contains hazards that can potentially affect human health. The goal of the risk assessment and management process is to estimate and reduce the risk of adverse outcomes to a level acceptable to society and the local community. A health risk assessment is undertaken to establish standards or performance goals which are used as a basis for the design of the treatment steps. In addition, health risk management is also implemented to ensure that water of a safe quality is provided to end-users. A generic framework of health risk assessment and management for non-potable water reuse is shown in Figure 1.

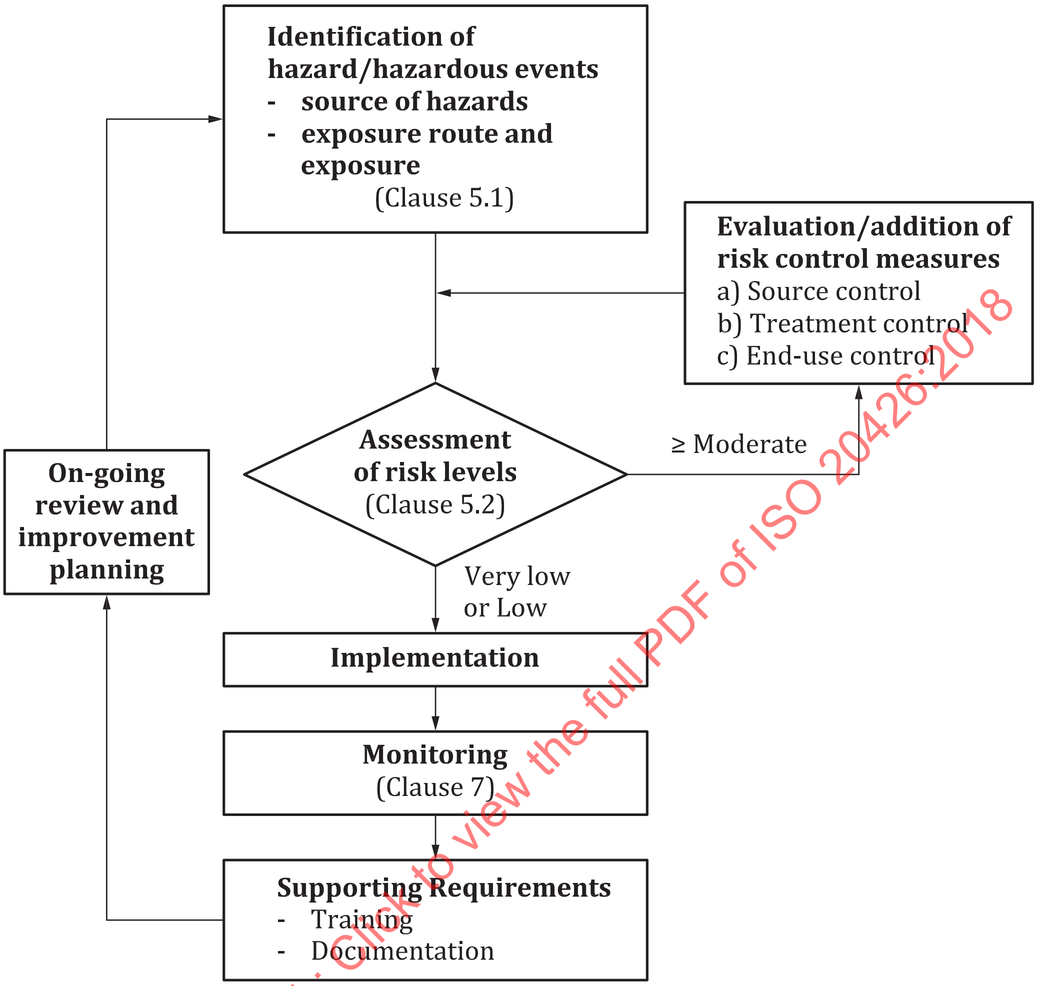


**Figure 1 — Framework of health risk assessment and management for non-potable water reuse**

## 4.2 Scope of end-uses of reclaimed water

This document can cover any kind of source water such as domestic/urban/industrial wastewater. In the case where industrial facilities are located within the catchment of a wastewater treatment plant, the risk for high contaminant loadings (e.g. chemicals, pathogens) from industries to the municipal wastewater should be taken into consideration. The main water reuse categories covered in the document are shown in Table 1.

