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Water Reuse in Europe

Relevant guidelines, needs for and barriers to innovation

A synoptic overview

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Abstract

Following the identification of the need to find innovative solutions to water challenges in the urban, industrial and agriculture contexts, an EU regulatory instrument for water reuse has to be developed by 2015. Despite the water reuse applications already developed in many countries, there are still a number of barriers which prevent the widespread implementation of water reuse around Europe and on a global scale. These barriers will have to be overcome. The scope of this JRC Science and Policy Report is to analyse the technical, environmental and socioeconomic challenges of related to water reuse as an innovation option. It presents and compares the most relevant national and international guidelines on water reuse, and evaluates existing water reuse standards in EU Member States.
Furthermore, the report presents a risk-based management approach for wastewater reuse and identifies needs for technological and regulatory innovation as well as barriers to overcome.

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List of Abbreviations and Symbols

Throughout this report the following abbreviations and symbols are used:

AGWR	Australian Guidelines for Water Recycling
AHMC	Australian Health Ministers Conference
BAT	Best Available Technique
BOD	biochemical oxygen demand
CIS	Common Implementation Strategy
DALY	disability adjusted life year
DSS	Decision Support System
EC	European Commission
EEA	European Environment Agency
EIPW	European Innovation Partnership on Water
EPHC	Environment Protection and Heritage Council
EU	European Union
GWI	Global Water Intelligence
GWRC	Global Water Research Coalition
HAAS	haloacetic acid
HACCP	Hazard Analysis and Critical Control Points
IED	Industrial Emissions Directive
IPPC	Integrated Pollution and Prevention Control
JRC	Joint Research Centre
MS	Member States
MTBE	methyl tertiary butyl ether
ND	Nitrates Directive
NDMA	N-nitrosodimethylamine
NHMRC	National Health and Medical Research Council
NRMMC	Natural Resource Management Ministerial Council
PFC	perfluorochemical
PPPD	Plant Protection Products Directive
QMRA	Quantitative Microbial Risk Assessment
SAR	Sodium Adsorption Ratio
SPUB	Singapore Public Utilities Board
THM	trihalomethane
TOC	total organic carbon
USEPA	United States Environmental Protection Agency
UWWTD	Urban Wastewater Treatment Directive
WERF	Water Environment Research Foundation
WFD	Water Framework Directive
WHO	World Health Organization
WRP	Water Reclamation Plant
WRSP	Water Reuse Safety Plan
WSP	Water Safety Plan
WWTP	Wastewater Treatment Plant

Chemical elements are identified by their respective symbol as set by the International Union of Pure and Applied Chemistry (IUPAC)

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1 Introduction

With an ageing population and strong competitive pressures from globalisation, Europe's future economic growth and employment will increasingly have to come from innovation in products, services and business models. This is why innovation has been placed at the heart of the Europe 2020 strategy for growth and jobs (COM(2010) 2020). With over thirty action points, the Innovation Union aims to improve conditions and access to finance for research and innovation in Europe, to ensure that innovative ideas can be turned into products and services that create growth and jobs.

Within this setting, eco-industries play a crucial role. Consequently, a key objective of EU policies is to identify and address market failures and regulatory barriers that hinder the competitiveness of environmental industries and influence the uptake of more sustainable solutions by other industries. The European Commission’s Action Plan on Sustainable Consumption and Production and Sustainable Industrial Policy also reflects this. A first step in the process of developing policy initiatives for environmental industries consists of carrying out an analysis of the competitiveness of environmental industries in Europe, with a view to identifying areas for future policy initiatives. Analysing which key factors influence the competitiveness of these industries is of utmost importance. All enterprises, including service enterprises, that have energy and environment issues as their core source of income are considered to be part of the eco-industry.

The water sector is a large and key component of the European eco-industrial landscape. Some figures may illustrate this. The world water market is growing rapidly, and is estimated to reach 1 trillion Euros by 2020. European water-related sectors operate worldwide in developing innovative water solutions, but often fail to reach their full economic potential. Eliminating the obstacles to market breakthroughs and promoting Europe's comparative advantages in the innovation value chain will help companies bring their solutions to the market. Unlocking the potential for innovation in the field of water management could significantly contribute to job creation and competitiveness: a 1% increase of the rate of growth of the water industry in Europe could create up to 20,000 new jobs.

To unlock the full potential of the European water sector, the European Commission proposed a European Innovation Partnership (EIP) on Water was proposed (COM(2012) 216) (Figure 1). The EIP Water aims to remove barriers to innovation, link supply and demand for water-related innovations, create dissemination strategies for proven solutions, and support the market acceleration of related innovations. It is linked to the Europe 2020 Resource-efficient Europe flagship initiative (COM(2011) 21), which underlines the importance of the sustainable management of water.

The EIP Water will build on the Eco-Innovation Action Plan, which focuses on boosting innovations that reduce pressure on the environment, and on bridging the gap between innovation and the market. Innovation is also identified as a key tool to support the policy options developed by the “Blueprint to Safeguard Europe's Water Resources” – the EU’s response to the vulnerability of the water environment – adopted by the European Commission in November 2012 (COM(2012) 673).

Water reuse and recycling has been identified as one of the five top priorities of the EIP Water. Furthermore, the Impact Assessment of the “Blueprint to Safeguard Europe's Water Resources” makes it clear that maximisation of water reuse is a specific objective, with a proposal for the development of a regulatory instrument for water reuse by 2015.

This report aims to highlight the current state of play in water reuse practices in the EU. Given that, at the European level, there were no formal definitions or guidelines to address the issue of treated wastewater reuse, the report compares relevant national and international guidelines and highlights needs for, and barriers to, innovation.

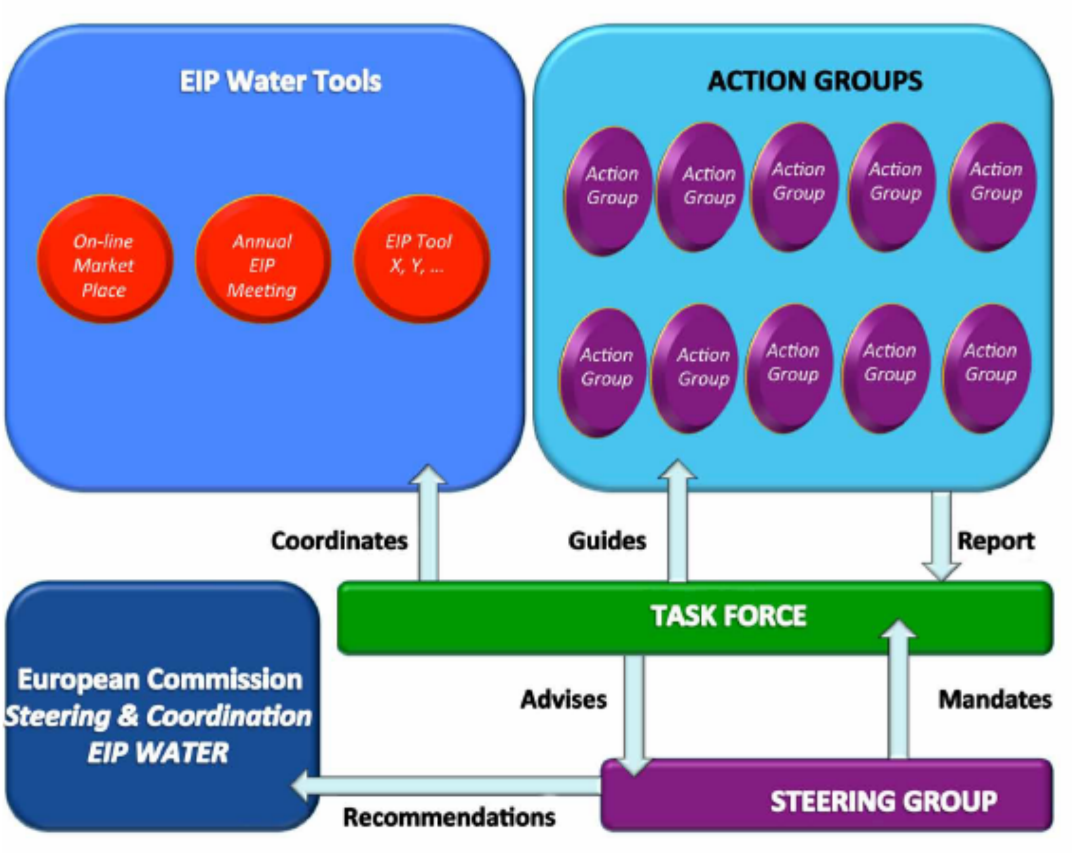

Figure 1 - Governance structure of the European Innovation Partnership on Water.

2 Background on water reuse

Pressures from climate change, drought and urban development have put a significant strain on freshwater supplies. The World Health Organization has recognised the principal driving forces for global wastewater reuse as

- increasing water scarcity and stress,
- increasing populations and related food security issues,
- increasing environmental pollution from improper wastewater disposal, and
- an increasing recognition of the resource value of wastewater, excreta and greywater (WHO, 2006).

Europe's water resources are coming increasingly under stress, leading to water scarcity and quality deterioration. This stress is characterised by a mismatch of the demand for, and availability of, water resources across time and geographical space (COM(2007) 414).

The world's population is becoming increasingly urbanised and concentrated near coastlines, where local freshwater supplies are limited or are available only at great expense. In addition to the need to meet the increasing demands for drinking water supply and other urban demands (e.g. landscape irrigation, commercial, and industrial needs), there is also increased demand for water for agricultural food production due to the greater incorporation of animal and dairy products into people's diets.

Water scarcity and droughts, which are increasingly frequent and widespread across Europe, have become a major challenge. At least 11% of the European population and 17% of its territory have been affected by water scarcity to date. An indicator of water scarcity, the Water Exploitation Index (WEI), provides the broadest depiction of water use compared to general availability, and describes the risk posed by over exploitation (Figure 2).

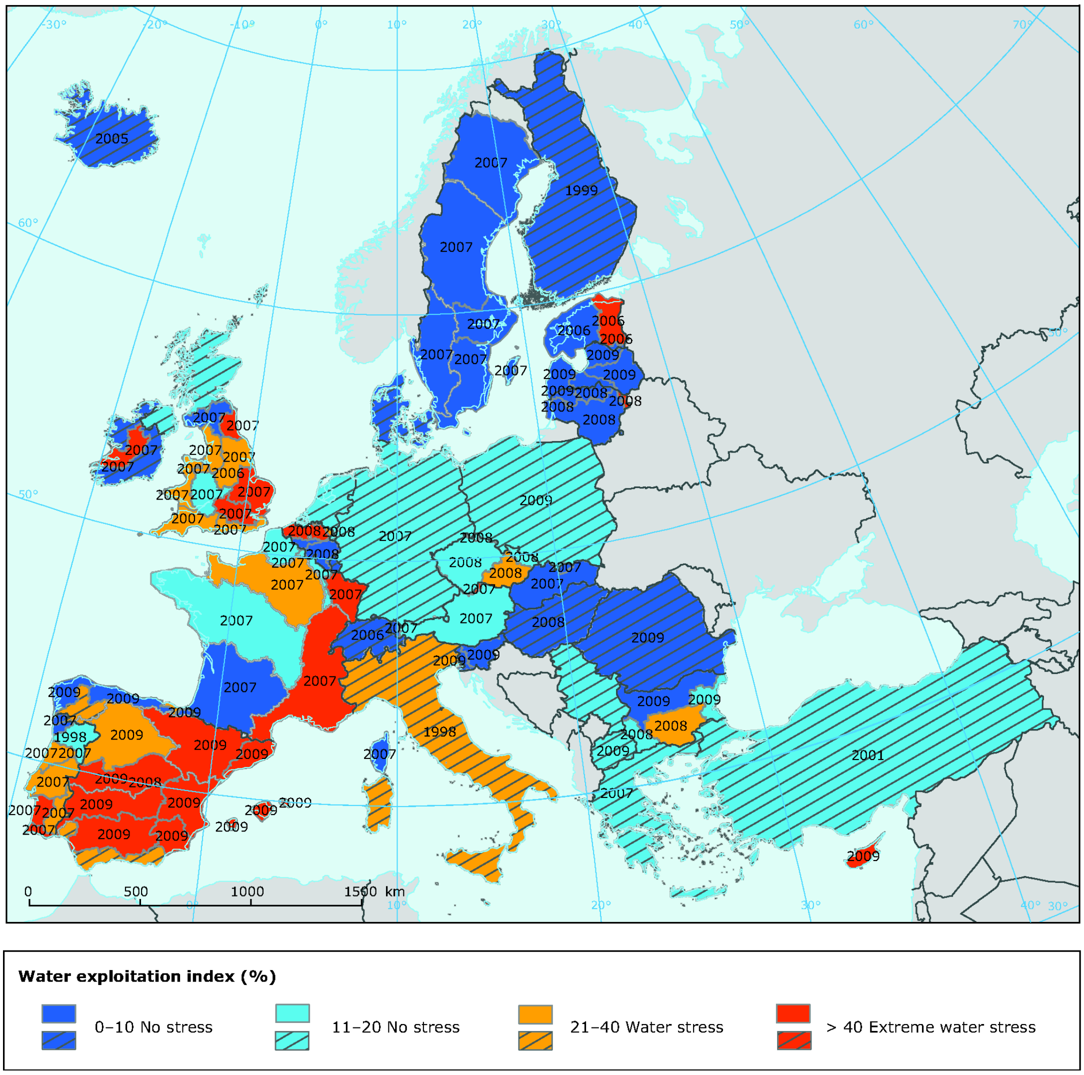

Figure 2 - Water Exploitation Index in Europe in the smallest available data disaggregation (EEA, 2012).

