AWARE

Innovative hybrid MBR systems to promote Water Reuse

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D15 aWARENESS MANUAL

CETaqua

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EXECUTIVE SUMMARY

Through the aWAREness manual a synthesis of the potential application of reclaimed water produced by state of the art and the innovative reclamation schemes is provided. Specific legislation for the regulation of water reuse of different Member States have been reviewed and compared in terms of the allowed uses and quality standards.

Recommendations of treatment schemes for water reclamation according to the different water qualities set by the Spanish regulation are provided together with the most feasible advanced water reclamation technologies for removal of persistent organic priority pollutants and pharmaceuticals based on the results of the LIFE aWARE project. Both state of the art and advanced water reclamation schemes have been compared in terms of economic and environmental impacts.

A set of guidelines comprising existing methodologies based on Sanitation Safety Plans have been summarized. The Sanitation Safety Plan methodologies applied to water reclamation systems represent not only a mean of providing a preventive risk control methodology that ensures safe use along the entire chain of production, distribution and reuse of reclaimed water but also represents a tool for the integrated management of water reclamation systems including engagement of the main actors, appropriate communication of the benefits of water reuse in order to further increase awareness and acceptance of water reuse needs and practices.

The aWAREness manual represent the basis for the creation of the ***Water Reuse Interpretation Centre***, which will aim to integrate technical, environmental, economic, social and regulatory aspects of water reuse in order to promote its wider implementation.

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1. Introduction and objectives of the aWAREness manual

1.1 Circular Economy

Up to now, our economic model has been based on the take-make-dispose line. This line, marked with a start (extraction of raw materials) and an end (disposal) depends on finite reserves. The products manufactured throughout this line ends with its dumping or incineration after its use. This scheme has reached its limits: our natural resources are beginning to decrease and a new economy based on not throwing, but restoring has to be implemented to assure an economic and environmental long-term model.

A circular economy aims at building a new society model where economy and sustainability interact. Its objective is to implement a new economy based on the idea of “closing the life cycle of goods, services, waste, materials, water and energy”. (Circular Economy Foundation, n.d.) Circular economy is based on maintaining the value of products materials and resources for as long as possible and minimizing waste generation. Its goal is the efficient use of resources.

1.2 Water Reuse

Water management is essential for the circular economy. Nowadays, most of the water that is used in urban areas or industry is transported to a Wastewater Treatment Plan (WWTP), where is treated and then returned to the environment. As we can see, this pattern is lineal, the treated water is returned without giving it a second life.

Water scarcity is one of the great problems our society will have to tackle in the near future. This situation has been given because of many factors, including population increase, climate change, changing consumption patterns and dependency on conventional water resources.

Knowing that water is one of the key limiting resources, regarding quantity and quality, in a circular economy, and being aware that in a near future, climate change will challenge water local and seasonal availability in many regions in Europe, it’s absolutely critical to include water as a cornerstone of a circular economy. (Drewes, 2016).

Water reuse is based on the treatment of (WWTP) effluents in order to produce water of sufficient quality for reuse in agricultural, environmental, urban and industrial applications. Water reuse is considered to be a sustainable way of producing high quality

water and features amongst the best solutions in terms of balancing the deficit between available freshwater and demand.

Water reuse is thought to constitute a global level great challenge, becoming an alternative to the conventional water resources. Thus, reused water would perfectly meet the requirements of what we know as Circular Economy.

1.3 Barriers and challenges for the implementation of water reuse

Water reclamation is being considered as a key component in integrated water management strategies, taking into account the currently water scarcity framework. Nevertheless, its implementation is still limited and demonstration projects focused on proving its reliability in environmental, technical, economic and social terms are needed to break the reluctance of the final users and widespread its application among the existing regulations.

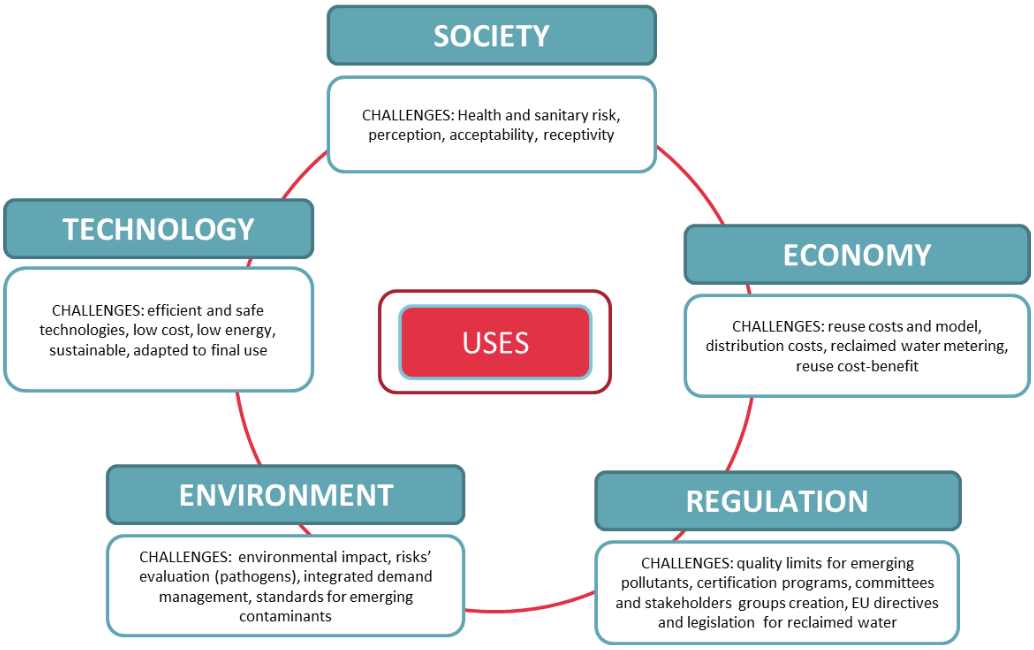

Figure 1. Main challenges and barriers for water reuse

The main factors to be considered in demonstration actions in order promote reuse as a tool for managing water resources are mainly technical, economic, environmental and social. The main aspects are summarized below:

- Water standards and technology required. There is a variety of existing treatments that can comply with the water quality requirements of the existing legislation. However, standards developed must focus on the quality of the reused water really required for the intended use. The bottom line is that standards are essential to maintain public health and environmental safety, creating confidence amongst the public that reused water is safe. Treatments should be adapted to the final use of the water pursued (fit for use approach) in order to fully optimize the technology used both in technical, environmental and economic terms. Selection of the most adequate water standards and technology for each application is the main challenge to address in this area, especially taking into account the need for decentralized treatments. Additionally, removal efficiencies of some compounds should be evaluated with new technologies in order to fully satisfy the health guarantees and reduce the risk associated, increasing its acceptance.
- Economic. Currently the price of reused water is too high to encourage its uptake, while the price of freshwater is too low. The high cost of implementing the solutions required to reclaim water creates a barrier to water reuse. Technologies enabling water reuse exist today, but the business, pricing and funding models for water reuse investments are lacking. Additionally, there is a lack of cost-benefit assessments of reuse systems and schemes so to further encourage its application.
- Environmental. Risk of water reuse to the environment and human health should be assessed by monitoring the pollutants of concern, such as emerging and priority pollutants, in the reuse scenarios and also, by quantifying the associated risk with integrated methodologies.
- There is still a high social reluctance to use reclaimed water in some applications, as they do not consider it as a safe option. Treated wastewater is still seen as wastewater, although quality could be far different and even better than some current resources for water production. Demonstrative actions should focus on communicating the reliability and benefits of reuse in order to boost the reuse implementation. Social benefits such as increasing water availability should be highlighted.

Through the aWAREness manual a synthesis of the potential application of reclaimed water produced by state of the art and the innovative reclamation schemes is provided based on the results of the LIFE aWARE project. In addition a set of

guidelines comprising existing methodologies in order to demonstrate the benefits of water reuse and overcome the main barriers are exposed in order to further increase awareness and acceptance of water reuse needs and practices.

The aWAREness manual also represent the basis for the creation of the ***Water Reuse Interpretation Centre***, which will aim to integrate technical, environmental, economic, social and regulatory aspects of water reuse in order to promote its wider implementation.

2. Reclaimed water standards and Technologies

2.1 European standards for water reuse

At European level, several countries such as Cyprus, France, Greece, Italy, Portugal and Spain have been developing specific legislation for the regulation of water reuse (Table 1).

Table 1. Standards on water reuse from EU Member States

Country	Standards reference	Issuing institution
Cyprus	Law 106 (I) 2002 Water and Soil pollution control and associated regulations KDP 772/2003, KDP 269/2005	Ministry of Agriculture, Natural resources and Environment Water development Department (Wastewater and reuse Division)
France	JORF num.0153, 4 July 2014 Order of 2014, related to the use of water from treated urban wastewater for irrigation of crops and green areas	Ministry of Public Health Ministry of Agriculture, Food and Fisheries Ministry of Ecology, Energy and Sustainability
Greece	CMD No 145116 Measures, limits and procedures for reuse of treated wastewater	Ministry of Environment Energy and Climate Change
Italy	DM 185/2003 Technical measures for reuse of wastewater	Ministry of Environment Ministry of Agriculture, Ministry of Public Health
Portugal	NP 4434 2005 Reuse of reclaimed urban water for irrigation	Portuguese Institute for Quality
Spain	RD 1620/2007 The legal framework for the reuse of treated wastewater	Ministry of Environment Ministry of Agriculture, Food and Fisheries, Ministry of Health

These specific legislation are based on European Directives and set consent limits for physicochemical parameters of treated effluents, limit environmental emission of pollutants or for instance regulate concentration limits of water bodies by specific contaminants such as nitrates (91/271/EEC, 2008/105/EC, 91/676/EEC).

