Urban wastewater reuse for landscape irrigation in a seaside resort: microbial requirements

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ABSTRACT

Landscape irrigation is currently the main demand of water reuse in France. However inappropriate health related regulation still hampers the development of municipal applications of water reuse. The microbial quality of the effluents of Le Grau du Roi activated sludge treatment plant (ASTP) and waste stabilisation ponds (WSP) was monitored. ASTP and WSP effluents were also submitted to ultra violet (UV) and ultra filtration (UF) disinfection tests. WSP effluent was found to be pathogen free and could be classified from *excellent quality* to slightly *insufficient quality* bathing. *Legionella spp* was not detected by the standard culture method. *E. coli* rarely exceeded and enterococci never surpassed the 1 CFU/100 mL detection limit after UV treatment of ASTP and primary pond effluents; the same limit was never exceeded after UF treatment. ASTP plus WSP treatment led to a reduction ≥ 4 $\log_{10}$ of enterococci, SBR spores and F specific RNA phages. Disinfection of primary pond effluent through UV or UF processes reached a more ambitious target of 5 $\log_{10}$. Considering the high microbial quality of the reclaimed waters and the high microbial reduction capacity of the treatments, the ban on reclaimed water aspersion of green spaces within a 100 m distance from buildings and roads is not justified.

INTRODUCTION

Recent droughts, recurrent threats of local and regional water shortage and announced consequences of the global warming have resulted in an increasing public awareness of water being a limited resource. In another hand, implementing the Urban Wastewater Treatment Directive of the European Union (EU) as well as the Water Framework EU Directive means ever more stringent requirements on the treatment and disposal of urban wastewater. Costly advanced secondary and tertiary wastewater treatment facilities have been and will be put into service to protect bathing places, shellfish farms and sensitive receiving water bodies. In order to save freshwater resource and recover part of increasing wastewater treatment costs, more and more municipalities are planning to reuse municipal wastewater for the irrigation of landscaped and recreational areas, including golf courses. This is especially true in coastal tourist areas in France and several Mediterranean countries.

Landscape irrigation is currently the main demand able to drive the development of water reuse in France. Indeed, there are many circumstances under which the cost of the additional treatment and of the separate distribution system required for a safe reuse of reclaimed water can be offset by the value of fresh water savings. However inappropriate and uselessly strict regulations still hamper the development of municipal applications of water reuse in France. Health related reuse guidelines and regulations are not yet well established in European and

Mediterranean regions; correlatively, the microbial quality required for urban landscape irrigation remains a matter of debate.

Most of these landscaped areas are mainly spray irrigated lawns located close to residential areas, lanes and roadways. According to US EPA guidelines, wastewater should be successively secondary treated, filtered and disinfected such that no faecal coliform could be detected in 100 mL and no level of viable pathogens measured in the reclaimed water (US EPA, 2004). In Australian guidelines, the microbial target is *E. coli* <1 per 100mL (NRMMC-EPHC, 2006). As high reclaimed water quality is anticipated, no setback distance between irrigation sites and residential areas and roadways is suggested. French guidelines illustrate a different approach. They allow using A quality water (A quality is defined by the following criteria: $\leq 10^3$ faecal coliforms per 100 mL and ≤1 intestinal nematode per L) but aspersion is forbidden during opening hours; low throw sprinklers should be used and a 100 m setback distance from houses, sport and recreational areas should be enforced (CSHPF, 1991). In most Mediterranean countries, no setback distances are stipulated, even when green spaces are spray irrigated. Regulations and draft guidelines focus more on a *E. coli* content criterion: ≤ 10 CFU/100 mL in Italy (but ≤ 100 CFU/100 mL for waste stabilization pond effluents), ≤50 CFU/100 mL in Cyprus, ≤100 CFU/100 mL in the Greek draft and ≤200 CFU/100 mL in the regulations of Andalusia, Balearic islands and Spain (BOE 2007). The recently published Spanish regulation requires ≤ 1 intestinal nematode egg per 10 L and, when irrigation generates aerosols, < 100 *Legionella spp* per litre.

Urban irrigation guidelines aim at addressing health risks related to human contact with the irrigated areas - mainly lawns – and to the spreading and subsequent absorption by dwellers and passers-by of pathogens borne by spray and aerosols. Specific risks resulting from spray irrigation were the main reason for including setback distances in the French guidelines. However, the special attention given to these risks is based on limited scientific evidence. Very few data have been published on pathogen or faecal indicator transport by spray and aerosols resulting from aspersion with wastewater or reclaimed water. Devaux (2001) searched for the presence of faecal indicators in spray and aerosols at 10-150 m distance from a gun-type sprinkler irrigating corn in the main French water reuse project of Clermont-Ferrand. No bacterial indicator of faecal contamination was observed with irrigation water concentrations of less than 10^3 thermotolerant coliforms or streptococci per 100 mL and exposure time of 20 minutes. The few epidemiological and serological researches that have been conducted, most of them in Israel and the USA, are summarized in WHO (2006). There has not been any documented disease outbreak resulting from spray irrigation with water of *E. coli* $\leq 10^3$ CFU/100 mL.

