
**Guidelines for treated wastewater use
for irrigation projects —**

**Part 1:
The basis of a reuse project for
irrigation**

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

Partie 1: Les bases d'un projet de réutilisation en irrigation



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Foreword

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

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

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#).

The committee responsible for this document is ISO/TC 282, *Water re-use*, Subcommittee SC01, *Treated wastewater re-use for irrigation*.

This first edition cancels and replaces ISO/CD 16075-2.

ISO 16075 consists of the following parts, under the general title *Guidelines for treated wastewater use for irrigation projects*:

- *Part 1: The basis of a reuse project for irrigation*
- *Part 2: Development of the project*
- *Part 3: Components of a reuse project for irrigation*

The following parts are under preparation:

- *Part 4: Monitoring*

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.

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 can induce an adaptation of the type of plant grown. Thus, the intended water reuse applications are to govern the degree of wastewater treatment required and, inversely, the reliability of wastewater reclamation processes and operation.

Treated wastewater can be used for various non-potable purposes. The dominant applications for the use of treated wastewater (also referred to as reclaimed water or recycled water) 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 reuse water consumer with recognized benefits and contribution to food security. Urban water recycling, landscape irrigation in particular, 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 treated wastewater 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, the public health and potential agronomic and environmental adverse impacts are 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 treated wastewater is essential.

The main water quality factors that determine the suitability of treated wastewater 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 into account local specificities.

From an agronomic point of view, the main limitation in using treated wastewater 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. Dissolved salts are not removed by conventional wastewater treatment technologies and appropriate good management, agronomic and irrigation practices are intended to be used to avoid or minimize potential negative impacts.

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

This guideline 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 treated wastewater has

to 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 guideline refers to factors involved in water reuse projects for irrigation regardless of size, location, and complexity. It is applicable to intended uses of treated wastewater 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 the following:

- meticulous monitoring of treated wastewater 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 treated wastewater 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 treated wastewater quality and its use to prevent or minimize possible contamination of groundwater or surface water sources.

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Guidelines for treated wastewater use for irrigation projects —

Part 1: The basis of a reuse project for irrigation

1 Scope

This part of ISO 16075 contains guidelines for the development and the execution of projects intending to use treated wastewater (TWW) for irrigation and considers the parameters of climate and soil.

The purpose of these guidelines is to provide specifications for all elements of a project using TWW for irrigation, including design, materials, construction, and performance, when used for the following:

- unrestricted irrigation of agricultural crops;
- restricted irrigation of agricultural crops;
- irrigation of public and private gardens and landscape areas, including parks, sport fields, golf courses, cemeteries, etc;
- irrigation of private individual gardens.

These guidelines are intended to provide assistance for the benefit of users of TWW for irrigation. The guidelines relate to the widespread and common ranges of water quality rather than exceptional or unique ones and are intended for the use by professionals, such as irrigation companies (designers and operators), agricultural extension officers or advisors, water companies (designers and operators), and local authorities. The use of these guidelines by farmers might require additional specifications.

None of the parts of this International Standard are intended to be used for certification purposes.

These guidelines suggest the parameters of TWW quality. These parameters include the following:

- agronomic parameters: nutrients (nitrogen, phosphorus and potassium) and salinity factors (total salt content, chloride, boron, and sodium concentration);
- other chemical element parameters (heavy metals);
- microbial parameters.

Each of these parameters can have possible impacts on the crops, soil, and public health. The guidelines discuss the possibility of preventing the contaminants' presence during wastewater production and the ability to remove them during the course of treatment.

Emerging pollutants (pharmaceuticals and personal care product residuals) are outside the scope of this part of ISO 16075 since at this time, they are not included in any national standard.

The project should be designed in accordance with the sanitary quality of the TWW in order to avoid disease transmission by the pathogens in the water.

The use of these guidelines is encouraged to ensure consistency within any organization engaged in the use of treated wastewater.

These guidelines provide the basis for a healthy, hydrological, environmental and agronomic conscious design, operation, monitoring, and maintenance of an irrigation system using treated wastewater.

This part of ISO 16075 is not intended to prevent the creation of more specific standards or guides which are better adapted to specific regions, countries, areas, or organizations. If such documents are written, it is recommended to reference this part of ISO 16075 to ensure uniformity throughout the treated wastewater use community.

2 Normative references

There are no normative references.

3 Terms, definitions, and abbreviated terms

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 activities, projects, or products 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 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, fiber, 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 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 activities, projects, or *products* (3.1.15)

3.1.18**public health parameter**

quantifiable attribute of a *public health aspect* (3.1.17)

3.1.19**soil**

layer of unconsolidated material consisting of weathered material particles, dead and living organic matter, air space, and *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 can 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 for beneficial use

Note 1 to entry: 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, and 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[10], 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[10], 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[10], 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[10], Table 1

3.3.5**category E: extensively TWW**

raw wastewater (3.3.6) which has undergone natural biological treatment process with long (minimum 10 d to 15 d) retention time and its quality is according to the description in ISO 16075-2[10], 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 by two symmetrical pipes (booms), with sprinkler 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**center-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

3.4.7

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 minispray 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

system characterized by water point sources similar to *sprinklers* (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/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 (sprinklers) 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

pipelined network systems under pressure

3.4.17

rotating sprinkler

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

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* ([3.1.17](#))/sprayers are placed on the lateral (also called wheel move).

3.4.19**self-propelled gun traveller**

gun sprinkler 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 systems ([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**traveler 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 to or less than 0,45 µm

Note 1 to entry: Membrane filtration can 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: The following 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 one day to two 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 storage and recovery for long-term storage which is commonly combined with soil 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, 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
COD	chemical oxygen demand
EC	electrical conductivity
NPW	non-potable water
NUT	nephelometric turbidity units
SAR	sodium adsorption ratio

TDS	total dissolved solids
TWW	treated wastewater
UV	ultraviolet
WW	wastewater
WWTP	wastewater treatment plant

4 Improving the quality and the use of TWW

The chemical quality of wastewater depends on the chemical quality of the background water. Background water is received from different sources (ground water, rivers, lakes, and desalination of seawater or brackish water). Dissolved salts, which are often added to the background freshwater during its use, are not removed by the conventional wastewater treatment.