Existing legislation agree on most of the control parameters for water reuse, which include microbiological indicators, physic-chemical parameters and specific chemical contaminants such as metals, phosphorus , nitrates or organic pollutants. Main similarities and differences between the water qualities parameters considered in the different legislation at European levels can be summarized as:

- All the countries with existent legislation for water reuse include suspended solids as a control parameter. However only Spain and Greece include turbidity as a control parameter for reclaimed water. Turbidity is one of the parameters related mainly to suspended solids concentration that can be monitored online, at lower cost for the control of disinfection efficiency and effluent quality.
- All the countries include microbiological indicators for monitoring reclaimed water quality and in most cases main preference is to control *Escherichia* coli as an alternative

to Total Coliforms or Fecal Coliforms given that the latter are naturally present in the environment, while the former is more specific and can be correlated to the presence of pathogens in wastewater and treated effluents.

Table 2. Analytical parameters included in the evaluated standards for water reuse

Analytical parameters	Cyprus	France	Greece	Italy	Portugal	Spain
Microbiological parameters						
- *Escherichia coli*	√	√	√	√		√
- Faecal coliforms					√	
- Total coliforms			√			
- Faecal enterococci		√				
- *Legionella* sp.						√*
- *Salmonella* sp.				√		√*
- Sulphate-reducing bacteria		√				
- Helminth eggs (Intestinal nematodes)	√				√	√
- F-specific bacteriophages		√				
Physical-chemical parameters						
- Total suspended solids (TSS)	√	√	√	√	√**	√
- Turbidity			√			√
- Biochemical oxygen demand (BOD_5)	√		√	√		√**
- Chemical oxygen demand (COD)	√	√		√		√**
- pH	√		√	√	√**	
- Heavy metals and metalloids	√		√	√	√**	√*
- Electrical conductivity (EC)	√		√	√	√**	√*
- Total dissolved solids (TDS)			√		√**	
- Sodium adsorption ratio (SAR)			√	√	√**	√*
- Chlorine (Cl, Chlorides)	√		√	√	√**	√*
- Nitrogen forms (Total, $N\text{-}NO_3$, $N\text{-}NH_4$)	√		√	√	√**	√*
- Total phosphorus	√		√	√	√**	√*
- Bicarbonate (HCO_3)			√			
- Toxic substances including priority substances			√**	√	√**	√**

The Spanish legislation (RD1620/2007) includes the control of *Legionella*, for those uses such as evaporative cooling towers in industries or spray irrigation in agricultural uses, in which the formation of mists may pose a risk for exposure of the population and consequently to public health. In this case the Spanish RD1620/2007 is based on previous legislation RD865/2003 that regulates the control and prevention of legionellosis in sites that employ water and generate mists. .

The control of nematode eggs or helminthic eggs is another water quality requirement that can be found in Southern European countries such as Cyprus, Spain and Italy, following recommendations of the WHO. In contrast several countries already implementing water reuse, such as United States and Australia don not include these pathogen indicators because they are considered as endemic mainly developing countries.

France is the only country at European level that includes in its water reuse legislation, in accordance with the opinion of the international scientific community, the control of pathogenic viruses, such as F-specific bacteriophages as well as indicators of parasitic protozoa such as *Giardia* and *Cryptosporidium*, although industrial, urban and environmental uses are not contemplated.

Table 3 Maximum limit values according to the intended use for parameters included in the EU Member States water reuse standards

Analytical parameters	Cyprus	France	Greece	Italy	Portugal	Spain
Microbiological parameters						
Escherichia coli (cfu/100ml)	$5\text{-}10^3$	$250\text{-}10^5$	5-200	10		$0\text{-}10^4$
Faecal coliforms (cfu/100ml)					$100\text{-}10^4$	
Total coliforms (cfu/100ml)			2			
Faecal enterococci (log reduction)		2-4				
Legionella sp. (cfu/l)						$0\text{-}10^3$
Salmonella sp.				absence		absence
Sulphate-reducing bacteria (log reduction)		2-4				
Helminth eggs (Intestinal nematodes) (eggs/l)	0				1	0.1
F-specific bacteriophages (log reduction)		2-4				
Physical-chemical parameters						
Analytical parameters	**Cyprus**	**France**	**Greece**	**Italy**	**Portugal**	**Spain**
Total suspended solids (TSS) (mg/l)	10-30	15	2-35	10	60	5-35
Turbidity (NTU)			2-no limit			1-15
Biochemical oxygen demand (BOD_5) (mg/l)	10-70		10-25	20		
Chemical oxygen demand (COD) (mg/l)	70	60		100		
pH	6.5-8.5		6.5-8.5	6.0-9.5	6.5-8.4	
Electrical conductivity (EC)(dS/m)	1.7-2.9		3.0	3.0	1.0	3.0
Total dissolved solids (TDS) (mg/l)			2000		640	
Sodium adsorption ratio (SAR)			12*	10	8	6
Chlorides (mg/l)	300		350	250	70	
Total nitrogen (mg/l)	15		30	15		10**
Total phosphorus (mg/l)	2-10		1-2	2		2**
Bicarbonate (HCO_3)			500			

* depending on the value of electrical conductivity
** only for aquifer recharge and recreational uses
*** minimum log reduction required.

- In terms of organic matter, Greece, Cyprus and Italy are the only countries that regulate the concentrations of the biodegradable fraction (BOD_5) in reclaimed water, while Cyprus, France and Italy also set chemical oxygen demand (COD) in their legislation.

- All the countries, except France, include inorganic constituents for controlling the concentrations of salts measured either as conductivity, total dissolved solids (TDS),

chlorides sodium adsorption ratio (SAR), mainly for uses in agriculture were excess presence of salts can be detrimental for soil quality and crop development.

The range of maximum limit values of the control parameters set by the different reuse standards in Europe are shown in Table 3. The limits presented in Table 3, represent the most restrictive values of the different uses included in each legislation. For instance France and Greece presents different levels of reclaimed water quality for the 4 uses included in their regulation, while Spain presents 12 different water qualities (Table 4). In contrast, Italy sets the same water quality independently of the intended use of reclaimed water, which is against the recommendations provided by the WHO.

The limits set for microbiological parameters are set by a maximum concentration reclaimed water, with the exception of France in which the existing legislation sets the minimum log removal efficiency for F-specific bacteriophages, sulphite reducing bacteria and faecal enterococci, which follows the criteria of the recommendations of the WHO and aligns with the Australian guidelines for Water Reclamation.

Comparison of the limit values included in the different European standards tend to be aligned (Table 3), although they vary according to the intended use. For instance *E. coli* as indicator of the presence of pathogens ranges between absences most restrictive use in Spain (Aquifer recharge) up to maximum value of 3 -5 log units for less restrictive uses (irrigation for crops not in contact with water). Italy, with a single level of water quality sets a restrictive maximum limit for *E. coli* of 10 cfu/100 mL. There is also agreement for other microbial indicators such as Salmonella spp. (absence in Italy and Spain) and Helminth eggs (0 -0.1 unit/ L in Cyrus, Spain and Portugal).

Maximum limit values of suspended solids concentration are commonly set between 5-30 mgSS/L, except in the case of Portugal in which higher concentration of 60 mgSS/L has been set. Inorganic constituents, which maximum limit values are set in order to preserve soil and crop quality are also aligned in most of the European regulations with values between 2000 and 3000 µS/cm for conductivity, 6-12 meq/L for sodium adsorption ratio and 250-350 mg/L of chlorides.

2.2 Spanish standards for water reuse and technologies

In the case of Spain, the Spanish royal decree RD1620/2007, sets the legal framework both at administrative and technical level for water reuse, specifying the quality requirements that reclaimed water must accomplish in order to guarantee health of the users. Besides the protection of public health associated to the use of reclaimed water, the RD1620/2007 also aims to accomplish the regulations related to Environmental Quality Standards (EQS) set by the Royal Decree RD60/2011 and subsequently by RD817/2015, in order to attain the objectives of good

chemical status of the water bodies set by European Directives (Water Framework Directive 2000/60/EC and EQS Directive 2008/105/EC).

2.3 State of the art water reclamation technologies

Reclaimed water quality for the 14 uses established in the Spanish legislation for water reuse (RD1620/2007) can be classified into 6 main categories (A, B, C, D, E and F) according to the microbiological parameters *E.coli*, Nematode eggs and *Legionella spp.* (Table 4). In this classification water quality A, corresponds to the highest quality for industrial (cooling towers and evaporative condenser), urban (irrigation of private gardens and toilette flushing) and environmental uses (direct aquifer recharge), while the lowest quality E and F corresponding to environmental uses such as irrigation of forest and green areas not accessible to general public and forestry (E) and maintenance of wetlands and ecological river flows (F) present the lowest microbial limits.