Otherwise outbreaks of the Legionnaires' disease, particularly in the vicinity of cooling water towers, have demonstrated the existence of risks related to the spreading of pathogens by spray and aerosols. This has led to including a specific criterion in the Spanish regulation.

Le Grau du Roi – Southern France - seaside resort includes more than 40 hectares of landscaped areas; most of these areas are spray irrigated with raw Rhône River water. Local authorities are planning to substitute reclaimed wastewater for the Rhône water currently used for landscape irrigation. This water reuse plan is driven by economic reasons and is eased by the existence of a separate irrigation network, a wastewater treatment plant (WWTP) flow rate that more than matches the irrigation needs, the high quality of the activated sludge treatment plant (ASTP) effluents and the existence of waste stabilisation ponds (WSPs) which provide both an additional treatment and a storage facility for the treated water. However, most of the landscaped areas of Le Grau du Roi are spray irrigated lawns close to buildings and roads. Given the current French guidelines, aspersion of these green spaces with reclaimed water should be prohibited.

The microbial quality of the effluents of Le Grau du Roi ASTP and WSPs was monitored from Spring to Summer 2006 and in Summer 2007. ASTP and WSP effluents were also submitted to ultra violet (UV) and ultra filtration (UF) disinfection tests in Summer 2007. The objective was (i) to determine whether these effluents contain pathogens and (ii) to assess the removal of micro-organisms through the actual treatment system, complemented or not by UV and UF disinfection systems. Based on the microbial quality of the effluents and the microbial performance of the treatment systems, the appropriateness of the current French regulations, which prohibits spraying treated wastewater in the vicinity of houses, buildings, roads and recreational areas whatever the quality of the treated water, will be assessed and a range of treatment options suggested.

MATERIALS AND METHODS

Le Grau du Roi, 100,000 p.e. WWTP, encompasses an ASTP achieving high dephosphatation, nitrification and denitrification, and a 21 hectares WSP system (Fig. 1).

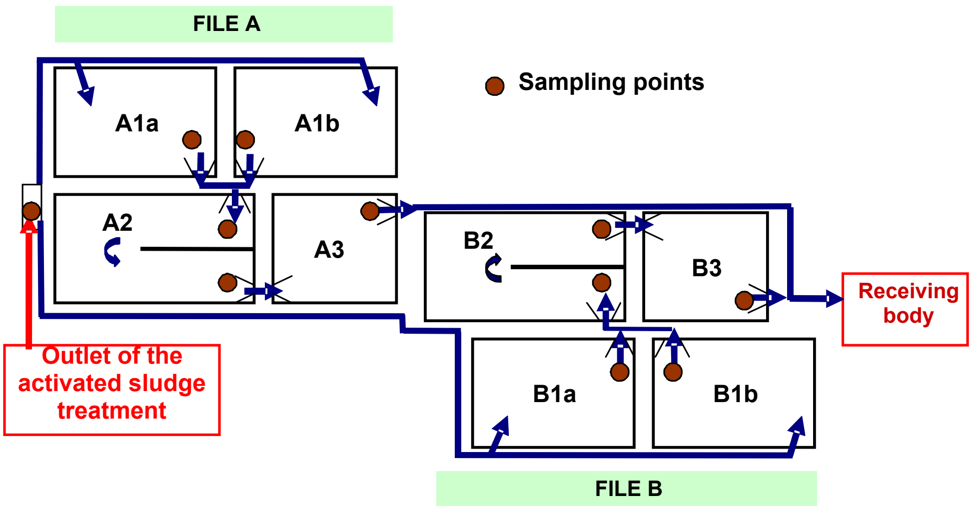

Figure 1. Lay out of Le Grau du Roi WSPs and location of the sampling points

A hydraulic modelling has shown that the ponds are watertight. The effluent flow rate of the ASTP varies from 4,000 m^3 per day in autumn and early spring to 10,000-12,000 m^3 d^{-1} in July and August. The ASTP started operating in 1997. Its treatment capacity is 24,000 $m^3 d^{-1}$. Two identical trains allow coping with seasonal variations. Mean ASTP effluent characteristics were respectively, 11, 3, 31, 3.5 and 0.8 mgL^{-1} for SS, BOD_5, COD, total N and total P.

