RECLAMO

The contribution of water REuse to a resourCe-efficient and sustainabLe wAter manageMent for irrigatiOn (RECLAMO)

Deliverable No.	**D1.1-PART I. Baseline report on the current state of reclaimed water reuse for irrigation in Spain**
Full title	**Current state of reclaimed water reuse for irrigation in Spain**
Work Package No. and Title	**WP1 – Knowledge base**
Lead beneficiary	**Universidad Politécnica de Madrid (UPM)**
Authors	**Antonio Bolinches, Irene Blanco-Gutiérrez, Paloma Esteve** **With contributions from Almudena Gómez-Ramos, Sergio Zubelzu, Alberto Garrido, Carlos G. Hernández Díaz-Ambrona, Augusto Arce, Raúl Sánchez, Javier Calatrava, Juan Manuel López Correa**
Status	**Final**
Planned delivery date	**31/05/2021 (M12)**
Actual delivery date	**31/05/2021 (M12)**
Dissemination level	**Public**
Project website	**https://blogs.upm.es/reclamo/**
Project start date and duration	**Start date of project: 01 June 2020** **Duration: 48 months**

The communication reflects only the author's view.

The project has received funds from the Spanish Ministry of Science and Innovation, State Research Agency. National Plan for Scientific and Technical Research and Innovation 2017-2020. Project R&D&i - Challenges 2019. Grant number PID2019-104340RA-I00.

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

0. General remarks

This report (Deliverable D1.1) is dedicated to presenting the current state of water reuse in Spain and selected case studies. For reasons of practicability, D1.1 consists of two separate reports:

- D1.1-Part I: Baseline report on the current state of reclaimed water reuse for irrigation in Spain
- D1.1-Part II: Baseline report on the current state of reclaimed water reuse for irrigation in selected case studies.

The following sections provide the documentation of Deliverable D1.1-Part I.

1. Introduction

The growing competition on water abstraction (agricultural, urban and industrial) and the perspective of diminishing resources due to Climate change (CEDEX, 2017) are pushing the agenda for the quest of alternative water sources. One of these sources is urban wastewater, which is normally discharged to rivers and seas after a convenient treatment. An additional treatment of regeneration/recycling/reuse (different terms are used in the literature) may adequate these waters for further use.

The technological development in water disinfection (Xylem, 2020) has allowed for a cost reduction that increases the economic viability of wastewater reuse, in particular for crop irrigation.

Figure 1 shows the potential for water reuse in Europe. Spain stands out as the country with the highest yearly reuse volume, as well as the country with the highest potential in the short term.

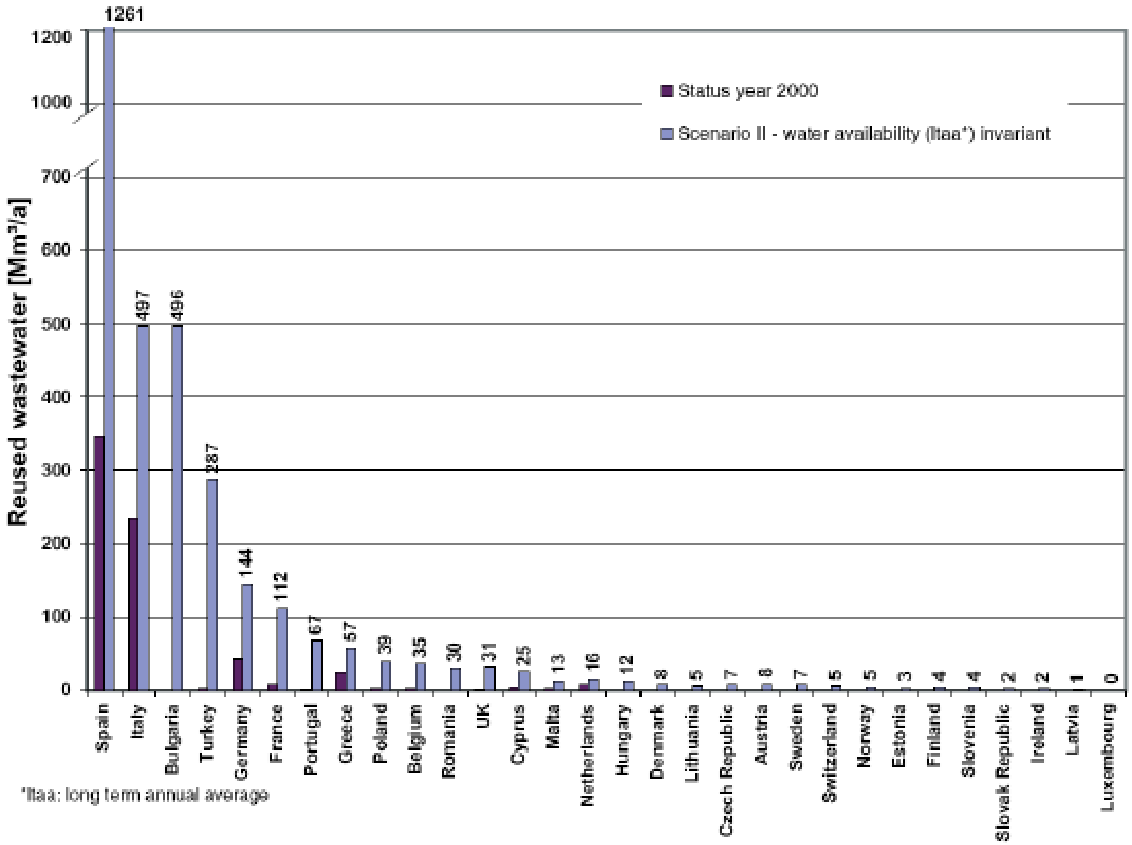

Figure 1. Wastewater reuse potential in Europe.
Source: TYPSA (2013)

2. Regulatory and policy framework

2.1. Regulatory context of the European Union and Spain

This paragraph presents a short introduction to the regulatory context in the European Union (EU) and Spain. The practical ways in which EU legal texts are applied in the Member States depend of their nature, as described in Article 288 of the Treaty on the Functioning of the European Union (European Union, 2012):

"To exercise the Union's competences, the institutions shall adopt regulations, directives, decisions, recommendations and opinions.

A regulation shall have general application. It shall be binding in its entirety and directly applicable in all Member States.

A directive shall be binding, as to the result to be achieved, upon each Member State to which it is addressed, but shall leave to the national authorities the choice of form and methods.

A decision shall be binding in its entirety. A decision which specifies those to whom it is addressed shall be binding only on them.

Recommendations and opinions shall have no binding force."

Thus, with respect to the binding force of the European legislation it must be noted that (European Commission, 2020a):

- Directives must be incorporated by EU countries into their national legislation. Each directive contains a deadline by which EU countries must incorporate its provisions into their national legislation.
- Regulations and Decisions become binding automatically throughout the EU on the date they enter into force.

If national authorities fail to properly implement EU laws, the Commission may launch a formal infringement procedure against the country in question and eventually refer the case to the European Court of Justice, as was the case when Spain failed to fulfil its obligations under those provisions of Directive 91/271/EEC in several agglomerations (Court of Justice of the European Union, 2011).

Spain is a regionalized state, also referred to as "Estado de las Autonomías". It comprises three levels of governance: central, regional (Autonomous Communities) and local (European Committee of the Regions, 2020). The Spanish legal system is subject to the principle of legal hierarchy described in Article 9.3 of the Constitution (Cortes Generales, 1978) and Article 1.2 of the Civil Code (Ministerio de Justicia, 2018). The hierarchical order is (European Justice, 2020): Spanish Constitution, International Treaties, Laws (Organic laws, Ordinary laws, Royal Decree-Law), executive norms (Royal Decree, Reglament).

2.2. Key policy documents at EU and Spanish level for natural waters

Starting from the first European Directives in the 80s decade of the twentieth century, European water legislation has followed an evolution during the last 40 years that has led to the recent water reuse Regulation:

- 1980: First drinking water Directive.
- 1991: Wastewater treatment Directive.
- 1998: Revision of drinking water and wastewater Directives.
- 2000: Water Framework Directive.
- 2006: Groundwater Directive.
- 2018: Guide of minimum requirements for reused water in the EU (Spanish law for reused water had been passed in 2007)
- 2020: Water reuse Regulation.

Water Framework Directive (WFD) 2000/60/CE (European Parliament and Council, 2000) was passed in year 2000 and designated the achievement of the good status of surface and groundwaters as the goal of water management of the European Union.

As shown in the previous paragraph, the Directive does not have a direct binding force, and has been transposed to the Spanish legislation mainly through the Water Law, Royal Decree-Law 1/2001.
The WFD defines the "water body" (surface or groundwater) as the unit of management. Surface waters status is defined as the poorer between the Chemical status (according to the concentration of hazardous substances) and the Ecological status (which is measured through biological, physico-chemical and hydromorphological elements). Groundwater status is defined as the poorer between the Chemical and the Quantitative status (i.e., that the abstractions are not larger than the renewable recharge).
In the case of surface waters, status change concentration limits are defined in the Spanish Royal Decree 817/2015 (MAPAMA 2015).
An important aspect of the legislation is the possibility to declare temporal exemptions to the environmental objectives and less stringent objectives, according to articles 4.4 and 4.5 of the WFD and articles 36 and 37 of Spanish Royal Decree 907/2007 on River Basin Planification (Ministerio de Medio Ambiente, 2007). The declaration of exemptions should be properly justified, using arguments like technical feasibility or cost disproportionality.
Also, Directive 91/676/EEC (Council of the European Communities, 1991a) and Spanish Royal Decree 261/1996 (Ministerio de la Presidencia, 2015) protect water bodies of agrarian nitrates accumulation. They require a balance of nitrogen for each area, and the identification of vulnerable zones that require special attention. In Spain, the declaration of vulnerable zones is under the jurisdiction of the Autonomous Communities.
The list of restrictions to chemical and physico-chemical concentrations in natural waters show a concern on the sustainability of water ecosystems:
- Hazardous and priority substances (heavy metals, hydrocarbons, pesticides) that may pose a direct threat to the flora and fauna. The WFD and the transposition to the Spanish legislation (Chemical status and Environmental Quality Norms) fix maximum concentration limits for short term exposure and mean concentration limits for long term exposures.
- Organic matter with oxygen demand, which may deplete the dissolved oxygen in water.
- Nutrients (nitrogenous and phosphorous compounds) that may entail an exponential grow of selective species that compromise the functioning of the ecosystem. Such as the eutrophication of a lentic body of water following an algal bloom.

2.3. Key policy documents at EU and Spanish level for wastewater treatment

Before presenting the water reuse legislation it is convenient to review the laws concerning wastewater treatment, since wastewater treatment plants discharge is the raw material of reuse plants.
In order to grasp the order of magnitude of the volumes treated at WWTPs we can consider that an agglomeration of 10’000 inhabitants consuming 200 l/person/day generate approximately 2’000 m^3 of wastewater daily. The big volumes imply that the discharge must be sent to the

drainage network (rivers and lakes) in inland agglomerations, and to the sea through emissaries in coastal agglomerations.

European Directive 91/271/EEC (Council of the European Communities, 1991b), revised by Directive 98/15/EC (Commission of the European Communities, 1998) define the pollutant concentration limits to be respected by Urban Wastewater Treatment Plants effluents to protect the receiving waters.

These directives are transposed to the Spanish legislation through the Royal Decree-Law 11/1995 (Jefatura del Estado, 1995), developed by Royal Decree 509/1996 (Ministerio de Obras Públicas, 1996), and Royal Decree 2116/1998 (Ministerio de Medio Ambiente, 1998).

The legislation fixes two limits that must be respected simultaneously in the discharge:

L1) The values set in the following tables, that should be respected in any case. These values represent maximum concentration of physico-chemical parameters. Table 1 shows the limits for biochemical (BOD5) and chemical (COD) oxygen demand and total suspended solids (TSS) concentrations, for inland WWTP above 2'000 population-equivalent (or p-e, a term describing the organic load of 60 g of BOD5 per day, representing the average discharge of a person) or coastal WWTP above 10'000 population-equivalent.

Table 1. Physico-chemical concentration limits of WWTP discharge.

Parameters	Concentration	Minimum percentage of reduction ([1])
Biochemical oxygen demand (BOD5 at 20 °C) without nitrification ([2])	25 mg/l O_2	70-90 40 under Article 4 (2)
Chemical oxygen demand (COD)	125 mg/l O_2	75
Total suspended solids	35 mg/l ([3]) 35 under Article 4 (2) (more than 10 000 p.e.) 60 under Article 4 (2) (2 000-10 000 p.e.)	90 ([3]) 90 under Article 4 (2) (more than 10 000 p.e.) 70 under Article 4 (2) (2 000-10 000 p.e.)

Source: Directive 91/271/EEC Annex 1 (Council of the European Communities, 1991b).

If the receiving waters are declared sensitive to eutrophication by nitrogen and/or phosphorus, the following limits (Table 2) would also apply.

Table 2. Nutrient concentration limits of WWTP discharge.

Parameters	Concentration	Minimum percentage of reduction (1)
Total phosphorus	2 mg/l (10 000-100 0000 p.e.) 1 mg/l (more than 100 000 p.e.)	80
Total nitrogen (2)	15 mg/l (10 000-100 000 p.e.) (3) 10 mg/l (more than 100 000 p.e.) (3)	70-80

Source: Directive 91/271/EEC Annex 1 (Council of the European Communities, 1991b).

In Spain, when river basins are located entirely within an Autonomous Community, the Community has the jurisdiction to declare zones sensitive to eutrophication. But when river basins cover more than one Community (intercommunity basins), it is the State that has the jurisdiction to declare zones sensitive to eutrophication. The Resolution of February 6th 2019 (Ministerio para la Transición Ecológica, 2019) is the standing legislation for intercommunity basins. The declared categories are:

"- aP - Bodies of water where phosphorus removal should be planned.

- aN - Bodies of water where nitrogen removal should be planned.

- b - Bodies of surface water intended for the production of drinking water that could contain a nitrate concentration higher than 50 mg / l.

- c - Bodies of water receiving discharges on which an additional treatment to the secondary one established in article 5 of Royal Decree 509/1996 is necessary to comply with the provisions of Community legislation."

L2) On top of the previous requirement, it should be verified that the receiving waters comply with their environmental objectives downstream of the discharge. Article 5 of RDL 11/1995 determines that more stringent requirements than the L1 values may be applied to comply with this second requirement.

In general, L1 values are sufficient to protect the receiving waters and they are rarely overrun by more stringent L2 values. The more stringent values would be typically needed in the case of large agglomerations discharging to low flow rivers.

