Reuse possibilities in view of the existing legislation in Greece

A. Andreadakis, D. Mamais, C. Noutsopoulos, S. Malamis

Sanitary Engineering Laboratory, National Technical University of Greece, 5 Iroon Polytechniou st, Zografos. Athens 15780, Greece
(E-mail: *andre1@central.ntua.gr)*

Abstract
The paper presents the existing Greek legislation concerning wastewater reuse. The main legal provisions are outlined, including administrative, quality and technical aspects. Emphasis is given to the microbiological requirements for unrestricted (excluding potable water) reuse, which are compared to similar requirement of other legislations. Furthermore, the feasibility of the criteria are investigated and proposals are made for the necessary treatment schemes to be adopted, depending on the reuse mode. In conclusion, due to the implemented in most cases wastewater secondary treatment and the administrative difficulties in ensuring the restricted reuse of the final secondary treated effluents, further tertiary treatment followed by appropriate disinfection is strongly recommended. The degree of advanced treatment varies from simple sand filtration to employment of membrane techniques, while disinfection can be achieved through chlorination, ozone and UV, at appropriate doses. Partly due the, until recently, lack of a specific for reuse regulatory framework the application of reuse in Greece was very limited, to less than 1% of the treated wastewaters. The establishment, since 2011, of a safe regulatory framework is expected to encourage further and expanded reuse A reasonable target is the, in average, reuse of some 8-10% of the produced effluents at a country level.

Keywords
Wastewater reuse, Legislation, Greece

INTRODUCTION

The sustainable management of water resources often requires the identification of wastewater as a valued source of water. The potential of wastewater reuse and reclamation have been recognized in Europe because of the advances in effectiveness of wastewater treatment and disinfection technologies.

However, wastewater reuse is not very widespread in the EU and it is characteristic that there is a lack of a unifying specific relevant Directive. This may be due to the variable interest among member states regarding reuse possibilities, probably as a result of diverse environmental conditions and available water resources. It is in the Mediterranean region that reuse is considered more important, is more widely practiced and is usually regulated by national or local/regional legislation. In Israel and in Cyprus more than 80% of the produced effluents are reused, but of course one should recognize the acute water shortage in both countries. In other Mediterranean counties, such as Italy and France, the percentages are much lower. In Spain it stands at 10%, with anticipated possibilities to reach 30%.

Greece, as one of the countries of this region, faces problems with the availability of water resources, thus reuse may offer a valuable additional source. At a country level the Water Exploitation Index (WEI) is below 20, so that the situation does not appear to be critical. However, due to a variable spatial distribution of rainfall in combination with a mismatch to the spatial distribution of demands, shortages can be acute in several regions (e.g.Thessalia, Aegean islands, Crete) with regional WEIs approaching or exceeding 40. Taking into consideration the conditions prevailing (distribution of rainfall, distribution of demands, allocation of effluent producing plants, the existence of major units such as the Psyttalia treatment plant in unsuitable for extensive reuse locations, alternative sources for industrial demands) it has been estimated that that the potential for reuse does not exceed 8-10% of the totally produced effluents. This is a feasible target since, due to the existing EU legislation concerning effluent discharge limitations, secondary biological treatment is the minimum treatment employed, usually with full or partial nitrogen removal in about 80% of the cases. Therefore, restricted wastewater reclamation is an already feasible possibility. Additionally the quality needed for unrestricted reuse can be achieved at a moderate cost, through upgrading of existing plants. It should however be stressed that currently reuse is practiced to not more than the level of 1% mostly (about 85%) for irrigation. To a significant extend this may be attributed to the until recently lack of a relevant to reuse national legislation, a weakness remedied by the 2011 KYA 145116 decree, which will be discussed in the following sections

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REUSE LEGISLATION IN GREECE

The Decree KYA145116 of 2011 is applicable for several types of reuse of both urban and industrial wastewaters, excluding reuse for direct potable consumption, reuse for swimming pools and in house domestic and industrial recycling (Table 1). The responsibilities of the main actors involved are outlined, namely of the producer (responsible for the operation of the treatment plant), the manager of the overall reuse scheme and the user. Furthermore, the procedures for the obtaining and maintaining the necessary permits are clearly defined.

