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Guidelines for treated wastewater use for irrigation projects —

Part 4: **Monitoring**

Lignes directrices pour l'utilisation des eaux usées traitées pour l'irrigation —

Partie 4: Surveillance

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 1, *Treated wastewater reuse for irrigation*.

A list of all parts in the ISO 16075 series can be found on the ISO website.

Introduction

The increasing water scarcity and water pollution control efforts in many countries have made treated municipal and industrial wastewater a suitable economic means of augmenting the existing water supply, especially when compared to expensive alternatives such as desalination or the development of new water sources involving dams and reservoirs. Water reuse makes it possible to close the water cycle at a point closer to cities by producing "new water" from municipal wastewater and reducing wastewater discharge to the environment. The reuse of treated wastewater could be also a beneficial solution to improve water body's quality, such as for example avoiding wastewater treatment plants discharge upstream sensitive areas (shellfish aquaculture area, swimming area).

An important new concept in water reuse is the "fit-to-purpose" approach, which entails the production of reclaimed water quality that meets the needs of the intended end-users. In the situation of reclaimed water for irrigation, the reclaimed water quality may induce an adaptation of the type of plant grown. Thus, the intended water reuse applications should govern the degree of wastewater treatment required, and inversely, the reliability of wastewater reclamation processes and operation.

Treated wastewater (TWW, also referred to as reclaimed water or recycled water) can be used for various non-potable purposes. The dominant applications for the use of TWW include agricultural irrigation, landscape irrigation, industrial reuse and groundwater recharge. More recent and rapidly growing applications are for various urban uses, recreational and environmental uses and indirect and direct potable reuse.

Agricultural irrigation was, is and will likely remain the largest TWW consumer with recognized benefits and contribution to food security. Urban water recycling, in particular landscape irrigation, is characterized by fast development and will play a crucial role for the sustainability of cities in the future, including energy footprint reduction, human well-being and environmental restoration.

It is worth noting again, that the suitability of TWW for a given type of reuse depends on the compatibility between the wastewater availability (volume) and water irrigation demand throughout the year, as well as on the water quality and the specific use requirements. Water reuse for irrigation can convey some risks for health and environment, depending on the water quality, the irrigation water application method, the soil characteristics, the climate conditions and the agronomic practices. Consequently, public health and potential agronomic and environmental adverse impacts need to be considered as priority elements in the successful development of water reuse projects for irrigation. To prevent such potential adverse impacts, the development and application of international guidelines for the reuse of TWW is essential.

The main water quality factors that determine the suitability of TWW for irrigation are pathogen content, salinity, sodicity, specific ion toxicity, other chemical elements and nutrients. Local health authorities are responsible for establishing water quality threshold values depending on authorized uses and they are also responsible for defining practices to ensure health and environmental protection taking in account local specificities.

From an agronomic point of view, the main limitation in using TWW for irrigation arises from its quality. Treated wastewater, unlike water supplied for domestic and industrial purposes contains higher concentrations of inorganic suspended and dissolved materials (total soluble salts, sodium, chloride, boron, heavy metals), which can damage the soil and irrigated crops. As dissolved salts are not removed by conventional wastewater treatment technologies and appropriate good management, agronomic and irrigation practices should be used to avoid or minimize potential negative impacts.

The presence of nutrients (nitrogen, phosphorus and potassium) may become an advantage due to possible saving in fertilizers. However, the amount of nutrients provided by TWW along the irrigation period is not necessarily synchronized with crop requirements, and the availability of nutrients depends on the chemical forms.

This document provides guidance for healthy, hydrological, environmental and good operation, monitoring and maintenance of water reuse projects for unrestricted and restricted irrigation of agricultural crops, gardens and landscape areas using treated wastewater. The quality of supplied

TWW should reflect the possible uses according to crop sensitivity (health-wise and agronomy-wise), water sources (the hydrologic sensitivity of the project area), the soil and climate conditions.

This document refers to factors involved in water reuse projects for irrigation regardless of size, location and complexity. It is applicable to intended uses of TWW in a given project, even if such uses will change during the project's lifetime; as a result of changes in the project itself or in the applicable legislation.

The key factors in assuring the health, environmental and safety of water reuse projects in irrigation are:

— meticulous monitoring of TWW quality to ensure the system functions as planned and designed;

— design and maintenance instructions of the irrigation systems to ensure their proper long-term operation;

— compatibility between the TWW quality, the distribution method and the intended soil and crops to ensure a viable use of the soil and undamaged crop growth;

— compatibility between the TWW quality and its use to prevent or minimize possible contamination of groundwater or surface water sources.

Guidelines for treated wastewater use for irrigation projects —

Part 4: Monitoring

1 Scope

This document provides recommendations regarding:

— monitoring the quality of treated wastewater (TWW) for irrigation;

— monitoring irrigated plants;

— monitoring the soil with regard to salinity;

— monitoring natural water sources in neighbouring environments;

— monitoring the quality of water in storage reservoirs.

It puts emphasis on sampling methods and their frequency. Regarding the methods of analysis, this document refers to standard methods or, where not available, to other bibliographical references.