Articles 100 to 108 of the Spanish Water Law (Ministerio de Medio Ambiente, 2001) determine that any discharge to natural waters must have a Discharge Permit delivered by the River Basin Authority. The main purpose of this Discharge Permit is the “achievement of the environmental objectives” i.e. the good status of the receiving waters described in the previous paragraph.
In the case of very small agglomerations (below 2’000 p-e inland and below 10’000 p-e in coastal towns), Directive 91/271/EEC and RDL 11/1995 simply require an “adequate treatment” that respects the environment, without defining maximum concentration limits.
It is important to highlight that urban wastewater legislation does not limit the microbiological pollution in the discharge. This aspect may have undesired consequences, as exposed in section 8.1 on unplanified reuse of wastewater.
The list of restricted physico-chemical compounds show that the main concern is the sustainability of water ecosystems, in a similar fashion to the previous paragraph.
It is worth noting that the Directive 91/271/EEC is currently under a revision process (European Commission, 2020b) that may produce a new version, not before 2022.

2.4. Key policy documents at EU and Spanish level for water reuse

The WFD only mentions water reuse in the Annex VI, Part B of supplementary measures to achieve the environmental objectives:

“The following is a non-exclusive list of supplementary measures which Member States within each river basin district may choose to adopt as part of the programme of measures required under Article 11(4):

(…)

(ix) demand management measures, inter alia, promotion of adapted agricultural production such as low water requiring crops in areas affected by drought

(x) efficiency and reuse measures, inter alia, promotion of water-efficient technologies in industry and water-saving irrigation techniques

(xi) construction projects

(xii) desalination plants

(…)”

The small presence of reuse in the WFD may echo the lack of availability of cost-effective disinfection technology in the 90s (when the Directive was developed). The legal aspects of wastewater reuse are to be found in subsequent legislation.
In the year 2007 Spain passed the Royal Decree 1620/2007 (Ministerio de la Presidencia, 2007) on water reuse, and the European Union the Regulation 2020/741 (Parlamento Europeo y Consejo Europeo, 2020) in 2020. Point 3 presents an introduction to the requirements of these norms.

2.5. DSEAR Plan

The compliance of the requirements of the Water Framework Directive and the Directive 91/271/EEC on urban wastewater requires the implementation of water infrastructure projects, implying major investments. In the case of Spain, despite a continuous effort to upgrade the wastewater treatment infrastructure, some interventions are taking longer than expected, triggering the application of sanctions from the European Union (Court of Justice of the European Union, 2018, 2011).

In this context, the Spanish Ministry of the Environment began in 2018 the preparation of a governance plan to simplify and streamline the process of implementation of wastewater treatment, reuse and energy efficient measures, the DSEAR Plan (Dirección General del Agua, 2020).

The desired outcome is the release of Best Practices codes, as well as the reform of water legislation to speed up the process of implementation of measures. Furthermore, a clarification on prioritization of measures is expected, in the current process of preparation of the Third Cycle of River Basin Management Plans.

As a result, the Plan should provide an integral approach to the water infrastructure challenges, align the investments with the European Green Deal (European Commission, 2020c), and facilitate the implementation of European Recovery Funds (European Commission, 2020d)

DSEAR Plan is organized in seven governance objectives (Dirección General del Agua, 2020), namely:

- Definition of criteria to prioritize measures
- Reinforcement of administrative cooperation
- Better definition of measures to be undertaken by the state (as opposed to local administration)
- Amelioration of energy efficiency of WWTP and reuse plants.
- Amelioration of financing mechanisms
- Promotion of wastewater reuse
- Promotion of innovation and technological transfer.

The aim in the case of reused water is to increase the capacity and use of the resource, to alleviate the pressure on water bodies with a high level of detraction.

3. Review of quality of reclaimed water requirements and main treatment technologies

The main concern of water quality for human consumption (directly for drinking water or indirectly through agricultural irrigation) is the prevention of health hazards. Thus, microbiological pollution is restricted in water reused for irrigation of agricultural products intended for human consumption. A short introduction of microorganisms of concern is presented, followed by a description of the current restrictions in the Spanish and European legislation.

It is worth clarifying the difference between the various microorganism types in the norm:

- A pathogen is a microorganism that may cause disease. The ultimate goal of the Regulation is to make sure that the concentration of pathogens in reused water is low enough to avoid health concerns. But since measuring certain pathogens may be complex, costly and timely (WHO, 2006), microbial testing is usually limited to indicator organisms.
- An ideal index/indicator is an organism that is universally present in human and animal faeces, does not multiply in natural waters, responds to treatment in a similar fashion to pathogens and is readily detected by simple methods (WHO, 2006). The denomination index is reserved to the detection of faecal matter, while the denomination indicator is reserved to the measure of effectiveness of a particular process.

The different microorganism types of concern are:

-Virus (typical size < 0.1µm): Virus do not have an independent metabolism and need a host organism to reproduce. Waterborne pathogen virus of concern are Rotavirus, Hepatitis A and E, Norovirus and Polio. There is no scientific evidence that the recently discovered SARS-CoV-2 virus is transmitted through water. Coliphages are used as non-pathogen virus indicators.
- Bacteria (typical size 1 µm): Bacteria are singe-celled prokariotes (lacking a distinct nucleus with a membrane) that are present virtually in all-natural environments. Waterborne pathogenic bacteriae of concern are (digestive infections): Shigella, Salmonella, Campylobacter and Vibrio Cholerae among others; and (respiratory infections) Legionella. Escherichia Coli family of bacteria are usually non-pathogenic and are used as indicators, although there are some instances of E. Coli (like Enterotoxigenic E. Coli) that are pathogenic.
- Protozoa (typical size 10 µm): Protozoa are eukariotic singe-celled organisms that may form egg-like schists to resist unfavorable environments. Waterborn pathogenic protozoa are Malaria, Giardia, Cryptosporidium and Entamoeba. Chlostridium Perfringens is used as an indicator of protozoa presence.
- Helminths (typical size 1000 µm): Helminth is a general term that includes different types of parasitic worms/verms such as nemathodes.

Most pathogenic microbia are able to persist in water for periods that range from days to months, although some of them like Legionella and Vibrio Cholerae may even multiply (WHO, 2018).

3.1. Quality requirements for reused water: Title 22 of California Code

The next fundamental aspect of wastewater reuse is the water quality requirement. Before presenting the current legislation in Spain and Europe, a short introduction to the Californian Title 22 for Recycled Water is presented, since it was the pioneer law in reused water quality.

The norm defines four categories for reused water quality, according to the microbiological concentration (Table 3).

Table 3. Recycled water quality categories according to Title 22 of California Code.

Table D-1. Water Quality Standards for Various Water Recycling Sites		
Water Type[1,2]	**Parameter**	**Quality Criteria[4,5]**
Disinfected Tertiary[3,6] (recycled water that has been oxidized, filtered and disinfected)	Total Coliform	• Median concentration must not exceed 2.2 MPN/100 mL using the last 7 days analyses were completed • Must not exceed 23 MPN/100 mL in more than one sample in any 30 day period • Must not exceed 240 MPN/100 mL at any time
	Turbidity for Filtration Using Natural Undisturbed Soils or a Filter Bed	• Must not exceed average turbidity of 2 NTU within a 24-hour period • Must not exceed 5 NTU more than 5 percent of the time within a 24-hour period • Must not exceed 10 NTU at any time
	Turbidity for Filtration Using Microfiltration, Ultrafiltration, Nanofiltration or Revere Osmosis	• Must not exceed 0.2 NTU more than 5 percent of the time within a 24-hour period • Must not exceed 0.5 NTU at any time
Disinfected Secondary – 2.2 (recycled water that has been oxidized and disinfected)	Total Coliform	• Median concentration must not exceed 2.2 MPN/100 mL using the last 7 days analyses were completed • Must not exceed 23 MPN/100 mL in more than one sample in any 30 day period
Disinfected Secondary – 23 (recycled water that has been oxidized and disinfected)	Total Coliform	• Median concentration must not exceed 23 MPN/100 mL using the last 7 days analyses were completed • Must not exceed 240 MPN/100 mL in more than one sample in any 30 day period
Un-disinfected Secondary (recycled water that has been oxidized but not disinfected)	---	---

[3]The filtered wastewater must be disinfected using:

a. A process that provided a CT (product of total chlorine residual and modal contact time measured at the same point) or not less than 450 mg-min/L at all times with a modal contact time of at least 90 minutes based on peak dry weather flow; or

b A process that, when combined with filtration, has been demonstrated to inactivate and/or remove 99.999 percent of plaque forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. A virus that is at least as resistant to disinfection as polio virus may be used for demonstration

Source: Brown et al. (2020)

Article 3 of the norm describes which use is authorized for each water category.

Table 4. Excerpt of category of recycled water required for each use in Title 22 of California Code

Category\Section	*§60304*	*§60305*	*§60306*	*§60307*
Disinfected tertiary	Food crops, including all edible root crops, where the recycled water comes into contact with the edible portion of the crop, parks and unrestricted access golf courses	nonrestricted recreational impoundments	industrial or commercial cooling or air conditioning (special restrictions on legionella)	Flushing toilets and urinals, structural firefighting, decorative fountains, commercial laundries
Disinfected secondary 2.2	food crops where the edible portion is produced above ground and not contacted by the recycled water			
Disinfected secondary 23	Pasture for animals producing milk for human consumption, restricted access golf courses			Mixing concrete, cleaning roads and sidewalks
Un-disinfected secondary	Fodder and fiber crops and pasture for animals not producing milk for human consumption, food crops that must undergo commercial pathogen-destroying processing			

Source: Water, G.R.U.R. (2014)

The concern is set on microbiological contamination and the minimization of the risk of pathogen transmission to humans, as opposed to the concern on ecosystem sustainability described in the natural waters and wastewater legislation.

3.2. Quality requirements for reused water: Spanish Royal Decree 1620/2007

Annex I.A of RD 1620/2007 describes the water quality criteria for 13 uses of recycled water.

Table 5. Reused water types in RD 1620/2007

Quality	*Use*
1.1	Residential (irrigation of private gardens, discharge of sanitary devices)
1.2	Services (irrigation of urban green areas, street washing, fire systems, industrial vehicle washing)
2.12	Irrigation of crops, direct contact of water with edible parts for fresh human consumption
2.2	Crop irrigation, non-fresh edible parts, pasture irrigation, aquaculture
2.3	Localized irrigation of woody crops without contacts with fruits, irrigation of ornamental flowers, irrigation of non-food industrial crops, nurseries, silage forages, cereals and oilseeds
3.1	Process and cleaning waters
3.2	Cooling towers and evaporative condensers
4.1	Irrigation of golf courses
4.2	Ponds, ornamental water bodies without public access
5.1	Aquifer recharge by localized percolation through the ground
5.2	Aquifer recharge by direct injection
5.3	Irrigation of forests and green areas not accessible to the public
5.4	Other environmental uses (maintenance of wetlands and minimum flows)

Source: Annex I.A of RD 1620/2007 (Ministerio de la Presidencia, 2007).

According to each use, maximum limits are fixed for Turbidity, Total Suspended Solids, Escherichia Coli and Nematodes. Additionally, Legionella spp. limits are fixed if there exists risk of aerosolization, and hazardous substances and nutrient limits when needed.

Table 6. Maximum allowed concentration for each water use and pollutant in the RD 1620/2007.

Uso del agua previsto	*Valor Máximo Admisible (VMA)*			
	Nematodos Intestinales (huevos/10 L)	*Escherichia Coli (ufc[(1)]/100 mL)*	*Sólidos en Suspensión (mg/L)*	*Turbidez (unt[(2)])*
1.- Usos urbanos				
Calidad 1.1	1	0	10	2
Calidad 1.2	1	200	20	10
2.- Usos agrícolas				
Calidad 2.1	1	100	20	10
Calidad 2.2	1	1.000	35	No se fija límite
Calidad 2.3	1	10.000	35	No se fija límite
3.- Usos industriales				
Calidad 3.1.	No se fija límite	10.000	35	15
Calidad 3.1.	1	1.000	35	No se fija límite
Calidad 3.2.	1	Ausencia	5	1
4.- Usos recreativos				
Calidad 4.1	1	200	20	10
Calidad 4.2	No se fija límite	10.000	35	No se fija límite
5.- Usos ambientales				
Calidad 5.1	No se fija límite	1.000	35	No se fija límite
Calidad 5.2	1	0	10	2
Calidad 5.3	No se fija límite	No se fija Límite	35	No se fija límite
Calidad 5.4	La calidad mínima requerida se estudiará caso por caso			

Source: Canal de Isabel II (2020)

Table 7. Other criteria that apply to each water use in RD 1620/2007.

Uso del agua previsto	*Otros contaminantes (ver Anexo II. RD 849/1986)*	*Legionella spp. (UFC/L)*	*Otros criterios*
1.- Usos urbanos			
Calidad 1.1	Contenidos en la autorización de vertido de aguas residuales [3]	100[4]	-
Calidad 1.2 [1]			
2.- Usos agrícolas [2]			
Calidad 2.1	Contenidos en la autorización de vertido de aguas residuales [3]	1000[4]	Detección de patógenos[5]
Calidad 2.2		-	
			Taenia saginata y Taenia solium: 1 huevo/L
Calidad 2.3		100	-
3.- Usos industriales			
Calidad 3.1. a) y b)	Contenidos en la autorización de vertido de aguas residuales [3]	100	-
Calidad 3.1. c)			Detección de patógenos [5]
Calidad 3.2.	-	Ausencia	Se requiere autorización (RD 1620/2007)
4.- Usos recreativos			
Calidad 4.1	Contenidos en la autorización de vertido de aguas residuales [3]	100 [4]	-
Calidad 4.2		-	P_T: 2 mg P/L (en agua estancada)
5.- Usos ambientales			
Calidad 5.1	-	-	N_T: 10 mg N/L NO_3: 25 mg NO_3/L
Calidad 5.2			
Calidad 5.3	Contenidos en la autorización de vertido de aguas residuales [3]		-
Calidad 5.4	La calidad mínima requerida se estudiará caso por caso.		

[1] Cuando exista un uso con posibilidad de aerosolización del agua, es imprescindible seguir las condiciones de uso que señale, para cada caso, la autoridad sanitaria.

[2] Características del agua regenerada que requieren información adicional. Ver Tabla 3.

[3] Se deberá limitar la entrada de estos contaminantes al medio ambiente. En el caso de que se trate de sustancias peligrosas (ver Anexo IV del RD 907/2007) deberá asegurarse el respeto de las NCAs (Norma de calidad ambiental dispuesta en el artículo 245.5 del RD 849/1986).

[4] Si existe riesgo de aerosolización.

[5] Según criterios del RD 1620/2007.

