AquaNES

Demonstrating Synergies in Combined Natural and Engineered Processes for Water Treatment Systems

Deliverable D3.1

Combining constructed wetlands and engineered treatment for water reuse

COLOPHON

Project

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BOD_5	Biochemical Oxygen Demand
$Cl._{res.}$	Residual chlorine
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
CW	Constructed Wetland
E. coli	Escherichia coli
EC	European Commission
E.C.	Electrical conductivity
HSSF	Horizontal subsurface flow
I.N.	Intestinal Nematodes
LOQ	Limit of quantification
Mm^3	Million m^3
NH_4-N	Ammonium nitrogen
NO_3-N	Nitrate nitrogen
p.e.	population equivalent
RSF	Retention soil filter
SAR	Sodium Adsorption Ratio
STDEV	Standard deviation
TC	Total coliforms
TiO2	Titanium dioxide
TN	Total nitrogen
TP	Total phosphorus
TSS	Total Suspended Solids
UF	Ultrafiltration
UWWTD	Urban Wastewater Treatment Directive
VSSF	Vertical subsurface flow
WFD	Water Framework Directive
WHO	World Health Organization
WW	Wastewater
WWTP	Wastewater treatment plant

Executive Summary

In this report, the treatment efficacy of four demonstration sites combining constructed wetlands with engineered pre- or post-treatment processes for wastewater treatment is evaluated focusing on the achievement of effluent quality suitable for water reuse. Special focus is given on the performance of disinfection processes and their combination with constructed wetlands targeting water reuse applications for treatment of primary effluent and polishing of secondary effluent. Monitoring results of the demonstration sites are compared to five existing legally binding national water reuse regulations of European countries, highlighting similarities and differences between these regulations. Results are furthermore compared to the EU-level water reuse standards proposed by the European Commission in May 2018: "Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse" (COM337, 2018).

The first part of this report focuses on the comparison of the application of water reuse in the EU and the different national regulations in Cyprus, France, Greece, Italy and Spain – countries, which incorporated water reuse standards into their national laws.

Water reuse legislations vary significantly among the EU member states. Different reclaimed water uses associated with different water quality classes and varying levels of detail in definitions are considered in each regulation. The number of classes defined in the regulations varies from 1 class including 3 categories of reuse purposes in Italy to 12 classes including 24 categories of reuse purposes in Spain. The allocation of a reuse purpose to the relevant class in the different regulations may change when looking at the level of definition of the regarded reuse purpose. For example, differences in individual definitions for use types of agricultural products, such as irrigation of a "crop consumed processed" and a "vegetable consumed cooked", may lead to the inclusion or exclusion of the same reuse purpose into different classes in some of the regulations. The same is true for restrictions of irrigation types, which can differ regarding temporal or spatial restrictions. The number of water quality parameters which are restricted by each national regulation also differs considerably, ranging from six parameters regulated by the French water reuse legislation to 55 parameters regulated in Italy. In certain cases, the number of restricted parameters can increase up to 80 (Greek reuse regulation for WWTP > 100,000 p.e.) or even 90 in Spain (when requested by regional government depending on external regulations concerning the protection of the receiving environment). Apart from defined water reuse classes, regulated parameters and relevant limit values, the national reuse regulations also differ with regard to compliance requirements, which further complicates evaluations. While some regulations specify a percentile of samples required to comply with the set limit values (e.g. 80% of annual samples need to meet the limit), others require the annual mean to comply with the limits. In addition, sometimes maximum allowed deviation limits for samples exceeding the limit values are defined. As these specifications may not only vary among different regulations but also for different parameters in the same regulation, as well as among different quality classes for the same parameter in the same regulation, an evaluation of monitoring results of the different demonstration sites in regard to the national water reuse regulations is challenging and might become confusing.

The proposal of the European Commission for an EU-level regulation on water reuse includes 4 water quality classes and 4 restricted quality parameters (with two additional for certain reuse purposes). However, water reuse in this proposal is only limited to agricultural irrigation. In contrast to national regulations, the EC proposal includes performance criteria for unrestricted irrigation on top of effluent quality limits.

The variability of standards and definitions for water reuse across European countries poses a barrier for the wide application of reclaimed water, resulting in an underdevelopment of the water reuse sector in Europe.

The second part of the report provides a comparison of the monitoring results of four AquaNES constructed wetlands (CW) demonstration sites in Greece and Germany with European water reuse regulations. Because of the regulatory heterogeneity described above, a direct comparison of the different European water reuse regulations with monitoring data of the demonstration sites is only possible for well-defined cases, as the allocation to the relevant class in the different regulations may change when looking at the level of definition of the regarded reuse purpose. Therefore, three specific reuse cases have been defined (for details see 3.1):

- restricted irrigation (irrigation of beans using drip irrigation),
- unrestricted irrigation (irrigation of tomatoes using any irrigation methods) and
- urban irrigation (irrigation of a public park).

For both Greek sites, monitoring results were evaluated regarding respective water reuse classes of these use cases for all national legislations, while for both German sites, evaluation was only done in respect to the standards proposed by the European Commission.

The two Greek sites, Antiparos and Thirasia wastewater treatment plants (WWTP), are both located on the Cyclades island group of the Aegean Sea, and are full-scale WWTPs subjected to significant season fluctuations in the hydraulic and pollution loads between summer and winter periods. The combination of a two-stage CW with chlorination-disinfection realized at Antiparos WWTP results in water quality suitable for "restricted irrigation" according to the French and Greek regulation as well as to the EU-level proposed regulation (COM337, 2018). TSS and electrical conductivity (E.C.) have been identified as the two main parameters limiting possible reuse options. Before implementation of reconstruction measures in clogged wetland beds and pond, and managerial changes for optimization of plant performance (restriction of sewage trucks per day during peak season) some limits for "restricted irrigation" were exceeded. This was mainly due to elevated TSS concentrations and temporarily due to elevated concentrations of *E. coli* resulting from insufficient chlorination at peak flows that exceeded the design capacity of the plant. Different constructional and managerial improvements in this plant were found to improve and equalize the performance of the plant under peak and low flow conditions in summer and winter periods. However, high values for E.C. in WWTP effluent would prevent application in countries with reuse legislations that include this parameter (i.e. Cyprus, Italy, Spain).

The Thirasia WWTP combines primary treatment and photocatalysis before horizontal subsurface flow (HSSF) CWs with subsequent ultrafiltration and chlorination. The quality of treated effluent meets the requirements for the defined case of "restricted irrigation" only according to the French regulation and the EU-level proposal. Parameters limiting the effluent's suitability for reuse are more variable among the three defined reuse purposes and among the different reuse regulations compared to the Antiparos WWTP. The only parameter exceeding the Greek limits for "restricted irrigation" is total nitrogen. Performance of the HSSF CW regarding total nitrogen (TN) removal is not optimal, thus, the average concentration of total nitrogen in WWTP effluent (50 mg/L, n=24) exceeds the limit of class 3 of the Greek reuse regulation (45 mg/L). However, values since August 2018 show an improved removal of TN that always meets the limit (mean: 34 mg/L, n=11). Further analyses are suggested to ensure the sufficient removal of TN to reliably meet the Greek limit for water reuse. Testing different dosages of titanium dioxide (TiO_2) in the photocatalysis stage led to the conclusion that adding the catalyst does not considerably improve the removal of relevant parameters, and therefore is economically unfeasible. Similar and relevant removal for BOD_5 and COD (~60%)

and TN (~30%) were found regardless of TiO2 dosage, even without addition of the catalyst and associated chemicals. Thus, it is recommended to run this stage as aeration stage with sedimentation.

In the two German sites (Schönerlinde and Erftverband), polishing stages were tested at pilot scale after full-size WWTPs. Effluent quality was evaluated for compliance with the proposed EU-level water reuse quality standards.

In Schönerlinde, the combination of ozonation with two CWs differing in substrate composition (sand or lava gravel with biochar) was demonstrated. Regarding *E. coli*, most of the removal was accomplished during ozonation (>2 log units), which also achieved removal of various micropollutants (see D3.2). The subsequent removal in both wetland types was similar, reaching a further reduction of *E. coli* by about 0.5 log units and resulting in effluent quality that meets class B limits according to the proposed limits of COM337. When ozonation was not in operation, the conventional wetland (with sand as substrate) still achieved a similar effluent concentration for *E. coli* (2.7 log-reduction), demonstrating the robustness of this combination for water reuse purposes. TSS and turbidity were well removed by CWs reaching the best class A limit for these parameters. Overall, the combination of ozonation with CWs for polishing of WWTP effluent is a good option to achieve a very good effluent quality suitable for water reuse, with the potential to reach class A quality suitable for irrigation of crop that is consumed raw with further reduction of *E. coli* by about 0.5-1 log units.

At Erftverband, a full-scale system is built at WWTP Rheinbach for flexible treatment of combined sewer overflow (CSO) during storm events, and polishing of WWTP effluent during dry weather. Three pilot-scale retention soil filters (RSF, specific form of vertical flow CWs for the treatment of rain water and/or wastewater) were tested for >3 years with one system containing an additional layer of activated carbon, and one RSF being subjected to simulated CSO events. Regarding *E. coli*, only class C limit is achieved (mean log removal in wetlands about 1.5). During CSO events with high peaks of *E. coli* in the influent of the RSF, effluent quality does not meet the requirements for any reuse purpose defined in the EC proposal, even though a log removal of about 2.5 is achieved. A temporary disinfection during heavy rain events would be necessary in order to provide effluent suitable for water reuse. BOD_5 and TSS do not limit water reuse according to the EC proposal, thus, a sufficient disinfection would allow water reuse even for class A reuse purposes.

Overall, systems, which include a combination of CWs with some sort of technical system with disinfection capabilities, achieved class B effluent quality according to the proposed EU-level standards. The Erftverband site containing a natural treatment stage without an additional disinfection achieved class C quality when not subjected to CSO events. Thus, effluents of all sites would be suitable for the following reuse purposes defined in the EC proposal: (a) food crops consumed raw, where the edible portion is produced above ground and is not in direct contact with reclaimed water; (b) processed food crops and (3) non-food crops including crops to feed milk- or meat-producing animals. Whereas in class B the irrigation method is unrestricted, in class C only drip irrigation is allowed.

The combination of CWs with disinfection treatment processes for wastewater treatment in small communities is a promising option for the wider application of water reuse, at least for restricted irrigation purposes.

1 Introduction

In this report, the treatment efficiency of four AquaNES demonstration sites combining CWs with engineered pre- or post-treatment processes for wastewater treatment is evaluated, focusing on the achievement of effluent quality suitable for water reuse. Special focus is given on the performance of disinfection processes and their combination with constructed wetlands targeting water reuse applications for treatment of primary effluent. This report is related to deliverables D3.2 and D3.3, which provide more detailed technical information and results with regard to other parameters not relevant for water reuse (e.g. micropollutants), and design recommendations of the regarded demonstration sites.

After a summary of constructed wetland types, functions, advantages and limitations (chapter 1.1), chapter 2 concentrates on the status of water reuse in Europe in regard to application and regulation in countries with water reuse legislations, highlighting similarities and differences between existing national laws. In addition, the recent water reuse standards proposed by the European Commission in May 2018 for water reuse regulation on a European level ("Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse.", COM337, 2018) is also considered. Then, monitoring results of the four demonstration sites combining constructed wetlands and engineered pre- or post-treatments are thoroughly evaluated and compared to the water reuse regulations in Europe (chapter 3).

Two of the demonstration sites are located on the Greek Aegean islands Antiparos and Thirasia (AquaNES sites 10a and 10b). These systems are full-scale wastewater treatment plants (WWTP) designed to treat the municipal wastewater of the islands' population (< 2,000 p.e. during winter), which is subject to significant seasonal fluctuations of hydraulic and pollution loads. In Antiparos, the main treatment step comprises of a two stage vertical subsurface flow constructed wetland combined with subsequent chlorination. The treated water is reused for irrigation of public spaces in the proximity of the WWTP (drip irrigation method) or for fire protection purposes. In Thirasia, pretreated effluent is subjected to solar heterogeneous photocatalysis followed by horizontal flow wetlands, ultrafiltration and chlorination. The treated water is reused for irrigation of trees and ornamental plants inside the plant premises, or for aquifer recharge through subsurface disposal by underground perforated pipes. The acquired effluent quality data of both Greek demonstration sites are compared to the limits set by the Greek water reuse legislation, as well as to the limits set by existing water reuse regulations of other EU countries (i.e. Cyprus, France, Italy and Spain).

The two remaining demonstration sites are located in Germany (in Western Germany - Erftverband and in Northern Germany - Schönerlinde). Both systems are pilot-scale units treating effluent of existing WWTPs. In Erftverband (AquaNES site 11), retention soil filters (a specific type of vertical flow constructed wetlands) are used for flexible treatment of secondary effluent during dry weather conditions as polishing step and combined sewer overflows during heavy rainfall events. The addition of granular activated carbon to one layer of the filter medium for improved removal of micropollutants is also tested in one pilot filter. In Schönerlinde (AquaNES site 12), the combination of ozonation followed by two different types of constructed wetlands for further treatment of WWTP effluent is assessed.

A comprehensive comparison of the monitoring results of all four sites with European water reuse regulations is conducted to highlight differences between national regulations and evaluate the marketability of the examined cNES solutions in different EU member states in light of the proposal of the European Commission for a water reuse regulation on a European level.

1.1 Constructed wetlands for water treatment

Constructed treatment wetlands (including "reed bed treatment systems" or "planted soil filters" which are special CW types and are often used as synonyms) are near-natural wastewater treatment technologies which can treat raw, primary, secondary or tertiary treated sewage in a sustainable and environmentally friendly way. Their main implementation area is the treatment of domestic wastewater, but CWs are also applied to purify many types of agricultural and industrial sewage as well as stormwater runoff and surface waters.

Constructed filtration wetlands (also called "subsurface flow wetlands") consist of basins filled with porous filter media, usually sand or gravel, and planted with wetland vegetation tolerant of saturated conditions (most often common reed, reed canary grass, and cattail, iris, reed sweet grass, papyrus). Their design and the high biological activity in wetland ecosystems result in an improved treatment capacity (Dotro et al., 2017; Kadlec & Wallace, 2009; Rozkošný et al., 2014; UN-HABITAT, 2008).

1.1.1 Types

CWs can be designed in a variety of hydrologic modes (Kadlec & Wallace, 2009). There are three main types of CWs:

- Surface flow wetlands (also known as "Free Water Surface (FWS)" wetlands) – SF;
- Subsurface flow wetlands – SSF;
- Hybrid systems (combine different types of CW).

FWS CWs are densely vegetated units with areas of open water (see Figure 1). They resemble natural marshes and are commonly implemented for tertiary wastewater treatment. SF wetlands are typically low loaded and therefore require large areas (Dotro et al. 2017; Kadlec & Wallace, 2009).

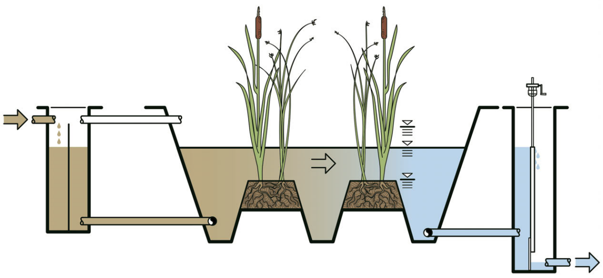

Figure 1 Overview schematic of FWS wetland (Dotro et al. 2017).

SSF CWs are divided in two types according to flow direction (Figure 2):

- Horizontal subsurface flow (HSSF) wetlands;
- Vertical flow (VF) wetlands.

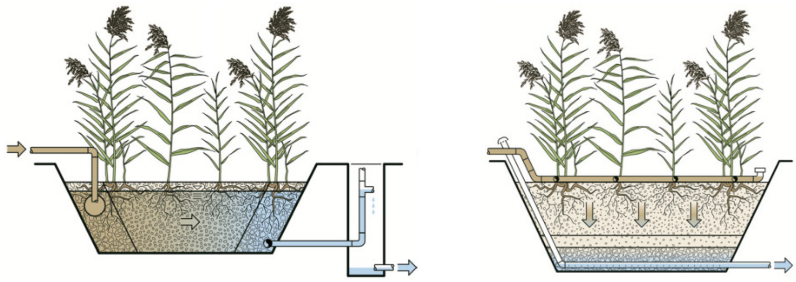

Figure 2 Overview schematics of HSSF (left) and VF (right) CW (Dotro et al. 2017).

The water level in SSF CWs is kept below the surface of the filter medium. In HSSF CWs the water flows horizontally from the inlet to the collection zone, while in VF CWs it percolates through the plant root zone (see Figure 2). Mainly anaerobic processes occur in HSSF CWs due to the saturated conditions. VF CWs are dominated by aerobic processes through the aeration of the pores between the intermittent loadings. In general, SSFs are used to treat primary or secondary treated wastewater (Dotro et al. 2017; Kadlec & Wallace, 2009).

A special combination of VF CWs is the so-called "French System". The system is designed to treat raw wastewater, thus providing an integrated sludge and wastewater treatment (most common application is as a two-stage system; see Figure 3) (Dotro et al. 2017; Hoffmann et al 2010; Kadlec & Wallace, 2009).

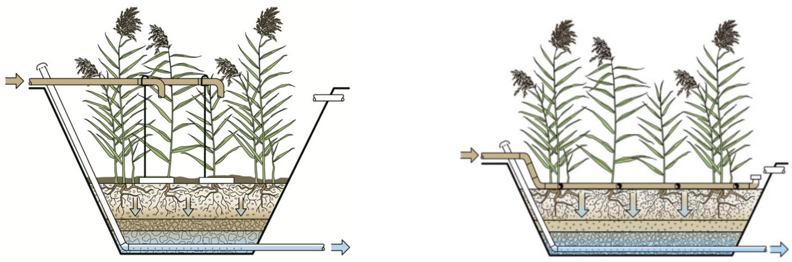

Figure 3 Two-stage system of French VF wetland (left: first stage, right: second stage) (Dotro et al. 2017).

1.1.2 Function

The basic principle of SSF treatment is the flow of wastewater through the porous filter media. Pollutants in these CWs are removed by several complex physical, chemical and biological processes. Aerobic degradation mechanisms play an essential role in the pollutant removal process (see Table 1). Aerobic organic degradation depends on the relation between oxygen demand (load) and oxygen supply (CW design) (Hoffmann et al. 2010). In passively aerated systems oxygen is provided mostly by convection of air in the pours media when batch loading of the fully drained VF CWs takes place.

Vegetation plays a vital role in the treatment, providing surfaces and a suitable environment for microbial growth and filtration in FWS CWs. The movement of plants by wind and the continuous growth of roots, rhizomes and sprouts maintain a permeable filtration layer in VF CWs (Dotro et al., 2017; Kadlec & Wallace, 2009; Rozkošný et al., 2014; UN-HABITAT, 2008).

The filter environment must fulfil the pre-defined requirements in terms of hydraulic conductivity and load of wastewater by pollution, flow rate, frost penetration, or the possibility to bind phosphorus and heavy metals. Filter material must be permeable enough to avoid clogging and subsequent surface flow (Rozkošný et al., 2004; UN-HABITAT, 2008).

Table 1 Pollutant removal mechanisms in CWs (Dotro et al., 2017; UN-HABITAT, 2008).

Wastewater constituents	Removal mechanisms
Suspended solids	– Sedimentation – Filtration
Soluble organics	– Biological degradation (aerobic and/or anaerobic)
Phosphorous	– Adsorption-precipitation reactions – Plant uptake (usually of minor relevance)
Nitrogen	– Ammonification followed by microbial nitrification and denitrification – Plant uptake (usually of minor relevance) – Matrix adsorption (temporary) – Ammonia volatilization (mostly in FWS CWs)
Metals	– Adsorption and cation exchange – Complexation – Precipitation – Plant uptake – Microbial oxidation /reduction
Pathogens	– Natural die-off – Predation – UV irradiation (in FWS CWs) – Excretion of antibiotics from roots of macrophytes

1.1.3 Advantages

CW systems for the treatment of wastewater, combined sewer overflow, surface water, or for polishing of WWTP effluent, are (Geller & Höner 2003; Kadlec & Wallace, 2009; Lombard Latune & Molle, 2017; Vymazal, J. 2010):

- Cost efficient operation (low maintenance costs, low need of energy);
- Resilient/robust to (seasonal) changes of hydraulic and organic loading;
- Easily operated (thus optimal for small decentralized treatment systems);
- Environmentally friendly (no use of chemicals, treatment systems as habitats, providing additional ecosystem services);
- Socially beneficial (no visual obstruction, potential recreational use);
- Able to remove pathogens by 1,5-2,5 log-units in SSF wetlands.

1.1.4 Limitations

The performance of CWs can be limited by several parameters (DWA, 2017; Kadlec & Reddy, 2001; Li et al., 2014):

- Space: depending on system choice, (1-4 m^2/p.e. for secondary SSF CWs).
- Climate: As for any other treatment system microbiological degradation processes are reduced at low temperatures; SSF CWs show retarded slow down in nitrogen transformation processes in winter due to immobilized and underground protected biofilm; for very cold climates with long freezing periods SSF CWs with insulation layer and activated aeration technology have been developed.

- Removal of specific compounds: other than activated sludge plants, substances can not be removed by sludge (except by French systems to some degree). That means P-removal is restricted to binding capacity in plants and humus accretion or to adsorption capacity of reactive filter media. Special parameters may need combination with engineered systems such as oxidation, precipitation or disinfection.

  Dimensioning rules for parameters besides COD/BOD, TSS, NH4-N, TN need to be developed individually for special combinations.

2 Water reuse in Europe

The spatial distribution of water resources varies globally. In Europe, a significant spatial variance exists for allocation of water resources across different countries and even within the same country (especially in the Mediterranean area), as pointed out by a review on the current status of water reuse in Europe done in 2018 (Water Reuse Europe, 2018). One third of Europe was said to have a water availability of less than 5,000 m³ per person and year, and about 17 percent of the EU territory faces water scarcity (Jeffrey, 2019). Increasing water scarcity is mainly driven by climate change, urbanization and the growing water demand of competing water uses. Degrading water quality puts further pressure on the availability of high quality water resources for drinking purposes and may increase the financial cost of water supply (BIO by Deloitte, 2015; EC, 2016; EC, 2016a). Although water reuse is a widely recognized strategy to relieve water scarcity, the European water reuse sector is rather small in the global context. On a global scale 30 Mm³/day of water are being reused, while only 2.6 Mm³/day are being reused in Europe in 2006 (Water Reuse Europe, 2018). Annually, this results in an amount of 1,100 Mm³/year of water that is reused in Europe, which is about 2 to 3% of the total volume of treated wastewater and 0.5% of the total annual fresh water extractions in the EU (BIO by Deloitte, 2015; Helmecke, 2019). The main consumer of reclaimed water in the EU is Spain producing about half of the total amount of reclaimed water in Europe. However, overall the quantity of reclaimed water corresponded to only 5 to 12% of the total treated urban effluents in Greece, Italy and Spain (Bio by Deloitte, 2015). Cyprus on the other hand was reported to reuse about 90%-97% of all treated wastewater (Bio by Deloitte 2015, WRE review 2019). In Malta, the share of reused water was is about 60% (BIO by Deloitte, 2015).

Across the EU a total of 787 reuse schemes distributed across 16 countries were identified in the Water Reuse Europe Review from 2018, indicating an increase by 437 schemes since 2006 (45 of which are pilot-scale). An overview of the countries with the majority of the schemes can be found in Table 2 together with the percentage distribution of intended reuse purposes in all schemes. Application in agriculture was the highest intended purpose for reclaimed water (39%: 307 of 787 schemes). And more than half of the total volume of reclaimed water in the EU (52%) is being used for agricultural purposes (Bio by Deloitte, 2015; Jeffrey 2019). The European market was estimated to have the potential to increase its reuse capacity to 6,000 Mm³ per year until 2025, considering around 71,000 wastewater treatment plants in the 28 member states (Water Reuse Europe, 2018).

Table 2 Water reuse schemes and common reuse purposes across the EU (Source: Water Reuse Europe Review, 2018)

Country	Number of reuse schemes
Southern Europe	**537**
Spain	361
Italy	99
Greece	44
Northern Europe	**250**
France	112
Germany	36
Netherlands	28

Percentage distribution of reuse purposes across the 787 schemes	
Agriculture	39%
Industry	15%
Recreation	12%
Environment	11%
Mixed	11%
Other users	12%

As pointed out in the Water Reuse Europe Review (2018), the demand for alternative water resources and the application of water reuse varies between European countries according to the quantity of accessible natural water resources. This is underpinned by the fact that 62 percent of the 787 reuse schemes are located in water scarce areas, particularly "along coastlines where fresh water resources are limited and adversely affected by environmental issues such as drought as well as over-abstraction of water due to tourism and agricultural activities" (Water Reuse Europe Review, 2018). This strongly concerns the Mediterranean coast at which 47 percent of the schemes are located. For example, out of the 361 Spanish reuse schemes 200 are located at the Mediterranean coast. Another 17 percent of the schemes were found on islands, including 16 sites on Greek islands (similar to the demonstration sites Antiparos and Thirasia which are being evaluated in this report).

Water reuse is applied in a limited number of European countries, the most comprehensive water reuse regulations and standards have been developed in Cyprus, France, Greece, Italy, Spain and Portugal. Besides Portugal, the standards in these countries are legally binding.

Below, a short summary on the status of water reuse is provided for European countries which have a legally binding water reuse regulation. The summaries are based on information provided in the final report to support the European Commission's Impact Assessment (EC, 2016).

2.1 National status of water reuse

2.1.1 Cyprus

Cyprus is facing the most severe water stress in Europe. Drought incidents are increasing both in magnitude and frequency. The only natural input to the country's water systems comes from precipitation. However, 89% to 95% of precipitation is lost due to evaporation. The irrigation demand of most crops is significant, putting a high pressure on groundwater resources. At the same time water scarcity and water quality deterioration are limiting the development of the tourism sector, which is very important for the national economic development. Because of this, water reuse as an option to relieve the pressure on the natural water resources is of high interest in Cyprus.

Domestic and agricultural sectors have the greatest water demand in Cyprus. Water consumption for irrigation accounts for 60% of the country's total water consumption and fluctuates around 150 Mm^3/year. A national objective has been set to replace 40% of agricultural water demand using reclaimed water in order to reduce over-abstraction of groundwater sources.

Cyprus was reported to reuse about 90% of all treated wastewater in the Bio by Deloitte report from 2015 and about 97% in the WRE review published in 2019. Irrigation was the main application for reclaimed water in 2011 with about 25 Mm^3 of tertiary treated wastewater being reused for irrigation that year. These irrigation purposes include agricultural irrigation (orchards of citrus and olive trees and fodder crops) as well as recreational purposes (e.g. irrigation of parks, hotel gardens and golf courses). Agricultural irrigation uses about 12 Mm^3/year of reclaimed water, covering about 10% of the sector's water demand.

Groundwater resources are being overexploited (sustainable abstraction rates exceeded by 40%), with decreasing groundwater quality. This is mainly due to saline water intrusion caused by over-abstraction and nitrate pollution caused by agricultural activities, which increasingly makes untreated groundwater unsuitable for domestic water supply. Although the recharge of depleted aquifers with reclaimed water could potentially alleviate these issues, it is also associated with potential risks (e.g. groundwater quality degradation by pathogenic viruses and other pollutants). So far, only 15% of the reclaimed water is being used for aquifer recharge.

An increased use of reclaimed water in the future depends on the available capacity of treated wastewater and the public acceptance. The capacity of wastewater treatment plants is estimated to increase from 59 Mm^3 in 2012 to 85 Mm^3 until 2025, of which 90% is estimated to be reused for irrigation and aquifer recharge.

2.1.2 France

In France water availability and water stress levels vary significantly among regions. Thus far, a good water supply infrastructure prevents water shortages, especially in the Mediterranean water scarce regions of southern France. The optimal climatic and economic conditions for gardening, fruit farming and tourism in these regions, put a significant pressure on available water resources, especially during the summer period of already low natural water availability (EC, 2016).

Water reuse in France is mainly promoted to address the “poor ecological status” of water bodies as defined by the Water Framework Directive (WFD), which is mainly due to pollution by nitrate from agricultural activities and pesticides, and not for alleviation of water scarcity (Paranychianakis et al., 2015). However, water reuse applications in are mostly limited to peripheral small communities and islands.

The most recent quantitative data on water reuse in France is from 2007, stating a total volume of reclaimed water of about 19,200 m^3/day. In 2015, 40 reuse schemes were operating in France, covering an area of more than 3,000 ha. The most recent Water Reuse Europe Review published in 2018 states 112 water reuse schemes being operated in France. Most of the reclaimed water was used for irrigation of crops, public areas, golf courses and racecourses.

2.1.3 Greece

Water scarcity in Greece varies between regions and seasons. The east of Greece and the Aegean island face more scarcity due to lower rainfall. In addition, water intensive economic activities like irrigated agriculture and tourism put significant pressure on the seasonal water availability. In coastal areas over-abstraction from groundwater aquifers leads to salt water intrusion. Furthermore, nitrate release from agriculture, urban sprawls and uncontrolled industrial emissions put pressure on the water quality of water bodies. Nevertheless, 80% of the groundwater bodies in Greece are in good state (as defined by the WFD), while 15% of them are classified to be in bad chemical state and 17% in bad quantitative state.

Irrigation for agriculture is responsible for the main water demand in Greece, using 84% (3,897 Mm^3) of the total water consumption. Irrigation intensity is high (3,800 m^3 of water per hectare, 6th highest in Europe). Abstraction from groundwater resources accounts for about 38% of the total water abstracted. Although aquifer recharge with reclaimed water is included in the Greek water reuse regulation, there are only very few cases of aquifer recharge in Greece. In the Water Reuse Europe Review (2018) 36 reuse schemes have been identified in Greece.

It is estimated that the average daily volume of reused water is about 28,000 m^3/day, equaling about 10.2 Mm^3/year. In the EU project AQUAREC “Integrated concepts for reuse of upgraded wastewater” an average volume of 23 Mm^3/year of reused water was estimated, and a potential increase to 57 Mm^3/year was projected for 2025 (Hochstrat et al. 2006, as cited in EC, 2016). Another study cited in EC (2016) is by Tsagarakis et al. (2001) and estimated a potential increase of up to 242 Mm^3/year. However, experts express skepticism about the calculation of both estimates and consider them to be too ambitious and difficult to achieve in a cost-effective way. Overall, less than 5% of the treated effluents are being reused in Greece, contributing less than 1% to the total water use of the country. The main water reuse sites are located in the cities of Thessaloniki and Chalkida, as well as in the areas Heraclion and Hersonissos in Crete.

