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Reuse of treated municipal wastewater effluents in Spain: Regulations and most common technologies, including extensive treatments

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ABSTRACT

This paper analyses the factors which have influenced the significant development of treated wastewater reuse in Spain, whose volume is currently estimated at about 368 Hm^3/y. Likewise, it will review current legal requirements affecting such water reuse, especially Royal Decree 1620/2007 [1] which establishes the "legal regime for reuse of treated municipal wastewater". It will also describe and assess the most widely-used technologies for getting reclaimed water in Spain, and discuss the role that extensive technologies may have in small communities.

Keywords: Wastewater; Reuse; Regulations; Reclamation; Treatment; Extensive treatments

1. Introduction

The reuse of wastewater is an intrinsic component of the natural water cycle since the discharge of effluent into water courses and its dilution in the circulating water flow has traditionally allowed it to be reused downstream for urban, agricultural and industrial purposes. It is necessary to make a distinction between this *indirect reuse*, which is the commonest way of reusing water, and *direct reuse*, which is a new use given to water after it has been properly purified and treated to meet the necessary quality requirements for this intended use before being returned to public water domain (continental or maritime).

The facilities where effluent from secondary treatment (treated wastewater), are subjected to the additional treatment processes required to match its quality to the intended use are called *water reclamation treatments*, and purified water produced by such a process is called *reclaimed water*. The facilities comprising both the regeneration treatment plant and the storage and distribution infrastructure until the regenerated waters reach the end user are called the planned reuse *system*.

The remarkable development of direct reuse in Spain has been due to the need to increase water availability while solving the problem of wastewater discharge. The difficulty in finding new sources of supply in areas of strong urban or agricultural growth, due to the increasing distance from such sources, to environmental constraints on the construction of new reservoirs, or to multi-annual periods of drought together, at times, with the degradation of existing resources, have lead many populations to view the reuse of purified wastewater as an additional source for uses which do not require the quality of drinking water. Likewise, the increasing sanitary and environmental requirements applicable to the quality of continental and maritime waters, as well as the ever stricter treatment levels imposed on wastewater discharge have made reclaimed wastewater an inexpensive safe, alternative source of supply taking sanitary and environmental considerations into account.

Two aspects have particularly induced this development: a) the huge impulse given to wastewater treatment by Directive 91/271/EEC [2], which has led to the treat-

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ment of large volumes of treated effluents in areas of very high water demand; and b) the development of regeneration technologies for purified effluents, which have produced reliable systems at affordable costs.

The enforcement of Directive 91/271/EEC in Spain was carried out under the National Sanitation and Purification Plan (NSPP), which set up coordinated actions by the different Administrations (Central, Regional and Local), with an estimated total investment of about 14,400 million Euros. The degree of compliance with the Directive in the year 2006 was 77%, and 14% of the infrastructure was under construction (Table 1 and Fig. 1). The number of water treatment plants had increased to 2,533, treating a volume of 3,370 Hm^3/y. The Plan essentially targeted towns with a population equivalent of over 5,000.

After the completion of the NSPP, the Ministry of the Environment, in collaboration with the Autonomous Communities, drew up the 2007–2015 National Plan for Water Quality, Sanitation and Purification (NPWQSP), the aim of which is to ensure compliance with Directive 91/271/EEC requirements which have not yet been met, and to implement actions stemming from the application of the Water Framework Directive (Directive 60/2000/EEC, [3]), whose estimated investment is € 19,000 million. Its main challenges are as follows:

- Wastewater treatment for small communities, priority being given to rural areas where this is being discharged into national parks or protected spaces (Natura 2000 Network).
- Compliance of existing wastewater treatment plants with the new requirements stemming from the enlargement of sensitive areas or from the new obligations under the Water Framework Directive.
- Improvement of the network of collectors and treatment of loads after rainfall.
- To improve the management, operation and maintenance of existing infrastructure.
- To promote research, development and innovation in the field of water sanitation, purification, quality, biodiversity and associated ecosystems.

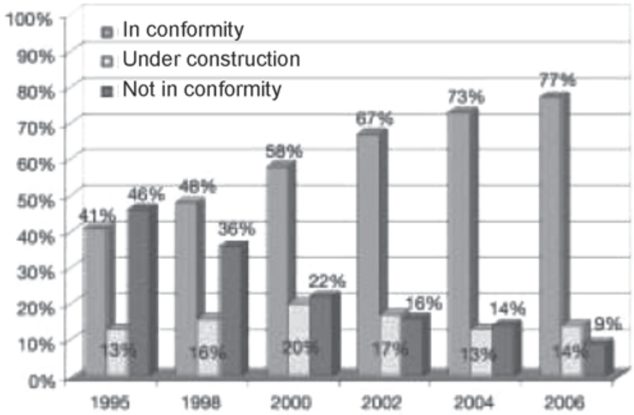


Fig. 1. Evolution of the Directive 91/271/EEC, population equivalent conformity.

The development of this new plan will further enhance wastewater treatment, and therefore increase the production of treated effluents suitable for reuse, this time covering small communities. Therefore, it will be necessary to carry out WHO and MED POL reuse guidelines [8,9] and to study adequate technologies in depth for this population segment, both for wastewater treatment and for the reclaimed water.