Table 4- Classification of uses of reclaimed water according to water quality in Spanish Royal Decree 1620/2007

Uses	Quality	*E.coli* UFC/100 mL	Nematodos eggs/10 L	*Legionella spp* CFU/100 mL
Cooling towers and evaporative condensers	A	Absence	Absence	Absence
Irrigation private gardens Toilette flushing		Absence	<1	<100
Direct aquifer recharge		Absence	<1	No limit
• Urban services, fire extinguish systems and vehicle cleaning • Unrestricted irrigation • Golf courses	B	< 100 -200	< 1	< 100
Irrigation of crops not consumed fresh • Irrigation of pasture for livestock • Aquiculture	C	< 1.000	< 1	No limit
Process water in industries and cleaning in food industry				< 100
• Aquifer recharge through land percolation		< 1000	No limit	No limit
• Irrigation of crops with edible fruits /vegetables not in contact with water • Irrigation of flowers, garden centres without contact with the products. • Irrigation of industrial crops not for food industry	D	< 10.000	< 1	< 100
• Other industrial uses				
Ponds, ornamental water flows , and water bodies with restricted access to public				
Irrigation of woods, and green areas with no access to public. • Forestry, Silviculture	E	No limit	No limit	No limit
Maintenance of wetlands and ecological river flows.	F	Quality will be set in depending on the case		

For environmental uses under quality F, microbial limits are not set by the RD1620/2007 given that the specific catchment authority is responsible for specifying these values in a case by case basis. In these cases nitrogen is limited to values of TN < 10 and NO_3 < 25mgNO_3/L while phosphorus is limited to TP < 1-2 mg/L

The most efficient treatment schemes in order to attain the required level of quality for the different uses have been proposed in the Spanish National Water reuse plans based on the previous classification into the different groups and taking into account treatments with and without salinity reduction.

<u>State of the art treatment schemes for water reclamation without salinity reduction</u>

The most adequate water reclamation schemes for each of the water quality groups are represented in Figure 2.

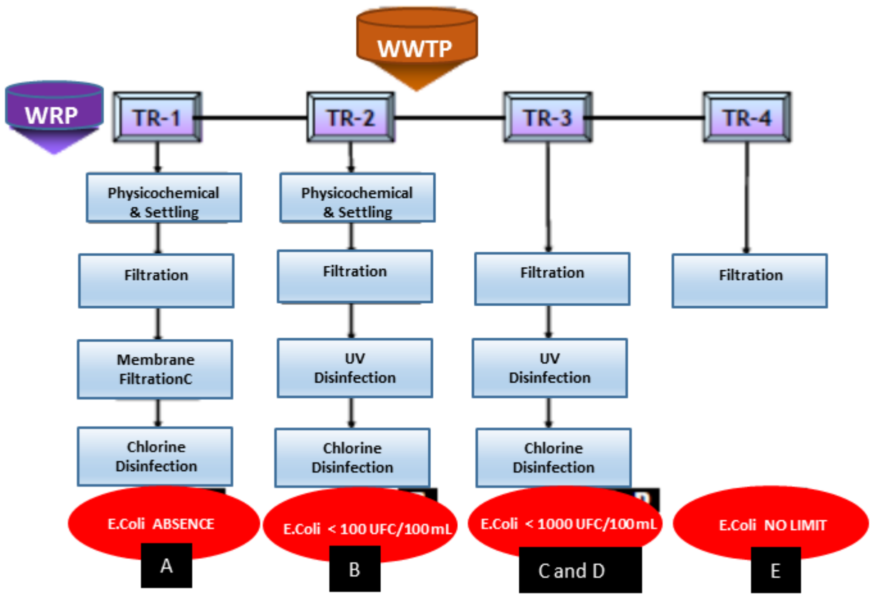

Figure 2. Recommended treatment schemes for production of reclaimed water qualities without salinity reduction indicated in Table 4

Treatment 1 (TR1): In order to obtain the highest water quality without salinity reduction and absence of microbial indicators (Group A), the proposed treatment includes a physic-chemical treatment with settling followed by membrane filtration and maintenance disinfection with sodium hypochlorite. In the case of reclaimed water for direct injection into the aquifer, included in group A, it is recommended to include Reverse Osmosis (see treatment 5) in order to remove nitrates to the levels required for this use as well as persistent priority and emerging pollutants.

Treatment 2 (TR 2): Water quality B, which requires *E.coli* limit below 100-200 UFC/100 mL and turbidity below 10 NTU can be accomplished by coagulation-flocculation treatment with settling

followed by conventional sand filtration and UV-hypochlorite disinfection. This treatment scheme would allow to comply with microbial parameter limits of group A (TR1) although it will not provide consistent effluent turbidity below 1-2 NTU.

Treatment 3 (TR 3). Production of water quality of group C and D, which requires *E.coli* > 1000 UFC/100 Ml and effluent suspended solids below 35 mg SS/L, can be adequately produced by direct sand filtration of secondary effluent, followed by UV- hypochlorite disinfection.

Treatment 4 (TR4): For the lowest quality (group E), in which there is no limit established for microbial parameters the treatment scheme consists in sand filtration of secondary effluent as a mean of assuring that filtered secondary effluent does not exceed 35 mg SS/L. In this case, although the required water quality corresponds to the secondary effluent, sand filtration is recommended for adequate management and operation of the distribution network for the supply of the reclaimed water.

State of the art treatment schemes for Water reclamation with salinity reduction

Proposed treatment schemes for water reclamation schemes that require salinity reduction are depicted in Figure 3. These treatment schemes are mainly considered for reduction of salinity for reuse in agriculture as well as for aquifer injection for reduction of nitrates.

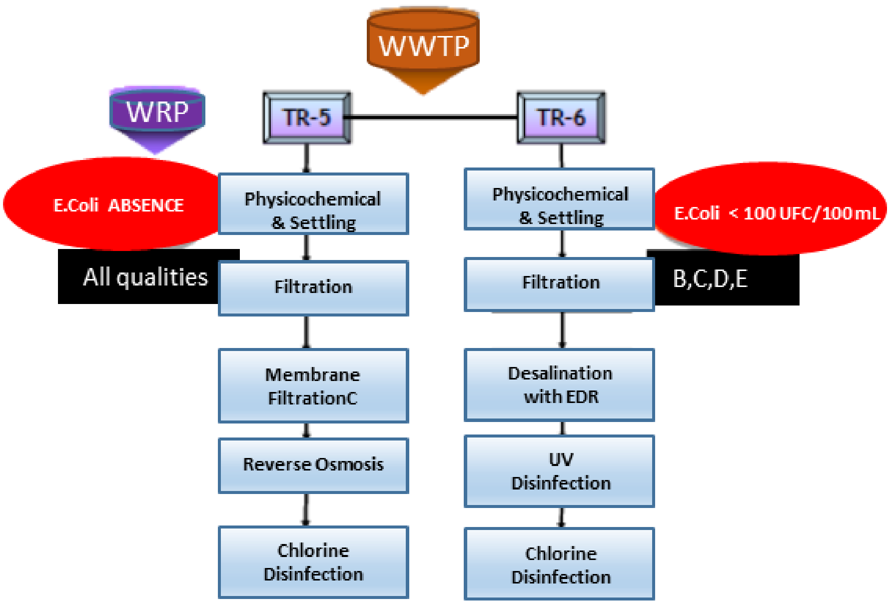

Figure 3. Recommended treatment schemes for the production of reclaimed water qualities with salinity reduction indicated in Table 4

Treatment 5 (TR5): This treatment scheme produces reclaimed water that fits all the group categories considered in Table 4, and consists in a treatment train comprising coagulation-flocculation with settling, sand filtration, membrane filtration and reverse osmosis treatment followed by maintenance disinfection (usually with UV). Treatment scheme 5 is recommended for direct aquifer injection.

Treatment 6 (TR6): This treatment scheme, comprises a coagulation-flocculation stage followed by sand filtration and Electro dialysis reversal (EDR), followed by disinfection with UV and hypochlorite disinfection.

2.4 Advanced water reclamation technologies

The European Commission, through the **Water Framework Directive** (2000/60/EC) and the **Environmental Quality Standards Directive** (2008/105/EC) -EQS, established a water policy strategy for control of 45 priority pollutants -PP (after 2013/39/EU Directive) and their maximum and annual average concentrations in natural water bodies. In order to achieve ‘‘good chemical status’’ and accomplish the EQS for the PPs (biocides-pesticides, heavy metals, detergents, dissolvent, Polyaromatic hydrocarbons) member states should implement measures to control their emissions.

The EQS within the RD1620/2007 are specified for those uses with a direct impact on the receiving water bodies such as agricultural reuse, environmental uses (maintenance of ecological river flows or wetlands) as well as aquifer recharge (Table 5).

The EQS apply to the superficial and ground water bodies and therefore if for the intended use of reclaimed water there is no mixing with the surface water or ground water or their flux is limited, the maximum and average concentrations of the EQS in reclaimed water needs to be taken into account. The most recent RD817/2015 establishes that a mixing area is to be established in the discharge point and where the EQS can be exceeded whenever they remain below the maximum and average concentrations outside of the mixing area. The list of contaminants and the average and maximum concentrations according to the EQS directive (2008/105/EC) -as well as the limits set by other criteria by the RD1620/2007 are shown in Table 6.