Greece has a high compliance with the Urban Waste Water Treatment Directive. About 83% of effluents from wastewater treatment plants are produced in regions with a water deficit, and more than 88% of the treated effluents are discharged nearby available farmland. So, there is significant availability of high quality treated wastewater, which could be potentially reused for agricultural irrigation in areas facing severe water stress. Hence, there is great potential for water reuse for irrigation, providing an economically and technically feasible option. The number of projects implementing water reuse for agricultural irrigation is increasing. However, the administrative burden concerning water reuse in the current socio-economic context is still high. The review on "EU-level instruments on water reuse" prepared for the European Commission by Amec Foster Wheeler Environment & Infrastructure UK Limited in 2016 (EC, 2016) concluded that there is a need to revise the regulatory, policy and economic instruments to enable the wider uptake of water reuse in Greece.

2.1.4 Italy

In Italy, 50% of abstracted water is abstracted for application in the agricultural sector, whereas about 19% is abstracted for domestic use (rest: industrial and cooling purposes). The domestic water demand decreased by 17.8% in recent years due to an increase in efficiency of the distribution system and the enhancement of public awareness. The distribution of freshwater resources varies between 59% in the north of the country to 18% in the center and south and 4.5% on the islands. About 70% of the annually available groundwater resources (13 billion m³) are located in Northern Italy.

Surface and groundwater quality has increased in recent years due to less intense agricultural production, investments in sanitation and reduction of industrial pollution. However, industrial wastewater as well as industrial and domestic solid waste discharge put the main pressure on small or medium sized streams close to industrial and urban centers.

The annual amount of WWTP effluent in Italy is estimated to be 2,400 Mm³. Only medium to large-sized plants (>100,000 p.e.) which produce about 60% of the treated urban wastewater are able to meet the high quality standards required by the national water reuse regulations at a favorable cost/benefit ratio. Italy reused approximately 233 Mm³ of water per year in 2016 (Bio by Deloitte, 2015). In the Water Reuse Europe Review (2018) 99 reuse schemes have been identified in Italy that provide reclaimed water primarily for the agricultural sector. However, of the 2.4 million hectares of irrigated agricultural area only around 4,000 ha are irrigated with reclaimed water. Another financial disincentive for the uptake of more water reuse in Italy next to the cost of treating water to the high required quality is the cost of upgrading the distribution networks and irrigation systems to meet the strict legal requirements for water reuse. The fragmented management of infrastructure does not increase the chance of reducing these costs. The average cost of reclaimed water was calculated by ISPRA (Instituto Superiore per la Protezione e la Ricerca Ambientale; Italian Institute for Environmental Protection and Research) that conducted a survey of several Italian recycling plants in 2009. The cost was found to range from 0.083 to 0.48 EUR/m³ among the different plants and uses, with a typical value of about 0.25 EUR/m³ (EC 2016). In contrast, the cost of surface or groundwater abstraction is estimated to range only from 0.015 to 0.2 EUR/m³ with typical values about 0.03 EUR/m³ (Paranychianakis et al., 2015). Overall, water reuse is not widely applied. This is mainly due to the high cost of water reclamation, distribution and monitoring of water reuse schemes, in order to meet the strict quality requirements for reclaimed water, which makes water reuse feasible only for large WWTPs (>100,000 p.e.).

2.1.5 Spain

Water reuse plays an important role in Spain, not only for the prevention of water shortages, but also in order to improve the quality and resilience of freshwater systems. The economic development and an increasing number of drought events put an increasing pressure on natural water resources. In the most water stressed area in south-eastern Spain, a high population density is combined with water intensive economic activities such as tourism. The resulting water demand in this area already exceeds the capacity of natural water resources, even without facing a drought event.

Overall, the total national water abstraction is decreasing. However, since increasingly scarce sources like groundwater come at a very low cost, alternative sources are only used in emergency situations and do not achieve an economy of scale. The total annual water demand is covered to 80% (26,949 Mm^3) by surface water and to 20% (6,595 Mm^3) by groundwater abstraction with agriculture being the largest consumer of water (63%) followed by cooling and power generation (19%) and domestic water use (16%). For 2013, the volume of treated wastewater was estimated at 4,998 Mm^3. Of this, the volume of reclaimed water was reported by the Office for National Statistics to have been 413 Mm^3, while the River Basin Management Plans reported a total volume for reclaimed water of 531 Mm^3. Reclaimed water is mainly used for golf course and agricultural irrigation, groundwater recharge and river flow augmentation (Paranychianakis et al., 2015). The overall water reuse in Spain remained at a steady level of 10 to 12% of the volume of treated wastewater, after the national water reuse regulation was implemented in 2007. Nevertheless, in south-eastern Spain, in the Segura and Júcar River Basin Districts and on the Balearic Islands about 62%, 55% and 48% of treated effluent was being reused respectively.

In 2016, an increase in use of reclaimed water from around 500 to around 700 Mm^3/year was expected without any policy intervention. A maximum amount of approximately 1,200 Mm^3/year of reclaimed water was expected in 2018, given the ongoing governmental awareness raising initiatives. The AQUAREC project projected a potential coverage of about 4% of Spain's total annual water demand (~1,300 Mm^3) through reclaimed water by 2025 (EC, 2016). In the Water Reuse Europe Review (2018) 361 reuse schemes have been identified in Spain.

Even though the amount of reclaimed water used in Spain accounts for half of the total water reuse in the EU, its full potential has not been exploited yet mainly due to the high financial costs associated with treatment and distribution.

2.1.6 EU level

To compare the current volumes of reclaimed water used in European countries, existing data must be thoroughly reviewed. There is no EU-wide harmonized reporting scheme so Member States have adopted differing definitions of water reuse. For example, volumes of internally recycled water in the industry and of water which is used for planned indirect reuse purposes may or may not be included in the reported data (BIO by Deloitte, 2015).

Overall, the application of water reuse in Europe is well below its potential. The most cited reason for this fact is the lack of EU-level environmental and health standards for water reuse practices. There is limited confidence in the environmental and health safety of water reuse practices without a harmonized European legal framework and relevant standards (Alcalde-Sanz & Gawlik, 2017). Limited awareness and knowledge of the actual risks and benefits of water reuse practices can negatively affect public acceptance. In countries like France, Italy and Greece the complex and strict water reuse regulations combined with high administrative burden prevent the exploitation of the full potential of water reuse (EC, 2016).

To foster the wider implementation of water reuse practices, the European Commission published in 2018 a proposal for an EU-wide regulation of minimum requirements for water reuse for agricultural irrigation (COM337, 2018). It is estimated that without changing the current reuse regulation in the EU the current amount of 1,1 billion m^3/year of water reused is expected to increase to 1,7 billion m^3/year by 2025, which equals an amount of 2 to 3% of the total amount of treated wastewater (Bio by Deloitte, 2015). However, in the "Impact Assessment" (SWD 249, 2018 - Commission Staff Working Document accompanying the COM337 proposal), the implementation of a legal instrument applying the "fit for purpose approach" which provides minimum quality requirements according to the category of food crop and the applied irrigation method, was analyzed to potentially enable a reuse of "more than 50% of the total water volume theoretically available for irrigation from wastewater treatment plants in the EU and avoid more than 5% of direct abstraction from water bodies and groundwater, resulting in a more than 5% reduction of water stress overall." – SWD 249 (2018). Furthermore, a uniform water reuse regulation on European level is expected to boost public confidence in the safety of water reuse applications (COM337, 2018).

2.2 Comparison of water reuse regulations in the EU

To date, there is no legal framework for Europe as a whole restricting water reuse practices and providing quality standards to ensure environmental and health safety of water reuse applications. The Water Framework Directive only mentions water reuse in Annex VI, Part B as one of the "*supplementary measures*" in the list of measures to be included to achieve the environmental objectives of the Directive (WFD, 2000), while the Urban Wastewater Treatment Directive (UWWTD, 1991) states that "*treated wastewater shall be reused whenever appropriate*". But none of them define health and environmental safety standards for water reuse (Alcalde-Sanz & Gawlik, 2017; EC, 2016a, SWD 249, 2018).

In 2012, the necessity to address water reuse on an EU-wide level was identified by the European Commission in the blueprint on the safety of European Water Resources (COM 673, 2012) in order to address the barriers hindering the uptake of water reuse. Subsequently, the Joint Research Centre (JRC) proposed minimum requirements based on relevant EU regulations (e.g. Urban Wastewater Treatment and Drinking Water Directives) incorporating widely applied international guidelines such as the WHO guidelines for drinking water and for the safe use of wastewater (WHO, 2017 and 2006), the ISO standard 16075 for use of treated wastewater for irrigation projects, the Australian guidelines for water recycling, and the US EPA's and Californian guidelines for water reuse (Alcalde-Sanz & Gawlik, 2017). These minimum requirements were then adopted in the European Commission's "*Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse*" in May 2018 (COM337, 2018). A legally binding EU wide regulation has not entered into force yet.

The individual national water reuse regulations of EU member states differ significantly from each other and follow different approaches to classify water quality levels for different water uses, even though they are based on the same principles. This results in varying water quality classes and combinations of permitted reuse options across the different national regulations. Furthermore, the number and type of quality parameters to be monitored and the defined limits which have to be met for each quality class vary to a great extent. Table 3 provides an overview of the quality parameters regulated by the national water reuse regulations of individual EU member states as well as of those proposed for the EU-level regulation (COM337 2018).

Table 3 **Quality parameters considered in the national water reuse regulations of individual EU member states and in the EU-level regulation proposal (adapted from Alcalde-Sanz & Gawlik, 2014)**

Analytical parameters	CY	FR	GR	IT	ES	COM337 (2018)
Microbiological parameters:						
Escherichia coli (E. coli)	●	●	●	●	●	●
Total coliforms (TC)			●*			
Fecal enterococci		●				
Legionella sp.					●*	●*
Salmonella sp.				●		
Sulphate-reducing bacteria		●				
Helminth eggs (Intestinal nematodes)					●[1]	●*
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 (E.C.)	●		●***	●	●*	
Sodium adsorption ratio (SAR)			●***	●	●*	
Chlorine (Cl2 residual)	●		●	●		
Chlorides	●		●***	●		
Nitrogen forms (Total N, NH4-N)			●	●	●*	
Total phosphorus				●	●*	
Fat & oil	●			●		
Coarse solids				●		
Toxic substances including priority substances			(●)	●	●**	

* Only for certain uses or irrigation methods
** According to the existing related legislation
*** Proposed (not required) for specific cases
[1] In addition T.saginata & T.solium for certain use
(●) Applicable depending on size of WWTP

Standards for water reuse were developed by Cyprus, France, Greece, Italy, Spain and Portugal. For the first five countries, these standards were adopted as regulations into the national legislation, in Portugal they are guidelines to be considered by the national government whenever issuing water reuse permits. The standards of France, Greece, Italy and Spain refer to the reuse of urban and industrial wastewater effluents, the standards of Cyprus and Portugal, however, refer only to the reuse of urban wastewater. As the Portuguese standards are not legally binding, they will not be further considered in this report.

In Annex 6.1, a detailed overview of the existing and proposed water reuse regulations in the EU can be found, including water quality classes, permitted water uses, quality parameters and relevant limits, as well as monitoring requirements. Below, an overview of national water reuse regulation in the EU is given for the 5 countries with legal requirements.

2.2.1 Cyprus

In Cyprus water reuse regulations are fully adopted into the legislation on urban wastewater treatment and discharge. The quality criteria for wastewater treatment are customized to specific Cypriot conditions. Therefore, they are favoring conventional secondary treatment in comparison to stabilization ponds in areas with high cost of land like coastal areas; additionally they are favoring reuse with an environmental protection purpose (EC, 2016). The Cypriot Regulation K.D.P. no. 269 (2005) amended by K.D.P. no. 379 (2015) specifies the reclaimed water quality criteria for treated wastewater generated by agglomerations with less than 2,000 population equivalent (p.e.). For agglomerations of more than 2,000 p.e., the quality limits that must be met for the use of treated effluent are specified within the individual wastewater discharge permits, issued by the Ministry of Agriculture for the Sewerage Boards and the Water Development Department (EC, 2016). Five water quality classes have been defined by the Cypriot water reuse regulation according to different irrigation purposes, as presented in Table 4.

Table 4 Cypriot water quality classes and reuse purposes

Class	Use Type
1	All crops and green areas with unrestricted public access
2	Vegetables consumed cooked (potatoes, beetroots)
3	Products for human consumption; Green areas with restricted public access
4	Fodder crops
5	Industrial crops

* There is no numbering of classes in the Cypriot regulation. The presented numbering was added in this report for uniformity with other regulations.

The use of reclaimed water for the irrigation of leafy vegetables, bulbs or tubers consumed raw, crops for exporting and ornamental plants is prohibited by the Cypriot regulation (BIO by Deloitte, 2015; EC, 2016; Paranychianakis et al., 2015). Class 1 has the strictest and Class 5 the least strict limits. A full overview of regulated classes, water quality parameters and limits for Cyprus is shown in Annex 6.1.1.

2.2.2 France

The French regulatory framework for water reuse was first released in 2010. In 2014, the combination of permitted uses for the different classes of water quality was adjusted and the monitoring requirements were increased, but the limit values stayed the same for each class. The latest changes were made in 2016. Standards for the quality of reclaimed water are set by the national legislation, which also regulates the reuse of sludge for agricultural purposes. In case of agricultural reuse, monitoring is required not only of the quality of reused water, but also of the sewage sludge produced by the WWTPs and of the soil. This adds to the high administrative burden of the current French regulation, which is considered to be very strict, especially regarding the monitoring requirements (EC, 2016).

The regulation concerns 6 water quality parameters in total (*E. coli*, COD, TSS, fecal enterococci, sulphate-reducing bacteria and F-specific bacteriophages). The required compliance of samples with the limit values is 100%, so no sample may exceed the required limits for the targeted water quality class. However, in case of justified reasons, authorities may accept short term exceedances (personal communication Rémi Declercq and Marie Pettenati).

The French standards regulate the water reuse only for irrigation of agricultural and urban / peri-urban areas (other urban or industrial water uses are not allowed). Aquifer recharge with treated wastewater is prohibited in France (EC, 2016).

Four permitted classes for irrigation with reclaimed water are defined in the French regulation, as presented in Table 28. Additional requirements are specified in footnotes and may vary for the same purpose in different classes. For details see Annex 6.1.2..

Table 5 French water quality classes and reuse purposes

Class	Use Type
A	Market gardening, fruit and vegetable crops not processed by suitable industrial heat treatment (except cressiculture), Green areas open to the public + class B
B	Vegetable crops, fruit crops, vegetables transformed by a suitable industrial heat treatment, Pasture, Flowers sold cut, Fresh fodder + class C
C	Nurseries and shrubs and other flower crops, Other cereals and fodder crops, Fruit arboriculture + class D
D	Short-rotation or very short rotation mulch with controlled public access

* The presented numbering of classes A – D is the original numbering in the regulation. Class A contains the strictest limits, comparable to class 1 in other regulations.

The following reuse purposes are prohibited by the French regulation (EC, 2016; BIO by Deloitte, 2015):

- Irrigation with raw sewage;
- Irrigation with treated wastewater from WWTPs connected to certain animal by-products processing installations;
- Irrigation with treated wastewater from WWTPs whose sewage sludge do not comply with the limit values specified by the French legislation on agricultural use of sewage sludge;
- Irrigation with treated wastewater on soils that do not comply with the limit values specified by the French legislation on agricultural use of sewage sludge;
- Irrigation with treated wastewater within the close protection perimeters of drinking water abstraction points (with some exceptions).

Apart from limit values and monitoring requirements, the French regulation also provides constraints regarding characteristics of the land to be irrigated with reclaimed water, as well as on the applied irrigation method (Annex 3.3 of the regulation). It furthermore regulates the minimum distance of any part of land irrigated with reclaimed water to specific sensitive areas and activities (Annex 3.2), as well as the required distance of sprinklers to sensitive public areas. Specific characteristics of sprinklers used for irrigation with reclaimed water (e.g. sprinkler reach) are also regulated (Annex 1) (JORF, 2014).

A full overview of the regulated classes and limits set by the French regulation is provided in Annex 6.1.2.

2.2.3 Greece

The currently applicable regulatory framework in Greece is defined by the Joint Ministerial Decision (JMD) No. 145116, which came into force in 2011. The Greek water reuse legislation defines a comparatively high number of permitted uses of reclaimed water, grouped into three categories of effluent quality which are presented in Table 6 starting with the most restricted class (JMD, 2011). Greek reuse standards have a high administrative burden, which may prevent the implementation of potential water reuse projects (EC,2016).

Table 6 Greek water quality classes and reuse purposes

Class	Use Type
1	a) Urban uses: cemeteries, golf courses, public parks, freeway embankments, recreational facilities, fire protection, street cleaning and decorative fountains. Sprinkler irrigation is not allowed b) Aquifer recharge: by wells (not allowed for potable use) c) Peri-urban green spaces: including groves and forests
2	a) Unrestricted irrigation: All crops including all irrigation methods. b) Industrial use: One use cooling disposable; reticulated water, cooling water for boilers, water processes, etc.
3	a) Restricted irrigation: Areas where public access is not expected, fodder and industrial crops, pastures, trees (except fruit trees), provided that fruits are not in contact with the soil, seed crops, and crops whose products are processed before consumption Sprinkler irrigation is not allowed b) Industrial use: Cooling water c) Groundwater recharge: Aquifer recharge not falling in the cases described by Article 7 of Decree 51/2007 “Water systems used for drinking water abstraction”

* There is no numbering of classes in the Greek regulation. The presented numbering was added in this report for uniformity with other regulations, matching their order of classes (starting from the class with the strictest to the one with the least strict limits). Class 1 corresponds to table 3, Class 2 to table 2 and Class 3 to table 1 in annex 1, JMD (2011) No. 145116.

The Greek water reuse legislation also states the required treatment level for each class to achieve the relevant water quality. The restricted quality parameters are *E. coli*, BOD_5, TSS and Turbidity. For class 1 (urban uses), the parameter *E. coli* is replaced by total coliforms (TC). Also, there are two limit values for TC in the first and *E. coli* in the second class to be met concurrently with different limits for a required compliance of 80% and 95% of the samples, respectively. For the third class the median value of all samples must comply with the limit value given for *E. coli*. For BOD_5 and TSS only one limit is given, which must be met by 80% of the samples in class 1 and 2. For class 3, the limit values and required compliance of these parameters is regulated through the Greek adaptation of the UWWTD (Joint Ministerial Decision 5673/400/1997). No limit for the maximum allowed deviation from the defined limit values is stated for any class or parameter. Additional requirements for total nitrogen (TN) and ammonium nitrogen (NH_4-N) are applicable for certain reuse purposes depending on the vulnerability of the receiving environment (see footnote 1 of Table 32 in Annex 6.1.3). For an overview of classification, limits and monitoring requirements see Table 32 and Table 33 in Annex 6.1.3.

In addition to the water quality requirements defined for these three classes, there is a set of limit values for 19 heavy metals and metalloids which need to be met by WWTPs serving more than 2,000 p.e., if the treated effluents are used for crop irrigation. This is in order to preserve soil quality in case of irrigation of specific crops. A list of desirable limits of parameters relevant for agronomic characteristics of the soil in case of agricultural reuse is also proposed (these parameters are not mandatory). Furthermore, there is a set of 40 organic compounds, which is required to be monitored by WWTPs serving more than 100,000 p.e., as well as in case of reuse of industrial effluents.

2.2.4 Italy

The currently applicable regulatory framework in Italy is defined by the Ministry Decree (DM) No. 185, which came into force in 2003. This regulation defines three categories of water reuse, which are presented in Table 7. All three categories are regulated with the same set of water quality parameters and therefore fall into the same single quality class defined in the Italian regulation.

Table 7 Italian reuse purpose categories

Category	Use Type
1	Irrigation of crops for human and animal consumption, non-food crops, irrigation of green and sport areas
2	Urban uses: street washing, heating and cooling systems, toilet flushing
3	Industrial uses: fire control, processing, washing, thermal cycles of industrial processes (reclaimed water cannot get in contact with food, pharmaceutical products and cosmetics)

* There is no definition of quality classes in the Italian regulation. There are three categories of reuse, for all of which the same quality requirements apply. The presented numbering was added in this report for uniformity with other regulations.

The set of limits applicable for all three categories does not differentiate between types of crops and applied irrigation methods. This "*one size fits all*" approach must address the environmental and health risks associated with all permitted reuse purposes, requiring a high reclaimed water quality suitable for the most strictly regulated water reuse purpose (SWD 249, 2018).

The Italian regulation is considered very strict with an overabundant number of restricted parameters. The total number of parameters is 55 (see Annex 6.1.4); around 20% of them have the same limit values required for drinking water quality, while 37% of the parameters are not even included in the requirements for drinking water quality (EC, 2016). The monitoring requirements for all these parameters make water reuse economically feasible only for large WWTPs.

The limit value for *E. coli* depends on the treatment with a higher limit value applying for wastewater treated in constructed wetlands and stabilization ponds. The *E. coli* limit value must be met by 80% of the samples, while a maximum deviation value must not be exceeded by any sample. Salmonella must be absent in 100% of samples; if Salmonella is detected in any sample, reuse is suspended until concentrations of Salmonella are not found in at least three successive and consecutive samples (DM 185, 2003). For all physico-chemical parameters the defined limit value must be met by the annual average of samples. Only for electrical conductivity a specific (different) value limiting the maximum deviation is provided. An overview of parameters and limits is provided in Annex 6.1.4.

Aquifer recharge with reclaimed water is neither forbidden nor regulated, but it is not being applied, since groundwater recharge in general is not common in Italy (EC, 2016).

2.2.5 Spain

The currently applicable legal framework for water reuse in Spain is defined by the Royal Decree (RD) no. 1620, which came into force in 2007. The Spanish regulation defines the highest number of permitted reclaimed water uses. It is the only one of the regarded frameworks which includes water reuse for irrigation of private gardens and for aquaculture. While differentiating urban, agricultural, industrial, recreational and environmental reuse categories, it follows the categorization of the US EPA, the Australian guidelines, and the Californian regulations (EC, 2016). Classes and use types are summarized in Table 8 (Mujeriego and Hultquist, 2011).

Table 8 Spanish water quality classes and reuse purposes

Class	Use Type
Urban uses:	
1.1	a) Irrigation of private gardens b) Supply to sanitary appliances
1.2	a) Irrigation of urban green areas (parks, sport fields etc.) b) Street cleaning c) Fire hydrants d) Industrial washing of vehicles
Agricultural uses:	
2.1	Crop irrigation with an application method which allows direct contact of reclaimed water with the edible part of the crop consumed uncooked
2.2	a) Crop irrigation with an application method which allows direct contact of reclaimed water with the edible parts of the crop which is not consumed fresh but after processing b) Fodder irrigation for meat or milk producing animals c) Aquaculture
2.3	a) Localized irrigation of tree crops without contact of reclaimed water with fruits consumed by humans b) Irrigation of ornamental flowers, nurseries & greenhouses without direct contact of effluent with crops c) Irrigation of industrial non-food crops, nurseries, silo fodder, cereals and oilseeds
Industrial uses:	
3.1	a) Process and cleaning water but not for food industry b) Other industrial uses c) Process and cleaning water for food industry
3.2	Cooling towers and evaporative condensers
Leisure uses:	
4.1	Golf courses irrigation
4.2	Ornamental ponds and lakes in which public access to water is prohibited
Environmental uses:	
5.1	Aquifer recharge by localized percolation through the ground
5.2	Aquifer recharge through direct injection
5.3	a) Irrigation of woodland, green areas and other spaces without public access b) Silviculture
5.4	Other environmental uses (wetlands maintenance, minimal stream flows etc.)

The Spanish regulation prohibits the following uses for reclaimed water (EC, 2016; BIO by Deloitte, 2015):

- Human consumption (not applicable in case of catastrophic events);
- Food industry (except for process and cleaning water, as defined by the Royal Decree 140/2003);
- Hospitals and alike;
- Filter-feeding mollusc aquaculture;
- Bathing waters (recreational uses);
- Fountains and ornamental products in public or interior spaces of public buildings; and
- Any other use public health or environmental authorities may consider risky.

The main parameters regulated by the Spanish water reuse legislation are *E. coli*, intestinal nematodes, TSS and turbidity. In addition, certain classes require compliance to additional parameters, such as *Legionella* or nutrients. For example, in case of aquifer recharge with reclaimed water additional requirements exist for total nitrogen and nitrate, while total phosphorus is regulated for stagnant waters in ornamental ponds and lakes with restricted public access. For all classes in the "Agricultural use" category a list of additional parameters including: EC, SAR, as well as 12 metals. In general, at least 90% of samples must comply with the set limit values, while additional maximum deviation limits apply for intestinal nematodes, *E. coli*, TSS, turbidity, Legionella spp., T. saginata, T. solium, nitrate, total nitrogen and total phosphorus.

Further details on classes, limits and monitoring requirements set by the Spanish water reuse legislation can be found in Annex 6.1.5.

2.2.6 Proposal by the European Commission

The proposal for a water reuse regulation on EU level (COM337, 2018) suggests a "*fit for purpose*" approach based on risk management. This approach is regarded to provide a higher environmental, economic and social benefit compared to a "*one size fits all*" approach (as in the case of Italian water reuse legislation).

The proposed regulation only considers reuse options for agricultural irrigation, differentiating between the crop types (food and non-food crops, crops consumed raw/unprocessed, processed crops) and the irrigation methods used. For unrestricted irrigation, the EC proposal includes performance criteria on top of effluent quality limits, in contrast to national regulations (minimum $\log_{10}$ reduction for specified indicator microorganisms for bacteria, virus and protozoa). Urban or industrial uses are not considered in this proposal, as agricultural irrigation is responsible for about 60% the total freshwater abstraction in southern and south-eastern Europe. In some river basin districts this share may increase up to 80%. Agricultural irrigation is seen to have the highest potential for application of water reuse in Europe in order to alleviate water scarcity problems (COM337, 2018).

The water quality classifications proposed by the COM337 (2018), is presented in Table 9.

Table 9 Proposed water quality classes and reuse purposes by the European Commission

Class	Use Type	Irrigation Method
A	All food crops, including root crops consumed raw and food crops where the edible portion is in direct contact with reclaimed water	All irrigation methods allowed
B	(a) Food crops consumed raw where the edible portion is produced above ground and is not in direct contact with reclaimed water (b) Processed food crops	All irrigation methods allowed
C	(c) Non-food crops including crops to feed milk- or meat-producing animals	Drip irrigation only
D	Industrial, energy, and seeded crops	All irrigation methods allowed

* The presented numbering of classes A – D is the original numbering in the regulation. Class A contains the strictest limits, comparable to class 1 in other regulations.

The proposal includes restrictions for four water quality parameters: *E. coli*, BOD_5, TSS and turbidity (restricted for class 1 purposes only). There are additional requirements for *Legionella spp*. and intestinal nematodes for certain water reuse purposes. For classes 2 to 4, the parameters BOD_5 and TSS are regulated by the discharge limits of the UWWTD (91/271/EEC, Annex 1, table 1).

The limit values for the biological parameters *E. coli*, *Legionella spp*. and intestinal nematodes must be met by at least 90% of the samples, with a maximum deviation limit of 1 log unit above the limit value for *E. coli* and Legionella, and 100 % of the limit value for intestinal nematodes. In class 1, limit values for BOD_5, TSS, and turbidity must be met by at least 90% of the samples, with a maximum deviation of 100% of the limit value. In classes 2 to 4 the required compliance for BOD_5 and TSS lies between 75%-93% of the samples, depending on the total number of samples according to UWWTD (Annex 1, table 3). The maximum deviation limit is 100% for BOD_5 and 150% for TSS.

Details on classes, limits and monitoring requirements can be found in Annex 6.1.6.

2.2.7 Comparison of national water reuse regulations in the EU

Water reuse legislations vary significantly among EU member states. Each regulation considers different reclaimed water uses associated with different quality classes and respective definitions. In Italy, for example three classes of water reuse are specified and only one set of water quality requirements applies to all of them. On the contrary, 24 water reuse purposes, which correspond to 14 water quality classes, are defined by the Spanish water reuse legislation.

The number of water quality parameters which are restricted by each national regulation also differs (see also Table 3). Six (6) parameters are regulated by the French water reuse legislation (the lowest number of parameters involved in national regulations), three of which are solely included in the French regulation. In the Greek reuse legislation also 6 parameters are being regulated for WWTPs serving less than 2,000 p.e., however, for WWTPs with higher capacity the number of restricted parameters can increase up to 80. The Cypriot legislation regulates 10 and the Italian legislation regulates 55 parameters. In Italy, the limit values for certain parameters can be adapted by the regional government under the supervision of the Ministry of Environment, considering the limit values for water discharge into surface waters. In Spain, the number of regulated parameters varies with the type of reuse, and can be extended on a case by case basis by the regional government by up to 90 possible quality parameters, depending on external regulations concerning the protection of the receiving environment.

The proposal of the European Commission for an EU-level regulation for water reuse includes only 4 water quality classes and 4 restricted quality parameters (with two additional for certain reuse purposes). However, water reuse in this proposal is limited to agricultural irrigation purposes, as urban and industrial reuse purposes are not being considered.

Apart from defined water reuse classes, regulated parameters and relevant limit values, the national reuse regulations also differ regard to the compliance requirements. While some regulations specify a percentile of samples required to comply with the set limit values (e.g. 80% of annual samples need to meet the limit), others require the annual mean to comply with the limits. In addition, sometimes maximum allowed deviation limits for any sample exceeding the limit values are defined. These specifications may not only vary among different regulations, but also for different parameters in the same regulation, as well as among different quality classes for the same parameter in the same regulation.