2. Scope of water reuse in Spain

According to the information from the Reuse Database (RDB), gathered by the CEDEX for the Ministry of the Environment (RDB, 2005–2007), the number of existing reuse systems in Spain at the end of 2006 was 322 and the volume of reclaimed water was 368 Hm^3/y, which is about 10.6% of the total treated wastewater volume. Although reused water only accounts for a small percentage of the total Spanish water demand, in some areas, like the Canary Islands, Valencia or Murcia, this percentage is quite high, meaning that water there has become a strategic non-conventional resource. The breakdown by uses is shown in Fig. 2, and it can be observed that agricultural irrigation is the most frequent use, although environmental uses seem to be increasing.

Action taken on water reuse and future potentiality is essentially focused on the coastal areas of the Mediterranean and South-Atlantic Arc, and the Balearic and Canary Islands. Such expectations are due to strong urban and tourist population growth and agricultural development, which entail a greater demand for water, and

Table 1
Situation of sanitation and wastewater treatment with reference to Directive 91/271/EEC, September 2006

Conformity	Number of served towns	Population affected (population equivalent)	Percentage of population (%)
In conformity	1,276	56,608,111	77.0
Under construction	280	10,140,864	14.0
Not in conformity	800	6,516,753	9.0
	2,356	73,265,728	100.0

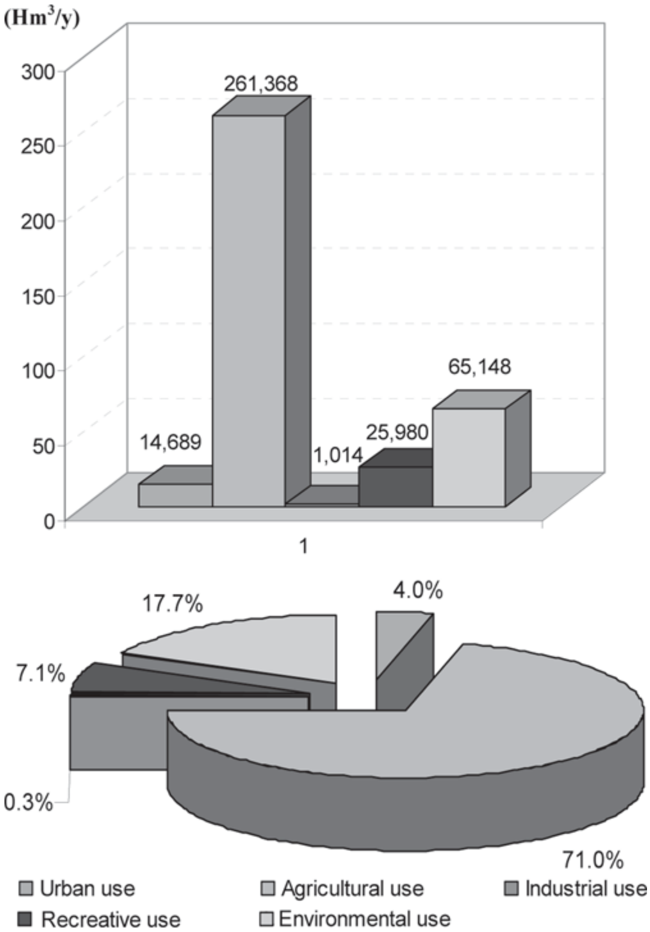
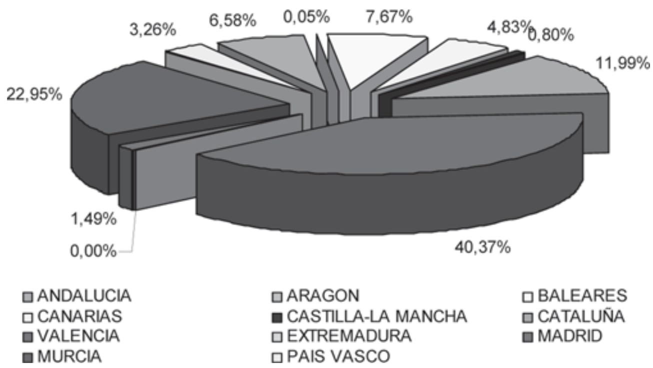


Fig. 2. Volume and percentage in Spain in 2006, broken down by use (Source: BDR CEDEX-MMA, Ministry of the Environment).



Autonomous communities	(Hm^3/y)(*)
Andalucia	24.21
Aragon	0.17
Baleares	28.24
Canarias	17.8
Castilla-La Mancha	2.96
Cataluña	44.16
Valencia	148.66
Extremadura	0
Madrid	5.48
Murcia	84.52
Pais Vasco	12
Total	**368.2**

(*) Rest of communities without reuse

Fig. 3. Volume of water reused broken down by autonomous regions (Source: BDR CEDEX-MMA, Ministry of the Environment).

also to the difficulty in obtaining additional resources within an acceptable distance, in view of the depletion and deterioration of traditional supply sources, the progressive salination of aquifers and the frequent droughts that affect these areas. Singular places in inland Spain include Madrid and Vitoria-Gaztei [22]. Figs. 3 and 4 show the distribution of reused water reclaimed water broken down by Autonomous Community.