Source: Canal de Isabel II (2020).

There are limits for the Sodium Absortion Ratio (RAS) and heavy metal concentrations for water intended for irrigation.

Table 8. Water reuse for agricultural use.

Parámetro	*Valor límite*
Conductividad	3,0 dS/m
RAS[1]	6 meq/L
Boro	0,5 mg/L
Arsénico	0,1 mg/L
Berilio	0,1 mg/L
Cadmio	0,01 mg/L
Cobalto	0,05 mg/L
Cromo	0,1 mg/L
Cobre	0,2 mg/L
Manganeso	0,2 mg/L
Molibdeno	0,01 mg/L
Níquel	0,2 mg/L
Selenio	0,02 mg/L
Vanadio	0,1 mg/L

[1] Relación de Adsorción de Sodio calculado según RD 1620/2007

Source: Ministerio de la Presidencia (2007).

3.3. Water quality requirements for reused water: European Regulation 2020/741

The European Union has recently passed the Regulation 2020/741 (Parlamento Europeo y Consejo Europeo, 2020), which shall apply from 26 June 2023. As it was presented in section 12.1 a Regulation does not need transposition to Member States to enter into force.

The Regulation (article 1.2) is restricted to agricultural irrigation, so it only affects uses 2.1, 2.2 and 2.3 of RD 1620/2007.

Four different classes of water quality are defined in the Regulation:

Table 9. Water quality classes in Regulation 2020/741

Minimum reclaimed water quality class	Crop category (*)	Irrigation method
A	All food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw	All irrigation methods
B	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	All irrigation methods
C	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	Drip irrigation (**) or other irrigation method that avoids direct contact with the edible part of the crop
D	Industrial, energy and seeded crops	All irrigation methods (***)

(*) If the same type of irrigated crop falls under multiple categories of Table 1, the requirements of the most stringent category shall apply.

(**) Drip irrigation (also called trickle irrigation) is a micro-irrigation system capable of delivering water drops or tiny streams to the plants and involves dripping water onto the soil or directly under its surface at very low rates (2–20 litres/hour) from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers.

(***) In the case of irrigation methods which imitate rain, special attention should be paid to the protection of the health of workers or bystanders. For this purpose, appropriate preventive measures shall be applied.

Source: Parlamento Europeo y Consejo Europeo (2020).

And the following quality requirements are required for each of these classes:

Table 10. Quality requirements per class

Reclaimed water quality class	Indicative technology target	Quality requirements				
		E. coli (number/100 ml)	BOD_5 (mg/l)	TSS (mg/l)	Turbidity (NTU)	Other
A	Secondary treatment, filtration, and disinfection	≤ 10	≤ 10	≤ 10	≤ 5	*Legionella* spp.: < 1 000 cfu/l where there is a risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage
B	Secondary treatment, and disinfection	≤ 100	In accordance with Directive 91/271/EEC (Annex I, Table 1)	In accordance with Directive 91/271/EEC (Annex I, Table 1)	-	
C	Secondary treatment, and disinfection	≤ 1 000			-	
D	Secondary treatment, and disinfection	≤ 10 000			-	

Source: Parlamento Europeo y Consejo Europeo (2020).

In the case of Class, A (the most strict class), an initial validation is required with the values shown in Table 11. The norm describes three indicators to validate a process, one for each type of microorganism of concern: bacteria (E. Coli), Virus (Coliphages) and Protozoa (Clostridium perfringens spores), while the alternative method would consist of using pathogens directly: bacteria (Campylobacter), Virus (Rotavirus) and Protozoa (Cryptosporidium). Experience in the Murcia region (Simón, 2020) has shown that the removal of Clostridium perfringens spores is so costly that the method is more easily validated with the reference pathogens.

Table 11. Validation process of Class A reused water

Reclaimed water quality class	Indicator microorganisms (*)	Performance targets for the treatment chain (log_{10} reduction)
A	*E. coli*	≥ 5,0
	Total coliphages/F-specific coliphages/somatic coliphages/coliphages (**)	≥ 6,0
	Clostridium perfringens spores/spore-forming sulfate-reducing bacteria (***)	≥ 4,0 (in case of *Clostridium perfringens* spores) ≥ 5,0 (in case of spore-forming sulfate-reducing bacteria)

(*) The reference pathogens *Campylobacter*, Rotavirus and *Cryptosporidium* may also be used for validation monitoring purposes instead of the proposed indicator microorganisms. The following log_{10} reduction performance targets shall then apply: *Campylobacter* (≥ 5,0), Rotavirus (≥ 6,0) and *Cryptosporidium* (≥ 5,0).

(**) Total coliphages is selected as the most appropriate viral indicator. However, if analysis of total coliphages is not feasible, at least one of them (F-specific or somatic coliphages) shall be analysed.

(***) *Clostridium perfringens* spores is selected as the most appropriate protozoa indicator. However, spore-forming sulfate-reducing bacteria are an alternative if the concentration of *Clostridium perfringens* spores does not make it possible to validate the requested log_{10} removal.

Source: Parlamento Europeo y Consejo Europeo (2020).

3.4. Point of compliance

Both norms (RD 1620/2007 and Regulation 2020/741) give a special significance to the point where water quality must be observed.

In RD 1620/2007 the point of compliance is described as follows:

“In some cases, operators of the water regeneration station also transport and store reclaimed water beyond the outlet of the water regeneration station, before its supply to other actors in the chain, such as the reclaimed water distribution operator, the reclaimed water storage operator or the end user. It is necessary to determine the point of compliance so that it is clear where the responsibility of the operator of the water regeneration station ends and where the responsibility of the next actor in the chain begins.”

On the other hand, the Regulation 2020/741 preliminary article 15 says:

“It is necessary to define the point of compliance, to clarify where the responsibility of the reclamation facility operator ends and where the responsibility of the next actor in the chain starts.”

Preliminary article 19 specifies that:

“In order to effectively protect the environment and human and animal health, reclamation facility operators should be primarily responsible for the quality of reclaimed water at the point of compliance.”

And Article 4:

“Beyond the point of compliance, the quality of the water shall no longer be the responsibility of the reclamation facility operator.”

Article 5 specifies that the reuse risk management plan should *“identify additional barriers in the water reuse system and set out any additional requirements, which are necessary after the point* *of compliance to ensure that the water reuse system is safe"*. In the current state of the art, additional barriers usually come in the form of remaining chlorine that may work as a buffer against any potential microbial contamination during distribution.

In a comparison of both norms, the Spanish Ministry of the Environment (Ministerio para la Transición Ecológica y el Reto Demográfico, 2020) points out that:

"It is necessary to identify the stakeholders of water reuse, especially with regard to the determination of the points of compliance indicated by Regulation 2020/741 and the consequent establishment of responsibilities for water quality and its control. While RD 1620/2007 grants those responsibilities to the holder of the concession or authorization from the moment the treated water enters the reuse system until the point of delivery of the reclaimed water, Regulation 2020/741 exempts the operator of the regenerating station of responsibility beyond its point of fulfillment, where the following actors in the chain come into play, each with their share of responsibility."

3.5. Minimum requirements for monitoring

Another important aspect of water quality is how often it should be monitored.

The RD 1620/2007 defines in the Annex I.B the minimum sampling frequency and the analysis of each parameter:

Table 12. Minimum requirements for monitoring in RD 1620/2007

Uso	Calidad	Nematodos Intestinales	*Escherichia Coli*	SS	Turbidez	NT y PT	Otros contaminantes	Otros criterios
1.- USO URBANO	1.1 y 1.2	Quincenal	2 veces semana	Semanal	2 veces semana	–	El Organismo de cuenca valorará la frecuencia de análisis sobre la base de la autorización de vertido y del tratamiento de regeneración.	Mensual
2.- USO AGRARIO	2.1	Quincenal	Semanal	Semanal	Semanal	–		Mensual
	2.2	Quincenal	Semanal	Semanal	–	–		Quincenal
	2.3	Quincenal	Semanal	Semanal	–	–		–
3.- USO INDUSTRIAL	3.1	–	Semanal	Semanal	Semanal	–		Mensual
	3.2	Semanal	3 veces semana	Diaria	Diaria	–		*Legionella spp.* 3 veces semana
4.- USO RECREATIVO	4.1	Quincenal	2 veces semana	Semanal	2 veces semana	–		–
	4.2	–	Semanal	Semanal	–	Mensual		–
5.- USO AMBIENTAL	5.1	–	2 veces semana	Semanal	–	Semanal		–
	5.2	Semanal	3 veces semana	Diaria	Diaria	Semanal		Semanal
	5.3	–	–	Semanal	–	–		–
	5.4							Frecuencia igual al uso más similar

Source: Annex I.A of RD 1620/2007 (Ministerio de la Presidencia, 2007)

On the other hand, the Regulation 2020/741 sets the following frequency.

Table 13. Minimum requirements for monitoring in Regulation 2020/741

	Minimum monitoring frequencies					
Reclaimed water quality class	*E. coli*	BOD_5	TSS	Turbidity	*Legionella* spp. (when applicable)	Intestinal nematodes (when applicable)
A	Once a week	Once a week	Once a week	Continuous	Twice a month	Twice a month or as determined by the reclamation facility operator according to the number of eggs in waste water entering the reclamation facility
B	Once a week	In accordance with Directive 91/271/EEC (Annex I, Section D)	In accordance with Directive 91/271/EEC (Annex I, Section D)	-		
C	Twice a month			-		
D	Twice a month			-		

Source: Parlamento Europeo y Consejo Europeo (2020)

There are no major differences between both norms.

3.6. Risk management plan

Regulation 2020/741 article 5 requires the establishment of a risk management plan (RMP) in line with existing guidelines like ISO 20426:2018 (Guidelines for health risk assessment and management for non-potable water reuse), ISO 16075:2015 (Guidelines for treated waste water use for irrigation projects), or WHO guidelines. The RMP should identify potential hazards, preventive and corrective measures, and identify additional barriers to avoid health issues after the point of compliance. Annex II points out the key elements to be taken into account in the RMP: description of the entire water reuse system, identification of all parties involved, of potential hazards and environments and populations at risk. The RMP shall include:
"(a) an assessment of risks to the environment, including all of the following: (i) confirmation of the nature of the hazards, including, where relevant, the predicted no-effect level; (ii) assessment of the potential range of exposure; (iii) characterisation of the risks; (b) an assessment of risks to human and animal health, including all of the following: (i) confirmation of the nature of the hazards, including, where relevant, the dose-response relationship; (ii) assessment of the potential range of dose or exposure; (iii) characterisation of the risks."
According to previous studies on Risk Assessment (Demoware, 2016), the following four steps should be considered:
- Hazard Identification
- Hazard characterization/ effects assessment
- Exposure assessment
- Risk characterization

Where the following questions should be tackled:
- What can happen?
- How likely is it to happen?
- What are the consequences?
- How do we control/prevent it to happen?
- How do we know that the barriers and reduction measures in place work the way we expect them to?

Table 14. Similarities and differences between microbial risk assessment for drinking water and water reuse systems.

Characteristic	Drinking Water	Water reuse
Exposure route	Drinking water consumption Inhalation (e.g. *legionella spp.)*	Depending on use category, generally several different routes of exposure during various steps of water reuse (pre-treatment, storage, post-treatment, distribution)
Raw water quality	Depends on water source: Protected groundwater source (usually of high microbiological quality), surface water: high variability, prediction of source water quality at a given time challenging	Low microbial and chemical quality of secondary effluent but: Quality of source water (effluent wastewater treatment) can be controlled and predicted to a certain extend
Sources of contamination	Surface water: often multiple sources of contamination, hard to identify unknown sources, microbial source tracking as a major field of research	Main sources of pollution: human and animal faeces and industrial discharges (toilet flushing, surface runoff), prior information of presence of pathogens and chemical substances exist through epidemiological and local data
Risk management approaches	Water Safety Plans, country specific approaches depending on the organisation of the water sector	Sanitation Safety Plans, Water Reuse Safety Plans (in progress)
Ingested volume	High volume (0.5-2L) intentionally ingested Unintentional inhalation	Usually small volumes unintentionally ingested (except from potable reuse applications) Exposure via other routes of exposure products (e.g. raw vegetables) possible
Type of barriers	Multiple barrier principle (source protection, treatment, network, installations in buildings), Focus on water quality control	Control measures may include treatment and non-treatment options aiming at water quality and exposure reduction, respectively.

Source: Demoware (2016)

Different approaches to risk characterization (WHO, 2016) are:

• Sanitary inspection: An on-site visual evaluation of observable features, based on standardized forms/checklists to identify the most common issues that may lead to the introduction of hazards into a system.

• Risk matrix: semiquantitative evaluation of the likelihood that a hazardous event will occur and the severity or consequence of the hazard.

• Quantitative microbial risk assessment (QMRA): A formal, quantitative risk assessment approach that combines scientific knowledge about the presence and nature of pathogens, their potential fate and transport in the water cycle, the routes of exposure of humans and the health effects.

A typical risk matrix analysis should assess the severity and probability of each hazard.

Table 15. Probability and severity of events

Source: Simón (2020a)

And then combine these parameters to range the importance of each event.

Table 16. Risk matrix

Source : Simón (2020a)

Other documents being used as a reference (Simón, 2020a) for the development of Risk Management Guidelines are WHO's practical guide to auditing water safety plans (WHO, 2015) and the European Standard EN 15975-2 (UNE, 2014).

4. Technological processes to achieve quality requirements

There are different cost-effective treatments available to minimize the presence of microorganisms in water:

- Physico-Chemical treatment: Based on floculation, coagulation and decantation (often in lamellar modules). While this treatment does not have a direct impact in the reduction of microorganism concentration, it may further reduce the presence of organic matter, suspended solids and reduce the turbidity, so that further treatments are more efficient.
- Open and closed sand filtration: Can be used to further reduce turbidity and remove bigger microorganisms like bacteria.
- Membrane filtration: water is passed through membranes where microorganisms larger than the pore size may be trapped. Depending on the pore size there exists Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis. The smaller the membrane pore size, the better the filtration but the higher the backpressure needed and the operational costs.