3 Constructed wetlands for water reuse

Constructed wetlands are widely used to treat raw, primary or secondary treated sewage in a sustainable and environmentally friendly way. Various biological and physical processes provide the removal of total suspended solids (TSS), soluble organics, phosphorous, nitrogen, metals and pathogens. One main parameter group in regard to water reuse are pathogens, as these pose a risk for infection when contained in water used for irrigation. Therefore, all regulations for water reuse contain one or more microbiological parameters that are restricted depending on the reuse type (see chapter 2.2). As pathogens are difficult to analyse, all regulations include *E. coli* as indicator organism for pathogens. However, data on removal of *E. coli* and other microbiological parameters such as viruses in CWs are far less abundant compared to the removal of non-microbial parameters (i.e. TSS, BOD_5, COD or nutrients), which are well investigated. Therefore, a literature review has been conducted to determine typical log-removal ranges for different microbiological parameters in constructed wetlands (Figure 4). Each point in Figure 4 represents the average reduction of microbiological parameters (grouped into the three categories bacteria, parasites and viruses) in a constructed wetland system of an individual study.

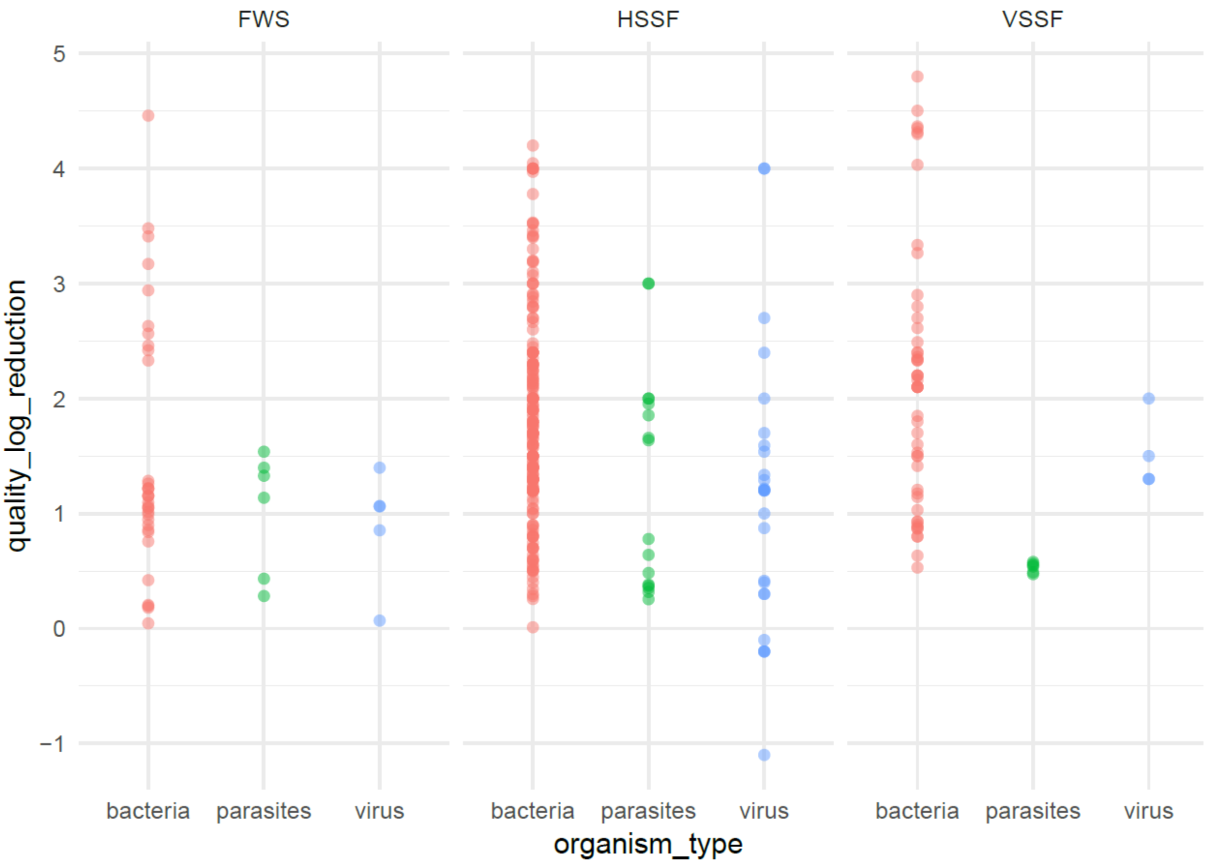

Figure 4 Log-removal of bacteria, viruses and parasites in CWs of different types: FWS – free water surface wetlands, HSSF – horizontal subsurface flow wetlands, VSSF – vertical subsurface flow (Sources: Abdel-Shafy & El-Khateeb, 2012; Abou-Elela & Hellal, 2012; Ansola, G., 2003; Arias, 2003; Avelar et al., 2014; Ayaz, 2008; Azaizeh et al., 2013; Barrett et al., 2001*; Caselles-Osorio, 2011; Coleman et al., 2001; Dahab & Surampalli, 2001; Davison et al., 2001; Garcia et al., 2008; Garcia et al., 2013; Headley et al., 2013; Hench et al., 2003*; Karimi et al., 2014; Langergraber, 2009; Masi et al., 2007; Morató et al., 2014; Mustafa, 2013; Neralla et al., 2000; Nokes et al., 2003*; O'Luanaigh & Gill, 2012; Perkins & Hunter, 2000; Quiñónez-Dìaz et al., 2001*; Reinoso et.al., 2008*; Richter & Weaver, 2003; Sleytr et al., 2007) *includes virus data

Three different CW types were considered (FWS, HSSF and VSSF). For this analysis a total number of 29 scientific papers, including review papers that provide data of several sites (e.g. Stefanakis et al. 2016; Wu et al. 2016), were considered. Most studies investigate the reduction of bacteria HSSF CWs. An average bacterial reduction in HSSF wetlands of 1.8 (±0.9) log was calculated on the basis of 199 values provided in the literature. For VSSF wetlands, an average log-reduction of 2.2 (±1.1) was calculated on the basis of 50 values, indicating a higher removal in VSSF CWs compared to HSSF CWs. Data on the removal of viruses by CWs was more difficult to find. An average virus reduction of 1.2 (±0.9) log was calculated on the basis of 35 values for all three system types, found in five papers (see Figure 4). For parasites, an average reduction of 1.1 (±1.0) log was calculated on the basis of 28 values for all three system types (see Figure 4).

In water reuse regulations, the most frequently regulated microbiological parameters are *E. coli* and TC. The removal rates provided in the literature for these two parameters are shown in Figure 5. The average log-removal for *E. coli* calculated to be 1.8 (±1.0), taking into account the removal rates in 55 CW systems described in the literature. The same average log-removal was calculated for TC based on data found in the literature for 82 CW systems (1.8 ±1.0).

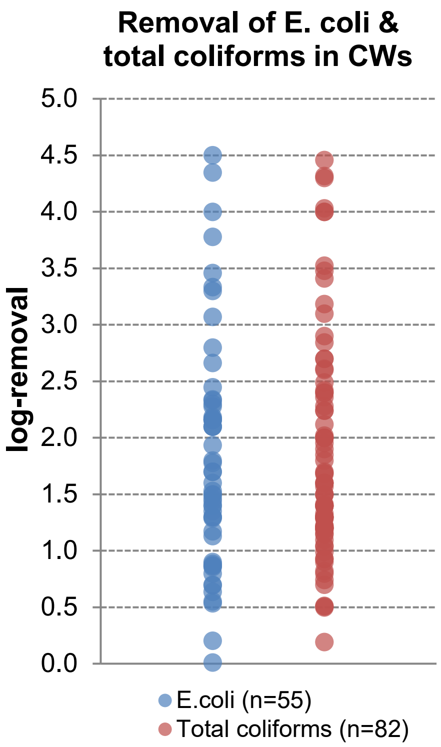

Figure 5 Log-removal of *E. coli* (blue dots) and TC (red dots) in literature data.

3.1 Methodology for comparison of monitoring results from demo sites with water reuse regulations

As described in chapter 2, the suitability of reclaimed water quality for different reuse applications is regulated by varying numbers and types of parameters in different EU countries. Hence, different parameters have been monitored in the different AquaNES demo sites, according to the relevant legislations. In the Greek demo sites all parameters relevant in the Greek reuse regulation are being monitored. In the following analysis, only parameters of the national regulations that were monitored at the demo sites will be regarded; a complete list of parameters regulated in each national regulation can be found in Annex 6.1.

Furthermore, the regulated reuse purposes included in the different national regulations vary in number and detail of description. Therefore, a direct comparison of quality classes of the different regulations is difficult, as similar reuse purposes might be included in different water quality classes. Consequently, in order to compare the suitability of the reclaimed water for reuse purposes within the national regulations, three specific reuse cases are defined, which can be placed in one of the classes in all regulations:

- **Case 1 "Restricted irrigation"**: Irrigation of beans using drip irrigation exclusively (vegetable that is not eaten raw and not in contact of reclaimed water).
- **Case 2 "Unrestricted irrigation"**: Irrigation of tomatoes with no limitation in the irrigation method used (vegetable consumed raw and being in potential contact with reclaimed water).
- **Case 3 "Urban irrigation"**: Irrigation of a public park with restrictions either to the opening hours for the public during irrigation, or to the irrigation method used (to reduce either the production of potentially hazardous aerosols, or to reduce the probability of contact between aerosols and humans).

Table 10 shows which water reuse classes as defined in each national regulation applies for these three reuse cases.

Table 10 Relevant water quality classes in national water reuse regulations and in the EC proposal for the three considered water reuse cases specified above (see 2.2 for details of reuse classes).

Country	"Restricted irrigation"	"Unrestricted irrigation"	"Urban irrigation"
Cyprus	2	1	3
France	B	A	A
Greece	3	2	1(1)
Italy	1	1	1
Spain	2.2	2.1	1.2
COM337 (2018)	C	A	n.a.(2)

(1)In the Greek regulation sprinkler irrigation is prohibited for "urban irrigation" purposes.
(2)The EU proposal includes only agricultural irrigation purposes for water reuse.

When comparing the monitored data with the relevant water quality classes for the three reuse cases (Table 10), the data need to be analysed for each regulation individually. This is due to the varying required compliance of sample results with the limit values in different regulations. A condensed overview of the applied limits and compliance requirements in the different regulations are presented in Table 11 to Table 16. Only the relevant quality classes which are being used to evaluate the three defined reuse cases above and only the parameters which have been monitored in the Greek sites are included. The full requirements of each regulation, including quality classes missing here and the parameters that have not been monitored but would be necessary for a full evaluation of the suitability of the reclaimed water for the regarded reuse purpose, can be found in Annex 6.1.

3.2 Relevant parameters and compliance requirements of national reuse regulations and the EC proposal

Cyprus

Table 11 shows the limit values of the Cypriot water reuse regulation for parameters included in the monitoring of the two Greek demo sites. In Cyprus, two out of minimum twelve samples taken per year may deviate from the limit value set for BOD_5, COD and TSS. This leads to a required compliance of the 83-percentile of samples. For all other parameters no exceedance of the limit is allowed (communication with Department of Environment which is the competent authority for the relevant legislation). The parameters not measured at both Greek sites and missing for a full evaluation of water quality for reuse purposes in Cyprus are fat and oil, chlorides and boron. Furthermore, pH has not been measured in Antiparos.

Relevant reuse classes for defined reuse cases (see chapter 3.1):

Reuse case	"Restricted irrigation"	"Unrestricted irrigation"	"Urban irrigation"
Relevant class (CY)	2	1	3

Table 11 Cypriot limit values and required compliance of samples (Req. compl.) for water quality classes relevant for the three defined reuse cases.

<table>
<tr><th colspan="2" rowspan="2">CY</th><th>E. coli</th><th>BOD_5</th><th>COD</th><th>TSS</th><th>$Cl_{res.}$</th><th>pH</th><th>EC</th></tr>
<tr><th>cfu/100mL</th><th>mg/L</th><th>mg/L</th><th>mg/L</th><th>mg/L</th><th></th><th>µS/cm</th></tr>
<tr><td>Class 1*</td><td>Limit</td><td>5</td><td rowspan="2">10</td><td rowspan="2">70</td><td rowspan="2">10</td><td rowspan="3">2</td><td rowspan="3">6.5-8.5</td><td rowspan="3">2500</td></tr>
<tr><td>Class 2*</td><td>Limit</td><td>50</td></tr>
<tr><td>Class 3*</td><td>Limit</td><td>200</td><td>25</td><td>125</td><td>35</td></tr>
<tr><td>Class 1-3</td><td>Req. compl.</td><td>100%</td><td>83%(1)</td><td>83%(1)</td><td>83%(1)</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table>

* There is no numbering of classes in the Cypriot regulation. The presented numbering was added in this report for uniformity.
(1) 83% equals the required compliance with an acceptable deviation of 2 out of the min. 12 annual samples required by the Cypriot regulation

France

Table 12 shows the limit values of the French water reuse regulation for parameters included in the monitoring of the two Greek demo sites. The microbiological parameters fecal enterococci, F-specific RNA bacteriophages and anaerobic sulfate-reducing bacteria spores that are required by the French regulation have not been monitored in Antiparos and Thirasia, as they are not required by the Greek reuse legislation. Therefore, only the parameters *E. coli*, COD and TSS were considered in the evaluation. Values for COD and TSS for class B may exceed the specified limits; the number of samples which are allowed to exceed the limit value depends on the total number of samples for these parameters as defined in the UWWTD (Table 3 of Annex 1). The associated maximum deviation limits for samples exceeding the limit values can be found in the Arrêté du 21 juillet 2015 (Table 3 of Annex 3). They are dependent on the daily organic load of BOD_5 being "less than" or "greater or equal to" 120 $kgBOD_5$/day. In Antiparos and Thirasia, the value for ≥120 $kgBOD_5$/day is applicable.

Relevant reuse classes for defined reuse cases (see chapter 3.1):

Reuse case	"Restricted irrigation"	"Unrestricted irrigation"	"Urban irrigation"
Relevant class (FR)	B	A	A

Table 12 French limit values and required compliance of samples (Req. compliance) for water quality classes relevant for the three defined reuse cases.

FR		*E. coli*	COD	TSS
		cfu/100mL	mg/L	mg/L
Class A	Limit	250	60	15
	Req. compliance	100%	100%	100%
Class B	Limit	10,000	125	35
	Req. compliance	100%	75%-93%(1)	75%-93%(1)
	Max. deviation limit**		250(1)	85(1)

** Maximum deviation limit: maximum limit for samples outside the required compliance percentile.
(1) According to Arrêté du 21 juillet 2015 (Required compliance depends on the total number of samples; In the case of Antiparos: 86-perc. & Thirasia: 88-perc. for both parameters)

Greece

Table 13 shows the limit values of the Greek water reuse regulation for parameters included in the monitoring of the two Greek demo sites. In the Greek reuse legislation, TC replaces the parameter *E. coli* for the evaluation of the class 1 reclaimed water quality. Two limits are provided for TC, which must be met by 80 and 95% of the samples in order to achieve the required quality for this class. The same double limit applies to *E. coli* for class 2. In class 3, the *E. coli* concentration of the median of samples should comply with the set limit (Table 13). The limits and required compliance for BOD_5 and TSS is regulated by the Greek adaptation of the UWWTD, i.e. the JMD 5673/400/1997, and can be found in Tables 1 and 3 of Annex 1 of the UWWTD. Equally to the French regulation, the required compliance is dependent on the regarded number of samples and ranges between 75 and 93 percent. Lastly, the limits considered for TN and NH_4 were for reuse in non-nitrate vulnerable zones. In Antiparos, turbidity has not been measured.

Relevant reuse classes for defined reuse cases (see chapter 3.1):

Reuse Case	“Restricted irrigation”	“Unrestricted irrigation”	“Urban irrigation”
Relevant Class (GR)	3	2	1(1)

(1)In the Greek regulation sprinkler irrigation is prohibited for “Urban irrigation” purposes.

Table 13 Greek limit values and required compliance of samples (Req. comp.) for water quality classes relevant for the three defined reuse cases.

GR		*E. coli*	BOD_5	TSS	Turbidity	TN	NH_4
		cfu/100mL	mg/L	mg/L	NTU	mg/L	mg/L
*Class 1**	Limit	TC(1): 2 & 20(2)	10	2	2	15	2
	Req. comp.	80 & 95%	80%	80%	median	annual avg.	annual avg.
*Class 2**	Limit	5 & 50(2)	10	10	2	45(3)	no limit(3)
	Req. comp.	80 & 95%	80%	80%	median	annual avg.	annual avg.
*Class 3**	Limit	200	25(4)	35(4)	--	45(3)	--
	Req. comp.	median	75%-93%(4)		--	annual avg.	--

* There is no numbering of classes in the Greek regulation. The presented numbering was added in this report for uniformity (starting from the class with the strictest to the one with the least strict limits). Class 1 corresponds to table 3, Class 2 to table 2 and Class 3 to table 1 in annex 1 of JMD (2011) No. 145116.
(1) Limit for TC instead of *E. coli* for class 1 (2) Required compliance of 80% and 95% of samples to different limit values
(3) Less strict limit, for reuse outside nitrate vulnerable zones (NVZ)
(4) The required compliance is dependent on the number of samples (JMD 5673/400/1997 from UWWTD, Annex 1, Table 3); In case of Antiparos: 86-perc. for both parameters; in case of Thirasia: BOD: 86-perc. & TSS: 88-perc.

Italy

Table 14 shows the limit values of the Greek water reuse regulation for parameters included in the monitoring of the two Greek demo sites. The Italian regulation is based on a one size fits all approach and has a very high number of parameters applicable to all three defined reuse categories. 45 of the regulated quality parameters have not been monitored in Antiparos or Thirasia. Additionally, in Antiparos pH was not monitored. While there is only one set of limits applicable to all defined reuse cases, there is a second, less strict limit for *E. coli* in case the wastewater has undergone treatment in constructed wetlands or stabilization ponds. There is a similar exception for the parameters total nitrogen and total phosphorus with a less strict limit for irrigational reuse purposes. All three exceptions are applicable for all three reuse cases considered in this report.

Relevant reuse classes for defined reuse cases (see chapter 3.1):

Reuse case	"Restricted irrigation"	"Unrestricted irrigation"	"Urban irrigation"
Relevant class (IT)	1	1	1

Table 14 **Italian limit values and required compliance of samples (Req. comp.) for water quality classes relevant for the three defined reuse cases.**

IT		*E. coli*	BOD_5	COD	TSS	TN	NH_4	TP	$Cl_{res.}$	pH	EC
		cfu/ 100mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		µS/cm
*Cl. 1**	Limit	50[(1)]	20	100	10	35[(2)]	2	10[(2)]	0.2	6.0 - 9.5	3,000
	Req. comp.	80%	annual average								
	Max. dev.**	200[(1)]	---								4,000[(3)]

* There is no definition of quality classes in the Italian regulation. There are three categories of reuse, for all of which the same quality requirements apply. The presented numbering was added in this report for uniformity with other regulations.
** Maximum deviation limit: maximum limit for samples outside the required compliance percentile.
(1) Less strict limit for treatment in constructed wetlands/ stabilization ponds
(2) Less strict limit for irrigation use; according to DM (2003) no. 185, article 15(4)
(3) According to DM (2003) no. 185, article 15(3)

<u>Spain</u>

Table 15 shows the limit values of the Spanish water reuse regulation for parameters included in the monitoring of the two Greek demo sites. The number parameters not monitored at the Greek demo sites varies between the three reuse cases. Firstly, I.N. (Intestinal Nematodes) and *Legionella spp.* are applicable for all three cases. A list including SAR and 12 heavy metals is supposed to be monitored if the reuse purpose falls into the "agricultural uses" category. It is therefore relevant for the cases "restricted" and "unrestricted irrigation". For the case "restricted irrigation" *T. saginata* and *T. solium* are additional parameters which would have to be taken into account. And finally, there is a variable number of substances that could potentially be added by the concerned authority on a case by case basis. For Spain, the parameters *E. coli*, TSS, turbidity and E.C. can be evaluated in regard to the water reuse regulation (Table 15). Required compliance is 90% for all parameters.

Relevant reuse classes for defined reuse cases (see chapter 3.1):

Reuse case	"Restricted irrigation"	"Unrestricted irrigation"	"Urban irrigation"
Relevant class (SP)	2.2	2.1	1.2

Table 15 **Spanish limit values and required compliance of samples (Req. compliance) for water quality classes relevant for the three defined reuse cases.**

SP		*E. coli*	TSS	Turbidity	E.C.
		cfu/100mL	mg/L	NTU	µS/cm
Class 2.1	Limit	100	20	10	3,000
Class 1.2	Limit	200			*n.a.*
Class 2.2	Limit	1,000	35	no fixed limit	3,000
All classes	Req. compliance	90%	90%	90%	90%
	Max. deviation limit**	1 log	50%	100%	---

** Maximum deviation limit: maximum limit for samples outside the required compliance percentile (allowed percentage / log above limit).
n.a.: not applicable

Proposal by the EC (COM337, 2018)

Table 16 shows the limit values of the proposal made by the EC. Three of the four main parameters were monitored at both Greek sites, while turbidity was only measured in Thirasia. Limits and required compliance for the parameters BOD and TSS for class 3 are regulated by the UWWTD (Tables 1 and 3 of Annex 1). The associated maximum deviation limit is also stated in Annex 1 of the UWWTD. A missing relevant parameter could be *Legionella spp.* if the chosen method for irrigation of the tomatoes in case 2 “Unrestricted irrigation” contains the “risk of aerosolization in greenhouses”, since tomatoes are commonly grown in greenhouses.

Relevant reuse classes for defined reuse cases (see chapter 3.1):

Reuse case	“Restricted irrigation”	“Unrestricted irrigation”	“Urban irrigation”
Relevant class (EC)	C	A	n.a.(1)

(1)The EC proposal includes only agricultural irrigation purposes for water reuse.

The monitoring results of the demonstration sites in Erftverband and Schönerlinde are only being compared to the EC proposed regulation. This is why no definition of specific reuse cases is necessary and all water quality classes for all reuse purposes defined in the proposal are being considered. A brief summary of limits and required compliances is presented in Table 16.

Table 16 **Limit values and required compliance of samples (Req. compliance) for water quality classes and parameters defined in the EC proposal.**

COM337 (2018)		*E. coli*	BOD_5	TSS	Turbidity
		cfu/100mL	mg/L	mg/L	NTU
*Class A**	Limit	10	10	10	5
	Req. compliance	90%	90%	90%	90%
	Max. deviation limit**	1 log	100%	100%	100%
*Class B**	Limit	100	25	35	-
*Class C**	Limit	1.000			
*Class D**	Limit	10.000			
*Class B - D**	Req. compliance	90%	75%-93%(1)	75%-93%(1)	-
	Max. deviation limit**	1 log	100%(1)	150%(1)	-

* The presented numbering of classes A – D is the original numbering in the regulation. Class A concerns the strictest limits.
** Maximum deviation limit: maximum limit for samples outside the required compliance percentile (allowed percentage / log above limit).
(1) The required compliance is dependent on the number of samples (UWWTD, Annex 1, Table 3);
Antiparos: BOD & TSS: 86-perc.; Thirasia: BOD: 86-perc., TSS: 88-perc.; Erftverband: RSF1: BOD: 83-perc. & TSS: 82-perc.; RBF2: BOD & TSS: 80-perc.; RBF3: BOD & TSS: 75-perc.; In the case of Schönerlinde: TSS: 89-perc.;
The maximum deviation limits can be found in (UWWTD, Annex 1-D.4.(b)).

3.3 Comparison of demo site data with reuse regulations

In this chapter, evaluated demonstration sites are briefly described and results of selected parameters are summarized. Effluent qualities of the Antiparos and Thirasia demo sites are evaluated in regard to all national regulations, while effluent qualities for the demo sites Erftverband and Schönerlinde are evaluated in regard to the EC proposal, only.

3.3.1 Demo site Antiparos: WWTP combining CWs with chlorination

The Antiparos WWTP (AquaNES demo site 10b) is located on Antiparos island in Greece. Antiparos Island is part of the Cyclades complex, one of the Greek island groups which constitute the Aegean archipelago, located in the southeast Aegean Sea (Figure 6). It occupies an area of 35.1 km², and has a permanent population of 1,211 (census 2011), while, during summer, about 1,000 seasonal residents and tourists visit the island (census 2012). Administratively, the island falls under the authority of the Municipality of Antiparos (MUOA), a public entity.

Figure 6 Location of Antiparos Island, Greece

Figure 7 Location of Antiparos Island, Greece *(Source: Google Earth, 2019)*

The Antiparos WWTP was constructed in May 2015, for the treatment and reuse of municipal wastewater. It is located at Sifneikos Gyalos (500m from the Antiparos settlement), and occupies an area of 28,400 m² (Figure 8). The maximum daily design capacity of the WWTP (for the year 2035) is 480 m³/day (projected population of 1,500 permanent residents and 1,500 seasonal residents and tourists). The demo site is under the jurisdiction of the MUOA.

Due to the high tourist influx, especially during summer, the flow is subject to significant fluctuation. For 2018, estimated flow was about 600 m³/day in August, about 380 m³/day in September, about 150 m³/day in October and about 70 m³/day from November to January. The treated water is used for the irrigation of public spaces in the proximity of the WWTP and for fire protection purposes.

In the Antiparos WWTP, influent undergoes screening, grit removal, flocculation with polyaluminium chloride (18% Al_2Cl_3) and primary sedimentation. The main treatment step consists of two stages of VSSF CWs (the first stage comprises 4 sealed beds with an area of 460 m² each, and the second stage comprises 2 sealed beds with an area of 750 m² each). The outflow of the second stage of CWs is collected in one sealed stabilization pond (maturation pond) with an average water depth of 1.3 m. After the maturation pond the effluent undergoes disinfection (chlorination and dechlorination). The flow scheme of the Antiparos WWTP is presented in Figure 8.

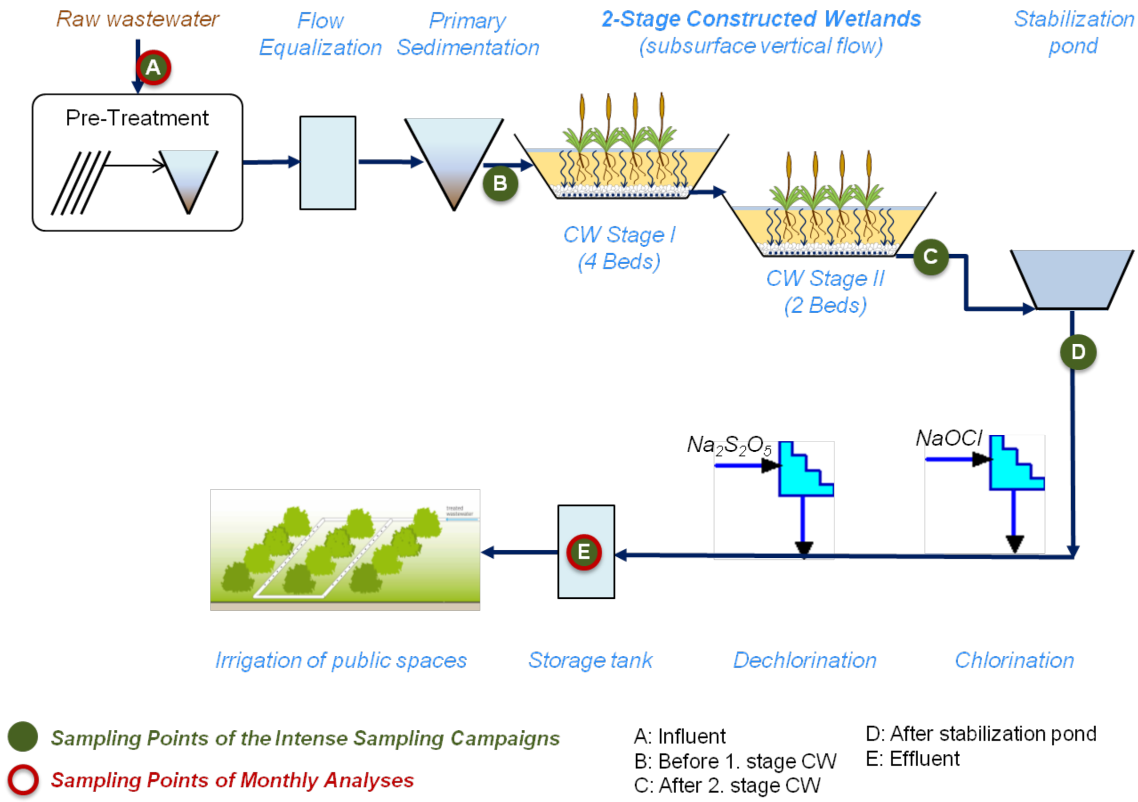

Figure 8 **Flow scheme of the Antiparos WWTP including sampling points**

Monthly influent and effluent samples (points marked in red on Figure 8) have been analyzed for the period February 2016 - January 2019. No samples were taken from February to April 2018 due to remedial actions for the rehabilitation of clogged CW beds (limited operation of the WWTP). In addition to the monthly samples, three intense sampling campaigns were conducted in 2017 and 2018, during which samples were taken more frequent and after each treatment stage (see Figure 8).

An overview of the mean influent and effluent concentrations for all measured parameters for the whole monitoring period is shown in Table 17. Standard deviation values (STDEV) show that there is high variability in the monitored data, which is due to the seasonal fluctuations of the hydraulic and pollution loads, as well as to the phases of limited operation of the WWTP during rehabilitation actions. It is interesting to notice that E.C. has high values, which can be explained by the high E.C. values in drinking water (drinking water is produced through desalination).

Table 17 **Mean and standard deviation (STDEV) of the influent and effluent concentrations for parameters monitored in the Antiparos WWTP (all data, n = number of samples)**

Parameter	Units	Influent (mean)	STDEV	Effluent (mean)	STDEV	n
BOD5	mg/L	316	168	17	6	29
COD	mg/L	731	328	52	24	29
TSS	mg/L	268	240	39	46	29
TN	mg/L	88	21	18	11	29
NO3-N	mg/L	1.2	1.1	17	11	29
NH4-N	mg/L	49	-	0.59	-	2

Parameter	Units	Influent (mean)	STDEV	Effluent (mean)	STDEV	n
TP	mg/L	8.6	4.5	0.40	0.35	29
TC	cfu/100mL	3.4E+06	3.4E+06	1.1E+02	5.5E+02	29
E. coli	cfu/100mL	1.4E+06	1.9E+06	8.0E+01	4.1E+02	29
E.C.	µS/cm	n.a.	-	6,414	-	1
Cl_{Res}	mg/L	n.a.	n.a.	0.30	0.48	23

End of September 2017, the top filter layer in the first stage of the CWs was clogged, causing anaerobic conditions in the filter. As a consequence the reeds of these beds died (see Figure 34 in Annex 6.4). On-site investigations of the layer material performed by project partners revealed that the grain size of the substrate applied at the top layer was too small to serve the incoming loads (different from the one proposed in the design specifications of the WWTP).