Table 1. Types of reuse in relation to wastewater origin

	Urban wastewater	Conventional Industries *	Non Conventional Industries
Restricted Irrigation	✓	✓	✓
Unrestricted Irrigation	✓	✓	Not allowed
Industrial Reuse	✓	✓	✓
Groundwater Recharge	✓	✓	✓
Sensitive Groundwater Recharge	✓	✓	Not allowed
Urban Reuse	✓	✓	Not allowed
Amenity/Recreational	✓	✓	Not allowed

*Conventional Industries as specified in the Urban Wastewater Directive

In terms of the quality criteria to be met, these depend on the type of reuse (restricted or unrestricted irrigation, industrial use, urban use, groundwater recharge) in combination with the origin and characteristics of the wastewater to be reused (urban wastewater, size of the agglomeration, type of industry). The required quality characteristics involve a variety of parametric values concerning agronomic aspects, heavy metals, micropollutants and microbiological indicators (in terms of *E coli*). Supplementing the quality criteria, reference is made to the minimum requirements with respect to the treatment schemes to be adopted for each case (Table 2). Disinfection should be employed as a final stage in all cases.

Table 2. Synopsis of the legal requirements

	Restricted Irrigation	**Unrestricted Irrigation**	**Groundwater recharge**	**Protected Groundwater**	**Urban, amenity/recreation**
Sewage and conventional industrial wastewaters	Coliforms Agronomic Metals **	Coliforms Agronomic Metals ***	Coliforms Metals **/***	Coliforms Metals ****	Coliforms Metals ****
Sewage from WWTPs serving more than100,000 p.e	Coliforms Agronomic Metals Micropollutants **	Coliforms Agronomic Metals Micropollutants ***	Coliforms Metals Mocropollutants **/***	Coliforms Metals Mocropollutants ****	Coliforms Metals Mocropollutants ****
Other industrial wastewaters	Coliforms Agronomic Metals Micropollutants **	Not allowed	Coliforms Agronomic Metals Micropollutants **/****	Not allowed	Not allowed

** Secondary treatment
*** Tertiary treatment involving sand filtration
**** Advanced treatment (based on membrane technologies)

Since secondary treatment is the minimum treatment allowed the required concentrations of BOD_5, SS, COD in the effluent to be reused should not exceed in any case the limiting values specified by the Urban Wastewater Directive. Regarding nitrogen, removal is needed mainly in the cases of irrigation or groundwater recharge in nitrate vulnerable areas. However, specific provisions are made for on site systems and/or small scale (<2000 p.e.) treatment plants. Whenever secondary treatment is normally prescribed (column 1 of Table 2), in the case of on site and small scale systems an appropriate technology is adequate and a median concentration for *E coli* of 1000/100ml is sufficient.

The agronomic requirements are identical to those proposed by FAO (1985) for irrigation water. Regarding heavy metals the maximum allowable concentrations are presented in Table 3, generally in accordance with the recommendations made by FAO (1985). Micropollutants are of concern only in the cases of reuse with effluents originating from large wastewater treatment facilities (serving more than 100,000 p.e.) or from treatment plants for non conventional industrial wastewaters. In these cases the monitoring should include some 40 potentially toxic substances, in order to ensure compliance with specified criteria.

The microbiological quality of the reclaimed water is specified in terms of *E coli* concentrations for various percentages of samples. A median parametric value of 200/100 ml is adopted in cases of restricted irrigation and similar uses (with the above mentioned exception for on site and small scale units), while for other types of reuse much stricter limiting values, with reference to 80 and 95 percentiles, are prescribed. A comparison of these criteria with corresponding criteria of other legislations is presented in Table 4 and Figure 1.

Table 3. Maximum heavy metals concentration

Metal	Max. Concentration (mg/l)	Metal	Max. Concentration (mg/l)
Al	5	Mn	0.2
As	0.1	Mo	0.01
Be	0.1	Ni	0.2
Cd	0.01	Pb	0.1
Co	0.05	Se	0.02
Cr	0.1	V	0.1
Cu	0.2	Zn	2.0
F	1.0	Hg	0.002
Fe	3.0	B	2
Li	2.5		