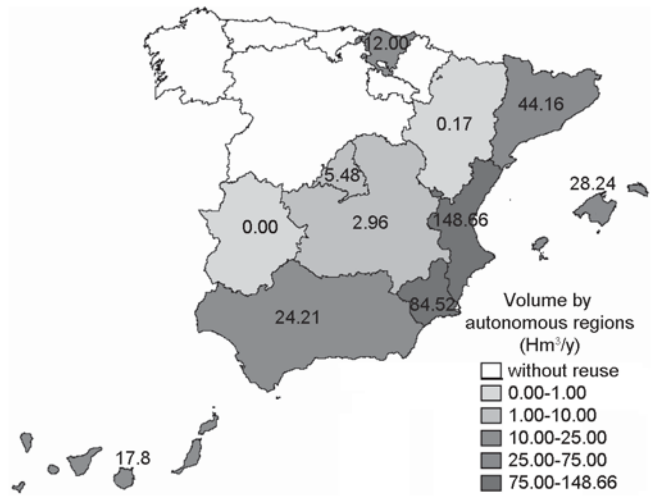


Fig. 4. Volume of reused water broken down by Spanish autonomous communities (Source: BDR CEDEX-Ministry of the Environment).

3. Spanish treated wastewater reuse regulations

At the national level, the reuse of treated wastewater is governed by a revised version of the **Water Act** (Royal Decree 1/2002 of July 20th), and by the Royal Decree 1620/2007, of December 7th, which establishes the legal regime for the reuse of treated wastewater. In some regions and in two Water Basin Plans, a series of laws and regulations related to water reuse have been enacted.

The Water Act provides that "the Government shall establish the basic requisites for water reuse, indicating the required quality for purified water for different uses". Likewise, it is established that water reuse will require an administrative concession, except when the application for reuse is made by the holder of the discharge permit which originated the treatment of that water, in which case only an administrative authorization will be required.

The **Regulation on Public Water Domain** (Royal Decree 849/1986[4] of April 11th) defines the requisites and steps for obtaining a concession for water reuse. The decision to issue such a concession, which is a binding decision, lies with the River Basin Authority, following the compulsory report made by the Health Authorities of the Autonomous Communities.

Royal Decree 1620/2007 of December 7th, which lays down the legal regime for the reuse of treated wastewater establishes both the basic requisites for water reuse, and the necessary procedures to obtain the concessions and authorizations.

It has taken many years to implement the regulations on the basic requisites for water reuse. Over a period of ten years, the Ministry of Public Works, Transport and the Environment, and thereafter the Ministry of the Environment, have drawn up several draft regulations which, for unknown reasons, were not passed by the Governments of the day. During this time, the requisites for water reuse have been established by the River Basin Authorities, in each concession, and this has led to differing criteria as regards the quality specifications for reclaimed water for each different use as well as a lack of equity regarding the obligations imposed on concession holders.

Since there is a gap in national legislation in this respect and because of the needs stemming from the great increase in water reuse in some regions of Spain, some river basin authorities have implemented regulations on water reuse requisites. Likewise, some autonomous regions, making use of their powers, have drawn up recommendations and rules on this issue. Table 2 shows these initiatives [10–18].

The Royal Decree 1620/2007 has been a considerable step forward in the regulation of water reuse, as it clarifies both the responsibilities of the Public Administrations and those of concession holders and end users, establishing permitted uses and quality criteria, the minimum frequency of sampling, the benchmark for analytical methods and the conformity criteria. It also specifies the procedures related to the concession, including an application form to obtain the concession or authorization for water reuse.

The quality criteria for reclaimed water are shown in Table 3, which differentiates 14 uses under five main headings: 1) urban, 2) agricultural irrigation, 3) industrial, 4) recreational and 5) environmental. The reuse of treated wastewater is forbidden for the following purposes: a) for *human consumption*, except in situations of declared disasters; b) for the specific uses of the *food industry*; c) for use in *hospital installations*; and other similar uses; d) for the breeding of *filtering molluscs* in aquaculture; e) for recreational use as swimming waters; f) for use in *fountains and ornamental waters in public spaces or inside public buildings;* g) for any other use that the health authorities may deem to be a hazard to human health. Use in *refrigerating towers and evaporation condensers,* is subject to very stringent requisites, and forbidden in urban areas and in places with public or commercial activities.

Minimum acceptable limits are established for each type of use under the following parameters: *intestinal nematode eggs, Escherichia coli, suspended solids* and *turbidity.* Furthermore, the following parameters have been

Table 2
Regulations and recommendations regarding reuse conditions established under the River Basin Hydrological Plans or by the autonomous regions

River Basin Hydrological Plans	
Tajo (1999)	Provides detailed sanitary requisites for reuse purposes: general aspects, quality of reused water according to use, toxicity parameters, compliance criteria, methods of analysis and frequency of sampling.
Guadalquivir (1999)	Includes quality criteria for wastewater for agricultural and forest uses.
Autonomous Regions	
Catalonia	"Guide for sanitary risk prevention from treated water reuse". Catalonian Regional Ministry of Health. 1994..
	"Guide for the design and control of reuse systems". Catalonian Regional Ministry of Health. 1994..
	"Quality criteria for purified water according to use". Catalonia Water Agency, 2003.
	"Guidelines for purified water reuse on golf courses". Catalonia Water Agency, 2005.
Balearic Islands	"Guide for treated water reuse". Regional Ministry of Health. 1995
	"Golf Course Act". (Balearic Government. 1988)
	"Balearic Islands Hydrological Plan", 2001.
Valencia	"2nd Sanitation and Purification Master Plan". Regional Government of Valencia, 2004.

