# INTERNATIONAL STANDARD

# ISO 16075-1

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# 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 dans les projets d'irrigation —*

*Partie 1: Les bases d'un projet de réutilisation pour l'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).

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

This document was prepared by Technical Committee ISO/TC 282 *Water reuse*, Subcommittee SC 01, *Treated wastewater use for irrigation*.

This second edition cancels and replaces the first edition (ISO 16075-1:2015), which has been technically revised. The main changes compared to the previous edition are as follows:

— updating the subject of public and private gardens irrigation by treated wastewater (TWW);

— added Annex A (New)- Examples of means to improve TWW quality.

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

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

# Introduction

The increasing water scarcity and water pollution control efforts in many countries have made treated municipal and industrial wastewater a suitable option for augmenting the existing water supply, especially when compared to 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.

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 treated wastewater 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.

An important new concept in water reuse is the "fit-for-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 to 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 water reclamation processes and operation.

Agricultural irrigation was, is, and will likely remain the largest reused 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.

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 guidelines for the use 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, concentration of heavy metals, 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 the 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:

— adequate 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.

This document 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 published, it is recommended to reference this document to ensure uniformity throughout the treated wastewater use community.



 

# Guidelines for treated wastewater use for irrigation projects —

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

## 1 Scope

This document 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 this document is to provide guidance on all elements of a project using TWW for unrestricted and restricted irrigation, including design, materials, construction, and performance, when used for the following:

— irrigation of agricultural crops;

— irrigation of public and private gardens and landscape areas, including parks, sport fields, golf courses, cemeteries, etc.

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 of professionals, such as irrigation companies (designers and operators), agricultural extension officers or advisors, water companies (designers and operators), local authorities and water utilities. The use of these guidelines by users might require additional specifications.

None of the parts of this document 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), salinity factors (total salt content, chloride, boron, and sodium concentration) and heavy metals' concentration;

— pathogen presence.

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

Contaminants of emerging concern (such as pharmaceuticals and personal care product residuals) are outside the scope of this document since up to day, there is no evidence of adverse effects on human health or environment via irrigation with TWW or via the consumption of crops irrigated with TWW.

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.

## 2 Normative references

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

ISO 20670:2018, *Water reuse — Vocabulary*

## 3 Terms, definitions, and abbreviated terms

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

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

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

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

### 3.1 Term and definitions

**3.1.1**
**additional disinfection**
disinfection of TWW in a water reuse project intended to raise the quality of the TWW just before irrigation in addition or not to previous disinfection in WWTP and/or a *reservoir* (3.1.26)

Note 1 to entry: See ISO 20670:2018, 3.21 for the definition of "disinfection".

Note 2 to entry: See ISO 20670:2018, 3.84 for the definition of "water reuse".

**3.1.2**
**boom sprinkler**
*mobile sprinkling machine* (3.1.17) composed of two symmetrical pipes (booms) with *sprinkler* (3.1.37) nozzles distributed in one of the pipes where the sprinkler action is complemented by a gun sprinkler placed at each end of both pipes

Note 1 to entry: The nozzles work through a reaction effect (similar to a hydraulic tourniquet) which drives the boom rotation at a desired speed.

**3.1.3**
**category A: very high quality TWW**
*raw wastewater* (3.1.25) which has undergone physical and biological treatment, filtration and disinfection and it average quality is: BOD: ≤5 mg/l (Max. 10 mg/l); TSS: ≤5 mg/l (Max. 10 mg/l); Turbidity: ≤3 NTU (Max. 6 NTU); Termo-tolerant coliforms (95 %ile): ≤10 no./100 ml (Max. 100 no./100 ml)

Note 1 to entry: See ISO 20670:2018, 3.27 for the definition of "filtration".

Note 2 to entry: See ISO 20670:2018, 3.21 for the definition of "disinfection".

Note 3 to entry: See ISO 16075-2 Table 1 for more TWW quality information values.

**3.1.4**
**category B: high quality TWW**
*raw wastewater* (3.1.25) which has undergone physical and biological treatment, filtration and disinfection, and it's average quality is: BOD: ≤10 mg/l (Max. 20 mg/l); TSS: ≤10 mg/l (Max. 25 mg/l); Termo-tolerant coliforms (95 %ile): ≤200 no./100 ml (Max. 1 000 no./100 ml)

Note 1 to entry: See ISO 20670:2018, 3.27 for the definition of "filtration".