Even if a country has sufficient water resources at the national level, there may be water stress in dry regions or around large cities. Drought occurrence has increased not only in southern and central Europe, but also in northern and Eastern Europe (EEA, 2012). Global climate change is already exacerbating these problems, with projections indicating significant and widespread impacts over the medium to long term (EEA, 2012).

Water scarcity is reported in nearly all river basin districts in the Mediterranean area. In two out of three groundwater bodies reported as not being in good quantitative status, abstraction is mentioned as a significant pressure. Poor or unsuitable water quality often further reduces availability, restricts use, and increases the costs of supply.

EU water policy has contributed to water protection over the past three decades. In 2000, the EU Water Framework Directive (WFD) (2000/60/EC) comprehensively addressed all the challenges faced by EU waters, making it clear that water management is much more than just water distribution and treatment. It involves land-use and management that affect both water quality and quantity (COM(2012) 673).

The EU addressed significant pollution in the aquatic environment by passing several pieces of legislation, including the Urban Waste Water Treatment Directive (UWWTD), the Nitrates Directive (ND), the Plant Protection Products Directive (PPPD), the Integrated Pollution Prevention and Control Directive (IPPCD), and the Industrial Emissions Directive (IED). These Directives protect water resources from pollution by nutrients and/or other chemicals from agriculture, households and industry.

Although the implementation of these Directives has progressed significantly, full compliance has not yet been reached, and this prevents the achievement of their environmental objectives. Diffuse and point-source pollution still put significant pressures on the water environment in about 38% and 22% of EU water bodies respectively. Eutrophication due to excessive nutrient loads remains a major threat to the good status of waters, as nutrient enrichment is found in about 30% of water bodies in 17 Member States (COM(2012) 673).

These developments will inevitably lead to growing competition between different water use sectors, with high quality resources being protected and reserved for drinking water production.

3 Water reuse as a strategic option

The pressures on water resources have encouraged more active consideration of using alternative water sources as a strategic option to supplement water supplies and protect natural resources. In its "Blueprint to Safeguard Europe's Water Resources", the Commission explicitly highlights the need to find solutions to water challenges in the urban, industrial and agriculture contexts. The recently launched European Innovation Partnerships on Water and on Agricultural Productivity and Sustainability aim to achieve challenging environmental objectives while creating market opportunities. There is a rapidly growing global water market, which is estimated to reach 1 trillion Euros by 2020. A 1% increase in the rate of growth of the water industry in Europe could create between 10 000 and 20 000 new jobs. By seizing new and significant market opportunities, Europe can increasingly become a global market leader in water-related innovation and technology. The European Innovation Partnerships will try to facilitate links between the supply and demand of innovative solutions and disseminate tested solutions, e.g. through the creation of an electronic 'marketplace' and the setting-up of specific networks (COM(2012) 673).

The potential role of water reuse in such a strategy is now well recognised and embedded within European and national policy communities. Water reuse is the top-listed priority area in the Strategic Implementation Plan of the European Innovation Partnership on Water (EIPW, 2012), and maximisation of water reuse is a specific objective of the aforementioned European Blueprint for Water (COM(2012) 673). In addition, the recently established work programme of the Common Implementation Strategy of the Water Framework Directive 2013-2015 calls for a Commission proposal on water reuse.

Water reuse, as an alternative water source, can provide significant economic, social and environmental benefits, which are key motivators for implementing such reuse programmes. These benefits include:

- Increased water availability
- Integrated and sustainable use of water resources

- Drinking water substitution – keep drinking water for drinking and reclaimed water for non-drinking use
- Reduced over-abstraction of surface and groundwater
- Reduced energy consumption compared to using deep groundwater resources, water importation or desalination
- Reduced nutrient loads to receiving waters
- Reduced manufacturing costs of using high quality reclaimed water
- Increased agricultural production
- Reduced application of fertilisers
- Enhanced environmental protection by restoration of streams, wetlands and ponds
- Increased employment and local economy (e.g. tourism, agriculture)

The report on water reuse by the Water supply and sanitation Technology Platform (WssTP, 2013) notes that "Although investors and water utilities are becoming increasingly enthusiastic about water reuse … the capability of Europe's water sector to deliver reuse projects is being compromised by a lack of suitable regulation, skills and public understanding". This report also notes that "with appropriate investment in people, knowledge, and technology, Europe could be a global leader in this rapidly developing market", and highlights the "huge eco-innovation potential in terms of technologies and services around water recycling in industry, agriculture and urban water systems".

Water reuse also contributes to achieving other European ambitions on, for example, a resource-efficient Europe (COM(2011) 21), highly resource-efficient cities & communities (Smart Cities, http://eu-smartcities.eu/), and global agendas such as the Water Environment Research Foundation (WERF) and the Global Water Research Coalition (GWRC) report, which call for more efforts to improve the perceived role of water reuse and the setting up of Associations and Institutes to promote water reuse (Linden et al., 2010; McClelland et al., 2012).

A substantial range of water reuse practices are already applied worldwide, many of these in Europe (Bixio and Wintgens, 2006; GWI, 2010), that bring about significant savings of drinking water (Table 1). Over 3 000 water reuse projects were assessed in a survey conducted a few years ago (Bixio et al., 2005), some of which were in an advanced planning phase. The majority of water recycling schemes are located in Japan (>1 800) and the USA (>800), followed by Australia (>450), Europe (>200), the Mediterranean and Middle East area (>100), Latin America (>50) and Sub-Saharan Africa (>20). Nowadays, this number is likely to be significantly higher given the rapid development of water reuse in China, India and the Middle East. Reclaimed water is primarily used for agricultural and urban irrigation.

The potential for replacing freshwater by water reuse was estimated to vary between 1-17% in European countries, with even higher levels of potential on local and regional scales (Hochstrat et al., 2006).

Table 1 - Main reclaimed water applications in the world (NRMMC-EPHC-AHMC, 2006; USEPA, 2012).

Categories of use	Uses
Urban uses	Irrigation of public parks, sporting facilities, private gardens, roadsides; Street cleaning; Fire protection systems; Vehicle washing; Toilet flushing; Air conditioners; Dust control

Categories of use	Uses
Agricultural uses	Food crops not commercially processed; Food crops commercially processed; Pasture for milking animals; Fodder; Fibre; Seed crops; Ornamental flowers; Orchards; Hydroponic culture; Aquaculture; Greenhouses; Viticulture
Industrial uses	Processing water; Cooling water; Recirculating cooling towers; Washdown water; Washing aggregate; Making concrete; Soil compaction; Dust control
Recreational uses	Golf course irrigation; Recreational impoundments with/without public access (e.g. fishing, boating, bathing); Aesthetic impoundments without public access; Snowmaking
Environmental uses	Aquifer recharge; Wetlands; Marshes; Stream augmentation; Wildlife habitat; Silviculture
Potable uses	Aquifer recharge for drinking water use; Augmentation of surface drinking water supplies; Treatment until drinking water quality

Figure 3 shows a model output for wastewater reuse potential of European countries with a project horizon of 2025. Spain shows by far the highest reuse potential, the calculations suggesting a value of over 1 200 Mm³/yr. Italy and Bulgaria both exhibit estimated reuse potentials of approximately 500 Mm³/yr. Wastewater reuse appraisals for Turkey amount to 287 Mm³/yr, whereas Germany and France could potentially reuse 144 and 112 Mm³/yr, respectively. Portugal and Greece account for reuse potentials of less than 100 Mm³/yr (67 and 57 Mm³/yr, respectively). Overall, the estimates suggest a wastewater reuse potential of 3 222 Mm³/yr (Hochstrat et al., 2005; TYPSA, 2013).

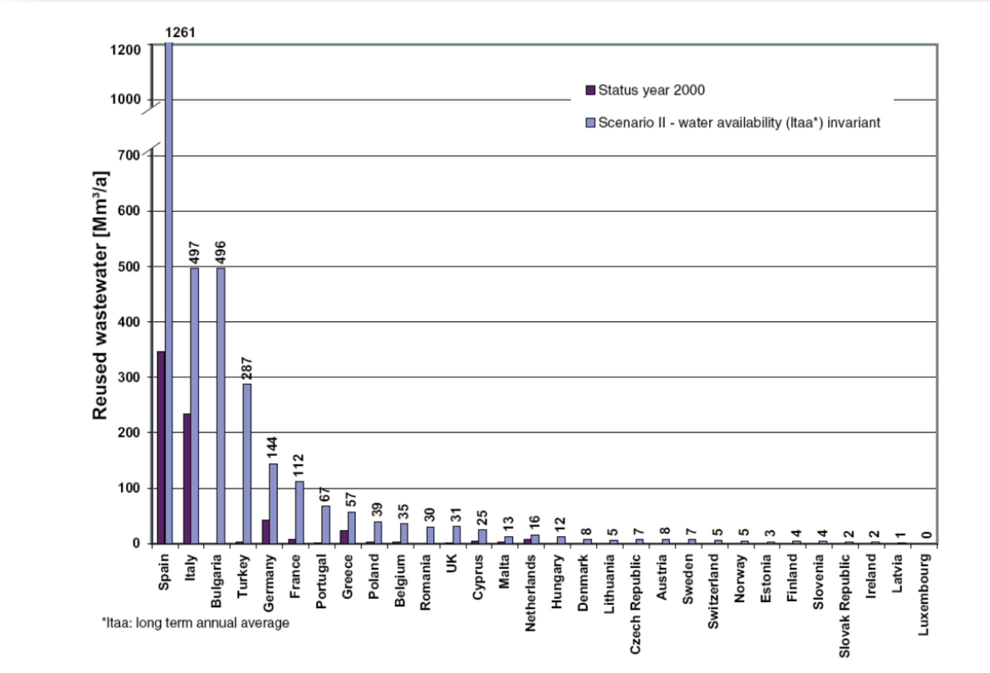

Figure 3 - Model output for wastewater reuse potential of European countries with a projection horizon 2025 (TYPSA, 2013).

4 Health and environmental risks of water reuse

Sources of reusable water may contain a wide array of hazards including microbial, chemical, physical and radiological agents that could pose a risk to human health and environmental matrices. For the implementation of water reuse practices, these risks must be managed and the public must be kept informed in a transparent and clear way. The latter is key to promoting public acceptance.

The most significant health and environmental hazards of using reclaimed water are due to pathogen microorganisms and chemical contaminants. Many microbial pathogens found in reclaimed water are enteric in origin (Table 2). The numbers of pathogens will vary depending on rates of illness in the humans and animals that contribute to faecal waste.

Chemical hazards also need to be considered, particularly when reclaimed water may be used in direct contact or ingested. In terms of environmental health, the most significant hazards of reclaimed water are chemical, such as boron, nitrogen, phosphorus, chloride and sodium, with special concern for the emerging pollutants (Table 3 and Table 4) or mixtures thereof.

Risk assessments conducted in advanced reclamation systems in Orange County (California) for drinking water, and simpler reclamation systems such as Berlin's aquifer recharge for water supply, showed that trace levels of pharmaceuticals pose no risk to human health (Rygaard et al., 2011). However, such risk assessments are still based on the effects of individual compounds, and recently there is increased focus on the cumulative risks of simultaneous exposure.