The WSP system was constructed in 1966 and was the only wastewater treatment facility of Le Grau du Roi seaside resort until 1997. Nowadays, it provides a tertiary treatment. There are two parallel pond trains (Fig. 1). Effluents of the two trains mix beyond the outlet of the tertiary ponds and feed a brackish lagoon. Stored water volume varies between 23,600 and 48,700 m^3 from one pond to another. Besides, biological WWTP effluent is not equally distributed between the two pond trains A and B and between the two primary ponds of each train. Thus, water residence times vary from one pond to another and with seasonal flow rate variations. As a consequence, the total WSP residence time varies from 19 days in summer in file B1b-B2-B3 to 186 days in winter in file A1b-A2-A3. SS – mainly algae - contents in WSP effluent varied between around 40 mgL^{-1} in early spring and 8 mgL^{-1} in August and July, BOD_5 between 10.5 mgL^{-1} in spring and 7 mgL^{-1} in summer, COD between a mean spring value of 65 mgL^{-1} and 44 mgL^{-1} in summer. The organic matter balance showed that algae development was partly due to atmospheric CO_2 synthesis. Most $N\text{-}NH_4$ concentrations were ≤0.2 mgL^{-1}.and $N\text{-}NH_4$ never exceeded 0.5 mgL^{-1}. N-NOx content was always less than 0.5 mgL^{-1}. Total P content remained around 0.4 mgL^{-1}. Mean values of SS contents, COD, N and P concentrations in effluents of A1a primary pond were respectively 6, 39, 1.6 and 0.7 mgL^{-1} in summer 2007.

The UF and UV pilot plants were operated in July and August 2007 in order to assess their disinfection performance and identify the related operation constraints when applying these disinfection treatments to either the effluents of the activated sludge plant or the effluents of a primary pond, A1a (Fig. 2). These tests were expected to assist the design of the full scale disinfection plant, the identification of its operation conditions and the choice of the point of withdrawal of the effluent to be disinfected.

The UV pilot plant included an AMIAD surface filtration unit and an OZONIA low pressure 254 nm UV reactor. After several tests, a 75 µm woven stainless steel sieve was shown to lead to an acceptable backwashing cycles and was adopted. The maximum acceptable flow rate was determined after total coliforms, *E. coli* and enterococci removal tests; this flow rate corresponded to a UV dose of around 60 $mJcm^{-2}$ and a turbidity reduction by the AMIAD filter of 0.3 NTU.

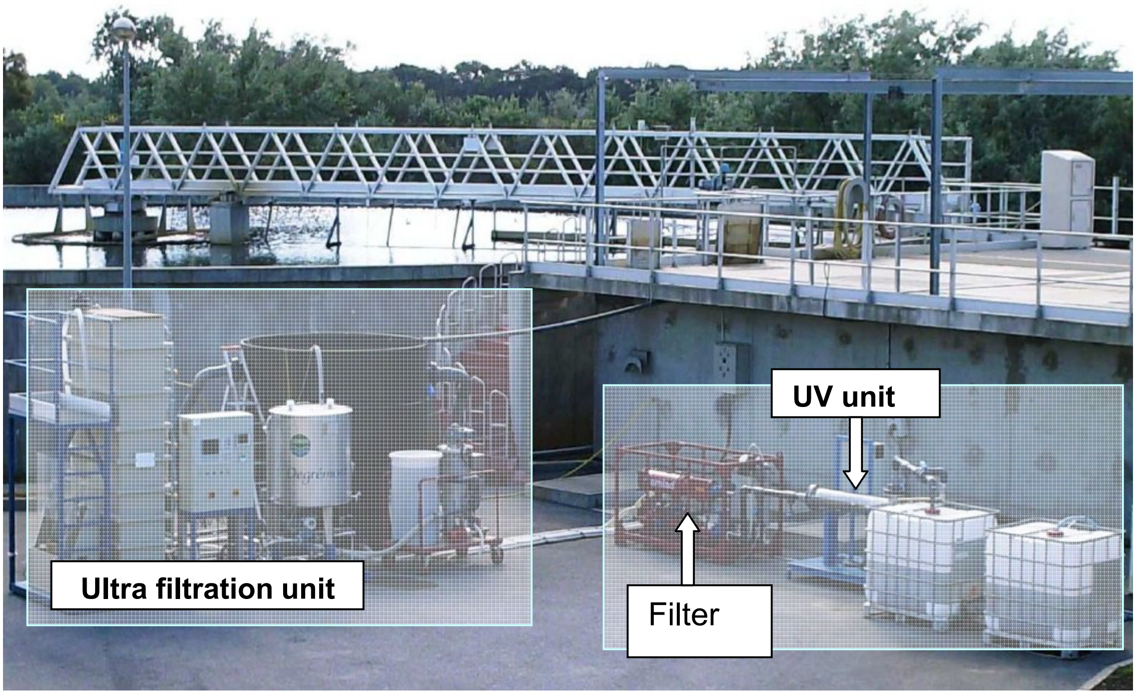

Figure 2. Ultra-filtration *(left)* and Ultra violet radiation *(right)* pilot plants

The ZENON UF pilot plant supplied by DEGREMONT consisted of a 1 mm mesh filtration preceding 3 hollow fiber submerged membrane modules. The membrane pore size was 0.035 µm. The pilot plant was operated under a water flow rate of 0.03 $m^3m^{-2}h^{-1}$.

