CIHEAM BARI
Centre International de Hautes Etudes Agronomiques Méditerranéennes
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Training module 3:
Hands-activity: Explore international guidelines to compare and interpret the difference between water quality standards for reuse in agriculture

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International and national water reuse regulations and guidelines

For trace elements, agronomic and physico-chemical parameters and compounds, FAO guidelines are the key documents to which the water reuse standards, guidelines and regulations of other organizations and countries have referred. These parameters are of critical importance for the implementation of safe agricultural water reuse practices due to their influence on crops quality and yield, as well as soil properties and productivity.

Table 2 illustrates the microbial water quality and treatment requirements of the most important cornerstone water reuse guidelines and regulations which have been followed in many countries (WHO, USEPA, California, FAO, Australia, ISO standard, European Commission and FAO).

Table2: Comparison of common water quality criteria for agricultural irrigation of selected guidelines and regulations

Class	Parameter	WHO (1989)	WHO (2006)	FAO (1992[a])	USEPA (2012)	California (2000)	Australia AGWR (2006)	ISO 16075-1 to 4 (2015, 2016)	European Union (2020)
		Guideline	Guideline	Guideline	Guideline	Regulation	Guideline	Guideline	Regulation
Unrestricted irrigation of food crops/consumed raw	**Microbial indicator**	Fecal coliforms	E. coli	Fecal coliforms	Fecal coliforms	Total coliforms (TC)	E. coli	E. coli	E. coli
	Coliforms, number (cfu or MPP) per 100 mL	≤1000 crops eaten raw ≤200 for public lawns	10 to 10^5 E.coli depending on treatment, additional health barriers and type of crops	≤1000 (more stringent (<200) for public lawns)	Not detected (daily, 7-day median, 14 max)	≤2.2 (daily, 7-day median, 23 max in 30 days, 240 max)	≤1 (weekly)	≤10 (weekly, 100 max, 95%ile)	≤10 (weekly, 90 %ile)
	Helminths, eggs/L	≤1	≤1	≤1[b]	NS	NS	NS[d]	NS	NS
	BOD_5, mg/L				≤10 (weekly)	NS			
	Total suspended solids TSS, mg/L				NS			≤5 (average, 10 max)	≤ 10 (weekly)
	Turbidity, NTU	NS	NS	NS	≤2 (on-line, av. 24h, 5 max) Membranes ≤0.2 any time	≤2 (on-line, av. 24h, 5 max) Membranes ≤0.2 (max 0.5)	NS[e]	≤2 (average, 5 max)	≤5
	Chlorine residual				>1 mg/L (on-line)	>1 mg/L		optional (0.2 to 1 mg/L)	NS
	Log removal requirements (pathogens)	NS	6-7 logs in total via various combinations of pathogen barriers, water treatment and natural die-off	NS	NS	5 log of MS2 bacteriophages of disinfection process	6 log viruses 5 log for bacteria and protozoa	NS	>5 log E. coli >6 log coliphages[h] >4 log Clostridium perfringens[i]
	Minimum treatment requirements	Stabilisation ponds	NS	Series of stabilization ponds	Secondary, filtration, disinfection	Tertiary + disinfection; chlorination Ct 450 mg.min/L	Secondary, filtration and disinfection[f]	Secondary, filtration and disinfection[g]	Secondary, filtration, disinfection
Others	**Coliforms / 100 mL**	NS	Restricted irrigation: 3-4 log units removal requirement	NS	Processed/non food crops ≤200 FC (median, 800 max)		Commercial food crops, pastures, fodder ≤100 to ≤1000 E. coli	≤200 E. coli processed food crops, ≤1000 non-food crops (+ 1 log max)	
	Legionella		NS	NS		NS		<1000 cfu/L if risk of aerosolization (twice a month)	
	Helminths, eggs/L	≤ 1	≤ 1	≤ 1[c]	NS		NS	≤ 1 for categories C, D and E	≤ 1 for pastures or fodder[j]

FAO Guidelines

The most commonly cited FAO health protection recommendations were developed on the basis of the WHO 1989 guidelines, taking into account epidemiologic studies. Depending on the risk of contact, three water quality categories were defined:

01 **Category A: Irrigation of crops likely to be eaten uncooked, sports fields, and public parks.**