Note 2 to entry: See ISO 20670:2018, 3.21 for the definition of "disinfection".



 

Note 3 to entry: See ISO 16075-2 Table 1 for more TWW quality information values.

**3.1.5**
**category C: good quality TWW**
*raw wastewater* (3.1.25) which has undergone physical and biological treatment and it average quality is: BOD: ≤20 mg/l (Max. 35 mg/l); TSS: ≤30 mg/l (Max. 50 mg/l); Termo-tolerant coliforms (95 %ile): ≤1 000 no./100 ml (Max. 10 000 no./100 ml); Intestinal Nematodes ≤1 Egg/l

Note 1 to entry: See ISO 16075-2 Table 1 for more TWW quality information values.

**3.1.6**
**category D: medium quality TWW**
*raw wastewater* (3.1.25) which has undergone physical and biological treatment and it average quality is: BOD: ≤60 mg/l (Max. 100 mg/l); TSS: ≤90 mg/l (Max. 140 mg/l); Intestinal Nematodes ≤1 Egg/l (Max. 5 Egg/l)

Note 1 to entry: See ISO 16075-2 Table 1 for more TWW quality information values.

**3.1.7**
**category E: extensively TWW**
*raw wastewater* (3.1.25) which has undergone natural biological treatment process with long (minimum 10 d to 15 d) retention time and its average quality is: BOD: ≤20 mg/l (Max. 35 mg/l); Intestinal Nematodes ≤1 Egg/l (Max. 5 Egg/l)

Note 1 to entry: See ISO 16075-2 Table 1 for more TWW quality information values.

**3.1.8**
**center-pivot and moving lateral irrigation machine**
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* (3.1.37) located along the pipeline

**3.1.9**
**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

**3.1.10**
**environmental parameter**
quantifiable attribute of an environmental aspect

Note 1 to entry: See ISO 20670:2018, 3.24 for the definition of "environmental aspect".

**3.1.11**
**gravity flow irrigation system**
irrigation system where water is applied directly to the *soil* (3.1.32) surface and is not under pressure

Note 1 to entry: See ISO 20670:2018, 3.43 for the definition of "irrigation system".

**3.1.12**
**in-line emitter**
*emitter* (3.1.9) intended for installation between two lengths of pipe in an irrigation lateral

**3.1.13**
**irrigation gun**
large discharge device being either a part circle or full circle *sprinkler* (3.1.37)

**3.1.14**
**irrigation sprayer**
device which discharges water in the form of fine jets or in a fan shape without rotational movement of its parts

**3.1.15**
**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* (3.1.16) are the main types of this system.

**3.1.16**
**micro-spray irrigation system**
system characterized by water point sources similar to *sprinkler* (3.1.37) 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

**3.1.17**
**mobile sprinkling machine**
sprinkling unit which is automatically moved across the *soil* (3.1.32) surface during the water application

**3.1.18**
**on-line emitter**
*emitter* (3.1.9) intended for installation in the wall of an irrigation lateral, either directly or indirectly by means such as tubing

**3.1.19**
**perforated pipe system**
emitting pipe *(emitter)* (3.1.9) 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

**3.1.20**
**permanent system**
stationary fixed-grid irrigation system (*sprinklers* (3.1.37)) for which sprinkler set positions are rigidly fixed by semi-permanent or permanently installed irrigation laterals

EXAMPLE Portable solid-set irrigation system, buried irrigation system.

**3.1.21**
**portable system**
system for which all or part of the elements can be moved

**3.1.22**
**pressurized irrigation system**
piped network system under pressure

**3.1.23**
**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 are generally planned and carried out under controlled conditions to add value.



 

**3.1.24**
**product**
any goods or services

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

**3.1.25**
**raw wastewater**
wastewater which has not undergone any treatment

Note 1 to entry: See ISO 20670:2018, 3.80 for the definition of "wastewater".

**3.1.26**
**reservoir**
system to store temporarily unused TWW depending on the balance between demand for water irrigation and the treatment plant discharge

Note 1 to entry: The following are different types of reservoirs that can be used to store temporarily unused TWW:

a) open reservoirs which are commonly used for short-term *storage* (3.1.39) 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 time when the treatment plant discharge is 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 seasons and specific needs;

d) aquifer storage and recovery for long-term storage which is commonly combined with *soil* (3.1.32) 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.