NOTE In cases where a monitoring plan already exists, these recommendations can be integrated into this plan. This is notably the case when a broader approach of risk management is implemented, such as the water safety plans (serving as a model for sanitation safety plans) developed by WHO.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

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

3.1 General

3.1.1
aquifer
underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand or silt) from which groundwater can be extracted

3.1.2
background water
freshwater (3.1.10) supplied for domestic, institutional, commercial and industrial use, from which *wastewater* (3.1.22) is created

3.1.3
barrier
any means including physical or process steps, that reduces or prevents the risk of human infection, by preventing contact between the TWW and the ingested produce or other means that, for example, reduces the concentration of microorganisms in the TWW or prevents their survival on the ingested produce

3.1.4
environment
surroundings in which an *organization* (3.1.13) operates, including air, water, land, natural resources, flora, fauna, humans and their interrelation

3.1.5
environmental aspect
element of an *organization's* (3.1.13) activities, projects or *products* (3.1.15) that can interact with the *environment* (3.1.4)

3.1.6
environmental impact
any change to environmental quality, whether adverse or beneficial, wholly or partly resulting from an *organization's* (3.1.13) activities, projects or *products* (3.1.15)

3.1.7
environmental parameter
quantifiable attribute of an *environmental aspect* (3.1.5)

3.1.8
fodder crops
crops not for human consumption such as: pastures and forage, fibre, ornamental, seed, forest and turf crops

3.1.9
food crops
crops which are intended for human consumption, often further classified as to whether the food crop is to be cooked, processed or consumed raw

3.1.10
freshwater
naturally occurring water on the Earth's surface (in ice, lakes, rivers and streams) and underground as groundwater in *aquifers* (3.1.1)

Note 1 to entry: Freshwater includes desalinated seawater and desalinated brackish water, but excludes seawater and brackish water.

3.1.11
irrigation project
design, development, construction, selection of equipment, operation and monitoring of works to provide suitable TWW irrigation

3.1.12
non-potable water
NPW
water that is not of drinking water quality

Note 1 to entry: It generally refers to *wastewater* (3.1.22) or TWW, but can also include other waters of non-drinking quality.

3.1.13
organization
group of people and facilities with an arrangement of responsibilities, authorities and relationships

3.1.14
process
set of interrelated or interacting activities which transform inputs into outputs

Note 1 to entry: Inputs to a process are generally outputs of other processes.

Note 2 to entry: Processes in an *organization* (3.1.13) are generally planned and carried out under controlled conditions to add value.

3.1.15
product
any goods or services

Note 1 to entry: This includes interconnected and/or interrelated goods or services.

3.1.16
public health aspect
element of an *organization's* (3.1.13) activities, projects or *products* (3.1.15) that can interact with the public health

3.1.17
public health impact
any change to public health, whether adverse or beneficial, wholly or partly resulting from an *organization's* (3.1.13) activities, projects or *products* (3.1.15)

3.1.18
public health parameter
quantifiable attribute of a *public health aspect* (3.1.16)

3.1.19
soil
layer of unconsolidated material consisting of weathered material particles, dead and living organic matter, air space and the *soil solution* (3.1.20)

3.1.20
soil solution
liquid phase of the *soil* (3.1.19) and its solutes

3.1.21
stakeholder
individual, group or *organization* (3.1.13) that has an interest in an organization or activity

Note 1 to entry: Usually a stakeholder can affect or is affected by the organization or the activity.

3.1.22
wastewater
wastewater collected principally by municipalities, that may include spent or used water from domestic, institutional, commercial or industrial sources, and can include storm water

3.1.23
water reuse
use of treated *wastewater* (3.1.22) for beneficial use; synonymous also to water reclamation and water recycling

3.2 Use of treated wastewater (TWW)

3.2.1
agriculture
science or practice of farming, including cultivation of the *soil* (3.1.19) for the growing of crops and the rearing of animals to provide food or other *products* (3.1.15)

3.2.2
landscape
all the visible features of an area of land, often considered in terms of their aesthetic appeal such as public and private gardens, parks, road vegetation including lawns and turfed recreational areas

3.2.3
restricted irrigation
use of TWW for non-potable applications in settings where public access is controlled or restricted by physical or institutional barriers

3.2.4
restricted urban irrigation
irrigation of areas in which public access during irrigation can be controlled, such as some golf courses, cemeteries, and highway medians

3.2.5
unrestricted irrigation
use of TWW for non-potable applications in settings where public access is not restricted

3.2.6
unrestricted urban irrigation
irrigation of areas in which public access during irrigation is not restricted, such as some gardens and playgrounds

3.3 Wastewater quality

3.3.1
category A: very high quality TWW
raw wastewater (3.3.6) which has undergone physical and biological treatment, *filtration* (3.5.3) and *disinfection* (3.5.2), and its quality is according to the description in ISO 16075-2:2015, Table 1

3.3.2
category B: high quality TWW
raw wastewater (3.3.6) which has undergone physical and biological treatment, *filtration* (3.5.3) and *disinfection* (3.5.2), and its quality is according to the description in ISO 16075-2:2015, Table 1

3.3.3
category C: good quality TWW
raw wastewater (3.3.6) which has undergone physical and biological treatment, and its quality is according to the description in ISO 16075-2:2015, Table 1

3.3.4
category D: medium quality TWW
raw wastewater (3.3.6) which has undergone physical and biological treatment, and its quality is according to the description in ISO 16075-2:2015, Table 1

3.3.5
category E: extensively TWW
raw wastewater (3.3.6) which has undergone natural biological treatment *process* (3.1.14) with long (minimum 10 to 15 days) retention time and its quality is according to the description in ISO 16075-2:2015, Table 1

3.3.6
raw wastewater
wastewater (3.1.22) which has not undergone any treatment

3.3.7
thermo-tolerant coliforms
group of bacteria whose presence in the *environment* (3.1.4) usually indicates faecal contamination (previously called *Faecal coliforms*)

Note 1 to entry: In order to determine the quality of TWW, one can test for *Escherichia coli (E. coli)* or for *Faecal coliforms*, since the difference in values is not significant.