ASTP effluents, pond water and WSP effluents were analysed for *Escherichia coli* and enterococci, helminth eggs, S*almonella spp*, enteroviruses, *Legionella spp* and *Legionella pneumophila* from April to September 2006. Effluents of ASTP and A1a and B3 ponds were monitored during the tourist high season of Summer 2007; *E. coli* and enterococci, helminth eggs, S*almonella spp*, *Giardia* and *Cryptosporidium*, spores of sulphite-reducing bacteria, F-specific RNA phages, *Legionella spp* and *Legionella pneumophila* were determined. All these micro-organisms were enumerated in the effluents of the UF and UV pilot plants in order to assess the performance of these disinfection treatments.

RESULTS

Disinfection performance of the WSP system

Faecal indicator bacteria were efficiently removed in the primary ponds (Fig. 3 and 4). At the outlet of primary ponds A1a, A1b, B1a and B1b, geometric mean *E. coli* and enterococci concentrations ranged between 480 and 24 CFU/100 mL and 61 and 38 CFU/100 mL respectively. High standard deviation values (Table 1) may be interpreted as seasonal variations; indeed, meteorological conditions highly depend on the season and, due to tourist population, the summer wastewater flow rate is three times the winter one.

Table 1. Mean (± s.d.) of $\log_{10}$ of faecal indicator concentrations at the outlet of the primary ponds

	2006				2007
	A1a	**A1b**	**B1a**	**B1b**	**A1a**
E.coli ($\log_{10}$ CFU/100 mL)	1.9 ± 0.9	2.5 ± 0.8	1.4 ± 0.4	1.4 ± 0.5	2.7 ± 0.8
Enterococci ($\log_{10}$ CFU/100 mL)	1.7 ± 1.1	1.8 ± 0.6	1.6 ± 0.7	1.6 ± 0.8	1.4 ± 0.4

At the tertiary pond (A3 and B3) outlets, most *E. coli* and enterococci values were below the detection limit of 10 CFU/100 mL in 2006, the geometric means being <14 and <17 *E. coli* /100 mL and <33 and <34 enterococci / 100 mL (Table 2). At the B3 outlet, *E. coli* and enterococci geometric means were respectively 6 and <36 CFU/100 mL during the July to August 2007 investigation.

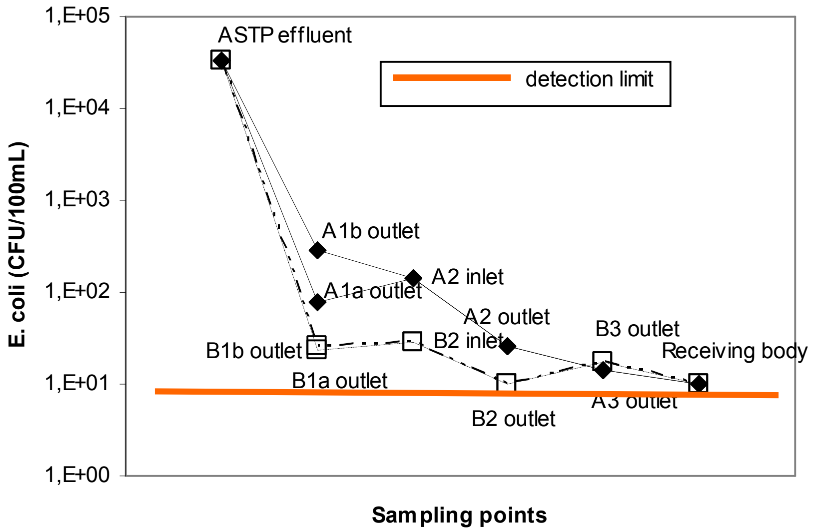

Figure 3. Fate of *E. coli* across Le Grau du Roi WSPs during the 2006 irrigation period (reported *E. coli* values are geometric mean concentrations).

E. coli contents in the effluents of the WSP system rarely exceeded 80 CFU/100 mL. Only one out of nine samples in 2006 and one out of twelve samples in 2007 were found to contain more than 80 CFU/100 mL. Regarding this criterion, WSP effluent quality was higher than the *excellent quality* water of the European Directive applying to bathing waters: *E. coli* <500 CFU/100 mL in freshwaters and <250/100 mL in coastal waters (EC 2006).