Although the chemical hazards of micropollutants such as pharmaceuticals, endocrine disruptors, pesticides, detergents and cosmetics are of increasing concern to the scientific community, their evaluation is beyond the scope of this document.

The risks of reclaimed water use are not yet well communicated to the public. It is crucial that science & technology, the public and government engage with each other and share information in order to reduce doubts regarding reclaimed water projects.

Table 2 - Main etiological agents potentially present in wastewater and their associated diseases (Rowe and Abdel-Magid (1995); Yates and Gerba (1998); Haas et al. (1999)).

Pathogen	Associated disease
Bacteria	
Campylobacter jejuni/coli	Gastroenteritis
Legionella spp	Respiratory disease
Salmonella typhi/paratyphi	Typhoid fever
Salmonella spp.	Gastroenteritis
Shigella spp.	Dysentery
Vibrio cholera	Cholera
Yersinia enterocolitica	Gastroenteritis
Virus	
Adenovirus (40 y 41)	Gastroenteritis
Agente Norwalk	Gastroenteritis
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis

Pathogen	Associated disease
Coxsackievirus	Meningitis
Echovirus	Meningitis
Hepatitis A virus (HAV)	Hepatitis
Hepatitis E virus (HEV)	Hepatitis
Rotavirus	Gastroenteritis
Protozoa	
Cryptosporidium parvum	Gastroenteritis
Entamoeba histolytica	Amebiasis
Giardia intestinalis	Gastroenteritis
Helminths	
Ascaris lumbricoides	Gastroenteritis
Taenia spp.	Taeniasis
Trichuris trichiura	Trichuriasis

Table 3 - Chemical stressors in reclaimed water and their adverse effects (USEPA, 2004; NRMMC-EPHC-AHMC, 2006).

Chemical agents	Adverse effects
Biodegradable organics such as proteins, carbohydrates	Eutrophication of surface water.
Oils, greases, cellulose, lignin…	Anoxic conditions in aquatic ecosystems.
Macronutrients (N, P, K)	Eutrophication of soils and surface water, plant toxicity, nutrient imbalance in plants, pest and disease in plants, loss of biodiversity.
Micronutrients (B, Ca, Cu, Fe, Mg, Na, Co, …)	Plant toxicity, accumulation in soils.
Metals (Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Zn, …)	Toxicity to plants and aquatic biota.
Inorganic salts (chlorides, sulphurs, nitrates, …)	Soil salinity due to a plant stressed from osmotic, soils contamination, increasing salinity of groundwater and surface water risk for human health (methemoglobinemia associated with nitrates).
Industrial chemicals (PFCs, MTBE, solvents, …)	Carcinogenic, teratogenic and/or mutagenic effects, risk for human health (cyanotoxins), bioaccumulation, toxicity to plants.
Pesticides, biocides and herbicides (e.g. atrazine, lindane, diuron, fipronil)	
Natural chemicals (hormones, phytoestrogens, geosmin, 2-methylisoborneol)	Various effects, often unexplored.

Table 4 - Selected categories of emerging pollutants in reclaimed water and their adverse effects (USEPA, 2004; NRMMC-EPHC-AHMC, 2006).

Chemical agents	Adverse effects
Pharmaceuticals and metabolites (antibacterials (sulfamethoxazole), analgesics (acetominophen, ibuprofen), beta-blockers (atenolol), antiepileptics (phenytoin, carbamazepine), veterinary and human antibiotics (azithromycin), oral contraceptives (ethinyl estradiol))	Carcinogenic, teratogenic and/or mutagenic effects, risk for human health (cyanotoxins), bioaccumulation, toxicity to plants. Various effects, often unexplored.
Personal care products (triclosan, sunscreen ingredients, fragrances, pigments)	
Household chemicals and food additives (sucralose, bisphenol A (BPA), dibutyl phthalate, alkylphenol polyethoxylates, flame retardants (perfluorooctanoic acid, perfluorooctane sulfonate)	
Transformation products (NDMA, HAAs, and THMs)	

The NEWater Visitor's Centre in Singapore and the Advanced Water Recycling Demonstration Plant (AWRDP) in Queensland, Australia are two initiatives that aim to convey information about water reclamation technologies to the public on two different scales. The AWRDP was a relatively small scheme with a full range of pilot-scale treatment units which have been used both for scientific investigations as well to explain treatment technologies to a broad public audience. The NEWater scheme is doing the same on a much larger scale with a permanent exhibition that includes displays and professional guidance on issues of integrated water resource management, and water recycling and treatment technologies. There are no similar initiatives in Europe that we are aware of, which shows the lack of public consultation in the water recycling sector in Europe (Hochstrat et al., 2006).

5 Guidelines and regulations for global water reuse

The need to minimise health and environmental risks of water reuse has led to the development of guidelines and regulations for the safe use of treated wastewater in an increasing number of countries.

Some international and national organisations have developed reference guidelines for water reuse applications, because a consistent approach to the management of health and environmental risks from water reuse requires high-level guidance based on a majority consensus (Table 5). Such guidance is provided in the form of a risk management framework for the beneficial and sustainable management of water reuse systems. Examples include guidance provided by international organisations such as the World Health Organization (WHO), and national organisations of federal governments such as the US Environmental Protection Agency (USEPA) and, in Australia, the Natural Resource Management Ministerial Council, the Environment Protection and Heritage Council, and the Australian Health Ministers Conference (NRMMC-EPHC-AHMC). These guidelines can be used by states that have limited, or no, regulations or guidelines.

Table 5 - Water reuse guidelines developed by international organisations

Organization	Guidelines	Comments
World Health Organization (WHO)	"Guidelines for the safe use of wastewater, excreta and greywater" (2006)	Volume 1: Policy and regulatory aspects. Volume 2: Wastewater use in agriculture. Volume 3: Wastewater and excreta use in aquaculture. Volume 4: Excreta and greywater use in agriculture.
United Nations Environment Programme (UNEP)	"Guidelines for municipal wastewater reuse in the Mediterranean region" (2005) "Development of performance indicators for the operation and maintenance of wastewater treatment plants and wastewater reuse" (2011)	
United Nations Water Decade Programme on Capacity Development (UNW-DPC)	Proceedings on the UN-Water project "Safe use of wastewater in agriculture" (2013)	
International Organization for Standardization (ISO)	ISO/TC282 Water reuse (under development)	The standardisation of water reuse of any kind and for any purpose. It covers both centralised and decentralised or on-site water reuse, direct and indirect reuse, as well as intentional and unintentional reuse. The scope of ISO/PC 253 (Treated wastewater reuse for irrigation) is merged into the proposed new committee. Excluded: the limit of allowable water quality in water reuse, which should be determined by governments, the WHO and other relevant competent organisations.
Food and Agriculture Organization (FAO)	"Water quality for agriculture" (1994)	

Generally, the guidelines available are very well structured and provide information on several aspects of water reuse practices. The WHO guidelines only refer to the safe use of wastewater in agriculture and aquaculture (WHO, 2006), but the USEPA and the Australian guidelines also consider several treated wastewater applications such as aquifer recharge and irrigation of golf courses (USEPA, 2012; NRMMC, 2006, 2008 and 2009). These guidelines include the following:

- *Water reuse applications:*

Specific categories of recommended use with the description of each type of use, such as urban reuse (restricted and non-restricted), agricultural reuse (food crops, non-food crops), aquifer recharge for drinking purposes, landscape irrigation, environmental enhancement, and other non-drinking uses.

- *Treatment processes:*

  Establishment of the required treatment methods for each use in order to comply with the water quality limits. These methods can be secondary treatment processes (e.g. activated sludge, rotating biological contractors), filtration (e.g. sand filtration), disinfection (e.g. chlorination, ozonation) and advanced treatments (e.g. carbon adsorption, membrane processes).

- *Water quality criteria:*

  Establishment of limits for microbiological (e.g. bacteria, protozoa, viruses, helminths), chemical (e.g. BOD, TOC, endocrine disruptors, minimum chlorine residual), and physical (e.g. pH, turbidity) parameters, sometimes including the requirement of meeting drinking water standards. These quality limits apply at the point of discharge from the reclamation facility.

- *Water monitoring:*

  Establishing the parameters to be monitored and at what frequency, depending on the use of the water (e.g. pH: weekly; turbidity and residual chlorine: continuously; *E. coli*: daily).

- *On-site preventive measures:*

  Recommendation of preventive measures to be established at the point of use to reduce health and environmental risks in combination with the treatment processes, according to the multiple barrier approach (e.g. drip irrigation, buffer distances to drinking water sources, no public access during irrigation).

- *Environmental monitoring:*

  Monitoring of environmental matrices potentially affected by the use of reclaimed water (e.g. soil, groundwater, biota).

- *Communication strategies:*

  Establishment of effective consultation and communication strategies to promote stakeholders' understanding and acceptance of water reuse practices (e.g. policy-makers, end-users, the public).

It must be noted that these guidelines apply to urban wastewater from municipal or other wastewater treatment facilities that have a limited input of industrial waste. Although these guidelines are neither mandatory nor legally binding, their adoption provides a shared objective, and allows for flexibility in responding to different circumstances at regional and local levels. However, the application of the framework may vary across jurisdictions, depending on the arrangements for water and treated wastewater management.

Non-EU countries, such as Canada, Australia, and some States from the USA, have also issued regulations and guidelines, mostly based on the guidelines described above (Table 6, Table 7, and Table 8).

Table 6 - Existing water reuse criteria within non-EU Member State countries.

Country	Type of criteria	Comments
Canada	"Canadian guidelines for domestic reclaimed water for use in toilet and urinal flushing" (2010)	These guidelines refer only to greywater
China	China National Reclaimed Water Quality Standard; China National Standard GB/T 18920-2002, GB/T 19923-2005, GB/T 18921-2002, GB 20922-2007 and GB/T 19772-2005.	
Israel	Ministry of Health regulation (2005)	Unrestricted agricultural irrigation use. Based on the California Title 22 standards, very restrictive. Methods of treatment and set-back distances are included
Japan	National Institute for Land and Infrastructure Management: Report of the Microbial Water Quality Project on Treated Sewage and Reclaimed Wastewater (2008)	
Jordan	Jordanian technical base n. 893/2006 Jordan water reuse management Plan (policy)	Irrigation purposes, artificial aquifer recharge for non-drinking uses. Stricter than WHO guidelines but less than California Title 22
Mexico	Mexican Standard NOM-001-ECOL-1996 governing wastewater reuse in Agriculture	
South Africa	Policies: The latest revision of the Water Services Act of 1997 relating to grey-water and treated effluent (DWAF, 2001) The latest revision of the National Water Act of 1998, 37(1) (DWAF, 2004a) relating to irrigation of any land with waste or water containing waste generated through any industrial activity or by a water works	Regulation: Government Gazette No. 9225, Regulation 991: Requirements for the purification of wastewater or effluent (EAF, 1984) Guidelines: The South African Guide for the Permissible Utilization and Disposal of Treated Effluent (DNHPD, 1978) The South African Water Quality Guidelines (DWAF, 1996)
Tunisia	Standard for the use of treated wastewater in agriculture (NT 106-109 of 1989) and list of crops that can be irrigated with treated wastewater. (Ministry of Agriculture, 1994) Wastewater reuse in agriculture is regulated by the 1975 Water Code (law No. 75-16 of 31 March 1975), the 1989 Decree No. 89-1047 (28 July 1989), by the Tunisian standard for the use of treated wastewater in agriculture (NT 106-003 of 18 May 1989)	Agricultural uses. The regulations prohibit wastewater irrigation of vegetables to be consumed raw and of heavily used pastures

Country	Type of criteria	Comments
Turkey	Water reuse was officially legitimised in 1991 through the regulation for irrigational wastewater reuse issued in by the Ministry of Environment. According to the "Water Pollution Control Regulations"	Agricultural uses. The regulation refers to the treatment methods and sustainability of industrial treated wastewater to be used for irrigation

Table 7- Existing water reuse criteria in the USA.