3.4 Irrigation systems

3.4.1
boom sprinkler
mobile sprinkling machine (3.4.11) composed of two symmetrical pipes (booms), with *sprinkler* (3.4.24) nozzles distributed in one of the pipes, with the sprinkler action complemented by a gun sprinkler placed at each end of both pipes; the nozzles work through a reaction effect (similar to a hydraulic tourniquet) which drives the boom rotation at a desired speed

3.4.2
centre-pivot and moving lateral irrigation machines
automated irrigation machine consisting of a number of self-propelled towers supporting a pipeline rotating around a pivot point and through which water supplied at the pivot point flows radially outward for distribution by sprayers or *sprinklers* (3.4.24) located along the pipeline

3.4.3
emitter
emitting pipe
dripper
device fitted to an irrigation lateral and intended to discharge water in the form of drops or continuous flow at flow rates not exceeding 15 l/h except during flushing

3.4.4
gravity flow irrigation systems
irrigation systems (3.4.8), where water is applied directly to the *soil* (3.1.19) surface and is not under pressure

3.4.5
in-line emitter
emitter (3.4.3) intended for installation between two lengths of pipe in an irrigation lateral

3.4.6
irrigation gun
large discharge device being either a part circle or full circle *sprinkler* (3.4.24)

3.4.7
irrigation sprayer
device which discharges water in the form of fine jets or in a fan shape without rotational movement of its parts

3.4.8
irrigation system
assembly of pipes, components, and devices installed in the field for the purpose of irrigating a specific area

3.4.9
micro-irrigation system
system capable of delivering water drops, tiny-streams or mini-spray to the plants

Note 1 to entry: Surface and sub-surface drip irrigation and *micro-spray irrigation* (3.4.10) are the main types of this system.

3.4.10
micro-spray irrigation systems
characterized by water point sources similar to *sprinkler's* (3.4.24) miniatures (micro-sprinklers), which are placed along the laterals, with a flow rate between 30 l/h and 150 l/h at pressure heads of 15 m to 25 m, and the corresponding wetted area between 2 m and 6 m

3.4.11
mobile sprinkling machine
sprinkling unit which is automatically moved across the *soil* (3.1.19) surface during the water application

3.4.12
on-line emitter
emitter (3.4.3) intended for installation in the wall of an irrigation lateral, either directly or indirectly by means such as tubing

3.4.13
perforating pipe system
emitting pipe [*emitter* (3.4.3)/emitting pipe] continuous pipe, hose or tubing, including collapsible hose, with perforations, intended to discharge water in the form of drops or continuous flow at emission rates not exceeding 15 l/h for each emitting unit

3.4.14
permanent system
stationary fixed-grid *irrigation system* (3.4.8) [*sprinklers* (3.4.24)] for which sprinkler set positions are rigidly fixed by semi-permanent or permanently installed irrigation laterals, for example, portable solid-set irrigation system, buried irrigation system

3.4.15
portable system
system for which all or part of the network elements can be removed

3.4.16
pressurized irrigation systems
piped network systems under pressure

3.4.17
rotating sprinkler
device which, by its rotating motion around its vertical axis, distributes water over a circular area or part of a circular area

3.4.18
self-moved system
unit where a lateral is mounted through the centre of a series of wheels and is moved as a whole

Note 1 to entry: *Rotating sprinklers* (3.4.17)/sprayers are placed on the lateral (also called wheel move).

3.4.19
self-propelled gun traveller
gun *sprinkler* (3.4.24) on a cart or sled attached to the end of flexible pipe/hose

3.4.20
semi-permanent system
similar to the *semi-portable system* (3.4.21), but with portable laterals and permanent pumping plant, main lines and sub-mains

3.4.21
semi-portable system
similar to the *portable system* (3.4.15), except that the water source and the pumping plant are fixed

3.4.22
solid-set system
temporary fixed network, where the laterals are positioned in the field throughout the irrigation season

3.4.23
spray
release of water from a *sprinkler* (3.4.24)

3.4.24
sprinkler
water distribution device of a variety of sizes and types, for example, impact sprinkler, fixed nozzle, sprayer, *irrigation gun* (3.4.6)

3.4.25
sprinkler irrigation systems
irrigation system (3.4.8) composed of *sprinklers* (3.4.24)

3.4.26
stationary sprinkler systems
network of fixed *sprinklers* (3.4.24)

3.4.27
traveller irrigation machine
irrigation machine designed to irrigate a field sequentially, strip by strip, while moving across the field

3.5 Wastewater system related components

3.5.1
additional disinfection
disinfection (3.5.2) of TWW in a *water reuse* (3.1.23) project intended to raise the quality of the TWW before irrigation

3.5.2
disinfection
process (3.1.14) that destroys, inactivates or removes microorganisms

3.5.3
filtration
process (3.1.14) or device for removing solid or colloidal material from *wastewater* (3.1.22) by physically trapping the particles and removing them

3.5.4
membrane filtration
filtration (3.5.3) by membrane with pore size equal or less than 0,45 µm

Note 1 to entry: Membrane filtration may also be considered as *disinfection* (3.5.2), according to the log units of pathogen reduction that it achieves.

3.5.5
reservoir
system to store temporarily unused TWW depending on the demand for water irrigation and the treatment plant discharge

Note 1 to entry: There are different types of reservoirs that can be used.

a) Open reservoirs which are commonly used for short-term storage with hydraulic residence times from 1 day to 2 weeks.

b) Closed reservoirs for short-term storage to limit bacterial regrowth and external contamination common with hydraulic residence time of 0,5 day to a week.

c) Surface reservoirs for long-term or seasonal storage of TWW to accumulate water during periods of treatment plant discharge higher than irrigation demand, and to satisfy irrigation requirements when the demand is higher than the treatment plant discharge. The hydraulic residence time changes according to the seasons.

d) *Aquifer* (3.1.1) storage and recovery for long-term storage which is commonly combined with *soil* (3.1.19) aquifer treatment (by means of infiltration basins). The residence time is also a variable that is affected by the TWW discharge and irrigation demand. This aquifer storage should not contribute to the aquifer recharge for potential potable water use.