**Table 1 — Categories of non-potable reuse applications (adapted from Reference [22])**

| Category | | Potential application | Issues/constraints |
|---|---|---|---|
| Agricultural uses | | — Food crop, eaten raw, processed or cooked<br>— Pastures for milk and/or meat production<br>— Fodder and industrial crops<br>— Ornamental plant nurseries | — Health risk related to food products and direct contact with reclaimed water<br>— Water quality impacts on soils, crops, and groundwater<br>— Runoff and aerosol control<br>— Farmers acceptance and marketing of crops<br>— Buffer zone requirements if applicable |
| Urban uses | Landscape irrigation uses | — Golf courses and landscape<br>— Public parks, private gardens<br>— Roadway medians, roadside plantings, greenbelts, cemeteries | — Health concerns related to direct contact with reclaimed water<br>— Water quality impacts on ornamental plants<br>— Runoff and aerosol control |
| | Non-potable urban uses | — In-building reuse, toilet flushing<br>— Landscaping (see irrigation)<br>— Air conditioning, fire protection<br>— Commercial car/trucks washing<br>— Sewer flushing<br>— Driveway and tennis court wash-down<br>— Snow melting<br>— Heavy construction (dust control, concrete curing, fill compaction, and clean-up) | — Health risk related to direct contact with reclaimed water<br>— Scaling, corrosion, fouling, and biological growth<br>— Cross-connection with potable water supply |
| Recreation and environmental uses | | — Recreational impoundments<br>— Wetlands or biodiversity restoration<br>— Snowmaking<br>— Environmental enhancement (freshwater or seawater protection)<br>— Fisheries<br>— Artificial lakes and ponds | — Health risk related to accidental ingestion or direct contact with reclaimed water<br>— Eutrophication (algae growth) due to nutrients<br>— Toxicity to aquatic life |
| Industrial uses | | — Cooling water<br>— Boiler feed water<br>— Process water<br>— Heavy construction in industrial parks or areas | — Health risk related to cooling tower aerosols<br>— Blowdown disposal<br>— Scaling, corrosion, fouling, and biological growth |



The detailed explanations of categories of non-potable reuse applications, which are included in Table 1, are as follows:

Agricultural uses: Agricultural uses include the use of reclaimed water to irrigate food crops, and/or non-food crops. Users of this document can refer to the following ISO documents.

— ISO 16075-1

— ISO 16075-2

— ISO 16075-3

— ISO 16075-4

Urban uses: Urban uses include the use of reclaimed water for non-potable applications in municipal settings including recreational field and golf course irrigation, landscape irrigation, fire protection and toilet-flushing. Users of this document can also refer to the following ISO documents.

— ISO 20760-1

— ISO 20760-2

— ISO 20761[2)]

Recreational and environmental uses: Recreational uses include the use of reclaimed water in an impoundment in which no limitations are imposed on body-contact water recreation activities. Environmental uses include the use of reclaimed water to create, enhance, sustain, or augment water bodies, including wetlands, aquatic habitats, or stream flow. Users of this document can also refer to the following ISO documents.

— ISO 20760-1

— ISO 20760-2

— ISO 20761

Industrial uses: Industrial uses include the use of reclaimed municipal wastewater for industrial process and related applications that do not require potable water including power generation, food processing, pulp and paper, oil and gas industries.

## 4.3 Risk management framework

Risk management framework and risk management planning are essential to implement safe water reuse schemes and to ensure compliance with reclaimed water quality standards. This framework typically includes four requirements[24].

a) Responsible use of reclaimed water: Engagement of agencies with expertise in water supply, wastewater management and protection of public health.

b) Regulatory and formal requirements: Identification of all relevant regulations, guidelines, and local requirements.

c) Partnerships and engagement of stakeholders: Identification of all agencies with responsibilities and all stakeholders influencing water reuse activities.

d) Reclaimed water policy: Development of a reclaimed water policy, permits and specific contracts with end users.

The risk management framework is used to develop a management plan that describes how the water reclamation system should be operated, monitored and managed. It is normally developed by a team comprising of representatives from various sectors with sufficient knowledge and expertise. These members typically include, but are not limited to, recycled water suppliers (e.g. technical staff), key decision makers, risk experts, regulatory agencies, local government and end-users. Other stakeholders such as the public are also invited to participate, as necessary.



2) Under preparation. (Stage at the time of publication ISO/FDIS 20761.)

# 5 Health risk assessment

## 5.1 Identification of hazard and hazardous events

### 5.1.1 Constituents in source water

Municipal wastewater can contain pathogens that can cause adverse impact on public health; consequently, human health hazards for non-potable water reuse applications are mostly related to these pathogens. Wastewater can also contains numerous chemical constituents, but experience with reuse applications to date indicates that chemicals present in reclaimed wastewater generally complies with drinking water quality requirements for most parameters, including heavy metals, organic chemicals, pesticides and disinfection by-products[24]. Therefore, although it is recognized that under certain circumstances, such as spill-events, and high industrial contributions to sewer, these constituents can pose a hazard, the subject is beyond the scope of this document. Pathogens that are typically identified in raw wastewater and are considered as key microbial hazards are shown in Annex A.

### 5.1.2 Hazardous events, exposure route and exposure at end-use

In addition to the identification of the key microbial hazards, the first step of risk assessment includes the identification of the most probable hazardous events, exposure routes and exposure, which depends on the type of end-use and the configuration of the water reuse scheme. The most common potential hazardous events associated with human health risks at the points of use of reclaimed water in non-potable water reuse projects are as follows[24]:

a) Potential non-compliance of reclaimed water quality due to failure of treatment or contamination of storage and distribution system;

b) Potential for deliberate or inadvertent misuse of reclaimed water (e.g. ingestion);

c) Accidental exposure to reclaimed water which arise from design or operational deficiencies (e.g. pipe bursts or leaks, inadequate irrigation timing);

d) Accidental exposure to reclaimed water caused by end-use system failures resulting from sabotage, natural disasters, or extreme weather conditions;

e) Cross-connection to higher quality water sources (e.g. drinking water) or to lower quality water sources; and

f) Inadequate education and information about permitted uses.