States of USA	Type of criteria
National: United States Environmental Protection Agency (USEPA)	"Guidelines for water reuse" (2012)
Arizona	Title 18. Environmental quality: Article 3. reclaimed water quality standards Permits required through Arizona Dept. of Water Quality
California	Groundwater Replenishment with Recycled Water - June 26, 2013 draft regulations Title 17 of the California Code of Regulations – for cross connections Title 22 – Water Recycling Criteria The compilations of recycled water-related laws once referred to as "The Purple Book", is described in " Statutes Related to Recycled Water & the California Department of Public Health, January 2011"
Colorado	Regulation 84 Reclaimed Water Control Regulation (amended 6/10/13, effective 7/30/13)
Florida	Chapter 62-610, F.A.C. "Reuse of Reclaimed Water and Land Application."
Georgia	Department of Natural Resources, 2002, Guidelines for Water Reclamation and Urban Water Reuse
New Mexico	Guidelines: NMED, Ground water quality bureau guidance: Above ground use of reclaimed domestic wastewater. January 2007
Texas	Title 30 Texas Administrative Code Chapter 210, Subchapters A-F
Wyoming	Standards for the reuse of treated wastewater Chapter 21, December 2010

Table 8 - Existing water reuse criteria in Australia

Administrative areas	Type of criteria	Comments
National level	Guidelines: Government of Australia (NRMMC-EPHC-AHMC) Guidelines for water recycling: managing health and environmental risks" Phase 1, 2006 Phase 2 - Augmentation of drinking water supplies – 2008 Phase 2: Stormwater harvesting and reuse – 2009 Phase 2 - Managed aquifer recharge - 2009	
Victoria	The use of treated sewage and greywater (recycled water) in Victoria is currently regulated under the *Environment Protection Act* 1970	Guidelines for Environmental Management: Use of Reclaimed Water (EPA publication 464.2) Guidelines for Environmental Management: Dual Pipe Water Recycling Schemes - Health and Environmental Risk Management (EPA publication 1015). Guide for the completion of a Recycled Water Quality Management Plan - For Class A water recycling schemes Guidelines for validating treatment processes for pathogen reduction: Supporting Class A recycled water schemes in Victoria
New South Wales	Environmental Guidelines: Use of Effluent by Irrigation (Dept. of Environment & Conservation, 2004) Managing Urban Stormwater – Harvesting and Reuse (Dept. of Environment & Conservation, 2006)	
Queensland	*Water Supply (Safety and Reliability) Act 2008* Approval required through Department of Energy and Water Supply including submission of a Recycled Water Management Plan (RWMP)	
South Australia		The South Australia Recycled Water Guidelines (2012)
Tasmania	Policy on Water Quality Management , 1997	Effluent Reuse Feasibility Study Guidelines, August 2011
Western Australia		Guidelines for the Non-Potable Uses of Recycled Water in Western Australia (2011)

5.1 WHO Guidelines

The WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (WHO, 2006) are an integrated preventative management framework for maximising the public health benefits of wastewater, excreta and greywater use in agriculture and aquaculture. They do not constitute a regulatory framework in themselves, but provide guidance on how to set one up.

An important feature of these guidelines is that they use a risk management framework, rather than simply relying on post-treatment testing as the basis for managing reclaimed water schemes. When recycling water, it is essential to protect the health of both the public and the environment, and a risk management approach is the best way to achieve this. The emphasis in the earlier guidelines was on end-point or post-treatment testing as the basis for ensuring that the scheme did not pose a public health or environmental risk. In addition, there was no holistic approach to the management of the reclaimed water scheme. With the movement towards the risk-based management of drinking and recreational water, and the use of multiple barriers for the management of public health, there was a need to update or develop more comprehensive national guidelines.

The WHO Guidelines detail a risk management framework based on the Stockholm framework, which involves the assessment of health risks prior to the setting of health-based targets that define basic control approaches, and evaluating the impact of these combined approaches on public health status. The framework allows countries to adapt their guidelines to local social, cultural, economic and environmental circumstances; and to compare the associated health risks with the risks that may result from microbial exposure through the use of wastewater and drinking-water, and recreational or occupational contact with water.

This framework is promoted for use with drinking water, wastewater use and recreational water supplies (Fewtrell and Bartram, 2001). This type of approach has been used in the food industry for many years, through the application of the Hazard Analysis and Critical Control Points (HACCP) system. More recently, it has been adopted in the water industry, for example in the latest edition of the World Health Organization's Guidelines for Drinking-water Quality (WHO, 2004 and 2011) and the Australian Drinking Water Guidelines (NHMRC-NRMMC, 2004 and 2011).

The control of the microbial and chemical quality of drinking-water requires the development of management plans, which, when implemented, provide the basis for system protection and process control to ensure that the numbers of pathogens and concentrations of chemicals present a negligible risk to public health, and that water is acceptable for use by consumers. The management plans developed by water suppliers are best termed "water safety plans" (WSPs). A WSP comprises system assessment and design, operational monitoring, and management plans, including documentation and communication.

The elements of a WSP build on the multiple-barrier principle, the principles of hazard analysis and critical control points (HACCP), and other systematic management approaches. The plans should address all aspects of the drinking-water supply and focus on the control of abstraction, treatment and delivery of drinking-water. The WHO water reuse document states that the regulatory framework should adopt the format of a safe reuse wastewater plan, in line with the concept of WSPs.

The WHO guidelines present the management of health risks from reclaimed water based on tolerable risk. This is achieved by determining the disability-adjusted life years (DALYs). The tolerable risk was established to be 10^{-6} DALYs per person per year. The risk associated with the scheme is calculated using quantitative microbial risk assessment. The quantitative microbial risk assessment process involves four main steps: hazard identification, dose-response, exposure assessment, and risk characterisation. Once this risk is determined, performance targets can be set for treatment processes.

It is expected that most new regulations for water reuse and for the development of specific guideline documents will look to use the framework presented in the WHO Guidelines (WHO, 2006).

5.2 Australian Guidelines for Water Recycling

Australia has a long-term experience in water reuse. Although most Australian states had their own treated wastewater reuse guidelines or regulations, they decided to produce national guidelines. The National Water Quality Management Strategy, Australian Guidelines for Water Recycling*:* Managing Health and Environmental Risks (Phase 1) (NRMMC-EPHC-AHMC, 2006) (AGWR), advocates a risk management framework based on that previously detailed in the World Health Organization‛s Guidelines for Drinking-water Quality (WHO, 2004 and 2011) and the Australian Drinking Water Guidelines (NHMRC-NRMMC 2004). The Strategy includes some of the most useful and appropriate guidelines for treated wastewater reuse. The AGWR adapts the risk management framework to the Australian environment, and includes the risk of higher exposure such as dual reticulation.

This significant change in the approach to the management of reclaimed water schemes aims to provide guidance on best practice for water recycling, and the guidelines are intended to be used by anyone involved in the supply, use and regulation of reclaimed water schemes, including government and local government agencies, regulatory agencies, health and environmental agencies, operators of water and wastewater schemes, water suppliers, consultants, industry, private developers, body corporate and property managers (NRMMC-EPHC-AMHC, 2006).

As the framework is generic, it can be applied to any system that recycles water. The framework involves identifying and managing risks in a proactive way, rather than simply reacting when problems arise. Internationally, the AGWR is significantly advanced and matches the recommendations outlined in the WHO guidelines (WHO, 2006). Therefore, a large number of countries will be looking to Australia to lead the way in developing regulations that incorporate the concepts of risk assessment and allow the adaption of these concepts to differently sized schemes.

5.3 Californian Purple Book and other US regulations

In the USA there are no federal regulations that govern water reuse, so the regulations have been developed on a state-by-state basis.

The underlying objectives of regulations and guidelines vary considerably from state to state. States such as Arizona, California, Florida, and Washington have developed regulations or guidelines that encourage water reuse as a water resource conservation strategy. These states have developed comprehensive regulations or guidelines that specify water quality requirements, treatment processes, or both, for the full spectrum of reuse applications. The objective in these states is to derive the maximum resource benefits of the reclaimed water while protecting the environment and public health (USEPA, 2012).

Other states have regulations or guidelines that focus on providing an alternative to discharging wastewater into surface waters, emphasising additional treatment or effluent disposal rather than reuse.

The state of California has been a pioneer in issuing water reuse regulations. The compilation of reclaimed water-related laws of the state of California was once referred to by staff and the regulated community as "The Purple Book". The Purple Book outlines the Californian health laws related to reclaimed water and includes excerpts from the Health and Safety Code, Water Code, and Titles 22 and 17 of the California Code of Regulations (State of California, 1978). These regulations, last updated in June 2001 (State of California, 2001), and with a latest revised draft from March 2013, have provided a basis for the development of further regulations worldwide.

Currently, 22 states have adopted water reuse regulations, and 11 states have guidelines or design standards for water reuse. Additionally, eight states have regulations and four have guidelines that implicate water reuse primarily from a disposal perspective. 27 states, including Arizona and Florida, have revised their current reuse regulations or guidelines.

To date, no states have developed or proposed regulations or guidelines that specifically govern direct reuse of drinking water. However, some states may issue project-specific permits for such reuse if requirements for detailed treatment, reclaimed water quality and monitoring are met. In states with no specific regulations or guidelines for water reclamation and reuse, water reuse projects may still be permitted on a case-by-case basis. Similarly, some states allow for the consideration of reuse options that are not specifically addressed within their existing rules or regulations.

In 2004, the USA produced the national Guidelines for Water Reuse, as there were no federal regulations on treated wastewater reuse practices. The last update of these guidelines was in 2012 (USEPA, 2012). The primary purpose of this document is to facilitate further development of water reuse by serving as an authoritative reference on water reuse practices. This document includes an updated overview of water-reuse regulations or guidelines that are promulgated in the USA, advances in wastewater treatment technologies relevant to reuse, best practices for involving communities in planning projects, and international water reuse practices. It also presents frameworks and standards for states or other authorities that may decide to develop new regulations or guidelines.

The national Guidelines for Water Reuse state that regulators may consider the use of quantitative microbial risk assessment to set guidelines or limits for selected pathogens in reclaimed water.

5.4 Water reuse regulations in Europe

In Europe, there are no guidelines or regulations at the European Union (EU) level. However, several environmental Directives must be taken into account when developing legislation to govern future water reuse at the EU level, as described in Section 6 of this document.

Among these Directives, Article 12 of the Urban Wastewater Treatment Directive (91/271/EEC) requires that "treated wastewater shall be reused whenever appropriate" and "disposal routes shall minimize the adverse effects on the environment", with the objective of the protection of the environment from the adverse effects of wastewater discharge.

Despite of the lack of water reuse criteria at the EU level, several Member States and autonomous regions have produced their own legislative frameworks, regulations, or guidelines for water reuse applications.

5.4.1 Evaluation of water reuse standards in EU Member States

The following countries have developed the most comprehensive standards developed specifically for water reuse practices and issued by EU Member States: Cyprus, France, Greece, Italy, Portugal and Spain (Table 9).

The standards of Cyprus, France, Greece, Italy and Spain are included as regulations in the national legislation. In Portugal, the standards on water reuse are guidelines, but they are taken into consideration by the national government when issuing any water reuse permits in the country.

All the standards evaluated refer to the reuse of urban and industrial wastewater effluents, except the standards of Cyprus and Portugal which refer only to urban wastewater.

Table 9 - Most representative 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

In Cyprus, the Code of Good Agricultural Practice (P.I. 263/2007) was created as part of the implementation of EC Directive 91/676/EEC on the protection of waters against pollution caused by nitrates from agricultural sources. The Code aims to promote guidelines to assist farmers in reducing and preventing water pollution caused by agricultural fertilisers, and to set acceptable environmental conditions for the use of urban wastewater for irrigation purposes. It mainly deals with land application of fertilisers, wastewater treatment, wastewater recycling, and sewage disposal.

The Portuguese Regulating Authority for Water and Sanitation Services has issued a Technical Guide on wastewater reuse, to support the implementation of water reuse projects. The Guide focuses on wastewater quality aspects of the proposed reuse applications, includes additional uses to those described in NP 4434, (i.e. urban uses), and considers the economic viability and public acceptance of water reuse projects.

The standards must be carefully compared as there is no homogeneity between the aspects covered by each Member State regulation. In general, the standards comprise the following criteria:

- Intended uses
- Analytical parameters
- Maximum limit value permitted for each parameter
- Monitoring protocols
- Additional preventive measures for health and environment protection

The selected standards have been compared by assessing the strength of each individual criterion.

The intended uses of the standards evaluated are summarised in Table 10. Most of the standards are intended for agricultural, urban and industrial applications.

The Spanish and Greek regulations apply to a high number of permitted uses, for most of which they include an accurate description.