To avoid adverse effect of TWW quality on irrigated crops and soil, different strategies can be implemented.

The first option is the improvement of TWW quality using the following methods, alone or in combination:

- a) improve the TWW quality for irrigation by supplying a higher quality of water (lower salt concentration) or desalinated water to municipal use;
- b) reduce salt additions by treating diffuse sources such as salt water intrusion in sewers, domestic additions through laundry detergents or dishwasher salts, and/or from point source such as industrial factories using large volumes of water and emitting large quantities of salt from their manufacturing processes.

The application of good agronomic and irrigation practices is another well approved option which includes the following:

- a) crop selection and management;
- b) leaching and drainage;
- c) management of soil structure;
- d) adjusting fertilizer application or amendment;
- e) adjusting the timing of water application and selecting appropriate irrigation technique.

When desalinated water is a relevant background freshwater source, attention might be needed to the boron concentration in the desalinated water if special processes to remove it during desalination cannot be carried out. Attention shall also be paid to the addition of calcium and magnesium in the post treatment step. In any case, the irrigated crops should be species adapted to the quantity and quality of dissolved salts in the TWW.

5 Basis of a reuse project for irrigation

An irrigation project using TWW should take into consideration water quality parameters, crop needs, as well as climate and soil regional conditions. TWW quality can affect the soil and crops. The project should be designed in accordance with the sanitary quality of the TWW in order to avoid disease transmission by the pathogens in the water.

6 Influencing factors for TWW irrigation projects: water quality, climate, and soil

6.1 General

The beneficial use of TWW for irrigation purposes demands serious consideration of public health risks including the safety and welfare of the workers. It requires close examination of the needed infrastructure including facilities planning, plant-siting, wastewater collection and treatment, TWW use, TWW transport to storage locations, transport to end use location, as well as post-use.

The public health and potential environmental impacts shall be considered as priority elements in the successful development of international TWW guidelines. To prevent negative impacts on public health and negative impacts on the receiving environment and water sources, the development and application of international guidelines for the re-use of TWW is essential.

The presence of nutrients (nitrogen, phosphorus, and potassium) can be an advantage due to possible saving in fertilizers.

6.2 Water quality

6.2.1 Wastewater components

The chemical quality of the wastewater is a result of the chemical composition of the background freshwater (the water supplied for the various domestic, industrial, and agricultural uses) and any additions during the water use at home or by industry. Various substances are added to the water in the course of its treatment and use which determine the composition of the wastewater, as well as its physical, chemical, and biological properties. The main chemical components of the wastewater are classified into organic and inorganic substances.

The organic substances can contain hormones, pharmaceuticals, personal care products, proteins, carbohydrates, oils, fuels and lubricants, surfactants, including pesticides, and other domestic and agricultural chemicals.

The inorganic substances can contain chloride, sodium, boron, nitrogen (some of the nitrogen and phosphorus is also included as part of the organic substances), phosphorus, potassium, sulfur, and other chemical elements, including heavy metals (e.g. zinc, manganese, copper, mercury, silver, chromium, nickel, lead, cadmium) and fluorine.

Furthermore and very important, wastewater contains a variety of living organisms that have originated from the waste products being disposed of in the wastewater system.

6.2.2 Nutrients

6.2.2.1 General

TWW can contain nutrients, including other chemical elements, in higher concentrations than normally found in freshwater. The TWW contains macro elements (elements consumed by the plant in large quantities – kg/hectare), mainly nitrogen and phosphorus. Potassium in TWW is generally found at concentrations which are lower than agronomic demands.

Nutrients within TWW, intended for the irrigation of crops, are usually referred to as a resource substituting chemical fertilizers that the farmer might make use of. However, the following three major questions arise as to the efficiency of replacing conventional plant fertilizers with the chemicals found in the TWW (i.e. the fertilizing value of the TWW).

- Quantity: Does the amount of nutrients provided by the TWW supply the needs of the plant?
- Availability: Can nutrients in the TWW be absorbed by the plants in the same way that nutrients normally supplied by the fertilizer are absorbed?

— Timing: Is the rate at which nutrients can be supplied during the season optimal for the crop?

The amounts of nitrogen and phosphorus applied with the TWW are the result of multiplying their concentration in the water by the volume of irrigation water provided to the crop. Since the quantity of irrigation water is determined by the climate conditions and crop requirements, the applied amount of nutrients will be directly related to the nutrient's concentration in the TWW for certain crops and regions.

6.2.2.2 Nitrogen

The nitrogen supplied in the TWW is added to the nitrogen found in the soil and enters the nitrogen cycle in the soil. The TWW can contain organic nitrogen, ammonium (NH_4^+), and nitrate (NO_3^-). In the soil, the organic nitrogen and ammonium turn into nitrate by the nitrification process. This way, most of the nitrogen in the TWW becomes available for the plants and can substitute the nitrogen forms supplied by commercial fertilizers. Only a part (depending on climate and soil conditions, crop, and forms of nitrogen) of the nitrogen applied to the soil supplied by commercial fertilizers, organic residues, or wastewaters is absorbed by the plants. Nitrate (NO_3^-) might be lost by percolation, especially in sandy soils. Under high pH conditions, in lime (high CaCO_3 content) soils, during irrigation, some of the ammonium (which the TWW contains) on soil surface might turn into ammonia (NH_3 -gas) and evaporate into the atmosphere.

Irrigation with TWW might result in nitrogen supplied at a type and frequency which does not coincide with cultivation requirements. When using freshwater, the grower fertilizes at varying concentrations through the cultivation period; however, in late ripening or maturity stages, it is customary to stop the nitrogen fertilizing altogether. Where TWW is concerned, the farmer cannot control the nitrogen concentrations, which are determined by the water source and the treatment level.