3.5.6
storage
retained temporary unused TWW for short or long term before their release for use in *irrigation systems* (3.4.8)

3.5.7
TWW pumping stations and transport systems
system of pipelines and pumps transporting the TWW from the WWTP to storage reservoirs and to the use site

3.5.8
wastewater treatment plant
WWTP
facility designed to treat *wastewater* (3.1.22) by a combination of physical (mechanical) unit operations and chemical and biological *processes* (3.1.14), for the purpose of reducing the organic and inorganic contaminants in the wastewater

Note 1 to entry: There are different levels of wastewater treatment, according to the desired quality of TWW and the level of contamination.

3.6 Abbreviated terms

BOD biochemical oxygen demand

CFU colony forming units

COD chemical oxygen demand

DO dissolved oxygen

EC electrical conductivity

HDPE high-density polyethylene

MPN most probable number

NDWQ non-drinking water quality

NTU nephelometric turbidity units

PP polypropylene

PVC polyvinyl chloride

RO reverse osmosis

SAR sodium adsorption ratio

SAT soil aquifer treatment

SS suspended solids

TDS total dissolved solids

TKN total Kjeldahl nitrogen

TN total nitrogen

TOC total organic carbon

TP total phosphorus

TSS total suspended solids

TWW treated wastewater

UV ultraviolet

VOC volatile organic compounds

WRF water reclamation facility

WW wastewater

WWTP wastewater treatment plant

4 Monitoring of the quality of TWW for irrigation

4.1 General

The development and implementation of an appropriate monitoring strategy is a crucial step for the health and environmental safety of water reuse projects. This compliance monitoring is performed usually at the outlet of the wastewater reclamation facility.

Monitoring can be undertaken for a range of purposes, and for each specific objective, different parameters can be selected. For example, water quality monitoring can be implemented for the following purposes:

a) human health protection: monitoring programs include selected microbial indicators at concentrations which depend on health risk (risk of direct contact, risk related to the type of crops, etc.), as well as few other parameters which indicate the reliability of operation of the wastewater treatment (e.g. turbidity, suspended solids, BOD, etc.);

b) prevention of adverse effect on crops: monitored parameters (named also agronomic parameters, include nutrients, soluble salts, sodium, trace elements, etc.);

c) prevention of adverse effects on environment (natural water sources and soil);

d) prevention of clogging of irrigation system, e.g. drip and sprinkler irrigation.

The selection of sampling points to control water quality and treatment performance, named "performance control points", depends on the type of application and the level of health and environmental risks.

The key water quality control point is located at the outlet of the wastewater reclamation plant. Sampling at the plant outlet follows ISO 5667-4. Treated wastewater is monitored either through grab sampling or composite sampling (see below), depending on the monitored parameters and local regulations.

Composite samples (as a rule for 24 h using refrigerated equipment) are very important for relevant monitoring of physico-chemical parameters as they represent the average quality of TWW. Microbiological parameters, dissolved oxygen, pH and temperature are monitored in grab samples *in situ*, if possible during diurnal peak flow.

Similarly, the sampling frequency of other parameters related to prevention of adverse effects on crops, soils and environment should be adapted to risk associated with sensitive crops and/or sensitive environment (e.g. shallow aquifers used for potable water supply), and/or specific irrigation equipment. The decision about the sampling (composite or grab) for these parameters should also take into account the daily variations in raw wastewater.

4.2 Sampling procedure

Depending on the type of the monitored parameters, there exist some basic sampling rules described in standard methods and ISO standards for water analysis or some specific analytical procedures defined by certified laboratories.

Sampling of TWW for irrigation should follow the list below.

— The type of samples can be either grab or composite samples to be used for water quality monitoring depending on the final objectives.

— All samples should be well labelled, indicating the type of water, site location, date, time and other pertinent data.

— Sampling frequency should be defined by water reuse granted permit.

— For the better planning and management of the irrigation scheme, seasonal samples should be taken depending on seasons in the concerned region, in order to obtain representative data on the variation in water quality, in particular nitrogen and salinity.

— The baseline monitoring for human health protection should be undertaken by sampling at the outlet of the treatment facility (see ISO 16075-2:2015, Table 1).

To check the reliability of operation of treatment processes, additional sampling points could be added when necessary, in particular in the case of non-compliance.

— For verification of potential contamination or regrowth in storage reservoirs and/or distribution network, additional control points for sampling can be established as a function of the final use, site location and irrigation method.

— Sampling bottles should be clean. Depending on parameters, and as some types of glass bottles yield boron to the samples, high-density polyethylene (HDPE) or polypropylene (PP) bottles with double caps or self-sealing caps should be used.

  As the sample quantity depends on the type of analysis to be performed, for the analysis of the basic water characteristics and the main anions and cations, 1 l of sample could be sufficient.

  Recommendations for sample preparation and handling are given in Table 1.

— Sampling and handling should be done safely with suitable precaution to avoid disease transmission by means of plastic gloves or using other protection.

Quality control samples should be collected as part of any routine sampling programme. Sampling and handling of raw wastewater and treated wastewater should follow Table 1.