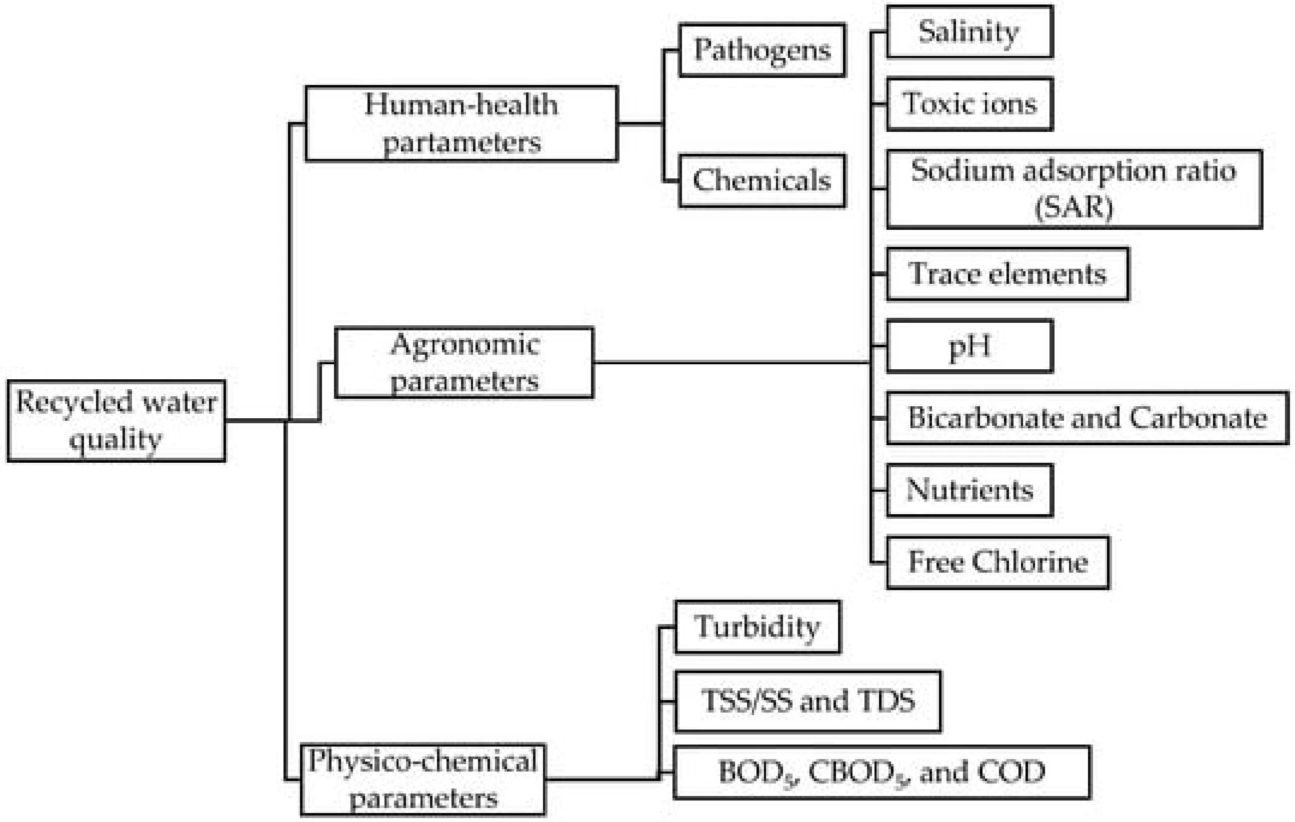
02 **Category B: Irrigation of cereal crops, industrial crops, fodder crops, pasture, and trees.**

03 **Category C: localized irrigation.**

Fecal coliforms have been used as microbial indicator only for category A (≤1000 FC/100 mL), where helminth eggs were introduced only for irrigation of pastures, fodder, cereals and orchards. These guidelines were indirectly superseded when FAO, as part of UN-Water, adopted the WHO (2006) guidelines as official position of the United Nations.

FAO Guidelines

General physico-chemical parameters (TSS, BOD, etc.) were not specified, but agronomic parameters and trace elements that could have adverse impacts on crops and soils were well defined and used as basic reference worldwide. The FAO water quality classifications are only indicative guidelines and their application must be adjusted to local conditions. In fact, the suitability of water for irrigation greatly depends on the climatic conditions, physical and chemical properties of the soil, the salt tolerance of the crop grown and the management practices. It is important to underline that FAO and some national water reuse guidelines and regulations provide lists of crop classifications according their tolerance and sensitivity to salinity. Salt tolerance depends also on the type, method and frequency of irrigation.