On the other hand, the increase of nitrogen concentration might decrease the pernicious effects of salinity to crop yield.

Some forms are highly soluble in water and can leach to ground water or flow with the surface runoff thus, affecting water sources and damaging the quality of surface water.

6.2.2.3 Phosphorus

The amount of phosphorus applied with secondary TWW is generally higher than the amount removed by most agricultural crops. Under high pH conditions, the mobility of phosphorus in the soil is limited and it tends to accumulate in the upper soil layers by various mechanisms according to soil properties (for example, soil's pH). In the case of phosphorus, the significance of application timing in these soils is less important. However, in acid soils (pH lower than 7), the mobility of phosphorus increases and in some cases, the timing of application can be relevant as with the nitrogen.

6.2.2.4 Potassium

The mobility of potassium in the soil is limited and is less than the mobility of phosphorous. The increase of potassium concentration might decrease the pernicious effects of salinity to crop yield but to a lesser extent than for nitrogen.

6.2.3 Salinity

TWW contains higher concentrations of inorganic dissolved substances than background water: total soluble salts, sodium, chloride, and boron which are likely to cause damage to the soil and the crop.

The main parameters in defining the quality of TWW with respect to salinity are

- total content of salts due to osmotic effect,
- concentration of chlorides, boron, and sodium for its specific toxicity, and
- sodium adsorption ratio (SAR) due to soil permeability issues.

6.2.4 Other elements

Examples of other chemical elements present in a natural environment at low concentrations though relevant for irrigation with TWW include fluoride, silicon, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, selenium, molybdenum, strontium, iodine, boron, and cadmium. This group of elements contains metals whose specific weight is relatively high, iron, chromium, mercury, molybdenum, lead, strontium, copper, zinc, manganese, nickel, cadmium, and cobalt. These elements differ in behaviour from the other elements.

Although wastewater treatment plants (WWTPs) are not designed to treat these metals, they are effectively removed from the liquid phase to the solid phase (sludge). These elements are adsorbed to organic and inorganic substances or create low-solubility sediments due to high pH, water hardness, and alkalinity.

6.2.5 Microorganisms

Wastewater sources for the reuse project originating from human or agricultural activities can contain microorganisms (bacteria, viruses, helminthes, and protozoa) that some of them are pathogens. The wastewater treatment plants reduce the concentration of the microorganisms but might not eliminate them. The remaining concentration of microorganisms depends on the treatment level of the wastewater.

Monitoring the concentration of all the microorganisms in the TWW is practically impossible; therefore, what is monitored is the concentration of microbial indicators. In this part of ISO 16075, the suggested indicators are thermo-tolerant coliforms, which include faecal coliforms or *Escherichia coli* (E. coli), as is customary in each country.

The barriers that will be used thereafter are an effective way to secure health and safety.

The design of any reuse project should ensure the general protection for population such as the workers and consumers who are exposed to the water and to the fruits and vegetables. This part of ISO 16075 describes a method that combines microbiological indicators and barriers concept (ISO 16075-2[10]) and monitoring protocols (ISO 16075-4[12]).

6.3 Climate

TWW is an important water source for farmers in arid and semi-arid climates[1]. The wastewater might be the only water source available for agriculture in some cases. Guidelines are established based on scientific knowledge obtained from arid and semi-arid climates, as it refers to Reference [2] and Reference [1]. However, the behaviour of substances (nutrients, heavy metals, microbes and chemicals) in soils supplied with irrigation water is strongly affected by soil conditions, crops, rainfall and evaporation that vary widely in response to climate. In addition, the climatic conditions also affect sanitary conditions. For this reason, it is necessary to assess irrigation related parameters and how they can be controlled according to climatic conditions.

Reference [3] classifies climate using the Aridity Index (AI) as shown in Table A.1. AI is defined as the ratio of precipitation to potential evapotranspiration as given in Formula (1):

$$AI = P / PET \quad (1)$$

where

P is the precipitation;

PET is the potential evapotranspiration estimated by the Penman-method.

Potential evapotranspiration depends upon the crop and two of the simple formulas used to determine it are Formula (2) and Formula (3) below:

$$ETp = Ep + Tp \quad (2)$$

where

Ep is the potential soil evaporation (mm/d);

Tp is the potential plant transpiration (mm/d).

$$ETp = kc \cdot ETref \quad (3)$$

where

ETp is the potential evapotranspiration rate (mm/d);

kc is the crop coefficient;

$ETref$ is the reference evapotranspiration rate (mm/d).

More complex formulas that take into account different parameters and have been developed from the original equations produced by Penman, Monteith[8], Feddes, Smith[9], and others are also available.

The effect of salts and heavy metals on soils and crops as described in this guide mainly target arid and semi-arid areas with AIs of 0,05 to 0,50. Potential evapotranspiration surpasses precipitation by far in these climates so preventing the accumulation of salts and heavy metals caused by irrigation water is an important issue. In contrast, climate areas where precipitation exceeds potential evapotranspiration ($AI > 1,0$) can be tolerant to the accumulation of salts and heavy metals because soil water is transported in a downward direction and leaches out the salts. In regions where groundwater is present, however, leaching of soluble salts, nutrients, and heavy metals from the upper soil could induce groundwater pollution. Additionally, the frequency and amount of rainfall during the planting season affect the criteria and monitoring strategies of the substances that will be monitored for hygienic management.

It should be noted that arid areas can occur in countries that can generally be humid due to regional rainfall variations. Hence, guidelines should only be developed or adopted for each area after understanding the climatic and regional characteristics.

6.4 Soil

6.4.1 General

The risks of TWW irrigation mainly depend on the local site properties and the water quality. Soil sensitivity is an inherent characteristic of each soil and is independent of water quality. The inherent soil quality is governed by the soil-forming process and each soil has a natural sensitivity to water quality.

Site acceptability should be based on pertinent soil and geologic properties, topography, hydrology, climate, zoning, and cropping intentions.