Emerging Pollutants (EP), which may be included in the PP list of updated versions of the WFD, also need to be considered. In particular, pharmaceuticals, personal care products and hormones are groups of emerging contaminants which are receiving increasing attention because of their potential harmful effects for the environment and human health

Table 5. Additional regulation criteria for chemical and microbiological parameters established in the Spanish RD 1620/2007 for the different uses of water

Reuse application	Quality (Group- Table 4)	Additional regulation-criteria
Urban uses	Quality 1.1(Group A)	EQS (RD817/2015 and RD 606/2003)
	Quality 1.2 (Group B)	
Agricultural uses	Quality 2.1 (Group B)	EQS (RD817/2015 and RD 606/2003)
	Quality 2.2 (Group C)	EQS (RD817/2015 and RD 606/2003)
	Quality 2.3 (Group D)	
Industrial uses	Quality 3.1 a b (Group D)	EQS (RD817/2015 and RD 606/2003)
	Quality 3.1 c (Group C)	
	Quality 3.2 (Group A)	
Recreational use	Quality 4.1 (Group B)	EQS (RD817/2015 and RD 606/2003)
	Quality 4.2 (Group D)	
Environmental uses	Quality 5.1-(Group C)	Contaminants defined in RD849/1986
	Quality 5.2 (Group A)	
	Quality 5.3 (Group E)	EQS (RD817/2015 and RD 606/2003)
	Quality 5.4 (Group F)	

State of the art water reclamation schemes enable to upgrade water quality according to water quality parameters that ensure safe use of water for the different applications. However water reclamation schemes have not been specifically designed for the removal of priority and emerging pollutants which are persistent in WWTP.

Adavanced water reclamation technologies and treatment schemes also need to be considered as an additional barrier of persistent PP and EP within the water cycle in scenarios where their levels of these can compromise the environment, and public health.

Table 6. List of chemical contaminants with maximum and average limit values established in the additional criteria of the RD162/2007

Requirements depending on the use	Unit	RD 1620/2007	EQS Maximum value	EQS- Mean annual average
Conductuvity	mS/cm at 25ºC	3000		
RAS	meq/L	6		
B	µg/L	500		
As	µg/L	100		
Be	µg/L	100		
Cd	µg/L	10		
Co	µg/L	50		
Cr	µg/L	100		
Cu	µg/L	200		
Mn	µg/L	200		
Mo		10		
Ni	µg/L	200		
Se	µg/L	20		
V	µg/L	100		
Alachlor	µg/L		0.3	0.7
Anthracene	µg/L		0.1	0.4
Atrazine	µg/L		0.6	2
Benzene	µg/L		10	50
Bromited diphenylethers (PBDE)	µg/L		0.0005	N.A.
Cadmium and its compounds	µg/L		0.25	1.5
Tetracholormetane	µg/L		12	N.A.
Chloroalkanes C10-13 (SCCP)	µg/L		4	1.4
Chlorofenvinphos	µg/L		0.1	0.3
Chloropyrifos (-ethyl)	µg/L		0.03	0.1
Aldrin Dieldrin Endrin Isodrin	µg/L		0.01	N.A.
DDT total	µg/L		0.025	N.A.
p,p, DDT	µg/L		0.01	N.A.
1,2dichloroethane (DCA)	µg/L		20	N.A.
Dicloromethane (DMC)	µg/L		20	N.A.
Di(2-ethythexyl) phthalate (DEHP)	µg/L		1.3	N.A.
Diuron	µg/L		0.2	1.8
Endosulfan	µg/L		0.005	0.01
Fluoranthene	µg/L		0.1	1
Hexachlorobenzene (HCB)	µg/L		0.01	0.05
Hexachlorobutadiene (HCBD)	µg/L		0.1	0.6
Hexachlorocyclohexane (HCH)	µg/L		0.02	0.04
Isoproturon	µg/L		0.3	1
Lead and its compounds	µg/L		7.2	N.A.
Mercury and its compounds	µg/L		0.05	0.07
Naphthalene	µg/L		2.4	N.A.
Nickel and its compounds	µg/L		20	N.A.
Nonylphenols	µg/L		0.3	2
4-Nonylphenol	µg/L		0.3	2
Octyphenols (PO)	µg/L		0.1	N.A.
Pentachlorobenzene (PeCB)	µg/L		0.007	N.A.
Pentachlorophenol (PCP)	µg/L		0.4	1
Benzo(a)pyrene	µg/L		0.05	0.1
Benzo(b)fluoranthene + Benzo(K)fluoranthene	µg/L		0.03	N.A.
Benzo(g,h,i)perylene, + Indeno(1,2,3-cd)pyrene	µg/L		0.002	N.A.
Simazine	µg/L		1	4
Tributyltin compounds (TBT)	µg/L		0.0002	0.0015
Tricholorobenzenes (TCB)	µg/L		0.4	N.A.
Trichloromethane (chloroform)	µg/L		2.5	N.A.
Triflurain	µg/L		0.03	N.A.

In the aWARE project, two main concepts have been tested as possible solutions for advanced water reclamation with removal of persistent PP and EP (Figure 4):

- **Advanced Oxidation Processes**: AOPs are based on the generation of oxidants (ozone and hydroxyl radicals) which applied to treated effluents enable to oxidize (break up) organic micropollutants. In the aWARE project different combinations of Ozone, hydrogen peroxide and UV light have been implemented in state of the arte water reclamation schemes

- **Powdered Activated Carbon**: PAC is a material that applied to water enables removal of organic micropollutants and other contaminants through adsorption. In the aWARE project PAC has been combined with two membrane based water reclamation technologies membrane bioreactors (MBRs) and capillary nanofiltration (NF) in an innovative scheme: MBR-PAC-NF

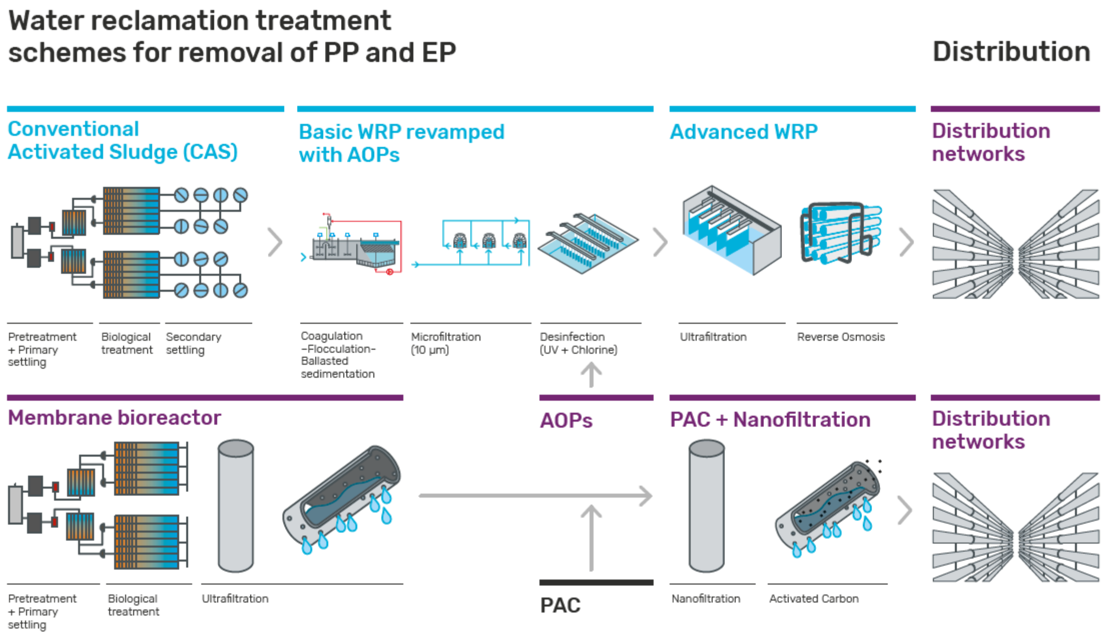

Figure 4 State of the art conventional and advanced water reclamation schemes evaluated in the aWARE project as barriers for persistent priority and emerging contaminants

Additional removal of PP and EP is required in order to maintain EQS most adequate treatment trains have been identified for water reclamation with and without salinity reduction.

Advanced water reclamation schemes for fulfillment of EQS without salinity reduction

State of the art water reclamation schemes involving water reclamation for the production of water quality A or B provide only marginal removal between 12-60% for priority and emerging

pollutants that are persistent to the biological processes (Table 7), while the use of an MBR which will achieve similar levels with removal efficiencies ranging from 15 to 70%.

Water reclamation schemes involving treatment schemes 1 to 4 present low removal efficiency of PP and EP. In the aWARE project the basic WRP of Baix Llobregat showed to contribute only marginally to the removal of persistent organics pollutants with maximum values of 30% observed for Diclofenac.