**3.1.27**
**rotating sprinkler**
device which distributes water over a circular area or part of a circular area by its rotating motion around its vertical axis

**3.1.28**
**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* (3.1.27) sprayers are placed on the lateral (also called wheel move).

**3.1.29**
**self-propelled gun traveller**
gun *sprinkler* (3.1.37) on a cart or sled attached to the end of flexible pipe/hose

**3.1.30**
**semi-permanent system**
system similar to the *semi-portable system* (3.1.31) but with portable laterals and permanent pumping plant, main lines, and sub-mains

**3.1.31**
**semi-portable system**
system similar to the *portable system* (3.1.21) except that the water source and the pumping plant are fixed

**3.1.32**
**soil**
layer of unconsolidated material consisting of weathered material particles, dead and living organic matter, air space, and *soil solution* (3.1.33)

**3.1.33**
**soil solution**
liquid phase of the *soil* (3.1.32) and its solutes

**3.1.34**
**solid-set system**
temporary fixed network where the laterals are positioned in the field throughout the irrigation season

**3.1.35**
**stationary sprinkler system**
network of fixed *sprinkler* (3.1.37)

**3.1.36**
**spray**
release of water from *sprinkler* (3.1.37)

**3.1.37**
**sprinkler**
water distribution device of a variety of sizes and types, for example, impact sprinkler, fixed nozzle, sprayer, *irrigation gun* (3.1.13)

**3.1.38**
**sprinkler irrigation system**
irrigation system composed of *sprinklers* (3.1.37)

Note 1 to entry: See ISO 20670:2018, 3.43 for the definition of "irrigation system".

**3.1.39**
**storage**
retained temporary unused TWW for short or long term before its release for use in irrigation system

Note 1 to entry: See ISO 20670:2018, 3.43 for the definition of "irrigation system".

**3.1.40**
**travelling irrigation machine**
irrigation machine designed to irrigate a field sequentially, strip by strip, while moving across the field

## 3.2 Abbreviated terms

| | |
|---|---|
| BOD | biochemical oxygen demand |
| COD | chemical oxygen demand |
| EC | electrical conductivity |
| ESP | exchangeable sodium percentage |
| FDS | fixed dissolved solids (mg/l) |
| LF | leaching fraction |
| LR | leaching requirement |
| NPW | non-potable water |

| | |
|---|---|
| NTU | nephelometric turbidity units |
| PET | potential evapotranspiration estimated by the Penman-method |
| 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

## 4.1 General

The chemical quality of wastewater depends on the chemical quality of the background water. Background water used at home, in the office, in commerce, and in industry is received from different sources (groundwater, rivers, lakes, and desalination of seawater or brackish water). Water soluble chemicals, which are often added to the background water during its use, are not removed by the conventional wastewater treatment.

To avoid adverse effect of TWW dissolved salts, quality on irrigated crops and soil, different strategies listed in 4.2 and 4.3 may be implemented (See Annex A, Table A.1).

## 4.2 Improving the quality of TWW for irrigation

TWW quality may be improved using the following methods:

a) supplying a higher quality of water (lower salt concentration) or desalinated water to municipal use;

b) reducing 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 sources such as industrial factories using large volumes of water and emitting large quantities of salt from their manufacturing processes.

## 4.3 Applying good agronomic and irrigation practices

Good agronomic and irrigation practices may be applied with 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.

Where desalinated water is a relevant background water source, attention should be given to the boron concentration in the desalinated water if special processes to remove it during desalination cannot be carried out. Attention should be given 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 concentration of dissolved salts in the TWW.

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

## 5.1 General

For a beneficial use of TWW for irrigation purposes, serious consideration should be given to public health risks including the safety and welfare of the workers, as well as the effect on the irrigated crops and the soil. 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 should be considered as priority elements in the successful development of international TWW guidelines. To prevent negative impacts on public health and the receiving environment and water sources, international guidelines should be applied when undertaking a TWW irrigation project.

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

## 5.2 Water quality

### 5.2.1 Wastewater components

The chemical quality of the wastewater is a result of the chemical composition of the background water (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 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 include hormones, pharmaceuticals, personal care products, proteins, carbohydrates, oils, fuels and lubricants, surfactants, including pesticides, microplastics, humic substances and other domestic and agricultural chemicals.

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

Wastewater contains a variety of living organisms originating from the waste products being disposed of in the wastewater system.

To assess the components of wastewater consider the characteristics of industrial wastewaters connected to the sewers, i.e., consider the specific characteristics of the industrial processes to find specific components in their wastewaters that may negatively affect the quality of the water for the reuse purposes.