A site is classed as suitable for wastewater application if it is found to possess hydrogeological, soil, climatic, and physical characteristics that enable effective utilization of the TWW applied without causing future damage to the land base or to the underlying groundwater.

Site conditions should also be such that they effectively restrict any detrimental offsite movement of the wastewater through leaching, groundwater migration, surface runoff, or drift from irrigation spray.

The main soil characteristics determining soil sensitivity to water quality are: texture, pH, organic matter content, bulk density, hydraulic conductivity and water retention capacity. Many soil indicators interact with each other and thus, the value of one is affected by one or more of the selected parameters.

The most important soil-related agricultural risks associated with TWW irrigation are presented in [Table A.2](#).

6.4.2 Mobilization of inorganic adsorbable contaminants

The risk of heavy metals mobility in soils increase with a decrease in pH values below 7. If the soil has higher amounts of organic matter and clay contents, it is expected that its mobility in soil will be reduced. However, an accumulation of heavy metals might occur at the top layer of the soil at high pH values.

6.4.3 Slaking of the upper soil layer

The sensitivity of the top soil to slaking is dependent on the texture. Soils with high silt content are more sensitive to slaking and splash effects on the soil surface, which can lead to reduced infiltration at higher runoff rate. The amount of soil organic matter is also important for stabilizing the soil structure. A higher amount of organic matter has a positive effect on the stability of the soil surface. However, other parameters such as clay mineralogy, oxides/hydroxides, carbonates, etc. have to be taken under consideration. The inherent sensitivity of the soil towards slaking is not to be confused with the potential sensitivity to soil dispersion as a consequence of high sodium adsorption ratios (SAR) in the soil as a result of high sodium concentration and SAR value in the TWW. Soil having high amount of clay content is more sensitive to the increase adsorbed sodium.

6.4.4 Salinization of soils

Salinization is the process of accumulation of salts in soils and is favoured by low leaching rates. Leaching rates are dependent on the water retention capacity of the soil, the hydraulic conductivity, the amount of precipitation and the irrigation water applied, as well as evapotranspiration. For the same rates of precipitation and evapotranspiration in a sandy soil, more water will move below the root zone than in a clayey soil. Preventing salt accumulation in clay and low-permeability soils is more difficult. Drainage is another important factor regarding salinization, as the dissolved salts have to be leached from the root zone^{[4][5]}.

6.4.5 Mobilization and accumulation of boron

Boron transport in soils and boron available for plant uptakes depend on boron concentration in the soil solution^{[4][5]}. Boron in soil solution is determined by

- a) soluble boron entering the soil-water system (irrigation water), and
- b) adsorption-desorption reactions on the soil solid phase.

Assuming that the same water quantity is applied with the same boron concentration, the adsorption of boron depends on soil characteristics such as clay content and mineralogy, aluminium and iron oxides content, and organic matter content.

The higher the clay content is, the higher the quantity of boron adsorbed. The adsorption depends on the clay minerals type: montmorillonite soils, for example, adsorb less than kaolinitic soils. Similarly, the higher the organic matter is the higher quantity of the boron adsorbed.

In contrast, the higher the adsorption of boron, the lower the concentration in the soil solution and therefore, the risk of an immediate toxic effect decreases. Accordingly, in soils that are rich in clay and organic matter content, the immediate risk of boron toxicity to plants is lower. If the period of irrigation with water rich in boron is prolonged, clay and organic matter can reach saturation and can result in boron toxicity.

As was previously mentioned, undesirable soluble salts, including boron, can be removed by excessive irrigation water applied for this purpose. The capacity for leaching boron is a function of water content and water movement in soils and it is affected by boron adsorption-desorption processes. In general, the amount of water needed to leach boron is much higher than that needed to remove non-reactive solutes (such as chloride). It is more difficult to leach boron if the water retention is high and the hydraulic conductivity (clayey soils) is low.

6.4.6 Groundwater pollution

Non-adsorbable substances such as nitrate and chloride can cause problems when leached to the groundwater and largely depend on the leaching rates at the site. Lower leaching rate results in longer retention time of the soil water within the rooting zone, allowing the possible uptake of part of the nitrate by plants. The leaching behaviour according to soil characteristics is assessed in relation to salts leaching.

6.4.7 Phosphorus accumulation and mobility

Several soil factors are evolved in phosphorus retention and mobility in soils. The various factors fall into the following groups:

- a) characteristics and amount of soil components (clays, organic matter, oxides);
- b) pH;
- c) other ions;
- d) kinetics;
- e) saturation of the sorption complexes.

Higher content of clay and hydroxides results in higher absorption and fixation of phosphorus, which increases its accumulation and decreases its mobility. Kaolinitic soils retain higher concentration of phosphorus than montmorillonitic soils.

In general, an increase in the pH decreases phosphorus mobility. Phosphorus availability is at its maximum at pH range of 6,0 to 6,5. At lower pH values, the retention stems from the reaction with iron and aluminium. Above pH 7,0 the ions of calcium and magnesium, as well as the presence of carbonates, result in precipitation of the added phosphorus.

7 Different effects on public health, soil, crops, and water sources

7.1 Public health effects

Public health risks resulting from irrigation with TWW that contain pathogens can originate from several transmission ways from the TWW to the population, including the following:

- a) contamination of food and fodder crops irrigated by the TWW;
- b) transmission of pathogens in the air when the irrigation is performed by spraying the TWW;
- c) direct contact of the workers and the general public with the TWW.

Some elements (i.e. selenium) that are naturally taken up by some food crops can adversely affect human and animal health.

ISO 16075-2^[10] will present the ways to protect the public health of the workers, the general public, and the livestock when TWW of different levels of qualities is used for irrigation.

7.2 Effects on soil and crops

7.2.1 Effect of nutrient levels

The determination of maximum levels of nitrogen and phosphorus in the TWW intended for irrigation is important to prevent surpluses likely to cause damage to the crop or the environment (see example in [Table B.1](#)). It should be noted that the concentrations might need to be adjusted in climate areas where water consumption by crops is significantly different (either higher or lower) due to differences in evapotranspiration. However, despite differences in climate and water consumption, there should be no difference in the consumption of nutrients by the crop per unit area.