Table 3
Quality criteria for the reuse of treated effluent reuse. Maximum allowed values (Royal Decree 1620/2007, December 2007)

Wastewater reclamation uses	Maximum allowed values				Other criteria
	Intestinal nematode eggs	*Escherichia coli* CFU/100 ml	Suspended solids mg/L	Turbidity NTU	
1. Urban uses					
Quality 1.1 Residential: a) Private garden watering b) Discharge of bathroom appliances	1 egg/10 L	0	10	2	*Legionella* spp. 100 CFU/L (in the case of aerosol hazards) Other contaminants (1)
Quality 1.2 Urban services: a) Watering of urban green areas (parks, sports grounds, etc.) b) Hosing down streets c) Fire-fighting systems d) Industrial car wash	1 egg/10 L	200	<20	<10	
2. Agricultural uses					
Quality 2.1. a) Irrigation of fresh food crops for human consumption, through water application systems allowing for direct contact of regenerated water with edible parts.	1 egg/10 L	100	20	10	*Legionella* spp. 1000 CFU/L (in the case of aerosol hazards) Presence/absence of pathogens Other contaminants (1)
Quality 2.2 a) Irrigation of crops for human consumption, through water application systems not avoiding direct contact of regenerated water with edible parts, but not for consumption as fresh food since there is subsequent industrial treatment. b) Irrigation of pastureland for milk or meat-producing animals. c) Aquaculture	1 eggs/10 L	1,000	35	No limit set	*Taenia saginata* and *Taenia solium* 1 egg/L (In irrigation of crops for consumption by meat producing animals) Presence/absence of pathogens Other contaminants(1)
Quality 2.3 a) Localised irrigation of ligneous crops impeding contact of regenerated water with food for human consumption b) Irrigation of ornamental flowers, greenhouses and nurseries with no direct contact of regenerated water with crops c) Irrigation of industrial crops, greenhouses, fodder stored in silos, cereals and oleaginous seeds	1 egg/10 L	10,000	35	No limit set	*Legionella* spp. 100 CFU/L Other contaminants (1)
3. Industrial uses					
Quality 3.1 a) Process and cleaning water except in food industry b) Other industrial uses	No limit set	10,000	<35	15	*Legionella* spp. 100 CFU/L Other contaminants(1)

Table 3 (continued)

Regenerated wastewater uses	Maximum permitted values				Other criteria
	Intestinal nematode eggs	*Escherichia coli* CFU/100 ml	Suspended solids mg/L	Turbidity NTU	
Quality 3.1 c) Process and cleaning water for use in food industry	1 egg/10 L	1,000	<35	15	*Legionella* spp. 100 CFU/L Presence/absence of pathogens Other contaminants (1)
Quality 3.2 a) Refrigeration towers and evaporation condensers	Absence	Absence	5	1	*Legionella* spp. Absence CFU/L Industrial use exclusively far from urban areas. Authorization is subject to the approval of the health authority responsible for the relevant control under RD 865/2003
4. Recreational uses					
Quality 4.1 a) Irrigation of golf courses	1 egg/10 L	200	20	10	If irrigation water is applied directly onto the soil (drip, micro-spray) the Quality 2.3 criteria are applicable. *Legionella* spp. 100 CFU/L (in the case of aerosol hazards) Other contaminants (1)
Quality 4.2 a) Ponds, bodies of water and running water with no public access	No limit set	10,000	35	No limit set	Total phosphorus: 2 mg P/L (in stagnant water) Other contaminants (1)
5. Environmental uses					
Quality 5.1 a) Recharge of aquifers by localised seepage through the soil	No limit set	1,000	<35	No limit set	Total nitrogen: 10 mg N/L NO_3^-: 25 mg NO_3^-/L
Quality 5.2 a) Recharge of aquifers by direct injection	1 egg/10 L	0	10	2	Art. 257 to 259 of Royal Decree 849/1986
Quality 5.3 a) Irrigation of forests, green zones and similar areas with no public access b) Forestry	No limit set	No limit set	35	No limit set	Other contaminants (1)
Quality 5.4 a) Other environmental uses (maintenance of wetlands, minimum flows and similar uses)	The minimum quality required is studied on a case by case basis				

(1): The liberation into the environment of the Other Contaminants contained in the wastewater discharge authorisation must be limited (See Annexe II of Royal Decree 849/1986, of 11 April). In the case of hazardous substances (See Annexe IV of Royal Decree 849/1986, of 11 April, modified by Royal Decree 606/2003, of 23 May), compliance with the Environmental Quality Regulations must be ensured (See Article 245.5 of Royal Decree 849/1986, of 11 April, modified by Royal Decree 606/2003, of 23 May).

added: a) *Legionella* spp. for use in industrial refrigerating systems or in case of hazards due to aerosols, pursuant to Royal Decree 865/2003, [5]; b) *Taenia saginata* and *Taenia solium,* in the case of irrigation of pastureland for milk or meat-producing animals; c) *total phosphorus* for environmental and recreational uses (pools, water bodies and running watercourses); d) *total nitrogen* in the case of groundwater recharge.

The implementation of these regulations, which impose rigorous quality requirements for reclaimed water, will make it necessary to adapt an important part of the current reuse systems[19,20]. The regulation itself sets a 2-year deadline for the current systems to comply with the requisites of the Royal Decree 1620/2007.

4. Water reclamation technologies used in Spain [21,23, 24].

During the past ten years, there has been a significant development of water reclamation technologies and these have substantially improved both the reliability of treatment and the quality of effluent. On one hand, new technologies have appeared especially in the field of membranes and advanced filtration systems. On the other hand, proven technologies from other fields, such as desalination and disinfection, have been developed so that they can be used efficiently with reuse systems.