## 5.2 Assessment of risk levels

### 5.2.1 Qualitative risk assessment

Once all of the risks associated with a given water reuse scheme have been identified, the level of each risk needs to be comprehensively assessed to establish priorities for risk management [20] [24]. Qualitative risk assessment is based on a combined evaluation of the magnitude of consequences and the likelihood that those consequences can happen. For the non-potable reuse projects, the qualitative risk assessment is the most appropriate and economically feasible methodology.

Consequences: For each hazard identified, the consequences that result from exposure to the hazard need to be clarified. "Consequence" in health risk assessment indicates a potential adverse health impact of hazard exposure scenarios. Consequence analysis can be performed through qualitative evaluation with a descriptive representation of the likely outcome for each hazard/hazardous event. Consequences in terms of adverse public health impacts can be classified into five categories in terms of a qualitative descriptor (for example, a scale of '1 = insignificant' – '5 = catastrophic' for event consequences). See Table 2.

**Table 2 — Suggested measures of consequence or impact (adapted from References [19] and [24])**

| Level | Descriptor | Description of health impact level |
|---|---|---|
| 1 | Insignificant | Hazard or hazardous event resulting in no or negligible health effects compared to background levels. |
| 2 | Minor | Hazard or hazardous event potentially resulting in minor health effects. |
| 3 | Moderate | Hazard or hazardous event potentially resulting in a self-limiting health effects or minor illness. |
| 4 | Major | Hazard or hazardous event potentially resulting in illness or injury; and/or may lead to legal complaints and concern; and/or major regulatory non-compliance. |
| 5 | Catastrophic | Hazard or hazardous event potentially resulting in serious illness or injury, or even loss of life; and/or will lead to major investigation by regulator with prosecution likely. |

Likelihood: The risks also need to be evaluated in terms of probability of occurrence. “Likelihood” in health risk assessment indicates the probability of occurrence of a hazardous event, in a certain period of time, with potential harmful effects. Likelihood analysis can be performed through historical data review or assessment of human error, fault trees and event trees. Likelihood associated with reclaimed water is determined mainly by the probability of human contact/exposure to hazardous substances/events. The human contact/exposure can occur through the combined likelihood of two scenarios:

a) Potential for human exposure to aqueous media containing hazardous substance(s), and

b) Probability of presence of hazardous substance(s) in reclaimed water.

As likelihood of the issues increases, the level of risk increases. The level of likelihood of occurrence can be prioritised according to the following qualitative descriptors: a scale of ‘1 = rare’ – ‘5 = almost certain’ for event likelihood. See Table 3.

**Table 3 — Suggested measures of likelihood that exposure events can happen (adapted from References [19] and [24])**

| Level | Descriptor | Example description |
|---|---|---|
| A | Rare | Has not happened in the past and it is highly improbable it will happen in the reasonable period. |
| B | Unlikely | Has not happened in the past but may occur in exceptional circumstances in the reasonable period. |
| C | Possible | May have happened in the past and/or may occur under regular circumstances in the reasonable period. |
| D | Likely | Has been observed in the past and/or is likely to occur in the reasonable period. |
| E | Almost certain | Has often been observed in the past and/or will almost certainly occur in most circumstances in the reasonable period. |
| NOTE The reasonable period depends on the level of risk and local jurisdiction. | | |

Risk level: Each risk needs to be evaluated qualitatively based on the levels of consequences and likelihood. The level of qualitative risk can be expressed by the following formula: a scale of ‘1 = very low’ – ‘5 = very high’, as shown in Table 4.

**Level of risk = Likelihood x Consequence**

If an event is likely to occur and has major consequences, the risk is categorised as a “high” risk. In contrast, any unlikely event with minor consequences is categorized as “low” risk.

**Table 4 — Suggested risk evaluation (adapted from References [23] and [24])**

| Likelihood | Consequences | | | | |
|---|---|---|---|---|---|
| | 1-Insignificant | 2-Minor | 3-Moderate | 4-Major | 5-Catastrophic |
| A-Rare | Very low | Very low | Low | Low | Moderate |
| B-Unlikely | Very low | Low | Low | Moderate | High |
| C-Possible | Low | Low | Moderate | High | High |
| D-Likely | Low | Moderate | High | High | Very high |
| E-Almost certain | Moderate | High | High | Very high | Very high |

If a risk is rated as 'moderate' or higher, it requires preventive risk control measures to lower the risk level. The aim of risk management is to reduce the level of all risks to 'very low' or 'low'. 'Very high' health risk is not common for non-potable reuse.

Outlining the type of response at different risk levels provides guidance for the risk evaluation stage of the process as described with generic examples below.

— Very low - Low: (Inherent risk) No specific actions required.

— Moderate - Very high: Reduce risk levels with risk management (See 6.1).

### 5.2.2 Quantitative risk assessment

Quantitative risk calculations is reasonable to adopt in water reuse scheme with 'very high' health risk, e.g. where exposure of humans to reclaimed water is likely (such as domestic use) to occur. In any case, a detailed quantitative risk assessment is possible only for a limited range of contaminants, and this with high uncertainties due to numerous knowledge gaps. Detailed information on the methodology of quantitative risk assessment are shown in Annex B (adapted from Reference [24]).

## 5.3 Limitations and uncertainties

The risk assessment with the identification of combined hazards (e.g. presence of multiple pathogens) or a single hazard (e.g. a specific pathogen) is a predictive activity that is very subjective to users' decisions; thus, there can be some uncertainties associated with unpredicted hazards and hazardous events. For example, changes in contaminant concentrations over time can be difficult to predict.