In spring 2018, the clogged top layer was removed, replaced with gravel and replanted with *Phragmitis australis* rather than the originally planted local plant species (*Arunda donax*). In order to evaluate the effectiveness of the rehabilitation measures, the monitoring data after the rehabilitation of the system (May 2018 – January 2019) are presented separately from the data of the entire monitoring period (Figure 9 and Figure 10). Figure 9 and Figure 10 also include the relevant Greek water reuse limits (class 3), which are required to be met by the effluent of the WWTP.

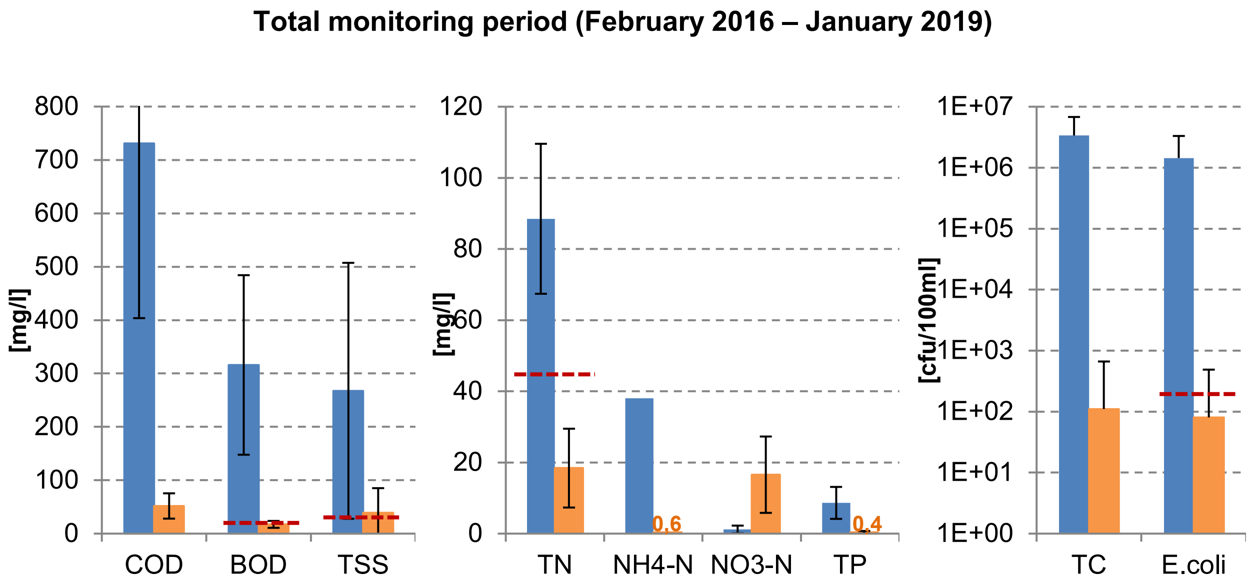

Figure 9 Average and STDEV values of the influent and effluent concentrations for parameters monitored in the Antiparos WWTP over the total monitoring period;
Red dotted line: class 3 limit of Greek reuse regulation (n=2 for NH4-N, n=29 for other parameters).

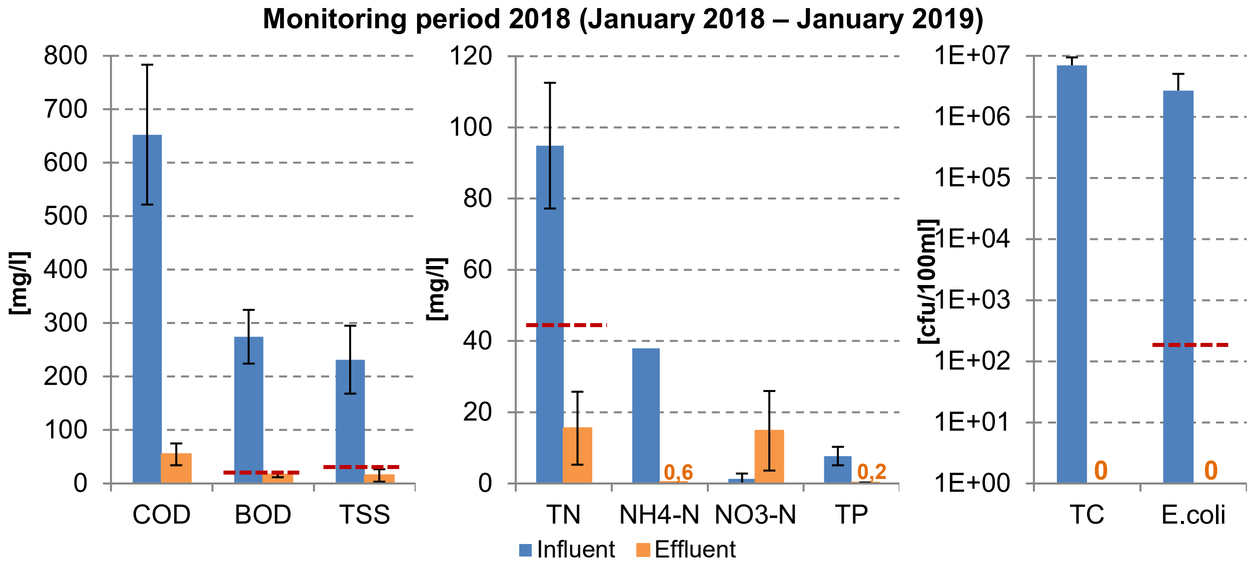

Figure 10 **Average and STDEV values of the influent and effluent concentrations for parameters monitored in the Antiparos WWTP in 2018, only;**
Red dotted line: class 3 limit of Greek reuse regulation (n=2 for NH4-N, n=10 for other parameters).

As shown in Figure 10, the STDEV values of the organic parameters in the inflow concentrations show high variability when looking at all data. Increased hydraulic and organic loads on the too fine substrate during summer months has been suspected to be the reason for the clogging of the wetlands. This assumption is supported by looking at the individual data for BOD_5 during the intense sampling campaign in August 2017 (Figure 11). On two days during this campaign (13. and 16. of August) significant peaks for BOD_5 and COD after the second CW stage could be associated with an unusual high number of six and five sewage trucks delivering additional amounts of wastewater during the peak touristic period. After detecting the overload of the wetlands at these occasions the number of trucks permitted to discharge wastewater to the plant was limited to maximum three trucks per day to avoid overloading of the plant. Looking at the data from 2018 only (Figure 10, lower part), the variability in the inflow concentration of the organic parameters decreased after implementation of this restriction.

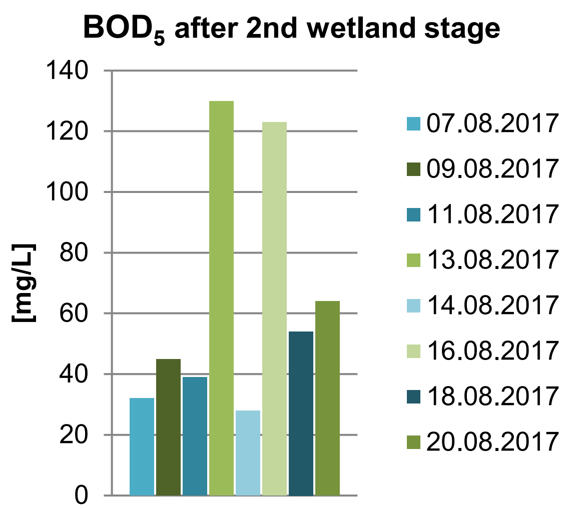

Figure 11 **BOD_5 concentrations after the second CW stage during the first intense sampling campaign in August 2017.**

The difference between all data and the data from 2018 only (Figure 10) is largest for the microbiological parameters. In 2018, neither TC nor *E. coli* were detected in any effluent sample. Looking at the total monitoring period, *E. coli* have been detected in the final effluent in five out of the twenty-nine samples. In August and September 2017 the amount of chlorine used for disinfection was insufficient and had to be adapted, as pathogen levels in the effluent even exceeded the lowest limits for "restricted irrigation" (intended reuse of the plants effluent). This can also be seen in Figure 12 (left), showing results of an intense sampling campaign in August 2017 (samples taken at all sampling points) with average concentrations for E. coli and TC >10^3 cfu/100 mL. The dosage for chlorination (12.5% NaOCl solution) was adjusted accordingly and set to 80 L/day for the summer months July to September, 50 L/day during the low flow period from December to February and 65 L/day in spring and autumn months, resulting in approximate concentrations between 15-27 mg Cl/L in summer and 50-140 mg Cl/L from autumn to spring.

At the outlet of the stabilization pond water passes through a stone wall in order to restrain suspended solids (e.g. algae growing in the pond) before entering the chlorination channel. In August and September 2017 the stone wall was damaged, causing an increase of TSS in the effluent of the stabilization pond from August to November. This damage was fixed until January 2018. While the TSS concentration in WWTP effluent shows an exceedance of the limit when looking at all data (Figure 10), the limit is met in all samples after January 2018.

Three intense sampling campaigns have been conducted in August 2017, August/September 2018 and November 2018 (sampling during 8 days each within 2 weeks) during which samples after each treatment step were taken. The average concentrations and STDEV values are presented in Figure 12 -Figure 15 (inflow concentration not shown for visual clarity). The three intense sampling campaigns enable a comparison of the course of concentration for individual parameters throughout the treatment stages during different stages of WWTP operation: peak flow conditions during phase with overloading, problems of chlorination dosage and stone wall as described above (August 2017), peak flow conditions after repairs (August/September 2018), and normal/low flow conditions (November 2018).

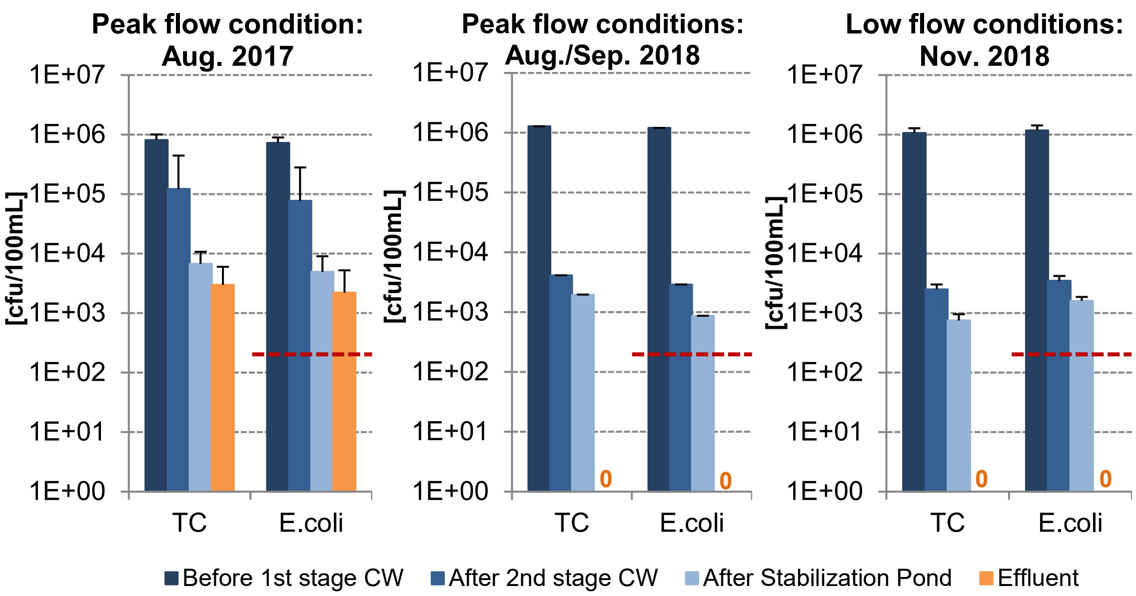

Figure 12 **Average and STDEV values for TC and *E. coli* concentrations during the intense sampling campaigns; Red dotted line: class 3 limit (Greek reuse regulation), n=8.**

Regarding the microbiological parameters, the comparison of the sampling campaigns during peak flow conditions in 2017 and 2018 shows the effect of insufficient chlorination in summer 2017 (see Figure 12; disinfection is implemented as last stage between stabilization pond and effluent sampling point). There is no significant difference between the performance of the plant during peak and low flow conditions in 2018.

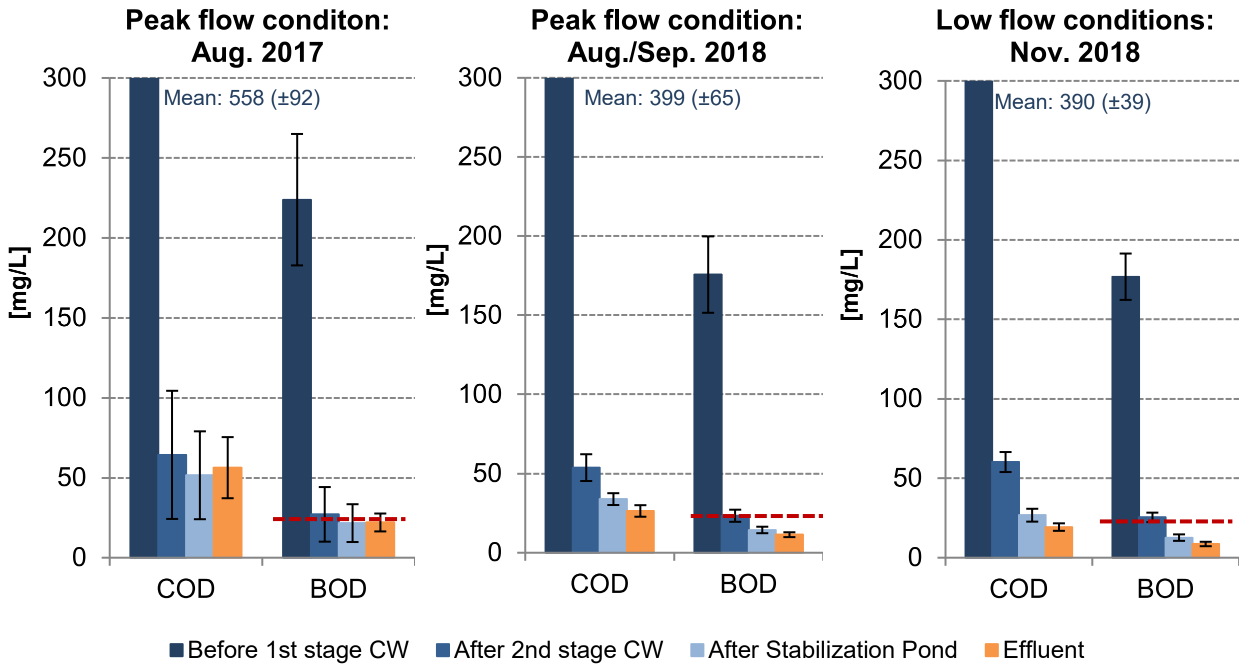

Figure 13 **Average and STDEV values for COD and BOD₅ concentrations during the intense sampling campaigns; Red dotted line: class 3 limit (Greek reuse regulation), n=8.**

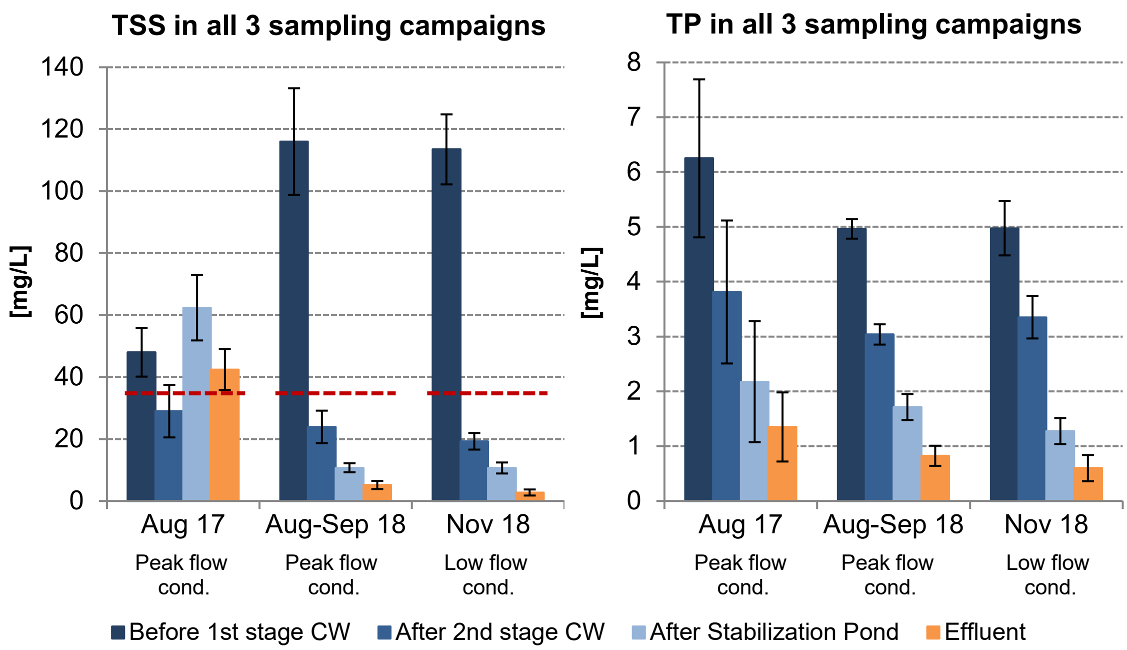

Figure 14 **Average and STDEV values for TSS and TP concentrations during the intense sampling campaigns; Red dotted line: class 3 limit of Greek reuse regulation, n=8.**

Regarding BOD_5, COD and TSS, the comparison of both peak flow campaigns shows lower effluent concentrations in 2018 (below the limit value) after reconstruction of the stone wall filter at the outlet of the stabilization pond and the restriction of wastewater inflow volumes (Figure 13 and Figure 14). In August 2017, the effect of the damaged stone wall filter can clearly be seen in the concentration increase for TSS in the stabilization pond likely due to algal growth (Figure 14 left). Similar to the microbiological parameters there is no significant difference in performance under peak or low flow conditions after reconstruction in 2018. TP effluent concentrations were consistently below 2 mg/L, which is a high quality level for WWTP <2000 p.e..

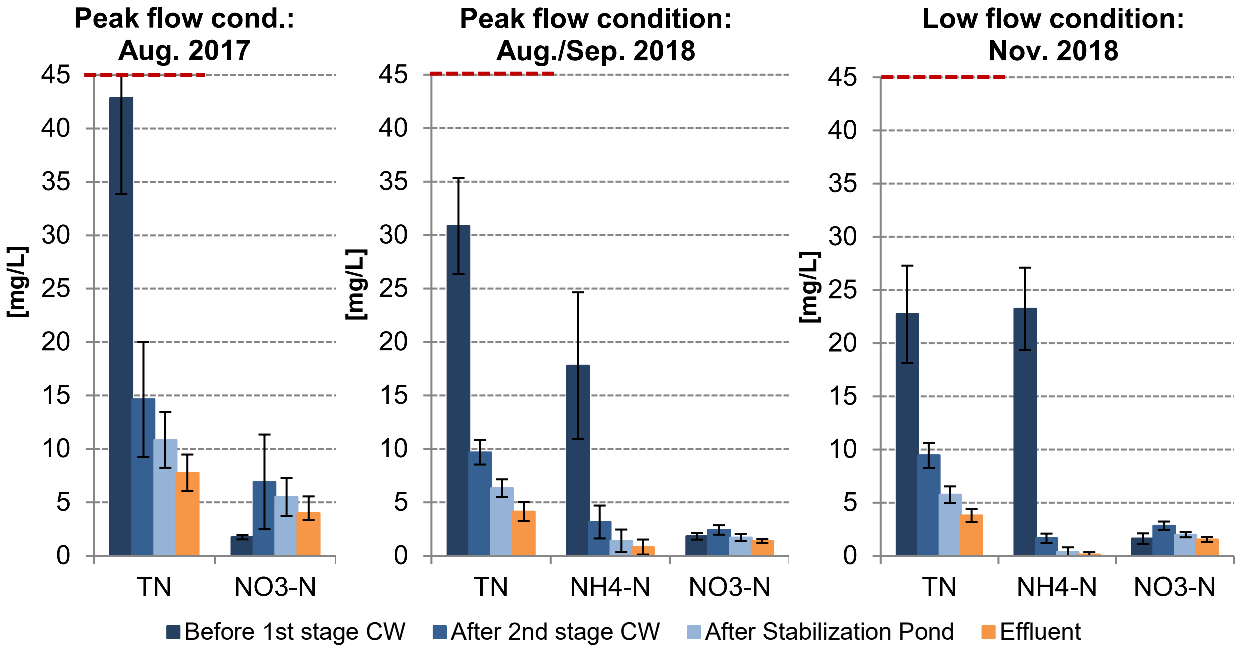

Figure 15 Average and STDEV values for TN, NH4-N and NO3-N during the intense sampling campaigns; Red dotted line: class 3 limit of Greek reuse regulation, n=8.

Lastly, regarding nutrients (i.e. nitrogen, phosphorous) a large decrease of total concentrations can be observed from primary treatment (= before CWs) to WWTP effluent (Figure 15). The reduction of TN in the two CW stages is significant (≥60%). In addition, a remarkably large decrease of TN also takes place in the primary treatment, during which inflow concentrations of 100-120 mg/L (see Table 39) are reduced to 20-40 mg/L (see Figure 15). Aeration of the equilibration tank and recirculation of pond water to the end of the Imhoff tank could contribute to this result. For NH_4-N (only analysed in 2018) a large decrease can be seen within the CWs that reduce ammonium concentrations to 2-3 mg/L. The removal efficiency for NH_4 seems to be more effective under low flow conditions in winter, when the retention time in the CWs and the stabilization pond is longer.

Compliance with European Water reuse regulations

In order to compare the effluent data to the different national water reuse regulations, the data has to be prepared as described in chapter 2.2. Due to concentration changes of relevant parameters caused by adaptations of the WWTP as described earlier (e.g. substrate exchange in CW beds and repair of stone wall filter in the maturation pond), the analysis of compliance of effluent data with reuse regulations has been conducted not only including all data collected over the full monitoring period, but also comparing data before (2016/17) and after the repairs and adaptations (2018 only), in order to evaluate the current compliance of the WWTP effluent with the quality requirements for water reuse. Below, results for evaluation of the compliance of WWTP effluent with reuse regulations of Greece and the European Commission's proposal are presented.

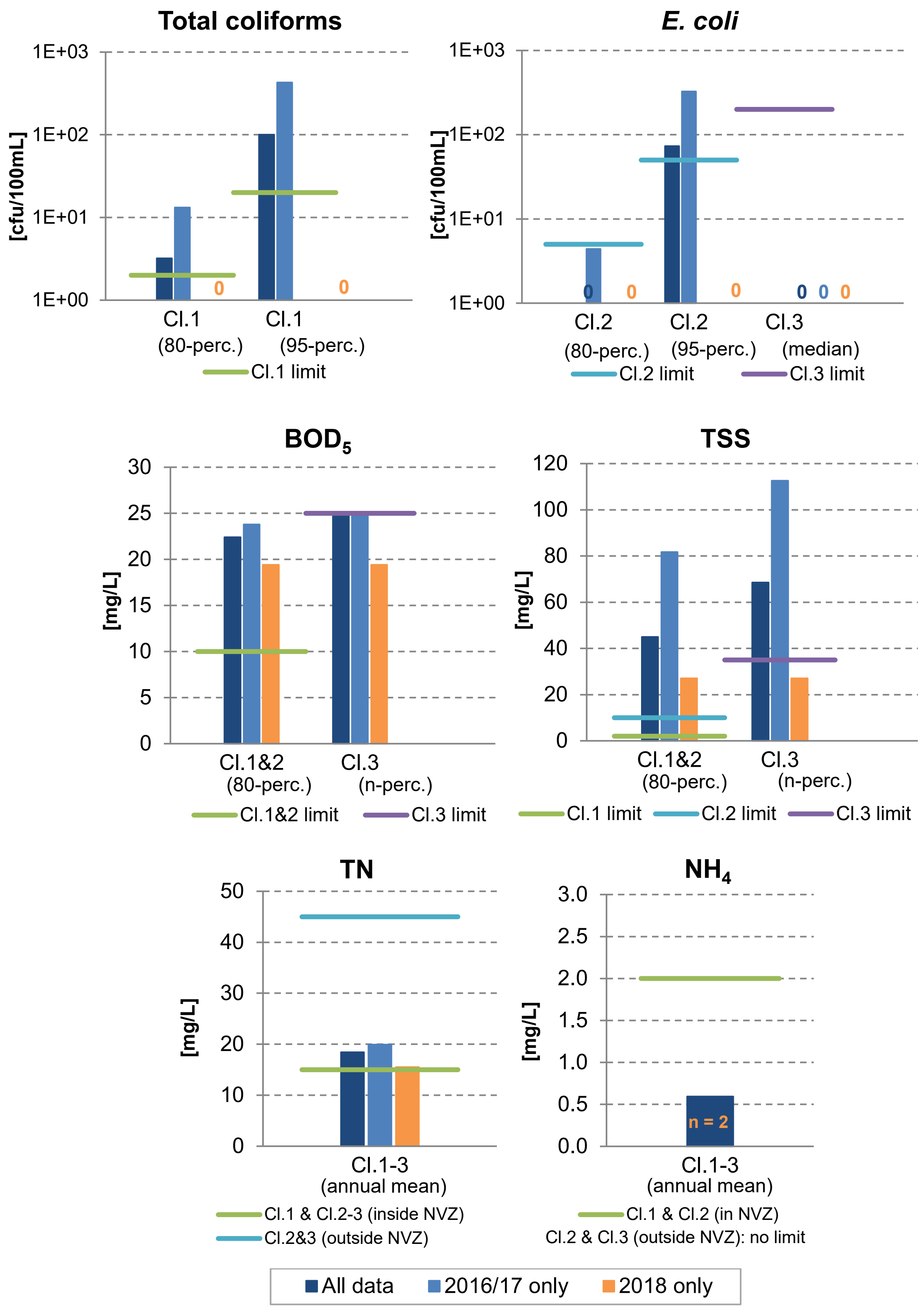

Figure 16 **Compliance of relevant percentiles for all samples (dark blue), samples taken 20167/17 before reconstruction measures (light blue) and 2018 after reconstruction (orange) with limit values of the Greek water reuse regulation [NVZ: Nitrate vulnerable zones], for n-perc.-values see Table 13.**

In Figure 16, relevant percentiles of WWTP effluent concentrations are compared to the Greek water reuse regulation. Looking at the microbiological parameters in 2018, class 1 quality can be achieved, since TC concentrations of 0 are below both required limits for the 80 and 95-percentiles. Evaluating the entire data set, only class 3 limit can be met due to high effluent concentrations in 2017. For BOD_5 and TSS, the required 80-percentile concentration exceeds both the limit for class 1 and class 2 water qualities, regardless of the considered data range. While for BOD_5 the limit value for class 3 quality is just met even before re-construction, for TSS the class 3 limit is clearly exceeded when 2017 data is included (Figure 16). After reconstruction, the relevant percentile for both parameters BOD_5 and TSS fell below the respective class 3 limits. As water reuse inside nitrate vulnerable zones is not being regarded in this study, TN and NH_4 levels are suitable for class 2 or 3 reuse purposes. Overall, when evaluating all data or the data collected before reconstruction measures only, TSS is a parameter preventing the achievement of a water quality suitable for any reuse purpose. However, BOD_5 is also a parameter which meets the class 3 limit closely. After reconstruction, a quality suitable for class 3 reuse purposes is being achieved, which is the intended reuse purposes for Antiparos WWTP effluent.