In Spain, in 2006, there were 322 reuse systems and 149 water reclamation plants in operation, a high percentage of which work efficiently. These types of treatment have been implemented during the past ten years; consequently, the Administrations and public and private companies have had to make a big effort to ascertain how the different technologies that have emerged in the market operate and perform. This has been done through pilot plants and full-scale studies. In this context, we must mention the creation of experimental centres, such as the Research and Demonstration Centre for Water Reuse (RDCWR), where the Canary Islands' Government assessed most available technologies for water reclamation treatments applied in the islands, or the Carrión de los Céspedes Experimental Plant in Andalusia (www.plantacarrion-pecc.com), in the field of extensive treatments.

Table 4 shows the water reclamation treatment systems used in Spain (2006), distinguishing between cases where it is not necessary to reduce the salt content, and those where, in view of the high salinity of the treated effluent, desalination is needed. As regards the former, the most frequent type of treatment is filtration with subsequent disinfection (39% of the total), then comes physical-chemical treatment, with filtration and subsequent disinfection (19%), extensive or natural treatment (12%) and, finally, membrane systems (micro-filtration, ultra-filtration and membrane bioreactors) (11%). In terms of the volume of reclaimed water, the leading method is

Table 4
Water reclamation treatment systems in Spain, 2006. (Source: BDR CEDEX-Ministry of the Environment)

Treatment systems			
Without desalination	Number	With desalination	Number
F + D	58	F + EDR	4
P/C + F + D	28	P/C + F + EDR+ D	2
F + M	8	M + EDR	1
P/C + F + M	1	M +RO	2
MBR	2	MBR + RO	1
NS	18	F +M + RO	4
D	18	P/C + M + RO	1
		P/C + F + M + RO	1
Total	133	Total	16

F = filtration; P/C = physical-chemical with settling; M = filtration with membranes; NS = natural systems; D = disinfection; EDR = electrodialysis reversal; RO = reverse osmosis; MBR = membrane bioreactor.

physical-chemical treatment with a lamella settling system plus sand filtration and subsequent ultraviolet disinfection. It is the proposal made by Title 22 from California [6,7] which is based upon multi-barrier criteria in order to avoid sanitary hazards. It is a safe, reliable, well-known treatment which can produce effluents of maximum quality at affordable operational costs (€0.06–0.10/m^3). With normal purified effluents (25 mg/L for BOD_5 and 35 mg/L of SS), we obtain reclaimed water with SS <10 mg/L, turbidity <5 NTU, *E. coli* <10 CFU/100 mL and absence of nematode eggs. With better quality treated water and/or by increasing the concentration of chemical products it is possible to achieve effluents with: SS <5 mg/L, turbidity <2 NTU and *E. coli* <2.2 CFU/100 mL. The first facilities of this kind were set up in Arrato (Vitoria-Gatzei) in 1996 with a capacity of 34,500 m^3/d.

The treatments including desalination account for 11% of the total, and the most frequent lines are: a) filtration followed by reversible electrodialisys reversal process (EDR) and disinfection with sodium hypochlorite; b) filtration through membranes (ultra-filtration, micro-filtration or membrane bioreactors) followed by reverse osmosis (RO). These are reliable, well-known treatments which were first used in the Canary Islands in the mid-nineties. By using ultra-filtration membranes (UF) in the first phase and RO membranes in the second, we can obtain maximum quality effluents (SS 0.2–1.0 mg/L, turbidity < 0.3 NTU, *Escherichia coli*: absent, nematodes eggs: absent). The disadvantages are the high installation and operating costs and the lack of knowledge about the duration and behaviour of the membrane over time.

Let us briefly review the most widely-used water reclamation technologies in Spain. Their performance with regard to the main parameters established by Royal Decree 1620/2007 is shown in Table 3.

4.1. Physical-chemical treatment

The objective of a physical-chemical treatment is the reduction of suspended solids and colloids, in order to ensure the efficient operation of the subsequent water reclamation phases, especially the disinfection phase. It is an excellent buffer against possible irregularities of the treated effluent. It can also reduce sulphide, phosphorus or heavy metals, if necessary.

It consists of three phases: coagulation, flocculation and settling, almost always lamella settling. Its efficacy for reducing SS, turbidity and *E. coli* is shown in Table 5.

An interesting innovation which is appearing in Spain with good results is the use of micro-sand to improve flocculation and settling, allowing clarification basins to operate under high loads for short retention times.

4.2. Filtration systems

Filtration aims a sufficient reduction of SS and water turbidity to obtain optimum disinfection. The choice of one or the other of the two systems will depend on the performance desired and on installation and operating costs. Table 5 shows the elimination rates for SS, turbidity, and *E. coli* using the most important filtration technologies.

In Spain, the most common filtration systems are *pressure or gravity sand filters*, which are well-known and reliable, with low installation and operating costs. Their main constraint lies in their poor performance in treatment of effluents with high levels of turbidity. *Ring filters* have proved to be the least efficient technique for SS, turbidity, and pathogens reduction. They also need a sieving process and prior disinfection to prevent bacterial growth, which is the reason why interest in them is waning.

To improve the efficiency rates, more complex systems like *pulsating bed filters* and *moving bed filters* have been developed. Several units are already in operation. The former have been operating efficiently for many years, but their installation and operating costs are the highest. Moving bed filters are more efficient in SS and turbidity reduction, although their operation is more complex and fine-tuning problems may occur.