Table 1 — Recommendations for sample preparation and conservation

Parameter	Type of bottle	Addition of chemicals	Conservation	Comments
Anions and cations (chloride, sulfate), as well as general physico-chemical parameters (pH, suspended solids, conductivity, turbidity)	1 l HDPE or PP bottles with double caps or self-sealing caps, with or without air	No additive	Dark, 4 °C	Temperature, pH and dissolved oxygen should be measured on site.
Phosphorus and N Kjeldahl	1 l HDPE or PP bottles with double caps or self-sealing caps, with or without air	H_2SO_4 to pH = 2	Dark, 4 °C	
Boron	100 ml HDPE or PP bottles with double caps or self-sealing caps	HNO_3 to pH = 2	Dark, 4 °C	
COD	100 ml HDPE or PP bottles with double caps or self-sealing caps, no air	H_2SO_4 to pH = 2	Dark, 4 °C	No additive is needed if the samples are analysed within 48 h.
BOD	500 ml HDPE or PP bottles with double caps or self-sealing caps, no air	No additive	Dark, 4 °C	Na_2SO_3 should be used for dealing with samples with residual chlorine. Preserve sample and add seed for chlorinated and dechlorinated wastewater samples.
Trace elements and heavy metals	250 ml HDPE or PP bottles with double caps or self-sealing caps, with or without air	HNO_3 to pH = 2	Dark, 4 °C	A special bottle [such as polytetrafluoroethylene (PTFE)] and additive are needed for the analysis of mercury (Hg).
Trace organics and pesticides	1 l dark glass bottle or PTFE bottle, no air rinsed with organic solvents	Ascorbic acid (1 000 mg l^{-1}) if residual chlorine is present	Dark 4 °C	
Microbiological parameters (total and *faecal coliforms*, helminths, viruses, or other additional microbiological parameters)	1 l to 5 l sterile HDPE or PP bottles with double caps or self-sealing caps bottle, with air	No additive	Dark, 4 °C	Additive of sodium thiosulfate at a well-defined concentration is mandatory in presence of residual chlorine and recommended in all cases.

4.2.1 Sampling from an irrigation system

Water quality should be checked by the end user according to the following procedure.

Water sampling should not be taken when fertigation (fertilization through irrigation) is taking place.

a) Turn on the irrigation system until the system operates to full designed pressure and let the system irrigate until the pipe have flushed of all stagnant water from the previous irrigation event.

b) Collect a sample from a control filter or from an irrigation emitter (a sprinkler, micro-jet or a dripper).

c) The water sample should be collected in bottles as provided or recommended by the analytical laboratory or procedure and the parameters to be tested (see Table 1). For bacterial sampling, a sterile bottle should be used. Write all necessary details on a sticker attached to the bottle (name, address, date, location, etc.) and seal the lid.

d) Preserve samples according to standard laboratory practice and transport them to an analytical laboratory within the time period recommended for the analysis (see Table 1).

For more information about sampling from an irrigation system, see ISO 5667-10.

4.2.2 Sampling from a storage reservoir

To evaluate a potential evolution of treated wastewater quality during storage, a sample from the storage reservoir should be taken according to the following procedure.

a) It is recommended to take the sample as close as possible to the pumping point.

b) Avoid sampling downwind to prevent the collection of floating materials (plant or algae residues) transported by water waves to the downwind side of the storage reservoir.

c) Tie an empty bottle to a weight and attach both to a pole.

d) Lower the bottle so that the neck is submerged in the storage reservoir to a depth of about 100 mm or 10 cm and fill the bottle.

e) Remove the bottle from the storage reservoir, seal it and label the bottle.

f) Preserve the sample if required or refer to Table 1 to determine if and what preservative is required. Store the sample and take them to the laboratory within the time period recommended by the analytical laboratory or procedure (see Table 1).

For more information about sampling from a storage reservoir, see ISO 5667-4.

4.2.3 Composite sample

To characterize TWW at the outlet of the plant in order to take into account the fluctuations of WW quality, a composite sample should be taken.

Composite sampling should be within a 24 h duration.

A refrigerated automatic sampler should be used.

Composite sample should be taken in typical conditions of flowing rate and pollutant load (wastewater generators).

4.2.4 Sample handling

Samples should be kept in a thermally insulated container and delivered immediately to the laboratory. If the samples cannot be delivered immediately, they should be temporarily stored in a refrigerator at 4 °C.

For more information about sample handling, see ISO 5667-1.

4.3 TWW monitoring plan

The plans presented in Table 2, Table 3 and Table 4 serve as examples of the monitoring frequencies to characterize TWW used for irrigation. The tables include the parameters to be tested, and the sampling frequency of the TWW flowing to reservoirs, directly to irrigation or from reservoirs. The monitoring plan should be adapted to the local conditions of each region.

Table 2 — Example of monitoring frequency at the outlet of the wastewater treatment plant (health-related parameters)

Monitored parameters	Monitoring frequency by quality categories[a]				
	Category A	**Category B**	**Category C**	**Category D**	**Category E**
Thermo-tolerant coliforms (see 3.3.7 and ISO 16075-2)	Daily to weekly	Weekly to twice a month	Twice a month to monthly	Not relevant	Not relevant
Intestinal nematodes (helminth eggs[b])	Not relevant	Not relevant	The frequency will be determined according to the number of helminth eggs in the wastewater	The frequency will be determined according to the number of helminth eggs in the wastewater	The frequency will be determined according to the number of helminth eggs in the wastewater
TSS[c]	Weekly	Weekly	Monthly to once every 2 months	Monthly to once every 2 months	Monthly to once every 2 months
Residual chlorine	Daily	Daily	Not relevant	Not relevant	Not relevant
Turbidity	Continuous	Not relevant	Not relevant	Not relevant	Not relevant
BOD	Weekly to twice a month	Weekly to twice a month	Monthly to once every 2 months	Monthly to once every 2 months	Monthly to once every 2 months

[a] Monitoring frequency may be increased or decreased according to local conditions, e.g. irrigated crops, climate, soil and irrigation technique. If frequency is increased or decreased, the fluctuations in water quality in WWTP should be taken into account.