FAO Guidelines

The most important agronomic parameter is the salinity of irrigation water, expressed either as total dissolved solids TDS or as EC_w, measured in dS/m (Table 3). In general, TDS over 2000 mg/L or conductivity higher than 3 dS/m could represent a significant quality problem for irrigation. In fact, dissolved salts increase the osmotic pressure of soil water, and consequently, lead to an increase of the energy, which plants must expend to take up water from the soil.

Table 3 represents the FAO classification for irrigation water includes three groups of potential crop yield problems based on salinity, sodicity, toxicity and miscellaneous hazards (Ayers and Westcot, 1985).

	Parameter	Pescod 1992 (Ayers and Westcot, 1985)		
		No impact	**Slight to moderate impact**	**Severe impact**
Impact on crop growth	**Salinity**			
	Electrical conductivity, EC_w dS/m	<0.7 (<1.0)	0.7 (1.0) to 3.0 (2.7)	>3.0 (>2.7)
	Total dissolved solids, TDS, mg/L	<450	450 to 2000	>2000
Impact on infiltration rate	Sodicity – effect of sodium ions expressed by SAR versus EC_w			
	SAR*: 0 to 3	>0.7	0.7 to 0.2	<0.2
	3 to 6	>1.2	1.2 to 0.3	<0.3
	6 to 12	>1.9	1.9 to 0.5	<0.5
	12 to 20	>2.9	2.9 to 1.3	<1.3
	20 to 40	>5.0	5.0 to 1.9	<1.9
Impact on crop growth	**Specific ion toxicity**			
	Sodium Na+, surface irrigation	SAR <3	SAR 3 to 9	SAR >9
	sprinkler irrigation	<3 meq/L	>3 meq/L = 69 mg/L	
	Chloride Cl^-, surface irrigation	<4 meq/L = 113 mg/L	4 to 10 meq/L (to 15)	>10 meq/L = 282 mg/L (>15)
	sprinkler irrigation	<3 meq/L	>3 meq/L = 85 mg/L	
	Boron	<0.7 mg/L (<1)	0.7 (<1) to 3.0 mg/L	> 3.0 mg/L
	Trace elements, maximum concentration, mg/L **Cd, Mo – 0.01 ; Se – 0.02; Co – 0.05; As, Be, Cr, V – 0.1; Cu, Mn, Ni – 0.2; F – 1.0; Zn – 2.0; Li – 2.5; Al, Fe, Pb – 5.0**			
Miscellaneous effects	Nitrogen, mgN/L	<5	5 to 30	>30
	Bicarbonates HCO_3^-, meq/L	<1.5 = 91.5 mg/L	1.5 to 8.5 (7.5)	>8.5 = 519 mg/L (>7.5 = 456 mg/L)
	pH	6.5 to 8		
Clogging of drippers	**Parameters related to clogging potential in drip irrigation**			
	Suspended solids, mg/L	<50	50 to 100	>100
	Dissolved solids, mg/L	<500	500 to 2000	>2000
	Manganese Mn, mg/L	<0.1	0.1 to 1.5	>1.5
	Iron Fe, mg/L	<0.1	0.1 to 1.5	>1.5
	Hydrogen sulphide H_2S, mg/L	<0.5	0.5 to 2.0	>2.0
	Bacterial count, number/mL	<10,000	10,000 to 50,000	>50,000