Table 5
Performance of different water reclamation technologies (Source: R. Iglesias, G. Batanero, CEDEX, 2006)

	Reduction of suspended solids (%)	Reduction of turbidity (%)	Removal of *E. coli* (log)
Physical-chemical	50–70	30–50	1–2
Filtration:			
Sand (gravity and pressure)	30–80	20–50	0.5–1
Rings	20–30	20–30	0.5–0.6
Pulsating bed	75–85	40–50	0.4–0.8
Mobile bridge	50–80	60–80	0.4–0.8
Double filtration (dualsand)	80–90 (1)	85–95	1–1.5
Sieve filtration	60–80	85–95 (2)	0.5–1
Membrane filtration:			
Microfiltration (3)	90–95 (<1 mg/L)	96–98 (<0.5 NTU)	3–4 (4)
Ultrafiltration (3)	90–95 (<1 mg/L)	96–98 (<0.3 NTU)	Absent
Elimination of salts:			
RED (5)	No reduction	No reduction	No reduction
Reverse osmosis (6)	100	—	Absent
Disinfection:			
Ultraviolet rays (7)	No reduction	No reduction	4–7 (<10 CFU/100 mL in effluent) (8)
Sodium hypochlorite (9)	No reduction	No reduction	4–7 (<10 CFU/100 mL in effluent) (10)

1) With 4–5 ppm of iron chloride or aluminium polychloride; 2) With an influent of <15 ppm of SS; 3) Influent turbidity must be <15 NTU to ensure efficacy; 4) Absent with a small dosage of sodium hypochlorite; 5) The influent must have maximum values of 20 mg/L for SS and 10 NTU of turbidity; 6) Input water quality is measured by the Silt Density Index (SDI) <3; 7) Influent turbidity must be <15 NTU to guarantee disinfection; 8) The value of <10 CFU/100 mL is achieved with a prior tertiary treatment with effluent of >10 mg/L of SS and turbidity of 5 NTU; 9) Influent turbidity must be <6 NTU to guarantee disinfection; 10) The elimination of Pathogens depends on the chlorine dosage and retention times. Values of <10 CFU/100 mL suppose prohibitive costs.

Two emerging systems in Spain are worth mentioning since they offer high performance: the dualsand double filtration system and sieving filters.

The dualsand double filtration system consists of two filters in series with a recirculation device from the second back to the first filter. The first systems have been recently installed in the Canary Islands and the results obtained have been very satisfactory. With a dosage of 4–5 ppm of ferrous chloride, it is possible to reduce SS by 80%. The logarithm removal rate for *E. coli* is 1-1 with absence of nematode eggs in the effluent. If 4–5 ppm of sodium hypochlorite is added, then the *E. coli* drops to 3–4 (Table 5).

Sieving filters consist of discs with polyester fabric panels with an absolute porosity of 10–500 μm. The filtration, by gravity, is carried out from the inside to the outside of the discs and cleaning is against the current. Several systems are currently being installed in Spain (Baix Llobregat. Benalmádena, etc.), and the first results are quite promising, with SS reduction rates of 60–80% (Table 5). According to a full-scale study of sieving filters installed in Baix Llobregat (2007), the log removal rates for *E. coli* were between 0.5 and 1, and there were no nematode eggs in the treated water.

4.3. Membrane treatments

The use of membranes for water reclamation purposes was introduced in Spain, in the Canary Islands, in the mid-nineties, with varying results given the sensitivity of the technology, the quality of water to be filtered (turbidity, high phosphate contents, oils and grease, etc.) [23]. Consequently, the competent Administrations had to make significant investments to test the existing technologies in pilot plants in order to adapt to the real conditions of the water to be treated. The technologies implemented, depending on whether they were used as filtration or salt elimination systems, were *microfiltration (MF)* and *ultrafiltration (UF)* for filtration and the *electrodialisys reversal (EDR)* and *reverse osmosis (RO)* for desalination. Their respective efficiency rates are shown in Table 6.

4.3.1. Microfiltration and ultrafiltration membranes

The main difference between these technologies is the pore size, since the nominal diameter of MF is 0.2 μm whilst it is less than 0.1 μm for UF (average value: 0.02–0.04).

Table 6 shows the normal values of the filtered effluents, based on the results obtained in existing MF and UF installations. We can observe that UF performance is superior to MF at similar operating costs. The current trend, therefore, is to install the former system rather than the latter. The main difference is the pathogens removal. MF removes *E. coli* by 3–4 log, while a dosage of 10–20 ppm of sodium hypochlorite is necessary for its total removal. UF achieves a total absence of *E. coli* from the effluent.

In both cases, the quality of influent water has a strong influence on performance, since these technologies respond poorly to sudden variations of SS and turbidity. The showed results have been obtained with influents <15 NTU. If an additional desalination phase is necessary, the micro-filtered or ultra-filtered water could directly feed a reverse osmosis plant.

For the past few years, *membrane bioreactors*, which combine the activated sludge process with membrane filtration, thus skipping secondary settling, are gaining ground. This technique eliminates the classical problems of activated sludge (bulking, uncontrolled de-nitrification, etc.), reduces the size of the works and ensures a quality effluent ready for most reuse purposes, as long as a reduction of salinity is not required. The efficiency in terms of BOD_5, SS, turbidity and pathogens are shown in Table 8, depending on the type of membrane used. The main problems with this technology are its high installation and operating costs and the current uncertainty about the behaviour and duration of the membranes, whose replacement could represent a high proportion of the amortisation costs.