The knowledge uncertainty linked with an inadequate state of knowledge of the characterization of the hazards and hazardous events can impede from a comprehensive risk evaluation. Risks associated with knowledge uncertainty can be reduced by performing a comprehensive characterization of source waters (including weekly and seasonal variations, and cultural background), feedback from operations, literature reviews and, ultimately, by conducting research and development for target hazards.

The application of best operation and application practices to improve consistency in maintaining reclaimed water quality targets and the implementation of complementary barriers and measures for health protection are proven methods to achieve safe water reuse projects.



# 6 Risk management

## 6.1 Risk management with risk control measures

Once hazards and hazardous events are identified through a risk assessment (see Clause 5), a risk management plan should be developed to minimize the potential for adverse health impacts on end-users. The risk management plan describes how maximum inherent risks for a specific application are to be managed and which control measures need to be implemented to reduce the level of residual risk to a minimum or acceptable level, e.g. low and very low risk level[24][26].

 

An overview of the risk assessment and management approaches is shown in Figure 1. Although it is essential that any risks associated with operational actions at water reclamation plant (e.g. handling and storing chemicals, collecting water samples, entering confined areas, etc.) are assessed and controlled through safety control and risk management, the guidelines presented here focus only on water quality-related health risks. Risk control measures associated with occupational health risks can be considered in accordance with the relevant ISO standards such as ISO 45001. Environmental and agronomic risks, related to crops, soils and water bodies can be assessed and managed according to the relevant ISO standards such as ISO 16075-1 to 4.

Step 1 – Risk level evaluation: Maximum inherent risk for a specific hazard and/or hazardous event is evaluated for a specific end-use, and wastewater source, through risk assessment. An example of risk assessment and management for residential use is shown in Table 5. Although each hazardous event (e.g. inadvertent misuse of reclaimed water) and chemical constituents can be important in some cases, risk evaluation for non-potable water reuse particularly focuses on the most important health risk – microbial risk related to pathogens. If the target is evaluated as "low" or "very low" risk, no risk control measures need to be provided to reduce health risks.

Step 2 – Addition of risk control measures: If the target is classified into the category of "moderate" or higher risks, additional risk control (preventive) measures need to be considered. Control measures are the actions that are taken to reduce potential risks to an acceptable level so that reclaimed water can be safely used without causing adverse health effects. Risk control measures that are comprehensive from source to the end-use point include the followings:

a) source control that prevents hazards from entering to the water reuse scheme;

b) treatment control that removes hazards from the source water;

c) end-use control that reduces the risk of exposure at the point of use.

In non-potable water reuse systems, a combination of treatment control and end-use control measures are typically incorporated to provide a safe quality of reclaimed water for the specific reuse application.

Risk control measures can be most efficient when they are implemented as close as possible to the hazards or hazardous events. The selection of risk control measures should be based on the following criteria [24]:

— cost;

— intended use and public access;

— existing treatment facilities;

— land availability;

— technical expertise.

Control measures performance (e.g. removal) is also a selection criterion. Details of such control measures are described in the following clauses.

Step 3 – Re-evaluation of risk level: The health risk associated with the target contaminant is re-evaluated with the control measures determined in Step 2. If the resulting risk classification is "moderate" or higher, additional/alternative risk control measures need to be identified, considered and implemented until the target hazard or hazardous event is evaluated with "low" or "very low", at which point the water reuse scheme can be safely implemented and managed. A multiple-barrier approach with multiple risk control measures (e.g. water reclamation processes, public access control, and additional health safety barriers) can significantly reduce the risk levels. The application of a multiple barrier approach provides more reliable risk management with less variability in performance than a single barrier [24].

Step 4 – Monitoring: Monitoring of water reuse projects is important to ensure that a safe quality of reclaimed water is provided to end users without causing adverse health impacts. Details of monitoring procedures are provided in Clause 7.

Step 5 – Supporting requirements: All individuals who are involved with water reclamation schemes (e.g. operators and end-users) should be appropriately trained to attain sound knowledge and sufficient skills. Training improves the likelihood of compliance with the risk controls determined in the risk management plan. Developing a system of documentation, including regular reporting, is an essential component of operating water reclamation schemes. Records including water quality, operating parameters and incident reports are evidences of compliance with the risk management plan. An audit may be conducted every certain period. These reports also allow for the review of the performance of the existing scheme and planning for continuous improvement.

**Table 5 — Example of risk assessment and management for potential contact with pathogenic bacteria in reclaimed water at the end-use points (C = consequence, L = likelihood, R = risk level)**

| Hazard | Source wastewater | Intended end-use | Considered event | Maximum inherent risk | | | Risk control measures | Residual risk | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | C | L | R | | C | L | R |
| Pathogenic bacteria | Municipal wastewater | Residential use | Infection through contact with or ingestion of reclaimed water | Major | Likely | High | Source control | Major | Rare | Low |
| | | | | | | | Treatment control | | | |
| | | | | | | | End-use control | | | |

## 6.2 Source control measures

The pollutants in industrial wastewater may compromise municipal treatment processes or contaminate the treated effluent by pass-through [28]. Therefore, control of industrial discharge needs to be taken into account in cases where industrial facilities are located upstream of municipal wastewater treatment plant. Depending on the risks identified, a monitoring program of chemical substances and pathogens can be defined. These discharges are controlled through industrial preliminary treatment in accordance with local regulations and/or best available technologies. Specific attention should be focused on hospital discharge in case that high concentrations of contaminants such as pathogens, pharmaceuticals and health-care products are released to the sewer. In addition, a monitoring program of these pollutants in the discharge with appropriate frequency are also important. In this case, regulations that prevent undesirable concentrations of pollutants from entering the intended water reuse scheme are very important.