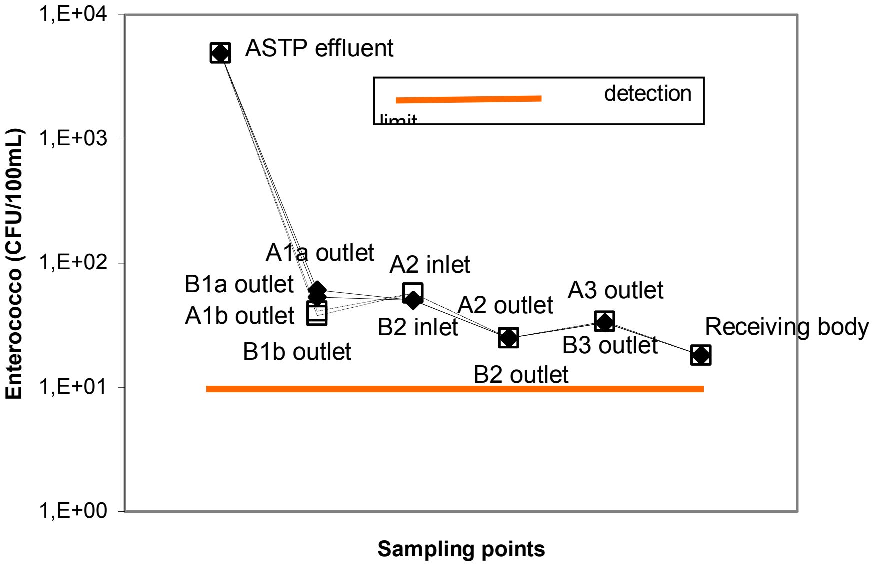

Figure 4. Fate of enterococci across Le Grau du Roi WSPs during the 2006 irrigation period (reported enterococci values are geometric mean concentrations).

In 2006, 8 out of 9 enterococci counts were lower than 100 CFU/100 mL at the outlet of the WSPs. However 4 samples out of 12 were found to be higher than 100 CFU/100 mL in 2007 but without exceeding 500 CFU/100 mL. According to this criterion, WSP effluent might have been classified as an *excellent quality* bathing water (enterococci < 200/100 mL) in 2006 but slightly insufficient quality bathing water in 2007. Enterococci did not appear being significantly reduced between the outlet of the primary ponds and the outlet of the whole WSP system; Abundant water fowls (ducks, flamingos, etc) and rodents (coypus) are likely to re-contaminate the ponds water. A 4.5-5 $\log_{10}$ reduction of enterococci was obtained between the raw wastewater entering the ASTP and the outlet of the WSP system.

Table 2. Mean (± s.d.) of $\log_{10}$ of faecal indicator concentrations at the outlets of the tertiary ponds and of the whole WSP system.

	2006			2007	
	A3	**B3**	**WSP syst**	**B3**	**WSP syst**
E.coli ($\log_{10}$ CFU/100 mL)	<1.2 ± 0.3	<1.2 ± 0.6	<1.0±0.7	0.8±0.8	<1.0±0.9
Enterococci ($\log_{10}$ CFU/100 mL)	<1.5±0.5	<1.5±0.9	<1.3±0.4	1.6	<1.8±0.5

The following pathogen parasites were searched: ascaris, trichurides, toxocara, taenia, hymenopolis (in 2006 and 2007), *Cryptosporidium* and *Giardia* (in 2007). No helminth egg was found in any 5 litres sample, neither in the biological plant effluent nor in the ponds. This result may be explained by the long water residence time in the ASTP and a possible low content of helminth eggs by in the sewage and the efficacy of the ASTP. Schwarzbrod *et al.*

(1989) found only 8 eggs per litre in raw wastewater in an investigation made in Eastern France, which points to the generally low helminth contamination in the country.

Table 3. *Giardia*, *Cryptosporidium* and spores of sulphite reducing bacteria in the ASTP and the WSPs (summer 2007).

	ASTP inlet	ASTP outlet	A1a outlet	B3 outlet	WSPs outlet.
Cryptosporidium (oocysts/20 L)	2100	0,5	Absence		
Nb samples	1	2	3	1	3
Giardia (kysts/10 L)	Absence				
Nb samples	1	2	3	1	3
Spores of sulphite-reducing bacteria (UFC/100 mL)	> 1.5 10^4	340	100	0	3
Nb samples	1	1	1	1	1

The abundance of *Cryptosporidium* oocysts in raw sewage was consistent with the observations of Harwood *et al*. (2005) while *Giardia* was detected neither in the raw sewage nor in the ponds (Table 3). *Cryptosporidium* oocysts were reduced by 3.7 log_{10} in the ASTP and were not detected in the ponds. Spores of sulphite reducing bacteria (SRB) have been proposed as potential indicators of parasite protozoa (Payment *et al*., 1993). They use to be abundant enough in raw wastewater to allow assessing the removal performance of the treatment processes, which was not possible with *Giardia* at Le Grau du Roi. A >1.5 10^4 CFU/100 mL content was found in raw sewage, which is consistent with the 5.7 10^4 CFU/100 mL geometric mean of 38 analyses performed at the inlet of 3 French sewage water treatment plants (Lucena *et al*., 2004). A 1.6 log_{10} reduction was observed in the ASTP. Though the primary pond A1a did not add much to their reduction, SRB spores were virtually completely removed at the outlet of the WSP system. Taking the value in Lucena *et al.* (2004) as representative of raw wastewater concentrations, the removal of SRB spores was assessed being more than 4 log_{10}.