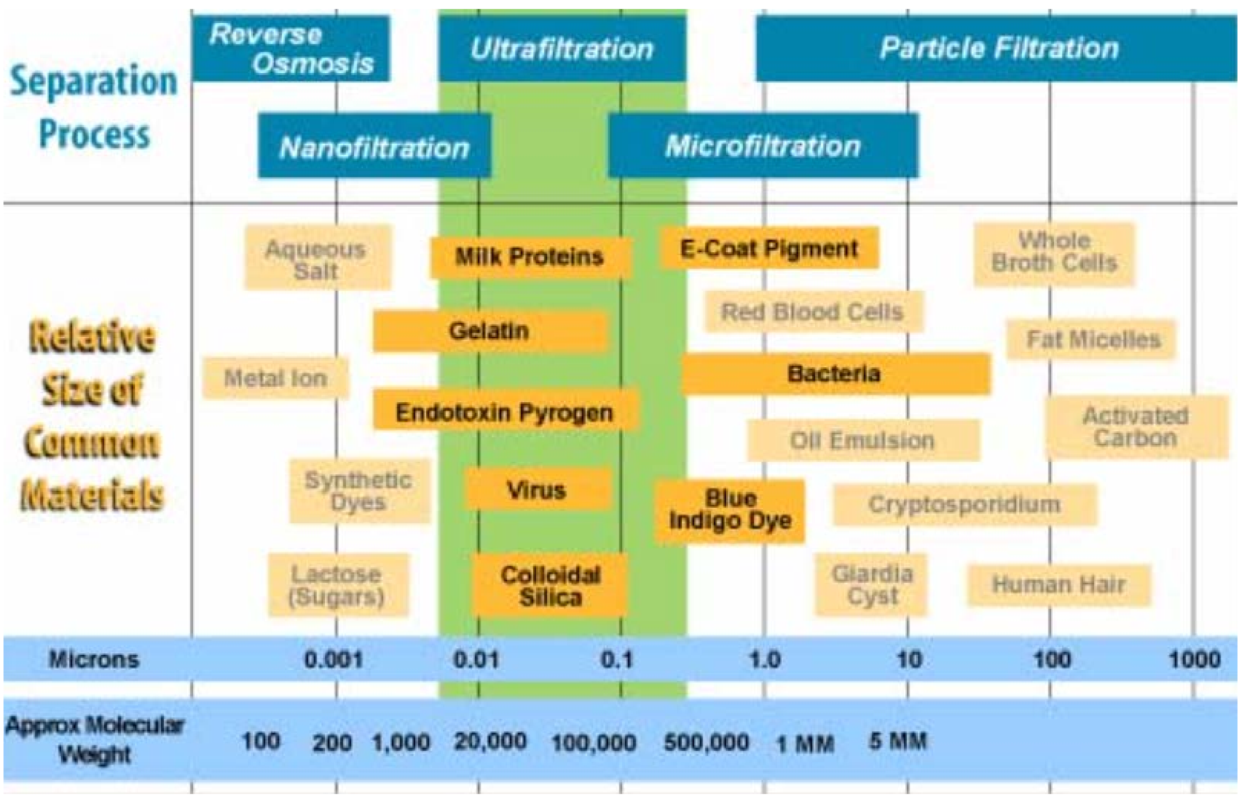

Figure 2. Typical pore sizes associated with membrane filtration
Source: KOCH Separation Solutions (2020); Safe Drinking Water Foundation (2020)

Figure 3. Separation capacity of membranes.
Note: MF: microfiltration; UF: ultrafiltration; NF: nanofiltration; RO: reverse osmosis.
Source: KOCH Separation Solutions (2020)

- Chlorine oxidation: Different Chlorine compounds (Chlorine gas, Sodium Hypochlorite, Chlorine Dioxide, etc.) are used to oxidize organic matter. Effectiveness and cost grow with chlorine concentration and contact time (United States Environmental Protection Agency, 1986).
- Ozone oxidation: Ozone has a higher oxidizing potential than Chlorine compounds, although it is typically more expensive to produce (United States Environmental Protection Agency, 1986; Xylem, 2020).

Table 17. Oxidation potential for different Oxygen and Chlorine compounds.

Oxidante	Potencial Oxidación (V)	Potencial Oxidación Rel. al cloro(V)
Radical Hidroxilo	2.80	2.05
Ozono	2.07	1.52
Peróxido de Hidrógeno	1.78	1.31
Permanganato potásico	1.70	1.25
Hipochlorito sódico	1.49	1.10
Cloro	1.36	1.00
Dioxido de cloro	1.27	0.93
Oxígeno	1.23	0.90

Source: Xylem (2020)

The effectivity of chemical disinfection can be described through Chick's law:

$$Cn \cdot t = -(\ln Nt/No)/K$$

Where N stands for the number of microorganisms, Cn for the chemical agent dose, t for contact time and K for the lethality, that depends on the particular agent and microorganism under study (United States Environmental Protection Agency, 1986).

Table 18. Typical Cn.t values

ORGANISM	FREE CHLORINE (pH 6-7)	CHLORINE DIOXIDE (pH 6-7)	OZONE (pH 6-7)
E.Coli	0.034-0.05	0.4-0.75	0.02
Rotavirus	0.01-0.05	0.2-2.1	0.006-0.06
Giardia Lamblia Cysts	47-150	-	0.5-0.6
Crystosporidium Parvum	7200*	79*	5-10*

Source: Xylem (2020)

- Ultraviolet radiation at a wave length of 254 nm is able to inactivate microorganisms through photooxidation of their genetic material (Xylem, 2020).

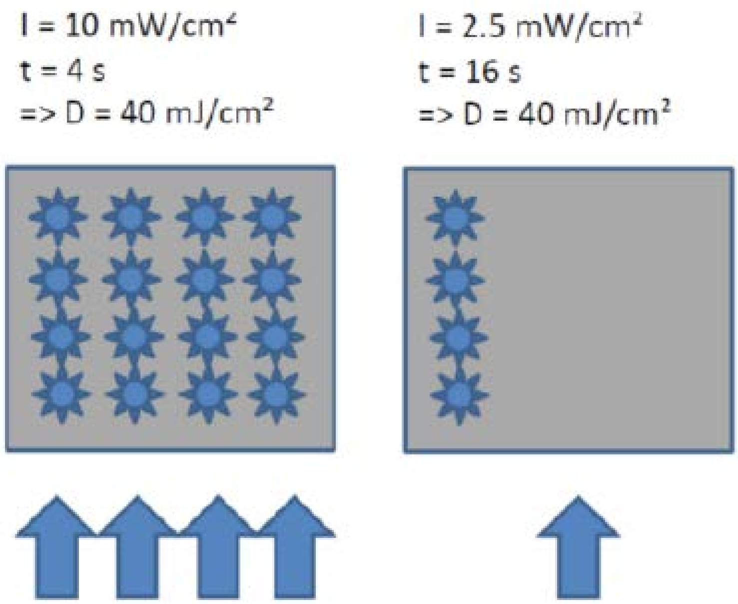

Figure 4. Different UV lamp configurations to achieve required dose
Source: Xylem (2020)

The cost depends on the radiation dose required (Pirnie et al., 2006). There are empirical values for the required inactivation dose of each microorganism type (Chevrefils et al., 2006).

Table 19. UV doses required for indicator and pathogen.

	[UV dose mJ/cm²]	1 log	2 log	3 log	4 log	5 log	6 log
	E. Coli	5	10	20	25	30	40
	Total Coliphages (MS2)	20	40	60	90	120	150
	Clostridium perfringens spores	45	95	145	220	-	-
	Campylobacter	2	4	6	8	10	20
	Rotavirus	15	25		35		60
	Cryptosporidium	2,5	5,8	12	22	45	85

References:

- W.A.M. Hijnen et al.; Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review; Water Research 40 (2006), p. 3 – 22.
- A. H. Malayeri et al.; Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae; IUVA News Fall 2016.
- US EPA UVDGM validation report
- University of Bonn

Source: Xylem (2020)

Virus are not very sensitive to Chlorine oxidation, often requiring Ultraviolet treatments. Bacteria are very sensitive to inactivation through Chlorine oxidation, and to Ultraviolet radiation. Protozoa are mostly insensitive to Chlorine and even Ozone oxidation (Simón, 2020b), but may be inactivated through Ultraviolet radiation. Due to their relatively bigger size, filtration treatment is feasible.
Due to the technical difficulties and high costs required to reduce the indicators or pathogen concentrations with only one technology, current implementations rely on the combination of two or more techniques: Ozone oxidation followed by Ultraviolet radiation (Xylem, 2020) (see Table 20) or Membrane Filtration followed by Ultraviolet ratiation (Simón, 2020b).

Table 20. Log reductions achieved with Ozone disinfection and Ultraviolet disinfection.

DESINFECCIÓN OZONO (Reducción logaritmica)

Objetivo desinfección	Objetivo	Dosis 1	Dosis 2	Dosis 3
E. Coli	$>5_{log}$	1_{log}	$1,5_{log}$	2_{log}
Total Coliphages (MS2)	$>6_{log}$	5_{log}	6_{log}	7_{log}
Clostridium perfringens spores*	$>5_{log}$	1_{log}	1_{log}	1_{log}
Campylobacter	$>5_{log}$	1_{log}	2_{log}	2_{log}
Rotavirus	$>6_{log}$	4_{log}	5_{log}	5_{log}
Cryptosporidium	$>5_{log}$	1_{log}	1_{log}	1_{log}

DESINFECCIÓN UV (mJ/cm2)

1 log	2 log	3 log	4 log	5 log	6 log
5	10	20	25	30	40
20	40	60	90	120	150
45	95	145	220	-	-
2	4	6	8	10	20
15	25		35		60
2,5	5,8	12	22	45	85

Source: Xylem (2020)

5. Cost of reused water

The estimation of the cost of reused water must take into account at least the following parts:
- Water treatment from wastewater plant effluent to reuse grade (capital expenditure (CAPEX) and operation expenditure (OPEX))
- Water storage (CAPEX)
- Distribution infrastructure (CAPEX)
- Distribution running costs (OPEX)

The next sub-sections will describe the main considerations for each of these elements.

5.1. Water treatment to reuse grade

The treatment of WWTP effluents to reach the reuse grade requires the implementation of infrastructure (the Water Reuse Plant) with infrastructure (CAPEX) and operation and maintenance (OPEX) costs. These costs will depend on the technology used and the water quality required and are subject to economy of scale considerations. An approximation to these costs is offered by (Iglesias, 2016) and (Joint Research Centre, 2017):

Table 21. Cost of different reuse treatments.

		CAPEX (EUR/(m3/day))		*OPEX (EUR/m3)*	
		min	max	min	max
Type 1	Physico-chemical treatment, gravity sand filter, Ultrafiltration and Sodium Hypochlorite disinfection.	164	351	0.14	0.20
Type 2	Physico-chemical treatment, gravity sand filter, Ultraviolet disinfection and residual Sodium Hypochlorite disinfection.	**27**	**47**	**0.06**	**0.09**
Type 3	Gravity sand filter, Ultraviolet disinfection and residual Sodium Hypochlorite disinfection.	9	22	0.04	0.07
Type 4	Gravity sand filter	5	11	0.04	0.07
Type 5a	Physico-chemical treatment, gravity sand filter, Ultrafiltration, Reverse Osmosis, residual Sodium Hypochlorite disinfection.	259	458	0.35	0.45
Type 5b	Physico-chemical treatment, double sand filter, Electrodyalisis and residual Sodium Hypochlorite disinfection.	248	405	0.35	0.45

Source:

Source: Iglesias (2016)

A more recent estimation is offered by (Simón, 2018), in light of the experience of the Murcia region in Spain:

Table 22. Cost of different reuse treatments

	CAPEX (EUR/(m3/day))		*OPEX (EUR/m3)*	
	min	max	min	max
Ultrafiltration	480	480	0.07	0.09
Class A	**> 200**	-	**0.16**	**0.20**
Class B	150	170	0.08	0.08

Source: Simón (2018)

The total cost in EUR/m3 can be then calculated adding up the operational costs and the equivalent investment costs. These equivalent investment costs in EUR/m^3 can be assessed annualizing the investment costs throughout the infrastructure lifespan (European Commission, 2003):

$$AEC = \frac{NPV * DiscountRate}{(1-(1+DiscountRate)^{-lifetime})}$$

AEC = annual equivalent cost
NPV = net present value of investment
Discount rate = chosen discount rate (the same as used to calculate the NPV)
Lifetime = lifetime of the capital equipment

Where the lifetime of the Water Reuse Plant may range between 15 and 25 years, and the discount rate depends on the economic conditions, but may range between 0.1% and 5%.
Once the annual equivalent cost AEC (EUR/year) has been calculated, dividing by the production of the plant (m^3/year) will yield an equivalent investment cost in EUR/m^3.
For example, a plant with a capacity of 2'000 m^3/day (roughly the production of a 10'000 people agglomeration with a 200 l/day use), treating water to Class A grade (approximately 200 EUR/(m^3/day) would have an investment cost of 400'000 EUR. For a lifetime of 20 years and a discount rate of 2%, the annual equivalent cost would be 24'500 EUR/year. If the plant is working an equivalent of 4 months (122 days) per year, the production would be 244'000 m^3/year, bringing the equivalent implementation cost to 0.10 EUR / m^3.
A part of the operational costs represents the energy consumption. It is interesting to quantify the expected consumption of a water reuse project, both to better understand the cost structure and to analyze the implications on climate change policies. The experience in California (Hartling, 2020) shows that energy represents 25% of non-labor operation and maintenance costs. The following table is built based on findings in the literature (Pearce, 2008; Voutchkov, 2018), and using the assumption that average energy cost is 0.1 EUR / (kW·h) (Joint Research Centre, 2017).

Table 23. Energy cost of water treatment and distribution

Water supply alternative	*Energy use (kW·h/m3)*	*Energy cost (EUR/m3)*
Conventional treatment of surface water	0.1 - 0.4	0.01 - 0.04
Wastewater reclamation	**0.5 – 1.2**	**0.05 – 0.12**
Brackish water desalination	0.8 – 1.7	0.08 – 0.17
Desalination of sea water	2.5 – 4.0	0.25 – 0.40

Source: Pearce (2008); Voutchkov (2018)

5.2. Storing costs

Different temporal patterns of offer and demand are among the technical problems to reuse urban wastewater for irrigation. The supply of wastewater can be considered roughly constant throughout the year (except for tourist agglomerations where the summer production may exceed the winter average), while the demand of water for irrigation is normally higher between March and October.