4.3.2. Desalination systems

In view of the salination problems in aquifers, structural water deficit and the need for non conventional resources, the Canary Islands have been the pioneer region in using desalination techniques for sea or brackish waters, such as reverse osmosis (RO) and electrodialysis reversal for the regeneration of purified effluents. Both processes have different fundamentals and their efficiency also varies.

Reversible osmosis is an electrochemical process of salt separation where ions are transferred through membranes from a lesser concentrated solution to a higher concentration as a result of a difference of potential. Due

Table 6
Comparison of normal values of effluent filtered through one MF and one UF

	BOD_5 mg/L	SS mg/L	*E. coli* log	Nematodes eggs/L	Turbidity NTU	SDI	Recuperation %
Microfiltration	<7	<1	3–4	Absent	<0.5	<2	85–90
Ultrafiltration	<5	<1	Absent	Absent	<0.3	<2	85–90

to its design, the process neither reduces SS nor removals pathogens.

EDR has the advantages of being a robust system which is easy to operate. A decisive factor as regards the operating cost is the replacement of protective cartridge filters. Problems in pre-treatment operations or poor influent quality (SS >20 mg/L and turbidity >10 NTU) may increase the cost of cartridge replacement to the point that the operation of the RED system might be inefficient.

RO is performed through cellulose acetate or aromatic polyamide membranes with a penetration size of between 10^{-3} and 10^{-4} μm, which can separate organic and inorganic micro-pollutants of the water and dissolved ions, as well as total removal of *E. coli* and viruses. The effluent obtained from this system can be reused for any purpose. The main problems detected are biological fouling affecting the membranes and organic, inorganic and colloid accumulation. The quality of the water to be treated by this technique should be checked in order to detect these possible problems.

This technology has improved its efficacy and efficiency, through the experiments carried out by the Administrations and companies over the past ten years, in particular as regards the search for specific membranes for wastewaters and the selection of adequate pre-treatment systems (advanced physical-chemical, micro-filtration, ultra-filtration, etc.).

4.4. Disinfection systems

In terms of health, *disinfection* is the most important phase of the water reclamation treatment systems since it removals the pathogenic micro-organisms (bacteria, viruses and protozoa) through physical and chemical processes.

In Spain, the disinfection of treated water has been performed using physical agents (ultraviolet radiation) or chemical agents, essentially sodium hypochlorite. Ozone has been used a few times and, in most cases, it has been replaced by other technologies due to its complexity and its high installation and operating costs.

Traditionally, disinfection technique has involved the use of sodium hypochlorite, which is still the most widespread solution (used in 53% of cases). However, the development of cheaper, more efficient ultraviolet rays, their wide disinfection spectrum and the growing concern over the possible toxic effects of chlorine-based organic compounds have made UV rays the most widely-applied technology used for water reclamation purposes today. The only drawback of this technique is that it only disinfects the water when it passes through the radiation chamber, without offering a residual capacity for disinfection. The current trend, therefore, is to combine UV radiation with a subsequent sodium hypochlorite dosage.

The level of disinfection achieved by the UV rays will depend on the exposure of micro-organisms to radiation. The components that absorb ultraviolet light play an important role here: dissolved organic matter, colloids and solids in suspension can lower the ray intensity in a designed system. Table 7 shows the disinfection rate achieved in several facilities depending on transmittance (UVT), SS, and the size of the particles in the water to be disinfected.

Sodium hypochlorite is a powerful disinfectant which is very widely used. The amount of chloride necessary will vary, depending on the quality of the effluent to be treated. The removal of pathogenic micro-organisms will depend on the chloride dose and the retention time in the chlorination tank. Thus, for a secondary effluent, we can obtain values of *E. coli* < 200 CFU/100 mL, with a dosage of 10 ppm chloride and a contact time of 15 min. When including a reclamation treatment through filtration, then the values obtained are *E. coli* <10 CFU/100 mL, with a dosage of 4–5 ppm chloride and the same contact time.

5. The role of extensive technologies in water reclamation

Extensive technologies are those which apply parameters and kinetics which are normally found in nature [27]. Their energy input requirement is much lower than that of intensive technologies but the land requirement is much higher and so it is used only for small communities.

Extensive technologies have been used as reclamation treatments in Spain for only a very few years, with the exception of lagooning, which is a traditional system for using treated water for agricultural irrigation purposes. As for the other techniques, there have been some one-off experiments in Catalonia, the Balearic Islands and Andalusia. The main activities in this field involve three types of treatment: *infiltration-percolation*, *stabilization ponds* and *constructed wetlands*.

Table 7
Disinfection levels with UV rays

Process	UVT (%)	SST (mg/L)	Average particle size (μm)	Disinfection level CFU/100 mL
Secondary	40–75	10–30	25–45	<200–240
Tertiary (filtration)	60–75	5–10	20–30	<14–23
Advanced tertiary	65–80	1–5	15–20	<1–2.2

The approval of the Water, Sanitation and Treatment Quality Act, one of whose objectives is to expand water treatment to small communities (<2.000 i-e), paves the way in Spain for the expansion of extensive technologies and the reclamation of treated effluents. However, to achieve this, it is necessary to solve some problems inherent to these types of treatment which tend to limit their application for many uses, since they do not comply with the quality criteria required for reclaimed water.

The main problem with such technologies, except for *stabilization ponds*, is that it is difficult to achieve sufficient reductions of pathogenic micro-organisms without subsequently having to apply conventional disinfection systems. Taking into account that the effluent from a secondary treatment has an *E. coli* content of between 10^5–10^6 CFU/100 mL, a log removal of 3–4 would be necessary to obtain the required quality for garden or agricultural irrigation purposes without restriction (< 100 CFU/100 mL) which has proved difficult to attain until now.