Italian regulations describe several urban, agricultural and industrial uses. Reclaimed water could be used for all crops destined for human/livestock consumption, for non-food crops and for public green areas (even sport facilities). Industrial use is allowed if no direct contact is made with food, pharmaceutical or cosmetic products. The characteristics and limit values for industrial reuse shall be set by the parties concerned depending on the requirement of the industrial process and they should, as a minimum, comply with the limit values set out for water discharges to surface water (table 3 of annex 5 to part III of the Legislative Decree 152/2006, article 4 of the 2003 regulation).

The Portuguese guidelines only refer to irrigation of urban areas and agriculture, although the Technical Guide issued in 2010 (Marecos do Monte and Albuquerque, 2010) does include other uses such as street cleaning, industrial water process and cooling towers. The major applications of water in Portugal are for agricultural and landscape irrigation, mainly golf course irrigation, therefore priority was given to issuing guidelines for water reuse for irrigation.

Table 10 - Intended uses for water reuse included in the standards of EU Member States.

Intended use of reclaimed water	Cyprus	France	Greece	Italy	Portugal	Spain
Irrigation of private gardens						√
Supply to sanitary appliances				√		√
Landscape irrigation of urban areas (parks, sports grounds and similar)	√	√	√	√	√	√
Street cleaning			√	√		√
Soil compaction			√			
Fire hydrants			√	√*		√
Industrial washing of vehicles				√		√
Irrigation of crops eaten raw	√	√	√	√	√	√
Irrigation of crops not eaten raw	√	√	√	√	√	√
Irrigation of pastures for milk or meat producing animals		√	√	√	√	√
Aquaculture						√
Irrigation of trees without contact of reclaimed water with fruit for human consumption	√	√	√	√	√	√

Intended use of reclaimed water	Cyprus	France	Greece	Italy	Portugal	Spain
Irrigation of ornamental flowers without contact of reclaimed water with the product		√	√	√		√
Irrigation of industrial non-food crops, fodder, cereals	√	√	√	√	√	√
Water process, and cleaning in industry other than the food industry			√	√**		√
Water process and cleaning in the food industry			√	√**		√
Cooling towers and evaporative condensers			√	√		
Golf course irrigation	√	√	√	√	√	√
Ornamental ponds without public access			√			
Aquifer recharge by localised percolation	√		√			√
Aquifer recharge by direct injection	√		√			√
Irrigation of woodland and green areas not accessible to the public		√	√	√	√	√
Silviculture						√
Environmental uses (maintenance of wetlands, minimum stream flows and similar)						√

* only for industrial uses.

** reclaimed water cannot be used in direct contact with food, pharmaceuticals or cosmetic products.

The French standards on wastewater reuse describe water reuse for the irrigation of agricultural lands and green areas, and exclude industrial uses, urban uses, and aquifer recharging.

Cypriot regulation does not allow for any industrial or urban use of reclaimed water.

Spanish legislation is the only one that includes the use of reclaimed water for the irrigation of private gardens. However, authorisation for this use will only be given provided that a marked dual circuit, i.e. a water pipe system with dedicated and separated lines for drinking water and reclaimed water, is implemented. It is also the only regulation that includes the reuse of water in aquaculture.

Aquifer recharging with reclaimed water is only described in the regulations of Cyprus, Greece and Spain, although this is mainly for non-drinking-water aquifers. Aquifer recharging with reclaimed water is likely to increase in the future because it can restore depleted groundwater levels, provide a barrier to saline intrusion in coastal zones, and facilitate water storage during times of high water availability. The main example of the use of treated wastewater for aquifer recharging in Europe was established several years ago in Belgium, in the Torreele facilities (Van Houtte and Verbauwhede, 2007). Specific standards have been set for the quality of the infiltration water within the environmental permit from the regional government, although there are no general criteria for water reuse in Belgium.

Regarding the intended uses described in the standards evaluated, the Spanish regulation includes the most uses of reclaimed water, including urban, agricultural, industrial, recreational and environmental categories. This resembles USEPA and Australian guidelines for water reuse, and also California State regulations, which describe all the uses in several categories with detailed specifications for each use, including indirect reuse of drinking water. Spain is followed, in number of permitted uses, by Greece, Italy, Portugal, France and Cyprus.

The analytical parameters included in the evaluated standards for wastewater reuse are summarised in Table 11. The standards comprise microbiological and physical-chemical parameters.

Table 11 - 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)**	√		√	√	√**	√*

Analytical parameters	Cyprus	France	Greece	Italy	Portugal	Spain
- **Nitrogen forms (Total, $N\text{-}NO_3$, $N\text{-}NH_4$)**	√		√	√	√**	√*
- **Total phosphorus**	√		√	√	√**	√*
- **Bicarbonate (HCO_3)**			√			
- **Toxic substances including priority substances**			√**	√	√**	√**

* only for certain uses or irrigation methods.

** according to the existing related legislation.

Regarding microbiological parameters, all the standards include a bacterial indicator to monitor reclaimed water quality, but the selected indicator is not always the same. The regulations of Spain, Cyprus, France, Greece, and Italy have selected *E. coli* as a surrogate for pathogenic bacteria. In recent years, this indicator has been used to substitute the use of total coliforms and faecal coliforms because it reflects more accurately the behaviour of pathogenic bacteria in water (Ashbolt et al., 2001). The use of total coliforms and faecal coliforms as bacterial indicators is more restrictive because these groups of microorganisms can be found in the environment, and are therefore not specific to the presence of pathogens of faecal origin.

The Portuguese standards only include faecal coliforms as a bacterial indicator, while Greek standards also include total coliforms, but only for urban uses, thus taking a more conservative approach regarding the health risks associated with this type of use, such as for the irrigation of public parks.

Spanish regulations include the analysis of *Legionella sp*. if there is a risk of water aerosolisation (e.g. sprinkler irrigation) in urban, industrial and agricultural uses. In such cases, the conditions of use must be followed as stipulated in a case-by-case basis by public health authorities, otherwise such uses will not be authorised. Within the same approach, tests must be carried out to detect the presence-absence of pathogens (e.g. *Salmonella* sp.) when using reclaimed water for the irrigation of crops for human or animal consumption, and as process and cleaning water in the food industry when *E. coli* results from a certain number of samples are above the maximum limit.

Italian regulations include *Salmonella* sp. analysis as a compulsory parameter for all the intended uses, requiring total absence of the pathogen.

Spain, Cyprus, and Portugal include the determination of helminth eggs as a compulsory parameter for most of the intended uses. However, this parameter does not appear in any of the other selected regulations. Helminth eggs, or intestinal nematode eggs, are a parameter recommended by the WHO guidelines for developing countries for agricultural irrigation with reclaimed water, but this parameter does not appear in any of the most relevant standards such as California regulations, and USEPA and Australian guidelines. This is due to the fact that these pathogens are endemic within developing countries but are very rare in developed countries, and so they are not a significant health risk in these countries.

In addition to *E. coli*, the French regulation includes faecal enterococci as a supplementary bacterial indicator. Faecal enterococci are used as indicators of pathogenic bacteria for their high resistance to wastewater treatment (Ashbolt et al., 2001). Moreover, it is the only regulation of the evaluated standards that considers the risk of pathogenic viruses and protozoan parasites in the use of reclaimed water by including renowned viral and protozoan parasites indicators, F-specific bacteriophages and sulphate-reducing bacteria, to be analysed in all the intended uses. Bacteriophages are known to be one of the more suitable indicators of pathogenic viruses in water (Jofre, 2007). Spores of sulphate-reducing bacteria are recommended as indicators of *Giardia* cysts and *Cryptosporidium* oocysts (Araujo et al., 2004). *Giardia* sp. and *Cryptosporidium* sp. have generated considerable interest in recent years regarding their occurrence and significance in reclaimed water (USEPA, 2012). This approach of the French standards complies with the recommendations from WHO and the scientific community for the use of not only bacterial but also viral indicators in order to properly assess the health risks in using reclaimed water.

Regarding physical-chemical parameters, all the standards reflect the requirements of several European Directives such as Directive 91/271/EEC on the quality of treated effluent disposal, Directive 2008/105/EC on environmental quality standards and emission limits, and Directive 91/676/EEC on water pollution from nitrates. In addition to this, some standards include additional parameters or stricter limit values.

There are similarities among the standards evaluated for parameters such as total suspended solids, pH, electrical conductivity, and nutrients. Turbidity is included as a parameter in the Spanish and Greek standards, but does not appear in any other regulation, although this parameter is essential to control the disinfection process of reclaimed water.

The maximum limit values permitted for most of the parameters included in the standards evaluated are shown in Table 12. The range of values depends on the type of use made of the reclaimed water. Italy, Spain, Greece and Cyprus include their own limit values for some parameters such as heavy metals and agronomic parameters (e.g. SAR, nutrients).

Italian standards include maximum limit values for physical-chemical parameters that have to be met for all the intended uses of reclaimed water. Some parameters have limit values similar to those designated for drinking water, even if the reclaimed water is used for uses such as irrigation of green areas.

The Spanish regulation includes specific parameters and limit values for agricultural uses, such as SAR and heavy metals, and applies limit values for nitrogen and nitrates for aquifer recharge, and phosphorus for ornamental ponds and lakes with standing water. In addition, it considers stricter limit values for total suspended solids for certain uses such as urban uses, use in cooling towers and evaporative condensers, golf course irrigation and aquifer recharge by direct injection.

Table 12 - Maximum limit values according to the intended use for parameters included in the evaluated water reuse standards.

Analytical parameters	Cyprus	France	Greece	Italy	Portugal	Spain
Microbiological parameters						
- ***Escherichia coli*** **(cfu/100ml)**	**5-10^3**	**250-10^5**	**5-200**	**10**		**0-10^4**
- **Faecal coliforms (cfu/100ml)**					**100-10^4**	
- **Total coliforms (cfu/100ml)**			**2**			
- **Faecal enterococci (log reduction)**		**2-4**				
- ***Legionella*** **sp. (cfu/l)**						**0-10^3**
- ***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.

The Greek standards apply strict limits for biochemical oxygen demand ($BOD_{5)}$ and total suspended solids for urban uses, some industrial uses, unrestricted irrigation and aquifer recharge by wells. Some of these criteria are based on the Food and Agriculture Organization (FAO) recommendations on water quality for irrigation (Ayers and Westcot, 1989), with some modifications.

The French regulation only considers stricter limits for BOD_5 and total suspended solids for the irrigation of green areas and certain agricultural uses. This regulation does not include agronomic parameters and heavy metals in the list of parameters to be analysed.

The Portuguese standards refer to the national legislation DL 236/98 that establishes criteria for water used for irrigation. Most of these criteria are based on the FAO recommendations on water quality for irrigation.

All the standards give numerical values for the maximum content allowed for each parameter, except the French regulation that states log reductions for faecal enterococci and F-specific bacteriophages. This approach is consistent with the WHO and Australian guidelines that establish the log reductions as health-based performance targets founded on a health-risk assessment approach.

It should be noted that the various water quality levels for each use are structured differently in the standards that have been evaluated in this analysis.

In the Cypriot legislation, numerical values for water quality parameters are included in the discharge permits, and differ slightly depending on the population equivalent (P.E.) served by the WWTP. There are quality limits for urban agglomerations above 2 000 P.E., and there are less stringent limit values for urban agglomerations with less than 2 000 P.E.

The French regulation considers four different categories of water quality (A, B, C and D), which each include the same microbiological and physical-chemical parameters with varying levels of strictness in their limits. In this approach, the intended uses are associated with one or more quality categories. Such a structure can lead to misinterpretations, and it is only used in the French regulation.

The Italian regulation applies the same water quality limits for all uses of reclaimed water aside from industrial uses. Limit values for industrial reuse are set by the parties concerned depending on the requirement of the industrial process. This approach does not consider the different risks associated with each particular use, and it is not consistent with the later approach recommended by the WHO (2006).

The Portuguese standards include the same microbiological and physical-chemical parameters for irrigation as those included in the DL 236/98, using these numerical limits for all intended uses, except for crops that are not eaten raw, for which the limits for faecal coliforms are less stringent. The two standards also include the monitoring of the soil quality irrigated with reclaimed water, taking into account the environmental risk for the soil matrix.

Spanish standards include 12 different water-quality categories with different numerical values for each microbiological and physical-chemical parameter, depending on the type of use. The Greek standards also follow this structure but only consider four different water quality categories into which all the intended uses are classified.