Table 4. Comparison of microbiological criteria for different legislations

Regulation	TC/100ml	FC/100ml	EC/100 ml	% samples	Proposed Treatment
WHO		200-1000		50	Oxidation ditches
California	2,2/23			50/max	Secondary +Filtration
Italy-1977	2			50	
Italy-2003			10 (50-100)	80	
EPA		14		max	
Cyprus		5-50		80	Secondary +Filtration
Greece (2008)	2			90	Secondary +Filtration
Greece –restricted (2011)		200		50	Secondary
Greece –unrestricted (2011)		5 (50)		80 (95)	Secondary +Filtration
Greece –recharge of protected groundwaters (2011)	2 (20)			80 (95)	Secondary +Membranes

Comparison in Figure 1 is based on the assumption that 1 *E coli* corresponds to 1 *Faecal coliform* and that 10 *Total coliforms* correspond to *1 E coli* or *FC*

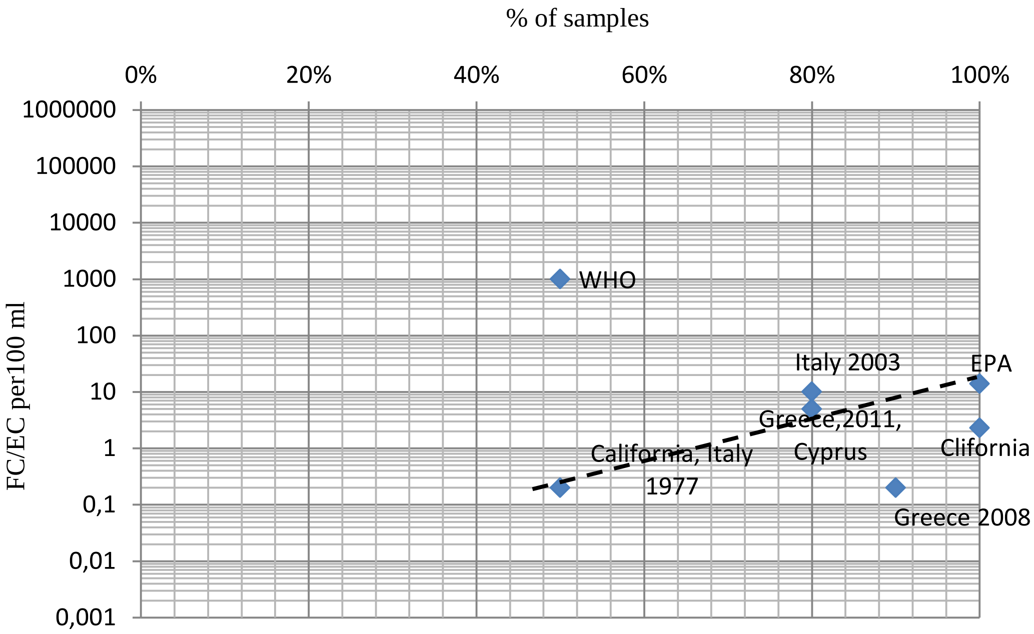

Figure 1 Comparison of microbiological criteria in different legislations

Figure 1 shows that in general there is a consistency among the different criteria, with two outliers. The one refers to the WHO regulation which is clearly less strict than the rest. The second refers to a temporary limit set in Greece in 2008, which is clearly unjustifiably conservative, and which was replaced by the criteria of the existing, since 2011, legislation.

As indicated in Tables 2 and 4 for each type of reuse and origin of the reclaimed water provisions are made for the necessary minimum treatment to be adopted (including appropriate disinfection doses), in addition to the parametric microbiological values to be achieved. The compatibility of the required parametric values and the minimum treatment prescribed is based on an extensive study which is outlined in the following section.

COMPATIBILITY OF TREATMENT AND MICROBIOLOGICAL CRITERIA

In order to evaluate the ability of secondary and tertiary/advanced treatment processes to produce effluents that meet the legal wastewater reclamation criteria and to develop treatment specifications for wastewater reuse in Greece, the Sanitary Engineering Laboratory (SEL) conducted series of lab scale experiments using non disinfected effluent samples from various wastewater treatment plants. The experiments were designed to study the feasibility of the following treatment schemes to produce treated wastewater suitable for reuse:

- disinfection of secondary effluent with UV radiation, chlorination and ozonation
- tertiary treatment followed by disinfection with UV radiation, chlorination and ozonation
- advanced treatment with membranes followed by disinfection with UV radiation, chlorination and ozonation

The efficiency of each method to disinfect secondary and tertiary effluent was evaluated by determining the reduction of both total and faecal coliforms. The experimental data were analysed using a stochastic statistical model that employs Monte Carlo simulation. The main scope of the stochastic approach was the regeneration of a greater set of data, based on the defined by the experimental information mathematical distribution of each parameter involved and the determination of relative probability distributions. The stochastic approach applied fulfils the statistical aspect of most guidelines that have been developed for wastewater reuse, enabling the estimation of the removal efficiency of each treatment scheme at a certain level of certainty.