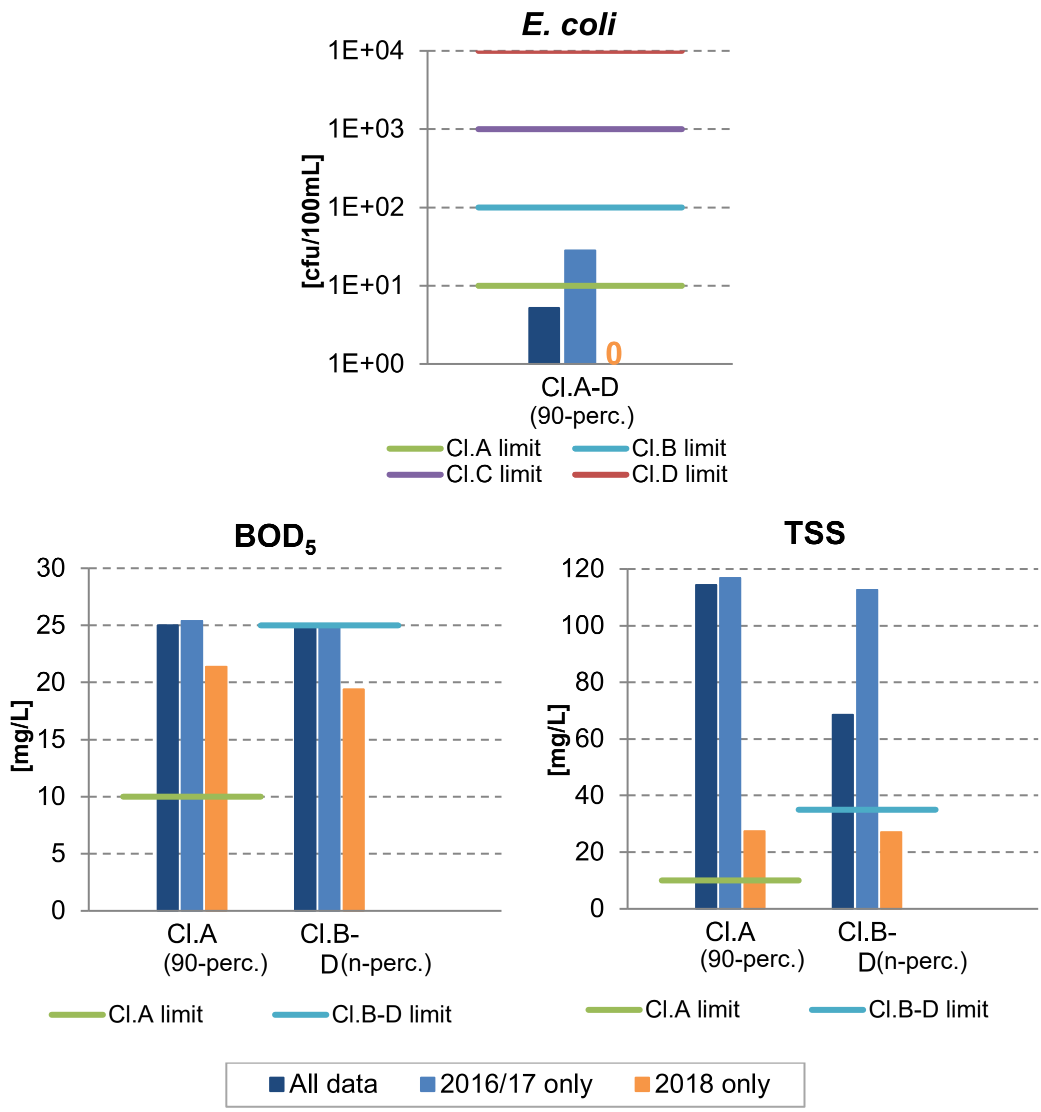

Figure 17 **Compliance of relevant percentiles for all samples (dark blue), samples before reconstruction measures taken 2016/17 (light blue) and after reconstruction in 2018 (orange) with limit values of the EC proposal for EU-wide water reuse regulation. For n-perc.-values see Table 16.**

In Figure 17, relevant percentiles of WWTP effluent concentrations are compared to the requirements of the EC-proposal. Regarding *E. coli*, class B level is met before reconstruction. After reconstruction, it improves to class A quality for this parameter. For BOD_5 and TSS, the limits for all classes except class A (which is not being achieved in any case) are the same limits as for class 3 in the Greek regulation (25 and 35 mg/L, respectively). As shown above, the limit for BOD_5 is met before reconstruction while the limit for TSS is being exceeded. After reconstruction, both parameters are below their limits of the relevant percentile. Overall, no reusable water quality could be achieved before reconstruction due to high TSS values, but after reconstruction the effluent achieves a quality suitable for all reuse purposes included in classes B to D of the proposal (see 2.2.6).

This method of evaluation was applied to the three specific reuse cases for restricted, unrestricted and urban irrigation defined in chapter 3.1, comparing the effluent concentrations to all selected national regulations as well as the EC-proposal. Results are shown in Table 18 to Table 20 with each table providing an overview regarding the compliance of Antiparos WWTP effluent (data of 2018 after rehabilitation measures of the WWTP) with the limits of the quality class for one of the three defined reuse cases. Tables with evaluation of the whole data set containing all samples from 2016 to 2018 can be found in Annex 6.3. The presented concentrations were determined according to the compliance definition of the respective regulation (e.g. 90-percentile). This is why there may be different concentrations of the same parameter presented for different regulations. The respective compliance definitions are summarized in chapter 3.1. The coloring of the cell containing concentrations indicates if the respective parameter meets the limit in the respective regulation. Furthermore, the number of individual samples which are exceeding the limit value is provided, as is the number of samples which are also exceeding the maximum deviation limit (in case such a limit is being provided in the regulation). The exceedance of the maximum deviation limit in any number of samples would render the water unsuitable for reuse in the respective country, whereas an exceedance of the limit value is possible in case of a required percentile (e.g. for 90-percentile, 10% of samples may exceed the limit).

Overall, it becomes apparent, that for the data set of 2018 *E. coli* is not a parameter limiting the reuse for all three defined purposes in any of the regulations, neither are the parameters TN, NH_4, TP and residual chlorine. The only exception is TN for the reuse purpose “urban irrigation” (16 mg/L), which just exceeds the relevant limit of 15 mg/L in this strictest quality class of the Greek regulation.

E.C. is a limiting parameter for all three cases in all the regulations in which E.C. is regulated, as this parameter is very high in the WWTP effluent due to high conductivity values in the drinking water (mainly produced from sea water on the Aegaen islands). For Italy, the relevant annual average of BOD_5 does comply with the limit value for all reuse cases, however, since the maximum deviation limit for this parameter is 0% (no single sample is allowed to exceed the limit), the two samples exceeding the limit value are at the same time exceeding the maximum deviation limit, which makes the water unsuitable for reuse even though the relevant percentile of the parameter complies with the limit.

Regarding the individual reuse purposes, the water quality requirements for “restricted irrigation of beans using drip irrigation” are in compliance with the French and the Greek regulation as well as with the proposal by the EC. Electrical conductivity is the only parameter exceeding the limit in the Spanish regulation, while it is E.C. and TSS in the Italian one. For Cyprus, the concerned purpose falls into a relatively higher, more restricted quality class than in the other regulations (see chapter 3.1). This is why the limits for most parameters are being exceeded.

For case two “unrestricted irrigation” of tomatoes using any irrigation method, TSS is the parameter (as well as E.C.) which exceeds the limit in every single regulation. Furthermore, BOD_5 and COD also exclude reuse for this purpose in all regulations except for Italy (and for Spain – both parameters not included in the Spanish regulation).

Case three “urban irrigation” of a public park is not included in the EC-proposal. For Cyprus this purpose falls in a comparatively low, less restricted quality class, which is why the limits are mostly met except for the parameter E.C.. TSS is the parameter exceeding the relevant limit in all other regulations. BOD_5 and COD also exceed the limits in the Greek and French regulation respectively.

All in all, restricted irrigation in France, Greece and in regard to the EC proposal is the only applicable reuse type for the WWTP effluent of Antiparos, mainly due to TSS and E.C. values.

Compliance of Antiparos WWTP effluent quality to reuse regulations (Jan 2018 – Jan 2019)

Table 18 Case 1 "Restricted irrigation": Effluent concentrations and number of samples exceeding the limits.

Compliance with national regulation of:	class	*E. coli*		BOD$_5$		COD		TSS		EC		TN		NH$_4$		TP		Cl.$_{res.}$	
		cfu/100mL		mg/L		mg/L		mg/L		µS/cm		mg/L		mg/L		mg/L		mg/L	
Cyprus	2	0		20		71		27		6,414								0	
# exceedings of limit / max. dev.		**0**	**0**	**9**	***n.l.***	**2**	***n.l.***	**6**	***n.l.***	**1**	**1**							**0**	**0**
France	B	0				69		27											
# exceedings of limit / max. dev.		**0**	**0**			**0**	**0**	**8**	**0**										
Greece	3	0		19				27				16		*n.l.*				*n.a.*	
# exceedings of limit / max. dev.		**0**	***n.l.***	**0**	***n.l.***			**0**	***n.l.***			**0**	***n.l.***						
Italy	1	0		17		55		15		6,414		16		0.59		0.20		0	
# exceedings of limit / max. dev.		**0**	**0**	**2**	**2**	**0**	**0**	**4**	**4**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Spain	2.2	0						27		6,414		*n.a.*				*n.a.*			
# exceedings of limit / max. dev.		**0**	**0**					**0**	**0**	**1**	***n.l.***								
COM337 (2018)	C	0		19				27											
# exceedings of limit / max. dev.		**0**	**0**	**0**	**0**			**0**	**0**										
Total number of samples (effluent)		**10**		**10**		**10**		**10**		**1**		**10**		**2**		**10**		**4**	

Table 19 Case 2 "Unrestricted irrigation": Effluent concentrations and number of samples exceeding the limits.

Compliance with national regulation of:	class	*E. coli**		BOD$_5$		COD		TSS		EC		TN**		NH$_4$**		TP		Cl.$_{res.}$	
		cfu/100mL		mg/L		mg/L		mg/L		µS/cm		mg/L		mg/L		mg/L		mg/L	
Cyprus	1	0		20		71		27		6,414								0	
# exceedings of limit / max. dev.		**0**	**0**	**9**	***n.l.***	**2**	***n.l.***	**6**	***n.l.***	**1**	**1**							**0**	**0**
France	A	0				76		31											
# exceedings of limit / max. dev.		**0**	**0**			**6**	**6**	**6**	**6**										
Greece	2	0	0	19				27				16		*n.l.*				0	
# exceedings of 80-perc. / 95-perc.		**0**	**0**	**9**	**--**			**6**	**--**			**0**	**--**					**0**	**--**
Italy	1	0		17		55		15		6,414		16		0.59		0.20		0	
# exceedings of limit / max. dev.		**0**	**0**	**2**	**2**	**0**	**0**	**4**	**4**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Spain	2.1	0						27		6,414		*n.a.*				*n.a.*			
# exceedings of limit / max. dev.		**0**	**0**					**4**	**1**	**1**	***n.l.***								
COM337 (2018)	A	0		21				27											
# exceedings of limit / max. dev.		**0**	**0**	**9**	**2**			**6**	**4**										
Total number of samples (effluent)		**10**		**10**		**10**		**10**		**1**		**10**		**2**		**10**		**4**	

*GR: (E. coli) Two limits must be met by 80 & 95-percentile; there is no maximum deviation limit
**GR: (TN & NH4) Limits for reuse in non-nitrate vulnerable zones

Table 20 Case 3 “Urban irrigation”: Effluent concentrations and number of samples exceeding the limits.

Compliance with national regulation of:	class	*E. coli**		BOD$_5$		COD		TSS		EC		TN		NH$_4$		TP		Cl$_{res.}$	
		cfu/100mL		mg/L		mg/L		mg/L		µS/cm		mg/L		mg/L		mg/L		mg/L	
Cyprus	**3**	0		20		71		27		6,414								0	
# exceedings of limit | max. dev.		**0**	**0**	**0**	***n.l.***	**0**	***n.l.***	**0**	***n.l.***	**1**	**1**							**0**	**0**
France	**A**	0				76		31											
# exceedings of limit | max. dev.		**0**	**0**			**6**	**6**	**6**	**6**										
Greece	**1**	0	0	19				27				16		0.59				0	
# exceedings of 80-perc. | 95-perc.		**0**	**0**	**9**	**--**			**7**	**--**			**6**	**--**	**0**	**--**			**0**	**--**
Italy	**1**	0		17		55		15		6,414		16		0.59		0.20		0	
# exceedings of limit | max. dev.		**0**	**0**	**2**	2	**0**	**0**	**4**	**4**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Spain	**1.2**	0						27		*n.a.*		*n.a.*				*n.a.*			
# exceedings of limit | max. dev.		**0**	**0**					**4**	**1**										
COM337 (2018)	**n.a.**																		
Total number of samples (effluent)		**10**		**10**		**10**		**10**		**1**		**10**		**2**		***10***		**4**	

*GR: Limit for TC instead of E. coli for class 1 (Two limits must be met by 80 & 95-perc.); there is no maximum deviation limit
**GR: Sprinkler irrigation is prohibited
***SP: EC only applicable for "Agricultural uses"

Legend:
- (green) The relevant percentile of samples meets the quality requirements for the defined reuse case
- (light orange) The relevant percentile of samples does not meet the quality requirements for the defined reuse case
- (orange) No compliance only due to exceeding of the maximum deviation limit

Footnote for all tables:

1. Parameters are presented in the percentile which is decisive in the water quality class that is required for the defined reuse case.
   - n.l.: no limit is fixed for the regarded water quality class
   - n.a.: the parameter is not regulated for the regarded reuse case
   - "empty cell": the regarded parameter is not regulated in the regarded national regulation
2. The number of samples exceeding the limit of the relevant class is presented in green; the number of samples exceeding the maximum deviation limit (max. dev.) is presented in red. The total number of samples is presented at the bottom of the table.
3. Only parameters which have been monitored in the Antiparos WWTP are included in the table. Missing parameters for the full quality evaluation vary in number and kind, for each of the national regulations.
4. IT: Less strict limit for E. coli in case of treatment in CWs / stabilization ponds and less strict limit for TN & TP in case of irrigation use, are applicable for all three of the regarded reuse cases
5. SP: NO_3 has been monitored, it is however not a relevant parameter for the regarded reuse case

3.3.2 Demo site Thirasia: Photocatalysis and ultrafiltration combined with CW

Thirasia Island belongs to the volcanic island group of Santorini in the Cyclades complex of the Greek Aegean Sea (Figure 18). Thirasia occupies a land area of 9.3 km² and has a permanent population of 319 inhabitants (census 2011), which increases significantly during the summer period (about 1,350 seasonal residents and tourists in 2013). Administratively, the island belongs to the Municipality of Thira.

Figure 18 Location of Thirasia Island, Greece

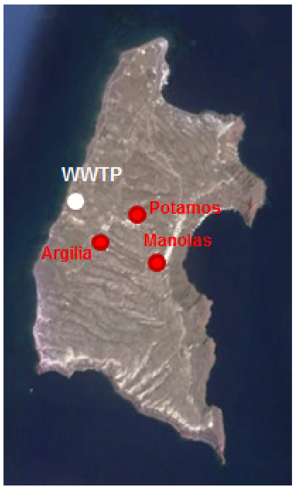

Figure 19 Location of Thirasia WWTP and served settlements (*Source: Google Earth, 2016*)

The construction of the Thirasia WWTP (AquaNES demo site 10a) was completed in October 2016, aiming to serve the resident and seasonal population of the settlements of Manolas (capital of the island), Potamos and Agrilia for a 30 year time horizon (400 permanent residents, and 1,500 seasonal residents and tourists; maximum daily capacity: 142 m³ in 2045). It is the first time that a WWTP involving solar heterogeneous photocatalysis is implemented in full-scale. The WWTP is under the jurisdiction of the DEYAT, the municipal company for the provision of water supply and sewage treatment services for the communities of Thira and Thirasia.

The operation of the plant started with an inflow rate of just 5 m³/day, as only a few houses were connected to the sewerage network at the beginning. Since summer 2017, about 60 households are connected to the plant, generating a wastewater inflow of 12 to 60 m³/d. The WWTP inflow over time is shown in Figure 20. Flow peaks can be observed during the summer (especially in 2018) due to the tourist influx to the island.

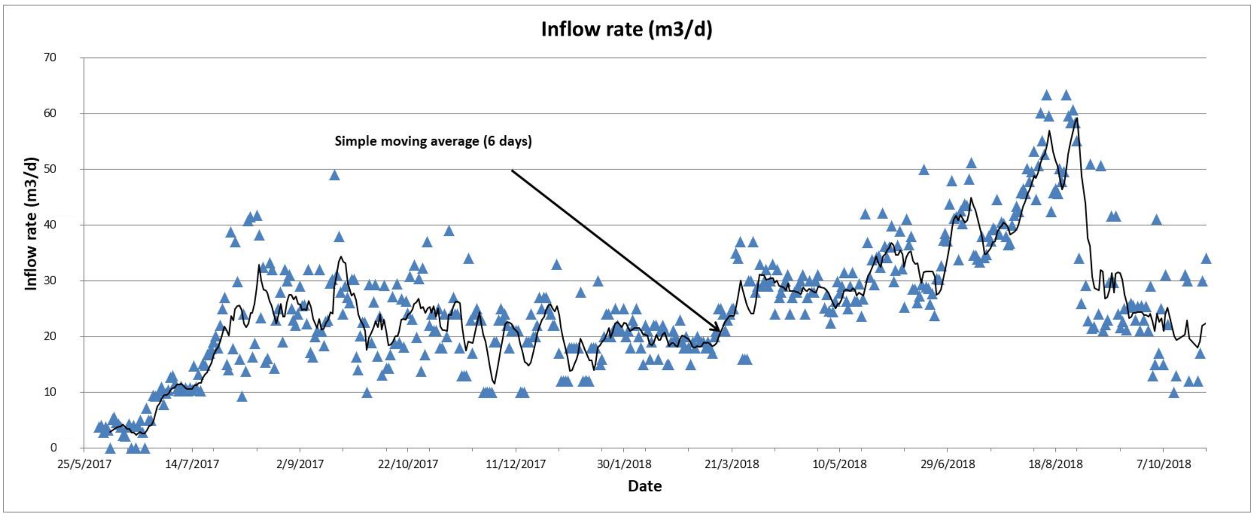

Figure 20 Inflow rate of wastewater into the Thirasia WWTP since the beginning of its operation.

The flow scheme of the Thirasia WWTP, including sampling points for the monitoring of the operation of the plant, is shown in Figure 21. The influent undergoes screening, grit removal and primary sedimentation - flocculation. The wastewater is then subjected to solar heterogeneous photocatalysis (two independent production lines each consisting of a reactor and a sedimentation tank; the second production line is used in cases of increased hydraulic loads, e.g. during summer months). After the photocatalysis process, wastewater is supplied to the CWs (two parallel rectangular sealed beds of horizontal subsurface flow, occupying an area of 208.2 m² each). The CWs are followed by an equalization basin (volume: 155 m3), used to minimize the variation of wastewater flow rate, due to non-continuous operation of the tertiary treatment unit which comprises an ultrafiltration unit (UF). Finally, the treated water undergoes chlorination– dechlorination. The treated effluent is reused for pressurized irrigation of trees and ornamental plants inside the premises of the WWTP, as well as for aquifer recharge through subsurface disposal with underground perforated pipes. During very low flow conditions in winter ultrafiltration can be by-passed.

Evaluation of the monitoring data was done for the period November 2017 - December 2018 (in November 2017 chlorination was started). The average concentrations of the analyzed parameters in the influent and effluent of the WWTP are presented in Table 21. The effluent of the Thirasia WWTP is usually discharged into a storage tank after ultrafiltration and chlorination stages (sampling point F in Figure 21) from where samples are taken. During times of very low inflow rates from February to March 2018 the ultrafiltration was bypassed and the samples were taken right after the CWs (sampling point E in Figure 21). After the bypass, the water is still chlorinated. As sampling point E is before the chlorination step, no final effluent concentrations are available during this time. Therefore, only the samples taken at sampling point F (after ultrafiltration and chlorination) were considered for evaluating the compliance of the effluent quality with water reuse regulations.

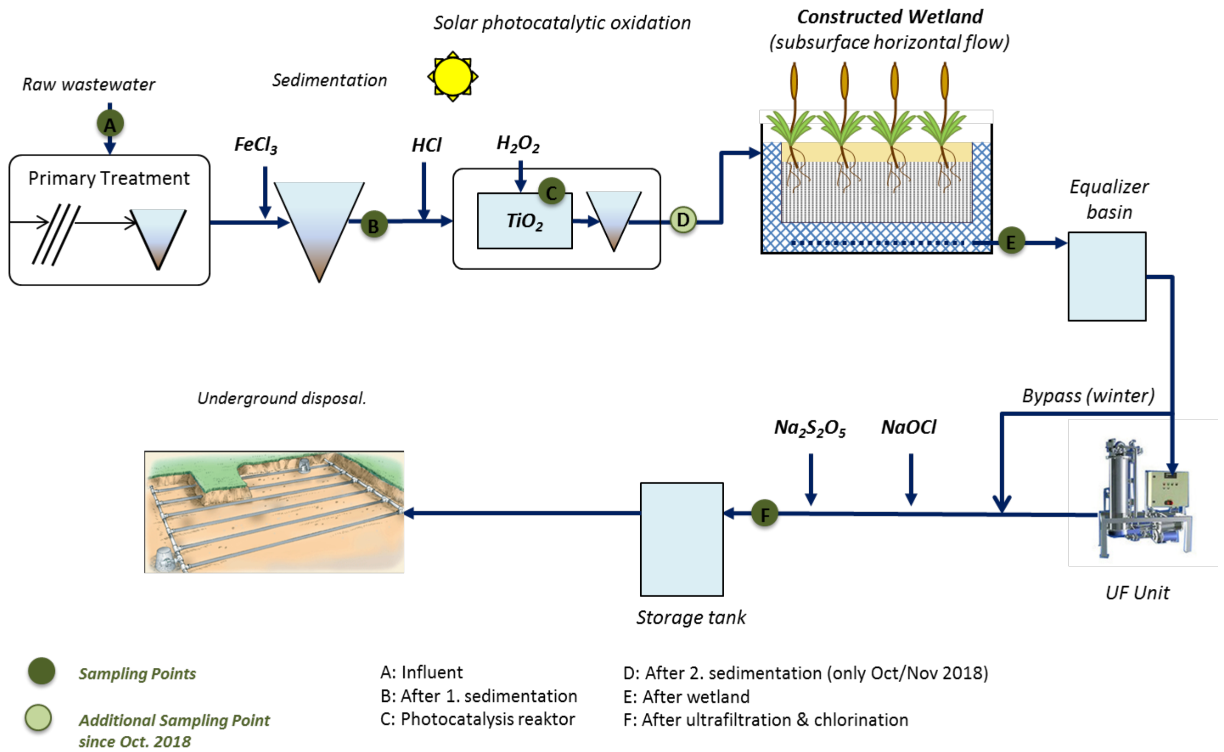

Figure 21 Flow chart of the Thirasia WWTP including sampling points.

Table 21 Mean and STDEV values of influent and effluent concentrations for all monitored parameters in the Thirasia WWTP.

Parameters	Units	Influent (mean)	STDEV	Effluent (mean)	STDEV	$n_{Eff.}$
BOD_5	mg/L	522	342	9.5	7.1	22
COD	mg/L	1,470	1,673	52	25	25
TSS	mg/L	653	1,045	7.9	4.0	25
Turbidity	NTU	n.a.	n.a.	1.9	1.1	13
TN	mg/L	159	72	50	19	24
NO3-N	mg/L	0.71	0.23	4.2	3.2	25
NH4-N	mg/L	91	30	34	22	24
TP	mg/L	15	4.6	5.7	1.9	22
TC	cfu/100mL	5.2E+07	9.7E+07	3.8E+03	4.0E+04	8
E. coli	cfu/100mL	2.3E+07	5.2E+07	3.1E+01	2.9E+01	8
E.C.	µS/cm	1,973	452	2,558	620	25
pH	-	7.5		8.1		25

$n_{Eff.}$: number of effluent samples (taken after ultrafiltration and disinfection)

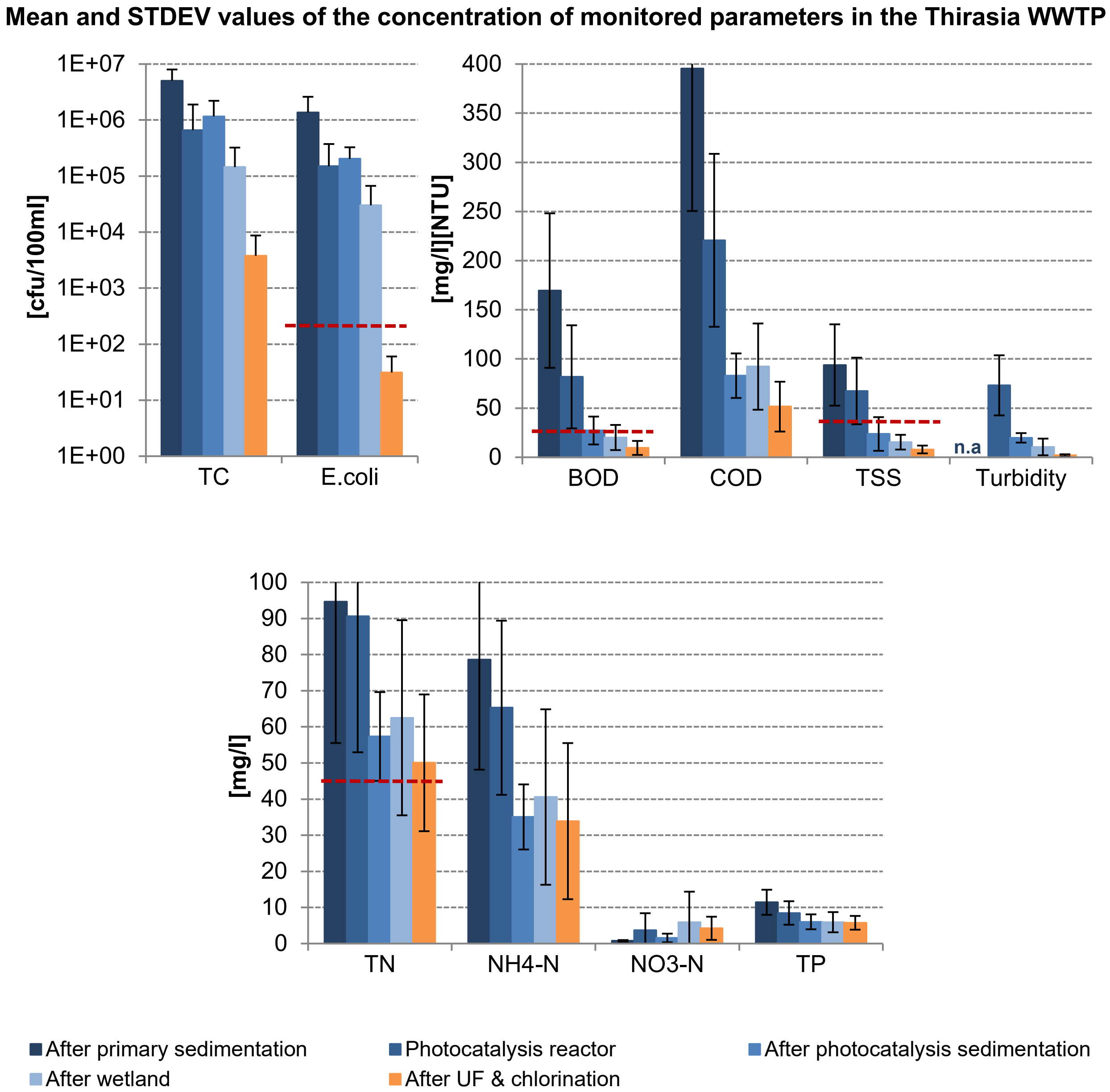

Figure 22 **Mean and STDEV values of the concentrations of monitored parameters in the Thirasia WWTP; Red dotted line: class 3 limit (Greek reuse regulation). n=4-7 for photocatalysis sedimentation, n=22-34 for all other sampling points.**

Concentrations for all monitored parameters throughout the treatment steps starting after the pre-treatment stage are presented in Figure 22. Sample taken from the photocatalysis stage were mostly taken directly from the photocatalysis reactor, in which the catalyst is added and stirred into the water. In order to obtain a concentration of the effluent of the entire photocatalysis stage (photocatalysis reactor and sedimentation) which is also the influent of the CWs, an additional sampling point (D, see Figure 21) was added after the photocatalysis sedimentation stage in October 2018. The number of samples taken at point D was therefore significantly smaller than the number of samples taken from all other sampling points (n=4-7, see text box in figures). The first sampling point from which turbidity was measured is inside the photocatalysis reactor. The concentrations of *E. coli* and TC after ultrafiltration and chlorination are high. It is recommended to review the sampling procedure for microbiological samples to rule out that results for *E. coli* and TC are increased due to sampling issues.

During the monitoring period the efficiency of different dosages of the catalyst TiO_2 added to the photocatalysis stage was compared. The standard dosage of 0.1 kg/m³ was increased by three and five times (0.3 and 0.5 kg/m³). As the catalyst is mixed into the water using turbulence caused by aeration, this enabled the additional evaluation of the efficiency of a simple aeration stage without adding any catalyst. The removal efficiency for the parameters TN, BOD_5 and COD are presented in Figure 23. The data shows that a simple aeration without adding any catalyst achieved similar levels of removal for these parameters as the standard dosage of the catalyst. The increased dosage of TiO_2 did not lead to an improved removal rate.

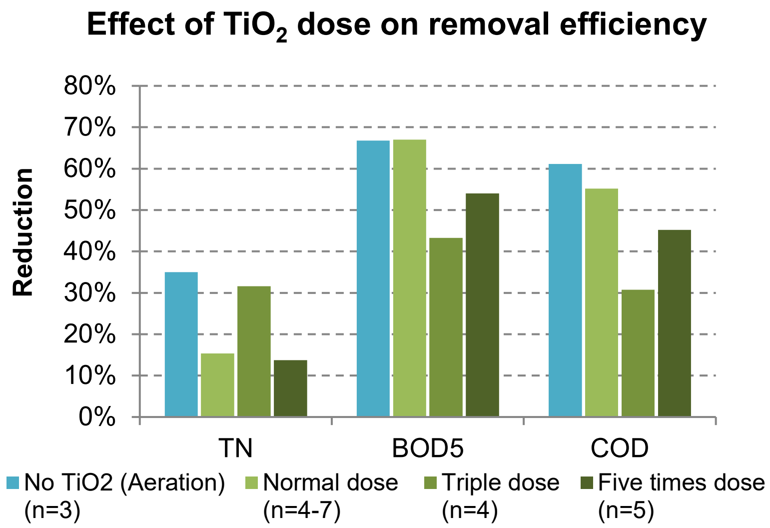

Figure 23 Removal of TN, BOD_5 and COD in the photocatalysis stage under different dosages of TiO_2.

Since the sampling point of the photocatalysis stage was located inside the reactor, the removal of substances in the subsequent sedimentation reactor is allocated to the CWs stage. This is creating an inaccuracy in the calculated and presented course of concentrations and removal efficiencies in those two stages. Results of samples taken at the additional sampling point added in October 2018 after the second sedimentation stage were used to quantify this inaccuracy. Data for this point is available only for the remaining two months of the project, which fell into the period of low flow conditions and while the five-time dose of the catalyst TiO_2 was being tested. When comparing the measured data at this point to the corresponding data measured after the primary sedimentation and after the wetland stage, an indication of the true distribution of the removal efficiency in the photocatalysis stage and the CWs stage for low flow conditions can be determined, as shown in see Figure 24. As can be seen, the contribution of the CWs to the removal in both stages is much smaller for BOD_5, COD and TSS, when the second sedimentation is attributed to the photocatalysis (sample “after photocatalysis sedimentation” = real effluent of photocatalysis stage) instead to the wetland (sample “photocatalysis reactor” = sampling point for which most data exists).