Based on the results of the aWARE project increasing removal of persistent priority and emerging pollutants for water reclamation without salinity reduction would involve the following treatment schemes

Treatment 7 (TR7): For the production of reclaimed water of Quality A, the application of an MBR with PAC dosing of 25 mg/L (Treatment 7) would consistently produce an effluent with turbidity below the limit of 1 NTU, complete and robust disinfection and removal of organic micropollutants of 75-80%. This treatment scheme would be mainly applied for urban uses (Quality 1.1 for residential uses in private gardens a toilette flushing) given that industrial uses in evaporative condensers and cooling towers are not subjected to EQS. In the case of direct aquifer injection, the MBR combined with PAC would require partial post treatment with RO in order to reduce the levels of nitrates and total nitrogen (see treatment 9 with salinity reduction below)

Treatment 8 (TR 8): For the production of reclaimed water of Quality B, C and D and E (Table 8), the application of ozone doses between 6 and 9 mg/L combined with the corresponding water reclamation schemes TR2, TR3 and TR4 represents removal of 80-95 % organic PP and PEP which are persistent to conventional treatment. In this case it would be necessary to consider that treatments C and D, need be efficient at removing turbidity and solids in order to avoid a reduction in the efficiency of the ozonation process

Table 7. Removal efficiency of persistent PP and EP in the state of the art and advanced water reclamation schemes without salinity reduction evaluated in the aWARE project

Water Reclamation Scheme	% Removal (Carbamazepine, Diuron)	% Removal (Diclofenac, Sulfametoxazol, Codeine)
Basic WRP	12	60
MBR	15	70
Basic WRP revamped with O_3	80	95
PAC-MBR (25 mg/L virgin PAC)	80	75

On the other hand the ozonation process, represents an additional barrier for microbial contamination when combined with the disinfection process of UV chlorination of treatments 2, 3 and 4.

Advanced water reclamation schemes for fulfillment of EQS with salinity reduction

Based on the results of the aWARE project, whenever partial salinity reduction is required through RO or EDR treatments together with additional removal of organic PP and EP, several treatment schemes involving the use of Ozonation and activated carbon can be considered.

Treatment 9 (TR9): In water reclamation schemes such as the proposed in Treatment 5 for partial reduction in salinity with RO for agricultural reuse or aquifer injection for reduction of TN < 10 mg/L and NO3 < 25 mgNO_3/L the overall removal of persistent PP and EP in a 50 -50% blend of UF-RO, would range between 60-80 %. In such treatment schemes the UF contributes to less than 20% to the removal of organic micropollutants and the RO, achieves complete removal but generates a concentrated bring in PP and EP.

Table 8. Removal efficiency of persistent PP and EP in the state of the art and advanced water reclamation schemes with salinity reduction evaluated in the aWARE project

RO pre-treatment scheme	% Removal (Carbamazepine, Diuron)	% Removal (Diclofenac, Sulfametoxazle, Codeine)
Basic WRP + UF	60	80
Basic WRP + revamped with AOP + UF	90	100
PAC-UF-RO (Based on NF)	80	90
PAC-MBR	90	95

The options for abatement of PP and EP form the RO permeate and concentrate streams can be summarized as:

- TR9.1 Ozone doses of 6-9 mg/L after the physicochemical treatment followed by filtration and before the UV and UF as pretreatment of the RO enables overall removal rates ranging from 90 to 100 % of persistent organic micropollutants.

- TR9.2 Removal of 80-90 % of PP and EP with PAC dosing are possible by dosing PAC directly to the UF. Results from the aWARE project have shown that PAC addition to a filtered effluent provides low-medium removal (30-80 %) for the lowest doses of 10-25 mg/L , with a further increase to medium-high removal rates (50-85 %) for higher doses of 47-52 mg/L.

- TR9.3 d Based on the cost-efficiency analysis evaluation of the different options a treatment scheme consisting in and MBR with PAC dosing of 25 mg/L would present a comparable cost to treatment scheme 5 and remove persistent PP and EP between 90-95 %(Table 8).

- Treatment 10 (TR10): For water reclamation schemes involving the use of EDR for salinity reduction after the EDR stage would provide additional removal of PP and EP of 80-95 %

3. Economic and environmental impacts of water reuse systems

In order to integrate water reclamation and reuse as an alternative resource in the management of the urban water cycle and widespread reuse practices it is necessary to establish a financial model that promotes the sustainable development of water reuse across the territory. The financial models required to achieve a sustainable development of water reuse for agriculture, environmental, recreational, industrial and urban uses, must take into account the principles of preservation, restoration and protection of the environment, public health safety as well as the availability and quality of water resources, taking into account the costs of technologies for production and distribution of reclaimed water.

In the following sections indicative costs of state of the art water reclamations schemes as well as of advanced treatment focused on the removal of PP and EP are provided.

3.1 Economic impact of state of the art water reclamation technologies

The costs of the state of the art treatment schemes, depicted in Figure 2 and Figure 3 which are required in order to obtain the different levels of water quality A, B, C, D E and F described in the previous section, have been indicated in Table 9.

The values depicted in Table 9 have been obtained from water management organizations and operators of the regions in which water reclamation and reuse is most widely implemented. The capital costs make reference to the contracted building budget before taxes. Operational costs include fixed costs (personnel, routine analyses, maintenance, general costs… etc) as well as variable costs (energy, chemicals, reposition of consumables etc…) all before taxes.

Table 9. Treatment cost of state of the art water reclamation schemes indicated in Figure 2 and Figure 3 obtained from full scale reclamation plants in Spain

Treatment type		Costs	
		CAPEX (€/m³/d)	OPEX (€/m³)
Without salinity reduction	TR1	164-351	0.14-0.20
	TR2	27-47	0.06-0.09
	TR3	9-22	0.04-0.07
	TR4	5-11	0.04-0.07
With salinity reduction	TR5a	259-458	0.35-0.45
	TR5b	248-405	0.35-0.45

3.2 Economic and environmental impact of state of the art and Advanced water reuse with removal of priority and emerging pollutants

The aWARE project has evaluated innovative hybrid water reclamation technologies form a the technical, economic and environmental perspective, in order to quantify the impact of implementing advanced water reclamation schemes as additional barrier for persistent priority and emerging pollutants within the water cycle.

The aWARE project evaluated an **innovative hybrid water reclamation scheme for removal of PP and EP (Figure 4),** which have been compared against state of the art systems. The state of the art systems consisted in a

- A basic water reclamation plant, with a treatment scheme suited for the same uses as water quality B and TR2 without salinity reduction.
- Advanced WRP, consisting in the treatment of the basic WRP effluent in a UF-RO scheme (50 % blend of each) suited for all the uses according to the existing legislation (TR5)

The innovative hybrid schemes in the application of powdered activated carbon to an MBR (TR7 and TR9.3), ozone to the state of the art basic WRP effluent (TR8 and TR9.1) and the application of PAC to a filtered effluent upstream of a capillary UF-NF membrane (TR9.2)

For the production of water quality for reuse, state of the art water reclamation schemes appear (TR1 to TR5) to deliver comparable water quality as the MBR advanced treatments at a lower cost and environmental impact (Tables 6 and 8 and Figures 14 and 15). Conventional water reclamation without the use of adsorbents such as PAC or oxidation processes such as ozone, provide only marginal removal for priority and emerging pollutants that are persistent to the biological processes (from 12-60% removal in the compounds studied). In case additional removal of PP and EP is required two different scenarios have been identified:

1-For basic WRP (reuse without salinity reduction) , the application of ozonation represents removal of 80-95 % PP and PEP which are persistent to conventional treatment with less than 20 % additional overall costs and approximately 30 % in environmental impact in comparison with conventional treatments.

Table 10. Cost and carbon footprint of state of the art and advanced water reclamation treatments without salinity reduction evaluated in the aWARE project for water reuse and removal of persistent PP and EP

Water reclamation scheme	Cost difference with Basic WRP	Environmental Footprint (Kg CO_2/m^3 relcaimed WW)
Basic WRP	-	0.21
MBR	+ 30 %	0.28
Basic WRP revamped with AOP	+ 19 %	0.28
PAC-MBR (25 mg/L virgin PAC)	+ 60 %	0.81

2-For advanced WRP (reuse with partial reduction in salinity) the PAC-MBR as pretreatment of RO , enables 90-95 % removal of PP and PP which are persistent to conventional treatment with comparable overall cost and less than 20 % of the environmental impact.

Table 11. Cost and carbon footprint of state of the art and advanced water reclamation treatments with salinity reduction evaluated in the aWARE project for water reuse and removal of persistent PP and EP

RO pre-treatment scheme	Cost difference with advanced WRP	Environmental Footprint (Kg CO_2/m^3 relcaimed WW)
Basic WRP + UF	-	0.63
Basic WRP + revamped with AOP + UF	+ 7 %	0.70
PAC-UF-RO (Based on NF)	+11 %	1.23
PAC-MBR	0 %	1.23

4. Risk assessment of water reuse systems: Sanitation safety plans

Existing legislation such as the Spanish RD 1620/2007 sets the technical requirements for water quality in order to guarantee that water reuse is safe from the public health and environmental point of view. However this water management methodology is based on a retrospective principle, given that reclaimed water might have already been distributed and supplied before quality analysis have been conducted.