United States Environmental Protection Agency (USEPA) Guidelines

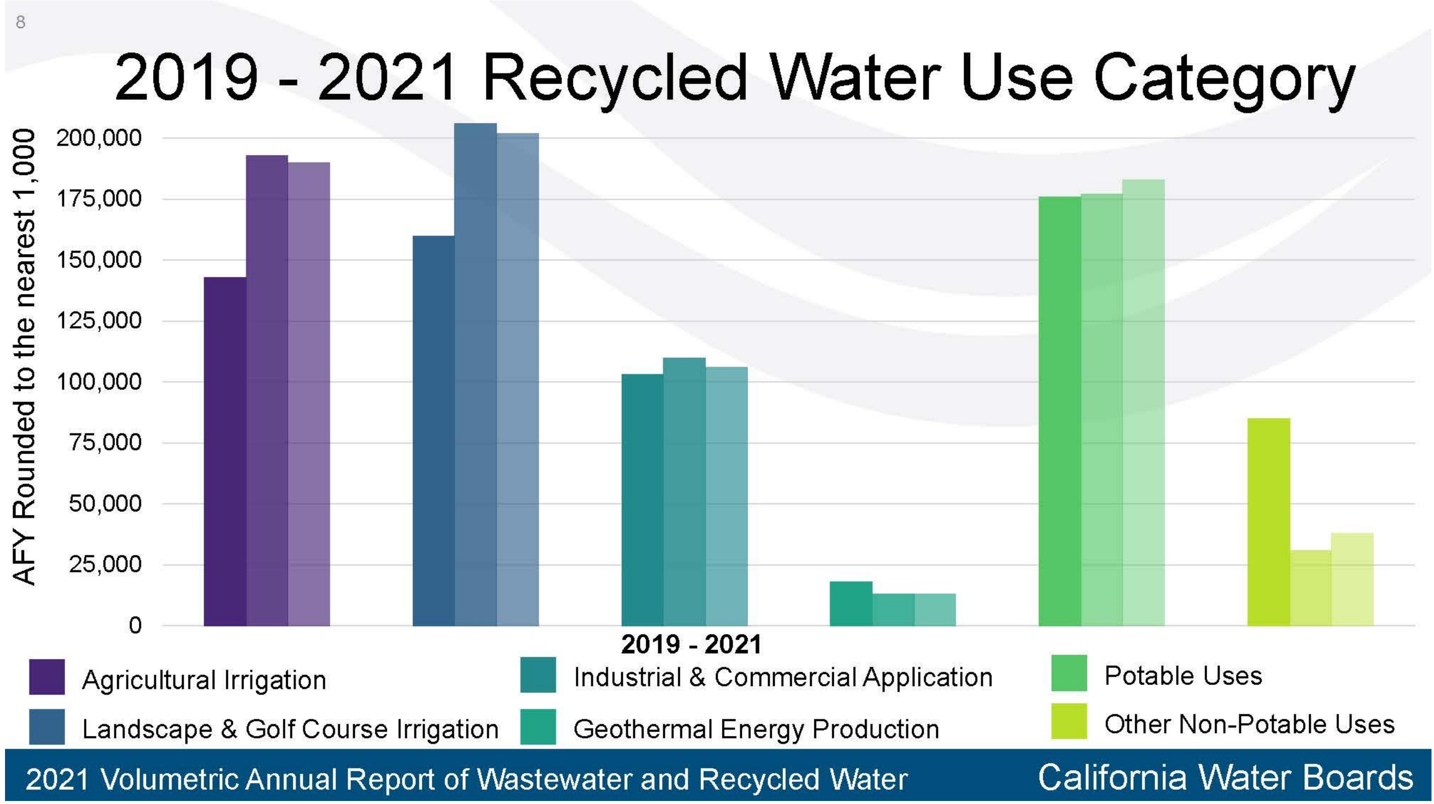
Following the first three editions (1980, 1992, 2004), the revised in 2012 guideline, developed by USEPA along with the United States Agency for International Development (USAID), aims to make the water reuse process easy to implement based on global databases from the different states and world experience. The new 2012 edition maintains the very stringent requirements for the microbial parameters, e.g. not detectable fecal coliforms in 100 mL, and high treatment level including secondary treatment, filtration, and disinfection for food crops irrigation (see Table 2). The USEPA guidelines are not intended to be used as definitive water reuse criteria, but mostly as reasonable guidance for states that have not developed their own criteria or guidelines.

California Water Recycling Criteria

The State of California has been a leader in the development of comprehensive water reuse regulations, and the California Department of Health Services last revised its' criteria in 2000. The California's Water Recycling Criteria, known also as Title 22 water reuse criteria, provide a very comprehensive set of water quality and other requirements and have served as the basis for similar criteria in other states and countries. This regulation has been considered as one of the most stringent and restrictive, but also as a very comprehensive and easy to implement approach.

California Water Recycling Criteria

Similarly to USEPA guidelines, this state regulation requires a high level of disinfection for almost total coliform inactivation (<2.2 TC/100 mL, Table 2) for unrestricted food crop irrigation. In this case, total coliforms are used as principal microbial indicator, considered as most conservative compared to fecal coliforms and *E. coli*. In addition, a specific treatment process train is required for production of such high-quality recycled water that includes after conventional secondary treatment, at a minimum filtration and disinfection that meets the state process requirements.