This paper presents the results obtained with disinfection using UV, but similar conclusions and appropriate doses were obtained for the other disinfection processes.

Secondary and tertiary effluent characteristics

In order to obtain an accurate representation of the WWTPs in Greece, secondary effluent samples from fifteen of the largest treatment plants were taken. The WWTPs included in the survey were selected in order to cover the greater part o Greece and their total capacity of was approximately 60% of the treatment capacity of all the biological WWTPs in Greece. According to the results of the survey most of the WWTPs appeared to provide satisfactory secondary treatment complying with the EC Directive 91/271 for wastewater disposal. Secondary effluent BOD_5 and TSS concentrations were in the range from 5 – 36 mg/l and 2 – 57 mg/l, respectively with approximately 90% of the samples having a BOD_5 and a TSS of less than 25 mg/l and 23 mg/l, respectively.

Water quality characteristics of the tertiary treated effluent for the various doses of coagulants and polymer employed, are shown in Table 5. Average turbidity removal ranged from 55 – 75 %. For all alum doses greater or equal to 10 mg/l, average tertiary effluent turbidity was below 2 NTU.

Table 5: Physicochemical characteristics of tertiary effluents from lab scale unit.

Tertiary effluent from lab scale on line filtration unit								
	Alum=0 mg/l polymer=0 mg/l		Alum=10 mg/l polymer=0.75 mg/l		Alum=50 mg/l polymer=0.75 mg/l		Alum=90 mg/l polymer=0.75 mg/l	
	T_{UV} * %	Turb. NTU	T_{UV} * %	Turb. NTU	T_{UV} * %	Turb. NTU	T_{UV} * %	Turb. NTU
Average	83.2	2.3	81.7	2.0	82	1.2	85.6	1.1
Median	86.7	2	78.5	1.6	83	1.1	87	1
Min	58	1.5	60.7	1	62.7	0.7	67.7	0.8
Max	95.1	5.9	95.2	6.0	96.3	2	97	1.7
90^{th} perc.	92	3.4	92.9	2.4	93.8	1.7	95.2	1.5

* Transmittance at 253.7 nm

UV disinfection performance

Ultraviolet light disinfection of secondary and tertiary effluent was evaluated for a range of UV doses from 10-150 mW-sec/cm^2. The first step in order to estimate treatment performance was to determine faecal and total coliform removal achieved by UV radiation. UV inactivation of bacteria in the ideal case of plug flow conditions and uniform UV exposure can be described by the following expression (Andreadakis, *et al.*, 1999, 2001):

$$Nt = N_o \exp(-kIt) + N_p \quad (1)$$

where: N_t=bacterial consentration after exposure to UV (FC/100 ml), N_o =initial bacterial consentration (FC/100 ml), k=inactivation rate constant (cm^2/mW-sec), I=the intensity of UV radiation (mW/cm^2), t= exposure time (sec), N_p=bacterial density associated with particulate matter (FC/100 ml) = c f(TSS), TSS = suspended solids concentration, mg/l.

According to previous studies (Scheible, 1987), the experimental disinfection results obtained using the UV collimated beam unit appear to follow the general trend described by the above equation. To estimate process performance, probability distributions for each of the parameters included in the above equation were identified based on the experimental results. The identified probability distributions were then used in a Monte Carlo simulation to estimate the distribution of fecal and total coliform density and associated variability, in the disinfected effluent. According to this stochastic approach coliform density in the disinfected effluent was calculated by the following equation:

$$N = f(N_O) \times e^{-f\ (k)\ D} + f(c) \times f\ (TSS) \qquad (2)$$

where the above functions correspond to the probability distributions of the various parameters included in the equation describing bacteria inactivation by UV radiation.