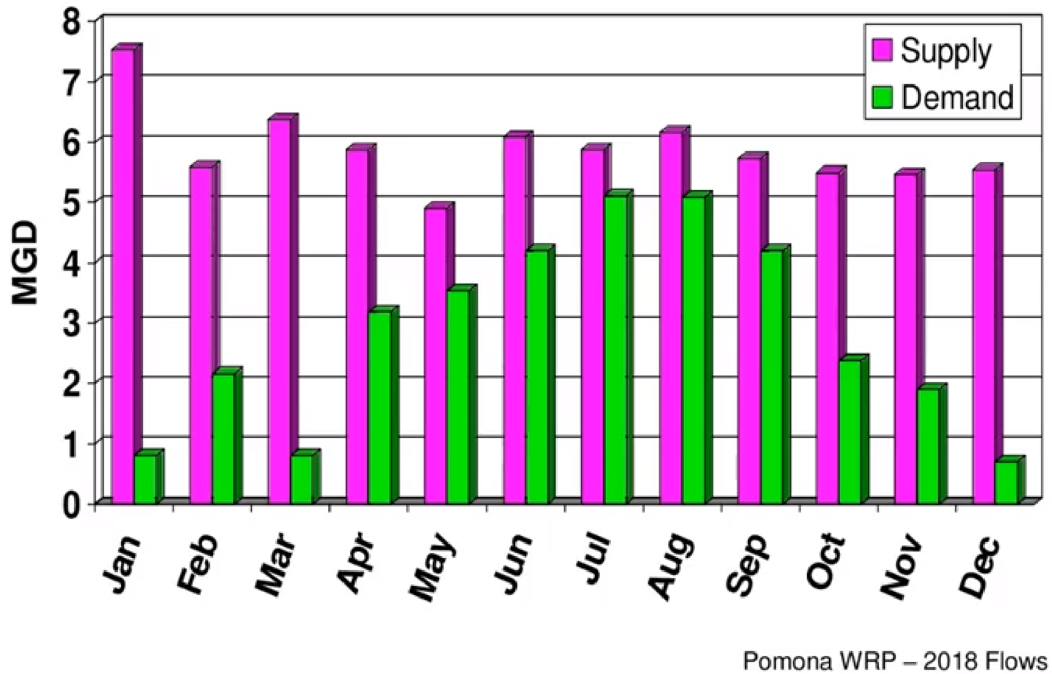

Figure 5. Example of intra-annual supply and demand of reused water. Pomona Water Reclamation Plant
Source: Hartling (2020).

The following formulae may indicate the volumes and areas involved. The offer of wastewater for resupply is calculated with the population and daily water use per person:

Of (m^3/year) = Population (pers) · Wuse (m^3/pers/day) · 365.25 (day/year)

A 10’000 people agglomeration with a 200 l/day use would produce 2’000 m^3/day and 730’500 m^3/year.

Demand can be calculated with the irrigated surface and the water needs:

Dem (m3/ year) = Wneed (m^3/ha/year) · Surface (ha)

For example, a surface of 100 ha with a yearly need of 2’000 m^3/ha/year would require 200’000 m^3 /year.

It would take 100 days for the population to produce this amount of water (neglecting losses). If half the volume was stored at the beginning of the irrigation season, the volume would indeed be 100’000 m^3. For an average elevation of 6m of water storage tank, the required surface of the tank would be 1.7 ha.

It is estimated that the cost of a water storage tank ranges between 2 and 8 EUR/m3 (Joint Research Centre, 2017), which for this example would imply a cost above 200’000 EUR.

5.3. Distribution network cost

The next cost to be considered is the implementation of water pipes linking the Water Reuse Plant to the irrigation fields. The total cost will depend on the material of the pipes, the diameter (that depends on maximum flow) and the distance.
It must be noted that the international convention is to use a purple (RAL 4001 or 4005, PANTONE 2577 U) color to indicate that the pipes carry reused water (Canal de Isabel II, 2020).

Table 24. Recommended materials for reused water pipes

Material clase mínima	*NORMA*	*DN (mm)*	0	100	200	300	400	500	600	700	800	900
Fundición dúctil	UNE-EN 545:2011	ID										
PVC-O 500	UNE-EN 17176:2019	OD										
PRFV SN 5000 (N/m²)	UNE-EN 1796:2014	ID (Serie a)										
		OD (Serie b)										
PE PE 100	UNE-EN 12201	OD										

RANGO DE DIÁMETROS NORMALIZADOS EN LAS NORMAS EUROPEAS

DIÁMETROS DE USO PREFERENTE POR CANAL DE ISABEL II

Source: Canal de Isabel II (2020)

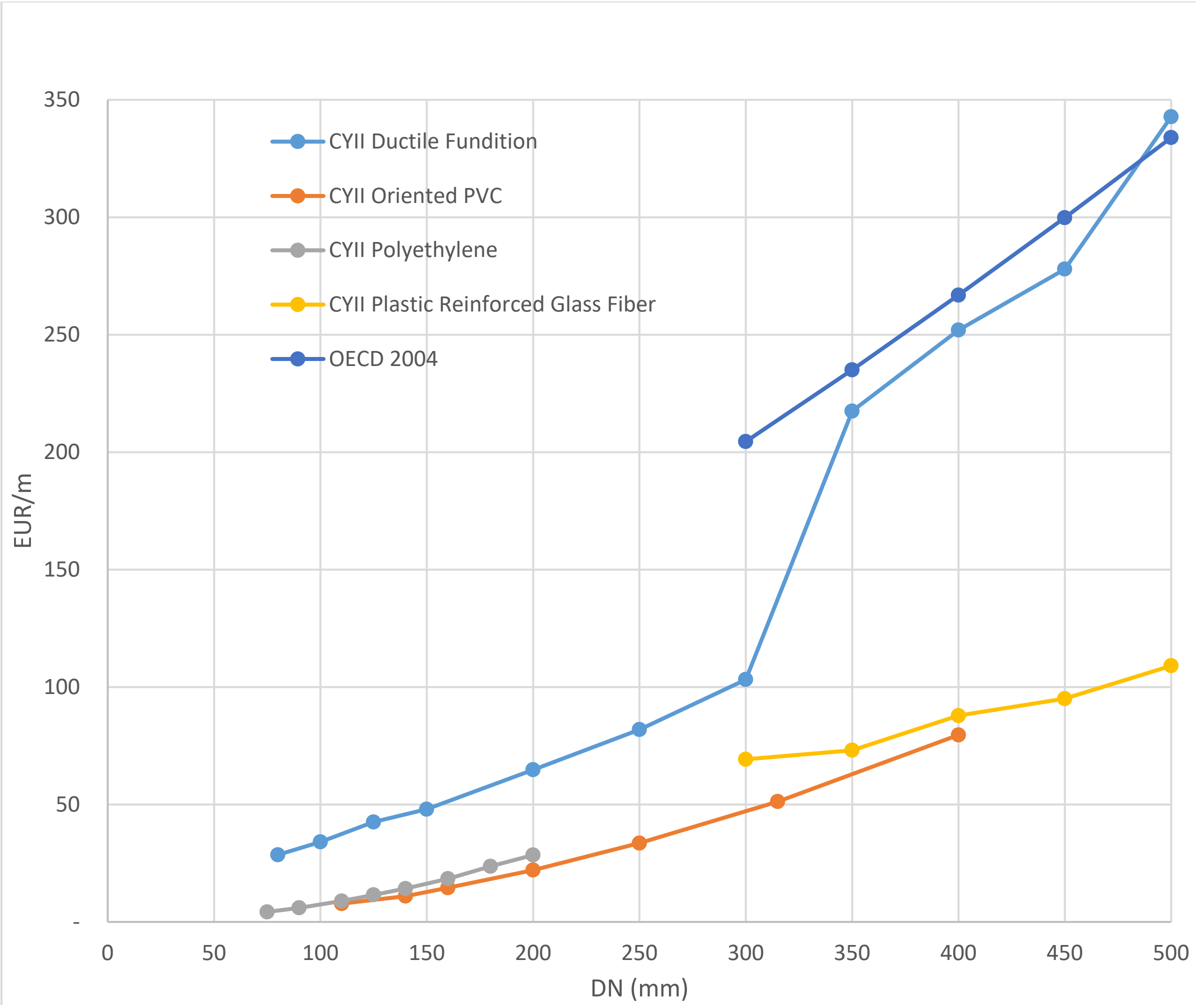

Figure 6. Unit cost of pipe supply and installation
Source: Canal de Isabel II (2018); Joint Research Centre (2017)

Special care must be taken to avoid any interconnexion between reused water pipes and water for human consumption pipes.

Table 25. Minimum recommended horizontal and vertical separation between reused water pipes and other conductions.

Servicio	*Separación en planta* (cm)	*Separación en alzado* (cm)
Abastecimiento	150	30
Saneamiento	100	20
Gas	50	50
Electricidad-alta	30	30
Electricidad-baja	20	20
Comunicaciones	30	30

Source*:* Canal de Isabel II (2018)

The energy consumption of water distribution is a function of water density, gravity, pumping efficiency and total head, according to the following formula:

$$EC\left(\frac{kW\cdot h}{m^3}\right)=\frac{P\ (kW)}{Q\ (\frac{m^3}{h})}=\frac{1\ kW}{1000\ W}\cdot\frac{1h}{3600s}\cdot\frac{\rho\left(\frac{kg}{m^3}\right)\cdot g\left(\frac{m}{s^2}\right)\cdot Head(m)}{efficiency}$$

For a density of 1000 kg/m3, an acceleration of gravity of 9.8 m/s2 and an efficiency of 70%, the consumption corresponds to:

$$EC\left(\frac{kW\cdot h}{m^3}\right)==0.004\cdot Head\ (m)$$

The total head can be calculated as an addition of the geometrical head (vertical distance between the Water Reuse Station and the irrigation fields), and the head losses, which can be approximated as a fraction of the total pipe length.

Previous literature (Pearce, 2008) estimated an average consumption of 0.6 kW·h/m3, which corresponds to an average total head of 150 m. With an average cost of 0.1 EUR/kW, the distribution costs would be in the order of 0.06 EUR/m^3, but would vary wildly depending on the relative position of the Water Reuse Plant and the irrigated fields.

The implementation cost of the pumping station can be approximated through the following formula (Joint Research Centre, 2017), as a function of the installed power.

Pumping Station Cost (EUR) = 33’140 · P(kW) $^{0.559}$

In the case of branched irrigation networks, the following objective cost function (*Z*) is proposed:

$$Z = CI_r + CI_t + CI_B + CA_E + CA_A =$$
$$= N \cdot C_{uDt} \cdot L_t + \frac{\gamma \cdot (H_0 + hf_F) \cdot Q_0}{\eta} \cdot C_{uP} + \frac{Et_a}{a_I \cdot UD_{1/4}} \cdot \left(C_{ua} + \frac{\gamma \cdot (H_0 + hf_F)}{\eta} \cdot C_{uE} \right)$$

Where L_t represents pipe length, γ the water specific weight, H_0 and Q_0 the upstream end pressure head and flow, hf_F the constant head losses of the pump station accessories (the required pressure head at the pump station is $H_B = hf_F + H_0$) and η the pump performance. The costs included in eq. 1 are:

- Pipelines investment costs: CI_t . The unitary cost per pipe unit length can be expressed with a power function dependent on the diameter (D), $C_{uD} = a \cdot D^e$. For plastic materials $e \approx 2$ while a depends on the pipe nominal pressure.
- Energy cost (CA_E). The annual energy cost depends on the consumed water (which is supposed to be the evapotranspiration, Et_a), the pump performance, the required energy head and the unitary energy cost (C_{uE}). This term is updated with a rate a_I to be compared with investment costs.
- Pump cost (CI_B). The upstream energy head and flow and the power unitary cost (C_{uP}) determine the pumping station investment cost.
- Cost of the consumed volume of water (CA_A). It depends on the unitary water cost (C_{ua}), the amount of water consumed, the costs updating rate and the distribution uniformity ($UD_{1/4}$).

6. Administrative management of water reuse: Concessions and Authorizations

6.1. The Spanish Water Law and the legal aspects of reuse: licenses and administrative authorizations

Water reuse is mentioned in Title V, Chapter III (article 109) of the Water Law RD1/2001 (Ministerio de Medio Ambiente, 2001):

"1. The Government shall establish the basic conditions for the reuse of water, specifying the required quality of treated water according to the intended uses.

The holder of the concession or authorization must defray the necessary costs to adapt the reuse of the water to the quality requirements in force at all times.

2. The reuse of water from a use will require administrative concession as a general rule. However, if the reuse is requested by the holder of a discharge permit of already treated water, only an administrative authorization will be required, in which the necessary conditions will be established to complement those included in the previous discharge permit."

Three main aspects are mentioned in the article:

- The water quality of reused water must be defined beforehand. This requirement is developed in the Royal Decree 1620/2007 (see section 3.2) and in European Regulation 2020/741 (see section 3.3).

- Water reuse requires an administrative concession (Concesión in Spanish), or an administrative authorization (Autorización administrativa) if the applicant is the holder of the discharge permit.
- The cost of treatment from urban WWTP discharge quality to reuse quality must be paid by the holder of the reuse concession or authorization.

The implementation of the third aspect is not straightforward (see section 8.3).

Article 110 of the Spanish Water Law mentions State grants to activities that ameliorate water quality:

"These grants will be extended to those who proceed to the purification and desalination of water and to the treatment of wastewater, through more appropriate processes or methods, to the implementation of systems for the reuse of wastewater or carry out research activities in these matters."

The legal aspects of concessions and authorizations (in general, i.e. not only for reuse) are covered in Title IV, Chapter III, Section 1 of the Spanish Water Law (articles 59 to 66). An excerpt is presented hereafter:

"Concessions will be granted taking into account the joint rational exploitation of surface and underground resources, without the concession title guaranteeing the availability of the flows granted.

All concessions will be granted according to the provisions of the River Basin Plans, on a temporary basis and a term not exceeding 75 years. Its granting will be discretionary, but any resolution will be motivated and adopted according to the public interest.

In the concessions, the order of preference established in the River Basin Plan of the corresponding basin will be observed, taking into account the requirements for the protection and conservation of the resource and its environment.

The water that is granted will be assigned to the uses indicated in the concession title. It cannot be applied for different uses, nor to different lands if they are irrigation.

The granting Administration may impose the substitution of all or part of the concession flows by others of different origin, in order to rationalize the use of the resource.

When the destination of the water is irrigation, the holder of the concession must also be the owner of the lands to which the water is destined.

The water authority may grant collective concessions for irrigation to a plurality of landowners who are integrated by agreement into a group of irrigators."

The Regulation of the Public Hydraulic Domain (Reglamento del Dominio Público Hidráulico, RD 849/1986) also describes the procedure in its Title II, Chapter III, articles 93 to 197. In particular, article 93 requires:

"1. All private use of water not included in article 54 of the consolidated text of the Water Law requires an administrative concession. Its granting will be discretionary, but any resolution will be motivated and adopted according to the public interest. The concessions will be subject to review in accordance with the provisions of article 65 of the revised text of the Water Law.