According to the maximum limit values established for microbiological parameters, the Italian standards are the most stringent considering the *E. coli* limit value. In the Italian decree, the limit value for *E. coli* of 10 cfu/100ml (in 80% of the sample in the year) is binding for irrigation and civil uses, although a value of 100 cfu/100ml can also be allowed in certain cases. Regarding industrial uses, limit values should, as a minimum, comply with the limit values set for water discharges to surface water (table 3 of annex 5 to part III of the Legislative Decree 152/2006, article 4 of the 2003 regulation). Table 3 does not set binding standards for *E. coli*, although a limit of 5 000 cfu/100ml is suggested (for discharges to surface water, the competent local authority sets *E. coli* limits for each discharge permit depending on the environmental status of the water body, sanitary conditions and possible downstream uses). The Greek standards are also stringent regarding *E. coli* limit values, although they consider different numerical values for certain uses. The Spanish criteria have stringent limits for the uses with higher risks, such as water for cooling towers and evaporators, and aquifer recharge by direct injection. However, there is a clear differentiation between these uses and uses that do not pose such great potential risk to health, such as irrigation of woodlands and silviculture, for which the numerical limit values for microbiological parameters are lower.

The regulation of Cyprus is similar to the Greek standards, in that it considers different limits for different types of crops irrigated with reclaimed water, and sets stricter limits for crops eaten raw than do the Spanish and French legislation.

The Portuguese standards consider the same limits for crops eaten raw as do the Spanish standards, although they take a more conservative approach by using faecal coliforms as indicators.

Regarding the frequency of analysis, although there are variations in the parameters and the types of use (Table 13), Spanish and Greek regulations generally set stricter monitoring protocols than do the other countries considered. However, Greek regulation allows for different frequencies of control depending on the P.E. served by the WWTP. The Italian and Portuguese standards do not consider a frequency of analysis. This frequency should be established by those responsible for the facility, in accordance with the authorities and always taking into account the variability of water characteristics.

The French regulations stipulate three types of frequency, not according to the parameter but to the desired level of quality (A, B, C and D).

All the standards evaluated include additional preventive measures following the multiple-barrier approach. The most important guidelines on water reuse (WHO, Australian, USEPA) and California State regulations emphasise the use of a multiple-barrier approach. This multiple-barrier approach is an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of reclaimed water from the treatment to the point of use in order to reduce risks to public health.

Most of the standards include the limitation of irrigation at night or outside of the public access period, and also indicate the irrigation methods allowed, depending on the contact of the crops with the reclaimed water. The use of reclaimed water should also be well communicated, and a dual pipe network should be established to avoid any connection between reclaimed water and drinking water pipes. Italian standards are the least explicit regarding preventive measures.

The French standards include the additional requirements of always taking into account the category of water quality, the minimum distances to be respected between areas irrigated using reclaimed water and the activities to be protected (e.g. drinking water abstraction, aquatic activities), and the slope of the field to be irrigated.

Table 13 - Frequency of analysis according to the parameter and intended use of the evaluated water reuse standards.

Analytical parameters	Cyprus	France	Greece	Italy	Portugal	Spain
Escherichia coli	1/15 days	1/week 1/two weeks 1/month	4/week 2/week 1/week	x		3/week 2/week 1/week
Faecal coliforms					x	
Total coliforms			7/week 3/week			
Faecal enterococci		1/week 1/two weeks 1/month				
***Legionella* sp.**						3/week 1/month
***Salmonella* sp.**				x		1/two weeks 1/month
Sulphate-reducing bacteria		1/week 1/two weeks 1/month				
Helminth eggs **(Intestinal nematodes)**	4/year				x	1/week 1/two weeks

Analytical parameters	Cyprus	France	Greece	Italy	Portugal	Spain
F-specific bacteriophages		1/week 1/two weeks 1/month				
Total suspended solids (TSS)	1/15 days	1/week 1/two weeks 1/month	24/year 12/year 4/year	x	x	1/day 1/week
Turbidity			4/week 2/week			1/day 1/week 2/week
Biochemical oxygen demand (BOD_5)	1/15 days		24/year 12/year 4/year	x		
Chemical oxygen demand(COD)	1/15 days	1/week 1/two weeks 1/month		x		
Heavy metals and metalloids	2/year		12/year 4/year 2/year 1/year	x	x	1/two weeks 1/month
pH	3/week		2/year 1/year	x	x	
Electrical conductivity (EC)	1/15 days		2/year 1/year	x	x	1/two weeks 1/month
Total dissolved solids (TDS)			2/year 1/year		x	
Sodium adsorption ratio (SAR)			2/year 1/year	x	x	1/two weeks 1/month
Chlorides	1/month		2/year 1/year	x	x	
Total nitrogen and Total phosphorus	1/15 days		24/year 12/year 4/year	x	x	1/week 1/month

X: frequency established by those responsible for the reclaimed water process, in compliance with the authorities

The Greek and Cypriot standards require a minimum level of treatment for each water quality level. A minimum level of treatment is also described in the Portuguese standard, together with the disinfection method. The Portuguese standards also establish maximum values for wind speed in the case of sprinkler irrigation, according to the distance to inhabited areas, and the slope of the irrigated fields.

The Spanish and Italian standards include the approval of the public health authorities for several uses, issuing the permit on a case-by-case basis.

After the evaluation carried out on the most comprehensive water reuse standards of EU Member States, it was found that none completely follow the approach recommended by the WHO and the Australian guidelines regarding carrying out a risk assessment to manage the health and environmental risks of water reuse practices. This risk management framework involves the assessment of risks prior to setting health or environmental targets, using a preventive approach that allows countries to adjust their guidelines to local circumstances.

6 EU legislation related to water reuse

Despite the lack of water reuse criteria at the European Union (EU) level, several environmental Directives should be taken into account for future water reuse legislation at the EU level. The Water Framework Directive (WFD, 2000/60/EC) establishes a legal framework to guarantee sufficient quantities of good quality water across Europe for the different water uses and environmental quality.

Its key objectives are:

- to expand water protection to all waters
- to achieve "good status" for all waters by 2015
- to base water management on river basins
- to combine emission limit values with environmental quality standards
- to ensure that water prices provide adequate incentives to use water resources efficiently
- to involve citizens more closely, and
- to streamline legislation.

The use of treated wastewater should be regarded as a means of increasing water availability, and can contribute to the good quality status of water resources. It should therefore be considered as an option in the plans of measures to be established when implementing the WFD. Some of the mandatory steps of the WFD are very favourable for strategic water reuse planning, such as the following:

- Article 5 reports on the characteristics of the river basin district, the review of the environmental impact of human activities. and economic analysis of water use: this analysis constitutes a well-grounded basis for identifying where treated wastewater reuse can be a useful option to be considered in the programmes of measures to achieve environmental objectives, without compromising further economic development.
- Article 9 refers to recovery of costs for water services, including environmental and resource costs, while providing adequate incentives for users to use water resources efficiently: this is essential for long-term reuse of treated wastewater.
- Article 11 refers to the establishment of a programme of measures, including measures to promote the efficient and sustainable use of water: establishing the framework for water reuse practices can be established as part of the programme of measures (CIS Working Group Programme of Measures).

- Article 14 refers to the active involvement of all interested parties, including users: this has also been identified as being necessary for water reuse implementation.
- Article 16 refers to strategies against the pollution of waters: the setting for the assessment and monitoring requirements of chemical status can be established.
- Annex VI (Part B) refers to emission controls; efficiency and reuse measures, inter alia, promotion of water-efficient technologies in industry and water-saving irrigation techniques; recreation and restoration of wetland areas; artificial recharge of aquifers, and other relevant measures; supplementary measures, including water reuse practices.

In addition to this framework, a number of EU water-related directives require specific standards for specific water resources and uses. These directives have a correlation with water reuse applications due to the health and environmental concerns of water reuse practices:

- The Urban Wastewater Treatment Directive (91/271/EEC) concerns the quality of the urban wastewater discharged into receiving waters that can be reused if it is additionally treated by reclamation technologies. The major concerns are chemical and/or biological hazardous substances.
- The Sewage Sludge Directive (86/278/EEC) deals with the use of treated wastewater for agriculture regarding the major concerns of contamination of soil, groundwater and agricultural produce with chemical and /or biological hazardous substances, and the health risk for workers and consumers.
- The Nitrates Directive (91/676/EEC) concerns water reuse for agricultural irrigation and for groundwater recharge with respect to the health and environmental impacts of nitrates, especially in vulnerable zones. It is necessary to avoid over-fertilisation.
- The Groundwater Directive (2006/118/EC) refers to water reuse for agricultural irrigation and aquifer recharge with respect to the contamination of groundwater by hazardous chemical substances.
- The Thematic Strategy for Soil Protection (COM(2006) 231) and the future Soil Protection Directive address the use of reclaimed water for irrigation and soil-aquifer recharge with a view to protecting soils from deterioration.
- The Drinking Water Directive (98/83/EC) addresses the indirect reuse of drinking water, for example through the recharging of aquifers used for the abstraction of water intended for human consumption and the augmentation of surface waters for human consumption, with respect to chemical and biological contaminants.
- The Bathing Water Directive (2006/7/EC) concerns the use of treated wastewater in recreational impoundments with/without public access (e.g. fishing, boating, bathing areas). The main concern is the risk to public health caused by pathogens.
- The Freshwaters Fish Directive (2006/44/EC) and the Shellfish Waters Directive (2006/113/EC) relate to water reuse in aquaculture and environmental enhancement, such as stream augmentation.
- The Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC) address the application of water reuse for environmental enhancement, such as wetlands improvement.
- The Industrial Emissions Directive (2010/75/EU) and the Environmental Quality Standards Directive (2008/105/EC) address the application of reclaimed water in industrial uses and uses that may affect the environmental matrices of surface- and groundwater, such as artificial aquifer recharge, stream augmentation, and irrigation.

When water reuse is applied to agricultural irrigation, the safety of the irrigated crops must be guaranteed. The objective of the EU's food safety policy is to protect consumer health and interests. In order to achieve this objective, the EU ensures that control standards are established and adhered to with regard to the hygiene of food and food products, animal health and welfare, plant health, and prevention of the risk of contamination from external substances. This approach involves both food products produced within the EU and those imported from third countries. Therefore, the water quality standards for agricultural irrigation using reclaimed water must be consistent with EU food safety regulations.

7 Risk-based management for wastewater reuse

When recycling water, it is essential to protect both human and environmental health. A risk management approach is the best way to achieve this. Such an approach has been employed in food processing industries in the EU for some years to ensure safe food production, through the application of the Hazard Analysis and Critical Control Points (HACCP) system, a systematic safety management tool (Jouve, 1994; Vanne et al., 1996).

More recently, a risk management approach has been adopted in the water industry; in the latest editions of the Australian drinking water guidelines (NHMRC-NRMMC, 2004) and of the World Health Organization's Guidelines for drinking-water quality (WHO, 2004), which embodies this approach in its Water Safety Plan (WSP). International guidelines on water reuse (WHO, 2006; NRMMC-EPHC-AHMC, 2006) recommend the development of a risk management framework similar to the WSP for water reuse systems - the Water Reuse Safety Plans (WRSPs).

A risk management framework or guidance such as a WRSP must be a systematic safety management tool that consistently ensures the safety and acceptability of water reuse practices. A central feature of the WRSP is that it is sufficiently flexible to be applied to all types of water reuse systems, including treated sewage, greywater and storm water, irrespective of size and complexity. A risk management approach involves identifying and managing risks in a proactive way, rather than simply reacting when problems arise. In applying this approach to water reclamation, the first step is to look systematically at all the hazards that the reclaimed water could potentially pose to human or environmental health. Once the hazards are identified, the risk of each hazard is assessed by estimating the likelihood and the consequences of its occurrence. The next step is to identify preventive measures to control such hazards, and to establish monitoring programmes to ensure that the preventive measures operate effectively. The complexity of the monitoring technology needs to reflect the infrastructural capabilities. The final step is to verify that the management system consistently provides reclaimed water of a quality that is fit for the intended use. The WRSP approach is a dynamic and practical system that incorporates the concept of identifying and producing reclaimed water of a quality that is 'fit-for-purpose'.

The responsibility for the implementation of WRSPs lies with the water utility managers, while the accountability for setting health-based targets falls to the corresponding authorities.

It must be pointed out that the implementation of the WRSP approach can save money and better target resources in the longer term.