### 5.2.2 Nutrients

#### 5.2.2.1 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, may be used as a resource in substitution of chemical fertilizers that the user might make use of. However, the following three major questions should be considered in relation 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 synchronized with crop demand curve?

The amounts of nitrogen and phosphorus and potassium applied with the TWW are the result of multiplication of 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.

#### 5.2.2.2 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 TWW 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 user cannot control the nitrogen quantity applied in each period of growth. The quantity is determined by nitrogen concentration in the TWW (depending on the TWW source and the treatment level) and the irrigation dose applied.

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 groundwater or flow with the surface runoff, thus affecting water sources and damaging the quality of surface water.

#### 5.2.2.3 Phosphorus

The amount of phosphorus applied with 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.

#### 5.2.2.4 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.

### 5.2.3 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 should be:

— total content of salts due to osmotic effect,

— concentration of chlorides, boron, and sodium for its specific toxicity to plants, and

— sodium adsorption ratio (SAR) due to soil permeability issues.

### 5.2.4 Other elements

Examples of other chemical elements present in industrial and urban environments 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.

### 5.2.5 Microorganisms

Wastewater sources for the reuse project originating from human or agricultural activities can contain microorganisms (bacteria, viruses, helminthes, and protozoa) some of which are pathogens. WWTPs can 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. However, the concentration of microbial indicators should be monitored. In this part of ISO 16075, the suggested indicators are thermo-tolerant coliforms, which include faecal coliforms and *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. ISO 16075 guidelines describe a method that combines microbiological indicators and barriers concept (ISO 16075-2) and monitoring protocols (ISO 16075-4).

## 5.3 Climate

TWW is an important water source for farmers and other users in arid and semi-arid climates[1]. TWW might be the only water source available for agriculture in some cases. These guidelines are established based on scientific knowledge obtained from arid and semi-arid climates[1][2]. However, the behaviour of substances (nutrients, heavy metals, microbes and chemicals) in soils supplied with TWW irrigation 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, irrigation related parameters and how they can be controlled should be assessed according to climate conditions.



 

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

$$AI = {}^{P}\!/_{PET} \tag{1}$$

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:

$$ET\mathrm{p} = E\mathrm{p} + T\mathrm{p} \tag{2}$$

where

$E\mathrm{p}$ is the potential soil evaporation (mm/d);

$T\mathrm{p}$ is the potential plant transpiration (mm/d).

$$ET\mathrm{p} = kc \cdot ET\mathrm{ref} \tag{3}$$

where

$ET\mathrm{p}$ is the potential evapotranspiration rate (mm/d);

$kc$ is the crop coefficient;

$ET\mathrm{ref}$ is the reference evapotranspiration rate (mm/d).

NOTE More complex formulas that take into account different parameters and have been developed from the original equations produced by Penman, Monteith[16], Feddes, Smith[17], and others are also available.

The effect of salts and heavy metals on soils and crops as described in this guideline 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.

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.

## 5.4 Soil

### 5.4.1 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 should be 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 B.2.

### 5.4.2 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 their 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.

### 5.4.3 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. should be taken under consideration.

The inherent sensitivity of the soil towards slaking should 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.

### 5.4.4 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].

### 5.4.5 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.

The concentrations of chloride in irrigation waters and in soils are usually some orders higher than the concentration of boron, but its toxicity to crops is 2-3 orders higher than boron. As so the influence of the chloride –soil reaction is insignificant.

#### 5.4.6 Groundwater pollution fixed

Low-absorbable (depending of the clay electrical charge in the soil) anions 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 should be assessed in relation to salts leaching.

#### 5.4.7 Phosphorus accumulation and mobility

Several soil factors are involved in phosphorus retention and mobility in soils. The various factors may be classified by the following categories:

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.

## 6 Different effects on public health, soil, crops, and water sources

### 6.1 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 (e.g. selenium) that are naturally taken up by some food crops can adversely affect human and animal health.

ISO 16075-2 presents 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.

## 6.2 Effects on soil and crops

### 6.2.1 Effect of nutrient levels

Maximum levels of nitrogen, phosphorus, and potassium in the TWW intended for irrigation should be determined to prevent surpluses which are likely to cause damage to the crop or the environment (see example in Table C.1). The nitrogen and phosphorus concentrations may 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 is no reason for 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.