2. The ordinary procedure for the granting of concessions shall be adjusted to the principles of publicity and processing in competition, preferring, under equal conditions, those that project the

most rational use of water and better protection of its environment. The principle of competition may be abolished when it comes to supplying water to populations (art. 79.2 of the Water Law).
3. The granting of authorizations and concessions referring to the public hydraulic domain is the responsibility of the River Basin Authority, except in the case of works and actions of general interest of the State, which will correspond to the Ministry of Public Works and Urban Planning, as established in Article 24, a), of the Water Law.
4. Notwithstanding the provisions of section 1, the bodies of the State Administration or the autonomous communities may access the use of the waters, with prior special authorization issued in their favor or by the State Patrimony, without prejudice to third parties."
By which the principles of rationalization of water use and protection of the environment are established.
It is worth mentioning that articles 272 and 273 of RD 849/1986 were devoted to wastewater reuse but were derogated by RD 1620/2007. Royal Decree 1620/2007 (see next section) deals with the specific aspects of concessions and authorizations for water reuse.

6.2. Royal Decree 1620/2007 for water reuse: concessions and administrative authorizations

A particular law for water reuse was passed in Spain in 2007, the Royal Decree 1620/2007. Article 3 confirms the requirements of Water Law article 109, requiring a concession for the reuse of wastewaters (or an administrative concession if the applicant is the holder the wastewater discharge permit).
The procedure to obtain the reuse concession follows the ordinary processing of any public water concession, although an additional report from health authorities is required.
When the applicant is not the holder of the initial water use or the discharge permit, article 10 of RD 1620/2007 declares:
"If the person who formulates the request for a concession for reuse is a third party who does not hold the condition of concessionaire for the first use, nor that of the holder of the discharge permit of wastewater, the procedure established by the Regulation of the Public Hydraulic Domain for concessions in general, upon presentation of the application to obtain the water reuse concession according to the model in Annex II. The proposal of the conditions under which the concession to reuse the water could be granted will determine the points established in article 8.6 of this Royal Decree."
Annex II of RD 1620/2007 includes a template of the request of concession of authorization for water reuse. The request should include a description of the reuse project, the WWTP where the waters originate, the location of the delivery point of the treated wastewater, the required volume, and the intended use.
Article 8.6 refers to the proposal of the River Basin Authority. It should include the conditions under which the reuse concession could be granted, describing the quality requirements for the reused water, the quality auto control programme, and the term of validity of the concession.

The procedure is described in the following outline.

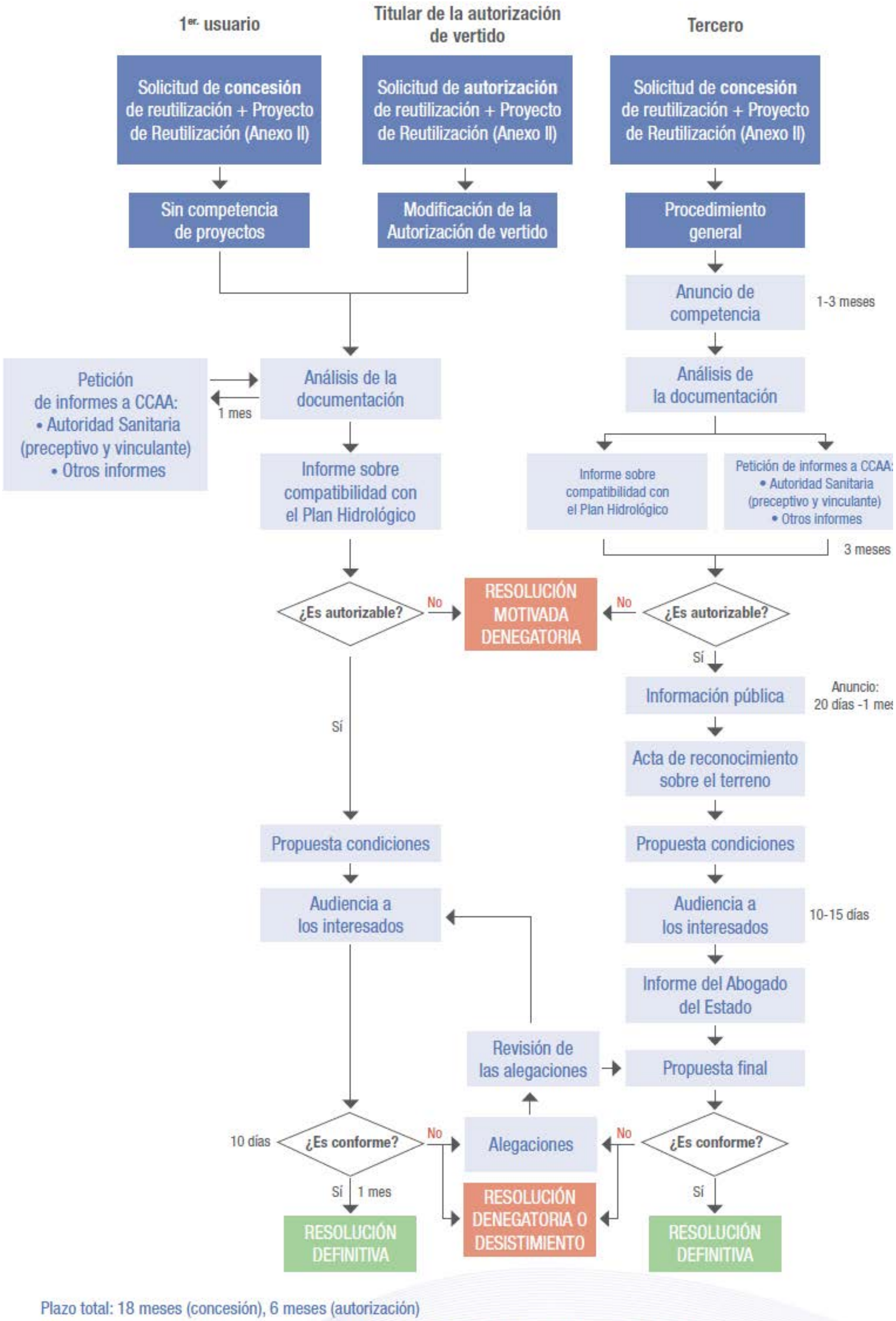

Figure 7. Procedure for obtaining a concession or authorization for water reuse.
Source: Ministerio de Medio Ambiente y Medio Rural y Marino (2010)

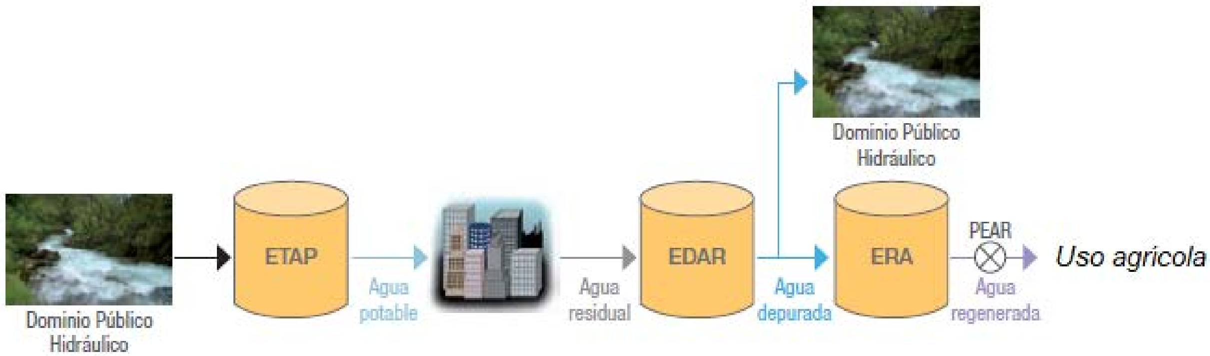

Figure 8. Outline of the urban water cycle and the ulterior reuse of wastewater for agricultural use.
Source: Ministerio de Medio Ambiente y Medio Rural y Marino (2010)

7. Volume of current water reuse in Spain

As it was advanced in the introduction, Spain stands out as the country with the higher yearly reuse volume of the European Union, with a quantity that exceeds the 300 hm^3/year. Albeit a high volume, it lacks behind the expectations set in the 2012 National Plan for Water Reuse, which set an objective above 1000 hm^3/year for 2020.

The accurate quantities of reused volumes remain elusive, since different administrations provide different volumes: infrastructure capacity, wastewater treated to reuse quality standards, treated water reused, etc.

Table 26. Declared reused volumes in Spain (hm^3/year), per river basin

Demarcación Hidrográfica	PH 2º ciclo		Año 2016/17		Año 2017/18	
	Capacidad máxima	Volumen suministrado	Capacidad máxima	Volumen suministrado	Capacidad máxima	Volumen suministrado
Cantábrico Occidental	-	2,60	-	3,40	-	3,60
Cantábrico Oriental	0,00	0,00	0,00	0,00	0,00	0,00
Ceuta	-	4,40	-	4,40	-	4,40
Cuenca Fluvial de Cataluña	100,00	27,40	100,00	31,74	100,00	30,56
Cuencas Mediterráneas Andaluzas	-	27,30	-	27,30	-	27,30
Duero	0,00	0,00	0,00	0,25	-	0,25
Ebro	14,00	4,77	12,05	5,00	12,05	5,00
El Hierro	0,03	0,02	0,03	0,02	0,03	0,02
Fuerteventura	14,31	6,08	14,31	6,08	14,31	6,08
Galicia Costa	0,17	0,00	0,17	0,00	0,17	0,00
Gran Canaria	-	12,70	-	12,70	-	12,70
Guadalete y Barbate	-	9,70	-	9,70	-	9,70
Guadalquivir	15,40	15,40	16,99	16,99	16,99	16,99
Guadiana	9,13	2,01	9,13	2,01	9,13	2,01
Islas Baleares	50,20	26,84	68,23	34,30	68,23	34,30
Júcar	285,46	121,49	308,32	101,94	303,14	106,31
La Gomera	0,74	-	0,74	-	0,74	-
La Palma	0,00	0,00	0,00	0,00	0,00	0,00
Lanzarote	1,37	0,65	1,37	0,65	1,37	0,65
Melilla	-	0,40	-	0,40	-	0,40
Miño-Sil	0,00	0,00	0,00	0,00	0,00	0,00
Segura	126,90	88,70	119,00	86,40	121,30	89,30
Tajo	103,00	10,00	83,02	21,45	82,93	21,27
Tenerife	-	11,13	-	11,13	-	11,13
Tinto, Odiel, Piedras	-	0,00	-	0,00	-	0,00
TOTAL	-	**371,59**	-	**375,86**	-	**381,97**

Source: Dirección General del Agua (2020)

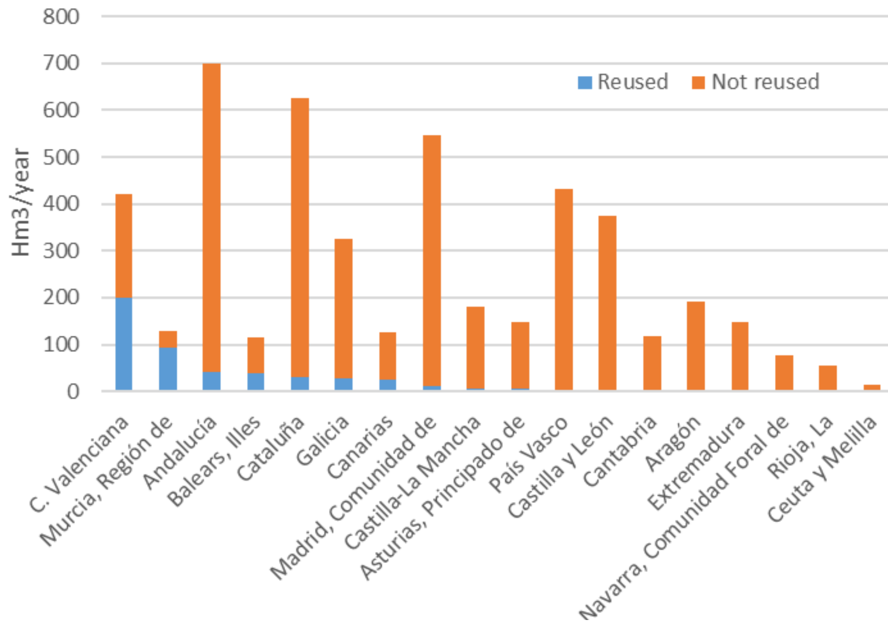

Figure 9. Volume of treated wastewater in Spain Autonomous Communities in 2016.
Source: INE (2020).

While the country as a whole reuses approximately 10% of its wastewater, there are huge regional differences. The region of Murcia in the South East of Spain, with a buoyant export industry of fruits and vegetables but scarce availability of water recycles up to 70% of its wastewater. Neighboring Comunitat Valenciana and the islands follow. On the other end of the chart, northern regions like Navarra and la Rioja with higher precipitation, or rainfed-crop regions like Aragón and Extremadura show negligible ratios of recycled water.

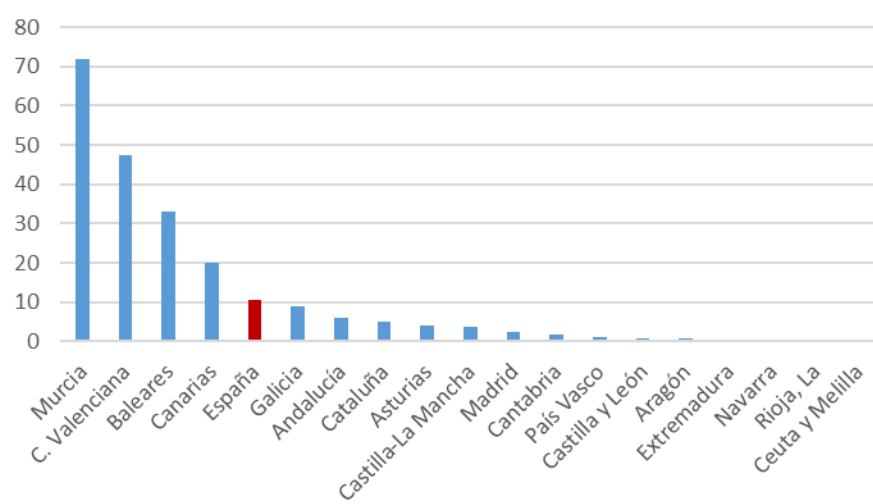

Figure 10. Reused volume as a percentage of treated wastewater
Source: INE (2020)

According to the available data for year 2016, more than 60% of treated water for reuse in Spain was destined for agriculture. Being the biggest consumer of water in Spain, it is natural that agricultural activity is the most impacted by water scarcity and the most interested in alternative sources. Gardens, leisure, and sport area irrigation (21%) is the second largest consumer, mostly represented by irrigation of public parks and golf courses. Industrial use represents only a 5% of the total, while street cleaning represents a tiny proportion, restricted to big cities.