California Water Recycling Criteria

The California's regulation includes also conservative requirements for water quality monitoring, treatment train design and process operation. For example, the turbidity requirements for Title 22 treatment (conventional tertiary treatment with disinfection), turbidity should be less than 2 NTU (max 5 NTU), and if membranes are used, the turbidity cannot exceed 0.2 NTU more than 5 percent of the time within a 24-hour period and cannot exceed 0.5 NTU at any time.

In California, laws and regulations exist that mandate water reuse under certain conditions (State of California, 1998). Section 13550 of the California Water Code states that the use of potable domestic water for non-potable uses, including, but not limited to, cemeteries, golf courses, highway landscaped areas, and industrial and irrigation uses, is a waste or an unreasonable use of the water if reclaimed water is available which meets certain conditions, *i.e.*, adequate quality, reasonable cost, no adverse effect on public health and environment.

Australian Regulation for Water Recycling

In 2006, the Australia's Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council issued a national guideline, intitled "Australian Guideline for Water Recycling: Managing Health and Environmental Risks". Developed on the basis of existing state's regulations in order to address water crisis and improve the management of health and environmental risks, these guidelines cover a broad range of applications, including agricultural and landscape irrigation, urban uses, managed aquifer discharge and stormwater harvesting and recycling.

Australian Government

Department of the Environment and Heritage

Australian Regulation for Water Recycling

Likewise the USEPA and California water quality requirements, a very high level of disinfection is required for almost total coliform removal (<1 *E. coli*/100 mL for irrigation of food crops consumed raw, Table 2). The threshold limits for commercial food crops vary from <100 to <1000 *E. coli*/100 mL depending on the treatment train). In addition, verification monitoring is proposed to demonstrate an adequate log removal of not only bacteria, but also of viruses and protozoa (defined by means of the microbial health risk assessment). Risk assessment and monitoring requirements are the most restrictive and conservative compared to other regulations. Chemical and agronomic parameters are also included.

ISO Standards on Water Reuse

In 2015, the first ISO standard on water reuse for irrigation was issued in 3 parts covering the main steps of project development (ISO 16075-1 to 3, 2015). Part 1 was focused mostly on wastewater treatment and water quality, while Part 2 is providing comprehensive recommendations for the management of distribution system and irrigation material. Part 3 was published in 2016 covering water quality, soil and aquifer monitoring to mitigate health and environmental risks (ISO 16075-4, 2016).

ISO Standards on Water Reuse

International Organization for Standardization (ISO) defined five categories of water quality for irrigation, from which the category A requires a higher quality of almost total disinfection (≤10 E. *coli*/100 mL, Table 2) for the irrigation of crops consumed raw. The recommended treatment to achieve this quality is the conventional combination of secondary treatment, filtration and disinfection.

In 2018, ISO issued a very comprehensive guideline for health risk assessment for non-potable reuse, including agricultural irrigation, based on qualitative health risk assessment (ISO 20426, 2018).

European Commission Water Reuse Regulation

The Water Reuse Regulations of the European Commission, discussed since 2015, were published in May 2020 in order to harmonise the minimum water quality and monitoring requirements for the safe reuse of treated urban wastewaters in agricultural irrigation (EU regulation 2020/741). Risk management provisions are included to assess and address potential health and environmental risks, as well as permitting requirements.

Monitoring and control

Minimum frequencies for monitoring of reclaimed water for irrigation purposes in agriculture.

	Minimum monitoring frequencies					
Reclaimed water quality classes	***E. coli***	**BOD_5**	**TSS**	**Turbidity**	***Legionella* spp. (when applicable)**	**Intestinal nematodes (when applicable)**
Class A	Once a week	Once a week	Once a week	Continuous	Twice a month	Twice a month or frequency determined according to the number of eggs in wastewater.
Class B	Once a week	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-		
Class C	Twice a month	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-		
Class D	Twice a month	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-		

Source: JRC analysis.

Monitoring and control

Minimum frequencies for monitoring of reclaimed water for irrigation purposes in agriculture.