### 6.2.2 Effect of water salinity

#### 6.2.2.1 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 ($\psi_o$), electrical conductivity (EC), total anions or cations, and fixed dissolved solids should be related as follows:

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

Total cations concentration (meq/l) = Total anions concentration (meq/l) = EC (dS/m) × 10

Fixed dissolved solids (mg/l (at 550°C) = EC (dS/m) × 640.

The total dissolved solids in TWW include inorganic and organic dissolved solids. The organics have a very low or null contribution to the electrical conductivity but are part of the solids weight. Therefore, the relation expressed in this equation is inaccurate if the TDS is used. Relation between dissolved solids and EC in TWW is better expressed by the fixed (i.e. non-volatile) dissolved, that is the solids determined after burning at 550 °C the dissolved fraction.

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.

#### 6.2.2.2 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 C.2).

This crop toxicity is due to excess of sodium or chloride ions absorbed through the leaves wetted by the overhead sprinklers. Table C.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.



 

#### 6.2.2.3 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 ions 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:

$$SAR = \frac{\left(Na^{+}\right)}{\sqrt{\frac{\left(Ca^{2+}+Mg^{2+}\right)}{2}}} \tag{4}$$

Formula (4), calculated from the concentration of sodium, calcium, and magnesium [($Na^+$) = sodium concentration in mEq/l; ($Ca^{2+}$+$Mg^{2+}$) = concentration of calcium + magnesium in mEq/l] in the soil saturated paste extract, may be diagnostic for predicting issues of soil sodicity (high levels of sodium) caused by irrigation water. Formula (4) should also be used to forecast 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):

$$\text{ESP}=100(-0{,}0126+0{,}0475\ \text{SAR})/\ (1+(-0{,}0126+0{,}01475\ \text{SAR})) \tag{5}$$

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 $[\text{mEq/l}]^{1/2}$.

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 C.4.

### 6.2.3 Effect of a specific toxicity of certain ions

#### 6.2.3.1 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 wilting.

#### 6.2.3.2 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.

#### 6.2.3.3 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.

#### 6.2.3.4 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 120 mg/l[14]. 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 C.5 are in accordance with experience in Israel.

### 6.2.4 Effect related to other chemical elements

Other chemical elements should not be added to the soil in an uncontrolled way to avoid accumulation in the soil, which will be subsequently difficult to remove as well as to avoid probable

— toxicity to the plants,

— excess absorption by the crops

— 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 groundwater.

Average arithmetic values and maximum values are presented in Table C.6.

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

### 6.2.5 Soil and crops effects management

#### 6.2.5.1 Above foliage sprinkling

In order to increase the crop tolerance, the following actions should be taken:

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 aerosol drift).

#### 6.2.5.2 Management techniques to avoid damage from salt accumulation in the soil

##### 6.2.5.2.1 General

To overcome damage from salt accumulation in the soil, management techniques should be implemented. Some practices may 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].

##### 6.2.5.2.2 Management principles

For a safe use of irrigation water and TWW in particular, management practices should include 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.

##### 6.2.5.2.3 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 the crops are annual, varieties may 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 for a new irrigation area, programmers should take into account the growth of crops suitable to the water quality.



 

### 6.2.5.2.4 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.



### 6.2.5.2.5 Irrigation practices

Some soil and water salinization are 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 should 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) should, over the long term, be applied in excess of that needed for evapotranspiration (ET) and should 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 should 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 should 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, 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, may be used to minimize the harmful effects of irrigation with saline water, and

— leaching fractions may 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 may be designed to minimize this problem. Seed placement and surface irrigation strategies (e.g. alternative furrow, depth of water in furrows, etc) may 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.

#### 6.2.5.2.6 Conjunctive use of water of different qualities

TWW may be used 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 are 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. These risks may be avoided by creating a mechanical separation, such as an air gap, between any non-potable water system and drinking water system. One possibility is pouring the drinking water to a separate tank and then pumping it to the TWW irrigation system.



## 6.3 Effects on water sources

### 6.3.1 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 or groundwater 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. TWW contaminates could reach these drinking water sources via the irrigation itself so irrigation close to drinking water wells and surface water should be prevented.

To prevent this risk, the TWW main supply lines should be separated from the drinking water sources (wells) to ensure that TWW does not flow to the wells and that TWW seeping to the soil will require at least 200 days to reach the well (the time during which annihilation of the pathogenic pollutants will occur).