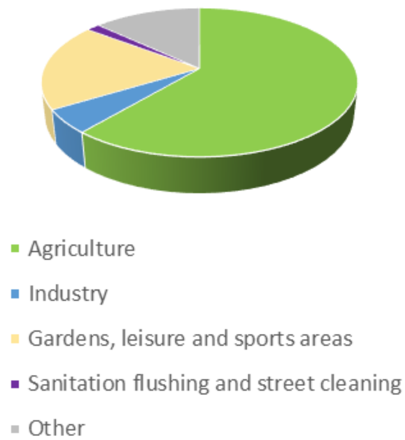

Figure 11. Destination of reused water in Spain in 2016.
Source: INE (2020)

8. Open issues in water reuse legislation and implementation projects

8.1. Non planified water reuse

While Regulation 2020/741 sets strict requirements on reused water quality, there are no restrictions for the microbiological quality of water directly abstracted from natural bodies of water. In the case of surface bodies of water, these may receive the effluent of WWTP which, according to current regulation (steaming from Directive 91/271/EEC) have no restriction on microbiological contamination.

The abstraction of water downstream of WWTP effluents is a de facto, non planified water reuse that is currently being practiced throughout EU Member States. Table 27 shows the expected concentration of pathogens and indicators in the surface waters according to the percentage of WWTP effluent with respect to stream flow.

Table 27. Microbiological pollutant concentration according to the dilution ratio of a WWTP effluent to pristine waters.

Parameters	Assumption secondary effl. quality	Scenario 5%	Scenario 10%	Scenario 20%	Scenario 50%	EU Com. (2017)*	JRC (2017)
E. coli (cfu/100 mL)	10^4 *	$5*10^2$	10^3	$2*10^3$	$5*10^3$	100 - 10^4	10 - 10^4
Enterococci (cfu/100 mL)	10^4 *	$5*10^2$	10^3	$2*10^3$	$5*10^3$	-	-
Clostridium perf. spores (cfu/100 mL)	10^3 *	$5*10^1$	10^2	$2*10^2$	$5*10^2$	-	-
Somatic coliphages (pfu/100 mL)	10^5 *	$5*10^3$	10^4	$2*10^4$	$5*10^4$	-	-
Noro viruses (gc/L)	10^4 **	$5*10^2$	10^3	$2*10^3$	$5*10^3$	-	-

Note: *'*Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene' (EU Commission, 2017); **Levantesi et al. 2010; Costan-Longares et al., 2008; **NRC, 2012

Source: Drewes et al. (2017)

Maximum concentration of pollutants in the current Regulation are presented in section 3.3. Measurements from WWTP influents in the Spanish region of Murcia (Simón, 2018) show that the concentration of Chlostridium spores and Coliphage Virus may be even higher.

Table 28. Microbiological pollutant concentration at WWTP effluent in Murcia

	Min	Max
Chlostridium (ufc/100ml)	23 000	3 000 000
Coliphages (pfp/100ml)	20 000	2 300 000

Source: Simón (2018)

8.2. Recovery of nutrients in wastewater

The preliminary articles of EU Regulation 2020/741 mention the possible contribution of reuse to the recovery of nutrients present in treated urban waters, so that irrigation was a way of returning these nutrients to natural cycles (preliminary article 12). The potential of using fertigation to reduce the application of inorganic fertilizers is also mentioned (preliminary article 11).

The practical application of these concepts entails some difficulties:

- The organization of the section of the water cycle proposed by the Regulation supposes a first stage of purification where the effluent from the WWTP complies with Directive 91/271/EEC. In cases of discharges to areas sensitive to eutrophication, the directive requires the removal of a large part of the nutrients (Nitrogen and/or Phosphorus) before delivering the water to the Reuse Station.
- In any case, the presence of large concentrations of nutrients in the reclaimed water could pose a risk to the receiving waters in the event that due to a system failure the irrigators were forced to dump the reused water directly into the Public Hydraulic Domain. This possibility should be dealt with in the risk management plan.

From the technical feasibility point of view, one of the processes that is successfully recovering nutrients from wastewater and has been implemented in Spain (for example in WWTP Sur in Madrid) is the recovery of struvite (Ye et al., 2020):

$$Mg^{2+} + PO_4{}^{3-} + NH_4{}^{+} + 6H_2O \rightarrow MgNH_4PO_4{\cdot}6H_2O\downarrow$$

It must be noted that this process takes place at the WWTP phase, before the delivery to the water reuse plant. The development of a market to commercialize this and other subproducts may create further incentives to the development of nutrient recovery plants at a larger scale.

8.3. Financing the costs of treatment from WWTP effluent to reuse grade

Section 6.1 presents how article 109.1 of the Spanish Water Law requires that "The holder of the concession or authorization must defray the necessary costs to adapt the reuse of the water to the quality requirements in force at all times."

In other words, the cost of treatment from the degree of purification effluent to the degree of reuse must be covered by the holder of the concession or authorization.

Article 61 of the Spanish Water Law specifies that "When the destination of the water is irrigation, the holder of the concession must also be the owner of the lands to which the water is destined. (…) The basin organization may grant collective concessions for irrigation to a plurality of landowners who are integrated into a group of irrigators by agreement. "

It is understood that the owner of the land or the group of irrigators must be holders of the concession and defray the costs necessary to treat the water from the grade of WWTP effluent (in accordance with Directive 91/271 / EEC) to reuse grade (according to European Regulation 2020/741).

However, Recital 2 of the European Regulation establishes that water management would improve with greater reuse of water, limiting the extraction of surface and underground water bodies. In this sense, the Guadiana Hydrological Plan specifies that "In deficit areas, and especially in the Upper Guadiana Subsystem, reuse will be granted exclusively to replace irrigation or industrial water rights". In other words, the reuse of water is intended to replace other sources (abstraction of surface or underground water masses). However, as reused water typically costs more than other sources, there is little incentive for irrigators to use it.
In certain contexts (Simón, 2020b) it has been considered that under the concept of "polluter pays" enshrined in article 9 of the WFD, it is up to urban users who generate wastewater to cover the costs of returning water to a usable status.

8.4. Secondary effect of water reuse on natural waters

The use of reused water can have unintended consequences on the functioning of the integral water cycle. In inland areas where the effluent from the treatment plants constitutes a non-negligible part of the circulating flow through the rivers, the excessive use of reuse could lead to a decrease in flow that compromises the sustainability of aquatic ecosystems or the guarantee of supply downstream from discharge points.
This effect is not directly dealt with by current legislation, so it is up to the River Basin Authorities to study it before granting new authorizations or reuse concessions.
Another effect that can be associated with lowering the costs of water reuse is a net increase in the supply of water that leads to an increase in demand, which could cause another instance of the Jevons paradox.

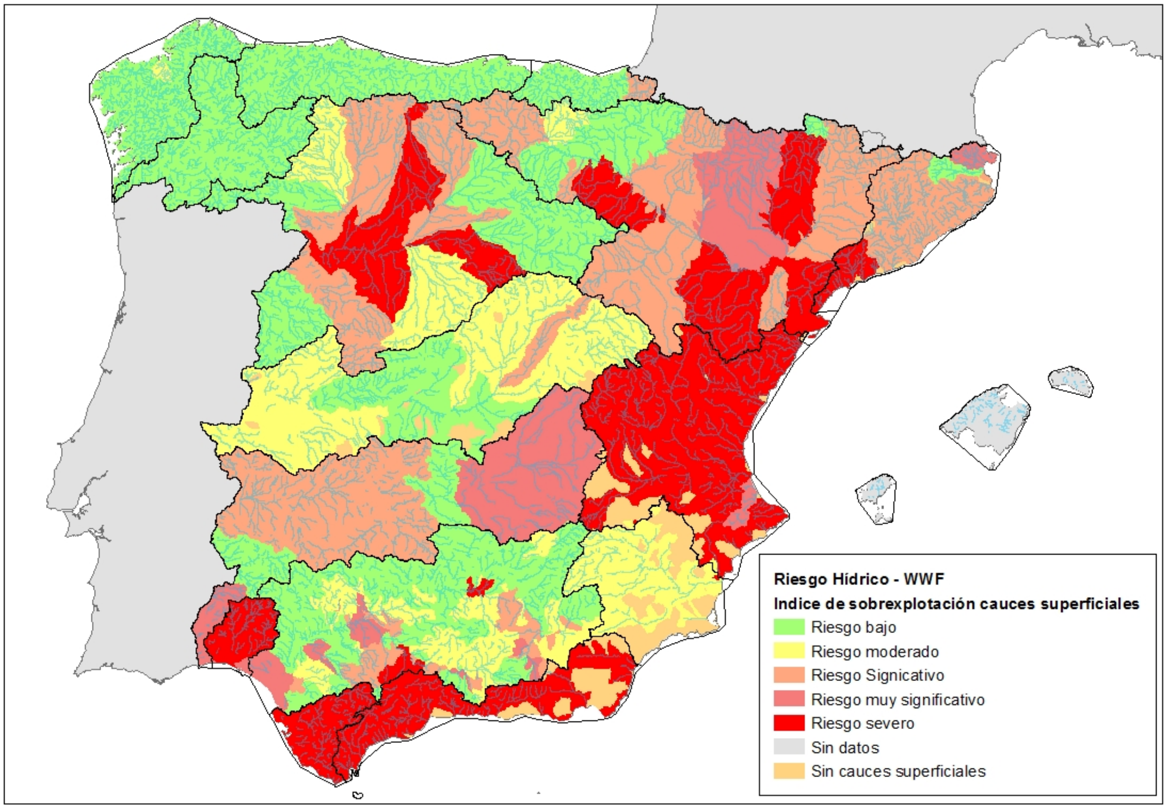

Figure 12. Surface water overextraction in Spain
Source: WWF (2019)

8.5. Priorisation of reuse projects to relieve pressure on water bodies

Some of the previous considerations can be combined to define the criteria of prioritization of future wastewater reuse projects at national level.

Plan DSEAR and European Regulation identify water reuse as a tool to relieve pressure on water bodies. Therefore, it is only natural to identify the regions with overexploitation risks as preferential candidates. Figure 13 shows the groundwater bodies with a higher risk of overextraction (WWF, 2019). A more precise profiling could be made following groundwater table evolution for each body of water (Mitecord, 2020).

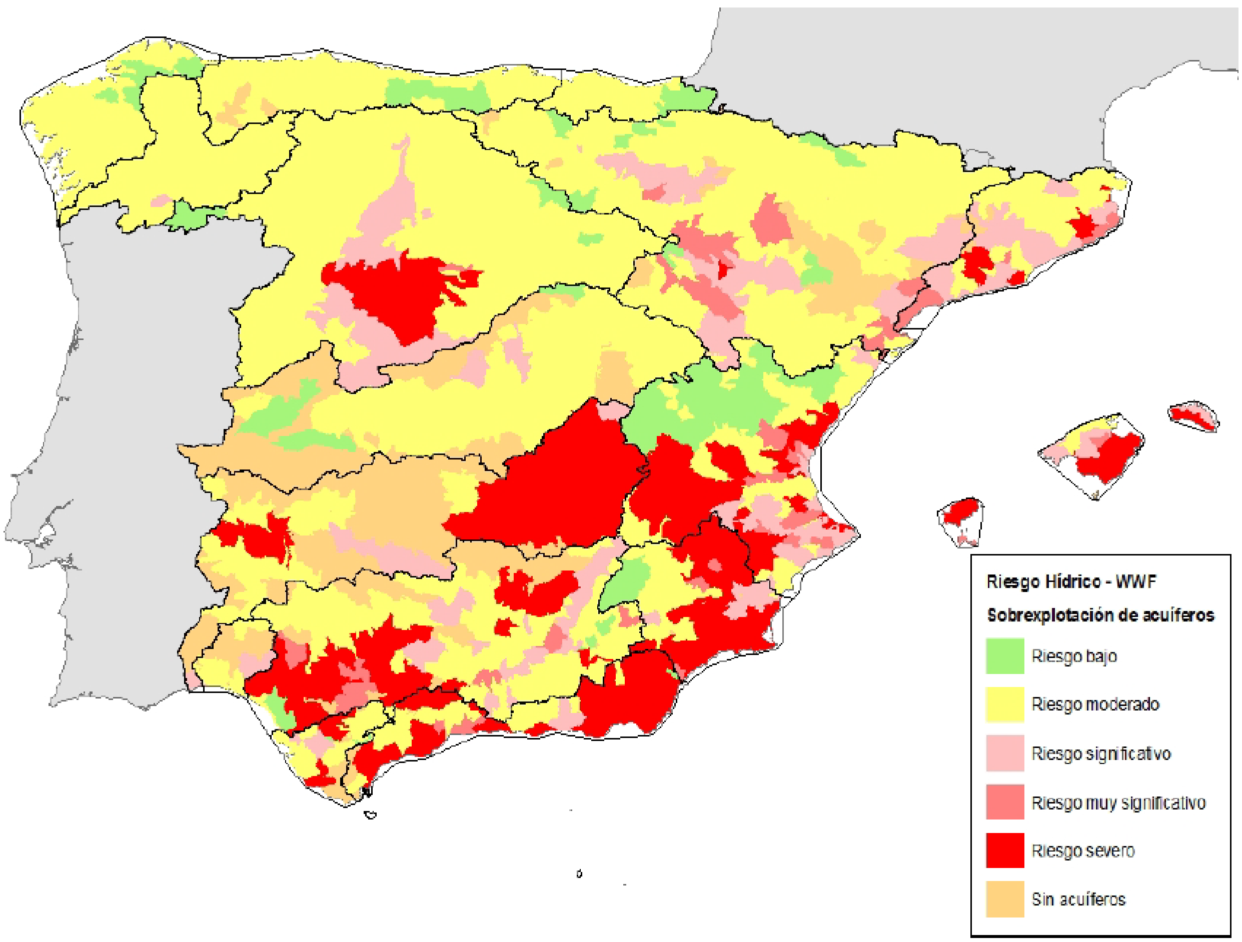

Figure 13. Groundwater overextraction in Spain
Source: WWF (2019)

Additional considerations should include the effect on surface waters and the economic added value of local agriculture.

8.6. Water reuse and the "Organic farming" label

Organic farming is a "sustainable agricultural system respecting the environment and animal welfare, but also includes all other stages of the food supply chain" (European Parliament, 2020). Agricultural area devoted to organic farming was nearly 13 million ha (out of a total of 160 million ha) in 2018 in the EU (European Commission, 2020e), with a steady 5% annual increase since 2012. It represents a growing market. To date, there is no reference to water reuse as an input for organic farming labeling.