7.1 Water Reuse Safety Plans

The WRSP framework for the management of reclaimed water quality incorporates several interrelated elements, each of which supports the effectiveness of the others. Because most problems associated with reclaimed water schemes are attributable to a combination of factors, these elements need to be addressed together to ensure a safe and sustainable supply of reclaimed water. The steps selected, based on the recommendations of international guidelines (WHO, 2004; NRMMC-EPHC-AHMC, 2006), are the following:

1. Assembly of a WRSP team;
2. Description of the water reuse system;

3. Identification of hazards and hazardous events, and risk assessment;
4. Determination of preventive measures to limit potential risks;
5. Development of operational procedures and process controls;
6. Verification of the water reuse and quality of the receiving environment;
7. Management of incidents and emergencies;
8. Validation of processes and procedures.

7.1.1 Assembly of a WRSP team

This step involves assembling a multidisciplinary team of individuals from the associated utility and, in some cases, from a wider group of stakeholders, with adequate experience and expertise in protecting public and environmental health, that understands the components of the water reuse scheme and is well placed to assess the associated risks.

7.1.2 Description of the water reuse system

The aim of this step is to provide a detailed understanding of the entire water reuse supply system from source to end use, and the receiving environmental matrices. It is necessary to assess the historical water quality data, taking into account the variability, and to construct a flow diagram of the water reuse system from the source to the application or receiving environments.

7.1.3 Identification of hazards and hazardous events, and risk assessment

Effective risk management involves identifying all potential hazards and hazardous events of the water reuse scheme, and assessing the level of risk they pose to human and environmental health. A hazard is a biological, chemical, physical or radiological agent that has the potential to cause harm to people, animals, crops or plants, other terrestrial biota, aquatic biota, soils or the general environment.

In recent years, quantitative risk assessment has been established as a key tool for identifying and describing relationships between reclaimed water quality and health, and environmental hazards associated with water reuse practices. It aims to provide a scientific, rational basis for the development of national standards that take social, economic and environmental factors into account (NRMMC-EPHC-AMHC, 2006, 2008 and 2009; WHO, 2006).

A comprehensive application of human and environmental risk assessment procedures should always include the following general steps:

- Hazard identification
- Dose–response assessment
- Exposure assessment
- Risk characterisation

7.1.3.1 Health risk characterisation

For human health risk characterisation, the main focus is on microbial hazards, although chemicals must also be considered, with some emerging areas of concern with long-term exposure to low levels of chemicals. An important basis for a sound risk assessment is the availability of reliable data based on applicable analytical parameters which exert a noticeable impact on the overall risk. Such data must be acquired in a manner that allows the parameters to be ranked and provides a quantitative result to describe a magnitude of risk associated with a specific microorganism or chemical. It must be noted that pathogens are the most important health risks for water reuse applications, therefore health risk characterisations are mostly based on microbial pathogen content. Quantitative risk assessment determines the likelihood of infection or illness. The DALYs (Disability-Adjusted Life Years) parameter converts these likelihoods into burdens of disease. The tolerable risk adopted by international guidelines is 10^{-6} DALYs per person per year (NRMMC-EPHC-AMHC, 2006; WHO, 2006 and 2011).

Establishing the tolerable risk underpins the derivation of other health-based targets. Health-based targets are measurable health, water quality or performance objectives that are established based on a judgement of safety and on risk assessments of waterborne hazards. International guidelines describe four distinct types of health-based targets, applicable to all types of hazards and water supplies (NRMMC-EPHC-AMHC, 2006; WHO, 2006 and 2011):

- health outcome targets (e.g. tolerable burdens of disease)
- water quality targets (e.g. guideline values for chemical hazards)
- performance targets (e.g. log reductions of specific pathogens)
- specific technology targets (e.g. application of defined treatment processes)

To ensure effective health protection and improvement, targets need to be realistic, measurable, based on scientific data and relevant to local conditions (including economic, environmental, social and cultural conditions), and financial, technical and institutional resources. Health-based targets should be part of an overall public health policy (WHO, 2011).

7.1.3.2 Environmental risk characterisation

When assessing and managing environmental risks, the focus is particularly on chemical rather than microbial hazards, because chemical hazards (stressors) pose a greater risk to the environment than microbial hazards. However, there are emerging areas of concerns with respect to microbial hazards, such as transfer of antibiotic-resistant bacteria through waste to the environment (NRMMC-EPHC-AMHC, 2006). Human health is at far greater risk from microbial than chemical hazards, particularly for non-drinking uses. Therefore, compliance with guidelines for microbial risks to human health will minimise most of the environmental risks posed by microbial hazards.

In managing risks posed by water reuse to the environment, the aim is to protect biological diversity and maintain essential ecological processes and life-support systems. In place of DALYS and health-based targets, environmental guideline values are used; these are guideline values that relate to the impacts on specific endpoints or receptors within the environment.

The different uses of reclaimed water lead to different pathways by which reclaimed water enters the environment. It is important to look at both the initial receiving environment for reclaimed water and the final location, known as the environmental endpoint. In assessing environmental risk, a large number of endpoints must be considered (in contrast to assessing health risk, which focuses on a single endpoint in humans). Environmental risk assessment can be simplified by grouping the endpoints into the following broad categories (USEPA, 2012; NRMMC-EPHC-AMHC, 2006):

- Air
- Soils
- Plants (a specific biota)

- Biota (all other aquatic and terrestrial biota)
- Groundwater
- Surface water

Environmental risk characterisation is very complex to assess due to the great relevance of spatial and temporal scales, and the need for long-term monitoring campaigns. Therefore, it is common to perform qualitative or semi-quantitative assessments using mathematical models to apply environmental risk assessment to larger and more complex scales (Hope, 2006).

7.1.4 Determination of preventive measures to limit potential risks

This step deals with the identification of the existing and additional preventive measures to prevent significant hazards from being present in reclaimed water or to reduce the hazards to acceptable levels. It also considers critical control points, which are activities, procedures or processes to which controls can be applied, and that are essential for preventing or reducing high risks to acceptable levels. The identification of critical control points in the water reuse system can be made by applying a decision tree (Figure 4).

Critical control points require critical limits to be established. A critical limit is a prescribed tolerance that distinguishes acceptable from unacceptable performance (NRMMC-EPHC-AMHC, 2006).

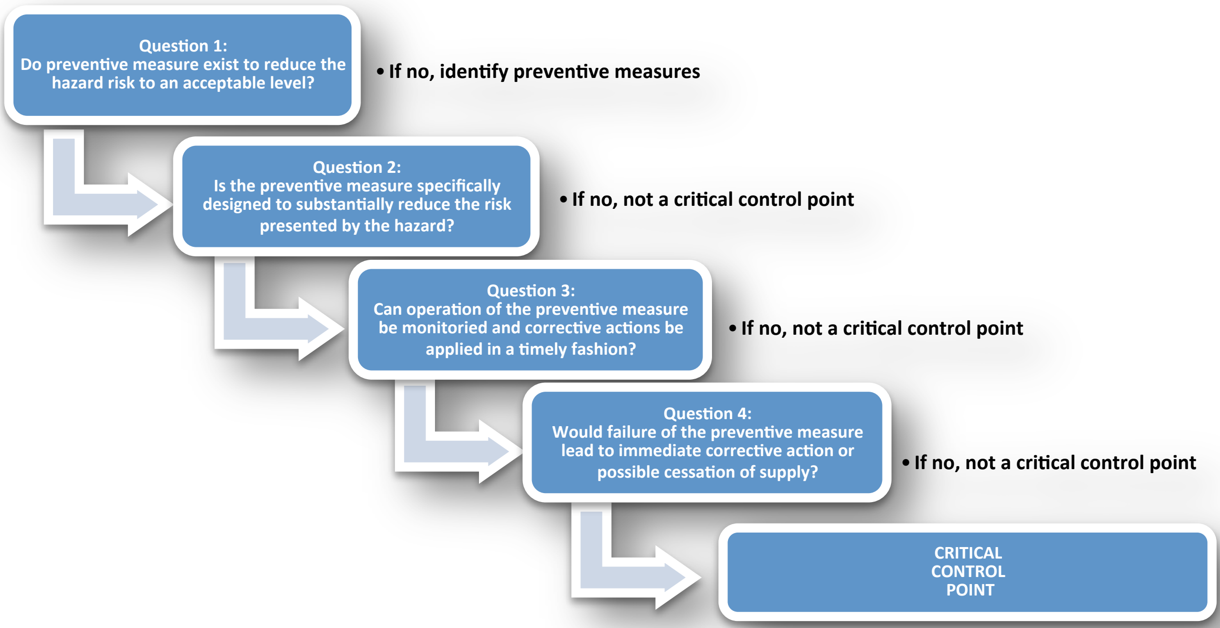

Figure 4 - Decision tree to identify critical control points (NRMMC-EPHC-AMHC, 2006).

7.1.5 Development of operational procedures and process controls

Proper use of water recycling technology requires the identification of operational procedures for all processes and activities applied within the whole reclaimed water system (source-to-use) to ensure that all activities are carried out effectively and efficiently. It is necessary to develop monitoring protocols for operational performance of the reclaimed water supply system, including the selection of operational parameters and criteria, and the routine analysis of results, to confirm that preventive measures implemented to control hazards are functioning properly.

Defining monitoring protocols also requires the inclusion of the corrective actions to be taken when operational parameters, the target criteria or critical limits are not met. It is important to verify whether a corrective action has been effective - this usually requires additional monitoring. Whenever possible, the underlying cause of the problem should be determined and measures implemented to prevent future occurrences. In this context, it is of paramount importance that the technology employed for monitoring is fit-for-purpose, and that the necessary infrastructure and human skills are available to operate it. Although this sounds trivial, numerous examples exist of water reuse processes running out of control due to an over-sophisticated monitoring technology (NRMMC-EPHC-AMHC, 2006).

7.1.6 Verification of the water reuse and quality of the receiving environment

This step comprises verification of the overall performance of the water reuse treatment system, the ultimate quality of reclaimed water being supplied, and the quality of the receiving environment. It provides confidence for all stakeholders, including users and regulators, in the quality of the water supplied and the functionality of the system as a whole. Verification involves three activities to provide evidence that the system is working properly (NRMMC-EPHC-AMHC, 2006):

- Quality monitoring of reclaimed water
- Monitoring of the application site and receiving environment
- Satisfaction of users of reclaimed water

Verification should be regarded as the final overall check that preventive measures are working effectively and that the target criteria or critical limits set by relevant guidelines are appropriate. As such, the purpose of verification is different from that of operational monitoring, and the two types of monitoring also differ in what, where and how often water quality characteristics are measured.

7.1.7 Management of incidents and emergencies

Incidents and emergencies are caused by processes running out of control. While appropriate contingency planning can increase the resilience of the water reuse process, one needs to consider the worst-case scenarios. Consequently, this element deals with considered and controlled responses to incidents or emergencies that can compromise the quality of reclaimed water. Such responses protect public and environmental health, and help to maintain user confidence in reclaimed water. It is necessary to establish incident and emergency protocols, and to develop and document response plans, with the involvement of relevant stakeholders.

In addition to the periodic review, it is important that the WRSP is reviewed following every incident, emergency, or unforeseen event to ensure that, if possible, the situation does not occur again, and to identify areas of improvement whether to cover a new hazard or revised risk for the risk assessment, or to revise an operating procedure, training issue or communication issue.

7.1.8 Validation of processes and procedures

This step aims to ensure that processes and procedures control hazards effectively. Validation involves evaluating available scientific and technical information (including historical data and operational experience) and, where necessary, undertaking investigations to validate system-specific operational procedures, critical limits and target criteria (NRMMC-EPHC-AMHC, 2006). The aim of process validation is to ensure the effective operation and control of the reclaimed water system. Validation is particularly important for innovative hazard-control processes and for schemes involving relatively high levels of exposure (e.g. residential use).

8 Water reclamation technologies

The implementation of the Urban Waste Water Treatment Directive (91/271/EEC) (UWWTD) resulted in an increase in the amount of treated wastewater ready to be reused. The main objective of wastewater treatment plants (WWTPs) is to remove suspended solids, organic matter, and, in certain areas, nutrients. These are the parameters enforced by the UWWTD with regard to discharging treated wastewater to the environment.

When treated wastewater is to be reused, there is a need for additional treatment in order to minimise health and environmental risks and ensure its quality and fitness for the foreseen use. The additional treatment is called reclamation treatment and is carried out in water reclamation plants (WRP) as an additional process in the WWTP. The main objective of reclamation treatment is to remove pathogens and chemical contaminants.