Today, these extensive treatments are mainly used in Spain in the field of the reclamation of purified effluents for environmental purposes (riverbank improvement, landscape or wetland recovery), as a method to improve the secondary treatment and the ligneous and industrial non-food crops.

Research and innovation work in this field aims at improving the design parameters for each technology and at combining extensive or intensive-extensive technologies, in order to comply reliably with the quality parameters established for most uses in the reuse regulations.

5.1. Infiltration seepage

This is a purifying treatment by biological aerobic filtration through a fine granular medium, whose efficiency will depend on the hydraulic load and the bed thickness [26].

In Spain, several experiments have been carried out using infiltration-seepage as a tertiary treatment for effluent from activated sludge tanks, notably in Piera (Barcelona), Orihuela (Alicante), San Lluis (Menoría), Val-Llobrega (Gerona) and Biar (Alicante). Generally, good results have been obtained for the reduction of SS and pathogenic micro-organisms. Table 8 shows the results obtained in some of the above-mentioned facilities.

5.2. Stabilisation ponds

The stabilisation ponds system for treating sewage usually consists of a series of three lagoons called anaerobic, facultative and aerobic ponds [25]. The *anaerobic pond* acts as a settling tank-digester and mainly eliminates the carbonated contaminant load and heavy solids. The *facultative* pond further reduces the carbonated organic matter but also reduces nitrogen and phosphorus. The aerobic *pond* improves the treatment, makes the system more reliable and is the main means of pathogens removal.

This capacity to reduce both contaminant load and pathogenic micro-organisms has traditionally been exploited in Spain in order to reuse the effluent from stabilisation ponds systems (anaerobic + facultative + aerobic ponds) for agricultural irrigation. This is done in Castile-La Mancha, the Balearic Islands, Catalonia and Andalusia. Aerobic ponds are also being used exclusively as a tertiary treatment for activated sludge or bio-film (bacteria beds or bio-discs) processes, as an improvement system and to reduce pathogens. Lagoons are used in this way in Navarre and Andalusia and can achieve pathogen log removal rates of 2–3. By using several aerobic ponds in line and with retention times of over 10 days, it would be possible, according to some studies, to achieve a log removal rate of 5.

Although stabilisation ponds treatment allows for significant reductions of BOD_5 (85–95%), they normally fail to obtain sufficient quality as regards solids in suspension due to the proliferation of algae coming out with the effluent. In order to mitigate the problems caused by suspended solids, in the case of localised irrigation, it is usual to install filtration systems (sand or ring filters) downstream from the aerobic ponds.

Table 8 shows normal removal rates for BOD_5, SS, *E. coli* and nematodes eggs, both for complete stabilisation ponds systems and for aerobic ponds when used alone as a tertiary treatment for secondary effluent.

5.3. Constructed wetlands

These systems reproduce artificially the conditions existing in natural wetlands. There are two basic types of constructed wetlands: the *surface flow system*, where water to be treated flows through the stems of the emerging plants covering the wetland, and the *sub-surface flow* where the water flows through a filtering substrate which provides support for vegetation.

1. In Spain, this technology is starting to take off and there are now over 40 such facilities, mainly located in Catalonia, Andalusia and Castile-León. For water reclamation purposes, both types of wetlands are being adopted. *Surface flow constructed wetlands* are intended to eliminate nutrients and improve the microbiological quality of water when recovering degraded areas. This is the case of the Ampuriabrava constructed wetlands, whose effluent is discharged into Lake Cortalet in the Aiguamoll de l´Emporda Nature Park, and the Son Cabanyes wetland, in the Granollers peri-urban park. The performance of these facilities varies a lot depending on the quality of treated waters feeding the wetlands. In Spain, constructed wetlands have achieved log. removal rates of 1–3 for faecal coliforms and reductions of 60–80% for SS, 60–70% for nitrogen and 50–60% for phosphorus [25].

Table 8
Output of extensive treatments to relate water reclamation values required

	Turbidity NTU	SS		E. coli		Nematodes eggs/10 L
		mg/L	%	CFU/100 mL	log	
Infiltration seepage	<5	<10	95–99	>1,000	2–4	Absent
	BOD_5 %	SS %		E. coli log		Nematodes eggs/10 L
Stabilisation ponds						
Complete stabilisation ponds system	85–95	70–90		4–6		Absent
Aerobic ponds	75–85	50–70		2–3		Absent
Constructed wetlands	60–80	60–80		1–3		Absent

In *sub-surface flow constructed wetlands*, such as Hostalets de Pierola, the objective is to treat the secondary effluent in order to make it suitable for irrigation purposes. There, the system treated the effluent of an infiltration-seepage system, obtaining good reduction rates for BOD_5 (70–80%) and SS (70–80%) and the log removal of faecal coliforms by 1–3.

The disadvantage of such systems is their long implementation time (2 years) and the increased salinity of the effluent due to water loss by evapotranspiration. With free-flow systems, the difficulty lies in maintaining the reduction of solids in suspension.

Table 8 shows the normal efficiency rates for constructed wetlands used for water reclamation purposes, but since there is little data available, these should be taken as approximate. At the Carrión de los Céspedes Experimental Centre, experiments combining constructed wetlands, working under different flow water, sustrate and planted and without vegetation, are under way and the first results give grounds for some optimism for improving efficiency rates.

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