The fertilization plan should take into account the quantity of nutrients in TWW used for irrigation.

7.2.2 Effect of water salinity

7.2.2.1 Effect of salt concentration in the soil solution on the crops

One of the possible effects of a high concentration of salts in TWW is a surplus of salts in the soil solution, which causes a change in the soil solution's properties and especially reduces its osmotic potential. A decrease in the osmotic potential of a solution outside the plant's root cells reduces the gap between the water potential in the soil and the plant and as a result, water availability to the plant might diminish and negatively affect the crop. Osmotic potential (ψ_o), electrical conductivity (EC), total anions or cations, and total dissolved salts are related as follows:

$$\psi_o (\text{atm}) = \text{EC} (\text{dS/m}) \times (-0,36)$$

$$\text{Total cations concentration (meq/L)} = \text{Total anions concentration (meq/L)} = \text{EC (dS/m)} \times 10$$

$$\text{Total dissolved solids (ppm or mg/L)} = \text{EC (dS/m)} \times 640$$

Agricultural crops significantly differ in their tolerance to the concentrations of salts dissolved 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). Above the threshold salinity value, the yield decreases as a linear function of salinity until the plant dies when it drops sharply to zero.

7.2.2.2 Effect of salinity on the direct injury to the foliage in sprinkler irrigation

Overhead sprinkling can cause toxicity effects on the foliage when using saline water with subsequent burning of leaves and ultimately, defoliation. Maximal electrical conductivity in water for overhead sprinkling depends on the crop foliage tolerance to salinity (see example in [Table B.2](#)).

In order to prevent negative effects of water salinity on the foliage, either high tolerant crops should be selected or the following actions are recommended:

- a) irrigating during the night;
- b) irrigating during low temperature and low windy periods;
- c) increasing the application rate (but keeping it lower than the soil infiltration rate);
- d) decreasing the irrigation frequency;
- e) changing the irrigation systems to, e.g. micro-irrigation systems, under canopy sprayers;
- f) increasing the size of the water drop (decreasing the sprayer degree or decreasing pressure).

This crop toxicity is due to excess of sodium or chloride ions absorbed through the leaves wetted by the overhead sprinklers. [Table B.3](#) shows the guidelines of the tolerance of several crops, according to sodium and chloride concentration when overhead sprinkler irrigation is used. Susceptibility of crops is based on direct accumulation of salts through the leaves.

7.2.2.3 Effect of sodium on the soil properties

The indirect damage caused due to the sodicity of soils and the harm to their structure and water-conductivity properties (deficient infiltration of rainwater or irrigation water and improper water movement in the soil, leading to drainage and aeration problems) is even more common than the direct damage caused to crops as a result of salinity.

The adsorbed ion and electrolyte concentration are the main causes affecting soil structure. It is customary, while examining the connection between cation composition in the soil solution and its hydraulic properties, to refer to the concentration ratios of sodium, calcium, and magnesium (which are the most common cations in the irrigation water and the soil) rather than the absolute concentration of sodium. The destructive effect of adsorbed sodium on the agricultural properties of the soil and the positive contribution of calcium and magnesium are well known. Sodic soils are soils where the exchangeable sodium percentage exceeds 15 % and where the electric conductivity of their solution is lower than 4 dS/m. According to this definition, the value ESP = 15 % (exchangeable sodium percentage) is considered a “critical threshold value”. When the ESP is higher than this critical value, the soil can exhibit properties of a sodic soil, i.e. considerable swelling and even dispersion of the clay, impaired hydraulic conductivity, poor aeration, drainage difficulties, and cultivation problems. Following this approach, the “sodium adsorption ratio” has been determined as follows:

$$SAR = \frac{(Na)}{\sqrt{\frac{1}{2}(Ca + Mg)}} \quad (4)$$

Formula (4), calculated from the concentration of sodium, calcium, and magnesium [(Na⁺) = sodium concentration in mEq/l; (Ca²⁺+Mg²⁺) = concentration of calcium + magnesium in mEq/L] in the soil saturated paste extract, is a useful diagnostic for predicting issues of soil sodicity (high levels of sodium) caused by irrigation water. It is also useful for forecasting the hazard of soil sodicity by irrigation water and for assessing the level of sodium adsorbed in the soil. The connection between ESP and SAR is expressed in Formula (5):

$$ESP = 100(-0,0126 + 0,0475SAR) / 1 + (-0,0126 + 0,01475SAR) \quad (5)$$

At levels higher than the “critical threshold value” presented above, the soil’s hydraulic conductivity changes with solutions at different SAR levels, a threshold value for each combination of electrolyte and SAR value has been determined. The threshold value has been defined as the SAR level in a given concentration of salts that causes a significant decrease in water permeability to the soil. In other words, a threshold value is not constant and therefore, can be lower than 15 [mEq/L]^{1/2}.

The connection between SAR and concentration of salts can also be affected by soil properties (mainly clay mineralogy and organic matter content).

Typical SAR and electrolyte concentration values (measured by electrical conductivity) that may be used to determine the likelihood of developing a problem with water permeability through the soil are presented in [Table B.4](#).

7.2.3 Effect of a specific toxicity of certain ions

7.2.3.1 General

In addition to the effect of the total salt concentration (osmotic effect), some of the ions in the soil solution might present a potential for damaging the agricultural crops irrigated by TWW. The absorption of such ions by the crop and their accumulation in the plant might lead to reduced yield to the level of plant withering.

7.2.3.2 Chloride effect

Chloride is an essential nutrient for plants for balancing ionic charges and for osmotic regulation. Moreover, it serves as a counter ion in cation transport in the plant and contributes to cell hydration and

turgor. Chloride is supplied to the plants by a number of sources: the soil, rain, irrigation, fertilizers, and air pollution. Under normal cultivation conditions, chloride toxicity is more common than deficiency, which is also the case in TWW irrigation. Plants vary significantly in their sensitivity to chloride concentration. On the other hand, trees are generally sensitive to excess chloride. The tolerance of crops differs among species, varieties, and rootstocks of the same crop. The differences between rootstocks usually reflect their ability to prevent or hinder the chloride movement from the roots to the foliage and its accumulation there.