When analysed in April, May, August and September 2006 and in July and August 2007, no *salmonella spp* was detected in 1 litre of water, wherever the sample was taken, at the inlet of the ASTP (one sample analysed in 2007), at the outlet of the ASTP and in the ponds. The literature reports that *salmonella spp* contents in raw wastewater vary from a few tens to several hundred thousands per litre (Crook, 1998; Yates & Gerba, 1998; Cooper & Olivieri, 1998; Jimenez, 2003; WHO 2006). In Europe, contents are in the lowest part of the range most of the time.

No enterovirus was detected in 10 litres when searched in April, May, June, August and September 2006 at the ASTP outlet and in the ponds. The absence of enterovirus in the ASTP effluent is noteworthy. Literature reports that the search for enteroviruses in raw wastewater is always positive, though concentrations vary within a large range with, for instance, 17,000 PFU/L by Pearson *et al*. (1995), from several thousands to several millions per litre in Jimenez (2003) or Dahling *et al*. (1989). Virus removal in conventional biological plants is estimated to be around 2 log units (Jimenez, 2003). In France, Gantzer *et al*. (1998) have found contents between 1.5 and 22.5 NPPUC (most probable number of cytopathogenous units) per litre at the outlet of a conventional biological plant and they have also observed the absence of enterovirus in 20 litres of the effluent of a plant similar to the Grau du Roi ASTP. Therefore, it appears that a biological treatment which eliminates most of the nitrogen and phosphorus is also able to efficiently eliminate enteroviruses. The absence of enterovirus did not allow assessing the efficiency of WSPs as regards virus removal. Therefore, as suggested by Payment *et al.* (1993), bacteriophages were used as surrogate indicators to evaluate the disinfection potential of treatment processes. F-specific RNA bacteriophages (FRNAPH) were analysed at the peak of the tourist season in August 2008 (table 4). It was deducted from the observed contents that the FRNAPH reduction in the whole treatment system (ASTP + WSPs) was at least 2.5 log_{10}. However, the raw wastewater FRNAPH content is likely to be higher than the upper quantification limit of the analytical method (1.5 10^4 PFU/100 mL). Referring to the mean value of 4.9 10^5 PFU/100 mL reported in Lucena *et al.* (2004), the reduction was very likely higher than 4 log_{10}.

Table 4. F specific RNA bacteriophage contents (August 2007)

	Raw wastewater	**A1a outlet**	**B3 outlet**	**WSPs outlet**
Bacteriophages (PFU/100 mL)	> 1.5 10^4	1300	< 50	< 50

Legionella develops in aqueous aerobic media at temperatures between 25 and 42°C. They use to colonize other organisms, such as amoebae or ciliates. Most often reported contamination sources are cooling towers and systems supplying hot or just warm water and producing aerosols. Risks related to *Legionella* must be considered for the following reasons:

- in summer, water temperature in the WSPs exceeds 20°C and reaches up to 30°C ;
- protozoa are a component of the ponds ecosystem which may participate in the survival of *Legionella*;
- aspersion of landscaped areas produces spray and aerosols.

It is admitted that among *Legionellae spp*, *Legionella pneumophila* is responsible for 75 to 90 % of Legionnaire's diseases detected in France. This is the reason why a particular attention was given to this species. The conventional enumeration of *Legionella* is a solid selective medium plating method (French NF T90-431standard). The culturing medium commonly used for *Legionellae spp* enumeration favours the development of *L. pneumophila*. In French hospitals, alert threshold related to warm water supply is *L. pneumophila* ≥1000 CFU/L. For water cooling towers, alert threshold is set at *Legionella spp* ≥ 1000 CFU/L which, given the characteristics of the NF T90-431 culturing medium, is not that different from *L. pneumophila* ≥1000 CFU/L; the call for action threshold is a concentration 100 times higher. *Legionella spp* and *L. pneumophila* were searched at the outlet of the ASTP and the primary pond A1a in July and August 2007. *Legionella spp* and *L. pneumophila* were not detected. The detection limit of the method used being 500 CFU/L, this means that, if *Legionella* were present, they were below the alert thresholds.

The PCR (*Polymerase Chain Reaction*) method (standard XP T 90 471) takes into account cultivable and non cultivable viable bacteria and those hosted in protozoa; its sensitivity does not depend on the species and has been shown to be higher than the one of the conventional plating method (Yanez *et al*., 2005, Yaradou *et al*., 2007 and Medema *et al*., 2004). *Legionella spp* content – as enumerated by the PCR method – in ASTP effluent and pond water was just one order of magnitude higher than in the Rhône River and consistent with concentrations observed in natural waters. *L. pneumophila* was detected by the PCR method but at not quantifiable contents at the ASTP outlet. It was not detected or detected but at contents too low for quantification in pond water.