## 6.3 Treatment control measures

### 6.3.1 Treatment barriers and monitoring methods

The use of treatment barriers is an effective and commonly used strategy to reduce the residual health risks in reclaimed water. The required level of treatment is determined based on the degree of required water quality, which is ultimately associated with intended end-use. It is noteworthy that treatment control is typically carried out along with end-use control to ensure public health protection. Typical treatment for non-potable water reuse includes, but is not limited to [17]:

— Preliminary treatment – Treatment for the removal of debris, grit, coarse solids, fats, oils and grease reduction;

— Primary treatment – Treatment for the removal of floating and settleable substances (e.g. primary sedimentation and chemically enhanced primary treatment);

— Secondary treatment – Treatment for the removal most of the organic matter (carbon), nutrients, total suspended solids (TSS) and inhibitor of disinfection (e.g. activated sludge + sedimentation; bio-discs or trickling filters + sedimentation; biofilters, constructed wetlands; and stabilization ponds);

— Tertiary treatment – Treatment for the removal of residual TSS and other constituents remaining after secondary treatment (e.g. coagulation/flocculation; granular/sand/media filtration; and membrane filtration);

— Advanced treatment – Treatment for the removal of total dissolved solids and/or trace constituents as required for specific water reuse applications (e.g. activated carbon adsorption, reverse osmosis, and advanced oxidation processes);

— Disinfection – Treatment to reduce the pathogen content most commonly accomplished by the use of chemical oxidants (e.g. chlorine based oxidants and ozone), and ultraviolet irradiation (UV). Disinfection can be used after secondary, tertiary, or advanced treatment as necessary; and

— Post-chlorination – Treatment to control and maintain a chlorine residual within the reuse water distribution system for the prevention of bacteria regrowth and/or bacterial contamination subsequent to treatment. Post-chlorination is applied depending on the end use.

A major water quality objective in non-potable water reuse is the inactivation and/or elimination of pathogens in the source water to reduce the potential of adverse health impacts. Chlorine plays an important role in disinfection in water reclamation processes, as well as to ensure chlorine residual in the distribution system to control regrowth of microorganisms or recontamination. Some other secondary/tertiary treatment processes (e.g. membrane filtration) are also capable of reducing pathogen content and enhancing disinfection by removing particulate matter prior to disinfection [17].

Some technical guidance is often provided to simplify the selection of water reclamation processes for achieving a specific level of reclaimed water quality. A typical example with four levels of water quality is shown in Table 6.

**Table 6 — Example of treatment processes at different water quality level**

| Water quality level | Typical treatment processes |
|---|---|
| A (High) | Secondary + Tertiary + Disinfection |
| B (Medium) | Secondary + (Filtration) + Disinfection |
| C (Low) | Secondary + Disinfection |
| D (Very Low) | Secondary |
| NOTE Disinfection can be used after secondary, tertiary, or advanced treatment as necessary. | |

For example, reclaimed water with the highest water quality (e.g. Class A reclaimed water) typically requires up to tertiary treatment along with disinfection which includes specific physical /chemical doses for the almost complete removal of microorganisms and pathogens. In contrast, low grade reclaimed water (e.g. Class D reclaimed water) typically requires up to secondary treatment without disinfection. In most non-potable water reuse schemes, secondary treatment followed by tertiary treatment is the minimum standard. However, it may vary depending on the risk level at the end-use point.

Monitoring of water reclamation systems is important to ensure the compliance with quality goals and to confirm the ongoing operational performance for the protection of public health. Typical monitoring strategies are shown in Figure 2. Water quality control (QC) is performed in most water reuse schemes by monitoring selected water quality parameters in the treated water prior to distribution or at the point of use. In the case of requirements for high reclaimed water quality, in addition to water quality monitoring, process performance control points (PCPs) should be used. Each monitoring approach is described in Clause 7.