The distance between irrigated plots to a well shall be such that the time for the TWW to reach the well will require at least 50 days, because only a very small portion of irrigated TWW seeps into the soil depth, and it goes through effective filtration through the soil, destroying most of the pathogens. The good management practices to protect drinking water sources are presented in ISO 16075-3, 6.6.

The effects of nutrients concentration in TWW on water sources pose two main risks;

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.

When nitrogen and phosphorus are removed from the wastewater, these risks may be reduced.

Due to the increasing shortage of freshwater for agriculture, sources of lower chemical and biological quality should be used. The main source of such water is reclaimed water (i.e. TWW). Criteria that will enable agricultural irrigation with TWW while, at the same time, minimizing the hazards to natural water sources should be considered as detailed in 6.3.2-6.3.3.

### 6.3.2 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. Individual tests on a specific TWW should be conducted to monitor the water sources and the systems supplying them to prevent their pollution. This part of document suggests the essential minimal requirements for TWW irrigation. In all cases, a more thorough study of the local hydrology should be undertaken.

b) This document aims to combine maximum protection of water sources with practical and easily applicable methods regarding criteria and testing methods.

c) This document suggests ways to reduce and even prevent the contamination of water intended for drinking purposes, with respect to all types of pollutants listed above.

Water quality parameters should be 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.

Water quality parameters should be classified as following:

— agronomic parameters: nutrients (nitrogen, phosphorus, and potassium) and salinity factors (total salt content, chloride, boron, and sodium concentration);

— public health parameters: microbial content, chemicals (i.e. heavy metals).

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 is practically impossible to create an International Standard which includes examples of threshold values of all potential contaminants found in wastewater. Therefore, users should determine levels for a number of representative elements out of the 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.

— In applications where the discharge of TWW is permitted by regulations, (such as permission to discharge TWW to a stream), 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 that should be used for characterizing soils by suitability for treated-wastewater irrigation is the content of clay. The content of clay is only an approximate index. In order to define a measurable and simple parameter the average clay content should be used to a depth of 2 m as the index of the site's sensitivity to groundwater pollution.

Annex D provides examples for sensitivity groups for protection of groundwater.

### 6.3.3 Examples of surface water sensitivity groups

Surface water sensitivity should be categorized according to the extent of water flow, directly or indirectly, from irrigation water to drainage systems leading to natural water systems.

a. 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:

b. 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.

c. 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.

d. Sensitivity group IV, the lowest from the aspect of surface water, is a system which does not include underground drainage at all.

Categories II, III and IV 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. This document does not deal with any surface runoff as a result of rain that leaches contaminants from the upper soil layer.

Examples of risk levels to define contaminants threshold in TWW are presented in Table D.1.

# Annex A
(informative)

# Examples of means to improve TWW quality

**Table A.1 — Examples of means to improve TWW quality**

| Parameter | Type of pollution | Means of treatment |
|---|---|---|
| Organic matter (BOD; COD) | Point source | Increasing of industrial wastewater control and monitoring.<br>Pre-treatment requirements. |
| Dissolved salts | Diffused | Improving background water by using low salinity fresh water or desalinated water for domestic and industrial use. |
| Dissolved salts | Point source | Evacuation of clean brine (without organic matter or other pollutants). |
| Dissolved salts (Sodium - Na) | Point source | Efficient use of cleaning materials containing sodium (e.g.: caustic soda – NaOH) or changing to other cleaning materials (e.g.: potassium hydroxide (KOH) |
| Dissolved salts (Boron – B) | Diffused | Changing standards of soaps and detergents to use low-content materials.<br>Countries having eutrophication problems will prefer detergents with boron instead of phosphorus. |
| Heavy metals | Point source | Increasing of industrial wastewater control and monitoring.<br>Pre-treatment requirements. |
| Pharmaceuticals | Diffused | Encouraging consumers to regularly remove unused or expired medications to collection points for centralized treatment. |
| Nutrients | Point source | Increasing of industrial wastewater control and monitoring.<br>Pre-treatment requirements. |