Ultraviolet irradiation and ultra-filtration

Effluents of the ASTP and the primary pond A1a were submitted to UV and UF disinfection treatment. Both treatments reduced very efficiently bacteria indicator of faecal contamination (Table 5). After these treatments, *E. coli* content rarely exceeded the detection limit of 1 CFU/100 mL while enterococci content never surpassed this limit. The reduction of enterococci between the ASTP inlet and the outlet of the UV and UF pilot units was higher than 6 $\log_{10}$.

Table 5. Mean (± s.d.) of $\log_{10}$ of faecal indicator concentrations before and after disinfection by UV and UF processes.

	ASTP outlet	A1a outlet	UV outlet	UF outlet
E.coli ($\log_{10}$ CFU/100 mL)	3.9 ± 0.52	2.68 ± 0.82	<0.19 ± 0.5	< 0*
Enterococci ($\log_{10}$ CFU/100 mL)	2.93 ± 0.53	1.44 ± 0.45	< 0*	< 0*

* As most values were less or equal to the detection limit of 1 CFU/100 mL, calculating a square deviation value would be meaningless.

Pathogen parasites, helminth eggs, *Giardia* kysts, *Cryptosporidium* oocysts, were never detected after either UV or UF treatment. The removal capability of these two disinfection processes as regards protozoa was assessed considering the removal of spores of sulphite reducing bacteria. A1a primary pond effluent contained 100 CFU/100 mL and 6 CFU/100 mL after UV treatment. SRB spores reduction was 1.2 $\log_{10}$, a result consistent with the literature (Hijnen *et al*., 2006). Ultrafiltration totally removed SRB spores.

Salmonella spp was never detected at the inlet and, therefore, at the outlet of UV and UF pilot plants.

Table 6. F specific RNA bacteriophage contents before and after disinfection by UV and UF processes (August 2007)

	A1a outlet	UV outlet	UF outlet
Bacteriophages (PFU/100 mL)	1300	< 2	< 2

The treatment of pond A1a effluent by the UV and UF processes resulted in a F RNAPH removal of at least 3 $\log_{10}$ (Table 6). Considering that the raw wastewater content was higher than 1.5 10^4 PFU/100 mL, the overall FRNAPH reduction, assessed between the ASTP inlet and the outlets of the UV and UF pilot plants, was at least 4 $\log_{10}$.

In July and August 2007, *Legionella spp* as well as *Legionella pneumophila* were not detected by the culture method in ASTP and A1a effluents and after these effluents were treated by UV or UF. Using PCR method, *Legionella pneumophila* was either not detected or detected with contents too low for quantification in ASTP and A1a effluents and in these effluents after they have been treated by UV and UF. The PCR method showed *Legionella spp* contents higher than 1.9 10^7 GU/L in ASTP effluent and 3.1 10^5 and 1.4 10^6 GU/L in A1a effluent. Evaluated through the PCR method, the UV treatment did not seem to reduce significantly *Legionella spp*. However PCR method does not account for damages caused to bacteria cells by UV radiation and therefore is not convenient for evaluating micro-organism inactivation by UV radiation. Ultrafiltration was very efficient with concentrations either too low for PCR either detection or quantification at the outlet of the pilot plant.

DISCUSSION

The microbial data obtained in 2006 and 2007 allow evaluating the health related risks that may result from the aspersion of landscaped areas in Le Grau du Roi seaside resort.

When faecal indicator bacteria concentrations were rather high at the outlet of the ASTP, the situation was completely different at the outlet of the WSP system. WSPs effluent could be classified as *excellent quality* water according to the European Directive applying to bathing waters when considering the *E. coli* criterion and between *excellent quality* and slightly *insufficient* quality when enterococci were taken into account. But there are clues that the recontamination of the tertiary (and even the secondary) ponds by water fowl flocks and rodents play an important part in enterococci content values. Though a number of pathogens have been searched, i.e. helminth eggs, *Cryptosporidium*, *Giardia*, *Salmonella spp*, *Legionella pneumophila,* enterovirus, ASTP effluent appeared virtually pathogen free and harmless. One *Cryptosporidium* oocysts was found only once in a 20 L sample. *Legionella spp* and *L. pneumophila* were not detected by the conventional culture method, meaning that, if present, their concentrations were too low to be a matter of concern. The results were even better in WSP effluents where no pathogen was ever detected. The only exception was *L. pneumophila* which was never detected by the culture method but has been detected by the very sensitive PCR method though at concentration too low for quantification. Owing to the absence of pathogens, irrigating landscaped areas with either the ASTP effluents or the WSPs effluents does not present any demonstrated risk. Even the risk most put forward when planning aspersion and stressed in the Spanish regulation, the legionnaires' disease, found no support in the observations made in 2006 and 2007.