The total and faecal coliform concentrations in the disinfected secondary effluent were determined for a variety of UV doses and suspended solids concentration. The cumulative distribution of faecal coliform concentrations in UV disinfected secondary effluent is presented in Figure 2 for UV doses in the 10–120 mW-sec/cm^2 range and effluent suspended solids concentration equal to 35 mg/l. According to the results of the Monte Carlo simulation compliance with the 200/100 ml FC (or EC) value for restricted reuse a UV dose in the 50–75 mW-sec/cm^2 range is required. On the other hand the requirements for unrestricted irrigation and other similar applications cannot be met at the range of UV doses studied, using secondary effluent.

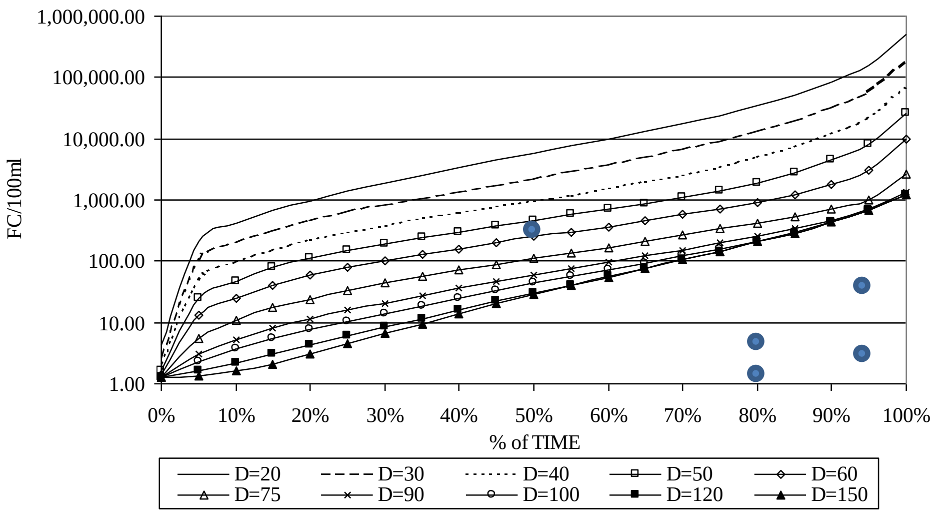

Figure 2: Cumulative distribution of faecal coliform levels in UV disinfected secondary effluent for TSS = 35 mg/l (UV doses in mW-sec/cm^2).

The total and faecal coliform concentration in the disinfected tertiary effluent were determined for the various alum and polymer doses employed. The cumulative distribution of fecal coliform density in UV disinfected tertiary effluent is presented in Figure 3 for UV doses in the 10 – 120 mW-sec/cm^2 range, alum and polymer doses of 10 mg/l and 0.75 mg/l, respectively. According to the results of the Monte Carlo simulation compliance with the parametric values for unrestricted irrigation and similar application (5 EC/100 for 80% of the samples and 50 EC/100 ml for 95% of the samples) requires a UV dose in the 45–60 mW-sec/cm^2 range. Tertiary treatment however is not to produce an effluent that after disinfection can meet the stringer regulation concerning protected groundwater recharge (2 TC/100ml and 20 TC/100ml for 80% and 95% of the samples respectively).