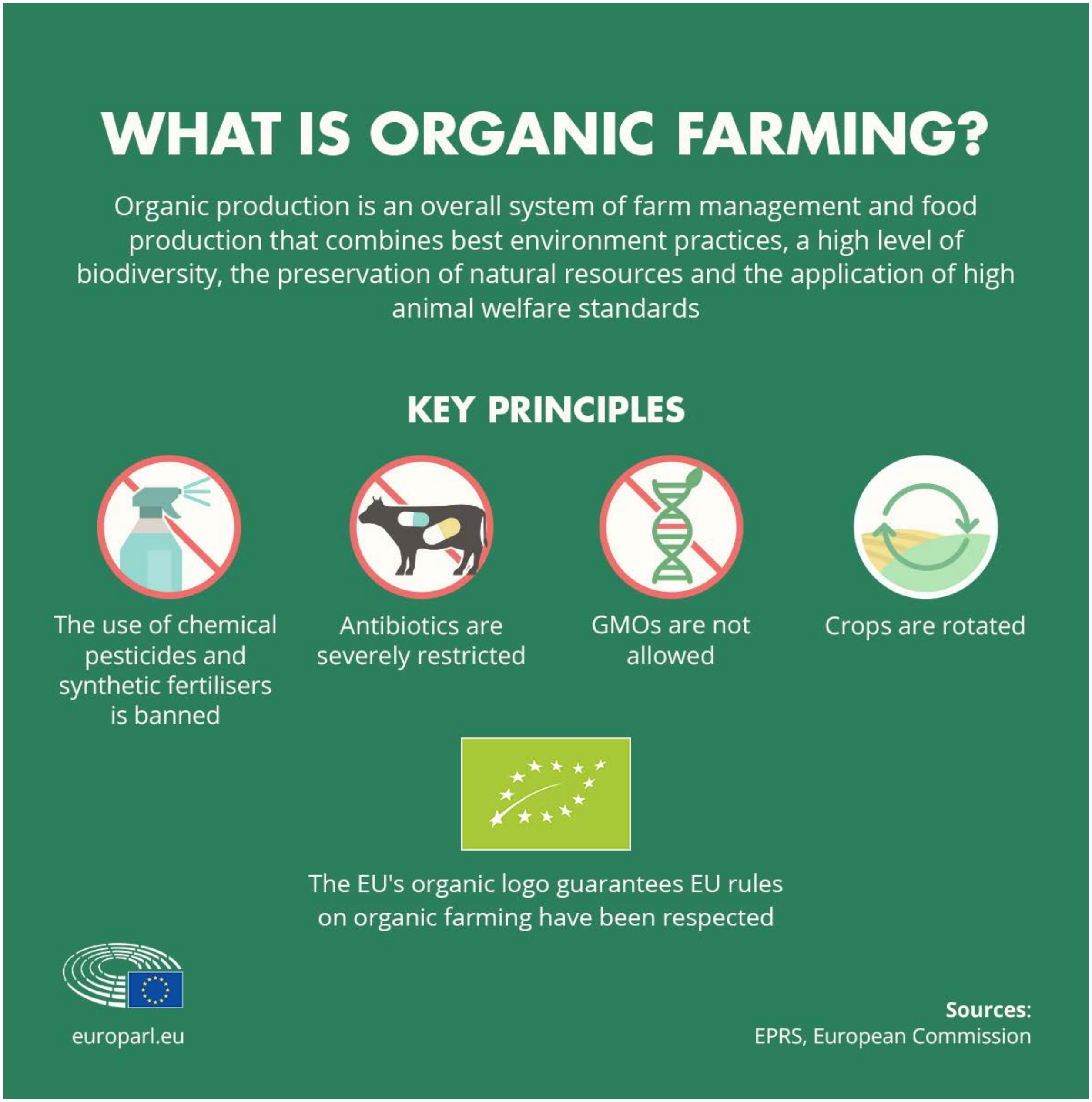

Figure 14. Organic farming
Source: European Parliament (2020)

8.7. Public acceptance of water reuse

Experience from previous implementation, particularly in California (Hartling, 2020), underline the importance of public acceptance for the success of water reuse projects. To avoid wrongly perceived health concerns and repulsion to waste reuse, it is advisable to promote transparency in all the stages of the project, accessibility to information online, active implication of the society (environmentalist groups, etc.) and initiatives like organizing visits to the facilities.

8.8. Reused water offer and demand seasonality

One important technical aspect in the potential exploitation of urban wastewater as a source of water for irrigation is the temporal pattern of water availability and need (see section 5.2). The higher summer demand may be met through a relatively bigger Water Reuse Plant that meets the daily demand in summer but is oversized for the winter demand, or through a smaller Water Reuse Plant (with a daily production smaller than the summer demand), combined with storage tanks. These storage tanks require space and initial investments, and special care must be taken to the evolution of water quality during the storage time.

These considerations may have a significant impact on the feasibility of water reuse projects.

8.9. Risk management plan application

Another open issue in the implementation of Water Reuse schemes is the scope of the Risk Management Plan (RMP) required by the regulation. The European Commission gave a mandate to the Joint Research Centre to prepare a guideline document before 2022 (Simón, 2020a). The obligations and level of detail required by this guidance document will set the standard for the newly proposed reuse schemes. A very demanding RMP template may hinder the feasibility of some reuse projects, while an excessively permissive version may increase the risk of accidents, putting health at risk and jeopardizing the public perception of water reuse.

References

Brown, Caldwell, Carollo, 2020. Wastewater Treatment Plant Master Plan Appendix D: Title 22 requirements [WWW Document]. URL http://www.napasan.com/DocumentCenter/View/276/Appendix-D-Title-22-Requirements-PDF (accessed 10.20.20).

Canal de Isabel II, 2020. Normas para redes de Reutilización. Versión 2. 2020.

Canal de Isabel II, 2018. Cuadro de Precios Número 1, Revisión 5.

CEDEX, 2017. Evaluación del impacto del Cambio Climático en los recursos hídricos y sequías en España. Madrid.

Chevrefils, G., Caron, É., Wright, H., Sakamoto, G., 2006. UV dose required to achieve incremental log inactivation of bacteria, protozoa and viruses. IUVA News 8, 38–45.

Commission of the European Communities, 1998. Directive 98/15/EC of 27 February 1998 amending Council Directive 91/271/EEC with respect to certain requirements established in Annex I thereof.

Cortes Generales, 1978. Constitución Española.

Council of the European Communities, 1991a. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources.

Council of the European Communities, 1991b. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment.

Court of Justice of the European Union, 2018. Sentence C-205/17.

Court of Justice of the European Union, 2011. Judgment of the Court (Eighth Chamber) of 14 April 2011 – Commission v Spain.

Demoware, 2016. Appropriate and user friendly methodologies for Risk assessment, Life Cycle Assessment, and Water Footprinting.

Dirección General del Agua, 2020. Plan Nacional de Depuración, Saneamiento, Eficiencia, Ahorro y Reutilización (Plan DSEAR). Madrid.

Drewes, J.E., Hübner, U., Zhiteneva, V., Karakurt, S., 2017. Characterization of unplanned water reuse in the EU Final Report Prepared by.

European Commission, 2020a. EU law and its application [WWW Document]. URL https://ec.europa.eu/info/law/law-making-process/applying-eu-law_en (accessed 9.16.20).

European Commission, 2020b. Water pollution – EU rules on urban wastewater treatment (update) [WWW Document]. URL https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12405-Water-pollution-EU-rules-on-urban-wastewater-treatment-update- (accessed 11.6.20).

European Commission, 2020c. European Green Deal [WWW Document]. URL https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed 11.11.20).

European Commission, 2020d. Europe’s moment: Repair and prepare for the next generation

[WWW Document]. URL https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940 (accessed 11.11.20).

European Commission, 2020e. Agri Organic Production Indicators [WWW Document]. URL https://agridata.ec.europa.eu/extensions/DashboardIndicators/OrganicProduction.html (accessed 11.6.20).

European Commission, 2003. Guidance document n.°1 Economics and the environment. https://doi.org/10.2779/53333

European Committee of the Regions, 2020. Division of Powers - Spain [WWW Document]. URL https://portal.cor.europa.eu/divisionpowers/Pages/Spain-intro.aspx (accessed 10.26.20).

European Justice, 2020. Fuentes del ordenamiento jurídico español [WWW Document]. URL https://e-justice.europa.eu/content_member_state_law-6-es-es.do?member=1 (accessed 9.16.20).

European Parliament, 2020. The EU's organic food market: facts and rules (infographic) [WWW Document]. URL https://www.europarl.europa.eu/news/en/headlines/society/20180404STO00909/agricultura-ecologica-en-la-ue-nuevas-reglas-mas-estrictas-infografia (accessed 11.6.20).

European Parliament and Council, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJ 2014–7001.

European Union, 2012. Treaty on the Functioning of the European Union.

Hartling, E., 2020. Regeneración y Reutilización del Agua, in: Asociación Española de Reutilización Sostenible Del Agua Open Webinar Series1.

INE (Instituto Nacional de Estadística), 2020. Estadística sobre el suministro y saneamiento del agua. Serie 2000-2018 [WWW Document]. URL https://ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t26/p067/p01/serie&file=pcaxis&L=0 (accessed 12.2.20).

Jefatura del Estado, 1995. Real Decreto-ley 11/1995, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas.

Joint Research Centre, 2017. The potential of water reuse for agricultural irrigation in the EU. A Hydro-Economic Analysis. https://doi.org/10.2760/263713

KOCH Separation Solutions, 2020. Membrane Filtration [WWW Document]. URL https://www.kochseparation.com/technologies/membrane-filtration/ (accessed 11.19.20).

MAPAMA (Ministerio de Agricultura y Pesca, Alimentación y Medio ambiente), 2015. Real Decreto 817/2015, de 11 de septiembre, por el que se establecen los criterios de seguimiento y evaluación del estado de las aguas superficiales y las normas de calidad ambiental. Off. Bull. Spain 219, 80582–80677.

Ministerio de Justicia, 2018. Código Civil.

Ministerio de la Presidencia, 2015. Real Decreto 261/1996, de 16 de febrero, sobre protección de las aguas contra la contaminación producida por los nitratos procedentes de fuentes agrarias.

Ministerio de la Presidencia, 2007. Real Decreto 1620/2007, de 7 de diciembre, por el que se

establece el régimen jurídico de la reutilización de las aguas depuradas.
Ministerio de Medio Ambiente, 2007. Real Decreto 907/2007, de 6 de julio, por el que se aprueba el Reglamento de la Planificación Hidrológica. Madrid.
Ministerio de Medio Ambiente, 2001. Real Decreto Legislativo 1/2001, de 20 de julio, por el que se aprueba el texto refundido de la Ley de Aguas. BOE.
Ministerio de Medio Ambiente, 1998. Real Decreto 2116/1998, de 2 de octubre, por el que se modifica el Real Decreto 509/1996, de 15 de marzo, de desarrollo del Real Decreto-ley 11/1995, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas.
Ministerio de Medio Ambiente y Medio Rural y Marino, 2010. Guía para la Aplicación del R.D. 1620/2007 por el que se establece el Régimen Jurídico de la Reutilización de las Aguas Depuradas. Madrid.
Ministerio de Obras Públicas, 1996. Real Decreto 509/1996, de 15 de marzo, de desarrollo del Real Decreto-ley 11/1995, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas.
Ministerio para la Transición Ecológica, 2019. Resolución de 6 de febrero de 2019, de la Secretaría de Estado de Medio Ambiente, por la que se declaran zonas sensibles en las cuencas intercomunitarias.
Ministerio para la Transición Ecológica y el Reto Demográfico, 2020. Fomento de la reutilización de las aguas residuales.
Mitecord, 2020. GeoPortal [WWW Document]. URL https://sig.mapama.gob.es/geoportal/ (accessed 12.3.20).
Parlamento Europeo y Consejo Europeo, 2020. Reglamento (UE) 2020/741 del Parlamento Europeo y del Consejo de 25 de mayo de 2020 relativo a los requisitos mínimos para la reutilización del agua .
Pearce, G.K., 2008. UF/MF pre-treatment to RO in seawater and wastewater reuse applications: a comparison of energy costs. Desalination 222, 66–73. https://doi.org/10.1016/j.desal.2007.05.029
Pirnie, M., Linden, K.G., Malley, J.P.J., 2006. Ultraviolet disinfection guidance manual for the final long term 2 enhanced surface water treatment rule.
Iglesias, R. 2016. La reutilización de efluentes depurados en España. Universidad Politénica de Madrid, Madrid.
Safe Drinking Water Foundation, 2020. Ultrafiltration, Nanofiltration and Reverse Osmosis [WWW Document]. URL https://www.safewater.org/fact-sheets-1/2017/1/23/ultrafiltrationnanoandro (accessed 11.18.20).
Simón, P., 2020a. III Taller SUWANU EUROPE [WWW Document]. URL https://www.youtube.com/watch?v=Q_CfsX8GmY8 (accessed 11.17.20).
Simón, P., 2020b. Regeneración y Reutilización del Agua, in: Asociación Española de Reutilización Sostenible Del Agua Open Webinar Series1.
Simón, P., 2018. La reutilización de aguas regeneradas en la región de Murcia, in: XIV Jornadas Técnicas de Saneamiento y Depuración. Lorca.

TYPSA, 2013. Update of the final report on wastewater reuse in the european union, 2013., Update of the final report on wastewater reuse in the european union.

UNE, 2014. UNE-EN 15975-2:2014 Security of drinking water supply - Guidelines for risk and crisis management - Part 2: Risk management.

United States Environmental Protection Agency, 1986. Inactivation of microbial agents by chemical disinfectants.

Voutchkov, N., 2018. Energy use for membrane seawater desalination – current status and trends. Desalination. https://doi.org/10.1016/j.desal.2017.10.033

Water, G.R.U.R. (2014). Title 22 California Code of Regulations.

WHO, 2018. Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum (chapters), WHO. World Health Organization.

WHO, 2016. Quantitative Microbial Risk Assessment: Application for Water Safety Management.

WHO, 2015. A practical guide to Auditing water safety plans.

WHO, 2006. Guidelines for Drinking-water Quality FIRST ADDENDUM TO THIRD EDITION Volume 1 Recommendations WHO Library Cataloguing-in-Publication Data.

WWF, 2019. Agua para hoy, sed para mañana.

Xylem, 2020. Nueva legislación de desinfección en los tratamientos terciarios, in: Serie de Webinars Xylem Water Solutions España S.L.U.

Ye, Y., Ngo, H.H., Guo, W., Chang, S.W., Nguyen, D.D., Zhang, X., Zhang, J., Liang, S., 2020. Nutrient recovery from wastewater: From technology to economy. Bioresour. Technol. Reports. https://doi.org/10.1016/j.biteb.2020.100425