7.2.3.3 Boron effect

Boron is an essential element for the normal growth of plants. It is involved in a large number of plant processes: cell division and elongation, nucleus acid metabolism, the metabolism and transport of sugars regulating photosynthesis and respiration. Its presence is vital for the hormonal system, and it is found in cell membranes. Where TWW irrigation is used, Boron is common. In excess, Boron is toxic for plants, causes chlorosis at plant tips, and during later stages its leaves begin to fall and the plant can even perish.

7.2.3.4 Sodium effect

Abnormal concentrations of sodium in the TWW might directly affect the plants due to sodium toxicity. This toxicity mainly affects fruit trees (avocado, citrus trees, and deciduous stone trees: plum, peach, apricot) at concentrations exceeding 5 mEq/L (120 mg/L)^[6]. In non-saline sodium-rich soils, calcium deficiencies might appear, as well as magnesium in herbaceous plants. The main effect of sodium in TWW is on soil structure and indirectly on soil aeration and water movement in it.

The values for maximum levels of salinity factors in TWW for irrigation presented in [Table B.5](#) are in accordance with experiences in Israel.

7.2.4 Effect related to other chemical elements

Adding other chemical elements to the soil in an uncontrolled way is undesirable because if they accumulate in the soil, it will be difficult to subsequently remove them and they are likely to cause toxicity to the plants, excess absorption by the crops followed by accumulation of toxic levels of other chemical elements in plant tissues (such levels are considered hazardous for humans or animals consuming the crop), and movement of other chemical elements into the ground water

Average arithmetic values and maximum values are presented in [Table B.6](#).

Sometimes the values are more significant (lower maximum values) in soils of acidic pH due to the high availability of heavy metals.

7.2.5 Recommendations to manage the effects on soil and crops

7.2.5.1 Recommendations to avoid damage by sprinkling above the foliage

In order to increase the crop tolerance, the following actions are recommended:

- a) selecting high tolerant crops;
- b) irrigating during the night;
- c) irrigating during low temperature and low windy periods;
- d) increasing the rotation speed of the sprinklers;
- e) increasing the application rate (but keeping it lower than the soil infiltration rate);
- f) decreasing the irrigation frequency;
- g) changing the irrigation system to one where water does not contact foliage, e.g. micro-irrigation systems, etc;

h) increasing the size of the water drop (decreasing the sprayer degree).

7.2.5.2 Management techniques to avoid damage from salt accumulation in the soil

To overcome damage from salt accumulation in the soil, management techniques need to be implemented. Some practices can be used to control salinity within the crop root zone. The “on-farm” practices usually consist of agronomic and engineering techniques applied by the farmer on a field-by-field basis^[4].

7.2.5.2.1 Management principles

Management practices for the safe use of irrigation water (and TWW in particular) for irrigation primarily consists of the following:

- selection of crops or crop varieties that will produce satisfactory yields under existing or predicted conditions of salinity or sodicity;
- special planting procedures that minimize or compensate for salt accumulation in the vicinity of the seed;
- irrigation to maintain a relatively high level of soil moisture and to achieve periodic leaching of the soil;
- use of land preparation to increase the uniformity of water distribution and infiltration, leaching and removal of salinity.

The crop grown, the quality of water used for irrigation, the rainfall pattern and climate, and the soil properties determine to a large degree the kind and extent of management practices needed.

7.2.5.2.2 Selection of crops or crop varieties

Where salinity cannot be kept within acceptable limits by leaching, crops should be selected so that they can produce satisfactory yields under the resulting saline conditions. In selecting crops, particular attention should be given to the salt tolerance of the crop during seedling development because poor yields frequently result from failure to obtain a satisfactory stand. Some crops that are salt tolerant during later stages of growth are quite sensitive to salinity during early growth.

TWW projects can be programmed to a region with existing agricultural crops. If they are annual crops, varieties can be changed to suit the water quality. However, in perennial crops such as fruit trees, change can be more difficult and come at a high economic cost. If, during TWW project, programming is developed a new irrigation area, programmers should take into account the growth of crops suitable to the water quality.

7.2.5.2.3 Special planting procedures

In many cases, failure to obtain a satisfactory stand of furrow-irrigated row crops on moderately saline soils is a serious problem, owing to the fact that the rate of germination is reduced by excessive salinity. The failures are usually due to the accumulation of soluble salt in raised beds that are “wet-up” by furrow irrigation.

Modifications in irrigation practice and bed shape should be used to reduce salt accumulation near the seed. The tendency of salts to accumulate near the seed during irrigation is greatest in single-row, round-topped beds. Sufficient salt to prevent germination can concentrate in the seed zone even if the average salt content of the soil is moderately low.

Planting in furrows or basins is satisfactory from the standpoint of salinity control but is often unfavourable for the emergence of many row crops because of problems related to crusting and poor aeration.

7.2.5.2.4 Irrigation practices

Some soil and water salinization is inevitable with irrigation; the salt contained in the irrigation water remains in the soil as the pure water passes back to the atmosphere through the processes of evaporation and plant transpiration. Therefore, water in excess of evapotranspiration shall be applied with irrigation to achieve leaching and prevent excess salt accumulation.

To prevent the excessive accumulation of salt in the root zone from irrigation with TWW, extra water (irrigation water or rainfall) shall, over the long term, be applied in excess of that needed for evapotranspiration (ET) and shall pass through the root zone in a minimum net amount. This amount, in fractional terms, is referred to as the “leaching requirement” (LR), the fraction of infiltrated water that shall move through the root zone to keep salinity within acceptable levels.

In fields irrigated to steady-state conditions with conventional irrigation management, the salt concentration of the soil water is essentially uniform near the soil surface regardless of the leaching fraction (LF), the fraction of infiltrated water that actually passes through the root zone but increases with depth as LF decreases. Similarly, average root zone salinity increases as LF decreases; crop yield decreases when tolerable levels of salinity exceed.