[b] Although helminth eggs are of concern with respect to TWW applied to agricultural crops and their concentration in TWW is regulated in many countries, there is little consensus among researchers, regulators and practitioners about the most reliable method for measuring them in water samples. Large sample volumes need to be filtered to collect the eggs and the efficiency in recovering the eggs from the filter is often poor and the helminth eggs differ in shape and size and, therefore, can only be identified by properly trained people. Additionally, eggs contained in even untreated wastewater are not always viable. To verify if the eggs are viable, they need to be incubated at a specific temperature and moisture level for a month to determine if they develop into larva. The combination of difficult and imprecise analytical procedures, and the extended time necessary to carry out the analysis, makes this an undesirable monitoring parameter. Intestinal nematodes (helminth eggs) might not be routinely monitored if it is demonstrated that the number of helminth eggs in untreated wastewater is consistently below 10 eggs/l. See ISO 16075-2:2015, Table 1.

[c] For greenhouses, monitoring may include *Legionella* if there is a risk of aerosolization, spp should be less than 1 000 CFU/l.

Table 3 — Example of monitoring frequency at the outlet of the wastewater treatment plant (agronomic parameters)

Monitored parameters	Units	TWW monitoring frequency[a, b]
Electrical conductivity in the water (EC_w)[c]	dS m^{-1}	High frequency(daily to monthly)
Boron[d, f]	mg l^{-1}	High frequency(daily to monthly) or Moderate frequency (once every 2 to 6 months)
Nutrients TKN Ammonia nitrogen Nitrites Nitrate-nitrogen Total nitrogen Total phosphorous	mg l^{-1}	Moderate frequency (once every 2 to 6 months)
Major solutes (Na, Ca, Mg, K, Cl, SO_4, HCO_3, CO_3)	mg l^{-1}	Moderate frequency (once every 2 to 6 months)
Trace elements (Al, As, Be, Cd, Cr, Co, Cu, F, Fe, Li, Mn, Mo, Ni, Pd, Se, Sn, Ti, W, V, Zn)[e, f, g]	mg l^{-1}	Low frequency (once every 1 to 5 years)

[a] Monitoring frequency should be adjusted to local conditions, e.g. irrigated crops, climate, soil and irrigation technique.

[b] Monitoring frequency depends on fluctuations in a parameter's concentration. If parameter's concentration is stable, monitoring frequency can be decreased. At the beginning of a new project, high frequency of monitoring is needed in order to identify the parameters with high variability and considered problematic for water use in local conditions.

[c] If fluctuations are observed in electrical conductivity, chloride and sodium monitoring frequency should be increased.

[d] Monitoring frequency of boron should be adjusted to the project needs.

[e] Frequency should be once a year to every five years. If industrial TWW are used, monitoring frequency should be increased.

[f] If TWW from animal source are used, monitoring frequency of zinc, potassium and boron should be increased.

[g] Sampling frequency for trace elements should be in accordance with the source of the wastewater flowing into the treatment plant. If industrial wastewater or agricultural wastewater is flowing into the treatment plant, the recommended sampling frequency is twice to thrice a year. If the treatment plant does not receive industrial wastewater or agricultural wastewater, then the sampling frequency can be once a year to every five years, as stated in the table.

Table 4 — Example of TWW monitoring frequency at the outlet of reservoir during the irrigation period (health-related parameters)

Monitored parameters	Monitoring frequency by quality categories[a]				
	Category A	Category B	Category C	Category D	Category E
Thermo-tolerant coliforms[b]	Monthly	Monthly to once every 2 months	Monthly to once every 2 months	Not relevant	Not relevant
Residual chlorine[c]	Daily	Daily	Not relevant	Not relevant	Not relevant

[a] Monitoring frequency should be adapted to the retention time in the reservoir. The longer the retention time, the lower the frequency.

[b] Monitoring will be done only during the irrigation period.

[c] Monitoring of residual chlorine will be done only when there is additional chlorination at the outlet of the reservoir.

4.4 Analytical methods for TWW

Analytical methods for TWW monitoring should be performed in accordance with national standards.

Where no national standards exist, international or regional standards may be used, or reference can be made to recognized analytical procedures [12].

5 Monitoring of the irrigated crops

5.1 General

Plots irrigated with TWW should be monitored through the crop in one of the following ways:

a) visual detection of deficiency or excess of elements, or

b) analysing and examining of any part of a crop.

Visual method may not be sufficient to detect/prevent salinity or toxicity damage to the crops or avoid yield loss. The same applies to deficiency in nutrients.

Laboratory analysis should be performed on a leaf or petiole sample, since the analysis is capable of determining toxic ion concentration (chloride, boron, sodium), as well as crop nutrients concentration (nitrogen, phosphorus, potassium and micronutrients).

For perennial crops, the results obtained in the current season are applicable in determining the fertilization programme for the following season.

Annual crops should be tested immediately, but this requires rapid organization and availability of the laboratory to determine the results quickly while they are relevant to the current crop season.

5.2 Frequency of monitoring

5.2.1 Field crops and vegetables

Frequency of field crops and vegetables monitoring should vary with the crop and the suitability for the crops of reference curves linking between the phenological stage of the crop and the expected concentration in the leaves or other plant part. Thus, samples may be obtained at various times during the growing season. The frequency varies with the crop and the ability to use the data to correct irrigation and fertilization management immediately during the current growing season.

5.2.2 Perennial crops

The concentration of elements in the leaves should be determined by sampling leaves at the time of the year for which there are reference data regarding the optimal concentration expected for the crop. Each crop has its recommended sampling and analysis period. In general, this period should be close to the fruit harvesting.