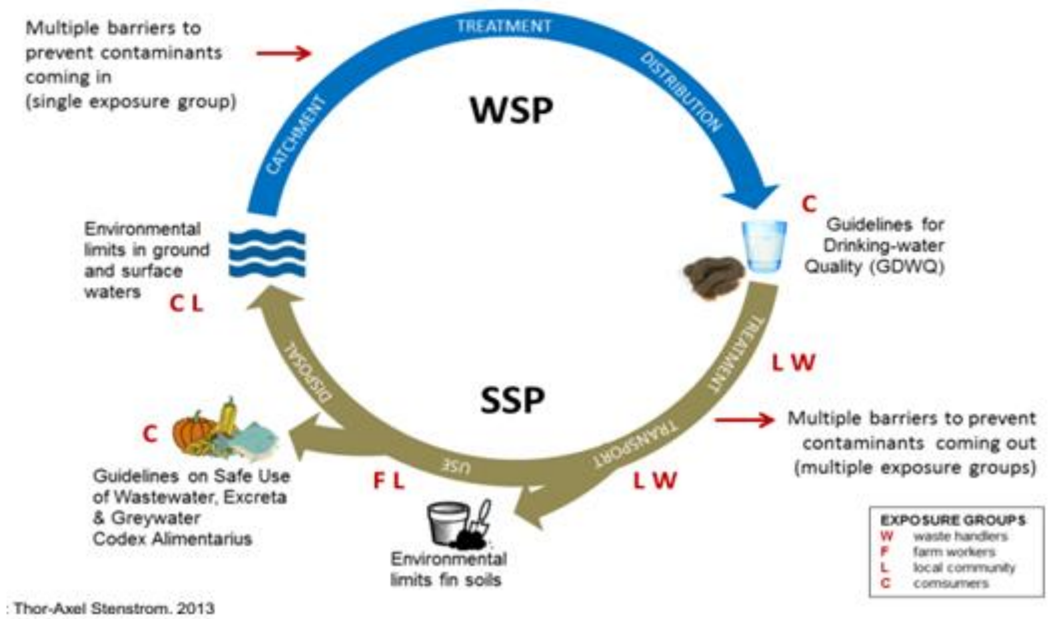

Figure 5 Water Cycle and the scope of the SSP (water reuse) and WSP (potable water treatment)

The implementation of Sanitation Safety Plans (SSP) to water reclamation, and reuse represents a change in the model of management of water quality from a retrospective to a preventive methodology. In a Sanitation Safety Plan all the stages of the process, going from wastewater generation, transport treatment to the reclamation treatment, distribution and use should be considered in order to identify the main dangers that represent significant risks for health of users of reclaimed water as well as for the environment. Once the risks along the process are identified, form the analysis of historical data, preventive control measures are implemented on the stages that have been identified form historical performance data as critical for the final effluent quality. In practice, this is implemented by establishing alert and critical levels for control parameters from and planning corrective actions in case these levels in the control parameters are exceeded.

These set of procedures, known as a preventive plan or Hazard Analysis Critical Control Points (HAPPCC), adapted to the production, distribution and use of reclaimed water, represents a solid technical methodology for the evaluation and control of associated risks and enable to demonstrate the safety of water reuse practices, improve social and users perception and promote its wider implementation.

The evaluation of the risks and the development of the prevention plan must be focused first in eliminating the acute risk associated to the exposure to pathogens, while chronicle risks, and are associated to chemical organic and inorganic contaminants as well as radionuclides. This classification of the risk means that in general due to their nature microbial risks require a closer control than chemical risks. The "safe" use of reclaimed water in the SSP involves not only the minimization of the risks related to its final use but also to the health of the operators or the population that can potentially be in contact with it as well as the protection of the environment.

In 2015, the World Health Organization (WHO), published general guidelines for the application of sanitation safety planning entitled "Manual for safe use and disposal of wastewater greywater and excreta ". These guidelines have been used as a basis for the development and implementation of SSP applied to water reclamation systems which include WWTP, WRP and distribution systems.

Figure 6. Sanitation Safety Planning guidelines published by WHO (2015)

In order to implement SSP for the production and reuse of reclaimed water several work packages have to be developed:

a. In order to ensure the viability of the production of reclaimed water it is necessary to monitor and control the factors that can have a major impact in its quality along the whole change of production and distribution:
   i. The variability and characteristics of the wastewater
   ii. The inherent variability of the biological processes of wastewater treatment plants
   iii. The variability of the water reclamation processes
   iv. The efficiency of the monitoring methodologies.

b. Define the treatment requirements of each treatment stage and the resulting water quality in order to guarantee legal requirements and the minimization of the microbiological and chemical risks.

In order to minimize the microbial risk, which are the one that can have a larger health impact in the short term, it is recommended to apply multi-barrier or multiple barriers. In practice it involves redundancy of equipment or treatment lines in order to ensure that there is always more than one unit which can provide the required treatment capacity and reduction of microbial contamination.

In terms of the chemical risks, the USEPA, has estimated that there are more than 85000 compounds of variable nature and origin (pesticides, personal care products, pharmaceuticals, household cleaning products, hormones. Etc…) present in reclaimed water with a wide range of concentrations and different physicochemical characteristics. The sanitation and reclamation process also need to take into account the removal of these chemical substances, especially in those applications which can negatively affect human health and the environment

c. Design treatment strategies, that are better adapted to face unknown chemical risks or to those which haven't been approached yet.

d. Identify methods in order to improve the performance of the treatment scheme and reduce associated treatment costs.

e. Identify efficient alternative treatment methods which enable a minimization of energy and chemical use as well as the production of residues.

Sanitation safety plans for stakeholder engagement and improvement of social perception

As shown in the next sections, the sanitation safety planning is targeted to different actors involved in water reclamation and reuse representing a tool for the generation of an enabling environment that guarantees an adequate management of the sanitation system. Main actors to be involved in a Sanitation Safety Plan implementation include:

- local authorities (e.g. as a tool for planning investment in sanitation);

- wastewater utility managers (e.g. to assist in managing effluent quality and safeguarding public and occupational health from source to end use or disposal);
- sanitation enterprises and farmers (e.g. to complement quality assurance procedures for safety of end products, workers, local communities, and consumers or users of the product);
- Community based organizations, farmers associations and NGOs (e.g. to support community based water and sanitation programs in safe use of human wastes).

Stages for implementation of a sanitation safety plan

Sanitation safety planning can be used both at the planning stage for new schemes, and to improve the performance of existing systems. In either case it represents a continuous and iterative preventive health assessment management tool involving the stages described below and summarized in Figure 7.

Figure 7. Stages in the preparation of a Sanitation Safety plan

4.1 Sanitation Safety Plan preparation

Preparing for the SSP process requires the following stages.

- *Establish priority areas or activities*

The different stages of the sanitation safety planning can be applied as tool for management of water reclamation and reuse at different levels;

- Authorities can employ SSP in order to plan investments or set control procedures in the specific area-region in which they are responsible of assuring public health and water resource security
- Water management companies and utilities as a preventive control tool to operate the water reclamation process, protect health from the personnel involved in the

operations and produce the water quality levels that can guarantee safe application of reclaimed water for the users.

- Users of reclaimed water such as farmers, municipalities, industrial users... etc. can employ SSP to assure a safe use of reclaimed water.

Depending on the objectives and system boundaries (point 1.2 and 1.3), the definition of the priority areas or activities might include one or several of the abovementioned levels.

In the following subsections the stages of the SSP implementation describe the priority areas and activities corresponding to the responsibilities of a water management company management of a water reclamation system.

- *Set objectives*

Objectives for Sanitation Safety planning for water reclamation systems might include the following

- Protect health of the personnel responsible for the production and supply in the chain of wastewater treatment and water reclamation and supply
- Protect health of the users exposed to reclaimed water including for instance industry operators, farmers and general public.
- Achieve water quality requirements according to existing legislation of water reuse. To establish controls and recommendation in order to improve the reclaimed water supply service in terms of water quality limits set by the existing regulation (RD1620/2007).
- To assist in the periodization of the investments to be done in the wastewater treatment and reclamation plant.

- *Define the system boundary and lead organization*

The scope of a Sanitation Safety Plan in the case of a water reclamation systems for a water management company and operator would consider the following boundary system:

- Primary treatment and biological wastewater treatment
- Regeneration process of biological treated effluents
- Distribution of reclaimed water from the production point in the water reclamation plant to the point of use.

- *Assemble the team*

In order to complete the SSP preparation, the main actors involved production, supply and use of reclaimed must be taken into account in order to assemble a SSP team. The aim of the SSP team is to manage the water reclamation process and procedures and their members are assigned specific roles and responsibilities. In order to achieve a better governance of the water reclamation system, the SSP includes not only members of the water management company or

operator but also local authorities and reclaimed water users. An example of list SSP team with their corresponding role is provided in the following table.

Table 12. Sanitation Safety Planning team and roles

SSP team	Role in the SSP
Wastewater-water reclamation plant manager	Team LEADER
Wastewater water reclamation operation manager-Operational Manager	Manger of WWTP and WRP operation and water quality analysis
Local authority representative responsible for effluent discharge monitoring and	Expert in water quality
Local authority representative that provides concession for operation of reclamation	Admisntrations and maintenance of reclamation plant assets/investments. Assurance of water
User 1-Farmers/agricultural community representative	Responsible for control/monitoring of use of reclaimed water during agricultural reuse
User 2-Municipality representative	Responsible for control/monitoring of use of reclaimed water during urban reuse
User 3- Industrial association representative	Responsible for control/monitoring of use of reclaimed water during industrial
Health and safety advisor representative of water management utility	Prevention and risk assessment for operators of wastewater treatment and reclamation plant
University representative	Addition studies risk assessment

4.2 Description of the sanitation system

The description of the sanitation system provides information to allow the SSP team to identify where the system is vulnerable to hazards and hazardous events, and to validate the effectiveness of any existing control measures and the system performance. The description of the Water Reclamation System should include the following:

- *Map de system:*

Conceptual maps with the treatment schemes of the water reclamation system including every aspect within the system boundaries set during the preparation and definition of the SSP needs to be addressed. This mapping should be populated information regarding the characteristics of the reclamation system as well as the water and sludge streams inlet and outlet to each of the stages considered.