Reclamation technologies can be classified as intensive (conventional) and extensive technologies (non-conventional) (Table 14). Intensive technologies are characterised by the need for large quantities of energy and minimum space. They are accelerated artificial processes that can be rapidly modified if needed. In addition, they need highly specialised operation and maintenance personnel. Extensive technologies, on the contrary, require a large amount of land because they use environmental matrices and rely on natural processes for water treatment, so the processes occur at almost natural rates and the energy requirement is very low. These technologies also require low, but very important, levels of operation and maintenance.

Table 14 - Intensive and extensive reclamation technologies

Intensive technologies	Extensive technologies
Physical-chemical systems (coagulation-flocculation, sand filters)	Waste stabilisation ponds (maturation ponds, stabilisation reservoirs,…)
Membrane technologies (ultrafiltration, reverse osmosis, membrane bioreactor, …)	Constructed wetlands (vertical-flow, horizontal-flow,..)
Rotating biological contactors	Infiltration-percolation systems
Disinfection technologies (ultraviolet radiation, chlorine dioxide, ozone, peracetic acid, …)	

Each reclamation technology has its own characteristics and it is usually necessary to use a combination of two or more technologies to achieve the required water quality levels. The selection of the reclamation technology must take into account several premises such as the quality and the quantity of the water to be reclaimed, the final quality required for the specific use, the economic cost, and the environmental impact.

The concept of Best Available Technique (BAT), defined in the Industrial Emissions Directive (2010/75/EU), can be applied to reclamation technologies. The term BAT implies the selection of the most adequate technique that exists in the market for a specific aim, which is technically and economically viable and has the least environmental impact. The Best Available Techniques Reference Documents (BREFs) have a strong focus on water management in the relevant sectors, and also cover industrial water recycling (e.g. for the chemical sector). The BREF for industrial cooling systems explicitly mentions the reuse of reclaimed municipal wastewater in cooling water as a best practice reference (EC, 2001).

Energy consumption in the wastewater treatment sector has been subject to close examination, and methods for energy minimisation in wastewater treatment and/or water reuse through novel processes are currently being researched (Lazarova et al., 2012).

It is essential to have broad knowledge of the efficiency of the different reclamation technologies and their combinations. Regarding the efficiency and reliability of reclamation technologies, further research is needed on:

- The efficiency and reliability of WWTP (secondary treatment), in order to allow reclamation technologies to be more efficient in treating secondary effluents
- Extensive technologies in countries where these technologies are most likely to be appropriate (e.g. Mediterranean countries)
- The generation of removal capacities and byproducts by disinfection technologies
- Industrial-scale research with real operational conditions of WWTPs and WRPs (most of the research on reclamation technologies to date has been made on laboratory and pilot scales).

Once the water has been reclaimed, it is generally necessary to distribute it to the point of use. For such transport, reclaimed water has to be stored and distributed using storage and distribution systems which may microbiologically and chemically impact the quality of the water. This is why Water Reuse Safety Plans must cover the whole system, from the WRP to the point of use.

A water reuse scheme is likely to have many possible design options: type and degree of treatment, number and location of pumping stations, number, size and location of storage tanks, and layout and size of distribution pipe networks. These elements can be combined into a very large number of design options, even for apparently small systems. The planning of water reuse schemes is therefore highly complex, and a decision support system (DSS) is required that will help in the planning process (Joksimovic et al., 2006).

9 Barriers to water reuse implementation

Despite the water reuse applications already developed in many countries, a number of barriers still prevent the widespread implementation of water reuse throughout Europe and on a global scale. These barriers will have to be overcome if wastewater reuse strategies are to be adopted on a larger and more effective scale than at present, developing the huge eco-innovation potential in terms of technologies and services related to water recycling in industry, agriculture and urban sectors. The main barriers identified are:

- Inconsistent or inadequate water reuse regulations/guidelines, which lead to delays and misjudgements
- Inconsistent and unreliable methods for identifying and optimising appropriate wastewater treatment technologies for reuse applications, which are able to balance the competing demands of sustainable processes
- Difficulties in specifying and selecting effective monitoring techniques and technologies for the whole system

- Significant challenges in reliably assessing the environmental and public health risk/benefit of water reuse across a range of geographical scales
- Poorly developed business models for water reuse schemes, and markets for reclaimed water
- Low levels of public and government enthusiasm for water reuse
- Limited institutional capacity to formulate and institutionalise recycling and reuse measures
- Lack of financial incentives for reuse schemes

From a technical standpoint, water reuse is a logical part of the overall water supply and resource management solution. However, technically feasible water reuse projects often do not get implemented due to institutional, economic, and organisational barriers, or poor public perception and education. These non-technical barriers are a limitation to the expansion of water reuse planning.

A basic driver of reluctance to use wastewater, and barrier to wastewater treatment and planned reuse, is the dearth of effective collection and treatment systems for faecal matter and sewage around the world.

While the lack of appropriate infrastructure poses a constraint to water collection, treatment, and safe reuse in some areas, there are at least two broader barriers to planned water reuse: 1) limited institutional capacity to formulate and institutionalise enabling legislation and to subsequently conduct adequate enforcement and monitoring of water reuse activities, and 2) lack of expertise in health and environmental risk assessment and mitigation.

Additional barriers include public perceptions that may drive fear of the dangers of consuming food irrigated with reclaimed water. Public outreach programmes to build awareness and involve community members in planning could change public resistance to water reuse. An impressive public awareness programme has been carried out in Singapore to build a national commitment to water reuse (Singapore-NEWater). In the city of San Diego, California, intense public opposition to water reuse changed over a period of many years, largely because of public outreach campaigns and stakeholder involvement, in addition to the economic driver of local water scarcity (USEPA, 2012).

Long-term economic viability also represents an important barrier to water reuse. Reclaimed water is often priced just below the consumer cost of drinking water to make it more attractive to potential users, but this may also affect the ability to recover costs (Jimenez and Asano, 2008). Distortion in the market for drinking water supply complicates the pricing of reclaimed water, as does the lack of accounting for externalities, including water scarcity and social, financial, and environmental burdens of effluent disposal in the environment (Hochstrat et al., 2006).

Fragmentation of responsibilities for and authority over different parts of the water cycle is another impediment that must be overcome before water reuse projects can go forward. In many regions the authority over the water supply sector resides in an entirely different organisation than that responsible for wastewater management. This separation of powers leads to long periods of inaction, stalemates, disagreements, negotiations, and complex interagency agreements that make the resulting water reuse project far more costly and complex than necessary. Regions where the same authority manages water, wastewater, stormwater, and the watershed are far more nimble, implementing their water reuse projects quickly, efficiently, and at much lower cost (Sheikh, 2004). In order to implement integrated and sustainable water management, it is necessary to bridge the tight but artificial compartments of water supply and sanitation. Too often, water reuse is excluded from possible integrated water management scenarios due to the misperceptions of stakeholders.

The report "Municipal Water Reuse Markets 2010", published by Global Water Intelligence in collaboration with the Singapore Public Utilities Board (SPUB) (GWI, 2010), represents the most extensive research published about the market for water reuse to date. It reveals that urban development represents the largest potential for water recycling applications, and that growth in the global water reuse sector is expected to migrate from agricultural irrigation towards higher-value applications, mostly in municipal applications, such as drinking water supply, industry, and landscape irrigation reuse. In addition, the report states that water reuse will grow more quickly than desalination in percentage terms. The current capacity of water reuse plants which meet generally accepted public health standards is around 28 Mm^3/d. This compares to around 41 Mm^3/d of seawater desalination capacity. By 2016, the water reuse capacity is expected to grow by 180% to 79 Mm^3/d, whereas seawater desalination capacity is expected to grow by 120% to 89 Mm^3/d.

The agriculture sector has the highest water demand of all sectors. It is therefore a primary objective to expand the application of water reuse to agriculture, but issues such as storage, distribution and risk management as well as financing must be addressed. In the urban sector, substantial efficiency gains are possible from reuse schemes in terms of water, energy and cost savings. However, urban reuse schemes also present the biggest challenges in terms of delivering publicly acceptable, technologically robust and economically sound schemes. The water requirements of the industrial sector are quite diverse in terms of quality and quantity, but offer plenty of opportunities due to the potential cost savings achievable. However, technologies and services that address the specific needs of the industry sector have yet to be developed.

Only a limited number of countries have developed comprehensive water treatment and reuse standards, provide direction, and encourage and finance wastewater reuse programmes. Some countries, which do not have long-term planning, have adopted less comprehensive and rigorous standards in order to reflect the actual reuse practice. Often, overly strict standards have led to only a few instances of legal reuse and a high number of illegal - and thus unmonitored - reuse practices in some countries. It is clear that treated wastewater reuse plays an important and increasing role in meeting demands for water, even without special European-level guidelines or regulations. Member States' regulations should ensure safe wastewater reuse practices locally. However, the difference in standards between EU Member States can cause confusion over best practice and what is sustainable for local situations and type of applications. Lack of state regulation and EU guidelines are therefore not conducive to developing best practice. Harmonised and locally adapted guidelines for treated wastewater reuse are crucial to overcome the barriers that discourage the development of further reuse activities. These barriers hinge on the lack of understanding of the benefits of water reuse, and of the risks to public health and the environment whenever appropriate guidelines are not followed.

The Blueprint to Safeguard Europe's Water Resources (COM(2012) 673) calls for a proposal for the development of a regulatory instrument on standards for water reuse by 2015. The establishment of such EU guidelines and best management practices will help:

- Avoid unnecessary restrictions and disadvantages of national regulations (e.g. the excessive number of parameters to be monitored - 65, 72 and 55 parameters need to be monitored for Greece, Spain, and Italy, respectively)
- Improve the management of water resources and increase the protection of public health and environment in a sustainable way, as mandated by the WFD
- Reduce the cost of effluent reuse projects, and encourage the use of alternative water sources

The development of a regulatory instrument that includes treatment processes, reclaimed water quality, and monitoring frequency, should be based on:

- Water reuse experience in the EU Member States and elsewhere (e.g. USA, Australia)
- Research, pilot studies or demonstration study data
- Technical material from the literature

- Water reuse rules, regulations, policies, or guidelines
- Attainability
- Sound engineering practice
- Use with a multiple barrier approach

10 Conclusions and recommendations

Water recycling and reuse are rapidly growing practices worldwide that can provide sustainable, cost-competitive and energy-saving options to help increase water availability, while providing a viable solution to climate change adaptation. While the water reuse industry benefits from technological advances and innovations, it also faces several new challenges such as concerns about health impacts, energy footprints and social and economic considerations. Despite the growing development of water reuse worldwide, its full-scale implementation and operation still face several regulatory, economic, social and institutional challenges. Water reuse is quite an interdisciplinary and intersectorial issue which needs to be considered using an integrated approach. Water reuse practices must be adapted to each local situation in order to be safe, beneficial and sustainable, both financially and environmentally. Water reuse quality criteria should be consistent and enforced by good management of reclaimed water quality.

The convergence of water reuse regulations is a very important challenge for the worldwide development of water reuse and its integration into urban water management. New regulations should be based on health and environmental protection, and should include treatment goals and adequate and affordable water quality monitoring. Costly monitoring of compliance, such as that required by several recent regulations, could be an impediment to water reuse development.

The economic viability of water reuse projects is another significant challenge that can be met by means of adequate water management policies. The value of reclaimed water is determined by the use to which it is put. Full cost recovery is a desirable objective, but depends on ability to pay and the importance of other management objectives, including social and environmental criteria (Lazarova et al., 2012).

The social and cultural aspects of water reuse must be understood in order to develop sustainable water recycling schemes. Water reuse projects can fail as a result of lack of social support; reuse for drinking purposes meets with the strongest opposition. Even for non-drinking reuse purposes, public attitudes regarding their perception of water quality, and their willingness to pay or to accept a wastewater reuse project, play an important part. In every country, the public's knowledge and understanding of the safety and applicability of reclaimed water is key to the success of any water reuse programme. Consistent communication and easily understood messages must be delivered to the public and stakeholders, explaining the benefits of water reuse for long-term water security and sustainable urban water cycle management.

The bottleneck for high-end water recycling systems, which usually involve membrane technologies and consume substantial amount of energy, has been noted. In the near future, the main challenge that may face water reuse is likely to be the development of novel processes that consume less energy and/or enhance energy recovery.

In addition, the experiences from around the world where water reuse is a common consideration in integrated water management (e.g. USA, Australia) should be utilised.

There is still a long way to go to achieve the ultimate goal of sustainable water management worldwide, where water reuse plays a key role in establishing a beneficial linkage between water, nature and human society.

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