# Annex B
(informative)

# Examples of climate and soil criteria

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

<table>
<tr><th>Climate</th><th>AI value</th><th>Annual precipitation</th><th>Interannual rainfall variability</th><th>Remark</th></tr>
<tr><td>Hyper-arid</td><td>AI < 0,05</td><td></td><td><100 %</td><td rowspan="5">Annual moisture deficit</td></tr>
<tr><td>Arid</td><td>0,05 < AI < 0,20</td><td><200 mm</td><td>50 % to 100 %</td></tr>
<tr><td>Semi-arid</td><td>0,20 < AI < 0,50</td><td><800 mm<br>(in summer)<br><500 mm<br>(in winter)</td><td>25 % to 50 %</td></tr>
<tr><td>Dry sub-humid</td><td>0,50 < AI < 0,65</td><td>High seasonal rainfall</td><td><25 %</td></tr>
<tr><td rowspan="2">Humid</td><td>0,65 < AI < 1,00</td><td rowspan="2">High rainfall</td><td rowspan="2">—</td></tr>
<tr><td>1,00 < AI</td><td>Annual moisture surplus</td></tr>
<tr><td>Cold mountain</td><td>—</td><td>—</td><td>—</td><td>Too cold for crops to grow</td></tr>
</table>

**Table B.2 — Overview of soil-related risks (modified from Reference [15])**

| 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.

# Annex C
(informative)

# Examples of maximum levels of nutrients and salinity factors in TWW for irrigation

These levels have been derived for irrigating fields at seasonal irrigation doses of 500 mm to 600 mm (5 000 $m^3$/ha to 6 000 $m^3$/ha) and in relation to the nitrogen and phosphorus consumption of the crops.

**Table C.1 — Example of maximum levels of nutrients in TWW used for irrigation**

| Parameter | Units | Arithmetic monthly mean | Maximum value |
|---|---|---|---|
| Ammonium nitrogen | mg/l | 20 | 30 |
| Total nitrogen | mg/l | 25 | 35 |
| Total phosphorus | mg/l | 5 | 7 |

NOTE This table has been derived for irrigation in Israel and meets the Israeli Regulations approved in April 2010 by the Israeli Parliament: Public health regulation (regulation of TWW quality and rules for wastewater treatment), 2010 (Hebrew reference).

**Table C.2 — Example of maximum electrical conductivity of irrigation water, according to plant tolerance, when irrigated by overhead sprinkling (modified from Reference [14])**

| Crop foliage tolerance | Maximal electrical conductivity of irrigation water (dS/m) |
|---|---|
| Very low tolerance[a] | 0,5 |
| Low tolerance | 1,0 |
| Moderate tolerance | 2,0 |
| High tolerance | 4,0 |
| Very high tolerance | 8,0 |

[a] Includes most fruit trees (e.g. citrus, apple, pear, plum, apricot, peach, and others), beans, and strawberries.

**Table C.3 — Example of relative tolerance of selected crops to foliar injury from saline water applied by overhead sprinklers [14]**

| $Na^+$ or $Cl^-$ concentrations causing foliar injury (mEq/l) | | | |
|---|---|---|---|
| <5 | 5 to 10 | 10 to 20 | >20 |
| Almond | Grape | Alfalfa | Cauliflower |
| Apricot | Pepper | Barley | Cotton |
| Citrus | Potato | Corn (Maize) | Sugar beet |
| Plum | Tomato | Cucumber | Sunflower |
| | | Safflower | |
| | | Sesame | |
| | | Sorghum | |

NOTE 1 mEq/l $Na^+$ = 23 mg/l $Na^+$

1 mEq/l $Cl^-$ = 35.5 mg/l $Cl^-$.

**Table C.4 — Combined effect of electrical conductivity (ECw) of irrigation water and Sodium adsorption ratio (SAR) on the likelihood of water infiltration (permeability) problems[2]**

| Potential irrigation problem | Degree of restriction on use | | |
|---|---|---|---|
| | None | Slight to moderate | Severe |
| SAR $(mEq/l)^{1/2}$ | Electrical conductivity – Irrigation water (dS/m) | | |
| 0 to 3 | >0,7 | 0,2 to 0,7 | <0,2 |
| 3 to 6 | >1,2 | 0,3 to 1,2 | <0,3 |
| 6 to 12 | >1,9 | 0,5 to 1,9 | <0,5 |
| 12 to 20 | >2,9 | 1,3 to 2,9 | <1,3 |
| 20 to 40 | >5,0 | 2,9 to 5,0 | <2,9 |

NOTE 1 The problem of water permeability through the soil (resulting from clay swelling and dispersion and from soil aggregate destruction) depends not only on the soil's SAR value, which is a result of the water's SAR, but also on the concentration of salts in the water (electrolyte concentration). The higher the SAR value is, the higher the electrolyte-concentration is required to maintain proper water movement conditions in the soil. Therefore, each SAR value in the table has a corresponding value of electrical conductivity in which it might have or might not have water permeability problems.