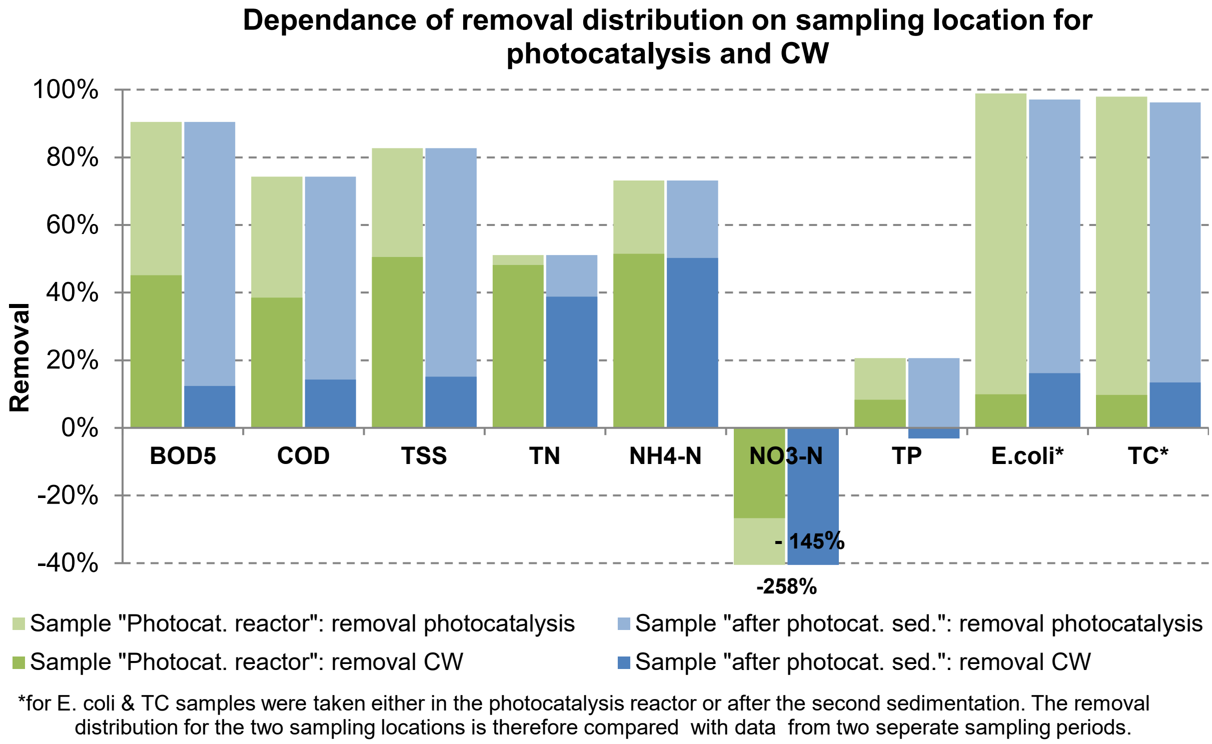

Figure 24 Removal efficiencies in photocatalysis and wetland stage determined with data from sampling point "photocatalysis reactor" (green) compared to data from sampling point "photocatalysis sedimentation" (blue = real effluent of photocatalysis stage) as wetland inflow.

Compliance of with European water reuse regulations

In order to evaluate the quality of Thirasia WWTP effluent in regard to different national regulations and the EU-level proposal, the relevant percentiles required in each regulation were calculated and compared to the different limit values. This comparison is presented exemplary for the Greek water reuse regulation and the proposal by the EC for an EU-wide regulation in Figure 25 and Figure 26. The figures show the compliance of the relevant percentile for all effluent samples taken after the UF and disinfection.

Looking at Figure 25 it becomes apparent that class 1 water quality of the Greek reuse regulation cannot be reached as all parameters beside turbidity exceed their respective limits. For class 2, TSS is within the limit value, however, *E. coli* and TN values exceed their respective class 2 limits. Regarding class 3, all parameters beside TN are within the limits. The mean concentration of all effluent values for TN (50 mg/L) just exceeds the class 3 limit of 45 mg/L. It has to be noted, though, that since July 2018 all effluent samples were below the limit (mean=34 mg/L, n=11).

In conclusion, TN is the only parameter that could limit the suitability of the reclaimed water for class 3 reuse purposes outside of nitrate vulnerable zones. Regarding class two, *E. coli* and BOD concentrations need to be lowered to reach the limits.

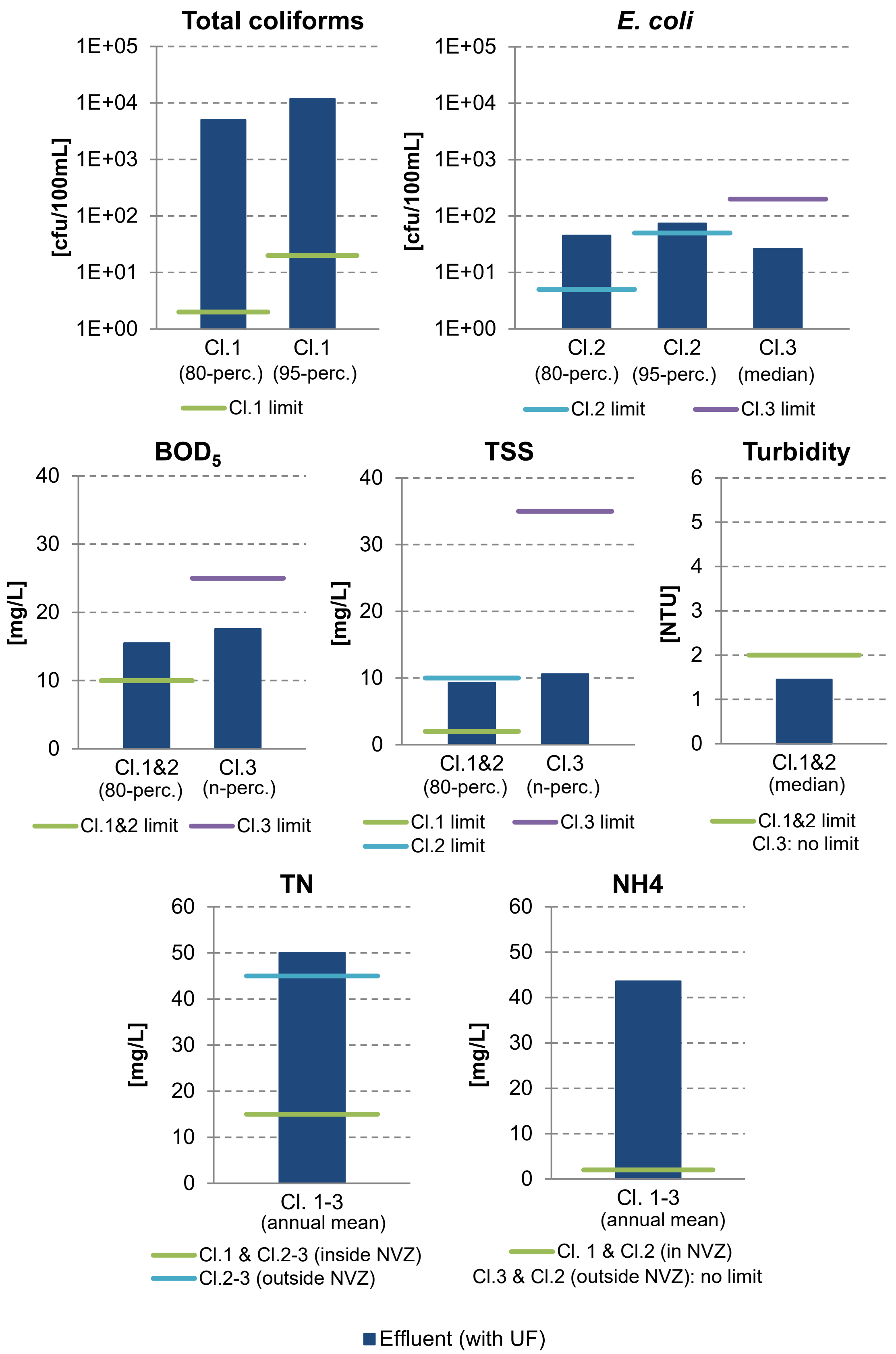

Figure 25 **Compliance of the relevant percentile of samples taken after UF & disinfection with the limit values of the Greek water reuse regulation [NVZ: Nitrate vulnerable zones, Cl.: Class]**

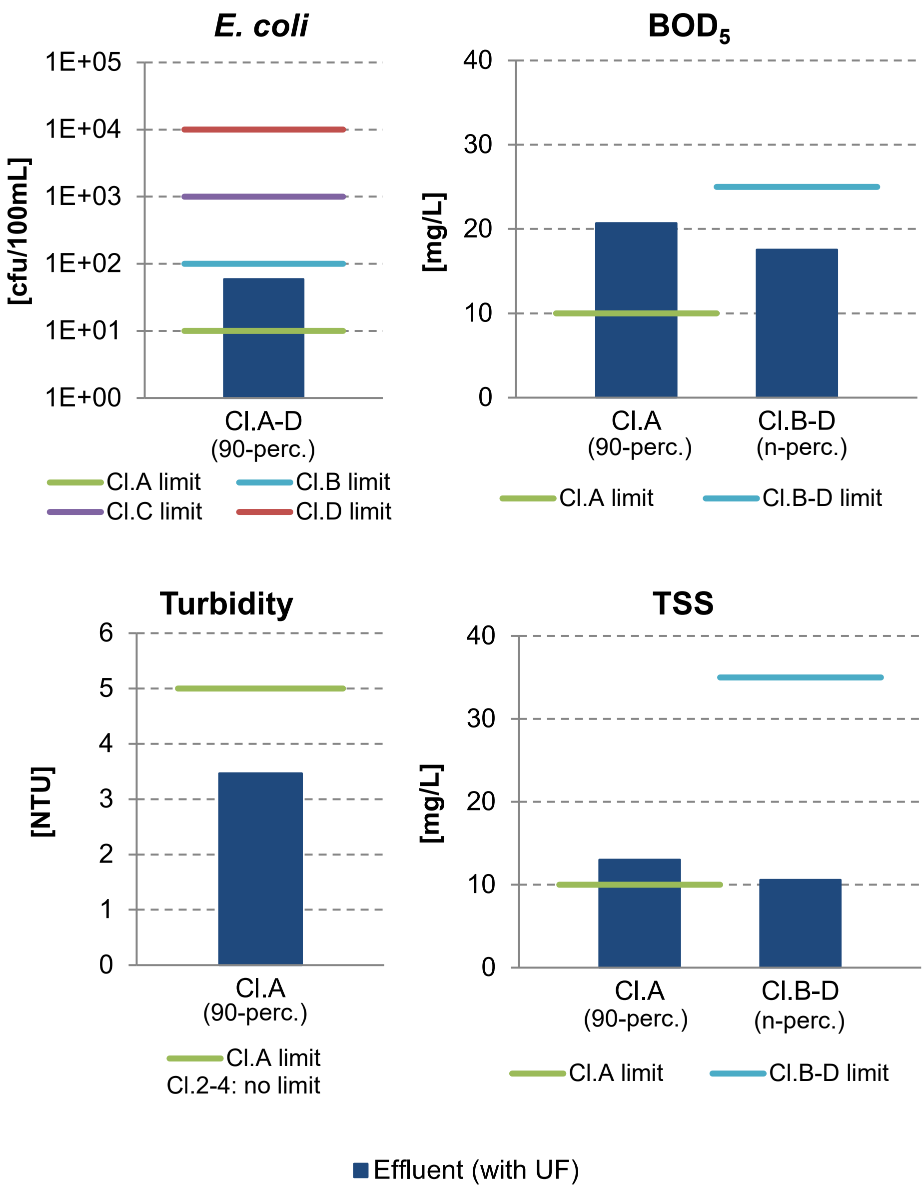

Figure 26 Compliance of the relevant percentile of samples taken after UF and chlorination with the limit values of the EC proposal (Cl.: class).

Evaluation of the water quality according to the EC-proposal (Figure 26) shows that class B can be achieved for all parameters. Looking at the individual parameters, the required 90-percentile exceeds class A for *E. coli,* BOD and TSS, while for turbidity this limit is achieved. Regarding TSS it is remarkable that despite of ultrafiltration the effluent concentration is above 10 mg/L (class A limit), which should be further investigated.

This method of evaluation was applied to the three specific reuse cases for restricted, unrestricted and urban irrigation as defined in chapter 3.1, comparing the monitoring data to all selected national regulations as well as the EC-proposal. Results are shown in Table 22 to Table 24 with each table providing an overview regarding the compliance of the Thirasia WWTP effluent with the limits of the quality class for one of the three defined reuse cases. The presented concentrations were determined according to the compliance definition of the respective regulation (e.g. 90-percentile). This is why there may be different concentrations of the same parameter presented for different regulations. The respective compliance definitions are summarized in chapter 3.1. The coloring of the cell containing concentrations indicates if the respective parameter meets the limit of the class that is relevant for this reuse purpose in the respective regulation. Furthermore, the number of individual samples which are exceeding the limit value is provided, as is the number of samples which are also exceeding the maximum deviation limit (in case such a limit is being provided in the regulation). The exceedance of the maximum deviation limit in any number of samples would render the water unsuitable for reuse in the concerned regulation, whereas an exceedance of the limit value is possible in case of a required percentile (e.g. for 90-percentile, 10% of samples may exceed the limit).

The first evaluated reuse case (restricted irrigation) is the irrigation of beans (cooked before consumption) irrigated by drip irrigation to minimize the contact of the product with the reclaimed water. The effluent of Thirasia WWTP complies with the limits of the concerned quality classes in the French regulation and the EC-proposal. For Greece and Italy the TN and NH4 concentrations are preventing a compliance for the defined purpose. This also means that the water shows too high TN levels to be suitable for the actually intended reuse purposes for the plant's effluent, which fall into the same class in the Greek regulation. For the Italian regulation it needs to be regarded that while BOD_5, COD, TSS and E.C. do meet the limit, any of the individual samples exceeding the limit will simultaneously exceed the maximum deviation limit which is 0% for these parameters. As there is only one class in this regulation, this applies to all three cases. For the Cypriot and Spanish regulation, which do not contain requirements for TN or nitrogen compounds for the assumed purpose, the electrical conductivity is another limiting factor for reuse.

For case two (irrigation of tomatoes (can be consumed raw) without restriction of the applied irrigation method), the non-compliance of individual parameters is more scattered throughout the different regulations. This is a reuse case with higher restrictions than the first one in all of the regulations resulting in the fact that for all regulations certain parameters prevent the reuse for this purpose.

For the case of restricted urban irrigation, there is no compliance with the relevant classes in any of the regulations, either. For Spain, TSS is the only analyzed parameter limiting the suitability of the water for this reuse purpose. For all other regulations the parameters preventing a compliance of the water with the relevant quality limits vary.

Overall, the Thirasia WWTP effluent complies with the quality requirements for the case of restricted irrigation according to the French regulation and the EC-proposal.

Compliance of Thirasia WWTP effluent quality to reuse regulations

Table 22 Case 1 "Restricted irrigation": Effluent concentrations and number of samples exceeding the limits.

Compliance with national regulation of:	class	*E. coli* cfu/100mL	BOD_5 mg/L	COD mg/L	TSS mg/L	Turbidity NTU	EC µS/cm	TN mg/L	NH_4 mg/L	TP mg/L	pH	$Cl_{res.}$ mg/L
Cyprus	2	8.8E+01	16	60	9.3		4,090				8.1	3
# exceedings of limit | max. dev.		1 | 1	11 | *n.l.*	3 | *n.l.*	3 | *n.l.*		13 | 13				5 | 5	6 | 6
France	B	8.8E+01		63	10							
# exceedings of limit | max. dev.		0 | 0		1 | 0	0 | 0							
Greece	3	2.7E+01	18		10	*n.l.*		50	*n.a.*			*n.a.*
# exceedings of limit | max. dev.		0 | *n.l.*	0 | *n.l.*		0 | *n.l.*							
Italy	1	4.5E+01	9.5	52	7.9		2,558	50	44	5.7	8.1	3
# exceedings of limit | max. dev.		1 | 0	3 | 3	1 | 1	3 | 3		6 | 1	17 | 17	24 | 24	0 | 0	0 | 0	9 | 9
Spain	2.2	5.9E+01			13	*n.l.*	3,408	*n.a.*		*n.a.*		
# exceedings of limit | max. dev.		0 | 0			0 | 0		6 | *n.l.*					
COM337 (2018)	C	5.9E+01	18		10	*n.l.*						
# exceedings of limit | max. dev.		1 | 0	5 | 0		0 | 0							
Total number of samples (effluent)		**8**	**22**	**25**	**25**	**13**	**25**	**24**	**24**	**22**	**25**	

Table 23 Case 2 "Unrestricted irrigation": Effluent concentrations and number of samples exceeding the limits.

Compliance with national regulation of:	class	*E. coli** cfu/100mL	BOD_5 mg/L	COD mg/L	TSS mg/L	Turbidity NTU	EC µS/cm	TN** mg/L	NH_4** mg/L	TP mg/L	pH	$Cl_{res.}$ mg/L
Cyprus	1	8.8E+01	16	60	9.3		4,090				8.1	3
# exceedings of limit | max. dev.		7 | 7	11 | *n.l.*	3 | *n.l.*	3 | *n.l.*		13 | 13				5 | 5	6 | 6
France	A	8.8E+01		143	20							
# exceedings of limit | max. dev.		0 | 0		7 | 7	3 | 3							
Greece	2	5E+01 | 7E+01	15		9.3	1.5		50	*n.l.*			3
# exceedings of limit 1 | limit 2		7 | 1	11 | --		3 | --	5 | --		11 | --				4 | --
Italy	1	4.5E+01	9.5	52	7.9		2,558	50	44	5.7	8.1	3
# exceedings of limit | max. dev.		1 | 0	3 | 3	1 | 1	3 | 3		6 | 1	17 | 17	24 | 24	0 | 0	0 | 0	9 | 9
Spain	2.1	5.9E+01			13	3.5	3,408	*n.a.*		n.a.		
# exceedings of limit | max. dev.		0 | 0			0 | 0	0 | 0	6 | *n.l.*					
COM337 (2018)	A	5.9E+01	21		13	3.5						
# exceedings of limit | max. dev.		7 | 1	19 | 8		12 | 3	0 | 0						
Total number of samples (effluent)		**8**	**22**	**25**	**25**	**13**	**25**	**24**	**24**	**22**	**25**	

*GR: (E. coli) Two limits must be met by 80 & 95-percentile
**GR: (TN & NH4) Limits for reuse in non nitrat vulnerable zones

Table 24 Case 3 "Urban irrigation": Effluent concentrations and number of samples exceedings the limits.

Compliance with national regulation of:	class	*E. coli**		BOD$_5$		COD		TSS		Turbidity		EC		TN		NH$_4$		TP		pH		Cl$_{res.}$	
		cfu/100mL		mg/L		mg/L		mg/L		NTU		µS/cm		mg/L		mg/L		mg/L				mg/L	
Cyprus	**3**	8.8E+01		16		60		9.3				4,090								8.1		3	
# exceedings of limit | max. dev.		**0**	**0**	**0**	***n.l.***	**1**	***n.l.***	**0**	***n.l.***			**13**	**13**							**5**	**5**	**6**	**6**
France	**A**	8.8E+01				143		20															
# exceedings of limit | max. dev.		**0**	**0**			**7**	**7**	**3**	**3**														
Greece	**1**	5E+03	1E+04	15				9.3		1.5				50		44						3	
# exceedings of limit 1 | limit 2		**7**	**7**	**11**	**--**			**24**	**--**	**5**	**--**			**24**	**--**	**24**	**--**					4	--
Italy	**1**	4.5E+01		9.5		52		7.9				2,558		50		44		5.7		8.1		3	
# exceedings of limit | max. dev.		**1**	**0**	**3**	**3**	**1**	**1**	**3**	**3**			**6**	**1**	**17**	**17**	**24**	**24**	**0**	**0**	**0**	**0**	**9**	**9**
Spain	**1.2**	5.9E+01						13		3.5		*n.a.*		*n.a.*				*n.a.*					
# exceedings of limit | max. dev.		**0**	**0**					**0**	**0**	**0**	**0**												
COM337 (2018)	**n.a.**																						
Total number of samples (effluent)		**8**		**22**		**25**		**25**		**13**		**25**		**24**		**24**		**22**		**25**			

*GR: Limit for TC instead of E. coli for class 1 (two limits must be met by 80 & 95-perc.)
**GR: Sprinkler irrigation is prohibited

Legend:
- The relevant percentile of samples meets the quality requirements for the defined reuse case
- The relevant percentile of samples does not meet the quality requirements for the defined reuse case
- No compliance only due to exceeding of the maximum deviation limit

Footnote for all tables:

2. Parameters are presented in the percentile which is decisive in the water quality class that is required for the defined reuse case.
   - n.l.: no limit is fixed for the regarded water quality class
   - n.a.: the parameter is not regulated for the regarded reuse case
   - "empty cell": the regarded parameter is not regulated in the regarded national regulation
6. The number of samples exceeding the limit of the relevant class is presented in green; the number of samples exceeding the maximum deviation limit (max. dev.) is presented in red. The total number of samples is presented at the bottom of the table.
7. Only parameters which have been monitored in the Thirasia WWTP are included in the table. Missing parameters for the full quality evaluation vary in number and kind, for each of the national regulations.
8. IT: Less strict limit for E. coli in case of treatment in CWs / stabilization ponds and less strict limit for TN & TP in case of irrigation use, are applicable for all three of the regarded reuse cases
9. SP: NO$_3$ has been monitored, it is however not a relevant parameter for the regarded reuse case

3.3.3 Demo site Schönerlinde: Combining ozonation and CWs for treatment of WWTP effluent

The WWTP Schönerlinde, north of Berlin (Germany), is going to be upgraded for advanced organic micropollutant (OMP) removal and disinfection of municipal secondary effluent. The combination of an ozone reactor plus a treatment wetland shall demonstrate safe and cost efficient treatment. A pilot plant was operated from May 2017 until December 2018 as AquaNES demonstration site No. 12 to demonstrate the performance of two different types of CWs combined with an ozonation stage as prior treatment. Results regarding relevant parameters were compared with the proposed EU-level regulation described in section 2.2.6 (relevant parameters: BOD_5, TSS, turbidity and *E. coli*). The wetlands were operated in parallel with one being filled with sand (0.2/2 mm, 55 cm, conventional design) and one containing a 80 cm mixed layer with 70% lava gravel (4/8 mm porous lava) and 30% “biochar” charcoal (8/20 mm). More detailed information on this site can be found in AquaNES Deliverable 3.2.

The sampling points are located at the inflow and outflow of the ozonation stage, as well as at the outflow of both CWs (see Figure 27).

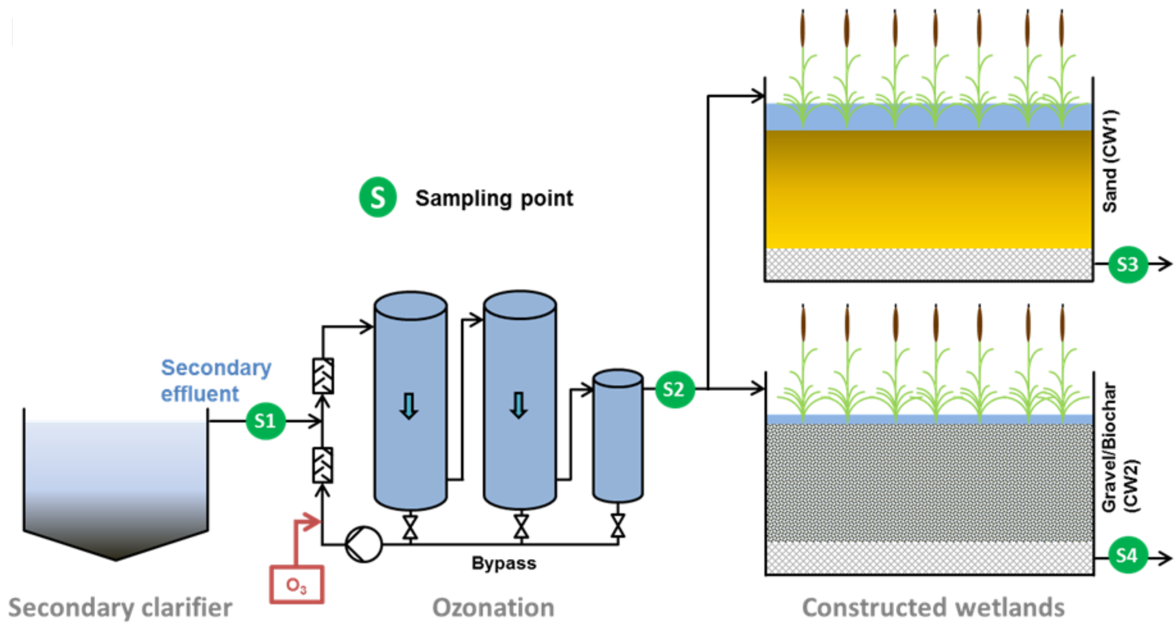

Figure 27 Flow scheme of the Schönerlinde site 12, including sampling points.

BOD_5 was only measured twice in CWs effluents, as both results were below the limit of quantitation (LOQ) of 3 mg/L and inflow of the demonstration site (= WWTP effluent) was already ≤ 5 mg/L, which is half of the limit for class A water quality according to the COM337 (2018). In order to support the conclusion that the BOD_5 concentration in the water is not a limiting factor for its reuse suitability for any purpose defined in the proposal, the BOD_5 concentration in the effluent of the Schönerlinde WWTP for 2018 is being compared to the strictest limit (class A limit) of the proposal. As can be seen in Figure 28, BOD_5 concentrations in WWTP effluent were always well below class A limit throughout the whole year 2018. As shown in the Deliverable 3.2, even the increase of BOD_5 by 50% during ozonation still leads to an inflow concentration below the class A limit (10 mg/L) into the CW stages.

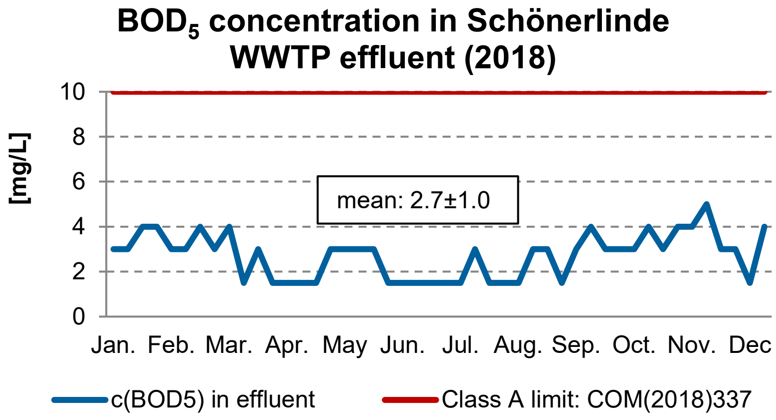

Figure 28 **BOD_5 concentration in the effluent of Schönerlinde WWTP in comparison to the class one limit of the proposed EU-level water reuse regulation (COM337, 2018).**

Concentrations for the other three parameters are presented in Figure 29 and Figure 30. For the combined operation of ozonation and CWs, between 12 (for *E. coli)* and 29 (for TSS) samples have been taken. For *E. coli*, data available for periods without ozonation (n=4) was also analysed to evaluate the log reduction of the investigated CWs with inflow concentrations of >10^4 cfu/100 mL (without ozonation) in comparison to 10^2 cfu/100 mL (usual concentrations after ozonation, see Figure 29, right).

As can be seen in Figure 29 and Figure 30, the performance of both CWs with prior ozonation is very similar for all three parameters. For *E. coli*, ozonation itself achieves a log reduction of 2.5 with further reduction of *E. coli* in both wetlands by about half a log unit, achieving class B quality regarding this parameter (Figure 29, left). When comparing the performance of the wetlands without prior ozonation (ozonation not in operation due to technical problems, n=4), a more obvious difference in disinfection performance becomes apparent. While CW1 (sand substrate) achieves similar log removal (2.7) compared to the combined removal with ozonation (2.5+0.43), the log-removal of CW2 with lava gravel/biochar (1.5) does not achieve the class B water quality for *E. coli*, which could be attributed to the lower filtration effectivity due to larger grain sizes of the lava gravel.