The UV and UF disinfection treatments efficiently removed bacteria indicator of faecal contamination from both ASTP and A1a effluents. *E. coli* rarely exceeded the detection limit of 1 CFU/100 mL, while enterococci never surpassed this limit. As no pathogen was detected after both disinfection processes, using UV and UF treated effluents for aspersion of landscaped areas can be considered safe.

However, the assertion that the absence of pathogens observed during the 2006 and 2007 monitoring periods guarantees that the aspersion of green spaces close to buildings and streets does not present any risk may be questioned. It may be argued that the observed absence of pathogens was somewhat lucky and due to a very low disease prevalence in the population of Le Grau du Roi during these monitoring periods. A requirement of health authorities might be that, in case of illness outbreak, the wastewater treatment should be able to remove the pathogen causing the illness to a level that reduces the risk of reusing the treated wastewater for urban irrigation to an acceptable level. The acceptable level is defined by a worldwide accepted criterion of $\leq 10^{-6}$ DALYs loss per person per year (WHO 2006). Taking into account the exposure of inhabitants and passers-by to aerosols, the effect of health protection control measures such as spray drift control or night irrigation, a wastewater treatment train providing a pathogen reduction of at least 4 log units may be assumed appropriate. Due to the low contents or the absence of the pathogens searched at Le Grau du Roi, evaluating the performance of the treatment required referring to indicators. It has been recognized that bacteria indicator of faecal contamination may not be suitable indicators of the fate of other pathogens such as protozoa and viruses (Lucena *et al*., 2004). As suggested by Payment and Franco (1993), Lucena *et al.* (2004) and Harwood *et al*. (2005), F specific RNA bacteriophages and spores of sulphite-reducing bacteria were chosen as surrogates for viruses and protozoa. Enterococci, often more resistant than *E. coli*, were considered to better represent the fate of pathogen bacteria.

The overall treatment, through ASTP and WSPs, was found to match this 4 $\log_{10}$ requirement. A 4.5-5 $\log_{10}$ reduction of enterococci was observed. Referring to raw wastewater contents provided by the literature, the removal of SRB spores and FRNAPH was estimated to very likely be higher than or at least equal to 4 $\log_{10}$.

Submitting primary pond effluents to either UV or UF treatment resulted in even better indicator removals. Indeed, from the inlet of the ASTP to the outlet of UV or UF treatments, the reduction of enterococci, SBR spores and FRNAPH was respectively higher than 6, 5.4 and 4.9 $\log_{10}$.

CONCLUSION

Owing to its *E. coli* and enterococci concentrations, the effluent of the WSP system could be classified from *excellent quality* to slightly *insufficient quality* water according to the European Directive applying to bathing waters. ASTP effluents appeared to be virtually pathogen free all over the 2006 and 2007 monitoring periods while no pathogen was found in the effluent of the WSP system. *Legionella spp* was always found to be below the detection limit of the standard culture method.

E. coli rarely exceeded the detection limit of 1 CFU/100 mL after UV treatment of ASTP and primary pond effluents while the same limit was never exceeded after UF treatment. Enterococci never surpassed this limit after either UV or UF treatment.

Moreover, the treatment of wastewater through the ASTP plus the WSP system was shown to lead to a reduction higher than or at least equal to 4 $\log_{10}$ of enterococci, SBR spores and F specific RNA phages, chosen as indicators of respectively bacterial, protozoan and viral contamination.

Disinfection of primary pond effluent through UV or UF processes reached a more ambitious target of 5 $\log_{10}$ removal of the same indicators through the train comprising ASTP, primary pond and UV or UF.

Considering the state of the art of ultra-filtration, it is considered that submitting ASTP effluent to UF disinfection would allow meeting the same target. Additional experiments should be performed to assess the performance of the UV treatment of ASTP effluent.

The high microbial quality of the treated wastewater together with the performance in the removal of the bacterial, protozoa and viral indicators obtained through either the existing wastewater treatment train, including ASTP and WSPs, or through the ASTP followed by a primary pond and a UV or a UF disinfection, show that the health related risks that may result from the aspersion of urban landscaped areas with treated wastewater are below the level considered acceptable for all water uses by the WHO. *Legionella pneumophila* enumerations did not demonstrate the existence of a specific risk linked to aspersion. Therefore, maintaining the ban on aspersion of green spaces within the 100 m buffer zone is not justified. Withdrawing this ban will lead to a dramatic development of water reuse in several tourist regions.

Pilot tests allowed identifying several characteristics and operation conditions of the filtration before UV and ultra-filtration facilities that can be extrapolated to the future real scale reclamation plant. The final choice of the reclamation train will depend on (i) tests to be performed on the irrigation system, particularly considering sprinkler clogging risks, (ii) the requirements of health authorities and (iii) economic considerations.

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