Occasionally, a comparative analysis between damaged and healthy leaves can be conducted at any time of the season when there is a visual sign for leaf damage and it is difficult to verify the cause of the damage. In this manner, it is easy to detect the source of the damage. This method should be used due to lack of criteria for normal concentration of elements in crops leaves in a period out of the time recommended for sampling.

The sampling method of leaves and the analytical methods techniques are not within the scope of this document; therefore, users should examine the appropriate method for each crop in the professional literature.

6 Monitoring of the soil with regard to salinity

6.1 Soil sampling

Irrigating with TWW may lead to greater salt accumulation in the root zone and affect the plants. In order to prevent crop damage and to optimize the irrigation management optimally, soil should be monitored for salinity.

6.2 Frequency of the soil sampling

All irrigation water contains salts. The concentration of soluble salts in TWW is usually higher than in fresh water. Salts are added to the soil every time it is irrigated and accumulates in the root zone. The crop removes much of the applied water to meet its evapotranspiration demand. During the irrigation season, a build-up of soil salinity can occur that depends on various factors: the salt concentration in irrigation water, soil texture and hydraulic characteristics, climate (evapotranspiration and temperature), irrigation method and irrigation regime.

Agricultural crops significantly differ in their tolerance to the concentrations of soluble salts in the soil solution around the root area. Soil salinity does not damage the crop as long as it does not exceed a certain threshold of salinity value (plant tolerance) (see ISO 16075-1).

In order to manage soil salinity, you should apply leaching doses when needed. Monitoring soil salinity is achieved by soil sampling.

First sampling during irrigation season should be at the beginning of each irrigation season. Afterwards, the soil should be sampled in the root zone at a frequency according to water quality, soil characteristics, irrigation regime and crop tolerance to salinity. In general, sampling should be more frequent when there is higher salt concentration in the TWW, the soil has higher clay content, large volumes of irrigation water are applied or the crop has lower salt tolerance.

Sampling in soil for trace elements (heavy metals, pollutants of emerging concern and persistent organic chemicals) should reflect the risk identified during project design (e.g. initial soil and TWW characterization). As mentioned previously, monitoring is a costly process and it is important to design a monitoring program that gives sound information at an affordable cost.

Among the best methods for analysing trace elements from soil extracts is Inductively Coupled Plasma Mass Spectrometry (ICP-MS). However, the extract method and the analytical methods to determine the trace elements would need to adapt to the methods used to set the limit values used locally and according to local regulations.

The most commonly recommended sampling interval for soil monitoring is 10 years. Higher frequency can be adopted in the case if significant risks of accumulation of one or several trace elements have been identified. Trace element accumulation in soils in relation to uptake by plants depends on the chemical forms of elements and their interactions with soil components (e.g. exchangeable, sorbed, organic-bound, carbonate and sulfate forms). Their absorption and accumulation by plants depends on the soil supplying these elements to plant roots, on the rhizosphere environment, and on the characteristics of the plant root system.

Soil pH has been shown to have a significant influence on plant uptake of trace elements because it affects the solubility of trace elements in soils. The pH effect is substantially more consistent than other soil variables such as organic matter content, cation exchange capacity and soil texture. Trace element toxicities to plants are more common in acid soils. Other soil components can also react to prevent trace element movement such as clay, organic matter, hydrous iron and hydrous manganese oxides, organic acids, amino acids, humic and fulvic acids.

6.3 Sampling procedure

6.3.1 Drip irrigation

Soil samples should be taken along the drip lateral, at about 10 cm distance from the dripper, to depths of 0 cm to 30 cm, 30 cm to 60 cm and 60 cm to 90 cm, or according to the crop root zone depth. The upper 3 cm to 5 cm of the soil surface should be discarded.

For general cases without the high risk of salinization (quality of the water), limited soil sampling to the root zone can be carried out. When salinization risk is very high, soil mapping should be carried out. About 20 randomly distributed samples should be taken from a plot in order to have a representative and random composite sample.

Each composite sample of a certain depth should be put in a separate bag.

6.3.2 Sprinkler and micro-jet irrigation

Soil samples should be taken at about 70 cm to 100 cm distance from the micro-jet and at about 100 cm to 120 cm distance from the mini-sprinkler. The distance should be within the range of the discharge and water distribution of the emitter.

6.3.3 Sample preparation

The same depths and number of samples for a composite representative and random sample should be taken as specified for drip irrigation.

The following steps describe the procedure on how to prepare the sample before its delivery to the soil laboratory.

a) Each composite sample of a certain depth should be well mixed.

b) About 1 kg of the mixed sample should be put in a bag on which all details are recorded (name, address, plot, crop, date of sampling, depth, etc.).

c) The samples should be delivered as soon as possible to the laboratory.

6.4 Soil test methods

Soil test methods for analysis need to be adapted to the characteristics of soils in each area.

7 Receiving environment monitoring

7.1 General

Source water monitoring should be required when a risk has been identified (e.g. surface and ground water pollution, etc.) by a qualified technician (e.g. engineer or hydrogeologist).

Although reuse applications for irrigation purposes are intended to meet the evapotranspiration requirements, TWW can be applied in excess, contributing to groundwater and/or surface water flows. Further, TWW can contain residual levels of contaminants including dissolved metals, organics, inorganics and pathogenic microorganisms that can be of concern with respect to the down-gradient extraction of water that could be affected by these contaminants.

If a risk has been identified, it is necessary to establish a receiving environmental water quality monitoring program intended to monitor the influence of the TWW in down-gradient groundwater and surface water body water quality to detect the presence and contribution of contaminants associated with the TWW.

NOTE According to regulations in many countries, specific monitoring of water bodies is required for both drinking water protected area and sensitive zones.