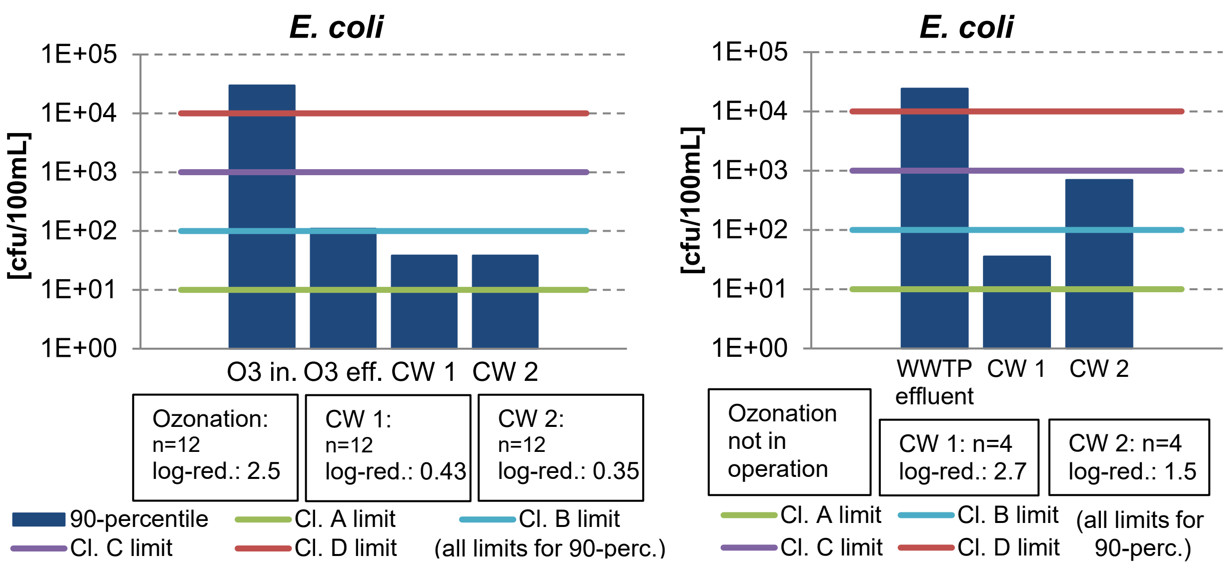

Figure 29 **Concentration of E. coli (in the relevant percentile) during ozonation and treatment in two parallel CWs, with relevant limits of COM337 (2018). Log-red: log reduction, Cl.: class.**

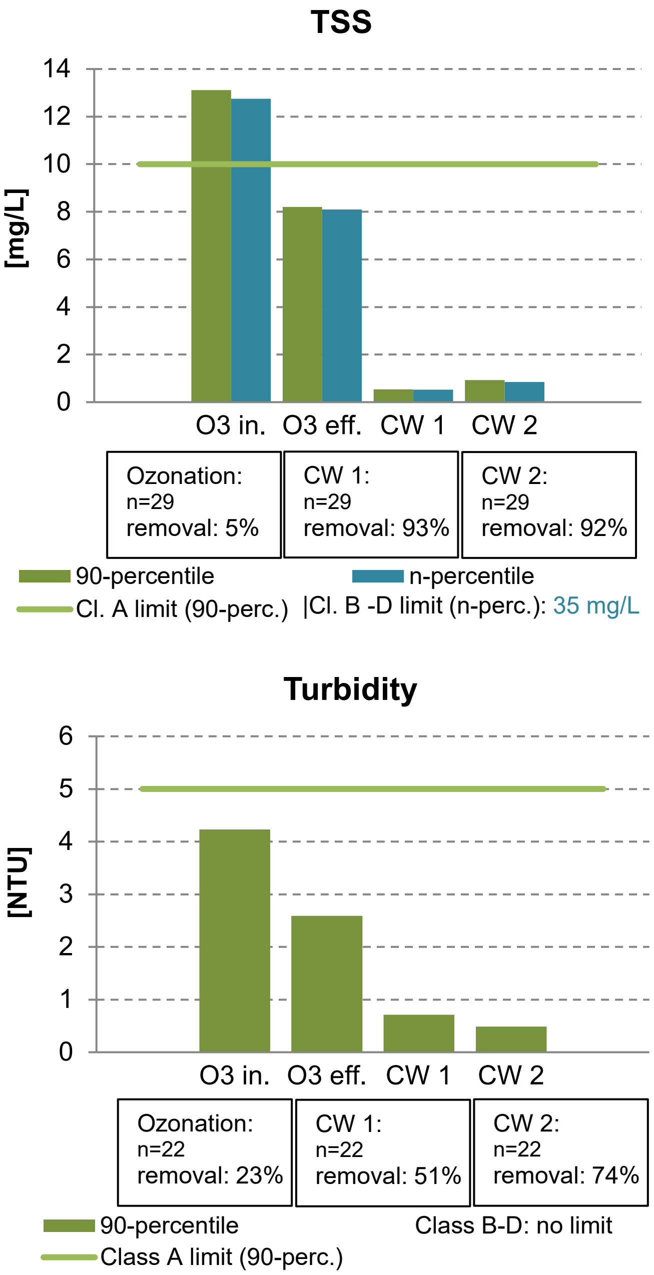

Figure 30 **Concentration of TSS and turbidity (in the relevant percentile) during ozonation and treatment in two parallel CWs, with associated limits of COM337 (2018).**

For TSS, effluent of ozonation (8 mg/L) already achieves a class A quality. Both CWs further reduce TSS concentrations to about 1 mg/L. Same is valid for turbidity with effluent values (after CWs) below 1 NTU, also resulting in class A quality. Overall, the water is suitable for all reuse purposes included in classes B to D of the proposed EU-level water reuse regulation as can also be seen in Table 25 showing the relevant percentiles for the evaluation of compliance with the proposed EU-level water reuse standards. With further reduction of *E. coli* concentrations by about 0.5 log units, class A could be achieved.

Table 25 Overview of relevant concentrations for the compliance of CW effluents at site 12 (Schönerlinde) to water quality classes of the proposed EU-level regulation (COM337, 2018).

Class	*E. coli*		TSS		Turbidity	
	CW1	CW2	CW1	CW2	CW1	CW2
Class 1	3.80E+01	3.80E+01	0.54	0.92	0.71	0.49
Class 2	3.80E+01	3.80E+01	0.53	0.85	--	--
Class 3	3.80E+01	3.80E+01				
Class 4	3.80E+01	3.80E+01				

Legend:
The relevant percentile of samples meets the quality requirements for the defined quality class
The relevant percentile of samples does not meet the quality requirements for the defined quality class

3.3.4 Demo site Erftverband: Reduction of microbiological parameters in dual use wetland for CSO and WWTP effluent

The WWTP of Rheinbach in North-Rhine-Westphalia, Germany, is connected to the river Wallbach. In order to improve the water quality of the sensitive river a pilot system has been used to demonstrate the feasibility of a new combined filter system for the treatment of CSO plus advanced organic micropollutants (OMP) removal from secondary effluent. Its positive results have led to the construction of a full-scale tertiary treatment system for 27,000 p.e. called "RSF plus", that is used for flexible treatment of pre-filtered secondary effluent as polishing step during dry weather and combined sewer overflows during heavy rain events in one system. Three pilot filters (AquaNES demo site 11) were operated for several years and the results from their operation regarding reuse-relevant parameters are being compared. The first two filters are standard RSF, of which RSF 2 was subjected to simulated CSO events. The third filter is a RSF with an additional layer of granular activated carbon in the filter medium and was not subjected to CSO events (see Figure 31).

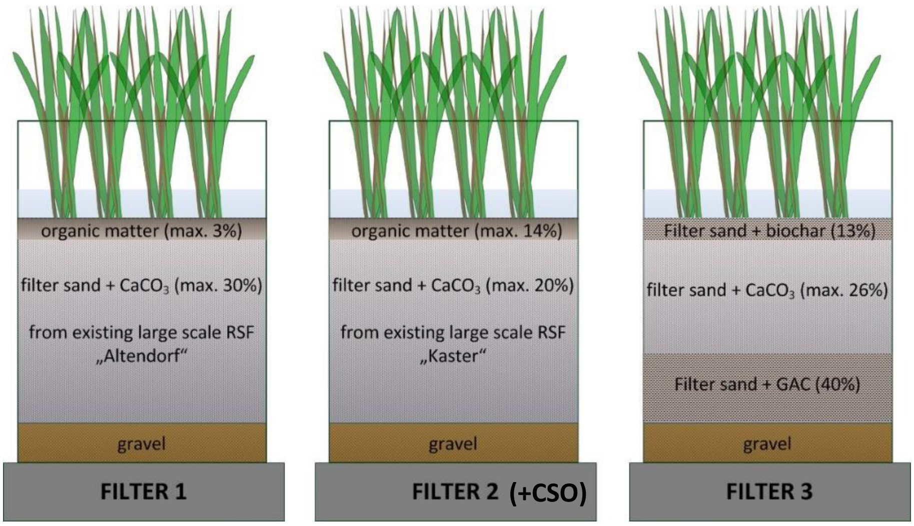

Figure 31 Schematic view of the three pilot RSF at at Rheinbach, Erftverband.

Samples have been taken at the influent and effluent of each filter. The measured data is being presented in the percentile relevant for the evaluation of water quality for reuse according to the proposed EU-level regulation by the EC (see Figure 32 and Figure 33). The data for RSF 2, which is subjected to artificial CSO events, contains measurements of a period covering from the start of the event (when the “overflow” water is expected to have highest concentrations) until two days after the event (when the filter effluent is expected to completely consist only of WWTP effluent again) to evaluate potential washout induced by CSO peak concentrations. For details regarding sampling schedules and more detailed results see AquaNES deliverable 3.2.

As shown in Figure 32 regarding *E. coli*, both filters which are not subjected to CSO events (1 & 3) may reach a water quality suitable for class C reuse purposes with RSF 3 (with GAC layer) reaching about 0.5 log units lower *E. coli* effluent concentrations compared to RSF 1 (standard RSF). Filter 2 (subjected to CSO events) does not meet the required limits for any reuse class for this parameter during the events. Highest effluent concentrations were found directly after the CSO event, whereas two days later effluent concentrations were at the same concentration level as influent concentrations. BOD_5 concentrations were always below level of quantification in filter 1 and 3 (already in influent), but also effluent of RSF 2 reaches effluent concentrations below LOQ, even though influent concentrations are above both limits set for this parameter due to CSO influence. Regarding TSS (see Figure 33), effluents of all three filters meet class A limit (<10 mg/L).

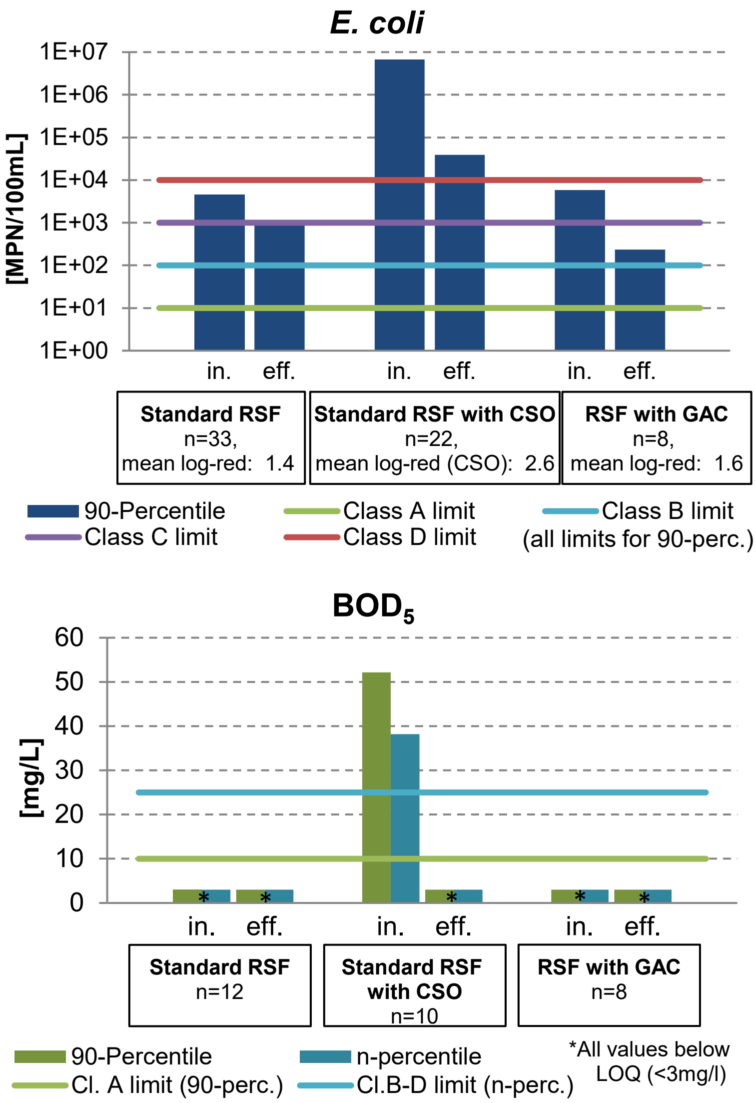

Figure 32 Concentrations of *E. coli* and BOD_5 in influent (in.) and effluent (eff.) of the three pilot RSF at Erftverband with associated limits of COM337.

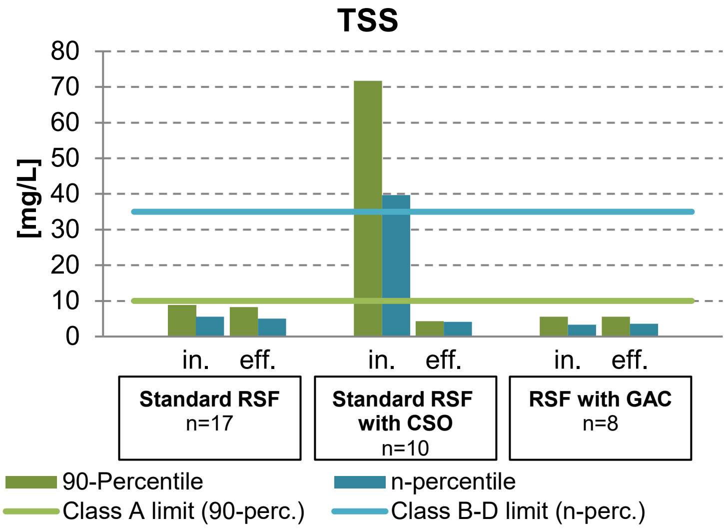

Figure 33 Concentrations of TSS in influent (in.) and effluent (eff.) of the three pilot RSF at Erftverband with associated limits of COM337.

Overall, both filters that treat WWTP effluent (RSF 1 and 3) comply only with the requirements for class C water reuse purposes due to elevated *E. coli* concentrations (RSF 1 meets class C limit for *E. coli* closely). The filter subjected to CSO events would require an additional disinfection stage to reduce the microbiological pollution during and shortly after CSO events in order to make the water suitable for reuse. Turbidity has not been measured and has been left out of consideration in this evaluation, but as shown in Figure 30 for site 12 (Schönerlinde), turbidity after CWs is likely to be below class A limit of 5 NTU and would not be a limiting parameter in regard to water reuse. TSS and BOD_5 are also not limiting. An overview of the compliance of relevant percentiles for all parameters with the quality class limits of the proposed EU-level standards is presented in Table 26.

Table 26 Overview of relevant concentrations for the compliance of RSF effluents at site 11 (Erftverband) to water quality classes of the proposed EU-level regulation (COM337, 2018).

<table>
<tr><th rowspan="2">Class</th><th colspan="3">E. coli</th><th colspan="3">BOD</th><th colspan="3">TSS</th></tr>
<tr><th>RSF1</th><th>RSF2 with CSO</th><th>RSF3 with GAC</th><th>RBF1</th><th>RSF2 with CSO</th><th>RSF3 with GAC</th><th>RBF1</th><th>RSF2 with CSO</th><th>RSF3 with GAC</th></tr>
<tr><td>Class A</td><td>2.8E+01</td><td>3.9E+04</td><td>2.3E+02</td><td><3</td><td><3</td><td><3</td><td>8.2</td><td>4.3</td><td>5.6</td></tr>
<tr><td>Class B</td><td>2.8E+01</td><td>3.9E+04</td><td>2.3E+02</td><td rowspan="3"><3</td><td rowspan="3"><3</td><td rowspan="3"><3</td><td rowspan="3">5.1</td><td rowspan="3">4.1</td><td rowspan="3">3.6</td></tr>
<tr><td>Class C</td><td>2.8E+01</td><td>3.9E+04</td><td>2.3E+02</td></tr>
<tr><td>Class D</td><td>2.8E+01</td><td>3.9E+04</td><td>2.3E+02</td></tr>
</table>

Legend:
The relevant percentile of samples meets the quality requirements for the defined quality class.
The relevant percentile of samples does not meet the quality requirements for the defined quality class.

3.3.5 Comparison of log-removal for *E. coli* in CWs

Table 27 provides an overview of log-reductions for *E. coli* and TC in the CW / RSF stage of the four demonstration sites, compared to the average log-reductions found for these parameters in the literature. The performance of the two-stage wetland in Antiparos is higher than the average performance found in the literature for single stage wetlands, while the average performance in Thirasia falls below that level. For Schönerlinde and Erftverband, both wetlands/RSF show log removals higher than 2.5 that are above the average removal found in the literature, when inflow concentrations are high due to CSO events (Erftverband) or periods without ozonation (Schönerlinde). At lower inflow levels, log removals are either below the average literature values (wetland after ozonation, inflow concentration of *E. coli* ≈10^2 cfu/100 mL) or close to it (RSF without CSO events, inflow concentration of *E. coli* ≈10^3 - 10^4 cfu/100 mL). Data for TC were not available for both demo sites in Erftverband and Schönerlinde.

Table 27 Comparison of the log-reduction of microbiological parameters in the CW / RSF stage in all four demo sites, with the average removal rates found in the literature.

	Average log removal	
Site	***E. coli***	**TC**
Literature	1.8	1.8
Antiparos	2.4	2.3
Thirasia	0.7	0.7
Schönerlinde	0.4 (with prior O_3) – 2.7 (no prior O_3)	-
Erftverband	1.6 (without CSO) – 2.6 (with CSO)	-

4 Conclusions

The variability of standards for water reuse across European countries poses a barrier for the application of reclaimed water resulting in an underdevelopment of the water reuse sector in Europe. This conclusion of different reports for the European Commission is also supported by the outcome of the comprehensible comparison of all current national water reuse legislations shown in this report (2.2). Each regulation considers different reclaimed water uses associated with different quality classes and respective definitions. In Italy, for example, all three defined categories of water reuse purposes are regulated with the same set of water quality requirements, while in Spain 24 individually defined water reuse purposes are regulated with different limits in 14 water quality classes. In addition, the number of water quality parameters which are restricted by each national regulation differs considerably from six parameters regulated by the French water reuse legislation to 55 parameters regulated in Italy. In certain cases, the number of restricted parameters can increase up to 80 (Greek reuse regulation for WWTP > 100,000 p.e.) or even 90 in Spain (when requested by regional government depending on external regulations concerning the protection of the receiving environment).

Apart from defined water reuse classes, regulated parameters and relevant limit values, the national reuse regulations also differ in regard to the compliance requirements, which further complicates evaluations. While for some parameters a percentile of samples required to comply with the set limit values is specified (e.g. 80% of annual samples need to meet the limit), for others the annual mean is required to comply with the limits. For certain parameters some regulations refer to compliance definitions originating in the UWWTD that depends on the total number of samples that is associated with a certain allowed number of samples exceeding the limit (resulting in a relevant percentile varying between 75% and 93%). Furthermore, some regulations define maximum allowed deviation limits for any sample exceeding the limit values. As these specifications may not only vary among different regulations but also for different parameters in the same regulation as well as among different quality classes for the same parameter in the same regulation, an evaluation of the monitoring results of the different demonstration sites in regard to the national water reuse regulations is challenging and might become confusing.

Because of this regulatory heterogeneity, a direct comparison of the different European water reuse regulations with monitoring data of the demonstration sites is only possible for well-defined cases, as the allocation to the relevant class in the different regulations may change when looking at the level of definition of the regarded reuse purpose. For example, differences in individual definitions for use types of agricultural products such as irrigation of a “crop consumed processed” and a “vegetable consumed cooked” may lead to the inclusion or exclusion of the same reuse purpose into different classes in some of the regulations. The same is true for restrictions of irrigation types, which can differ regarding temporal, spatial or methodical restrictions. In order to bypass this obstacle, three specific reuse cases have been defined (for details see chapter 3.1): restricted irrigation (irrigation of beans using drip irrigation), unrestricted irrigation (irrigation of tomatoes using any irrigation methods) and urban irrigation (irrigation of a public park). For both Greek sites, monitoring results were evaluated regarding respective water reuse classes of these use cases for the national legislations.

In comparison to national reuse legislations, monitoring results of all 4 evaluated demonstration sites were also compared to the proposal of the European Commission for an EU-level regulation for water reuse. This proposal includes only 4 water quality classes and 4 restricted quality parameters (two additional parameters for certain reuse purposes). However, water reuse in this proposal is limited to agricultural irrigation purposes, only, as urban and industrial reuse purposes are not being considered, including groundwater recharge.

4.1 Greek sites – example of water reuse in Aegaen islands

The two Greek sites, both located in the Aegean islands, are full-scale WWTP subjected to significantly varying flows in summer and winter time. Effluent data from both sites were compared to all legally binding European water reuse regulations as well as to the proposed EU-level regulation by the European Commission.

For Antiparos WWTP, TSS and E.C. are the two main parameters limiting the possible reuse options to the less strictly regulated “restricted irrigation” purpose in all of the regarded regulations. Before implementation of reconstruction and rehabilitation measures in CWs and maturation pond and managerial changes for optimization of plant performance, limits for “restricted irrigation” were exceeded mainly due to elevated TSS concentrations (presumably due to damaged stone wall to restrain algae) and temporarily due to elevated concentrations of *E. coli* at peak flows that exceeded the design capacity of the plant combined with insufficient disinfection. It was found that after limiting load peaks during summer times through limitation of the daily number of sewage trucks allowed to discharge (max 3), ensuring a continuous chlorine dosage for disinfection, and implementation of reconstruction measures in the CWs and the maturation pond, the concentrations for most parameters in WWTP effluent decreased to a lower level sufficient for water reuse. Specifically, the microbiological parameters were reduced below the detection limit after the adjustment of chlorination dose and restriction of the daily number of sewage trucks. The combination of the two-stage CWs with chlorination as disinfection realized in Antiparos achieved a water quality suitable for “restricted irrigation” according to the Greek and French regulation as well as according to the limits proposed by the EC (COM337, 2018). High values for E.C. in WWTP effluent would prevent application in countries with reuse legislations that include this parameter (Cyprus, Italy, Spain).

In the Thirasia WWTP, the parameters limiting the effluent’s suitability for reuse vary across the three different reuse purposes and the different reuse regulations. TN and NH4 are limiting factors for specific reuse purposes. The produced effluent quality from the combination of CWs with photocatalysis as pre-treatment stage and a subsequent UF and disinfection stage as realized in Thirasia meets the requirements for “restricted irrigation” only according to the French regulation and the EU-level proposal. It needs to be considered that three microbiological parameters, which are only included in the French regulation were not analysed. Performance of the HF CW regarding nitrogen removal is not optimal, possibly due to unfavourable flow paths caused by clogged geotextiles resulting in partial bypass of the substrate. Therefore, the average concentration of TN in the WWTP effluent (50 mg/L, n=24) marginally exceeds the limit of class 3 of the Greek reuse regulation (45 mg/L). However, values of past months since August 2018 show an improved removal of TN that always meet the limit (mean: 34 mg/L, n=11). Further investigations are suggested to ensure a sufficient removal of TN that reliably meets the limit for water reuse. Regarding photocatalysis as pre-treatment for the CWs it was found that this stage did achieve a relevant removal for BOD_5 and COD (~60%) and TN (~30%). However, this removal was also achieved without the addition of the catalyst (TiO_2) and associated chemicals (H_2O_2 and acid for pH adjustment) when the basin was working as an aeration unit only, as shown in test phases with varying dosages of the catalyst. Thus, adding the catalyst does not add an economically feasible value. Although effluent concentrations of the microbiological parameters *E. coli* and TC met the Greek class 3 limit for restricted irrigation, values were unusually high considering UF and chlorination as final stages of treatment. Further investigations are suggested to review the sampling protocols and exclude potential contamination of samples.

Overall, the application of CWs in combination with disinfection as part of a treatment train provides a promising option for treatment of municipal wastewater for subsequent water reuse. Especially for small communities with Mediterranean climate that is prone to water scarcity, such as the Aegean islands, this combination may provide an affordable solution to promote water reuse.

4.2 German sites – polishing of WWTP effluent with additional benefits

In the two German sites pilot scale CWs were tested as a polishing stage after full-size WWTPs. The effluent quality was evaluated for the compliance with required quality standards in the proposed EU-level water reuse regulation by the EC.

At Schönerlinde, the combination of ozonation with two CWs with different substrate composition (sand or lava gravel with biochar) operated in parallel was demonstrated. Regarding *E. coli*, most of the removal was accomplished during ozonation (>2 log units) that also achieves removal of various micropollutants (see Deliverable 3.2). The subsequent removal in both wetland types was similar, reaching a further reduction for *E. coli* by about 0.5 log units and resulting in effluent qualities that achieve class B according to the proposed limits. When ozonation was not in operation, the conventional wetland with sand as substrate still achieved a similar effluent concentration for *E. coli* (log-reduction: 2.7) compared to the combination with ozonation. The second wetland filled with lava gravel and "biochar" charcoal did not perform as well without ozonation and only achieved class C quality for *E. coli*, probably due to a lower filtration efficiency of the lava gravel. Regarding the remaining parameters, TSS and turbidity are well removed in CWs reaching the best class A limit for these parameters. Overall, the combination of ozonation with CWs for polishing of WWTP effluent is a good option to achieve a very good effluent quality suitable for water reuse with the potential to reach class A quality suitable for irrigation of crop that is consumed raw with some further reduction of E. coli by about 0.5-1 log units. Application at full-scale would be appropriate especially for smaller WWTP, as large WWTP would require large areas for CWs usually not available in larger urban areas.

At Erftverband, a full-scale system is built at WWTP Rheinbach for flexible treatment of CSO during storm events and polishing of WWTP effluent during dry weather. Three pilot-scale RSF were tested for several years with RSF 3 containing an additional layer of activated carbon, and RSF 2 being subjected to simulated CSO events. Regarding *E. coli*, only class C limit is achieved (mean log removal in wetlands about 1.5). When subjected to CSO events that result in high peaks of *E. coli* in the influent of the filter, effluent quality does not meet the requirements for any reuse purpose regarding this parameter during the CSO event, even though a log removal of about 2.5 is reached. A temporary disinfection during and shortly after CSO events would be necessary to enable water reuse. BOD_5 and TSS do not limit water reuse according to the EC proposal.

Overall, the additional layer of activated carbon did not improve the effluent quality for the parameters relevant for evaluation of the suitability of water reuse, as is the case for the removal of micropollutants. The effluent of the filter subjected to CSO events would need temporary disinfection during heavy rain events before reuse is possible, due to concentration peaks of microbiological parameters in the effluent.

4.3 Compliance of all sites with EC-proposal requirements for water reuse

Overall, both Greek systems, when fully operational as well as the Schönerlinde system, which all include a combination of CWs with a disinfection, achieved class B effluent quality according to the proposed EU-level standards. The Erftverband site containing a natural treatment stage without an additional disinfection achieved class C quality, when not subjected to CSO events. Thus, effluents of all sites would be suitable for the following reuse purposes: (a) food crops consumed raw where the edible portion is produced above ground and is not in direct contact with reclaimed water; (b) processed food crops, and (3) non-food crops including crops to feed milk- or meat-producing animals. Whereas in class B the irrigation method is unrestricted, in class C only drip irrigation is allowed.

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6 Annex

Table of contents

6.1 National and EU-level proposed water reuse criteria

6.1.1 Cyprus (KDP 379/2015)

KDP 379/2015: General terms for waste disposal from wastewater treatment plants in agglomerations with less than 2,000 p.e.

Table 28 Cypriot water reuse classification and standards

<table>
<tr><th rowspan="2" colspan="2">Class No.*</th><th>E. coli</th><th>BOD5 (1)</th><th>COD</th><th>TSS</th><th>Fat & oil</th><th>pH</th><th>EC</th><th>Chlo-rides</th><th>Boron</th><th>Residual Chlorine</th></tr>
<tr><th>[cfu/100 ml]</th><th>[mg/L]</th><th>[mg/L]</th><th>[mg/L]</th><th>[mg/L]</th><th></th><th>[µS/cm]</th><th>[mg/L]</th><th>[mg/L]</th><th>[mg/L]</th></tr>
<tr><td>1</td><td>All crops (See also Note (a)); Green areas with unrestricted public access</td><td>5</td><td rowspan="2">10</td><td rowspan="2">70</td><td rowspan="2">10</td><td rowspan="5">5</td><td rowspan="5">6.5-8.5</td><td rowspan="5">2.500</td><td rowspan="5">300</td><td rowspan="5">1</td><td rowspan="5">2</td></tr>
<tr><td>2</td><td>Vegetables consumed cooked (See also note (b))</td><td>50</td></tr>
<tr><td>3</td><td>Products for human consumption; Green areas with restricted public access</td><td rowspan="3">200</td><td rowspan="3">25</td><td rowspan="3">125</td><td rowspan="3">35</td></tr>
<tr><td>4</td><td>Fodder crops</td></tr>
<tr><td>5</td><td>Industrial crops</td></tr>
<tr><td colspan="2">Frequency of analysis</td><td>1/month</td><td>1/month (2)</td><td>1/month (2)</td><td>1/month (2)</td><td>1/month</td><td>1/month</td><td>1/month</td><td>1/year</td><td>1/year</td><td>1/month</td></tr>
</table>

* There is no numbering of classes in the Cypriot regulation. The presented numbering was added in this report for uniformity with other regulations.

Notes:

(a) Leafy vegetables, bulbs and tubers eaten raw and strawberries may not be irrigated.
(b) Potatoes, beetroots.
(1) BOD5 analysis should be carried out with a nitrification inhibitor.
(2) The maximum permissible number of samples deviating from the number of monthly samples taken during any year is 2 samples. The required compliance is therefore 10 out of 12 samples (83%).
(3) For the other parameters a 100% compliance is required (Communication with Cypriot Department of Environment which is the competent authority for the relevant legislation)

6.1.2 France (Journal Officiel de la Republique Francaise (JORF) 0153/2014)

Table 29 French water reuse standards

Class *	*E. coli*	TSS	COD	Entero-cocci	Bacterio-phages RNA F-	Anaerobic sulfo-reducing bacteria spores
	[cfu/100ml]	[mg/L]	[mg/L]	[logs]	[logs]	[logs]
A	≤250	<15	<60	≥4	≥4	≥4
B	≤10,000	35**	125**	≥3	≥3	≥3
C	≤100,000			≥2	≥2	≥2
D	-			≥2	≥2	≥2
Required compliance	100% of samples					

* The presented numbering of classes A – D is the original numbering in the regulation. Class A contains the strictest limits, as does class 1 in other regulations.
** Limits in compliance with the regulations of treated effluents from the plant outside the irrigation season (Arrêté du 21 juillet 2015, Annex 3, Table 6)

Table 30 French water quality classification

Type of use	Class A	Class B	Class C	Class D
Market gardening, fruit and vegetable crops not processed by suitable industrial heat treatment (except cressiculture (1))	+	-	-	-
Vegetable crops, fruit crops, vegetables transformed by a suitable industrial heat treatment	+	+	-	-
Pasture (2)	+	+(3)	-	-
Green areas open to the public (4)	+(5)	-	-	-
Flowers sold cut	+	+(6)	-	-
Nurseries and shrubs and other flower crops	+	+	+(6)	-
Fresh fodder	+	+(3)	-	-
Other cereals and fodder crops	+	+	+(6)	-
Fruit arboriculture	+	+(7)	+(8)	-
Short or very short rotation mulch with controlled public access	+	+	+(6)	+(6)
Forest, short-rotation coppice with controlled public access	-	-	-	-

Notes: + allowed, - prohibited

(1) The reuse of treated wastewater is prohibited for cressiculture.
(2) In the event of sprinkling, the animals must not be in the field at the time of the operation and the watering troughs, in case they are watered, must be rinsed before use.
(3) Subject to compliance with a period of 10 days after irrigation in the absence of a slaughterhouse connected to the wastewater treatment plant and 21 days otherwise.
(4) Green space includes: highways services area, cemeteries, golf courses, racetracks, parks, public gardens, common portions of subdivisions, roundabouts and other medians, squares, stadiums, etc.
(5) Irrigation outside opening hours to the public, or closure to users during irrigation and two hours after irrigation in the case of closed green spaces; Irrigation during hours of lower attendance and no access to passers-by during irrigation and two hours after irrigation in the case of permanently open green spaces.
(6) Only by localized irrigation as defined in Article 2 (JORF 2014).
(7) Prohibited during the period from flowering to harvesting for unprocessed fruits, except in the case of drip irrigation.
(8) Only by drop by drop.