Methods to calculate the leaching requirement and to predict crop yield losses due to salinity effects are described in manual texts cited in the bibliography for further reading. Once the soil solution has reached the maximum salinity level compatible with the cropping system, at least as much salt as is brought in with additional irrigations shall be removed from the root zone. This process is called “maintaining the salt balance.”

The time-averaged level of root zone salinity is affected by the degree to which the soil water is depleted between irrigations, as well as by the leaching fraction. As the time between irrigations increases, soil water content decreases as the soil dries and the matric and osmotic potentials of the soil water decrease as salts concentrate in the reduced volume of water. Water uptake and crop yield are closely related to the time and depth averaged total soil water potential, i.e. matric and osmotic. This implies that

- forms of irrigation that minimize matric stress, such as drip irrigation, can be used to minimize the harmful effects of irrigation with saline water, and
- leaching fractions can be used to minimize the buildup (hence harmful effects) of high levels of salinity in the root zone.

The distribution within and the degree to which a soil profile becomes salinized are also functions of the manner of water application, as well as the leaching fraction. More salt is generally removed per unit of leachate with sprinkler irrigation than with flood irrigation. Thus, the salinity of water applied by sprinkler irrigation can be somewhat higher, all else being equal, than that applied by flood or furrow irrigation with a comparable degree of cropping success, provided foliar burn is avoided.

The distribution of salts in the soil is also influenced by seedbed shape. Salts tend to accumulate to excess levels in certain regions of the seedbed under furrow irrigation. Seedbed and furrow shape can be designed to minimize this problem. Seed placement and surface irrigation strategies (e.g. alternative furrow, depth of water in furrows, etc) can also be used to optimize plant establishment under saline conditions. Sprinkler irrigation can be effective in leaching excessive salinity from the top-soil and in producing a favourable low-salinity environment in the upper soil layer which is necessary for the establishment of salt-sensitive seedlings. Under drip irrigation, the salt content is usually lowest in the soil immediately below and adjacent to the emitters and highest in the periphery of the wetted zone. Removal of salt that has accumulated in this wetting zone front should be addressed in the long term.

7.2.5.2.5 Conjunctive use of waters of different qualities

It is possible to use TWW in conjunction with other water to lessen the effects of salts. However, priority should be given to improving the quality of TWW by decreasing salt content during wastewater formation, before turning to the possibility of using dilution strategies which will be presented below^[5].

Blending: The mixing of TWW (or saline water) and non-saline water can result in a composite water suitable for irrigation. Adopting this strategy means that two mixing processes are possible; network blending or soil blending. Network blending means that water supplies are blended within the irrigation conveyance system. Soil blending means that two different water qualities are irrigated alternatively and the soil acts as the mixing media.

Cycling: Utilizing the water with the higher salinity (TWW) when irrigating salt tolerant crops in the rotation or when irrigating a salt sensitive crop during a salt-tolerant growth stage. The lower salinity water is used at all other times of growth.

Warning: In both strategies, the possibility that TWW will penetrate another water system with consequent health risk is plausible, especially if one of the systems supplies drinking water or is connected to a drinking water system. Creating a mechanical separation, such as an air gap, between any non-potable water system and drinking water system will avoid those risks. One possibility is pouring the drinking water to a separate tank and then pumping them to the TWW irrigation system.

7.3 Effects on water sources

7.3.1 General

Irrigation systems using TWW should not be considered in areas of hydrogeological vulnerability (i.e. with high risk of infiltration and percolation of surface water and areas providing surface water for drinking water systems). Due to possible ruptures or leaks in the TWW transport pipelines and the distribution system to the irrigated fields, the TWW leaks could reach the aquifer water or the surface water and contaminate it.

To prevent this risk, it is required to separate the TWW main supply lines from the drinking water sources (wells) at such a distance that will ensure that TWW does not flow directly to the wells and that TWW seeping to the soil will require at least 40 d to reach the well (the time during which annihilation of the pathogenic pollutants will occur). The good management practices to protect drinking water sources are presented in ISO 16075-3[11], 6.6.

The effects of nutrients concentration in TWW on water sources pose two main risks, such as

- a) leaching of phosphorus in acid soils, as well as nitrogen in all soils to the groundwater, and
- b) runoff of phosphorus from the upper layer of the soil in high pH soils to surface water sources.

NOTE When nitrogen and phosphorus are removed from the wastewater, these precautions can be reduced.

The increasing shortage of freshwater for agriculture requires the use of water sources of lower chemical and biological quality. The main source of such water is reclaimed water (i.e. TWW). The purpose of this subclause is to recommend criteria that will enable agricultural irrigation with TWW while, at the same time, minimizing the hazards to natural water sources.

7.3.2 Principles for protection of water sources

- a) Some of the difficulties facing those engaged in soil and hydrology are the heterogeneity and variation of natural systems. It is extremely difficult to refer to a local soil profile as being heterogeneous and even more difficult to generalize an entire field and certainly compare one field to another. Hence, this part of ISO 16075 is only a guideline and it does not substitute the need to conduct individual tests on a specific TWW to monitor the water sources and the systems supplying them to prevent their pollution. This part of ISO 16075 suggests the essential minimal requirements for TWW irrigation. In all cases, a more thorough study of the local hydrology should be undertaken.
- b) This part of ISO 16075 aims to combine maximum protection of water sources with practical and easily applicable methods regarding criteria and testing methods.

- c) This part of ISO 16075 assumes that a primary source of TWW is from a municipal sewerage system. Hence, it is likely that the TWW contains a fairly specific variety of contaminants typical in most municipal wastewaters. The use of industrial wastewater would require additional criteria.

The water quality parameters are described using maximum concentration values of substances in order to prevent or minimize damage to the soil, crop, and water sources (surface or groundwater), or public health hazards. The following is the classification of these parameters:

- agronomic parameters: nutrients (nitrogen, phosphorus, and potassium) and salinity factors (total salt content, chloride, boron, and sodium concentration);
- other chemical elements (heavy metals);
- microbial parameters.