NOTE 2 In TWW where the SAR value is high, there is generally a high enough concentration of salts to maintain a stable soil structure and prevent water movement problems in the soil. Nevertheless, in times of rain periods, the soil, in which the SAR has reached equilibrium with the SAR in the TWW, is exposed to rainwater of minimal electrolyte concentration. Under these conditions, there could be a sharp decrease in water permeability to the soil (its intensity depends on the other soil properties) resulting in surface-runoff and erosion problems.

NOTE 3 In Israel, the monthly average SAR value allowed in the TWW is specified as: 5 $(mEq/ l)^{1/2}$ with max value of 6,5 $(mEq/l)^{1/2}$

**Table C.5 — Example of maximum levels of salinity factors in TWW used for irrigation according to crop sensitivity (derived from the Israeli regulations for irrigation in Israel climatic, soil, and irrigation methods conditions in combination with FAO classification)**

| Parameter | Units | Crop sensitivity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sensitive | | Moderately sensitive | | Moderately tolerant | | Tolerant | |
| | | Arithmetic monthly mean | Maximum single value measurement | Arithmetic monthly mean | Maximum single value measurement | Arithmetic monthly mean | Maximum single value measurement | Arithmetic monthly mean | Maximum single value measurement |
| Electrical conductivity[a,b] | dS/m | 1,4 | 1,8 | 2,0 | 2,6 | 4,0 | 5,2 | 6,0 | 7,8 |
| Chloride | mg/l | 250 | 280 | 400 | 440 | 1 000 | 1 100 | 1 400 | 1 500 |
| Boron[c] | mg/l | 0,4 | 0,5 | 1,0 | 1,3 | 2,0 | 2,6 | 4,0 | 5,2 |
| Sodium[d] | mg/l | 150 | 200 | — | — | — | — | — | — |

NOTE 1 This table has been derived for irrigation in Israel and meets the Israeli Regulations approved in April 2010 by the Israeli Parliament: Public health regulation (regulation of TWW quality and rules for wastewater treatment), 2010 (Hebrew reference) and the FAO classification[22].

NOTE 2 The values presented in Table C.5 refer to conditions in Israel, with some crops irrigated by pressurized irrigation systems but the majority by drip irrigation.

NOTE 3 Plants' tolerance to salinity is a response to the actual concentration of salts in the soil solution. At the same water quality, the concentration of salts to which the plant's roots will be exposed, will also depend on the irrigation system and irrigation management (irrigation frequency). The smaller the water content in the soil is between irrigations, the higher the concentration of salts. Consequently, in a drip irrigation system, where irrigation intervals are short, it is possible to use water of higher salt concentration compared to areas where the same crops are irrigated by an irrigation system (sprinkler or open irrigation systems) where irrigation intervals are longer and there is a relatively greater utilization of the available water in the soil towards the subsequent irrigation.

[a] Crop sensitivity to salinity is often expressed in relation to the concentrations in the soil's saturated paste or in the soil solution. The meaning of the values to concentrations in the irrigation water concerning electrical conductivity is calculated according to the following ratio: soil's electrical conductivity = 1,5 × water's electrical conductivity, assuming that the leaching fraction given is of about 0,20 (20%).

[b] The concentration of dissolved salts in the water can also be expressed as the fixed dissolved solids (FDS) (mg/l) (at 550 °C). The connection between electrical conductivity (EC) and FDS is expressed in the following formula:

FDS (mg/L) ≈ EC (dS/m) × 640 for EC between 0,1 and 5,0-dS/m

FDS (mg/L) ≈ EC (dS/m) × 800 for EC >5,0-dS/m

[c] The boron concentration indicated in the Table refers to boron in the irrigation water, however the crops respond to the boron in the soil solution. Boron is an element which can be absorbed by clay and organic matter in the soil. Hence, the response of the same crop to the boron in the irrigation water will be different in soils with various clay contents. Generally, for the same concentration of boron in the water and the same crop, the crop's negative response will be delayed in a soil with higher clay content. This phenomenon is the result of a higher adsorption of boron in a clay soil and therefore a lower concentration in the soil solution from which the plant absorbs the boron.

[d] Where sodium is concerned, which also adsorbs to the clay in the soil, the main effect is on the soil's structure and properties.