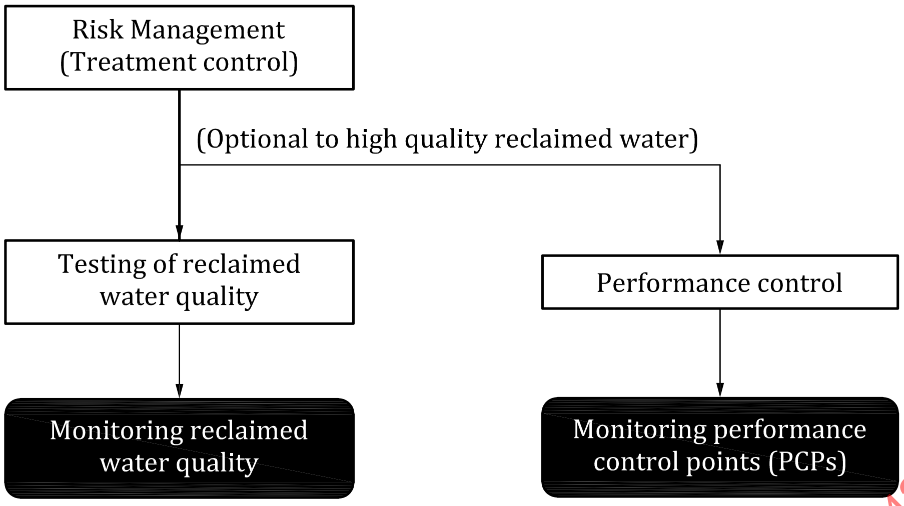


**Figure 2 — Treatment control and monitoring methods**



### 6.3.2 Monitoring of reclaimed water quality

Treatment control with water quality monitoring aims at reducing health risks to acceptable levels by continuously or intermittently monitoring water quality at the outlet of the water reclamation plant and at the point of use. The monitoring requirements (e.g. water quality parameters and frequency) vary depending on local regulations and the requirements outlined during the risk assessment process and approval of the water authorities. Key procedures on the development of reclaimed water quality testing protocols are provided as follows:

a) Establish water quality goals based on local regulations and guidelines, and outcomes from the health risk assessment;

b) Determine key parameters, indicators or surrogates to be monitored, as well as the maximum acceptable levels in the reclaimed water to ensure the protection of human health;

c) Determine frequency of sampling for water quality assurance (QA);

d) Select representative sampling points and appropriate sampling types (grab or composite);

e) Establish corrective actions in the case of non-compliance;

f) Perform routine monitoring and ensure reliability of analytical results (e.g. sampling procedure, laboratory QA/QC procedure, maintenance and calibration of online and field analytical instruments).

Since the exhaustive characterization of the hazards in water reuse and monitoring all single components are not practical, surrogate water quality parameters are generally used to readily ensure the compliance of water quality and the performance of water reclamation processes. Some of these representative parameters are described below [17]:

**Indicator microorganisms (e.g. *E. coli*):** Parameters associated with pathogens are of the major concern in non-potable water reuse [17]. Because pathogens are rarely measured at high concentrations, and measuring all pathogens of concern is not practically feasible, faecal indicators such as *E. coli* or thermo-tolerant coliforms are typically used as surrogate organisms in monitoring programs[25][29]. These microorganisms are not usually pathogenic but provide information on the potential for faecal contamination. Total coliforms are also used as a microbial indicator. The selection of indicator microorganisms is subject to local regulations and guidelines.

**Turbidity or TSS:** Particulate matter in reclaimed water can shield microorganisms from disinfectants, reducing the effectiveness of disinfection. As a result, turbidity or TSS is recommended to be monitored prior to disinfection process to ensure good performance of the disinfection process. Turbidity monitoring is preferably selected for reclaimed water with high likelihood of human exposure as it can be set online to activate alarm when the target level is exceeded.

**Biochemical Oxygen demand (BOD):** BOD is a surrogate associated with aesthetic and nuisance issues. This also indicates the potential for bacteria regrowth and biofilm formation, which ultimately influences the effectiveness of disinfection process.

**Chlorine residual:** Chlorine is typically used for disinfection downstream of the water reclamation plant. The efficiency of disinfection is generally evaluated with chlorine concentration multiplied by contact time (often referred as CT value), while the value differs significantly among regulators and countries. Monitoring residual chlorine concentration in the reclaimed water distribution systems is also important to avoid bacteria regrowth before reaching the end-use point. To ensure proper levels of chlorine concentrations and to minimize the disinfection by-products formation, the determination of chlorine demand can be evaluated. Continuous monitoring of chlorine at end-use point may be necessary in applications with high health risk.

Typical monitoring requirements for different levels of required water quality are shown in Table 7.

**Table 7 — 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, *E.coli*[a], Chlorine residual |
| B (Medium) | BOD, Turbidity or TSS, *E.coli*[a], Chlorine residual |
| C (Low) | TSS, *E.coli*[a], Chlorine residual |
| D (Very Low) | *typically no monitoring required* |

[a] Other microbial indicators may be used according to the local jurisdiction.

### 6.3.3 Performance control points (PCPs)

Treatment control with PCPs, e.g. monitoring parameters provided in Table 7, is a risk management approach of water QC that reduces risks to acceptable levels by ensuring that technological barriers to microbial hazards are performing as expected. Proper operation of PCPs provides a confidence that the reclaimed water remains safe[26]. In other words, the loss of treatment performance implies that the reclaimed water cannot be safe. Performance control is ensured through the selection of water quality criteria or surrogate parameters and the measurable control numerical limits that need to be set for each PCP. PCPs at water reclamation systems are determined with five criteria as follows [27]:

a) Significance: Is PCP significant to risk management?

b) Measurability: Can PCP be measured?

c) Actions: Are there any actions taken in case of the loss of PCP?

d) Reduction: Does PCP reduce the level of risks?

e) Timely: Can PCP and corrective actions be measured timely?

Typical procedures of PCP development and management are provided as follows:

a) Determine PCPs in the water reclamation system;

b) Establish monitoring performance limits (e.g. warning, action, and shut-down) for each PCP;

   1) Warning limit: No action is required but extra attention is needed to process performance.

   2) Action limit: Investigation is required to identify causes of deviation from baseline and subsequently corrective actions need to be implemented.