7.2 Monitoring program purpose

In order for a monitoring program to be effective and relevant, it needs to address a specific question or hypothesis.

This monitoring program will be designed in agreement with the risk identified depending on TWW quality, hydrological and geological context. It should discern between the influence of TWW applications and those of other sources (e.g. background contaminant concentrations due to up-gradient sources of contamination, geochemical contributions from the soil matrix, and point source contributions in the area) and take into account expected seasonal variations in contaminant concentration.

Based on the TWW characteristics (i.e. for projects with a higher risk level), monitoring plans should be more stringent and adapted to the local conditions of each region.

7.3 Groundwater sampling

The monitoring of groundwater (network of piezometers, sampling frequency and trigger values) should apply to a scheme with an identified risk on groundwater resources. The number and location of monitoring wells is site-specific and should be determined by a qualified technician (e.g. engineer or hydrogeologist), taking into consideration the monitoring program objectives and the soil hydraulic conductivity variability.

Groundwater sampling stations should be located in monitoring wells within the area irrigated by TWW, as well as immediately up-gradient and down-gradient of the area.

The purpose of the up-gradient monitoring wells is to assess the background groundwater quality. A sufficient number of up-gradient wells should be installed to assess the degree of area variability.

The purpose of the monitoring wells located within the irrigation area is to assess “worst-case” water quality conditions, as these stations are more likely to detect contaminant contributions from TWW before those effects may be masked by dilution from other groundwater sources down-gradient. The monitoring wells within the irrigation area also serve as an early warning indicator of potential downstream groundwater impacts.

The down-gradient monitoring wells provide verification of the overall water quality impacts of the TWW irrigation that may affect down-gradient groundwater extraction uses.

The piezometers should be located at a depth of at least 1 m lower than the expected minimum groundwater elevation at that location, with the piezometer's wall being perforated at least in the entire section between the location's minimum and maximum groundwater levels.

Sampling should be carried out by pumping a volume of at least 10 times the water volume found in the piezometer or when the conductivity is stabilized (i.e. sampling will be active rather than passive).

Parameters, frequency and trigger values are defined by a qualified technician on the basis of the potential impact of TWW.

If negative impacts on downstream groundwater are detected, a thorough hydrological examination should be conducted to identify the source of contamination. Corrective measures should be applied to prevent further pollution and irrigation should be interrupted when justified.

Monitoring plans may be reviewed and the sampling frequency decreased when the monitoring results show the absence of impact after a 3-year sampling procedure.

7.4 Surface water sampling

Surface water sampling stations should be established downstream of the upper hydrological system. The number, location of sampling points and the monitoring program are site-specific and should be determined by a qualified technician (e.g. engineer or hydrogeologist).

If negative impacts on the surface water due to the irrigation with TWW are detected, a thorough hydrological examination should be conducted to identify the source of contamination. Corrective measures should be applied to prevent further pollution and irrigation should be interrupted when justified.

Monitoring plans may be reviewed and the sampling frequency decreased when monitoring results show the absence of impact after a three-year sampling procedure.

Sample analyses should include all the parameters mentioned in the TWW quality standard (see ISO 16075-2).

For information about surface water sampling, see ISO 5667-6 and ISO 5667-11.

8 Quality assurance and quality control

Sampling and analytical error, as well as the maintenance and calibration of online analysers, need to be taken into consideration in the development of a quality assurance and quality control program.

While analytical laboratories typically implement a rigorous internal QA/QC program, it does not replace a monitoring- and operations-based QA/QC program, which can be of benefit in assessing the precision and accuracy of the laboratory protocol. It is important to acknowledge that TWW typically contains contaminant levels that are extremely low, often near the analytical detection limits. Under such conditions, the potential for sampling and analytical errors is high, and a rigorous QA/QC is critically important.

Consideration should be given to using two or more laboratories periodically during the monitoring program to carry out duplicate analyses as a means of assessing laboratory bias with respect to accuracy. Careful consideration should be given to ensuring the sample location is representative and that methods used to sub-sample do not introduce errors. For example, inadequate agitation of the collected sample during sub-sampling can result in particle-associated contaminants being under-represented in the sub-sample.

The QA/QC program should include field/travel blanks, replicate, split, surrogate and spiked samples. The sample bottles should be labelled in such a way as to keep the laboratory "blind" as to the sample source or the identity of duplicate samples. The sampling program should be evaluated in detail by an expert third-party at frequency of not less than every five years.

Field instruments should be checked frequently following the manufacturer's instructions and operational feedback, and the instrument recalibrated, if required. A calibration check should be carried out to determine calibration drift. If the calibration drift exceeds the manufacturer or QA/QC criteria, the amount of drift should be recorded, the readings taken since the last calibration check should be qualified, and the instrument recalibrated. Similarly, calibration checks should be carried out of online instruments using calibrated field instruments and/or calibration-sample analyses. If the calibration drift exceeds the manufacturer or program QA/QC criteria, the online instrument readings should either be adjusted or the instrument recalibrated, as appropriate.

The monitoring program should have a formal QA/QC program including an annual review to ensure each and every step of the sampling and post-sampling process follows documented protocols and that proactive method improvement practices are performed. Regular inspections by the QA Officer of every aspect of the sampling program on a regular basis and issue written QA/QC reports on a regular annual basis, and the sampling program should be re-evaluated in detail by an outside party not less frequently than every five years. Field instruments and equipment used should be regularly maintained and calibrated, and maintenance logs should be kept.

Major sampling programs should also have a formal QA/QC Manual that documents all resources, policies and procedures pertinent to that sampling program. The QA/QC Manual should include detailed descriptions of the topics outlined in this section and should clearly define the QA/QC responsibilities of management, supervisory staff, and field samplers.

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