Minimum monitoring frequencies				
Reclaimed water quality classes	**Total N**	**Total P**	**Salinity**	**Salmonella ssp.**
Class A **Class B** **Class C** **Class D**	Once a week or according to the Directive 91/271/CE	Once a week or according to the Directive 91/271/CE	Twice a month	Twice a month

Irrigation water quality

Classes of quality and quality parameters for reclaimed water in agriculture

Reclaimed water quality class	Indicative technology target	Quality criteria				
		E. coli (cfu/100 ml)	BOD_5 (mg/l)	TSS (mg/l)	Turbidity (NTU)	Additional criteria
Class A	Secondary treatment, filtration, and disinfection (advanced water treatments)	≤10 or below detection limit	≤10	≤10	≤5	*Legionella* spp.: ≤1,000 cfu/l when there is risk of aerosolization. Intestinal nematodes (helminth eggs): ≤1 egg/l when irrigation of pastures or fodder for livestock.
Class B	Secondary treatment, and disinfection	≤100	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class C	Secondary treatment, and disinfection	≤1,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class D	Secondary treatment, and disinfection	≤10,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	

Source: JRC analysis.

Irrigation water quality

Quality parameters for reclaimed water in agriculture

Analytical parameters	Italy
Chemical oxygen demand (COD) (mg/l)	100
pH	6.0–9.5
Electrical conductivity (EC) (dS/m)	3.0
Total dissolved solids (TDS) (mg/l)	
Sodium adsorption ratio (SAR)	10
Chlorides (mg/l)	250
Total nitrogen (mg/l)	15 (35)
Total phosphorus (mg/l)	2 (10)
Bicarbonate (HCO_3)	

Irrigation water quality

Reclaimed water quality classes and irrigation techniques and permitted agricultural purposes

Crop category	Minimum reclaimed water quality class	Irrigation method
All food crops, including root crops consumed raw and food crops where the edible portion is in direct contact with reclaimed water	Class A	All irrigation methods allowed
Food crops consumed raw where the edible portion is produced above ground and is not in direct contact with reclaimed water	Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Processed food crops	Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Non-food crops including crops to feed milk- or meat-producing animals	Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Industrial, energy, and seeded crops	Class D	All irrigation methods allowed

Source: JRC analysis.

Risk assessment and management

Risk management includes the proactive identification and management of risks to ensure that refined water is safely used and managed and that there is no risk to the environment or to human or animal health. To that end, a risk management plan for the reuse of water shall be established on the basis of the following:

A- Description of the water reuse system

B- Actors and roles

C- Identification of hazards, environments and populations at risk

D- Methods of health and environmental risk assessment

Risk assessment and management

A- Description of the water reuse system

A detailed description of the system is the starting point for the complete characterization of the entire water reuse system and begins with the identification of the system boundary that must include the point of entry of urban and/or industrial wastewater in the wastewater treatment plant and the final uses of the reclaimed water. The description should contain all necessary data (dimension of WWTP, water parameters, technologies used, irrigation techniques, type of crops and soil, climate, etc.)

Risk assessment and management

B- Actors and roles

All actors involved and their roles and responsibilities must be identified for each element of the water reuse system. This should include the actors responsible for (i) the management of the WWTP, (ii) the transport and storage, where appropriate, and (iii) the final use.

Risk assessment and management

C- Identification of hazards, environments and populations at risk

All hazards (pollutants and pathogens) or hazards (missed treatments, accidental spills, contamination) shall be identified which originate from the water reuse system and may pose a risk to public health and/or the environment. Hazard that can affect humans, animals or environments should be identified (populations and exposed environments). These elements are necessary in order to be able to subsequently assess the environmental and health risks.

Risk assessment and management

D- Methods of health and environmental risk assessment

The environmental and health risk assessment shall be conducted taking into account the hazards previously identified and the potential exposure within the water reuse system. The risk assessment may be carried out using qualitative or semi-quantitative methods. Qualitative risk assessment is suggested as the most appropriate and economically feasible methodology. Quantitative risk assessment could be used for high risk projects and when sufficient data are available for their implementation. The health risk assessment assesses any risk to human and animal health, while the environmental risk assessment aims to determine whether the contaminants identified in the refined water affect the quality status of the environmental matrices.

Case study

Considering

- Water quality
- Tertiary wastewater treatment
- Crops
- Pedoclimatic conditions
- Irrigation system

SET

- Water quality thresholds for irrigation reuse
- A minimum monitoring frequencies