3) Shut-down limit: The process needs to be shut-down if the process performance cannot be guaranteed while creating a risk for human health.

c) Establish corrective actions when exceeding PCP set limits;

d) Establish procedures for validation and/or verification of PCP;

e) Perform ongoing monitoring and assessment (including maintenance and calibration of monitoring equipment).

PCP parameters are typically set at multiple processes. These processes include secondary treatment processes, tertiary processes (including filtration process), and disinfection processes. For example, in secondary treatment, parameters such as dissolved oxygen, ammonia or nitrates are used as PCP monitoring parameters. In a membrane filtration process, PCP parameters such as turbidity and conductivity can be selected. Typical locations of PCPs in water reclamation plant with high quality reclaimed water are shown in Figure 3. Examples of PCPs and monitoring parameters are also shown in Annex C.

Each PCP can attain performance limits as shown in Table 8. When shut-down limit is exceeded, the treatment system will shut down. In addition to shut-down limits, action limits that provide an alarm of performance limits approaching are recommended to be set, so that corrective measures can be performed prior to failure at each PCP. These limits are critical in performance monitoring and need to be determined with experienced professionals.

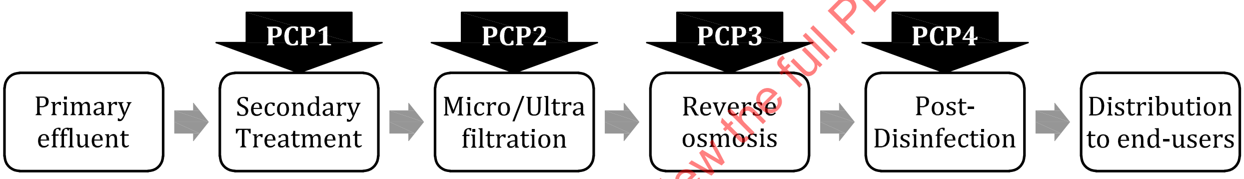


**Figure 3 — Examples of PCPs in water reclamation plant for production of high quality reclaimed water**

**Table 8 — Potential template of PCP monitoring parameters that correspond to Figure 3**

| | **PCP1 (Secondary treatment)** | **PCP2 (Micro/ Ultrafiltration)** | **PCP3 (Reverse osmosis)** | **PCP4 (Post-Disinfection – case of chlorine)** |
|---|---|---|---|---|
| Parameter | Ammonia concentration | Turbidity | Conductivity | Free chlorine, and/ or CT |
| Warning limits | __ mg/L | __ NTU | __ mS/cm | __ mg/L, __ mg·h/L |
| Action limits | __ mg/L | __ NTU | __ mS/cm | __ mg/L, __ mg·h/L |
| Shut-down limits | __ mg/L | __ NTU | __ mS/cm | __ mg/L, __ mg·h/L |
| NOTE Values of each parameter are provided with "__", and these values are prone to their local/national guidelines. | | | | |

## 6.4 Measures of end-use control

End-use control is a powerful barrier to minimize the potential of public exposure to health hazards at the end-use points. In general, high-level of end-use controls is required for the use of low quality reclaimed water. Representative measures of end-use control are as follows [24]:

Restricting uses of reclaimed water: Public exposure can be essentially minimized by restricting the uses of reclaimed water. For example, agricultural irrigation of food crops consumed raw needs better quality of reclaimed water than agricultural irrigation of processed food crops.



 

Controlling methods of application: Human exposure can also be controlled by the methods of application. For example, drip irrigation or subsurface irrigation reduces exposure drastically compared with spray irrigation.

Setting withholding periods: Setting withholding periods between production of reclaimed water and end-use can reduce public exposure. Substantial reductions in the number of viruses and bacteria can occur after withholding periods. In case of protozoa, the concentration reduction is mainly made by desiccation.

Access control: Controlling public access during irrigation of parks and gardens, and using buffer zones between areas of spray irrigation and points of public access can reduce exposure to reclaimed water. The selection of adequate irrigation equipment which can limit the risk of direct contact, such as micro-sprinklers for landscape irrigation and drip irrigation, can also improve health safety.

Cross-connection and backflow controls: Installation of the systems for cross-connection prevention and the devices for backflow prevention are important to prevent contamination of high-quality water such as drinking water.

Using signage, labelling, colour coding and communication at the end-use points to minimize accidental exposure: Signage at the site of water reuse to clarify that reclaimed water is being used and not suitable for drinking, can contribute to reduce accidental exposure. In addition, the labelling (e.g. colour coding) of distribution system such as valves and piping may be effective for minimising accidental exposure and cross-connections. Communication and education of end users is also of great importance.

Residual chlorine concentration: Maintenance of chlorine residual in the distribution system can provide additional health protection.



# 7 Monitoring

## 7.1 General

Monitoring of water reuse systems is undertaken to ensure that safe quality of reclaimed water is provided to end users. Two major types of monitoring need to be distinguished:

a) water quality monitoring (also referred to as compliance monitoring to check regulatory parameters); and

b) performance monitoring to verify the correct operation and effectiveness of treatment processes.

These two types of monitoring are complementary and performed both during reclaimed plant commission and during normal plant operation. In some cases, during commissioning, more stringent verification requirements can be set-up for water quality monitoring, in particular for new technologies or for projects with high risk of human exposure.

Water quality monitoring programs cover several points from source water to end-uses, but the typical water QC point of regulations is at the outlet of the water reclamation facility. Example of monitoring parameters in water reclamation system is shown in Annex D.