Table 31 French monitoring requirements

<table>
<tr><th rowspan="2">Class</th><th>Periodic monitoring</th><th colspan="2">Routine monitoring during each irrigation season</th></tr>
<tr><td>All 6 parameters of Annex II</td><td colspan="2">E. coli, TSS, COD</td></tr>
<tr><td>A</td><td rowspan="4">every 2 years;

Sewage sludge quality: min. 4/year*</td><td>1/ week</td><td rowspan="4">In case the irrigation season is shorter than 2 month the minimum annual number of samples to be taken is 2</td></tr>
<tr><td>B</td><td>1/15 days</td></tr>
<tr><td>C</td><td rowspan="2">1/ month</td></tr>
<tr><td>D</td></tr>
</table>

*In case of non agricultural sewerage

6.1.3 Greece (Common Ministerial Decision (JMD) 145116/2011)

Table 32 Greek water reuse classification and standard

Class No.*		***E. coli*** cfu/100 ml	**BOD_5** mg/L	**TSS** mg/L	**Turbidity** NTU	**Required treatment**
1	a. **Urban uses:** Irrigation of large areas (e.g. cemeteries, golf courses, public parks, freeway embankments), use of reclaimed water for recreational facilities, fire protection, soil compaction, street cleaning and decorative fountains. Sprinkler irrigation is not allowed. b. **Aquifer recharge by wells:** not allowed for potable use; only for cases where Article 7 of Decree 51/2007 “Water systems used for drinking water abstraction” does not apply c. **Peri-urban green area:** including groves and forests (f)	TC ≤2 & ≤20	≤10	≤2	≤2	Secondary biological treatment & Advanced treatment & Disinfection (a & b & c)
2	d. **Unrestricted irrigation:** All crops including all irrigation methods. e. **Industrial use (except for once-through cooling water):** reticulated cooling water, boiler water, water for industrial processes, etc. (e)	≤5 & ≤50	≤10	≤10	≤2	Secondary boil. tr. & Tertiary treatment & Disinfection (a & b & c)
3	f. **Restricted irrigation:** Areas where public access is not expected, fodder and industrial crops, pastures, trees (except for fruit trees), provided that fruits are not in contact with the soil, seed crops and crops whose products are processed before consumption. Sprinkler irrigation is not allowed. g. **Industrial use:** Once-through cooling water h. **Groundwater recharge:** Recharge of aquifers by filtration through a soil layer of sufficient thickness and suitability only for cases where Article 7 of Decree 51/2007 “Water systems used for drinking water abstraction” does not apply (d)	≤200	≤25 (Limits according to JMD 5673/400/1997 ≡ UWWTD (1991) Annex 1, Tab. 1)	≤35	-	Secondary biological treatment & Disinfection (a & b & c)
Required samples compliance with defined limit value	Class 1 & 2	80 & 95%	80%		median	
	Class 3	median	75%-93% (depends on no. of samples acc. to JMD 5673/400/1997 ≡ UWWTD(1991) Ann.1, Tab.3)		-	

* There is no numbering of classes in the Greek regulation. The presented numbering was added in this report for uniformity with other regulations, matching their order of classes (starting from the class with the strictest to the one with the least strict limits). Class 1 corresponds to table 3, Class 2 to table 2 and Class 3 to table 1 in annex 1, JMD (2011) No. 145116.

Notes:

(a) Class 1: TN: < 15 mg/L & NH4: < 2mg/L (with nitri- & denitrification for nitrogen removal)
Class 2: TN: < 45 mg/L (TN: < 15 mg/L & NH4: < 2mg/L in case of irrigation in areas designated as vulnerable to nitrate pollution; with nitri- & denitrification for nitrogen removal)
Class 3: TN: < 45 mg/L (TN: <15 mg/L in case of long storage of wastewater in reservoirs, irrigation of nitrate vulnerable zones or enrichment of the underground aquifer)
For the required compliance with the limit values for the parameters TN and NH4 the annual average will be regarded. This is based on the monitoring requirements for these parameters, which are to be found in the Greek adaptation of the Urban Wastewater Directive (UWWTD). According to the UWWTD the annual average should be regarded for parameters in this category.

(b) Class 1: Appropriate membrane system (at least Ultrafiltration recommended) or equivalent treatment system which achieves the limits for BOD5, TSS and turbidity. In case of the use of membrane bioreactors it is possible to merge the secondary and advanced processing.
Class 2: Appropriate system to achieve the limits for BOD_5, SS and the turbidity. Indicatively, at least a suitable flocculent (e.g., aluminum sulphate) is added at a dose greater than 10 mg/L and directly refined in a sand filter with the following characteristics: depth (L) ≥ 1,40 m, active grain diameter (De) ≈ 1 mm, grain uniformity factor sand (u) 1,45-1,60 and surface load ≤ 8 $m^3/m^2/hr$ for normal operating conditions.
Class 3: WWTP serving < 2,000 p.e. and private systems don´t have to comply with BOD_5 & TSS limits (provided that there is no contact of the public/ farmers with treated wastewater). In the case of community systems the limit value for E. coli is 1000 EC/100ml (median).

(c) Chlorination, ozonation, ultraviolet (UV) or other methods for the destruction of pathogens which ensure the required limit concentration of E. coli in the effluent.
Class 1 & 2: Chlorination: a residual-chlorine ≥ 2 mg/L, plunger flow (flow-through / width ratio greater than or equal to 40) and minimum contact time 60 min, while the need for dechlorination prior to reuse will be considered as appropriate. For UV disinfection, a minimum dose of 60 mW sec/cm^2 at the end of life of the lamps & the design of the UV system will not obtain a permeability value > 70%.
Class 3: Chlorination: residual chlorine should be obtained over a contact time (C · t) greater than or equal to from 30 mg · min/l, piston flow (flow / width ratio greater than or equal to 40) and minimum time 30 min; UV disinfection: a minimum dose of 70 mW sec/cm^2 at the end of life of the lamps & the design of the UV system will not obtain a permeability value > 50%.

(d) Class 3: The suitability of the soil to restrain organics should be documented in a detailed study.

(e) Class 2: Industrial process water will be treated by the industry concerned with additional advanced treatment systems for removing ions and other solvents compounds and/ or elements.

(f) Class 1: In the case of forests, the application of the requirements from class 2 or 3 may be applied on a case-by-case basis.

Table 33 Greek monitoring requirements

Class no.	Sampling frequency
1	BOD_5, TSS, N, P: according to CMD 5673/400/97 Turbidity & permeability: 4/week for WWTPs >50,000 p.e. and 2/week otherwise. Cl_2: continuously (if chlorination is applied)
2	BOD_5, TSS, N, P: according to CMD 5673/400/97 Turbidity and EC: 4/week for WWTPs >50,000 p.e. and 2/week otherwise. Cl_2: continuous
3	BOD_5, TSS, N, P: according to CMD 5673/400/97 (GJ 192/B/14.3.97). EC: 1/week. Cl_2: continuous (if chlorination is applied)

6.1.4 Italy (Ministry Decree (DM) 185/2003)

Table 34 Italian water quality classification

Class No.*	Reuse category	
1	(a) Irrigation of food and non-food crops, green areas, parks, and sport fields.	Same standards for all categories of reuse
	(b) Urban non-potable uses such as street washing, heating or cooling systems, dual networks, and toilet flushing.	
	(c) Industrial uses such as processing, washing and thermal cycling as well as firefighting; but it does not allow uses which may involve contact between the recycled water and food/ pharmaceutical products/ cosmetics	

* There is no definition of quality classes in the Italian regulation. There are three categories of reuse, for all of which the same quality requirements apply. The presented numbering was added in this report for uniformity with other regulations.

Table 35 Italian water reuse standards

Parameters	Unit	Limit value	Notes
E. coli	cfu/100ml	10	(in 80% of the samples)
		100	(max. value allowed)
		Constructed wetlands/ stabilization ponds:	
		50	(in 80% of the sample)
		200	(max. value allowed)
Salmonella		absent	(in 100% of the samples (f))
pH		6.0 - 9.5	a; b; c
SAR		10	a; b
Coarse Solids		absent	a; b
Total suspended solids TSS	mg/l	10	a; b
BOD_5	mgO2/l	20	a; b
COD	mgO2/l	100	a; b
Total Phosphorus TP	mg/l	2	10 (Limit for irrigation use (d)); a; b
Total Nitrogen TN	mg/l	15	35 (Limit for irrigation use (d)); a; b
Ammonium NH4	mg/l	2	a; b; c
Electrical conductivity	µS/cm	3000	(max. value allowed: 4,000 µS/cm (e)); a;c
Active chlorine	mg/l	0.2	a; b
Aluminum Al	mg/l	1	a; b; c
Arsenic As	mg/l	0.02	a; b
Barium Ba	mg/l	10	a; b
Beryllium Be	mg/l	0.1	a; b

Parameters	Unit	Limit value	Notes
Boron Bo	mg/l	1	a; b
Cadmium Cd	mg/l	0.005	a; b
Cobalt Co	mg/l	0.05	a; b
Total Chromium Cr	mg/l	0.1	a; b
Chromium VI Cr6+	mg/l	0.005	a; b
Iron Fe	mg/l	2	a; b; c
Manganese Mn	mg/l	0.2	a; b; c
Mercury Hg	mg/l	0.001	a; b
Nickel Ni	mg/l	0.2	a; b
Lead Pb	mg/l	0.1	a; b
Copper Cu	mg/l	1	a; b
Selenium Se	mg/l	0.01	a; b
Tin Sn	mg/l	3	a; b
Thallium (Tl)	mg/l	0.001	a; b
Vanadium V	mg/l	0.1	a; b
Zink Zn	mg/l	0.5	a; b
Total Cyanides Cn	mg/l	0.05	a; b
Hydrogen sulfide H_2S	mg/l	0.5	a; b
Sulfite SO_3	mg/l	0.5	a; b
Sufates SO_4	mg/l	500	a; b; c
Chloride ion Cl^-	mg/l	250	a; b; c
Fluoride F	mg/l	1.5	a; b
Animal/vegetal oils & fats	mg/l	10	a; b
Mineral oils	mg/l	0.05	a; b
Total Phenols	mg/l	0.1	a; b
Pentachlorophenol	mg/l	0.003	a; b
Total Aldehydes	mg/l	0.5	a; b
Tetra/trichloro-ethylene	mg/l	0.01	Sum of specific parameters; a; b
Total chlorinated solvents	mg/l	0.04	a; b
Trihalomethanes (THM)	mg/l	0.03	a; b
Total aromatic solvents	mg/l	0.01	a; b
Benzene	mg/l	0.001	a; b
Benzo(a)pyrene	mg/l	0.00001	a; b
Total org. nitr. Solvents	mg/l	0.01	a; b
Total surfactants	mg/l	0.5	a; b
Chlorinated pesticides	mg/l	0.0001	0.03 µg/L for Aldrin, Dieldrin, and

Parameters	Unit	Limit value	Notes
			Heptachlor; a; b
Organophosphorous pesticides	mg/l	0.0001	For any single substance; a; b
Other pesticides	mg/l	0.05	Total; a; b

Notes:

a: All chemical/physical parameters: The annual average of samples must comply with the defined limit values (DM (2003) no. 185, Article 15(5))

b: All chemical/physical parameters (except EC): No sample may exceed 100% of the limit value (Article 15(5))

c: Different limits can be fixed by provision of Italian Regions, under the supervision of Italian Ministry of Environment. They may not exceed the limits for discharge into surface waters referred to in legislative decree no. 152 from 1999, annex 5, table 3. (Article 15(3))

d: Less strict limit for irrigation use; according to DM (2003) no. 185, Article 15(4)

e: According to DM (2003) no. 185, Article 15(3)

f: According to DM (2003) no. 185, Article 15(7)

6.1.5 Spain (Royal Decree 1620/2007)

Table 36 Spanish water reuse classification and standards

Class No.		I.N. *(1)* egg/10 L	*E. coli* cfu/100 mL	TSS mg/L	Turbidity NTU	Other criteria
Urban uses						
1.1 *(2; 3)*	a) Irrigation of private gardens b) Supply to sanitary appliances	1	0	10	2	*Other Contaminants **; Legionella spp.**
1.2 *(9)*	a) Irrigation of urban green areas (parks, sport fields etc.) b) Street cleaning c) Fire hydrants d) Industrial washing of vehicles	1	200	20	10	
Agricultural uses *(10)*						
2.1 *(9)*	a) Crop irrigation with an application method which allows direct contact of recycled water with the edible part of the crop consumed un-cooked	1	100 (3-class sampling plan *(7)* with: n=10; m=100 cfu/100mL; M= 1,000 cfu/100mL; c=3)	20	10	*Other Contaminants**; Legionella spp**; Pathogen presence/absence test (Salmonella etc.) when results repeatedly show that c=3 for M=1,000
2.2	a) Crop irrigation with an application method which allows direct contact of recycled water with the edible parts of the crop which is not consumed fresh but after processing b) Fodder irrigation for meat or milk producing animals c) Aquaculture	1	1'000 (3-class sampling plan *(7)* with: n=10; m=1.000 cfu/100mL; M= 10,000 cfu/100mL; c=3)	35	no limit fixed	*Other Contaminants***; T. saginata and T. solium: 1 egg/L (if the fodder is used for feeding meat or milk producing animals. Pathogen presence/absence test when results repeatedly show c=3 for M=10.000
2.3	a) Localized irrigation of tree crops without contact of reclaimed water with fruits con-sumed by humans b) Irrigation of ornamental flowers, nurseries & greenhouses without direct contact of effluent with crops c) Irrigation of industrial non-food crops, nurse-ries, silo fodder, cereals and oilseeds	1	10'000	35	no limit fixed	*Other Contaminants**; Legionella spp.**

Class No.		I.N. *(1)* egg/10 L	*E. coli* cfu/100 mL	TSS mg/L	Turbidity NTU	Other criteria
Industrial uses						
3.1 *(9)*	a) Process and cleaning water but not for food industry b) Other industrial uses	no limit fixed	10’000	35	15	*Other Contaminants**; Legionella spp.**
	c) Process and cleaning water for food industry	1	1’000 (3-class sampling plan *(7)* with: n=10; m=1.000 cfu/100mL; M= 10,000 cfu/100mL; c=3)	35	no limit fixed	*Other Contaminants**; Legionella spp.**. Pathogen presence/absence test when results repeatedly show c=3 for M=10.000
3.2	Cooling towers and evaporative condensers	1	0	5	1	Absence of Legionella spp. Approval of a specific control program is required by the health authority. Use only for industry and in places not located in urban areas nor near areas with public activity.
Leisure uses						
4.1 *(9)*	Golf courses irrigation	1	200	20	10	*Other Contaminants***; *Legionella spp.*;* If effluent is directly applied to the soil (micro sprinklers, drippers) the criteria of Quality 2.3 are applicable
4.2	Ornamental pond and lakes in which public access to water is prohibited	no limit fixed	10’000	35	no limit fixed	*Other Contaminants**; ;* PT : 2 mg/l (in stagnant waters)
Environmental uses						
5.1	Aquifer recharge by localized percolation through the ground	no limit fixed	1’000	35	no limit fixed	TN *(8)*: 10 mg/L NO3: 25 mg/L Articles 257 to 259 of RD 849/1986
5.2	Aquifer recharge through direct injection	1	0	10	2	
5.3	a) Irrigation of woodland, green areas and other spaces without public access b) Silviculture	no limit fixed	no limit fixed	35	no limit fixed	*Other Contaminants***
5.4	Other environmental uses (wetlands maintenance, minimal stream flows etc)	The minimal required quality is defined in a case by case basis				

I. Limit values must at least be met by 90% of samples tested.					
	I.N. *(1)* **egg/10 L**	***E. coli*** **cfu/100 mL**	**TSS** **mg/L**	**Turbidity** **NTU**	
II. Maximum deviation limits, for samples exceeding the limit values	100% of limit	1 log unit	50% of limit	100% of limit	Legionella spp.: 1 log unit; T. saginata & T. solium: 100% of limit; Nitrate, TN,TP: 50% of limit
III. Hazardous substances must meet applicable environmental quality standards at the point of delivery of reclaimed water according to the legislation in force for the intended application.					

Notes:

***Other Contaminants** *(4)* included in the treated effluent disposal permit: discharge of these contaminants to the environment must be limited. In case of hazardous substances *(5),* use of reclaimed water must comply with environmental quality standards *(6).*

***Legionella spp.**: 100 cfu/L (if there is risk for aerosolization)

(1) Minimum of genera which must be included in all quality categories: Ancylostoma, Trichuris & Ascaris

(2) Controls must be performed to ensure the correct maintenance of facilities

(3) Authorization will only be given, if each section up to the point of use is a marked dual circuit

(4) See Appendix II of RD 849/1986

(5) See Appendix IV of RD 907/2007 (same in Amendment from 2013)

(6) Environmental quality standard; see Article 245.5.a of RD 849/1986, amended by RD 606/2003

(7) Where n=number of aliquot samples analyzed; m=(MAV) maximum acceptable value for the bacterial count; M=maximum permitted value for the bacterial count (MAV + Maximum Deviation Limit); c=maximum number of aliquot samples whose bacterial count falls between "m" & "M"

(8) Total nitrogen: the sum of the inorganic and organic nitrogen in the sample

(9) If there is a risk of water aerosolization, the conditions of use stipulated on a case by case basis by public health authorities must be followed; otherwise, such uses will not be authorized.

(10) Characteristics of recycled water which require additional information: EC: 3.0 dS/m; SAR: 6; Bo: 0.5 mg/L; As: 0.1 mg/L; Be: 0.1 mg/L; Cd: 0.01 mg/L; Co:0.05 mg/L; Cr: 0.1 mg/L; Cu: 0.2 mg/L; Mn: 0.2 mg/L; Mo: 0.01 mg/L; Ni: 0.2 mg/L; Se: 0.02 mg/L; Va: 0.1 mg/L.

Table 37 Spanish monitoring requirements

(exceptions see Appendix I.B)		I.N. *(1)*	*E. coli*	TSS	Turbidity	TN & TP	Other contaminants	Other criteria
Urban use	1.1 & 1.2	Every two weeks	Twice a week	Once a week	Twice a week		The water basin organization will assess the analytical frequency based on the effluent disposal permit and the water reclamation treatment	Once a month
Agricultural use	2.1	Every two weeks	Once a week	Once a week	Once a week			Once a month
	2.2	Every two weeks	Once a week	Once a week				Every two weeks
	2.3	Every two weeks	Once a week	Once a week				
Industrial use	3.1		Once a week	Once a week	Once a week			Once a month
	3.2	Once a week	Three times a week	Once a day	Once a day			Legionella spp. 3 times per week
Recreational use	4.1	Every two weeks	Twice a week	Once a week	Twice a week			
	4.2		Once a week	Once a week		once a month		
Environmental use	5.1		Twice a week	Once a week		once a week		
	5.2	Once a week	Three times a week	Once a day	Once a day	once a week		Once a week
	5.3			Once a week				
	5.4							Frequency similar to that of the most similar use

6.1.6 Proposal by European Commission (COM337, 2018)

<table>
<tr><th colspan="2" rowspan="2">Class No.*</th><th></th><th>E. coli</th><th>BOD$_5$</th><th>TSS</th><th>Turbidity</th><th rowspan="2">Additional criteria</th><th rowspan="2">Indicative technology target</th></tr>
<tr><th></th><th>cfu/100 ml</th><th>mg/l</th><th>mg/l</th><th>NTU</th></tr>
<tr><td>A</td><td>All food crops, including root crops consumed raw and food crops where the edible portion is in direct contact with reclaimed water</td><td>All irrigation methods allowed</td><td>≤10
or below detection limit</td><td>≤10</td><td>≤10</td><td>≤5</td><td rowspan="4">Legionella spp.: ≤1’000 cfu/l when there is risk of aerosolization in greenhouses;

Intestinal nematodes (helminth eggs): ≤1 egg/l when irrigation of pastures or fodder for livestock</td><td>Secondary treatment, filtration, and disinfection (advanced water treatments)</td></tr>
<tr><td>B</td><td rowspan="2">a. Food crops consumed raw where the edible portion is produced above ground and is not in direct contact with reclaimed water
b. Processed food crops
c. Non-food crops including crops to feed milk- or meat-producing animals</td><td>All irrigation methods allowed</td><td>≤100</td><td>25*</td><td>35*</td><td rowspan="3">-</td><td>Secondary treatment, and disinfection</td></tr>
<tr><td>C</td><td>Drip irrigation only</td><td>≤1’000</td><td colspan="2" rowspan="2">*According to Directive 91/271/EEC (Annex 1, Table 1)</td><td>Secondary treatment, and disinfection</td></tr>
<tr><td>D</td><td>Industrial, energy, and seeded crops</td><td>All irrigation methods allowed</td><td>≤10’000</td><td>Secondary treatment, and disinfection</td></tr>
</table>

Table 38 Water reuse classification and standards as proposed by the European Commission (COM337, 2018)

* The presented numbering of classes A – D is the original numbering in the regulation. Class A contains the strictest limits, as does class 1 in other regulations.

Notes:

(1) The indicated values for *E. coli*, *Legionella spp.* and intestinal nematodes are met in 90 % or more of the samples. None of the values of the samples can exceed the maximum deviation limit of 1 log unit from the indicated value for *E. coli* and *Legionella* and 100 % of the indicated value for intestinal nematodes.
(2) The indicated values for BOD$_5$, TSS, and turbidity in Class 1 are met in 90 % or more of the samples. None of the values of the samples can exceed the maximum deviation limit of 100% of the indicated value.
(3) The required compliance of samples with the limits for BOD5 and TSS in Classes 2 to 4 lies between 75%-93% depending on the total number of samples according to Directive 91/271/EEC, Annex 1, Table 3; The maximum deviation limit is 100% for BOD$_5$ and 150% for TSS

6.2 Maximum permitted number of exceeding samples (from UWWTD)

Council Directive of 21 May 1991, concerning urban waste water treatment (91/271/EEC)
Annex 1 Table 3

Series of samples taken in any year	Maximum permitted number of samples which fail to conform
4-7	1
8-16	2
17-28	3
29-40	4
41-53	5
54-67	6
68-81	7
82-95	8
96-110	9
111-125	10
126-140	11
141-155	12
156-171	13
172-187	14
188-203	15
204-219	16
220-235	17
236-251	18
252-268	19
269-284	20
285-300	21
301-317	22
218-334	23
335-350	24
351-365	25

6.3 Compliance of Antiparos WWTP effluent quality to reuse regulations (all data: 2016-2018)

Case 1 "Restricted irrigation": Irrigation of beans using drip irrigation exclusively.

Compliance with national regulation of:	class	*E. coli*		BOD$_5$		COD		TSS		EC		TN		NH$_4$		TP		Cl.$_{res.}$	
		cfu/100 ml		mg/l		mg/l		mg/l		µS/cm		mg/l		mg/l		mg/l		mg/l	
Cyprus	2	2.2E+03		23		74		51		6414								0.30	
# exceedings of limit / max. dev.		2	2	24	*n.l.*	7	*n.l.*	23	*n.l.*	1	1							1	1
France	B	2.2E+03				76		69											
# exceedings of limit / max. dev.		0	0			0	0	8	4										
Greece	3	0		25				69				18		*n.l.*				*n.a.*	
# exceedings of limit / max. dev.		1	*n.l.*	2	*n.l.*			8	*n.l.*			0	*n.l.*						
Italy	1	0		17		52		39		6414		18		0.59		0.40		0.30	
# exceedings of limit / max. dev.		2	1	10	10	0	0	21	21	1	1	2	2	0	0	0	0	7	7
Spain	2.2	5.2E+00						113		6414		*n.a.*				*n.a.*			
# exceedings of limit / max. dev.		1	0					8	0	1	*n.l.*								
COM337 (2018)	C	5.2E+00		25				69											
# exceedings of limit / max. dev.		1	0	2	0			8	4										
Total number of samples (effluent)		29		29		29		29		1		29		2		29		23	

Case 2 "Unrestricted irrigation": Irrigation of tomatoes using any irrigation methods.

Compliance with national regulation of:	class	*E. coli**		BOD$_5$		COD		TSS		EC		TN**		NH$_4$**		TP		Cl.$_{res.}$	
		cfu/100 ml		mg/l		mg/l		mg/l		µS/cm		mg/l		mg/l		mg/l		mg/l	
Cyprus	1	2.2E+03		23		74		51		6414								0.30	
# exceedings of limit / max. dev.		3	3	24	*n.l.*	7	*n.l.*	23	*n.l.*	1	1							1	1
France	A	2.2E+03				85		211											
# exceedings of limit / max. dev.		1	1			15	15	23	23										
Greece	2	0	7E+01	22				45				18		*n.l.*				0.30	
# exceedings of 80-perc. / 95-perc.		3	2	24	--			23	--			0	--					1	--
Italy	1	0		17		52		39		6414		18		0.59		0.40		0.30	
# exceedings of limit / max. dev.		2	1	10	10	0	0	21	21	1	1	2	2	0	0	0	0	7	7
Spain	2.1	5.2E+00						113		6414		*n.a.*				*n.a.*			
# exceedings of limit / max. dev.		2	1					18	11	1	*n.l.*								
COM337 (2018)	A	5.2E+00		25				114											
# exceedings of limit / max. dev.		2	2	24	10			23	18										
Total number of samples (effluent)		29		29		29		29		1		29		2		29		23	

*GR: (E. coli) Two limits must be met by 80 & 95-percentile; there is no maximum deviation limit

**GR: (TN & NH4) Limits for reuse in non nitrat vulnerable zones

Case 3 "Urban irrigation": Irrigation of a public park, with restrictions either to the opening hours for the public during irrigation, or to the irrigation method used.

Compliance with national regulation of:	class	*E. coli** cfu/100 ml	BOD$_5$ mg/l	COD mg/l	TSS mg/l	EC µS/cm	TN mg/l	NH$_4$ mg/l	TP mg/l	Cl.$_{res.}$ mg/l
Cyprus	3	2.2E+03	23	74	51	6414				0.30
# exceedings of limit / max. dev.		1 / 1	2 / *n.l.*	0 / *n.l.*	8 / *n.l.*	1 / 1				1 / 1
France	A	2.2E+03		85	211					
# exceedings of limit / max. dev.		1 / 1		15 / 15	23 / 23					
Greece	1	3E+00 / 1E+02	22		45		18	0.59		0.30
# exceedings of 80-perc. / 95-perc.		6 / 4	24 / --		25 / --		16 / --	0 / --		1 / --
Italy	1	0	17	52	39	6414	18	0.59	0.40	0.30
# exceedings of limit / max. dev.		2 / 1	10 / 10	0 / 0	21 / 21	1 / 1	2 / 2	0 / 0	0 / 0	7 / 7
Spain	1.2	5.2E+00			113	*n.a*	*n.a.*		*n.a.*	
# exceedings of limit / max. dev.		1 / 1			18 / 11					
COM337 (2018)	**n.a.**									
Total number of samples (effluent)		**29**	**29**	**29**	**29**	**1**	**29**	**2**	**29**	**23**

*GR: Limit for Total coliforms instead of E. coli for class 1 (Two limits must be met by 80 & 95-perc.); there is no maximum deviation limit
**GR: Sprinkler irrigation is prohibited
***SP: EC only applicable for "Agricultural uses"

Legend:
- (light green) The relevant percentile of samples meets the quality requirements for the defined reuse case
- (light orange) The relevant percentile of samples does not meet the quality requirements for the defined reuse case
- (orange) No compliance only due to exceeding of maximum deviation limit

Footnote for all tables:

1. Parameters are presented in the percentile which is decisive in the water quality class that is required for the defined reuse case.
   - n.l.: no limit is fixed for the regarded water quality class
   - n.a.: the parameter is not regulated for the regarded reuse case
   - "empty cell": the regarded parameter is not regulated in the regarded national regulation
2. The number of samples exceeding the limit of the relevant class is presented in green; the number of samples exceeding the maximum deviation limit (max. dev.) is presented in red. The total number of samples is presented at the bottom of the table.
3. Only parameters which have been monitored in Antiparos WWTP are included in the table. Missing parameters for the full quality evaluation vary in number and kind, for each of the national regulations.
4. IT: Less strict limit for E. coli in case of treatment in constructed wetlands/ stabilization ponds and less strict limit for TN & TP in case of irrigation use, are applicable for all three of the regarded reuse cases
5. SP: NO_3 has been monitored, it is however not a relevant parameter for the regarded reuse cases

6.4 Additional material for Antiparos

Table 39 Influent concentration of intense sampling campaigns in Antiparos

		Aug 17		Aug-Sep 18		Nov 18	
		Mean	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
E. coli	cfu/100 mL	1.0E+06	0	8.3E+06	7.1E+05	8.1E+06	6.4E+05
TC	cfu/100 mL	1.0E+06	0	9.1E+06	3.5E+05	8.8E+06	7.1E+05
COD	mg/L	771	124	643	67	588	34
BOD5	mg/L	322	59	286	22	269	18
TSS	mg/L	213	25	253	24	246	11
TN	mg/L	108	9	122	6	123	6
NH4-N	mg/L	--	--	49	6	49	3
NO3-N	mg/L	4	0.6	5	0.4	5	0.4
TP	mg/L	15	2	14	2	15	2

Figure 34 Dead local plants before rehabilitation actions in Antiparos WWTP due to clogging of top layer.