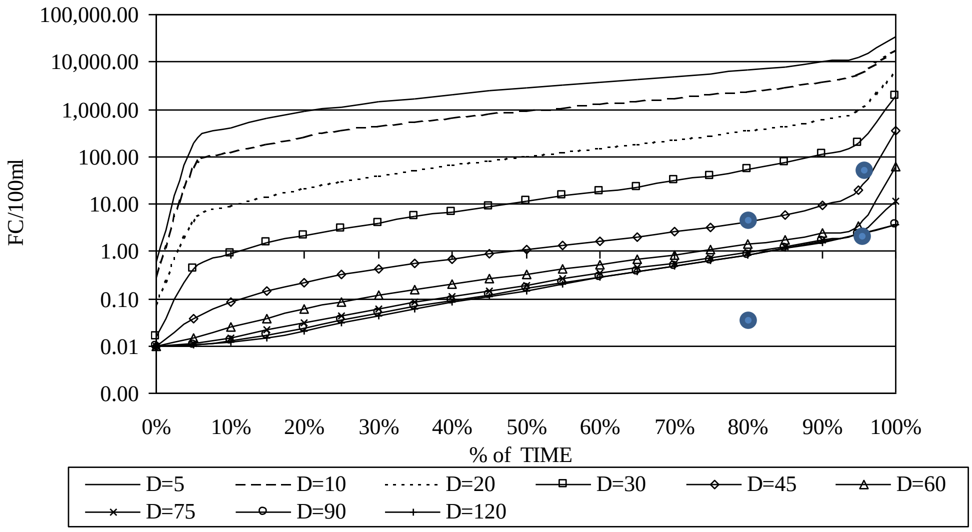

Figure 3: Cumulative distribution of FC levels in UV disinfected tertiary effluent, for various UV doses in mW-sec/cm^2 (TSS=5 mg/l, alum dose=10 mg/l, polymer dose=0.75 mg/l).

These strict requirements for recharge of protected groundwater can only be met by adoption of advanced treatment schemes based on membrane technologies, followed by moderate disinfection (30–40 mW-sec/cm^2), as indicated from the results presented in Table 6.

Table 6. Performance of UV disinfection after membrane treatment

		UV Dose in mW-sec/cm^2					
% of samples	Fc /100 ml after membrane treatment	3	5	10	20	30	40
50%	475	76	48	17	3	0	0
80%	820	140	92	44	6	0	0
95%	2050	480	360	200	84	16	4

CONCLUSIONS

Monte Carlo simulation was used to assess secondary and tertiary treatment processes for wastewater reclamation. The analysis of the previously presented experimental results with UV disinfection as well as similar evaluations dealing with chlorination and ozonation were used to develop the existing legal framework in Greece, concerning reuse. More specifically the major points regarding treatment specifications required to achieve the desired level of coliforms for each reuse type can be summarised as follows:

- Recommended methods for secondary treatment include various types of activated sludge process, biological filters and rotating biological contactors. Other systems producing effluents of equivalent quality (BOD_5/SS = 25/35 for 80% of samples) can be accepted on the basis of adequate documentation. Nitrogen concentrations in the effluent these must be lower than 35 mg/l except in cases of long term surface storage or irrigation of nitrogen vulnerable zones, where an average concentration of 15 mg/l for nitrogen must be adopted. In cases of small agglomerations with population equivalent less than 2000, it is possible to apply treatment systems that cannot achieve the BOD_5/SS standard, under the condition that there is no direct contact of the public or the farmers with the treated wastewater. In these cases a median value of 1000 FC/100 ml for faecal coliforms can be adopted.

- Chlorination, ozonation, UV radiation or other methods for reduction of pathogens may be used to disinfect secondary effluent as long as they can ensure the required median concentration of faecal coliforms at the effluent. In all cases during chlorination the product of residual chlorine and contact time (C·t) must be greater or equal to 30 mg·min/l. When disinfection is practiced with UV, a minimum dose of 70 m $Wsec/cm^2$ at the end of the life of the lamps should be ensured and the design of the UV system must be based at a maximum value of transparency equal to 50%.
- Appropriate tertiary treatment schemes should be based on the following minimum requirements: a) alum addition at doses greater than 10 mg/l and b) direct filtration at sand filters with the following characteristics: depth of sand filter (L) ≥ 1.40 m, effective diameter of sand (De) ~ 1 mm, uniformity coefficient of sand (u) 1.45-1.6 and hydraulic surface load $\leq 8\ m^3/m^2/h$ for normal operation.
- Chlorination, ozonation, UV radiation or other disinfection methods may be used to disinfect tertiary effluent as long as they can ensure the required concentration of fecal coliforms at the effluent, for 80% of the samples. In all cases during chlorination a minimum residual chlorine concentration of 2 mg/l and a minimum contact time of 60 min, must be ensured, while the necessity of dechlorination prior to wastewater reuse must be examined on a case-by-case basis. When disinfection is practiced with UV, a minimum dose of 50 m $Wsec/cm^2$ at the end of the life of the lamps should be ensured and the design of the UV system must be based at a maximum value of transparency equal to 70%.
- For the specific case of protected groundwater recharge, advanced treatment, based on membranes, followed by moderate disinfection should be adopted

On the basis of the investigation the standards proposed in the legislation are realistic and feasible and in the case of restricted reuse can be readily achieved by the existing wastewater treatment plants in Greece. Even in the case of most unrestricted reuse cases the additional treatment required can be achieved at a moderate cost, through upgrading of the existing plants with tertiary treatment.

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