- *Identify potential exposure groups:*

The description of the sanitation system also involves the identification of the exposure groups and of the hazards to which each of them is exposed along the chain of water reclamation, supply and use. Main exposure groups, which can be included in the system map may include:

- Workers: Persons who are responsible for maintaining cleaning and operating the wastewater treatment and reclamation technology.
- Farmers: Persons who are using the products
- Local community: Anyone who is living near to or downstream form the sanitation technology on which the water or sludge is reused, and that might be passively affected.
- Consumers: Anyone who consumes or uses products that are produced with the reused water or sludge.

- *Characterize waste fractions*

An inventory of the different streams including water to be reused, by products generated form the biological sludge treatment as well as form chemical usage has to be developed and the characteristics of each of these streams in terms of quantity and quality specified in order to quantify risks associated to the use and disposal of each of them.

- *Gather compliance and contextual information*

In order to have an global overview of the impact of water reuse it is necessary gather compliance and contextual information related to the legal requirements, potential health risks, the characteristics of the population exposed to reclaimed water and other environmental aspects. In the following table the sources of information and a summary of the relevant aspects in the case of water reclamation and reuse are summarized

Table 13. List of preliminary information to be collected for SSP implementation.

Source of information	Summary of the key aspects
Legal requirements and standards	
RD 1620/2007	Water quality requirements according to its final use.
Concession case file of the administration	Legal requirement that defines the conditions set by the administration
Effluent discharge to sensible areas and restriction on crops	RD 817/2015 on EQS
Regulations related to agricultural products	
Emergency plans	

Regulations related to monitoring, supervision and audit of the wastewater treatment and	ISO 9001
Information related to the management and performance of the reclamation system	
WWTP effluents quality and reclaimed water quality	Control plan and monitoring of the RD1620/2007
Studies of health authority regarding the use of reclaimed water	
Monitoring of deviations from baseline treatment performance and water quality	
Reclaimed water demand: seasonal use	
Population of the areas in which reclaimed water is reused and activities producing	
Variability of the influent load quantity and quality to the WWTP	
Seasonal variability in quantity and quality due to seasonal use of water in agriculture	
Impact of peak flows due to extreme rainfall events in the treatment performance	

- *Validate the system description*

Evidence should be provided in order to verify that the information produced during the development of the definition of the water reclamation system is complete and accurate. . This should be validate by the SSP team and should focus on the preliminary evaluation of exposure groups, water and waste health risk potential and WWTP-WRP treatment performance.

4.3 Identify hazardous events, asses existing control measures and exposure risks

Hazardous events in a water reclamation system can be related to different levels:

- Risk associated to infrastructures: risk related to the wear out of equipment-buildings of a water reclamation plant or distribution system (pipes, holding tanks).
- Risk associate to the work place: which can cause diseases due to exposure through ingestion, direct contact or inhalation of reclaimed water of workers in reclaimed water production facilities or for workers that use reclaimed water in industries or crop irrigation. In fact workers of the WWTP are the exposure groups which have a higher risk as they are very often exposed to contact with wastewater and treated effluents. Procedures for reducing risks often involve analysis of the workplace operations and the use of safety equipment that reduces the chances of getting in contact with pathogens.
- Risks associated to the sanitary and environmental safety: which are related to the quality of reclaimed water.

The methodology described below, focuses on the evaluation of the risks related to the quality of reclaimed water, which can be classified according to the limits set by the existing legislation or recommendation by health authorities:

- Wastewater sanitation risks: (discharge limits of a WWTP)
- Reclaimed water sanitation risks (chemical and microbiological risks according to the RD1620/2007
- Environmental risks (Environmental quality standards WFD and RD817/2015)
- Use specific risks case specific
    - Crop irrigation: Metals accumulated in soil RD
    - Environmental reuse-indirect potable reuse and injection in the aquifer: in situation in which aquifers are close to potable water treatment sources existing legislation on water quality for potable use of water should be taken into account.

One of the main differences between sanitation safety plans which apply to reuse of water with the Water Safety Plans which apply to potable water treatment is that in the latter the risk is evaluated by comparison to the existing legislation for potable water, and therefore only one exposure group and route is considered (drinking water). In opposition in the sanitation safety plans, given that different water quality applies for several uses the risk assessment contemplates different exposure groups which might make a different use of the wastewater.

In practice whenever reclaimed water is used for different purposes the risk assessment should consider the most restrictive use in terms of water quality limits. The risk assessment methodology starts with an analysis of historical data from all the streams and stages of the WWTP and WRP as well as form the distribution network and supply point which had been previously mapped in the description of the reclamation system (sanitation system).

From the first analysis of the historical data a semiquantitaive matrix with risks of each of the streams and stages is identified and those points that pose a significant risk are identified.

Although physicochemical and microbiological risks parameters are identified in the existing legislation it is convenient to analyze additional water quality parameters in order to identify additional risks which are not included in the legislation or water reuse guidelines.

It is also important to consider, in addition to the treatment performance of the different stages, which result in a reduction of associated risk, the risk introduced by the process itself. For instance in the case of a water reclamation system such as Treatment 2 consisting in coagulation-flocculation treatment with settling followed by conventional sand filtration and UV-hypochlorite disinfection the following considerations can be taken into account.

- The coagulation/flocculation process is carried out by adding iron and aluminum salts and also organic polyelectrolytes which are commonly inert at the concentrations applied, but which can exceed limit concentrations if they are not adequately doses.

- In the disinfection stage consisting in UV dosing does not contribute to increase risks as no chemicals are added to the treatment.

- In the disinfection stage with chlorination, the reaction of Chlorine with organic matter can generate disinfection by-products such as trihalomethanes. Although the Spanish legislation for water reuse does not consider this group of compounds for the different uses, the generation of these compounds together with residual chlorine concentrations need to be addressed especially for urban and environmental applications to sources of potable water treatment (indirect reuse)

<u>Hazard Analysis Critical Control Points applied to water reclamation</u>

A schematic representation of the procedures required to conduct the risk assessment in the sanitation safety plans is detailed in Figure 8.

The risk evaluation of the treatment scheme form the historical performance data in order to identify whether additional stages are required to obtain the water quality of reclaimed water. This first stage involves

- Hazard analysis, including all those physical, chemical or microbiological analyses that can pose a risk to the health of operators and users through the use of reclaimed water as well as those that can have a negative impact on the environment.
- Definition of the preventive control plans, using wherever possible online monitors as well as critical and alert limits, that can assist operators in the decision making process for the management and control of the risk.

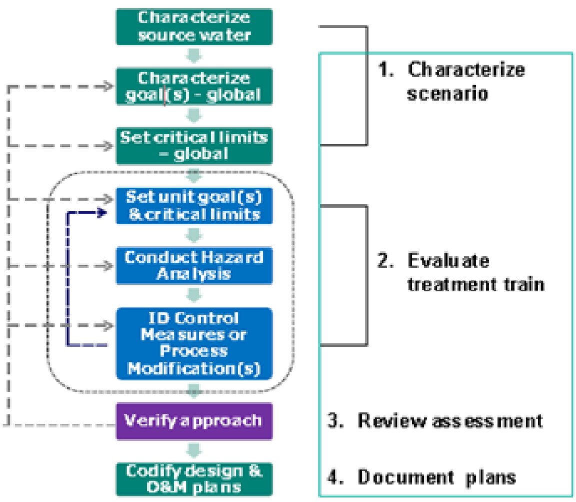

Figure 8 Stepwise approach for identifying evaluating and addressing risks in SSP

In order to conduct the risk evaluation and implement preventive control plans and operations, the methodology followed by the Sanitation Safety Plans, consists in the Hazard Analysis Critical Control Points (HAPPCC) which is described below:

From the point of view of preventive risk management, a risk is defined as any physical-chemical or microbiological parameters that can pose a risk for the operators, users or the environment. The risks are quantified taking into account the following factors

- **The probability** of the presence or detection of a specific risk. The probability is determined according to the occurrence of a risk in a specified timeframe from the analysis of the historical data and on the evaluation of the expected occurrence in the future. According to these criteria the probability of a hazard to be present is quantified in a scale that goes from 1 to 5, being one an very unlikely event and 5 an almost certain event (Table 14).

- **The severity** of the hazard on human health or on the environment, which reflect the impact or the effect of the hazard. In practice the level of severity associated to a hazard is quantified by comparing physical, chemical or microbiological parameter of the reuse legislation (for the most restrictive use of a given stream) with the limit value set by the regulation. Below the limit set by the regulation the severity would be low and above the limit set by the regulation the severity would depend on the concentration and know effects after exposure to the hazard. Based on the above mentioned criteria, the severity of a hazard is quantified in a scale ranging from 1 when the effect is insignificant to 10 when the effect is can cause severe injuries for health or the environment. (Table 14).