These parameters relate to the possible impacts each factor has, as well as to the possibility of preventing the contaminants' input during wastewater production and the ability to remove them during the course of treatment.

This guideline suggests guide values for the concentration of the most representative contaminants of each of the four groups (nutrients, heavy metals, salts, and organic micro-pollutants) and for the parameters that express salinity (EC and TDS).

- It should be clarified that it is practically impossible to create an International Standard which includes examples of threshold values of all potential contaminants found in wastewater. Therefore, as mentioned above, it is suggested that users determine levels for a number of representative elements out of the said four groups of contaminants, combined with a definition of the treatment level. Compliance with these threshold levels will, in most cases, ensure the protection of natural water systems. However, the levels might need to be adjusted for the relevant conditions of specific sites.
- The protection of natural water sources is possible only by preventing contaminants from reaching them. The time of reaching is not relevant where most contaminants are concerned (except in the context of degradable contaminants, pathogens, and mainly organic micro-pollutants). A physical barrier such as a plastic liner should prevent water permeation or leaching. In applications where the discharge of TWW is permitted and regulated a physical barrier is not required.
- Surface runoff flows at higher speeds, in terms of magnitude, than underground currents. As a result, it creates a potential immediate hazard to water sources. Hence, the aim should be to reduce the direct flow of TWW to drainage channels during rain. Therefore, the classification of hazards to surface water sources is based on estimations of the amounts of TWW which will flow, directly or indirectly, to surface drainage systems. There is a distinction between situations where the irrigation system is well designed (in which irrigation frequencies comply with the soil properties) so that no surface runoff is expected during irrigation and between less efficient irrigation systems. However, even in an optimally-design system, there is a chance of runoff. Therefore, the situation defined as "with no runoff" also includes the possibility where the volume of runoff from irrigation is less than 5 % of the irrigation water.
- The principle for underground contaminants is for them to move in the non-saturated zone but not reach any groundwater. The adsorption of contaminants, and mainly salts (cations) and heavy metals in the soil, takes place mainly by and on the surface of clays. Retention time is also controlled by the soil's composition and mainly the content of clay. Therefore, the main index to be used for characterizing soils by suitability for treated-wastewater irrigation is the content of clay. It should be emphasized that this is only an approximate index. In order to define a measurable and simple parameter, it is suggested to use the average clay content to a depth of 2 m as the index of the site's sensitivity to ground water pollution.

7.3.3 Examples of groundwater sensitivity groups

[Annex C](#) provides examples for sensitivity groups for protection of ground water.

7.3.4 Examples of surface water sensitivity groups

The surface water sensitivity groups are separated according to the extent of water flow, directly or indirectly, from irrigation water to drainage systems leading to natural water systems. Therefore, the category of water sensitivity needs to be determined. The category of the highest sensitivity (I) to a system is where there is surface runoff during irrigation or surface accumulation which is likely to wash in rain events. The correct design and operation of an irrigation system should, in principle, prevent such situations. Sensitivity groups II, III, and IV assume that surface runoff is not created during irrigation. Sensitivity group II includes systems which have an effective shallow underground drainage system (at a depth of 80 cm or less). In such systems, a considerable part of the irrigation water is drained to surface drainage systems immediately on irrigation completion. Sensitivity group III includes deep drainage systems (over 80 cm), where irrigation water is drained to surface drainage systems but only after retention in the underground. Sensitivity group IV, the lowest from the aspect of surface water, is a system which does not include underground drainage at all. It is important to understand that the three last categories are based on the assumption that the design and operation of the irrigation system prevents direct surface runoff of irrigation water. The passage in the underground section creates filtration of contaminants, similar to the underground-water risk criteria. The existence of effective land drainage reduces the water content from the soil but might lead to increased loads on surface water systems. Currently, this part of ISO 16075 does not deal with any surface runoff as a result of rain that leaches contaminants from the upper soil layer.

7.3.5 Summary of examples of criteria

Risk level to define examples of contaminants threshold in TWW is displayed in [Table C.1](#).

Annex A (informative)

Examples of climate and soil criteria

Table A.1 — Climate classifications using the aridity index (AI)^[3]

Climate	AI value	Annual precipitation	Interannual rainfall variability	Remark
Hyper-arid	$AI < 0,05$		$<100\%$	Annual moisture deficit
Arid	$0,05 < AI < 0,20$	$<200\text{ mm}$	50 % to 100 %	
Semi-arid	$0,20 < AI < 0,50$	$<800\text{ mm}$ (in summer) $<500\text{ mm}$ (in winter)	25 % to 50 %	
Dry sub-humid	$0,50 < AI < 0,65$	High seasonal rainfall	$<25\%$	
Humid	$0,65 < AI < 1,00$	High rainfall	—	Annual moisture surplus
	$1,00 < AI$			Too cold for crops to grow
Cold mountain	—	—	—	

Table A.2 — Overview of soil-related risks (modified from Reference [7])

Risks	Criteria	Soil parameters affecting the behaviour in soils
Mobilization of inorganic adsorbable pollutants	Buffering capacity for inorganic adsorbable pollutants (e.g.: heavy metals)	Texture, organic matter, and pH
Slaking of the upper soil layer	Slaking of the upper soil layer	Texture and organic matter
Salinization of soils	Salinization of soils	Texture, bulk density, depth of root zone, soil depth, field capacity, saturated hydraulic conductivity, and leaching rate
Mobilization of boron	Buffering capacity for boron	Texture, organic matter, and pH
Groundwater pollution	Buffer capacity for non-adsorbable substances (e.g. nitrate)	Texture, organic matter, and pH
Accumulation and mobility of phosphorus	Accumulation or leaching of phosphorus in soils	Clay content and mineral, oxides, organic matter, and pH

NOTE High mobility of heavy metals is expected in acid soils, which are common soils in humid areas.