## 7.2 Compliance monitoring

Water quality compliance monitoring is carried out to verify compliance with regulatory requirements. Examples of reclaimed water quality requirements are described in 6.3.2. Weekly monitoring of microbial indicators is typically required for water reuse projects with high health risks, while monthly or quarterly monitoring can be sufficient for projects with a low risk of public exposure. For projects with identified high health risks, the monitoring of surrogates on-line (e.g. turbidity, chlorine residual) ensures the safety of reclaimed water quality [24] [28].

## 7.3 Performance monitoring

Performance monitoring is undertaken with on-line or periodical monitoring of operational parameters to confirm that treatment processes are properly designed and operated. Performance monitoring parameters generally include simple measures of process control parameters that allow rapid and easy measurements. Performance monitoring is carried out at specific PCPs. Examples of performance limits of PCPs are provided in 6.3.3.

Performance monitoring can identify changes in operation, malfunctions or failures of water reclamation processes. The setting-up of warning limits enables to swiftly identify deviations from normal system performance in order to adopt immediate corrective measures, and thus avoid deterioration of produced water quality and associated non-compliance.

Performance monitoring is recommended for water reuse projects with high health risks to avoid distribution of reclaimed water with inadequate quality to end users.

Visual observations or inspections of assets and equipment are complementary to regular or online monitoring of control measures to verify the proper functioning of equipment and the absence of breach in the system.

## 7.4 Quality control and quality assurance

All phases of the monitoring program pertain to quality assurance and control procedures, which are used to help avoid likely errors and problems, and ensure that data collected are reliable. Those procedures can be implemented according to the relevant quality management standards.

# Annex A
(informative)

# Pathogens that are often detected in raw wastewater

Pathogens that are often detected in raw wastewater are shown in Table A.1.

**Table A.1 — Pathogens that are often detected in raw wastewater**

| Organisms | Pathogens | Disease |
|---|---|---|
| Bacteria | *Shigella* | Shigellosis (bacillary dysentery) |
| | *Salmonella* | Salmonellosis, gastroenteritis (diarrhoea, vomiting, fever), reactive arthritis, typhoid fever |
| | *Vibrio cholera* | Cholera |
| | Pathogenic *E. coli* | Gastroenteritis and septicemia, haemolytic uremic syndrome |
| | *Campylobacter* | Gastroenteritis, reactive arthritis, Guillain-Barré syndrome |
| Protozoa | *Entamoeba* | Amebiasis (amebic dysentery) |
| | *Giardia* | Giardiasis (gastroenteritis) |
| | *Cryptosporidium* | Cryptosporidiosis, diarrhoea, fever |
| Helminths | *Ascaris* | Ascariasis (roundworm infection) |
| | *Ancylostoma* | Ancylostomiasis (hookworm infection) |
| | *Necator* | Necatoriasis (roundworm infection) |
| | *Trichuris* | Trichuriasis (whipworm infection) |
| Viruses | Enteroviruses | Gastroenteritis, heart anomalies, meningitis, respiratory illness, nervous disorders, others |
| | Adenovirus | Respiratory disease, eye infections, gastroenteritis |
| | Rotavirus | Gastroenteritis |
| NOTE Adapted from References [24], [28] and [29] and modified. | | |

# Annex B
(informative)

# Quantitative health risk assessment

## B.1 General

Quantitative health risk assessment means the whole process of hazard identification, exposure assessment, dose-response assessment, and health risk characterization. Although a quantitative risk assessment can be possible for only a limited number of contaminants pertaining to water reclamation considerations, and requires time, experienced professional expertise and high cost, it may be of consideration for use for projects with an assessment of very high public health risk.

## B.2 Hazard identification

There are descriptions with respect to hazard identification in 5.1.

## B.3 Exposure assessment

Reclaimed water health risks are caused by unintended ingestion, inhalation or skin contact during use. Reclaimed water has various purposes of use, and frequency/duration of use, and the dose of unintended ingestion, inhalation or skin contact per use differ according to the purpose. These values also vary according to the country, region, and era for each purpose. The volume, frequency, and duration of unintended ingestion, inhalation or skin contact of use per purpose can be set appropriately only in the case where there exist adequate and reliable data/theory.

## B.4 Dose-response assessment

Dose-response assessment aims to establish the relationship between the dose of a pathogen that individuals or population groups are exposed to and the probability of adverse health effect (e.g. infection, illness, death). From the estimated quantitative relationship (dose-response model), the probability of potential adverse health effects of a given severity are estimated from a given exposure to specific pathogen. Dose-response modelling is the process of using mathematical relationships to describe the probability of an adverse health effect (e.g. infection, illness) occurring in an individual or the frequency of an adverse health effect in a population when that individual or population is exposed to a specific dose of pathogens. The output of a dose-response assessment is a value or a set of values for the dose-response parameters. However, these parameters can be set appropriately only in the case where there exists adequate and reliable data/theory.

## B.5 Health risk characterization

Health risk characterization involves the use of hazard identification, exposure assessment and dose-response assessment to determine the magnitude of health risk. The outputs of health risk characterizations are the values of the probability of adverse health effects (e.g. infection, illness, death) and are expressed by probability of infection or Disability-adjusted life years (DALY). DALY is an indicator expressing the severity of a health effect through its magnitude.