Table 14. Probability and severity ranking definition of SSP for risk assessment evaluation

Probability		
1	Very unlikely	Has not happened in the past and it is highly improbable it will happen in the next 12 months (or another reasonable period).
2	unlikely	Has not happened in the past but may occur in exceptional circumstances in the next 12 months (or another reasonable period).
3	possible	May have happened in the past and/or may occur under regular circumstances in the next 12 months (or another reasonable period).
4	Very likely	Has been observed in the past and/or is likely to occur in the next 12 months (or another reasonable period).
5	Almost certain	Has often been observed in the past and/or will almost certainly occur in most circumstances in the next 12 months (or another reasonable period).
Severity		
1	Insignificant	Hazard or hazardous event resulting in no or negligible health effects compared to background levels.
2	Minor	Hazard or hazardous event potentially resulting in minor health effects (e.g. temporary symptoms like irritation, nausea, and headache).
4	Moderate	Hazard or hazardous event potentially resulting in a self-limiting health effects or minor illness (e.g. acute diarrhoea, vomiting, upper respiratory tract infection, minor trauma).
8	Major	Hazard or hazardous event potentially resulting in illness or injury (e.g. malaria, schistosomiasis, food-borne trematodiases, chronic diarrhea, chronic respiratory problems, neurological disorders, bone fracture); and/or may lead to legal complaints and concern; and/or major regulatory non-compliance.
16	Catastrophic	Hazard or hazardous event potentially resulting in serious illness or injury, or even loss of life (e.g. severe poisoning, loss of extremities, severe burns, , drowning); and/or will lead to major investigation by regulator with prosecution likely.

The risk is defined as the product of Probability and Severity which allows to quantify the risk in a semiquantitaive matrix (Table 15) from 1 to 80. Risk values below 10 are considered low, while risk values exceeding 32 are considered very high. For risk values above 10 (moderate risks) preventive action plans are required to be developed for that specific risks.

Table 15. Semiquantitaive Risk evaluation matrix employed in SSP

		SEVERITY (S)				
		Insignificant	Minor	Moderate	Major	Catastrophic
PROBABILITY (PR)		1	2	4	8	16
Very unlikely	1	1	4	4	8	16
Unlikely	2	2	4	8	16	32
Possible	3	3	6	12	24	48
Very likely	4	4	8	16	32	64
Almost certain	5	5	10	20	40	80
Risk score R=(PR) X (S)		<10		10-20	20-32	>32
Risk Level		Low risk		Medium	High risk	Very high risk

Depending on the risk value obtained from semiquantitaive evaluation the preventive control plans will involve treating the risks as Critical Control Points, Operative pre-requirement or Program pre-requirement. These different levels of controlling the risks are summarized below:

Program pre-requirement (PPR)

The program pre-requirements gathers all the basic activities that are required in order to maintain all the stages of the supply and distribution of reclaimed water in a hygienic environment to consider the installation as safe for health.

The program pre-requirements might include activities such as:

- Systematic cleaning programs of tanks and equipment.
- Periodical control of Chemicals and materials.
- Systematic verification/*calibration of equipment 8 pumps, blowers, compressors, electrical equipment, online monitors of water quality)
- Design/adaptation of sites for adequate operation:
- Installation of fences and alarms for the access to deposits and holding tanks outside the premises of the production site (distribution holding and chlorination tanks), installation of covers in tanks to avoid contamination, installation of appropriate ventilation
- Operators training program
- Analytical control program

Non critical Control Point or operational control point program (PPR op)

The PPRop is a requirement identified by the risk assessment analysis as necessary to control the probability of introducing risk, but it is not considered as critical.

Critical Control Point (CCP)

Point in the Water Reclamation System in which the application of a control plan is essential in order to prevent or reduce the risk to a level that is considered innocuous or acceptable.

The control plans can be implemented as a **PPR, PPR op or CCP**. However in order to classify the preventive measures according to these different levels a decision tree such the one depicted in Figure 9 which is based JRC Report published by the European Commission in 2014.

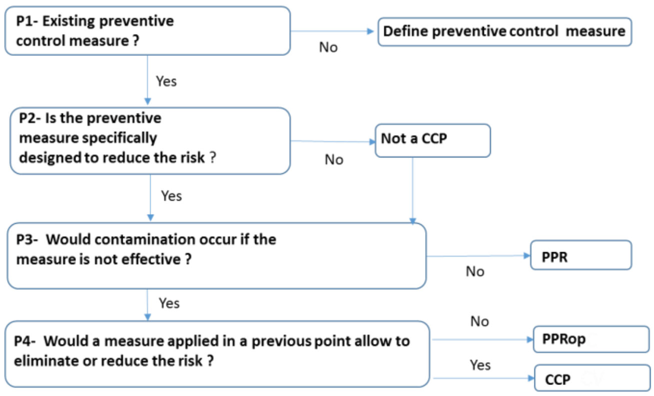

Figure 9. Decision tree employed for classification of critical control points (adapted from Joint Research Council Report -2014)

Once the **CCP**.have been identified in the reclamation system it is necessary to define one a several control parameters as well as the critical and alert levels. In case the critical or alert levels are exceeded, corrective actions must be established in each case, responsible for implementation designated and the monitoring procedure established.

4.4 Development of incremental improvement plan

In order to continuously improve the management of the reclamation process it is important to generate data bases with the historical data of each stage of the process in order to identify deviations from the treatment performance and anticipate to situations that can lead to non-acceptable risk. An incremental improvement plan consist in the following:

- Consider options to control each identified risks: the SSP should consider both short and long term plans as well as a range of locations for the control points along the sanitation system.
- Use selected options to develop an incremental improvement plan:
- Implement the improvement plan by the responsible designated by the SSP team

The fast and safe implementation of preventive actions in response to incidents, is better supported by online monitoring systems of the control parameters. Data sets obtained on the in real time monitoring favors a more accurate decision making process which responds more to the real behavior of the process. Most commonly implemented online monitors for the control of water reclamation process are:

- Conductivity
- Turbidity
- Chlorine
- UV intensity.

Although the chemical quality of reclaimed water is considered as the main feature that determines environmental risks, microbiological hazards are the priority for sanitary authorities in the case of reclamation of biological treated effluents given their higher severity.

For this reason incremental improvement plan applied to water reclamation should be focused in first instance on the implementation of the disinfection of treated effluent through the optimization of disinfection systems or the consideration of alternative ones, such as the use Chlorination followed by UV (instead of UV and chlorination) or Advanced oxidation processes such as peroxide/ozone followed by UV, which have been tested in the aWARE project for Baix Llobregat WRP effluents.

The use of advanced monitors for microbiological parameters also represents a field of future development for a better management of the risks in reclamation systems, which can further contribute to boost water reuse practices. Online monitors for detection of E.*coli*, spores, protozoa and cysts which can provide results of these parameters within a minute are currently commercially available and would require validation

- **Monitor control measures and verify performance**

Sanitation Safety plans are continuous, dynamic and iterative approaches in which a monitoring plan that regularly check that the system is operating as expected and defines the actions to implement whenever deviations are detected.

Verification of the implementation of the corrective action and the resulting performance provides assurance to the operators, authorities and users of reclaimed water that the system is managed adequately.

- **Monitor control measures**

The risk assessment and control measures efficiency must be verified periodically, not only to verify that the reclamation system is producing effluent qualities according to the existing legislation but also in order to evaluate the behavior and trends of the different stages of reclamation and reuse chain on the long term. The system verification is focused mainly on the critical control points by monitoring the control parameters which are define for instance as a minimum percentage of the legal requirement. Direct verification of the risk quantified through the semiquantitaive matrix (Table 15) and the routine analysis can also be employed as an indicator. Besides the indicators defined by the SSP team, internal analytical control plans, conditions established for the administrative concession of water reclamation and reuse by the authorities, monitoring of quality and operational parameters not established in the legislation and the control plans established in the water reuse legislation can also be integrated into the monitoring plans of the Sanitation System.

- **Audit system**

An audit system is required in order to assure that the SSP contributes to the improvement of the system hygienic environment and safety by checking the quality and effectiveness of its implementation. The audits enable a better implementation of the SSP by identifying areas of improvement. Audit systems for water reclamation systems can include the ISO standards.

4.5 Developing supporting programme and review plan

The capacity of achieving the goals set by a SSP is supported by the development of the skills and knowledge of the SSP team members. Therefore in order to improve SSP outputs and update the SSP methodologies to adapt to internal and external changes, supporting programme and periodical review of SSP are required.

- **Development of supporting programmes**

The supporting programme are a group of activities that indirectly support health safety, and are also necessary for the correct implementation of the control plans. Communication of health and safety with the main stakeholders and users of reclaimed water is a key aspect of the support programme. Communication activities as well as research project are amongst some of the supporting programme methods (Table 16).

Management of SSP methodology through the supporting programme consist in written procedures that describe the operation of the plant in standard conditions and the corrective measures to be implemented in case the control parameters are exceeded. Emergency plans can for unexpected failures should also be included in the SSP description.

Table 16. Examples of supporting programmes for SSP

Supporting programmes
Training programs for operators, industrial and agricultural users.
Presentation of the outputs achieved to the general public and main stakeholders
Incentives to the exposure groups for adapting their operations in order to achieve the
Provision of incentives and fines related to the fulfilment of requirements
Periodical maintenance program
Public awareness communication programme
Research programme for supporting key knowledge gaps
Management tools as system of quality assurance
Engagement of stakeholders in the SSP development co-creation

- **Review and update of SSP**

In order to adapt the SSP to internal and external changes the SSP must be periodically reviewed and updated. The review of the SSP must take into account the indicators set, the improvements achieved, changes in the operational conditions and any new sanitary risk related to the water reclamation system. In addition the review of the SSP must be updated if any the following situations occur:

- After an incident, emergency of limit situation
- After significant changes or improvements in the reclamation system.
- After an audit or external evaluation that involve major changes /improvements in the reclamation system.

5. References

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